

Bone refits and spatial analyses of units A5-A6 of Fumane Cave contribute to reconstructing the dynamics of Neanderthal use of space

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Abstract

This paper presents an initial spatial examination based on the refitting of animal bones scattered in late Middle Palaeolithic units A5-A6 of Fumane Cave. The main goal is to contribute to understanding past activities and space organisation developed by Neanderthals. The analysed sample includes 4,234 bone fragments, of which 50 sets of refits were horizontally assembled, and four refits documented a vertical connection between units A5+A6 and 6. The study highlights a preponderance of short connections, suggesting that they mainly remain in their original position, although there are some refits at medium and long distances. The absence of important post-depositional agents, which could have caused bone movements, indicates that the distribution is mainly due to human actions resulting from repeated short-term occupations. Applying bone refits, multivariate statistical techniques, and GIS tools allowed us to identify two main bone accumulations on the east wall of the cave, far from the hearth positions. This study shows the importance of bone refitting in determining variability in Middle Palaeolithic occupational patterns.

Keywords: ungulate; spatial distribution pattern; multivariate statistics; conjoined bones; Middle Paleolithic; MIS3; Italy

36 Introduction

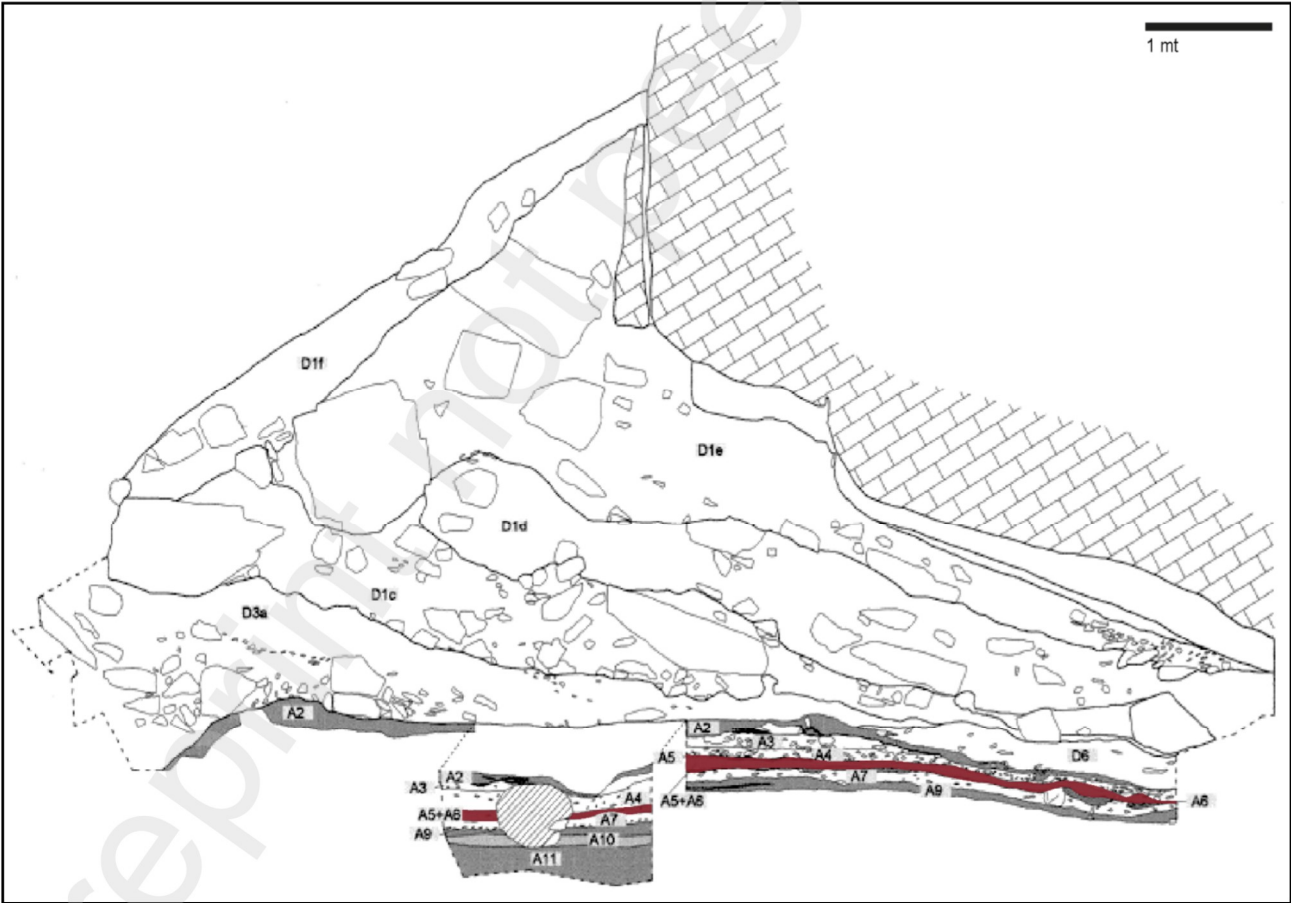
37 The refitting and conjoining, or the identification of two or more pieces of material of the same nature,
38 has a deep history in archaeology (Hofman, 1981; Schurmans, 2007; Villa, 1991), albeit the first
39 studies involved the accidental discovery of broken artefact pieces. Even though this method involves
40 significant time investment, benefits are evident as refit gives information about site formation,
41 activity areas, stratigraphic mixing (degree of vertical dispersal), and technology. The essential
42 assumption is that green bone fractures represent contemporaneity: two or more pieces found to refit
43 are assumed to represent contemporaneous events or processes (Lyman, 2008; Morin *et al.*, 2005).
44 However, contemporaneity must be evaluated in every single context because the movements of
45 elements are influenced by subsequent events (Hofman, 1992; Larson and Ingbar, 1992; Schurmans,
46 2007). The methodological protocol applies to all materials and foresees determining which fracture
47 edges or surfaces conjoin. However, for specific classes of materials, such as stone artefacts, there
48 are more features to be considered, like colour, texture, grain and inclusions, that can suggest the
49 derivation of flakes and tools from the same core/nodule (Larson and Komfeld, 1997). Applied
50 initially to lithic studies, this method has raised its importance also in Zooarchaeology (Fernández-
51 Laso, 2010; Gabucio, 2014; Gabucio *et al.*, 2016, 2017, 2018; Modolo, 2017; Modolo and Rosell,
52 2017; Rosell *et al.*, 2012a,b, 2019), because it is a unique method that consists of finding the joints
53 between skeletal elements. Moreover, bone refits related to green marrow-bearing bone breakage are
54 connected to nutritional activities, allowing the reconstruction of subsistence and economic strategies.
55 As archaeological formation processes can mix up different overlapped occupational events
56 (palimpsests) (Bailey, 2007; Lucas, 2004), it is necessary to distinguish between intra-site activity
57 areas and whether accumulations are related to anthropogenic features like fireplaces,
58 dumping/reworking areas, trampled surfaces, occupation horizons, isolated concentrations of
59 materials (Marañón *et al.*, 2022) drop- and toss zone (Binford 1978a,b, 1983). The comparison with
60 ethnographic models has facilitated the understanding of some aspects of the site organisations
61 (Audouze, 1987; Binford, 1980, 1983, 1998; Coinman *et al.*, 1986; Yar, 1994; Yellen, 1977) that
62 focused on hearths as the essential elements of household areas. Although Mousterian settlement
63 dynamics have applied these models, comparing archaeological assemblages and
64 ethnoarchaeological contexts (Binford, 1978a,b; Schiffer, 1985; Tschauer, 1996), these methods
65 could not be applied to a wide range of sites because they did not take into consideration the temporal
66 occupation dynamics. To address these problems, the study of refits, distance and direction of
67 connection lines, combined with taphonomic studies and spatial analyses of remains, allows the
68 identification of clusters between different domestic units (Chacón *et al.*, 2015; Fernández-Laso,
69 2010; Gabucio 2014; Modolo, 2017; Modolo and Rosell, 2017; Rosell *et al.*, 2012a,b, 2019; Vaquero
70 and Pastó, 2001). This approach could also contribute to the ongoing research on Fumane Cave, by

71 examining the faunal refits analysed in units A5-A6. Fumane represents an excellent study case
72 thanks to extensively excavated units and anthropic accumulations attested by hearths, trampling
73 features and archaeological remains. For the first time, methodology-based bone refits and statistical
74 analyses based on metric parameters of ethnographic accumulations have been applied to understand
75 occupational patterns.

76

77 **Fumane Cave and unit A5-A6**

78 Fumane Cave, a European Middle and Upper Palaeolithic reference site, is situated in the Lessini
79 mountain (Verona, Italy). Extensively explored over the last three decades, it preserves a stratigraphic
80 sequence resulting from an intense and complex combination of natural and anthropic accumulation,
81 as corroborated by archaeological remains (Peresani, 2022). The cave is part of a karst system and
82 comprises a large entrance with the convergence of three tunnels (A, B, C). The uppermost
83 Mousterian deposits document thin parallel levels and lenses grouped into nine stratigraphic units
84 (A13-A5) (Fig.1).



85 Fig.1

86

The complex of A5-A6 includes units TettoA5, A5, A5BR, A5+A6, A6, and A6BR, extensively excavated until 2006-2008 (Fig.2) and forming a sub-horizontal body of about 20 cm thick, with a slight east/southeast and northeast slope (Peresani *et al.*, 2011). The units are classified as follows:

- **A6** is divided into three zones: 1) the western protected by the two main galleries, where there are over 20 anthropogenic features, combustion structures and localised burnt products accumulations; 2) a discard area characterised by the accumulation of materials derived mainly from combustion or altered by heating; 3) a large area extending to the opposite wall, with dense scatters of lithic artefacts, tools, and anthropically modified bones. Combustion structures are rarely larger than 30 cm and are characterised by a reddened horizon, often covered by a charcoal layer, microcharcoal, ash, and dispersed organic matter. Such structures are set directly over the sands of unit A7 (archaeologically sterile) or maybe within or at the top of unit A6 (Marcazzan *et al.*, 2022). These structures document a sequence of human frequentations that maintain, over time, the general spatial organisation of the activities. The unit layer is 3-8 cm thick and gradually thinner toward the cave walls, decreasing to a 1-2 cm fine sheet. In the inner part of the cavity, it shows major variations in the form of folds due to post-depositional deformations.
- **A5+A6** is a unit (10 cm thick) of loose sediments rich in stones lying above unit A6 and underneath the discontinuous unit A5. Human occupations are more ephemeral and less intense compared to unit A6.
- **A5** is a horizon with combustion structures and dump material, documented in the westernmost zone and gradually vanishing in the rest of the excavated area. The unit preserves a combustion area (SIII) associated with artefacts in the immediate vicinity and partially surrounded by squared slabs. Using a modelled Bayesian sequence generated with OxCal 4.0, Higham *et al.* (2009) conclude that the latest Mousterian occupation occurred before 43,580-42,980 BP.

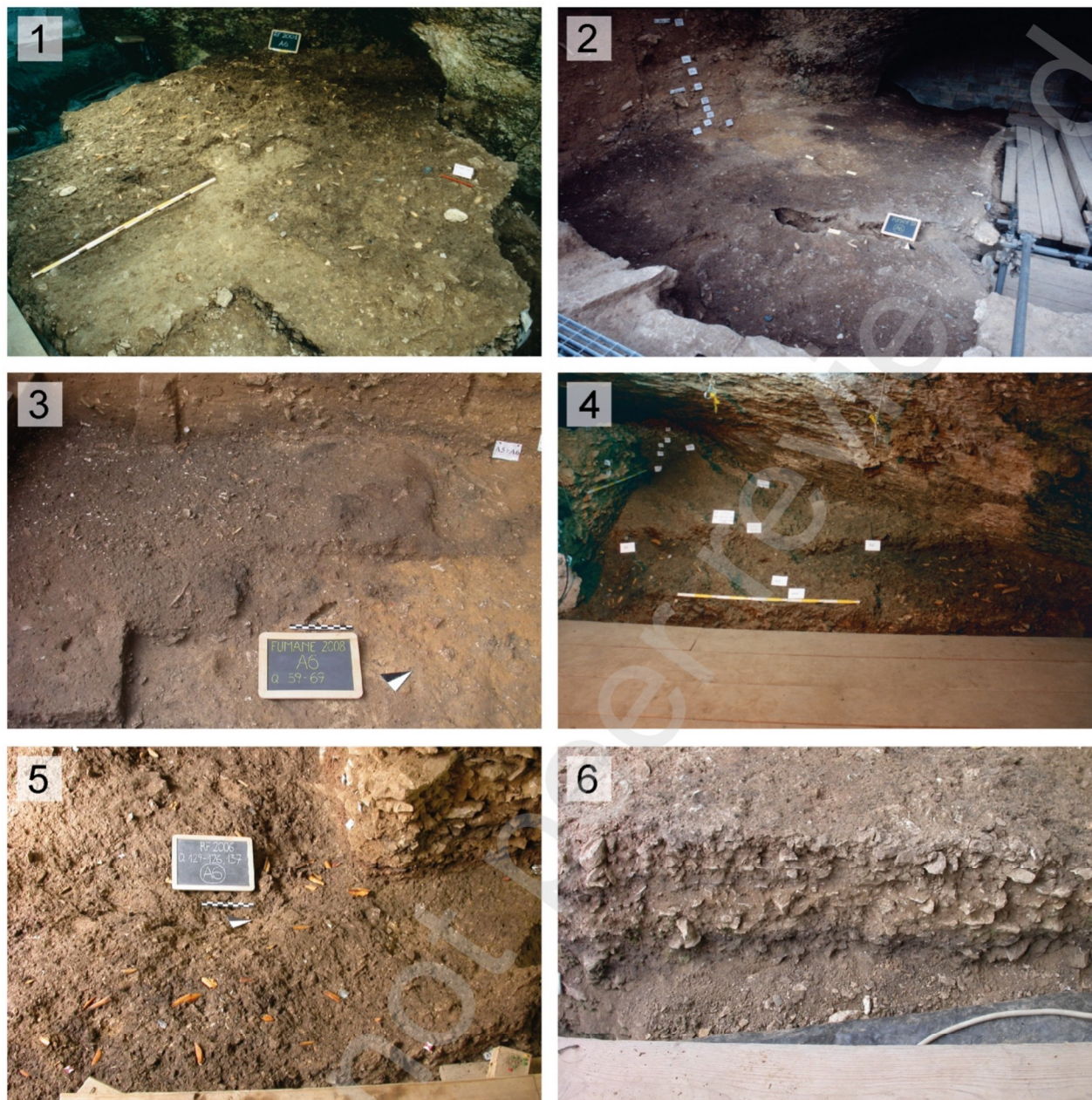


Fig.2

Materials and methods

We implemented an extensive refitting program to test the cultural sequence of units A5-A6 by observing spatial patterns. We analysed a sample of 4,234 bone remains (2.5%) (total for all levels), representing a selection of the NISP documented in these levels (171,271) (Romandini *et al.*, 2014). The choice, as well as for unit A9 (Modolo *et al.*, 2024), was based on the following criteria: the analysis of taxa identified in previous studies and here re-examined after refittings (Romandini, 2012; Terlato *et al.*, 2019), plus the integration of all fragments that were considered potentially suitable for refitting, like burnt bones, bones with cut marks, impact points, percussion notches, carnivore or other animal traces, flakes and percussion cones, also smaller than 2 cm. This choice was made for different

