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ORIGINAL PAPER

Refitting bones to reconstruct the diversity in Middle Palaeolithic human occupations: the case of the Abric Romaní site (Capellades, Barcelona, Spain)

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Abstract

The composition and organisational patterns of Pleistocene human groups are a main research when it comes to the evolution of human behaviour. However, these studies are often limited by the restricted characteristics of the archaeological records and do not show enough resolution to make approaches with the necessary precision. The travertinic formations of the Abric Romaní site (Capellades, Barcelona, Spain) provide an ideal scenario to answer some questions about the European Middle Palaeolithic occupational patterns. The hearth-related accumulations from this site show many similarities with those generated by several contemporary forager groups, so each could represent the activity area of a specific social unit. This work contributes to the existing research by examining the faunal refits recovered in six stratigraphic units (H, I, J-Ja, K, L and M) that cover the chronological period between 44 and 55 ka. Faunal refits are analysed using the metric parameters of ethnographic hearth-related accumulations (the hearth itself and its corresponding drop and toss zones); significant relationships are found between many of these elements and the areas of influence of the hearths. In addition, connections between the activity areas from these refits are seen in several stratigraphic units. This phenomenon allows for greater diversity in the occupational patterns of this site to be identified than those recorded only from taphonomic studies. From this perspective, two main occupational models are proposed: (1) the simple model, in which isolated and unconnected hearth-related accumulations are identified (units H, L and—to a lesser extent—K) and (2) the complex model, primarily represented by the identification of several long-distance faunal refits connecting different activity areas (units I, J-Ja and M). Thus, this work provides deeper insights into the behavioural diversity of Middle Palaeolithic human groups, their social organisation and composition and their evolution in the region.

Keywords Faunal refits · Hearth-related accumulations · Occupational patterns · Middle Palaeolithic · Abric Romaní

Introduction

An intrasite management analysis is one of the main archaeological tools used to uncover the details of past human behaviour. The initial research related to this issue was based on direct readings of maps that identified the relationships between objects, empty areas and possible structures (or similar elements) (e.g. Clark 1954; Leroi-Gourhan and Brézillon 1966, 1972; Leakey 1971). The interpretation of these associations was understood as a reflection not only of the cultural and technological capabilities of the human communities in each of the studied periods but also of the action of other non-anthropogenic taphonomic phenomena, such as animal activities, vegetables or post-depositional processes. Over time, these types of studies have been progressively enriched by the incorporation of data from other disciplines, chiefly by the application of statistical tests such as multivariate analyses of variance and nearest-neighbour or *k*-means tests, among others (e.g. Whallon 1973, 1974; Rigaud and Simek 1991).

Actualistic comparisons, which are mainly those based on ethnoarchaeology, have been a basic approach in the

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interpretation of results. Most observations describe a generalised pattern among which current and subcurrent forager groups are organised by the familial units around a fireplace (Yellen 1977). From this point of view, hearths appear to act as cohesive elements for the members of the group at the social level and, by extension, as main focus of many of the domestic activities carried out in settlements, such as in the preparation and consumption of food and the development of tools. This situation has been observed among geographically separate groups, including, among others, the Kua San (Bartram et al. 1991), !Kung (Yellen 1977), Hadza (O'Connell 1987; O'Connell et al. 1991) and Efe Pygmi (Fisher and Strickland 1991) in Africa, Alyawara (O'Connell 1987) in Australia and Ache (Jones 1993) and Inuit (Binford 1978, 1983) in America. Places shared by different social units (or families) usually follow a similar pattern. Individual social units organise around their hearth, leaving empty spaces that are considered communal and are used for leisure activities or to share products, among other functions. In most cases, therefore, each hearth can be understood as a posteriori as the product of a social unit (Gron 1991).

Based on observations carried out among the Inuit, Binford (1978) divides these domestic activity areas into three main subareas: (1) the hearth itself, (2) a drop area where group members congregate and conduct activities and (3) a toss area where waste is thrown, which is usually located behind the individuals. Binford uses the hearth centre as a reference point to provide radial measures of each subarea and reports that the drop area usually occupies the space between 0 and 1.2 m from the hearth's edge, while the toss area appears to be more external, mainly between 1.5 and 2.5 m from the hearth's edge. Although these measures are clearly subject to significant variables (such as the number of group members, their corporal volume and floor topography), the measures can generally be used to establish a valid model.

From an archaeological perspective, the role played by hearths as nuclear activity areas shares features with the hearth-related accumulations observed at many sites where fire is common, primarily during the Middle and Late Palaeolithic (Rolland 2004). Vaquero and Pastó (2001) used the well-preserved conditions of the Middle Palaeolithic upper stratigraphic units of the Abric Romaní (Barcelona, Spain) to describe the distinctive characteristics of the archaeological materials recovered around hearths, which can be extended to many other assemblages of the same period (see, e.g. Tor Faraj in Henry 2003). According to these researchers, the lithic and faunal remains located around hearths are often distinguishable by their small size: small flakes and fragments that are the result of knapping, configuration and bone breakage activities. On the contrary, larger objects that are more suitable for use and, therefore, more easily moved are usually located in more remote areas. Vaquero and Pastó (2001) interpreted the associations among these larger objects as a combination of cleaning activities and disposal after use in the production areas. The similarities between the archaeological record and the drop/toss ethnographic model observed by these researchers have led them to propose an extremely early origin date for these people's behavioural patterns using fire, which, according to new data, may even predate the Middle Palaeolithic (Blasco et al. 2016).

The living floors observed in archaeological sites, however, are usually the result of multiple and overlapped events (palimpsests), which adds a significant level of complexity to understanding how the space was used. In this respect, one of the main problems is how to establish whether different hearth-related accumulations are contemporaneous. Understanding these types of relationships would help to infer some aspects about the social composition of human groups. In the case of Abric Romaní, lithic refits have been used as a key tool to identify the connections between areas and to observe the preferential directions of tool movements (e.g. cores vs. flakes) (e.g. Vaquero et al. 2007, 2012, 2017; Romagnoli and Vaquero 2016). However, lithic materials can be subject to reuse and recycling processes that can be widely separated timewise. This occurrence has frequently been observed in different assemblages of Abric Romaní, hence reducing the ability of lithic refits to establish temporary criteria between areas (Vaquero et al. 2007, 2015).