126 reasons: a work plan configured according to the timescales established by the project, of which this
127 study is the result, and for the conservation of remains. Preliminary archaeozoological analyses of
128 the bone assemblages found during the 1989-2006 excavation campaigns (Tagliacozzo and Cassoli,
129 1994; Frescura, 2004-2005; De March 2010) have been followed by a deep comparison (Romandini,
130 2012; Terlato, 2012) and targeted publications (Jéquier *et al.*, 2010, 2012; Peresani *et al.*, 2011;
131 Terlato *et al.*, 2019). All units have been excavated in 33x33 cm squares, with dry collecting of
132 materials (bones and lithics) and then by wet sieving. All remains larger than 3 cm have been mapped
133 on-site with geographical coordinates. Several authors have documented a predominance of cervids,
134 mainly deer and roe deer, followed by elk. Caprids with large bovids are subordinated. Red fox
135 (sporadic), brown, and cave bears have been documented in all units (Cassoli and Tagliacozzo, 1994;
136 Peresani *et al.*, 2011; Romandini, 2012; Romandini *et al.*, 2018, 2020; Terlato *et al.*, 2019). Extensive
137 analyses have also been conducted on avifaunal remains (Peresani *et al.*, 2011). According to
138 Romandini and colleagues (Romandini *et al.*, 2014), the number of identified bones is low due to the
139 high rate of bone fragmentation (more than 88.8% are smaller than 2 cm) and combustion (47.8%).
140 The percentage of bones smoothed by natural mechanisms, like trampling, rolling, and micro-
141 scraping, is low (5.4%). Root marks are the most common alterations identified on the surfaces
142 (26.8%), followed by micro-fissures related to weathering (20.4%), manganese (17.6%) and
143 exfoliations (6.4%) (Romandini *et al.*, 2014). Some concretion traces affected fragments located near
144 the external area, at the limit of the drip line (17.6%). In comparison, the few with trampling abrasions
145 (0.5%) located in the eastern part of the cave are associated with the highest stoniness of the layer. A
146 high incidence of burned remains suggests the use of butchering refuse as fuel: 88% were subject to
147 moderate combustion (200-500°C, black/brown), while 12% were calcined (> 700°C, grey/white).
148 Data on carnivore remains, except for wolves, show only skinning and defleshing butchering marks
149 (Romandini *et al.*, 2014; 2018). Anthropoc traces have been documented on most ungulate remains,
150 especially on cervids (red and roe deer). Considering the whole ensemble, butchering traces have
151 been identified on 1442 remains, determined at the species level (butchering rate is 47% of the total
152 NISP) and 1954 determined bones (1.2% of the total undetermined) (Romandini *et al.*, 2014). The
153 diaphysis of tibias, femurs, metapodials, radii, and humeri from cervids (red deer, roe deer, giant deer,
154 or elk) and other ungulates (to a lesser extent) were used as retouchers. Some surfaces were scraped
155 before being used, probably to remove meat, tendon, and periosteum residues, but no further
156 preliminary preparation has been documented (Jéquier *et al.*, 2012).
157 Concerning refitting, we followed the terminology used by Todd (1983, 1987) and Lyman (1994,
158 2006, 2008), the methodology developed by Fernández-Laso (2010), standardised during different
159 works, applied to various Abric Romaní levels (Bargalló *et al.*, 2016; Gabucio *et al.*, 2016; Modolo,

160 2017; Modolo and Rosell, 2017; Rosell *et al.*, 2012a,b; 2019). There are four methods of refitting
161 bones used in this work:

- 162 • **Mechanical:** refitting two or more fragments from the same bone following the fracture plane.
- 163 • **Intermembral/anatomical** (Lyman, 1994): identification of usually articulating specimens (e.g.
164 distal humerus/proximal radius), disarticulated and dispersed specimens (e.g. distal
165 tibia/astragalus), inferring that specimens that fit snugly and move smoothly in articulation
166 represent refitting specimens deriving from the same individual (Todd, 1987).
- 167 • **Neighbourhood:** comparing specimens that normally articulate on the base of size, inferring that
168 two specimens that correlate closely are likely from the same individual, based on the rule of the
169 neighbourhood (Kurten, 1953).
- 170 • **Bilateral symmetry** (variant of the anatomical refitting, Lyman, 1994): identification of left and
171 right elements that seem to be mirror images of one another based on the principle of bilateral
172 symmetry (Lyman, 2006).

173 The work planning foresaw six months, for approximately 1890 hours (1 person), including the time
174 needed to recover, select, distribute, and divide the material over tables. Initially, we selected a sample
175 of the total fragments recovered in A5-A6 to perform the refitting program. Afterwards, the faunal
176 material was sorted by taxon and anatomical elements. The refitting program had a two-step process.
177 The first step compared taxonomically identified specimens with non-identified specimens from the
178 same size class at each level. In the second step, all fragments were compared across all levels. The
179 location, distance between refitted elements, and taphonomic modifications, particularly those of an
180 anthropic nature, have been documented and recorded. Due to the high fragmentation rates of A5-A6
181 complexes, fragments less than 3 cm showing significant anthropic traces have also been selected.
182 We adopted the same procedure for unit A9 (Modolo *et al.*, 2024). Spongy fragments and those
183 strongly altered by water action or trampling were not considered, as they are tough to conjoin. The
184 conjoined elements were taped with reversible glue pads (UHU patafix) to reconstruct bone
185 morphology, allowing the study of fracture patterns and the acquisition of photographic
186 documentation. The refits have been classified according to the taxa, weight-size group, and
187 taphonomic agent, particularly considering the green or dry bone breakage patterns. Following the
188 standard procedure (Fernández-Laso, 2010; Gabucio, 2014; Modolo, 2017; Morin *et al.*, 2021), all
189 cases that were not clear and did not show evidence of human involvement were put into the category
190 of dry-bone fractures (Haynes, 1983; Villa and Mahieu, 1991). The open-access software QGIS 3.28
191 was used to compute the length of each connection line, which was subdivided as follows: short (1-2
192 mt), medium (2-5 mt), and long connections (> 5 mt) (Tab.1). The directionality of connection lines,

193 corresponding to anthropic or natural movements has been established, whenever possible, and
 194 plotted into a Rose diagram.

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U.S.		Distance (m)					
		0-1	1-2	2-3	3-4	4-5	>5
6	N° c. lines	57		1			1
	%	96,61%		1,69%			1,69%
A5+A6	N° c. lines	12	1				
	%	92,31%	7,69%				
A5	N° c. lines	3					
	%	100,00%					
Totals		72	1	1			1
		96,00%	1,33%	1,33%			1,33%

203 Tab.1

204

205 Statistical tests were applied only to unit 6, as the quantity of the selected sample was statistically
 206 representative in determining potential differences in remaining distributions. We used density maps
 207 generated with kernel algorithms as an informal approach to spatial cluster analysis (Baxter *et al.*,
 208 1997). We considered the radius suggested by the results of Besag's L (r) functions. Kernel density
 209 estimation (KDE) uses point data to create a smoothed density map considering the proximity
 210 between the points (Baxter *et al.*, 1997). We used software R (R Core Team, 2018) to create 2D and
 211 3D density maps. In addition, complementary histograms were performed to evaluate the distances
 212 among refits and the distances from every refit to their closest hearth, anthropic feature or cluster of
 213 materials. K-means were used to identify how many clusters exist in unit A6. Before running the k-
 214 means, we used the package *factoextra*, the function *fviz_nbclust* and the *silhouette* method to
 215 determine how many clusters could be identified. Based on the number of clusters, we calculated the
 216 linear distance of each refit to its closest centroid.

217 We captured 2D images using an Epson Perfection V10 scanner at either 1200 or 2400 dpi resolution,
 218 depending on the bone type (tooth, long diaphysis, or tiny fragments), subsequently treating images
 219 with Adobe Photoshop 24.1.0.

220

221 Results

222 Refits of unit A6

223 In the sample selected for the analysis of refits (2,854 NISP, 1.6% of the total), the red deer is the
 224 most represented animal, with 979 remains, followed by cfr. *Cervus elaphus* (131) and *Capreolus*
 225 *capreolus* (128). Caprids are second to cervids, with *Capra ibex* (42) and *Rupicapra rupicapra* (37)
 226 as the main species. Among large cervids, *Megaloceros giganteus* is the most represented, with 28
 227 remains (20 of them attributed to cfr. *Megaloceros giganteus*). Both carnivores and small mustelids

are attested, although with a low frequency of remains. Among the non-taxonomically identified elements, all weight size classes of mammals have been documented: 332 of big-size, 145 of medium/big-size, 101 of medium-size, 10 of medium/small size, and one fragment of small size. For the remaining 120 fragments, it was not possible to attribute a size/weight category. Finally, the number of unidentified remains amounts to 35.

We identified 34 bone refits in this unit, involving 82 fragments (2.8% of the selected bones) translated into 59 connection lines (Tab.2).

U.S.	Taxa	Skeletal element	n° R. fr.	D (cm)	Anthropic modifications						R O	Post-depositional agents							
					CM	SM	I P	PN	PC	R		B	T	CN	CR	E	WA	MO	RT
A6	Cervus elaphus	I2+I3+I4 (r)	6	1,5 - 4 - 6,5 - 2 - 10										4				1	
		I2+I3+I4 (l)																	
	Humerus (r)	2	46	1		1	1		1			1				2	1		
			2	in situ	1		1	1			1					1	1		
	Radius	2	68	1												2	2		
	Metacarpal	2	in situ			2	1					1					1		
		2	in situ	1								1							
		2	in situ	1	1	3	1		1		1	2							
	Femur (l)	3	118	1	1	1	1		2	1	2		1			1	1		
		2	221	2							1	1				1	1		
	Tibia (r)	2	142	1			2			1						2	2		
	Metatarsal	2	31,5	1						2		1			2	1	2	1	
		2	81	1		1	1									1	2	1	
	Metapodial	2	814	1								2		2			1	1	
	II phalanx	2	in situ						3										
	cfr. Cervus elaphus	Humerus	2	9				1						1				2	
		Metacarpal	2	in situ	1			1									1		
	Capreolus capreolus	Metacarpal (r)	5	in situ	1										1			1	
	Cervidae	Metapodial	2	4	2	1							2					2	2
	Ungulata ind.	Metapodial	2	27									2					2	
			2	49	1								2		2				1
		Diaphysis (B-size)	2	12						2								2	
	Mammal	Tibia	2	in situ								1	1		1				1
		Diaphysis (M/B-size)	3	1									2					1	2
			2	in situ						1				1				1	
			2	17									1				1	2	1
		Diaphysis (B-size)	3	in situ						1									1
			2	6								1				2	1	2	2
			2	2								1		2	1	2	2		1
			2	17						2								1	
		3	20 - 21 - 22						3										
	Unidentifi ed	Diaphysis	2	9						2									2

239 Classifying them according to the number of refitted fragments, we have one refit of six, two of five,
 240 four of three and 27 of two. Of these, one refit has been classified as bilateral symmetry (teeth of red
 241 deer), and one as intermembral with anthropic fractures (metacarpal + carpal of *Capreolus capreolus*)
 242 (Lyman, 1994). In contrast, all the others are mechanical, with green and dry bone fractures. By
 243 taxonomic group, we have 33 fragments of *Cervus elaphus* (14 refits), plus 4 of cfr. *Cervus elaphus*
 244 (two refits), five of *Capreolus capreolus* (one refit), two of Cervidae (one refit) and six of Ungulata
 245 ind. (three refits). Among the non-taxonomically identified elements and according to weight-size
 246 classes, 21 fragments belong to mammals (four refits on medium/big-size and five on big-size) and
 247 11 to unidentified (four refits). *Cervus elaphus* remains mainly documented short connection lines
 248 (*in situ* refits and distances between a few cm and 2.20 m) except in one case of the long connection
 249 that involves two fragments of metapodial for a distance of 8.14 m. The only anatomical refit has
 250 been attested on teeth (I2, I2, I4 right and I2, I3, I4 left), whereas all others concern long bone shafts,
 251 except for one II phalanx. The horizontal distribution of connection lines does not show refits between
 252 anthropic structures. In all these cases, anthropic marks and post-depositional agents have been
 253 attested (Tab.2).

254 Cfr. *Cervus elaphus* documented two refits on the humerus and metacarpal (maximum 9 cm). In
 255 contrast, *Capreolus capreolus* is attested by an anatomical refit on the metacarpal that shows
 256 anthropic fracture and butchering marks (*in situ*). We have refits on long bones with few anthropic
 257 marks and post-depositional agents (between 4 and 49 cm) among cervids and ungulates. Mammals
 258 classified into weight-size and unidentified fragments do not show particularly anthropic intervention
 259 on bone surfaces, except for a refit involving five elements (unidentified diaphysis), which
 260 documented the conjoin of three percussion cones, therefore attesting an impact action due to bone
 261 fracturing. Seven refits of this group of elements involved burnt fragments of variable size between
 262 3-5 cm. Instead, more traces of post-depositional agents are attested, mainly concretions and
 263 corruptions due to chemical agents, manganese oxides, roots, and weathering cracks.