Faunal refits from this site have been examined with the same objective. Research into several assemblages shows the significant and regular intrasite mobility of bone fragments (Fernández-Laso 2010; Rosell et al. 2012a, b; Gabucio et al. 2016; Modolo and Rosell 2017). Most of the interpretations derived from these studies are still based on the direct view of the connection lines traced between the refitted elements. However, the relationship between the various refitted objects and their respective hearth-related accumulation has always been made following the untested criteria of proximity. The present work contributes to these previous studies by considering this issue from three different perspectives: (1) establishing the relationship of the refitted fragments to the nearest activity area by using the metric features described in the *Mask Camp* by Binford (1978), (2) identifying the possible contemporaneous relationships between the activity areas using faunal refits and (3) contributing to understanding the motivation for mobility between areas with faunal fragments. Nevertheless, the comparison between the different stratigraphic units requires a better understanding of their main zooarchaeological features in terms of the type of prey and transport and consumption decision making. These aspects could vary from group to group because of external causes, such as climatic variations and the subsequent transformations of the environment, or because of changes in the cultural and social patterns of the groups (Blasco et al. 2013a, b); these aspects have been largely discussed in several works, specifically those related to the Abric Romaní (e.g. Fernández-Laso

2010; Rosell et al. 2012a, b; Gabucio et al. 2016; Marín et al. 2017; Modolo and Rosell 2017).

The main aim of the current work is to validate bone refits as another tool to understand the composition and occupational patterns developed in the different assemblages of the Abric Romaní site. In this respect, applying taphonomic techniques to the different studied assemblages and doing so specifically to the refitted bones helps test the origin (and intentionality) of such movements. The aim here is to avoid possible misinterpretations, as has been noticed by some authors in other sites where the main movements of the objects seem to respond to causes other than anthropogenic, such as from animal activity or geological and post-depositional processes, that is, debris flow and water transport (e.g. Villa 1982; Todd and Stanford 1992; Morrow 1996).

The Abric Romaní rock shelter

The town of Capellades (Barcelona, Spain) is built on a travertine platform that was generated by regional aquifer springs during the Lower and Middle Pleistocene (Giralt and Julià 1996; Vallverdú et al. 2012). Its coordinates are 1° 41′ 30″ longitude E and 41° 32′ latitude N, and it is located 265 m a.s.l. (Fig. 1). During the formation of this travertine platform, water drained through several cascades into the Anoia River via a cliff about 30 m high on the east side. These conditions generated a distinct cliff morphology (known today as *Cinglera del Capelló*), which resulted in multiple rock shelters.

The Abric Romaní is part of this complex of travertinic shelters. The site, discovered in 1909 by Amador Romaní, is known primarily for its Middle Palaeolithic record and is located at the northeast end of the *Cinglera del Capelló*. From a sedimentary point of view, the site is filled by a succession of travertine platforms that were generated largely by water surges located by the walls. These travertine platforms cover the entire surface of the site and are separated from one another by fine detrital deposits of silt, clay and red sand that were deposited during dry periods (Fig. 2). Thus, the archaeological layers can be found inside these interbedded detrital sediments. The travertinic platforms are ~ 50 m thick and have been dated by U-Series and ^{14}C AMS as being between 110 ka at the bottom and 40 ka at the top (Bischoff et al. 1988; Vaquero et al. 2013; Sharp et al. 2016).

Hearths are one of the most common archaeological elements that have been recovered from Abric Romaní. Usually, these structures are flat and without recognisable elements of preparation; only a few specific cases have identified associations constructed with travertine blocks. Lithic assemblages are mostly made from local raw materials: chert, quartz and limestone. Flakes, which are occasionally modified into denticulates, are the most common artefacts. Cores have been recovered in scarce numbers from all assemblages, and they usually show advanced cases of exploitation. This phenomenon, together with the high number of small flakes, indicates the significance of the site's knapping and retouching activities. In contrast, important intra- and extra-site stone tool mobility at several archaeological units has been identified thanks to the discovery of isolated objects, the absence of elements configured at the site and several instances of use and reuse of previously patinated or burned artefacts (Vaquero et al. 2007).

Materials and methods

The present study examines the faunal refits from stratigraphic units H, I, J–Ja, K, L and M, which cover the chronological period between 44 and 55 ka (Vaquero et al. 2013) (see Fig. 2). Many of these data have been previously discussed in other works (e.g. Rosell et al. 2012a, c; Fernández-Laso 2010; Vaquero et al. 2017). All assemblages were excavated following a modern methodology based on the simultaneous intervention of the entire site surface and the 3D location of all recovered objects (~ 10 mm) (Table 1).

The zooarchaeological and taphonomic characteristics of the archaeological assemblages presented here have also been published in several separate works (e.g. Cáceres et al. 1998; Vallverdú et al. 2005; Rosell et al. 2012a, b, c; Fernández-Laso 2010; Vaquero et al. 2017). The samples were quantified following the main standards defined by several authors: number of identified specimens (NISP), minimum number of elements (MNE) and minimum number of individuals (MNI). MNE is calculated according to the age, portion and size of the bones; MNI is obtained chiefly from the repetition of dental pieces and the reconstruction of dental series according to the individuals' age at death. These indices provide the data required to establish the percent of skeletal survival rate (%SSR) and percent of minimal anatomic units (%MAU), which are used to estimate the proportion between the recovered and expected elements (%SSR) and the main represented elements according to their abundance (%MAU) (e.g. Brain 1969, 1981; Grayson 1984; Lyman 1994, 2008a). Unidentified remains are classified according to their morphological criteria—long, flat and compact bones—hence allowing for a more accurate view of the assemblages. The remains can be separated into very large-sized (> 1000 kg), large-sized (1000–300 kg), medium-sized (300–100 kg) and small-sized animals (< 100 kg) by considering the weight of the identified ungulates.