265 *Refits of unit A5+A6*

266 We analysed a sample of 1,105 bone fragments, 832 of which were identified at the level of species
 267 or families. The other remains (273) represent weight-size mammals (260) and unidentified remains
 268 (13). As for the different levels, *Cervus elaphus* is predominant, with 318 remains, followed by cfr.
 269 *Cervus elaphus* (60) and *Capreolus capreolus* (56); 23 pieces of Cervidae can be included in these
 270 categories. Among large cervids, *Megaloceros giganteus* is less present than in level A6, with four
 271 fragments, plus 4 attributed to cfr. *Megaloceros giganteus*. Caprids are second to cervids, with

272 *Rupicapra rupicapra* (33) and *Capra ibex* (19) as the main species. Carnivores and small mustelids
273 are attested, although with few remains.

274 This unit documented 13 bone refits involving 29 fragments translated into 13 connection lines. Of
275 these, one refit is composed of five remains and 12 of two (Tab.2). By taxonomic group, we have 15
276 fragments of *Cervus elaphus* (six refits), plus two cfr. *Cervus elaphus* (one refit), two of *Capreolus*
277 *capreolus* (one refit), two of *Capra ibex* (one refit), 2 of *Rupicapra rupicapra* (one refit) and six of
278 Ungulata ind. for a total of three. Of these, one refit is anatomical (teeth of chamois), whereas all the
279 others have been included in the mechanical category, with both green- and dry-bone fractures.

280 *Cervus elaphus* remains show only short connection lines (*in situ* and between 35 cm and 1,60 mt).
281 The horizontal distribution of connection lines does not show refits between anthropic structures. In
282 all these cases, anthropic marks and post-depositional agents have been attested (Tab.2), whereas
283 caprids and ungulates are uncommon for roe deer. The position in which these elements have been
284 found is primarily *in situ* or at a relatively close distance, between 20 and 93 cm.

285

286 *Refits of unit A5*

287 A sample of 207 bone fragments was analysed, of which 154 were identified at the level of species
288 or families. The other remains (53) represent weight-size mammals (49) and unidentified remains
289 (four). *Cervus elaphus* is predominant, with 31 remains, followed by cfr. *Cervus elaphus* (nine),
290 *Capreolus capreolus* (nine) and cfr. *Capreolus capreolus* (seven). Follow *Rupicapra rupicapra*
291 (seven), cfr. *Rupicapra rupicapra* (two), *Capra ibex* (two) and cfr. *Capra ibex* (one). Among large
292 cervids, only two elements of cfr. *Megaloceros giganteus* are present, whereas carnivores (bears and
293 foxes) are poorly attested. Considering the reduced number of selected remains for refitting protocol,
294 only three refits of two fragments were identified: a tibia of *Cervus elaphus* with cut marks and
295 percussion stigmata, two pieces of molar, and a diaphysis of Ungulata. Both anthropic and post-
296 depositional traces are very poor, attesting to short-distance refits (Tab.2).

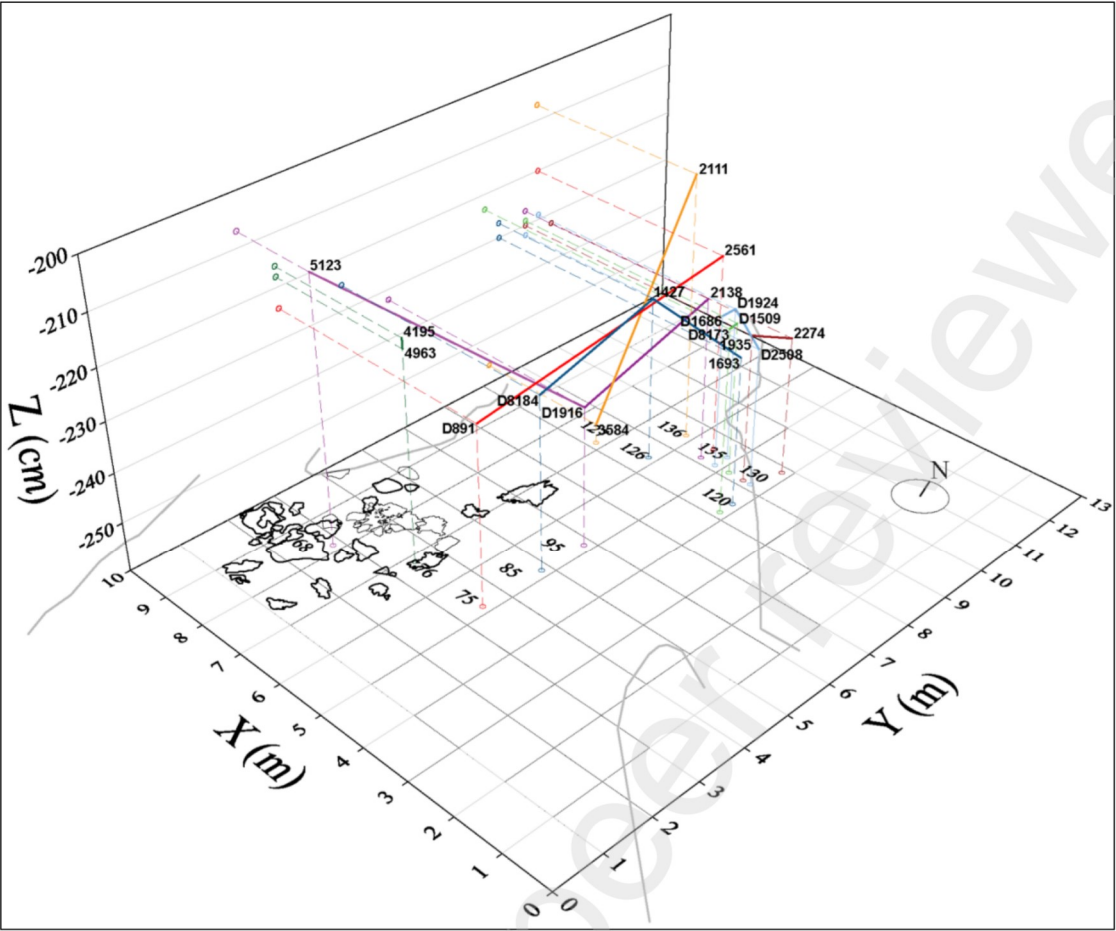
297

298 *Vertical connections*

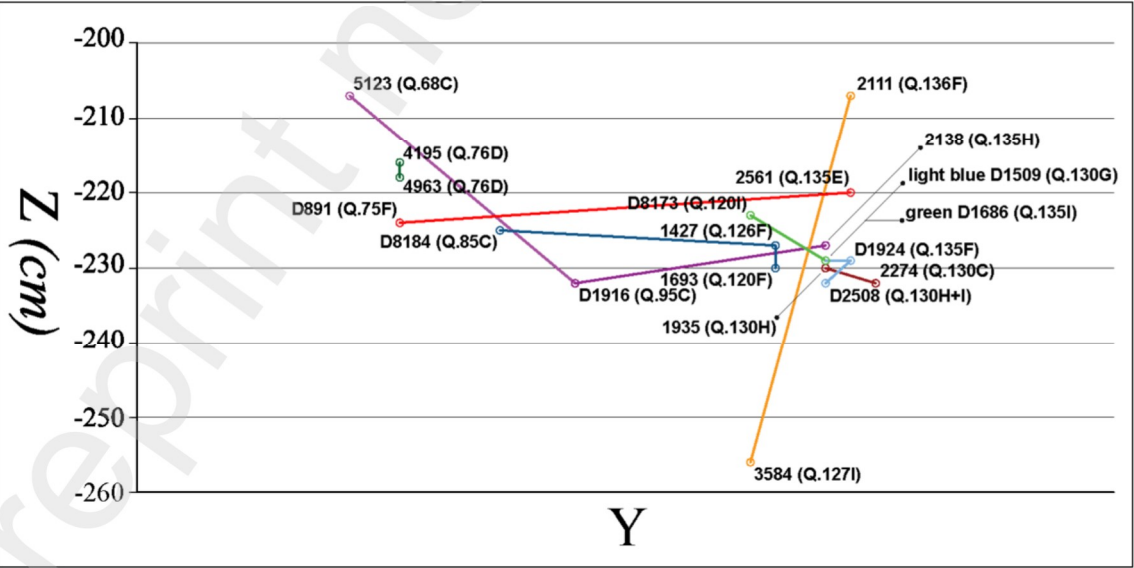
299 Data analysed at Fumane Cave show that four refits connect unit A5+A6 with A6, highlighting a
300 preponderance of long connections, except one case of medium-distance (Tab.2, Fig.3, Fig.4). The
301 specimens involved are the red deer and the chamois, and concern the following elements:

- 302 - Metatarsus (red deer, between 3.4 and 6.9 m - vertical distance between 5 and 25 cm).
- 303 - Tibia (deer, 5.8 m - vertical distance of 8 cm).
- 304 - Dental series (chamois, between 1.8 and 3.8 m – vertical distance between 3 and 5 cm).
- 305 - Metapodial (deer, 1.6 m – vertical distance of 49 cm).

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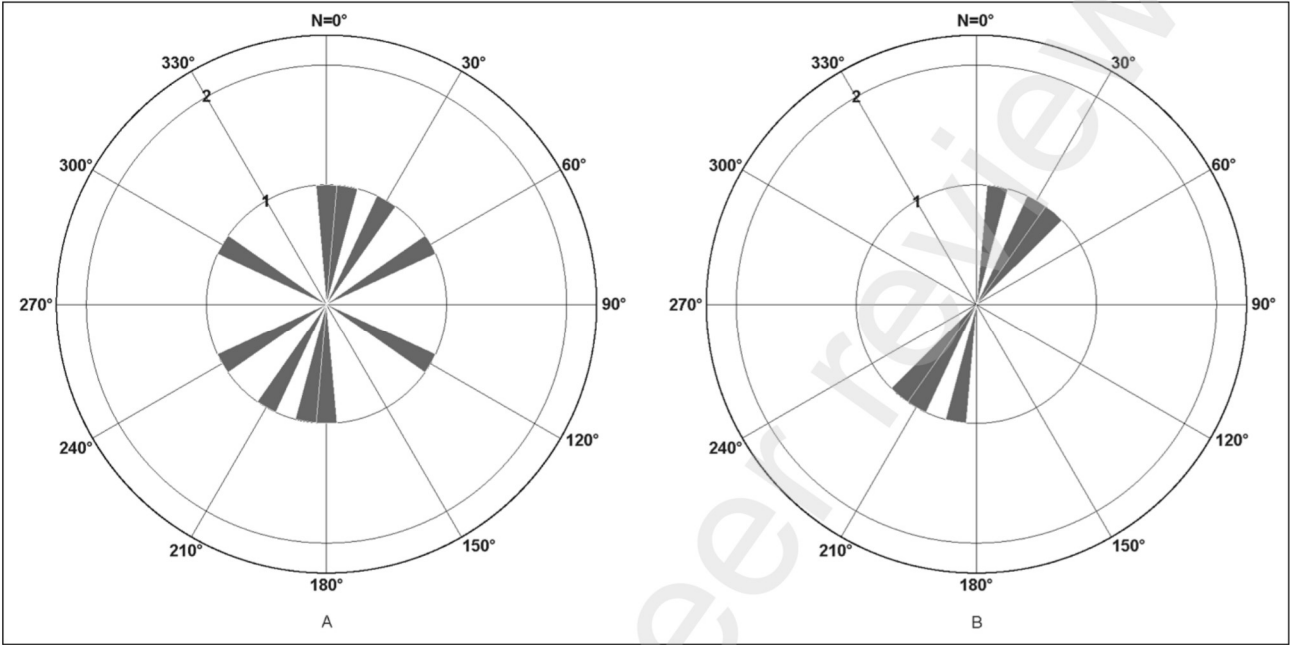


308
309 Fig.3
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312 Fig.4
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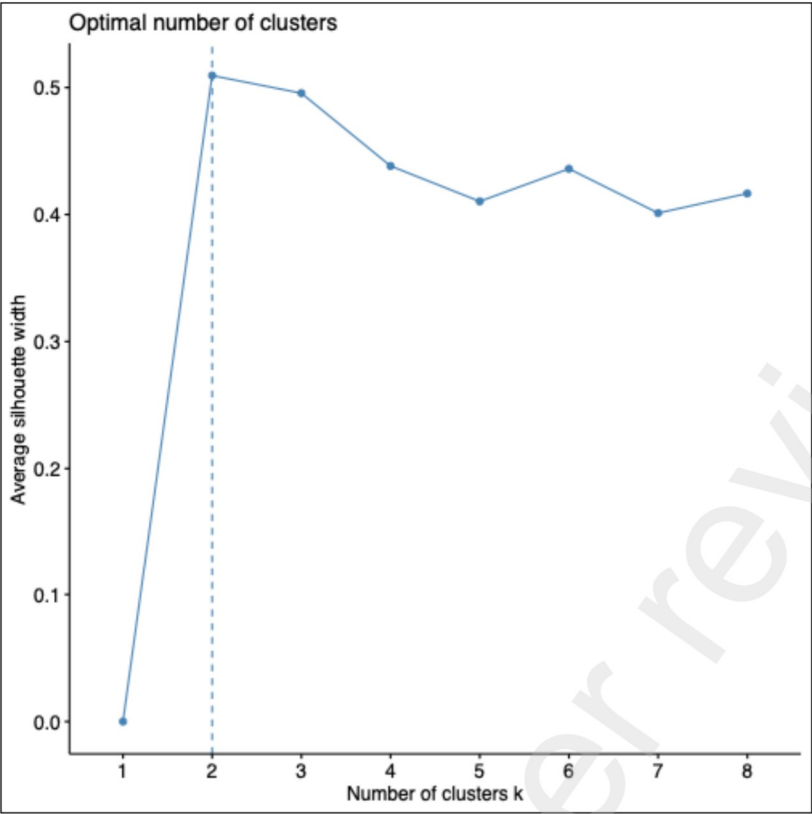
314 The difference in depth between these refits can be minimal (a few cm) or important, reaching about
315 half a meter, with directions from northeast to southwest (close to the hearth area) (Fig.5). There are
316 no traces of post-depositional agents that could have led to the movement of these pieces, except in
317 one case in which trampling marks have been attested.
318



319
320 Fig.5

321
322 *Clustering patterns*

323 We plotted the selected bone sample horizontally (X/Y) and then compared the distribution of these
324 remains with the location of the anthropic elements (e.g. combustion structures). K-means analyses
325 were used to identify the number of clusters in unit A6. The optimal number of clusters in the k-
326 means analysis is 2 (Fig.6). However, the average silhouette widths of 3 and 4 clusters are similar. In
327 this sense, we calculated the means as having either 2, 3, or 4 clusters (Fig.7).