Horses and red deer are the most dominant ungulates in all of the studied assemblages (in NISP, MNE and MNI) although a slight increase of aurochs in the lower units is observed (Table 2). Other ungulates, such as proboscidean, rhino and chamois, are also documented but in smaller proportions. Therefore, the assemblages of Abric Romaní are composed mainly of large- and medium-sized ungulates, with the

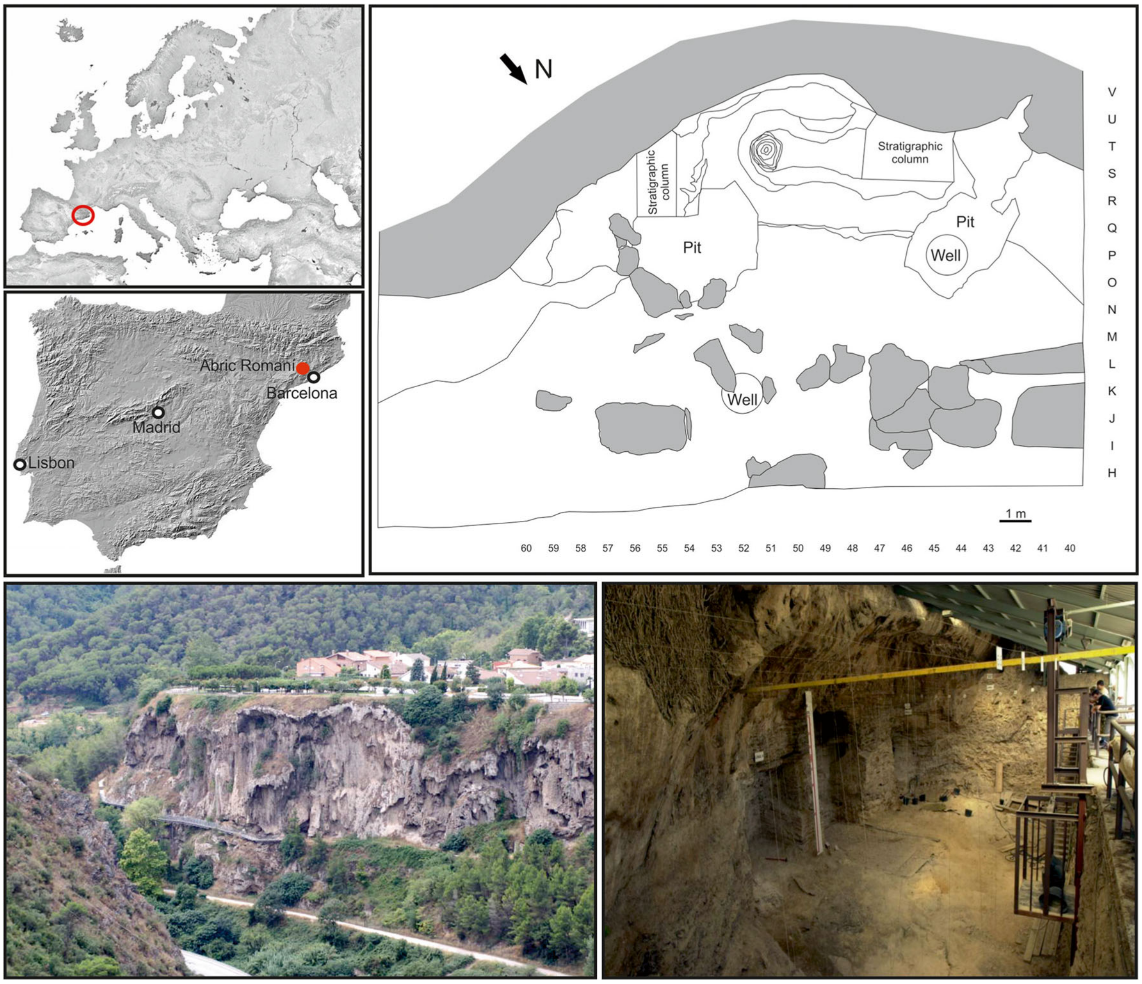

Fig. 1 Location of Abric Romaní in Europe and a map of one of the surfaces of the site (unit J–Ja). At the bottom is the view of the Cinglera del Capelló (left) and a view of the surface of unit M (right)

occasional presence of very large- and small-sized animals. In contrast, carnivores correspond to isolated individuals and show a higher diversity at the taxonomical level. Some are located inside the travertinic tufa and hence are unrelated to the archaeological contexts. These remains indicate the use of the rock shelter as a den or refuge during some site formation periods. Other remains, however, appear inside the archaeological assemblages although only two cases show the presence of cut marks on their bones that would indicate direct contact between the animal and human groups (Saladié and Aïmene 2000; Gabucio et al. 2014). The rest of the remains seem to correspond to natural intrusions during periods without human presence. These individual remains, together with the evidence of their activities (carnivore tooth marks and coprolites), display the palimpsest character of most of the assemblages.

The faunal assemblages in this archaeological context are composed mainly of mid-shafts of long bones of large- and medium-sized animals. Maxillae, mandibles and isolated teeth are also common. In contrast, axial bones (pelvis, vertebrae, ribs and flat bones in general) are exceedingly scarce in all of the assemblages (Tables 3, 4 and 5). The isolated teeth, maxillae and mandibles indicate that prime adults are the most represented individuals although the occasional remains of immature and aged animals have also been recovered. However, the high degree of bone fragmentation (~ 80% of the 3D-located fragments did not exceed 5 cm in maximum length) that has resulted in a low percentage of identification must be considered. The bones identified at the anatomical and taxonomical level never exceed 16%. Instead, the ends and shafts attached to the ends are quite scarce. These bone parts never represent more than 3% of the total bones in all of the assemblages and usually are small fragments or isolated portions of spongy tissue of reduced dimensions.

According to the criteria set by Villa and Mahieu (1991), a high percentage of bones broken in fresh state describes right and oblique angles and curved edges, and the surfaces are usually smooth. These features can be observed in ~ 70% of the analysed bones in all of the assemblages. On the contrary, dry fractures (~ 30%) seem to correspond to different

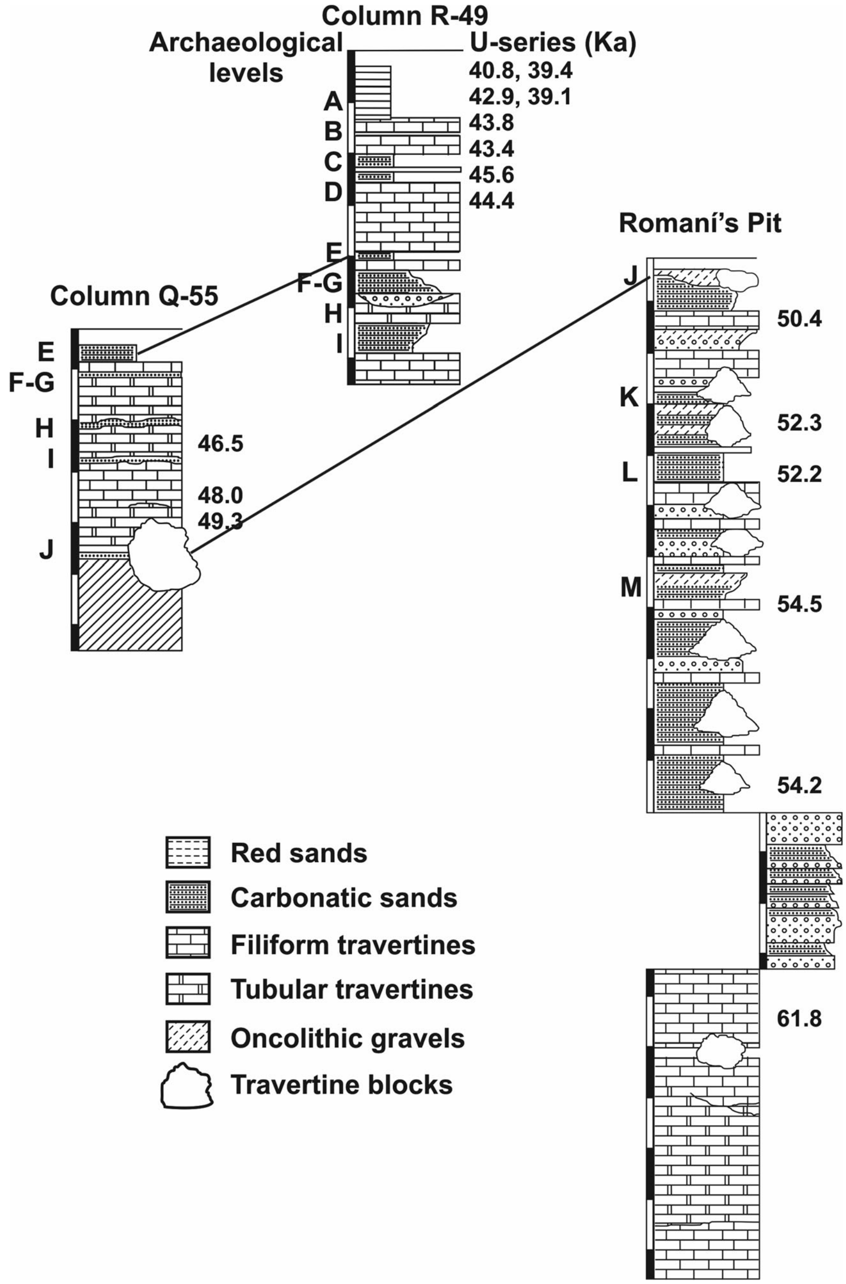

Fig. 2 Synthetic stratigraphic sequence from the Abric Romaní archaeological site

processes; of these, fire appears to play a role because the way fire rapidly dries remains produces high fragility in bones. In addition, other processes, such as trampling and weathering, must also be considered. Burning damage is the most significant anthropogenic damage among all the assemblages, with a general average of 44.9% of the total remains. This damage can be observed in different degrees for all of the assemblages, per the criteria described by Stiner et al. (1995). However, this modification seems to be stronger in the lower units: the average for units H, I and J-Ja is 35.3%, while the same value for units K, L and M is 54.4%.

Evidence of anthropogenic bone breakage is also common (average of 8.1%) (Table 6). This modification is analysed using the criteria described by several authors (see, e.g. Blumenschine and Selvaggio 1988; Capaldo and Blumenschine 1994; Pickering and Egeland 2006; Blasco et al. 2014). Notches and impact flakes are the most common evidence although percussion pits, adhered flakes and peeling are also recorded but not as frequently. Cut marks are also present, here with an average of 5.9% for all of the studied assemblages. Most cut marks are isolated and clustered incisions on mid-shafts. Scraping and saw marks have occasionally been recorded as well.

Carnivore activity appears to be scarce in all stratigraphic units. Tooth marks are analysed following the criteria proposed by several authors (see, e.g. Haynes 1980, 1983,

Table 1 Main archaeological features of the stratigraphic units and faunal refits

Stratigraphic unit	Used surface (m^2)	No. lithics	Fauna (NISP)	Identified hearths	Identified hearth-related areas
H	220	320	1164	9	8
I	225	555	1833	18	8
J–Ja	300	5446	6738	52	8
K	279	1796	2570	25	5
L	260	1191	1002	23	7
M	247	6087	7656	37	6

1988; Binford 1981; Stiner 1994; Blumenschine 1995). Only at unit K does the number of tooth marks reach 3%, while in the other units, carnivore activities never exceed 1% of the total number of bones. Regarding post-depositional processes, the presence of root-etching and eroded edges on some bone surfaces appears to be indicative of water and vegetable roots during the formation of the site. These processes seem to have occurred with a different intensity in each archaeological unit and sometimes are relatively located at the spatial level.

Faunal refits are made in the current study following the methods established by Fernández-Laso (2010). Based on the Lyman's (1994, 2008b) works, Fernández-Laso (2010) established four types of faunal refits: (1) mechanical refits by conjoining fragments, (2) anatomical refits, (3) bilateral pairs and (4) intermembral refits. The characteristics of the faunal assemblages presented here are composed mainly of fragments from the mid-shafts, with an almost total absence of epiphyses and axial bones (vertebrae, ribs and pelvises) —this has led mainly to mechanical refits, and in the case of the dental series, to anatomical refits. These refits involve all of the diaphyseal fragments larger than 2 cm. To identify the activity areas where the bones were broken, smaller bone flakes resulting from intentional breakage are also included because of their spatial and technical significance.