329 Fig.6

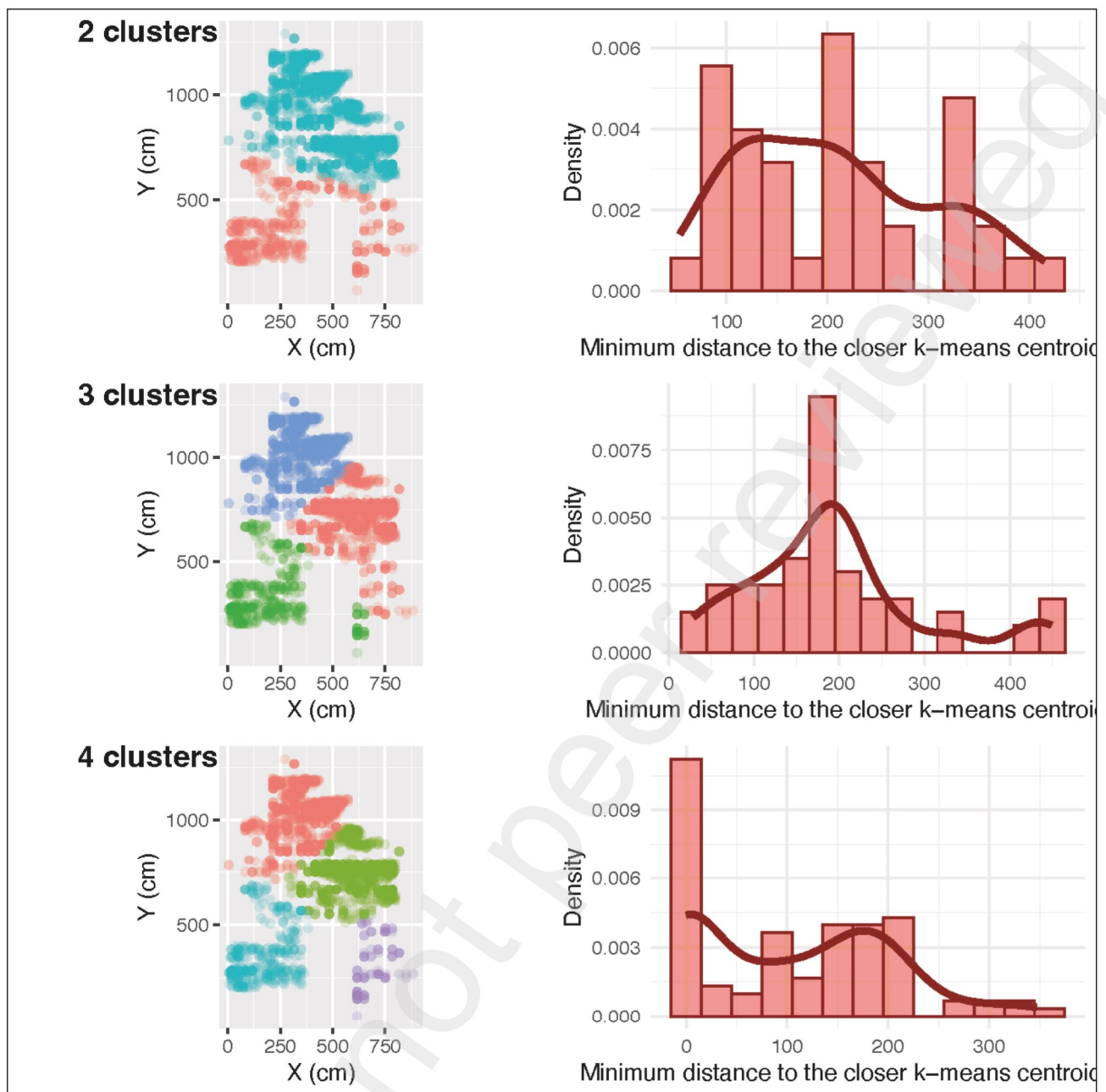


Fig.7

The resulting scatterplots show that the archaeological remains tend to cluster on the east wall of the cave (3 clusters). One cluster is located around and within the hearths in the west part of the cave (Fig.8). In the distribution of refits within the identified clusters, the black squares inside the dots indicate the burnt fragments. Within those documented, only one refit presents a burnt fragment that conjoins with a non-burnt bone (square 92c). Overall, most refits are concentrated in proximity to the large bone accumulations. Furthermore, these areas seem far from the hearths and the anthropic structures identified by other studies (Marcazzan *et al.*, 2022).

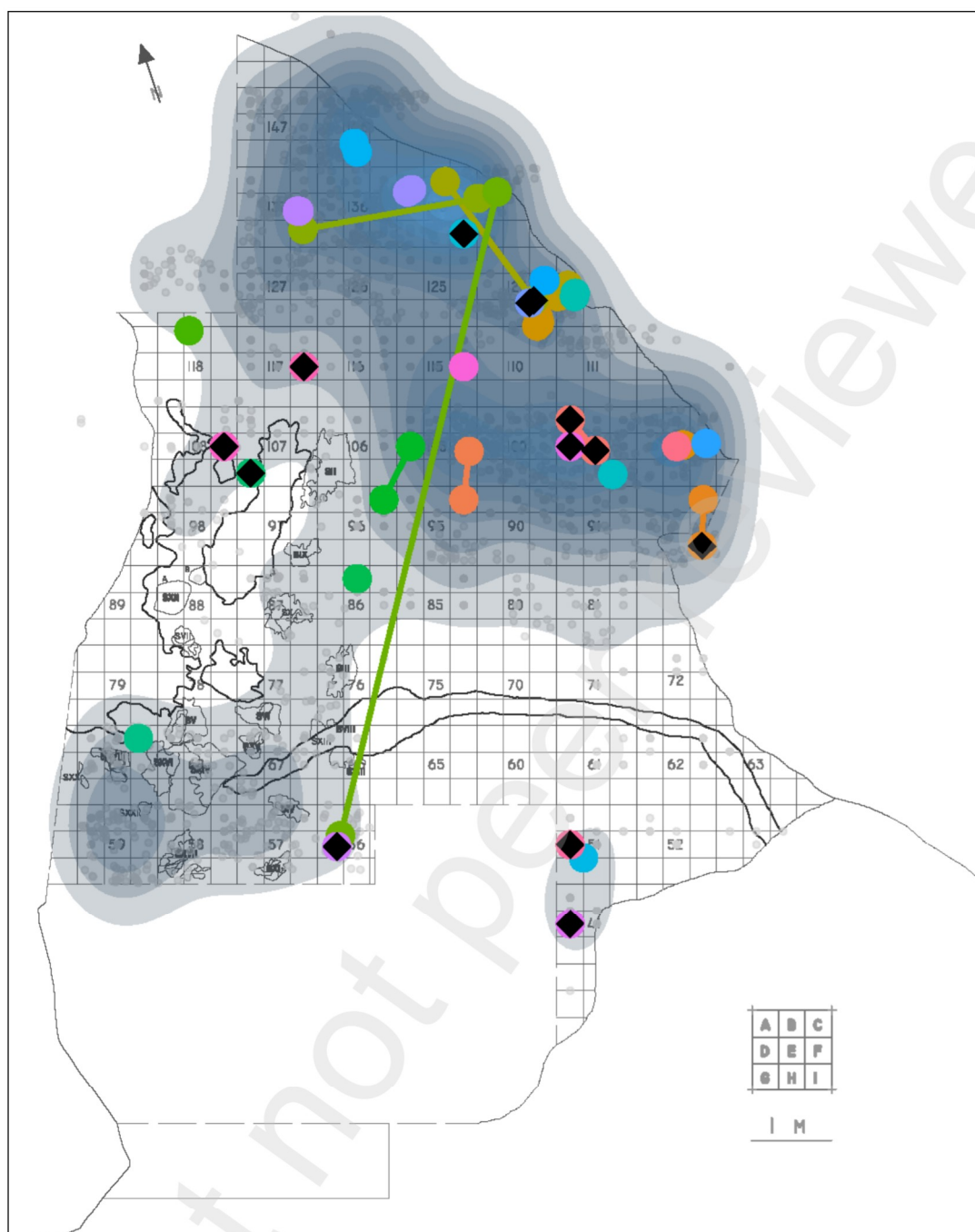
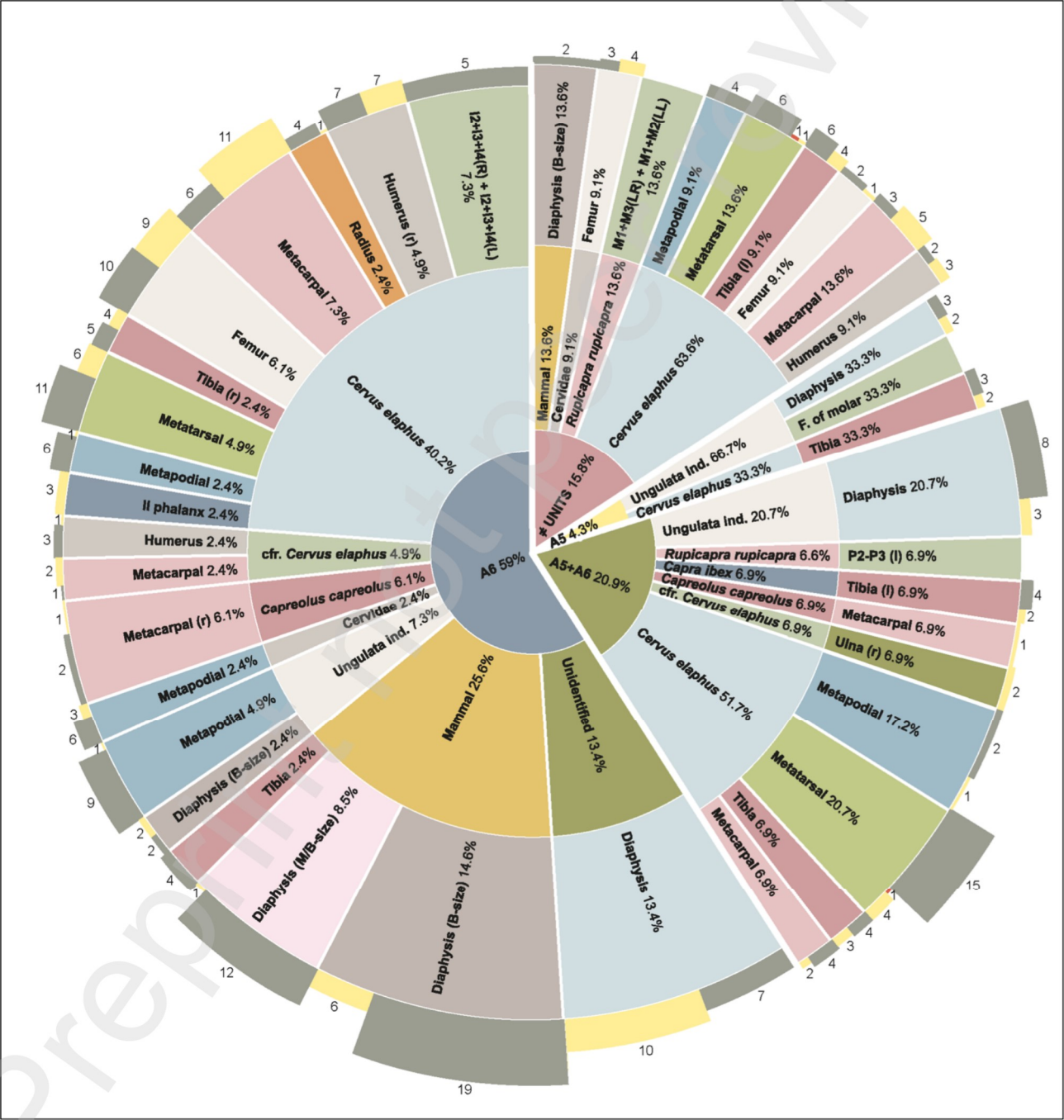


Fig.8

Discussions

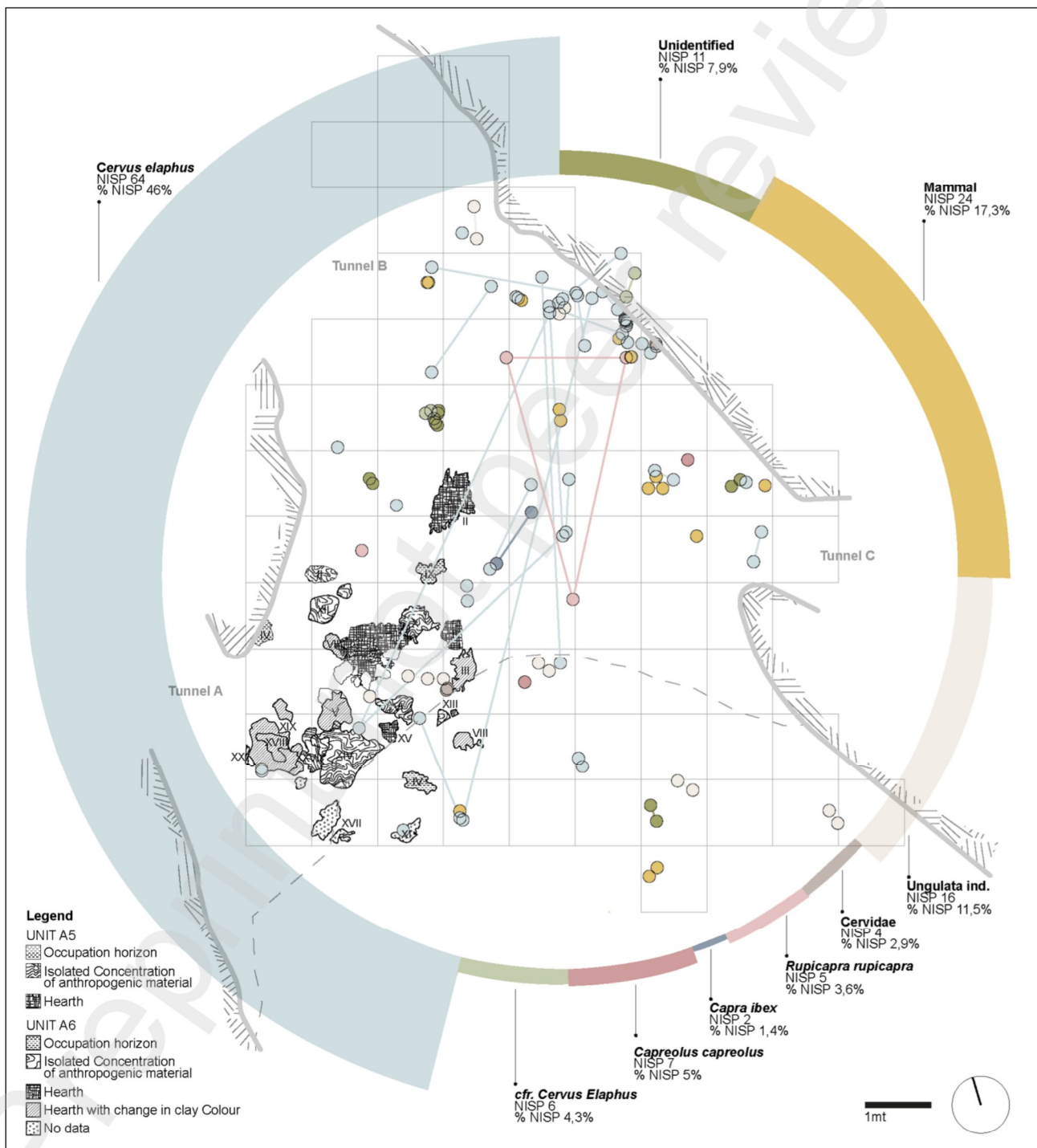
The analysis of refits carried out in units A5-A6 of the Fumane Cave shows a prevalence of cervids (*Cervus elaphus*, *Capreolus capreolus*), followed by caprids (*Capra ibex*, *Rupicapra rupicapra*) as the most hunted species. Consequently, this data is reflected in the sample of bones refitted for this study. The pie chart (Fig.9) summarizes the documented refits between species, also including weight-size mammals and unidentified fragments, specifying the affected anatomical portions, with the relative percentages and the quantity (in terms of number of remains) of anthropogenic and post-

351 depositional traces found on each refit. The less frequent anatomical portions are teeth, represented
 352 by two dental series from unit A6 (red deer incisors), one from A5+A6 (premolars of chamois) and
 353 one from A5 (fragments of ungulate molars). A vertical refit between unit A6 and A5+A6 comprises
 354 molar fragments of chamois. The other refitted elements are characterised by diaphysis of long bones,
 355 classified as follows based on the number of refits: metacarpals (eight), metatarsals (six) and
 356 metapodials (six), tibiae (five), humerus (four), femurs (three), radius (one) and ulna (one), phalanx
 357 (one) while the rest are elements of undetermined diaphyses (18).
 358



359 Fig.9

The distribution of refits in units A5-A6 (Fig.10) greatly differs from unit A9 because, in almost all cases, they are connected by short distances or *in situ*. Moreover, unlike unit A9 (Modolo *et al.*, 2024), the presence of carnivores is totally absent in the refitted bones. Only a few traces of rodent teeth have left incisions on a red deer metatarsus of unit A5+A6, documented by a refit that connects two fragments located in square 56d and 68c (1,60 m of distance). Considering post-depositional agents, some remains show trampling or water action marks (rounding/smoothing), but none of these documented refits on medium/long distance.



367
368 Fig.10

369 The taphonomical study of refits perfectly aligns with the anthropogenic origin of the assemblage.
370 The abundance of small fragments in the identified clusters, the optimal preservation of brittle
371 remains, and the local or *in situ* connections exclude the possibility of accumulations due to other
372 agents. Other post-depositional modifications, such as root etching, exfoliation, and micro-cracks,
373 appear minimal across the refitted sample, consistent with findings from the overall assemblage, but
374 no significant displacement was recorded (Fig.11) (Romandini, 2012; Romandini *et al.*, 2018, 2020;
375 Terlato *et al.*, 2019).
376



377
378 Fig.11

379 The horizontal distribution of the bones, primarily found at a rather close distance or *in situ*, suggests
380 an exploitation of anatomical portions at the point where they were found during excavation. Thus,
381 they have not been subject to secondary movements by man or other important post-depositional
382 agents. A separate discussion regarding the vertical projections between refitted elements among
383 units must be tackled. The generation of profile projections is considered a key factor in the study of
384 site formation processes, though is not applied systematically in all studies (see Gabucio *et al.*, 2023
385 for more discussions). For instance, vertical profiles show the thickness and slope of the layer, the
386 possible existence of different sublayers with a greater temporal resolution, and the morphology of
387 the palaeosurface on which the layer accumulated. In addition, vertical distribution analyses help to
388 identify massive processes and differentiate between autochthonous and allochthonous assemblages.
389 The fragments affected by refits between units (mainly deer and chamois remains) show movements
390 over medium-long distances and a variation in depth between 2 and 50 cm. Since no traces are
391 attributable to trampling or water action, which may have favoured these movements, we should
392 consider that man intentionally moved them towards the areas of greatest accumulation, i.e. near the
393 eastern wall.

394 Considering the identified clusters, there is a positive skew in all the histograms, indicating a cluster-
395 based location of refits. This analysis cannot resolve whether this pattern is intentional or taphonomic,
396 but if there were no pattern, we would not expect any skew but to be flat. Moreover, the low presence
397 of post-depositional agents on the documented refits indicates that there were practically no post-
398 depositional processes during the fossilization of all contexts of A5-A6 that could have moved the
399 finds, except in some cases; therefore, the location of the bones can be defined as *in situ*.

400 The considerations discussed above lead us to affirm that the distribution patterns of refitted bones in
401 these units can largely be attributed to human activities, as corroborated by previous
402 zooarchaeological studies (Peresani *et al.*, 2011; Romandini *et al.*, 2018). The presence of percussion
403 cones, notches, and impact scars on unidentified bones further supports the evidence of an intense
404 intentional breakage, meaning that humans are the only agents responsible for bone movements,
405 especially in the case of medium/long-distance connections. Neanderthals organised their activities
406 around hearths and other anthropic features, rearranged the space, and left clear evidence of fitting it
407 and distributing activities and resources. Evidence from refits supports this conclusion: of the total
408 number of refitted elements, 96% of the connection lines are on short distance or *in situ* (72), followed
409 by medium and long (Tab.1). Short-distance connections dominate across all levels and often occur
410 in isolated areas with no connections or temporal relationships, suggesting repeated site use. These
411 indicators are related to the short-term occupation hypothesis, where the group size will likely be
412 small, based on the occupied areas' reduced surface and single hearths' presence.

413

414 **Conclusions**

415 Arrangements of artefacts and features within archaeological sites have often been employed to
416 isolate activity areas and draw inferences about site function; this assumes that objects found in
417 proximity were used for the same task and that artefacts were usually discarded where they were
418 used. In this regard, refitting studies performed at Fumane Cave provided valuable data to achieve
419 topics like assemblage formation processes, post-depositional dynamics, settlement patterns, and the
420 definition and integrity of stratigraphic units. The distribution of remains and documented connection
421 lines in the late Middle Palaeolithic context of units A5-A6 of Fumane Cave (Verona, Italy) that
422 includes refits, spatial archaeology, and multivariate statistical techniques contributed to interpreting
423 the anthropogenic use of the site during the occupation of these units, validating the degree of
424 synchronicity between hearths, other features, and activity areas. In this sense, the spatial organisation
425 of these ancient human groups reflects several types of adaptive modes in response to internal and
426 external constraints. Compared with ethnographic data, a multidisciplinary study of the
427 archaeological record, spatial analysis, and bone refits is essential to identify relevant aspects of space
428 management.

429

430 **Acknowledgements**

431 Fieldwork and research at Grotta di Fumane are coordinated by the Ferrara University (M.P.) in a
432 project supported by the Ministry of Culture – SABAP Superintendency, public institutions (Lessinia
433 Regional Natural Park, Fumane Municipality, BIMAdige), and private associations and companies.
434 This project has received funding from the European Union's Horizon 2020 research and innovation
435 programme under the Marie Skłodowska-Curie Grant Agreement N°897841. The authors are grateful
436 to Lorenzo Fattorel for the graphic modification of the figures and the rose diagram. We also thank
437 Theppa Mudiyansele Kalangi Irushika Rodrigo for revising language and grammar.

438

439 **Figures and table captions**

440 **Fig.1** Sketch of the sagittal section of the cave, with evidence of the late Mousterian (A11-A5),
441 Uluzzian (A4-A3) and earliest Aurignacian layers (A2) and of their variable content in archaeological
442 remains (increasing from light grey to dark grey and black). The units A5-A6 are marked in dark red
443 (by Cremaschi, M. & Peresani, M., redrawn by S. Muratori and modified by Fattorel, L.).

444 **Fig.2** Fumane, A5-A6 Mousterian units: 1) the setting of layer A6 in the internal area of the cave
445 (sqs. 120,125,126) constrained from the left wall (looking NE, excavation campaign 2002); 2) layer
446 A6 exposed in the western sector of the cave, with a marmot gallery in the foreground and exposure
447 of the yellowish-brown sediment patches of layer A7 due to the lack of A6 (looking N, excavation
448 campaign 2007); 3) A6 during excavation in the western sector of the cave entrance (sqs. 59-69,

449 looking W, campaign 2008); 4) transverse section in the inner eastern sector of the cave (sqs. 120-
450 126/130-136) exposing the stratigraphy from A7 to A5+A6, with ripples produced from post-
451 depositional deformation in proximity of the wall (looking NE, campaign 2002); 5) bones and chert
452 artefacts at the top of A6 in sqs. 129-126 and 137 (looking NW, campaign 2006); 6) sagittal section
453 exposed in sq. 86 showing the regular bedding of A5, A5+A6 and A6, their gradual thinning towards
454 the inner cave and layers A7 and A9 in the lower half of the section (looking NW, campaign 2006)
455 (Photo by Peresani, M., and Duches, R., graphic edit by Fattorel, L.).

456 **Fig.3** 3D plotting of refits among units (Graphic edit by Fattorel, L.).

457 **Fig.4** Vertical projection of refitted elements among units (Graphic edit by Fattorel, L.).

458 **Fig.5** Rose diagram with the orientation or refit lines related to medium- and long-distance
459 connections (Graphic edit by Fattorel, L.).

460 **Fig.6** Number of clusters identified in unit A6.

461 **Fig.7** On the left is the distribution of all archaeological remains, depending on the cluster to which
462 they belong, in each k-means analysis. The plots to the right represent the density of the distances of
463 each refit to the closest centroid of the cluster.

464 **Fig.8** Density maps showing refitted element distributions inside the identified clusters, with the
465 position and distance between all elements within each refit. Most of the refitted elements are less
466 than 2 meters apart; 15 refits are located next to each other, so there is no difference in their position
467 ($x = 0$). Only two refits have more than 4 meters of distance.

468 **Fig.9** Pie chart summarising the documented refits between *taxa*, weight-size mammals and
469 unidentified fragments, specifying the affected anatomical portions, with the relative percentages and
470 the quantity (in terms of number of remains) of anthropogenic and post-depositional traces found on
471 each refit. Forest green: post-depositional marks documented over bone surfaces. Yellow: anthropic
472 marks.

473 **Fig.10** Spatial and graphic distribution of the refits documented in units A5-A6, with NISP and
474 percentages of the taxa affected by refitting.

475 **Fig.11** Examples of refitted bones from units A5-A6. A) Red deer: anatomical refits on teeth (adult -
476 5 years) (short connection - same square); B) Red deer: shaft of radio with anthropic fracture,
477 manganese oxides and roots (short distance); C) Red deer: diaphysis of left femur with cut-marks,
478 impact point, scraping marks (long distance); post-depositional damages (trampling, exfoliation,
479 roots and weathering); D) Red deer: shaft of right femur with cut-maks (long distance); post-
480 depositional damages (trampling, concretion, fluitation, roots and weathering); E) Red deer: right
481 tibia with cut-marks and percussion notches; one of the two fragment is a retoucher. Among post-
482 depositional agents trampling, roots and manganese oxides have been document (short distance).

483 F) Red deer: diaphysis of metatarsal with cut-marks, rodent marks and post-depositional damages
 484 (roots and weathering) (long distance); G); Roe deer: diaphysis of right metacarpus + epiphysis; cut
 485 marks and anthropic fractures (short distance); post-depositional agents (exfoliation and roots); H)
 486 Ungulata: shaft of metapodial with cut-maks, weathering and exfoliation (short distance); I)
 487 Ungulata: shaft of metapodial with anthropic fracture (short distance); post-depositional damages
 488 (roots).

489 **Tab.1** Distribution of connection lines by length (m.).

490 **Tab.2** Bone refits of all levels. Legend. N°R.fr: number of refitted fragments; D (cm): distance in
 491 centimetre; CM: cutmarks; SM: scraping marks; IP: impact point; PN: percussion notches; PC:
 492 percussion cones; R: retoucher; B: burned; RO: rodents marks; T: trampling; CN: concretion; CR:
 493 corrosion; E: exfoliation; WA: water action; MO: manganese oxides; RT: roots; W: weathering.