The methods used in the current study consider the spatial position of the involved specimens and their correspondence to specific hearth-related areas. To simplify the work, faunal fragments are grouped by their taxa and anatomical portions. In the case of unidentified mid-shafts, these are classified by weight sizes (large- or medium-sized animals). Bones are tested square by square, progressively extending the test to the surrounding squares of the same hearth-related area. This

Table 2 Macro-mammals from Abric Romaní classified by archaeological units

	Unit H			Unit I			Unit J–Ja			Unit K			Unit L			Unit M		
	NISP	MNE	MNI	NISP	MNE	MNI	NISP	MNE	MNI	NISP	MNE	MNI	NISP	MNE	MNI	NISP	MNE	MNI
Equus ferus	101	22	2	83	16	9	351	88	15	56	15	4	34	9	4	58	15	6
Equus hydruntinus	2	2	1															
Cervus elaphus	53	33	2	168	42	6	497	202	12	335	72	8	96	39	5	479	110	9
Bos primigenius				3	2	1	88	47	5	15	9	1	6	6	1	15	10	3
S. hemitoechus	1	1	1				33	17	3									
Rupicapra pyrenaica							6	5	2									
Ursus sp.							1	1	1							1	1	1
Lynx sp.							1	1	1							1	1	1
Canis lupus							2	2	2									
Vulpes vulpes							1	1	1									
Carnivora indet.				1	1	1	4	2										
Large size	238	20		290	32		2150	87		60	10		60	9		123	17	
Medium size	444	30		304	21		2165	109		957	28		214	18		555	56	
Small size	76	19		19	8		352	35		158	17		59	11		423	41	
Unidentified	244			628			1087			983			669			5959		
Total	1159	127	6	1496	122	17	6738	597	42	2564	151	13	1138	92	10	7614	251	20

Taxa recovered inside the travertine layers (outside the anthropogenic contexts) are not listed

Table 3 NISP, MNE and MNI of each archaeological unit

	Unit H		Unit I		Unit J–Ja		Unit K		Unit L		Unit M	
	LS	MS	LS	MS	LS	MS	LS	MS	LS	MS	LS	MS
NISP	347	574	398	477	2622	3020	131	1450	100	369	196	1034
MNE	45	82	40	63	239	313	34	117	24	68	42	207
MNI	3	3	10	6	23	14	5	8	5	5	9	9

The indexes are classified by weight size into large- (LS) and medium-sized (MS) animals

method is applied to all accumulations separately. The last step is trying to conjoin bones among the different accumulations: first among the closest ones and, finally, all together.

Both the anatomical refits (including dental series) and conjoined fragments of the same bone as classified by mechanical processes are considered (Table 7). The hearth-related areas of each archaeological unit are determined schematically by using the centre of the hearth as the centroid and establishing two outer circles (the drop and toss areas) according to the measures observed by Binford (1978). These pre-established areas of influence are considered when the refitted elements are examined to determine how they corresponded to the hearth-related areas. However, the palimpsest conditions of the studied archaeological units and their possible differences in time-scale formation make it difficult to establish direct comparisons between them. In this respect, all of the units are treated using R statistical language. This software is used to analyse the dimensions of hearths and the location of hearths and bone refits. Several R packages are used to obtain histograms, clusters and maps: ggplot2, ggpubr, ggforce and pvclust. First, bivariant tests (Pearson's r and Spearman's ρ) that search for the number of hearths with NISP and MNI are used to identify the (dis)similarities between the faunal assemblages of each archaeological unit. In this context, the north-south (NS) and east-west (EW) dimensions of the hearths are recorded for each archaeological unit. Statistical tests are applied to determine the potential differences in hearth dimensions between the archaeological levels. Concerning the 3D location of the hearths, bootstrapped cluster analyses are run using the Ward method and Euclidean distance for every archaeological unit. The goal of these analyses is to see how many hearth areas could be identified. Red bootstrapping p-values for every unit are considered, and here, the higher the level, the higher the support of the cluster in that specific unit. Two complementary histograms are created per level. First, the distances among the refits themselves are evaluated. When a refit is formed by two bones, only one distance is considered (1 to 2); when it is formed by three bones, three distances are considered (1 to 2, 1 to 3 and 2 to 3). Then, the distances from every refit to their closest hearth are measured. Finally, the

Table 4 Large-sized mammals percent skeletal survival rate (%SR) vs. percent minimum animal units (%MAU) by each archaeological unit

	Unit H		Unit I		Unit J–Ja		Unit K		Unit L		Unit M	
	%SSR	%MAU	%SSR	%MAU	%SSR	%MAU	%SSR	%MAU	%SSR	%MAU	%SSR	%MAU
Cranium	100	100	0	0	47.1	60.9	0	0	33.3	40	0	0
Maxilla	100	100	40	50	50	60.9	50	75	33.3	40	42.8	75
Mandible	100	100	100	100	64.7	87	50	75	83.3	100	57.1	100
Vertebra	0	0	0	0	0.3	0.3	1.1	1.9	1.1	1.5	0	0
Rib	1.9	1.9	0	0	0.6	0.7	1.8	3.8	0.9	1.5	0	0
Pelvis	0	0	0	0	5.9	8.7	0	0	0	0	0	0
Scapula	75	75	5	6.3	20.6	26.1	33.3	50	16.7	20	14.3	25.0
Humerus	75	75	20	25	55.9	100	50.0	75	16.7	20	14.3	25.0
Radius	50	50	15	18.8	61.8	82.6	33.3	100	50.0	60	0	12.5
Metacarpus	0.0	0	0	0	11.9	21.7	0	0	16.7	20	0	0
Femur	50	50	5	6.3	47.1	69.6	33.3	50	16.7	20	21.4	37.5
Tibia	100	100	15	18.8	64.7	87.0	66.7	100	33.3	40	21.4	37.5
Metatarsus	50	50	0	0	11.9	26.1	0	0	0	0	14.3	25
Metapodial	37.5	37.5	0	0	14.3	17.4	33.3	25.0	16.7	10	14.3	12.5
Phalanx	4.2	4.2	0	0	10.9	1.4	2.1	4.2	0	0	0	0
Carpal/tarsal	4.2	4.2	0	0	0.3	1.1	0	0	0	0	0	0

Table 5 Medium-sized mammals percent skeletal survival rate (%SR) vs. percent minimum animal units (%MAU) by each archaeological unit