494

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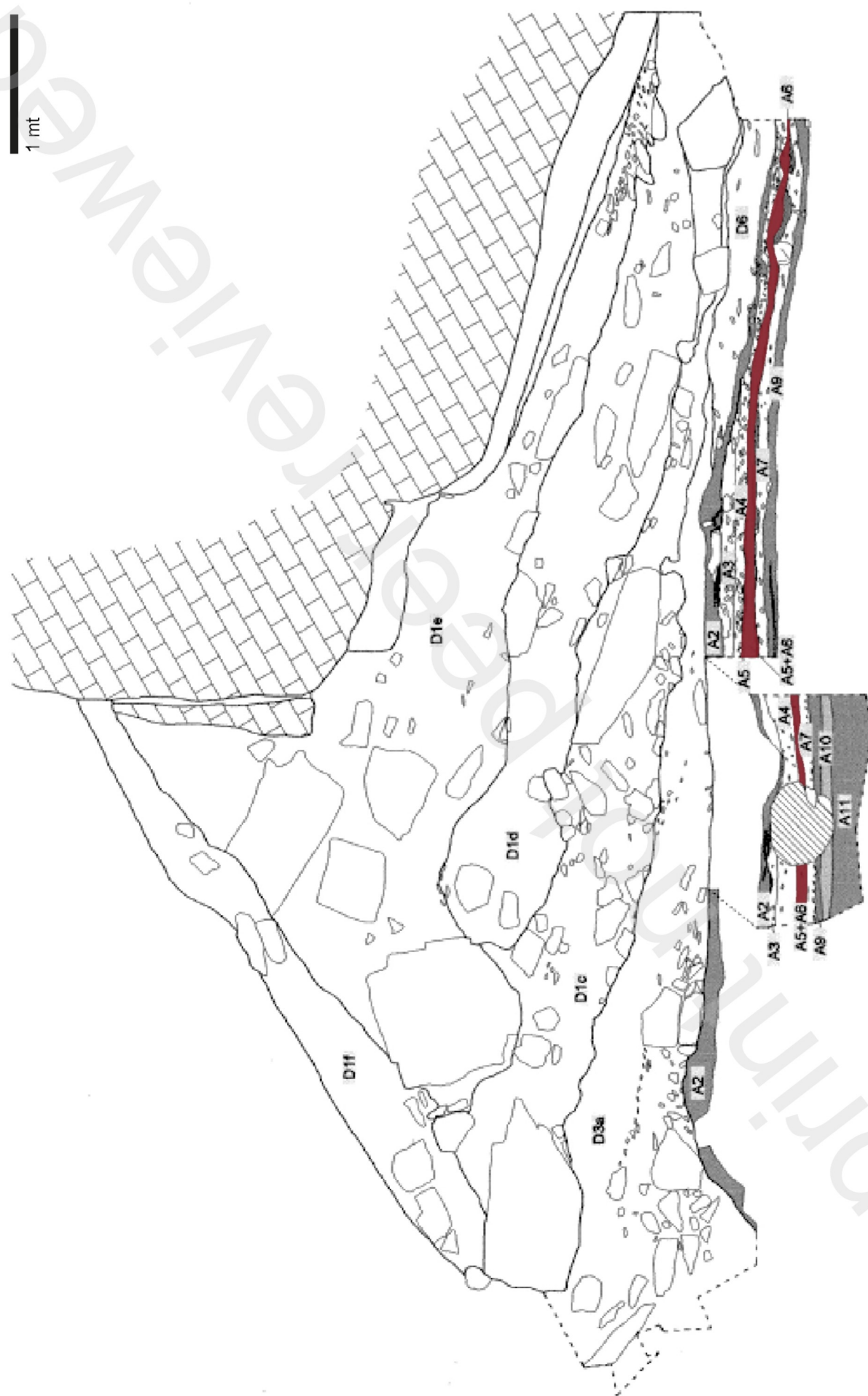
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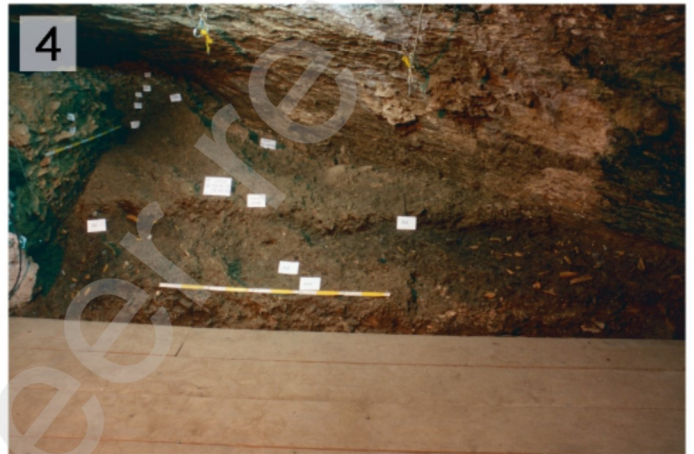
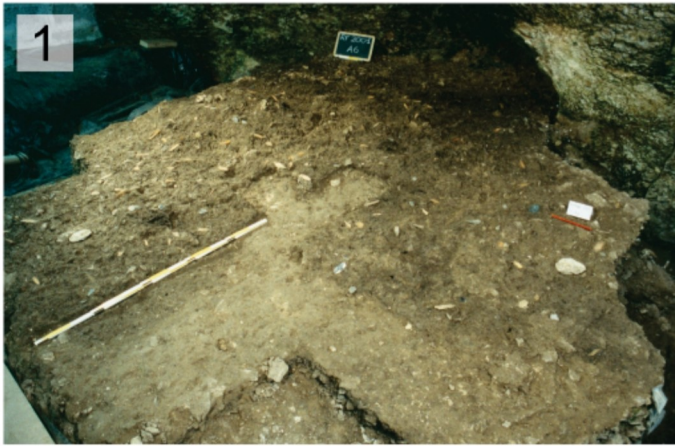
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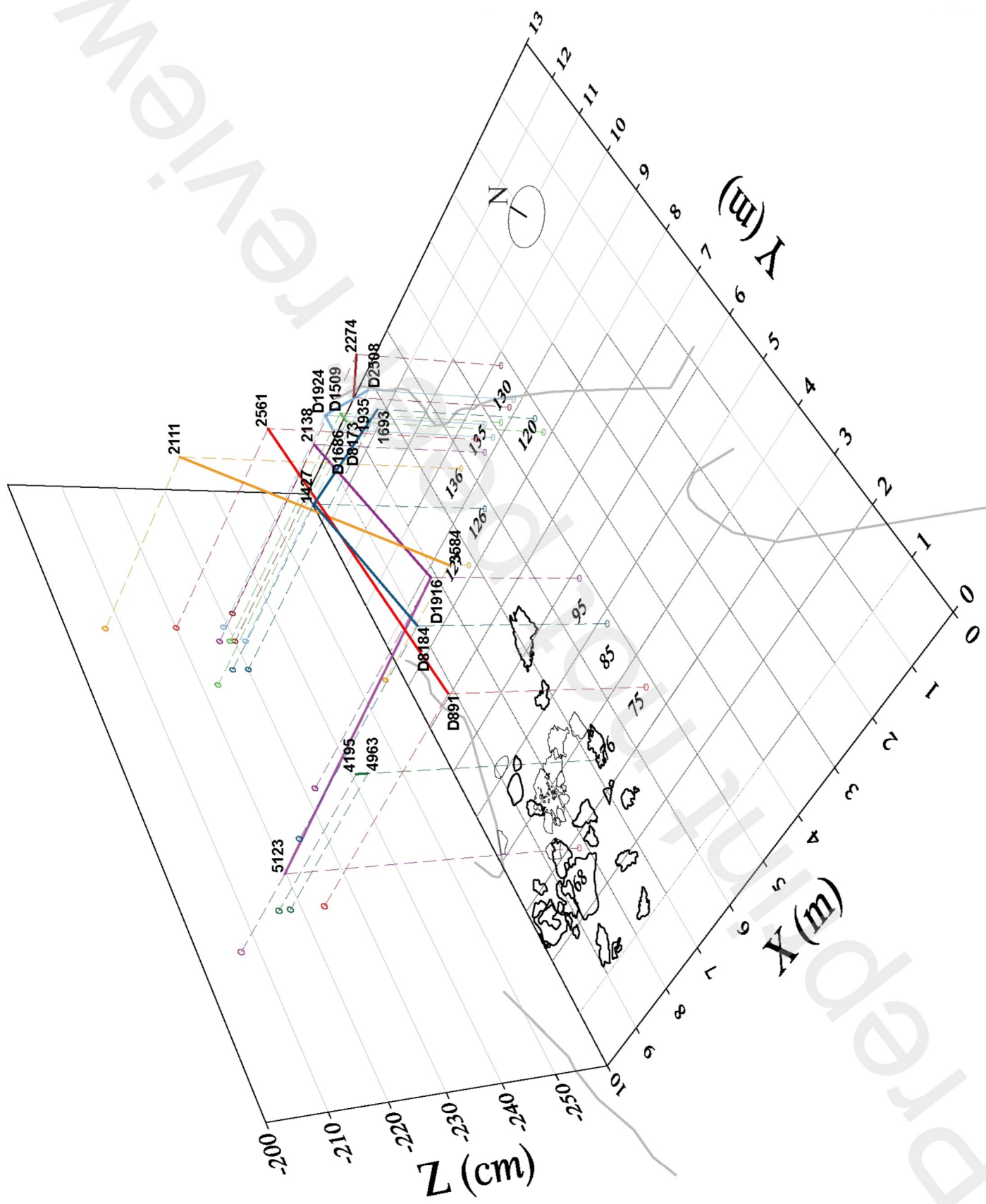
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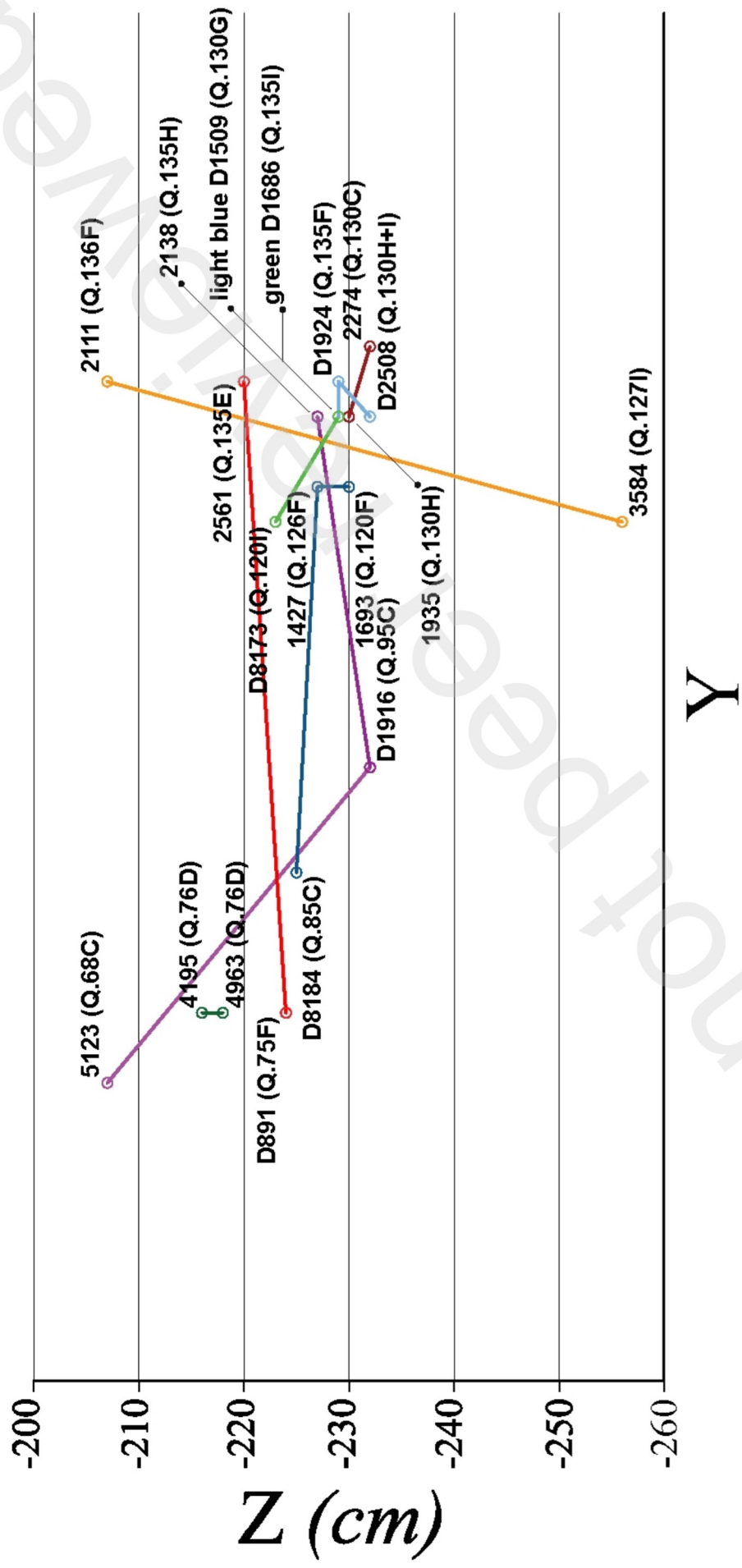
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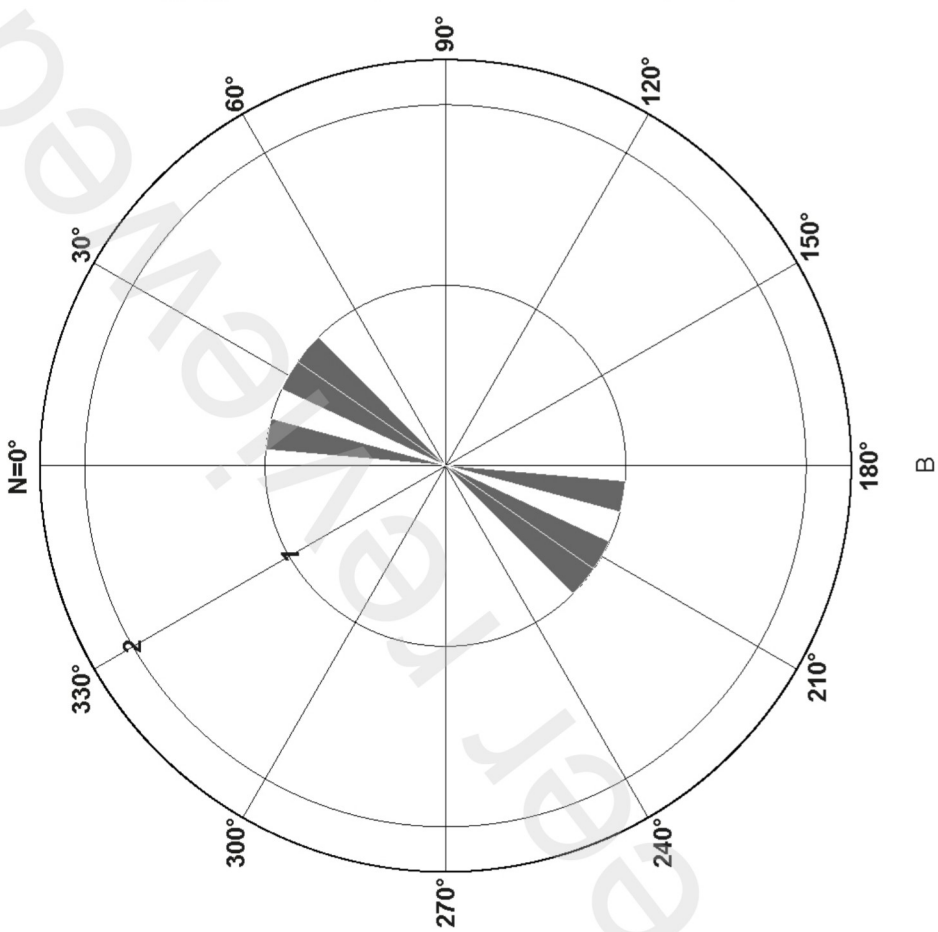
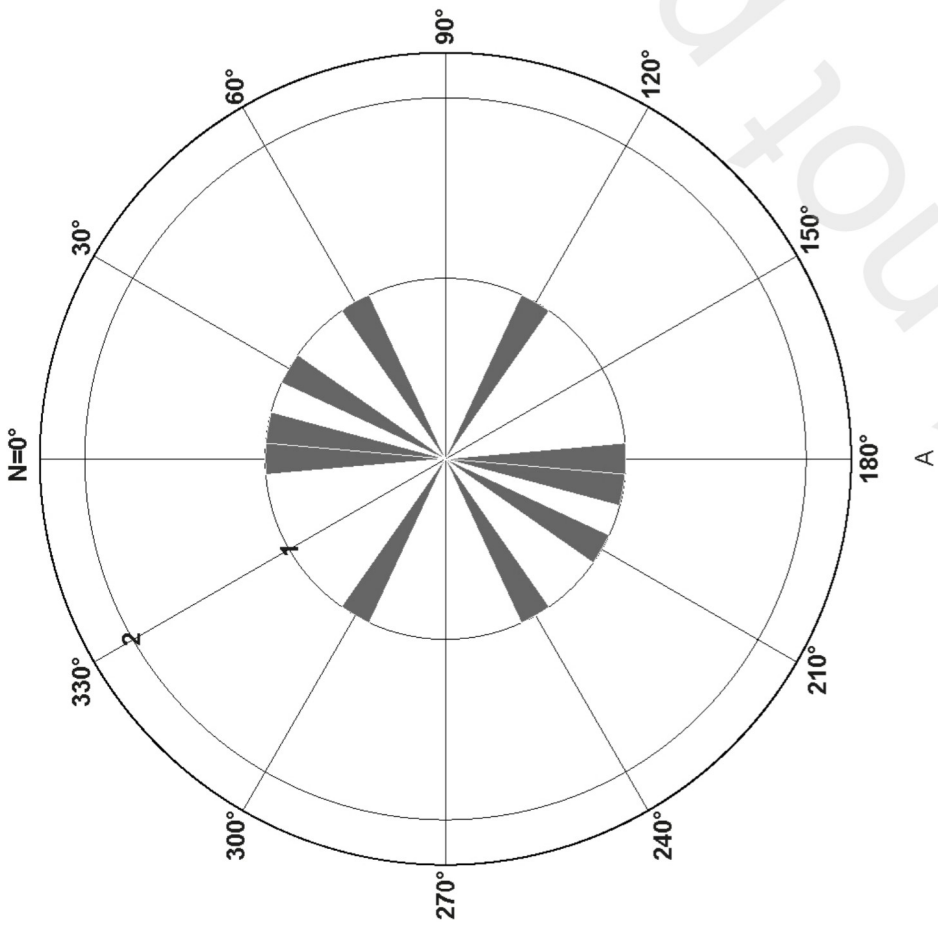
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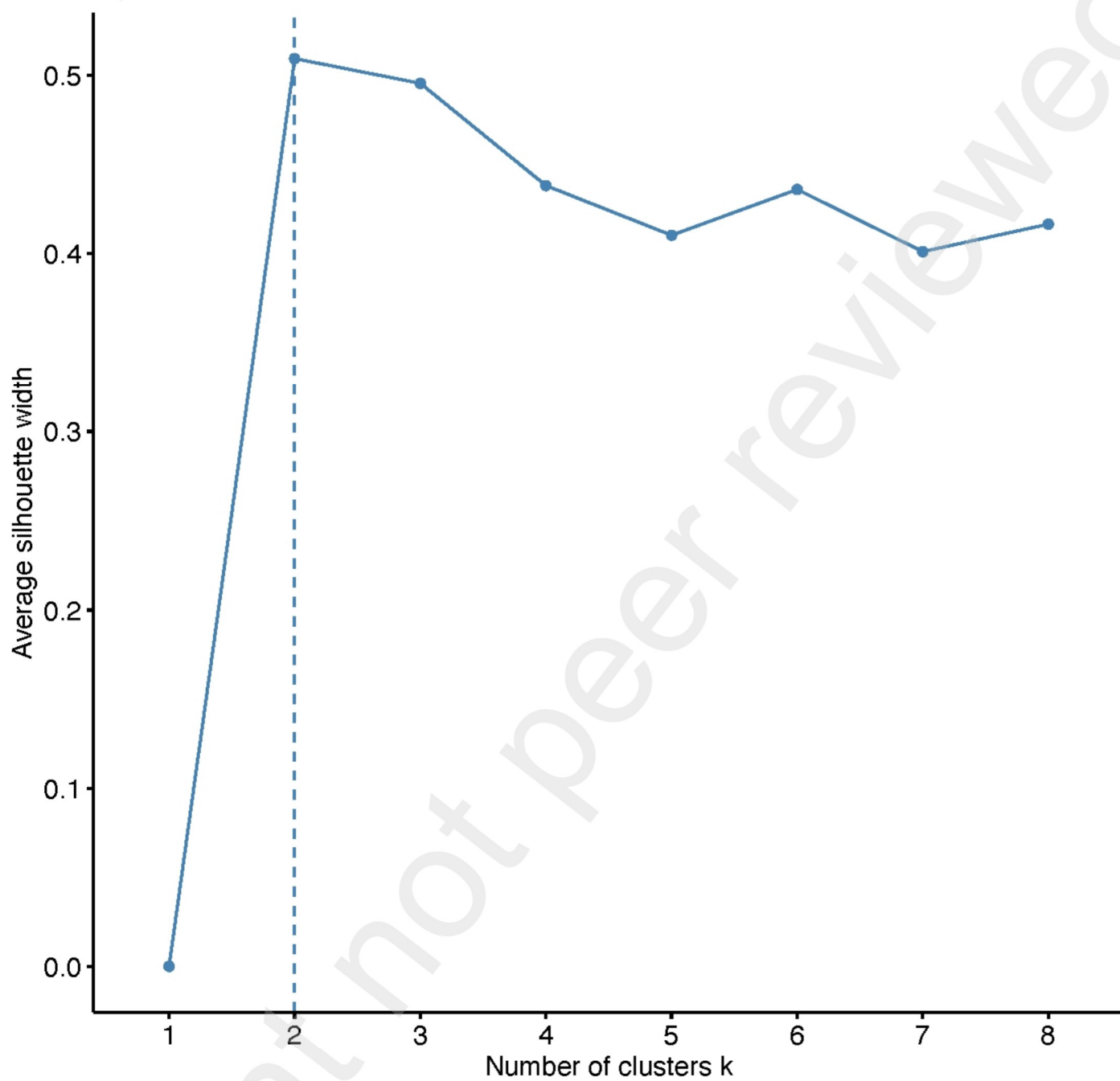




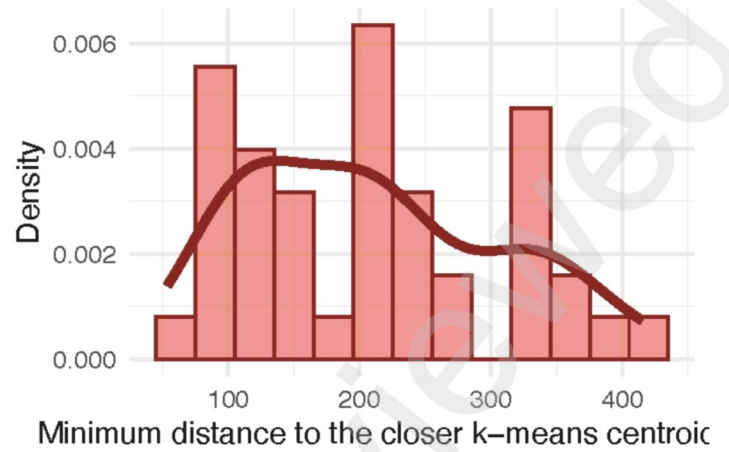
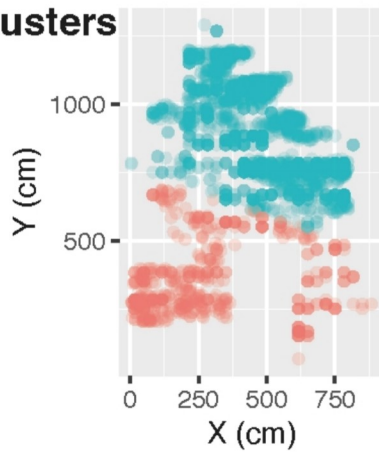




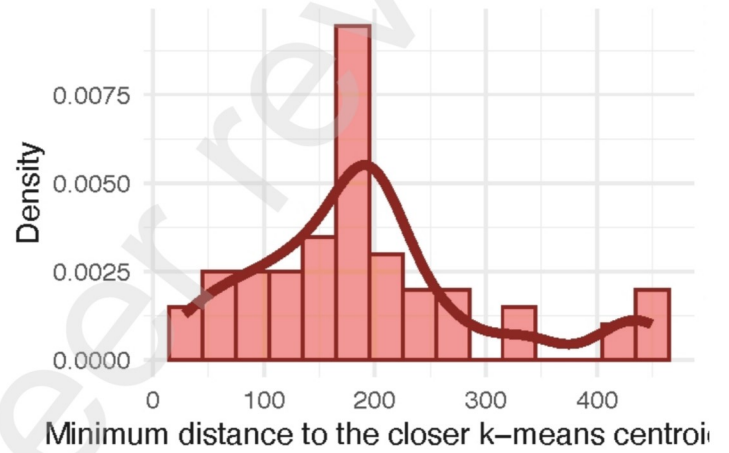
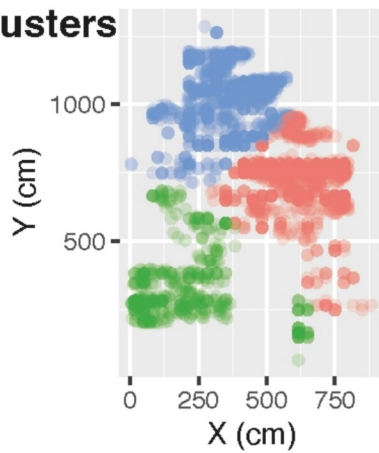
Optimal number of clusters



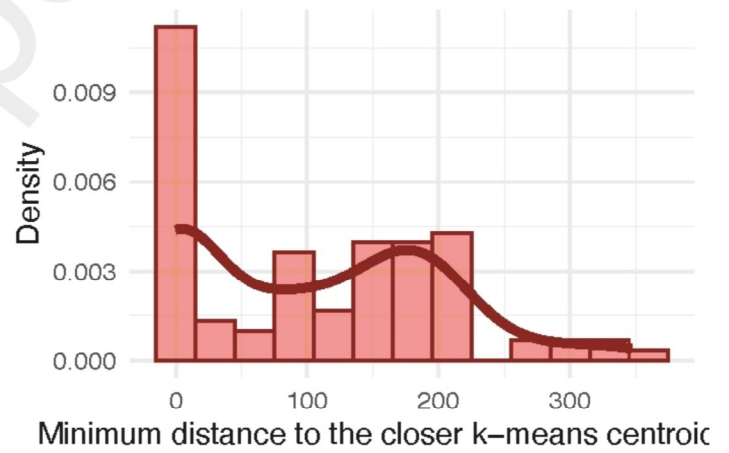
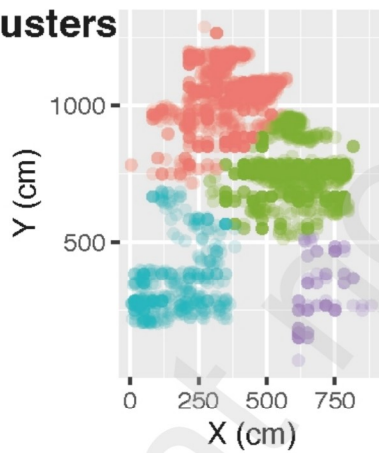
2 clusters