	Unit H		Unit I		Unit J–Ja		Unit K		Unit L		Unit M	
	%SSR	%MAU	%SSR	%MAU	%SSR	%MAU	%SSR	%MAU	%SSR	%MAU	%SSR	%MAU
Cranium	100	100	16.7	16.7	81.8	54.5	22.2	33.3	16.7	25	33.3	37.5
Maxilla	100	100	50	50	50	63.6	12.5	8.3	33.3	50	38.9	43.8
Mandible	50	100	100	100	45.5	59.1	44.4	66.7	41.7	62.5	88.9	100
Vertebra	3.6	0	0.6	1.3	5.6	8.0	0.8	1.3	0.6	1	2.1	2.4
Rib	8.9	1.9	0.9	1.9	5.6	5.9	3.8	5.8	1.3	1.9	1.7	1.9
Pelvis	0	0	0	0	0	0	11.1	16.7	8.3	12.5	5.5	6.3
Scapula	25	75	8.3	8.3	27.3	31.8	5.5	8.3	8.3	12.5	2.1	25
Humerus	75	75	33.3	33.3	95.5	90.9	16.7	25	25	37.5	33.3	37.5
Radius	50	50	50	50	45.5	50	27.8	50	25	37.5	11.1	56.3
Metacarpus	25	0	50	50	86.4	86.4	44.4	66.7	41.6	62.5	66.7	75
Femur	100	50	41.7	41.7	77.3	77.3	22.2	33.3	25	37.5	38.9	43.8
Tibia	50	100	41.7	41.7	95.5	100	38.9	58.3	66.6	100	83.3	93.8
Metatarsus	100	50	50	50	68.2	68.2	66.7	100	25	37.5	66.7	75
Metapodials	0	37.5	8.3	16.7	4.6	9.1	11.1	16.7	8.3	12.5	22.2	25
Phalanx	6.3	4.2	1.4	1.4	3.8	3.4	2.8	4.2	0	0	37.5	4.7
Carpal/tarsal	8.3	4.2	1.4	1.4	2.2	3	0	0	0	0	0	0

density maps of the hearths and bone refits are generated to see how these areas overlap in every archaeological unit. Additional maps with XY coordinates are drawn for the size and drop and toss zones (radii of 120 and 250 cm, respectively, from the centre) of the hearths and the bone refits; each refit is identified by a different colour.

Results

Hearths are one of the most characteristic elements of the Abric Romaní site and are very well defined macro- and micro-stratigraphically (Vallverdú et al. 2012). Their general dimensions show significant variations, even in the same stratigraphic unit (from a few centimetres in diameter to more than 1 m). Taken together, however, they show a progressive reduction in size from the lower units to the upper ones (Fig. 3). Unit I is the only exception to this general tendency, which could invalidate the idea of a correlation between hearth size and the lithological composition of the units (more detritic in the lower units and more travertinic in the upper ones, especially for units H and I).

The number of identified hearths differs significantly for each unit. Unit H has the fewest (nine hearths), and all of them are scattered across the excavated surface without any apparent relationship. In contrast, unit J-Ja has the highest quantity of hearths (52); most are clustered, and many overlap, forming areas of hearths that can be identified by their clustered and overlapping centroids. According to this, eight distinct areas could be identified; they are situated at regular intervals and separated by zones relatively empty of archaeological materials (see more details in Carbonell 2012). The remaining archaeological units do not appear to be as organised. However, in a more discrete way, they seem to reproduce a pattern similar to unit J–Ja. The maps show a preference for hearths that are positioned centrally and close to walls. In the case of units H, I and—to a lesser extent—J-Ja, the areas closest to the wall have been previously dug by other researchers and hence show possible biases in this respect. Even so, unit J-Ja contains the highest number of used zones.

Table 6 Summary of hominid and carnivore-induced damage (%) on faunal record by archaeological units

% Damage	Unit H	Unit I	Unit J–Ja	Unit K	Unit L	Unit M
Cut marks	9	8.1	6.6	4.1	6.7	3
Bone breakage	9.4	9.9	11.9	10.7	3.4	3.1
Burned bones	35.8	33.5	31.3	50.7	51.2	61.3
Carnivore tooth marks	0.9	0.8	0.9	3	0.8	0.3

Specific data and details can be found in Fernández-Laso (2010), Rosell et al. (2012a, b, c) and Modolo and Rosell (2017)

Table 7 Main features of faunal refits by archaeological units

Unit	NISP	Green	Dry	Anatom.	2 frg	3 frg	4 frg	5 frg	> 5 frg	Total refits	%
H	1164	23	2	2	18	4	3			25	2.15
I	1833	19	9	9	23	5				28	1.53
J–Ja	6738	185	9	11	162	26	6	1	1	196	2.91
K	2570	38	5	1	26	10	2	1		39	1.52
L	1002	26	4		21	4			1	26	2.59
M	7656	139	14	5	113	22	3	2	4	144	1.88

Specific data and details can be found in Fernández-Laso (2010), Rosell et al. (2012a, b, c) and Modolo and Rosell (2017)

Frg number of fragments involved in the refit

The faunal assemblages also differ quantitatively. J-Ja is the unit with the most elements (NISP), as reflected in both MNE and MNI. However, all of the units are similar regarding the diversity of the ungulates: horses and red deer dominate for all the units. However, tests comparing the number of hearths to the NISP in the stratigraphic units seem to indicate that there are certain similarities between the different studied assemblages: Pearson's r test produces a value of 0.8601034 (p value = 0.02799, 95% confidence), and Spearman's ρ test produces a value of 0.7714286 (p value = 0.1028). The same seems to occur between the number of hearths and MNI: Pearson's r test produces a value of 0.9170403 (p value = 0.01004, 95% of confidence), and Spearman's ρ test produces a value of 0.8285714 (p value = 0.05833).

Among all of the studied units, 466 elements are refitted, affecting a total of 1049 bone and dental fragments (Table 7). Most of these refits (430) are mechanical (direct) (Fig. 4). The other 28 are anatomical and correspond only to dental series. However, it is necessary to consider that the generalised lack of epiphyses in all of the assemblages makes the identification of anatomical conjoins difficult. That being said, the number of achieved refits is proportional to the NISP for all of the archaeological units. From this point of view, the bivariant tests show a correspondence between the number of hearths and the number of refits: Pearson's r test produces a value of 0.9382625 (p value = 0.0056, 95% of confidence), and Spearman's ρ test produces a value of 0.9428571 (p value = 0.01667).