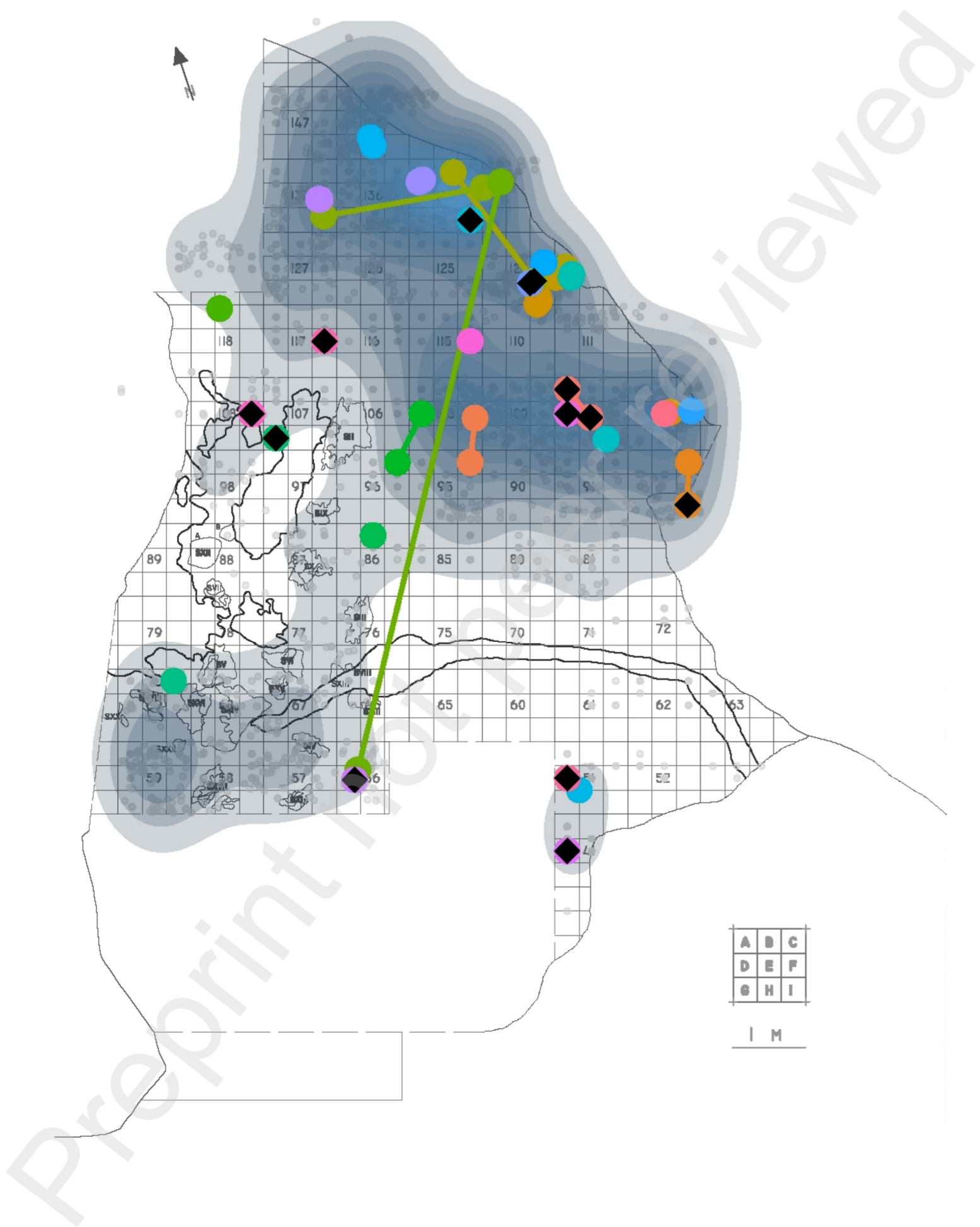


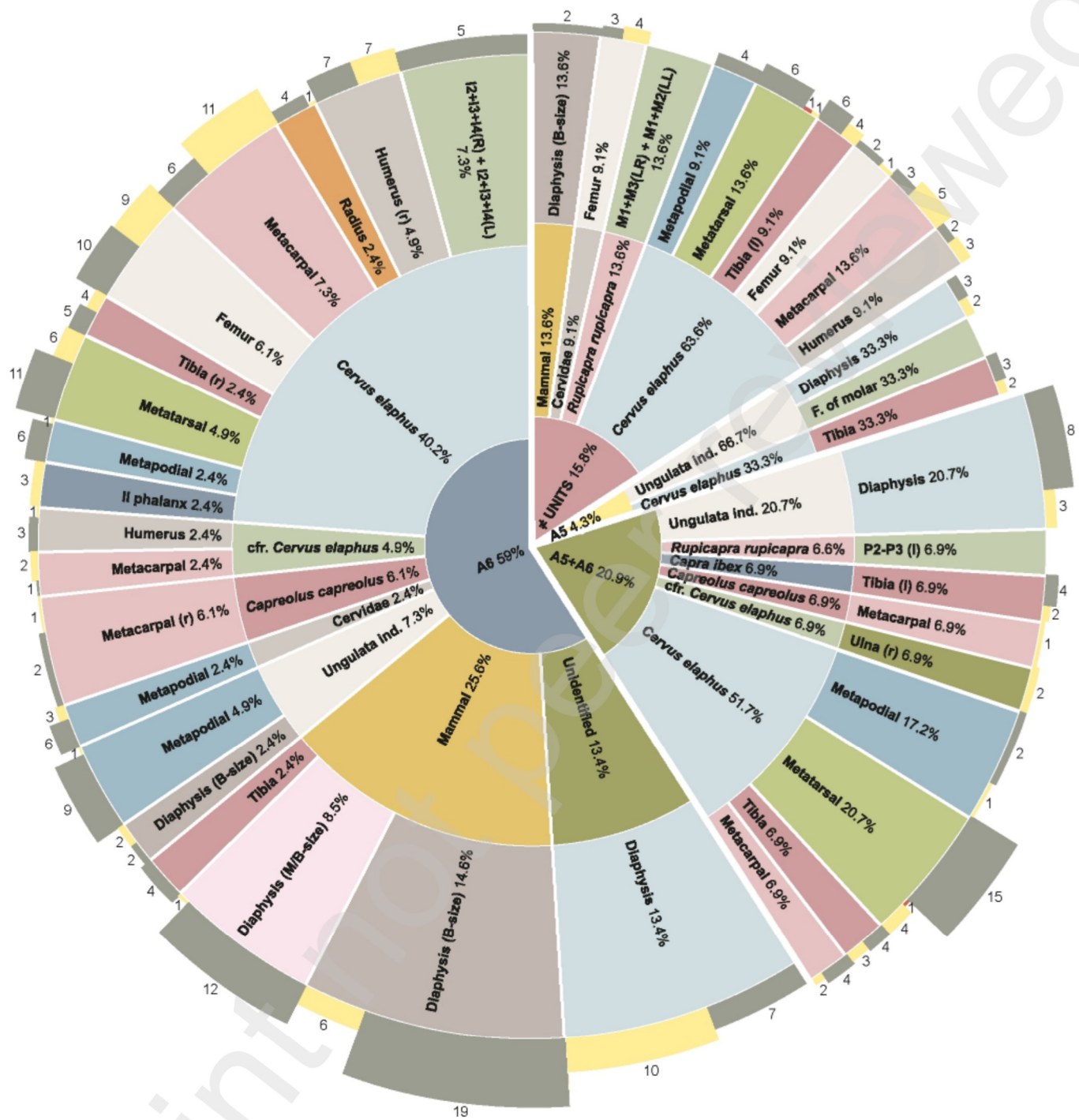
3 clusters

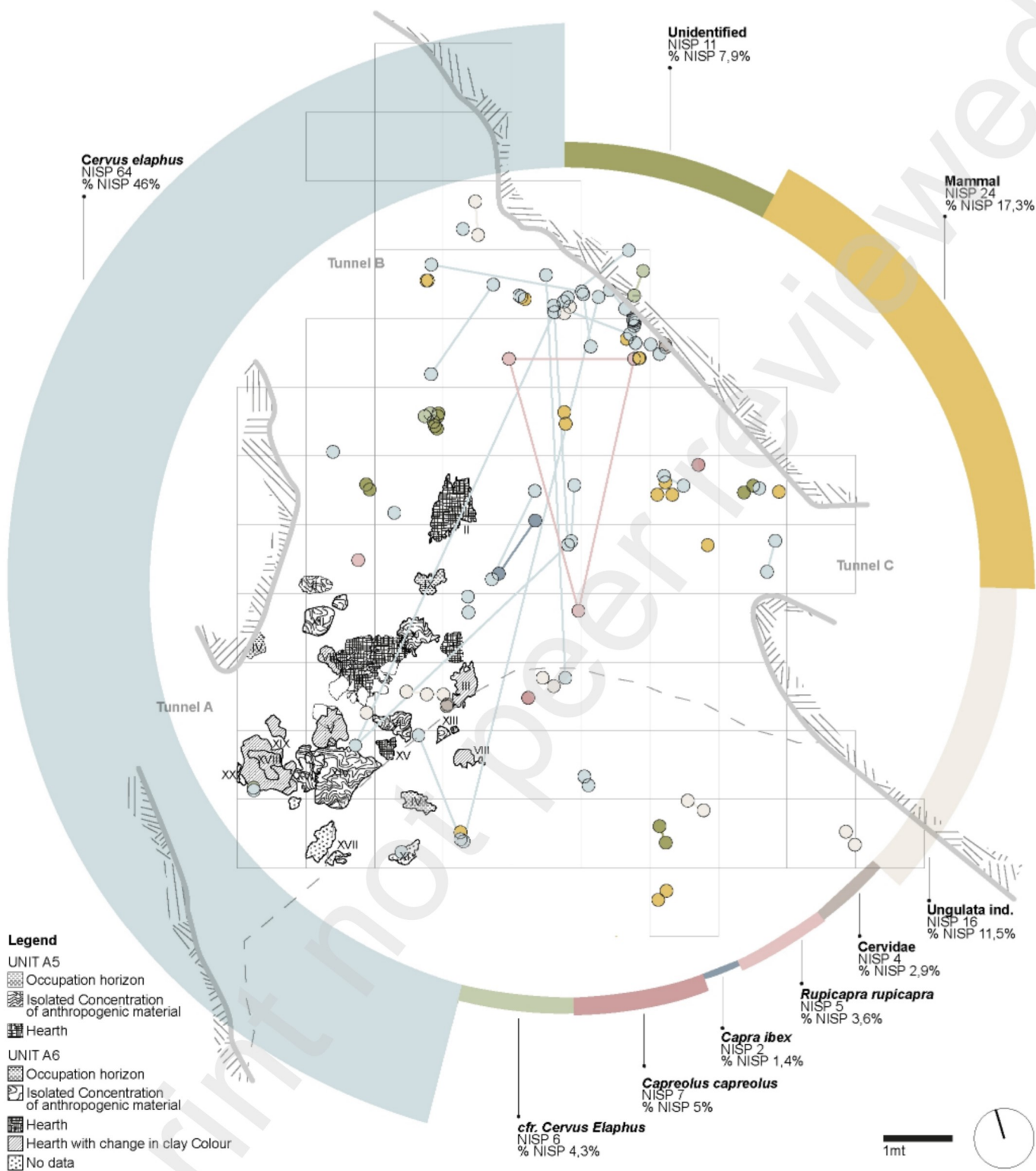


4 clusters











U.S.		Distance (m)					
		0-1	1-2	2-3	3-4	4-5	>5
6	N° c. lines	57		1			1
	%	96,61%		1,69%			1,69%
A5+A6	N° c. lines	12	1				
	%	92,31%	7,69%				
A5	N° c. lines	3					
	%	100,00%					
Totals		72	1	1			1
		96,00%	1,33%	1,33%			1,33%

U.S.	Taxa	Skeletal element	n° R. fr.	D (cm)	Anthropic modifications							RO	Post-depositional agents							
					CM	SM	IP	PN	PC	R	B		T	CN	CR	E	WA	MO	RT	W
A6	<i>Cervus elaphus</i>	I2+I3+I4 (r) I2+I3+I4 (l)	6	1,5 - 4 - 6,5 - 2 - 10												4				1
		Humerus (r)	2	46	1		1	1			1					1			2	1
			2	<i>in situ</i>	1		1	1					1					1	1	
		Radius	2	68	1													2	2	
		Metacarpal	2	<i>in situ</i>			2	1						1						1
			2	<i>in situ</i>	1									1						
			2	<i>in situ</i>	1	1	3	1	1				1	2						
		Femur (l)	3	118	1	1	1	1	2		1		2			1			1	1
			2	221	2								1	1				1	1	1
		Tibia (r)	2	142	1			2		1			1					2	2	
	Metatarsal		2	31,5	1						2		1			2		1	2	1
			2	81	1		1	1										1	2	1
	Metapodial	2	814	1										2		2			1	1
	II phalanx	2	<i>in situ</i>								3									
	cfr. <i>Cervus elaphus</i>	Humerus	2	9				1							1				2	
		Metacarpal	2	<i>in situ</i>	1			1										1		
	<i>Capreolus capreolus</i>	Metacarpal (r)	5	<i>in situ</i>	1											1			1	
	Cervidae	Metapodial	2	4	2	1								2					2	2
	Ungulata ind.	Metapodial	2	27										2					2	
			2	49	1									2		2				1
		Diaphysis (B-size)	2	12							2								2	
		Tibia	2	<i>in situ</i>									1	1		1				1
	Mammal	Diaphysis (M/B-size)	3	1										2					1	2
			2	<i>in situ</i>							1				1				1	
			2	17									1					1	2	1
		Diaphysis (B-size)	3	<i>in situ</i>							1									1
			2	6									1				2	1	2	2
			2	2									1		2	1	2	2		1
			2	17							2								1	
			3	20 - 21 - 22							3									
	Unidentified	Diaphysis	2	9							2									2
			5	5 - 6 - 10 - 11 - 13 - 14 - 18 - 18 - 22					3		3								2	
			2	25,5							2									
			2	16,5										2					1	
A5+A6	<i>Cervus elaphus</i>	Metacarpal	2	43					2					2					2	
		Tibia	2	<i>in situ</i>	1			1		1			1					1	1	1
		Metatarsal	2	<i>in situ</i>									1					1	1	1
			2	163	1							1		1	1			1	2	
			2	35	1	1					1			2				2		2
	Metapodial	5	<i>in situ</i>	1												1				1
	cfr. <i>Cervus elaphus</i>	Ulna (r)	2	38							2									
	<i>Capreolus capreolus</i>	Metacarpal	2	<i>in situ</i>							1									
	<i>Capra ibex</i>	Tibia (l)	2	93	2													1	2	1
	<i>Rupicapra rupicapra</i>	P2-P3 (l)	2	<i>in situ</i>																
	Ungulata ind.	Diaphysis	2	<i>in situ</i>										1					1	1
			2	23	2			1						1					2	
			2	20										2						
A5	<i>Cervus elaphus</i> Ungulata ind.	Tibia	2	<i>in situ</i>	1					1				1		1			1	
		Fr. of molar	2	53																
		Diaphysis	2	<i>in situ</i>	1			1										1	1	1

A6 SXI + A7	<i>Cervus elaphus</i>	Humerus (r)	2	<i>in situ</i>	1	1	1								1		1			
A5+A6 + A6	<i>Cervus elaphus</i>	Metatarsal	3	339 - 423 - 691	1						1	1					2	3		
		Metapodial	2	158									2				2			
A6 + A5+A6	<i>Cervus elaphus</i>	Metacarpal	3	8 - 112 - 120	1	1	3										3			
		Femur	2	76,5		1						1					1			
		Tibia (l)	2	585	2	1	1				1				1	2	2			
	<i>Rupicapra rupicapra</i>	M1+M3 (lower – r) + M1/M2 (lower – l)	3	181,5 - 374,5 -379																
A5+A6 + A5+A6/A 6	Cervidae	Femur	2	8	2	1	1					1					2			
A4II + A5+A6	Mammal	Diaphysis (B- size)	3	<i>in situ</i>								1						1		
TOT.			139		34	4	10	17	8	5	31	2	14	32	7	17	5	21	59	35