Direct refits of two elements are the most common for all of the assemblages. However, all of the units show direct refits involving three or more fragments (Fig. 5). Regarding the spatial location inside the site, local refits (> 2 m between fragments) are dominant. Most correspond to fragments broken in a dry state and whose fragments are narrowly separated. Given the aims of the present work, however, the most significant results are the long-distance bone refits, which involve fragments from different hearth areas (or groups of hearths). These types of refits are the least common. Units H and L are the only assemblages without long-distance refits. On the contrary, unit J–Ja shows a larger number of long-distance bone refits. The remaining units (I, K and M) also have long-distance refits but not to the same extent as observed in unit J–Ja. Most of the fragments involved in these long-distance refits are from different hearth areas. Only on rare occasions are fragments found to be from outside the rock shelter or far from the commonly used zones (centre or close to the wall). These conditions are observed in units I, J–Ja and M, which show some accumulations of refitted bones from the outer areas.

Regarding the distances between the refitted elements, four patterns can be identified (Fig. 6): (1) units H/L, where all of the distances are below 5 m; (2) units I/K, where the number of refits is low compared with the other levels and where the refit distances are present until around 10 m but are distributed in a slightly flat pattern; (3) unit J–Ja, which contains a large number of refits showing a pattern of negative exponential regression from the shortest distances to the largest ones (> 15 m); and (4) unit M, which contains a high number of short-distance refits (> 1 m), even though the presence of some long-distance refits is remarkable (12–13 m). However, the number of these patterns can be reduced to three if each refit closest to the fireplace is considered (Fig. 7): (1) units H–I, where this distance is flatly distributed until the fourth metre; (2) units J–Ja/M, where most of the refits are very close to the fireplaces, following a negative exponential regression; and (3) units K/L, where most of the refits are very close to the fireplaces but show a clear disruption approximately at 1.5 m (from this distance and farther, it is relatively flat).

Discussion

The described anthropogenic assemblages show faunal similarities, providing some homogeneity among the units. First, the dominance of horses and red deer in all of the stratigraphic units could be the result of the specific palaeoecological conditions of the landscape that made it very favourable for the development of both taxa. However, the presence of other ungulates, such as aurochs, rhino and chamois, along with a relatively high diversity of carnivores, indicates a more diversified landscape in which human groups focused their hunting activities mainly on

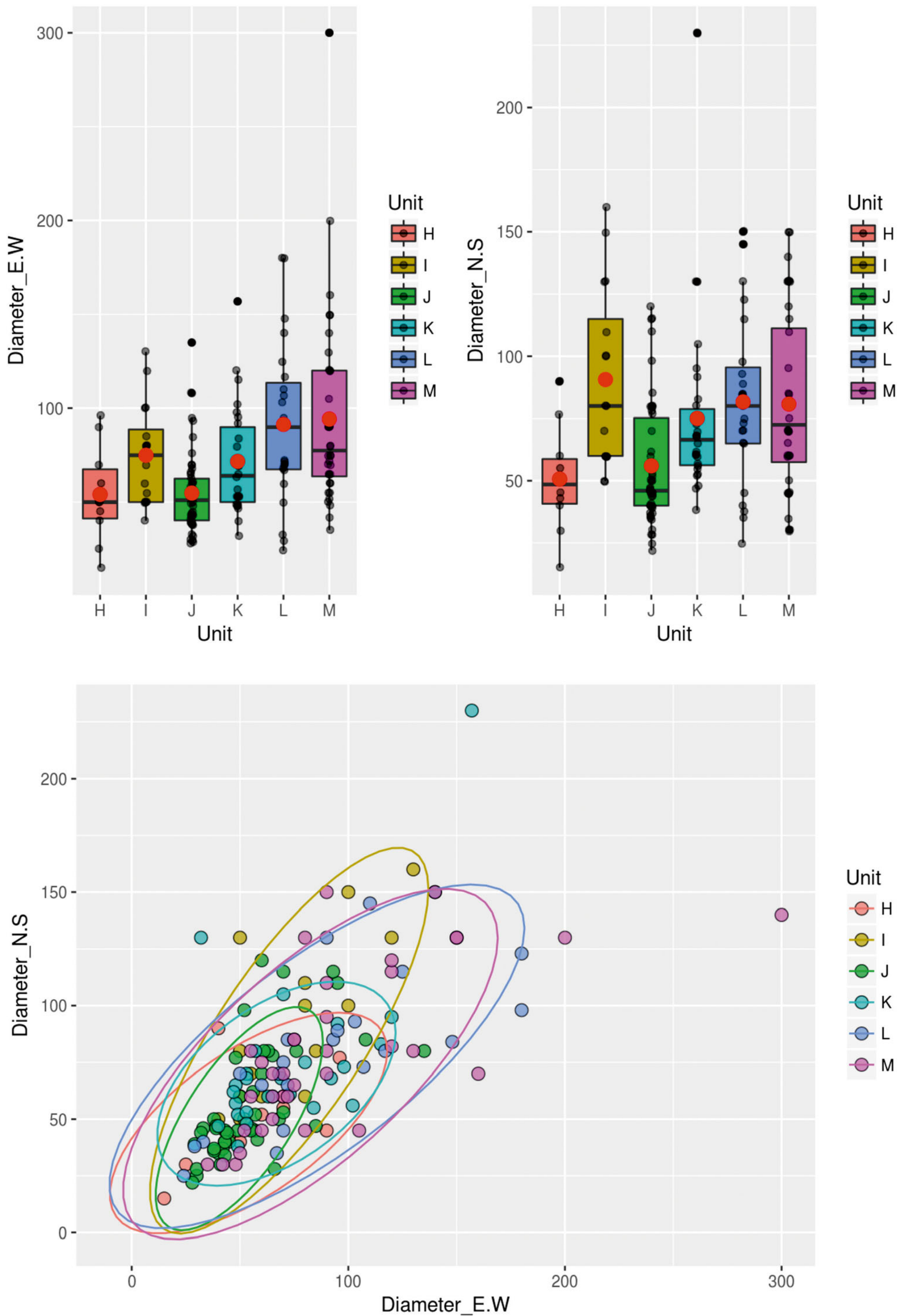

Fig. 3 Comparison of the hearths' size by archaeological units: **a** a box plot comparing the diameter E-W (in centimetre), **b** a box plot comparing the diameter N-S (in centimetre) and **c** a scatter plot comparing the areas of the hearths (in square centimetre)

these two taxa (Rosell et al. 2012a, b, c). Second, the anthropogenic assemblages are predominantly composed of mid-shaft fragments, mandibles and maxilla of large- and medium-sized prime-adult animals (Fig. 8). These skeletal profiles can initially be interpreted as the product of the different methods used to transport the portions of the carcasses, which include mainly heads and limbs. Indeed, bones from the trunks are usually abandoned where the carcasses are obtained, and portions of the axial skeleton are rarely included in the pack. Alternatively, the lack of epiphyses could be explained by their posterior destruction that occurred through a combination of different processes. The first could be the anthropogenic activities related to consumption and cleaning. In this respect, Abric Romaní does not differ from many other Middle Palaeolithic sites in which the crushing of the epiphyses for fat procurement

Fig. 4 Some examples of bone refits from unit M showing anthropogenic and/or green fractures. Modified from Fernández-Laso (2010)

and/or their burning for cleaning or as fuel have been suggested (see a discussion in Costamagno and Rigaud 2014; Yravedra and Uzquiano 2013). Another possibility is the action of scavengers, as has been observed in several current and experimental assemblages (Isaac 1983; Binford et al. 1988; Marean and Bertino 1994; Blumenschine 1995).

Recently, this hypothesis has been criticised by Marín et al. (2017). Following the methods of Faith and Gordon (2007), these researchers analysed the skeletal profile of units K, L and M and compared their results with the assemblages generated by the Hadza in Tanzania; they found that Faith and Gordon's method produced significant differences between

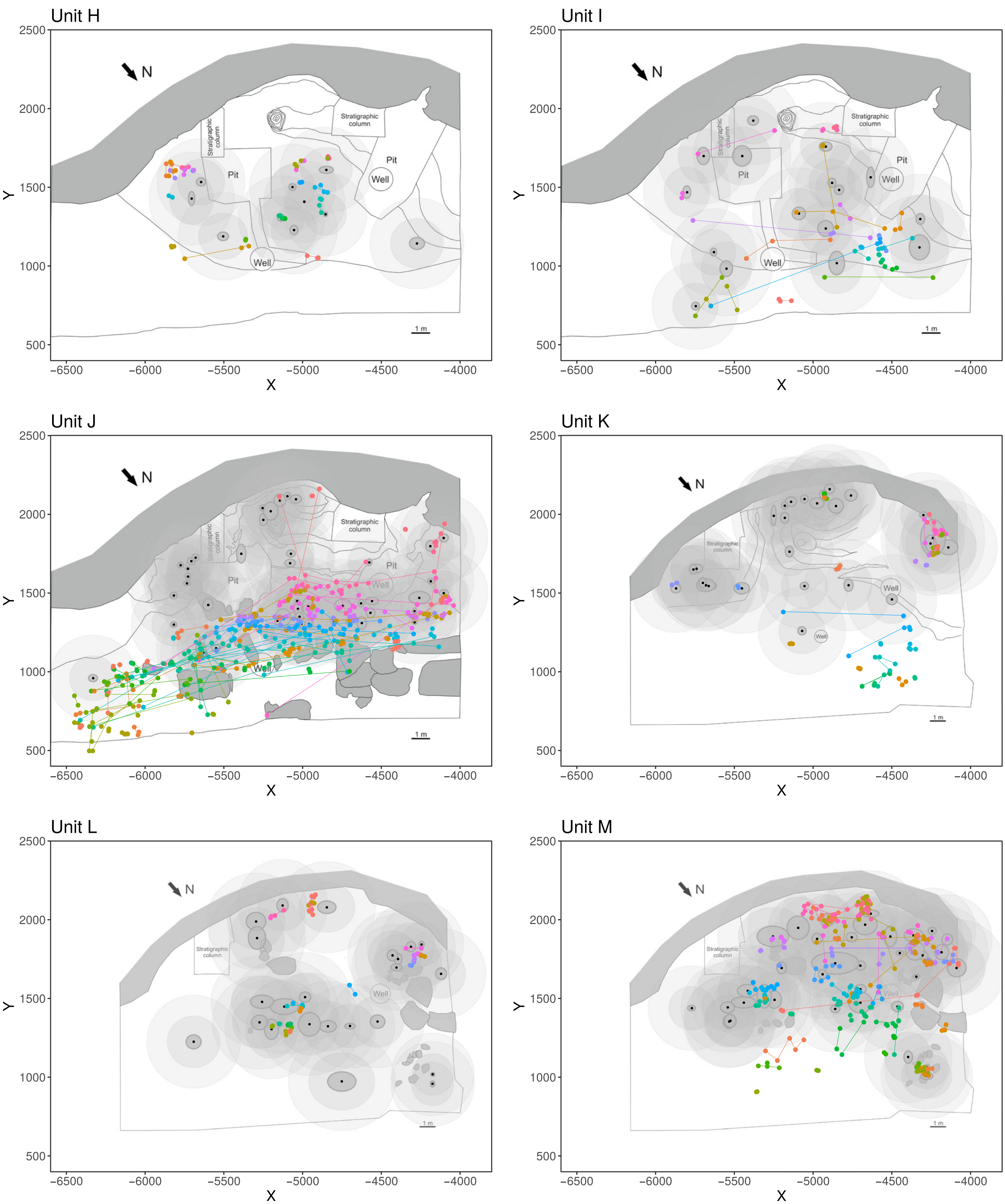

Fig. 5 Map of the different archaeological units showing the hearth centroids (black), their area of influence (grey) and the faunal refits (colours). The dark grey colour corresponds to the wall and travertine blocks

the units, leading them to suggest a higher diversity in the strategies of transport than what has been proposed in previous works. Such diversity could range from the complete transport of carcasses to preferential transport of the anatomical portions considered to be of high and medium nutritional value. On the other hand, they interpreted the lack of

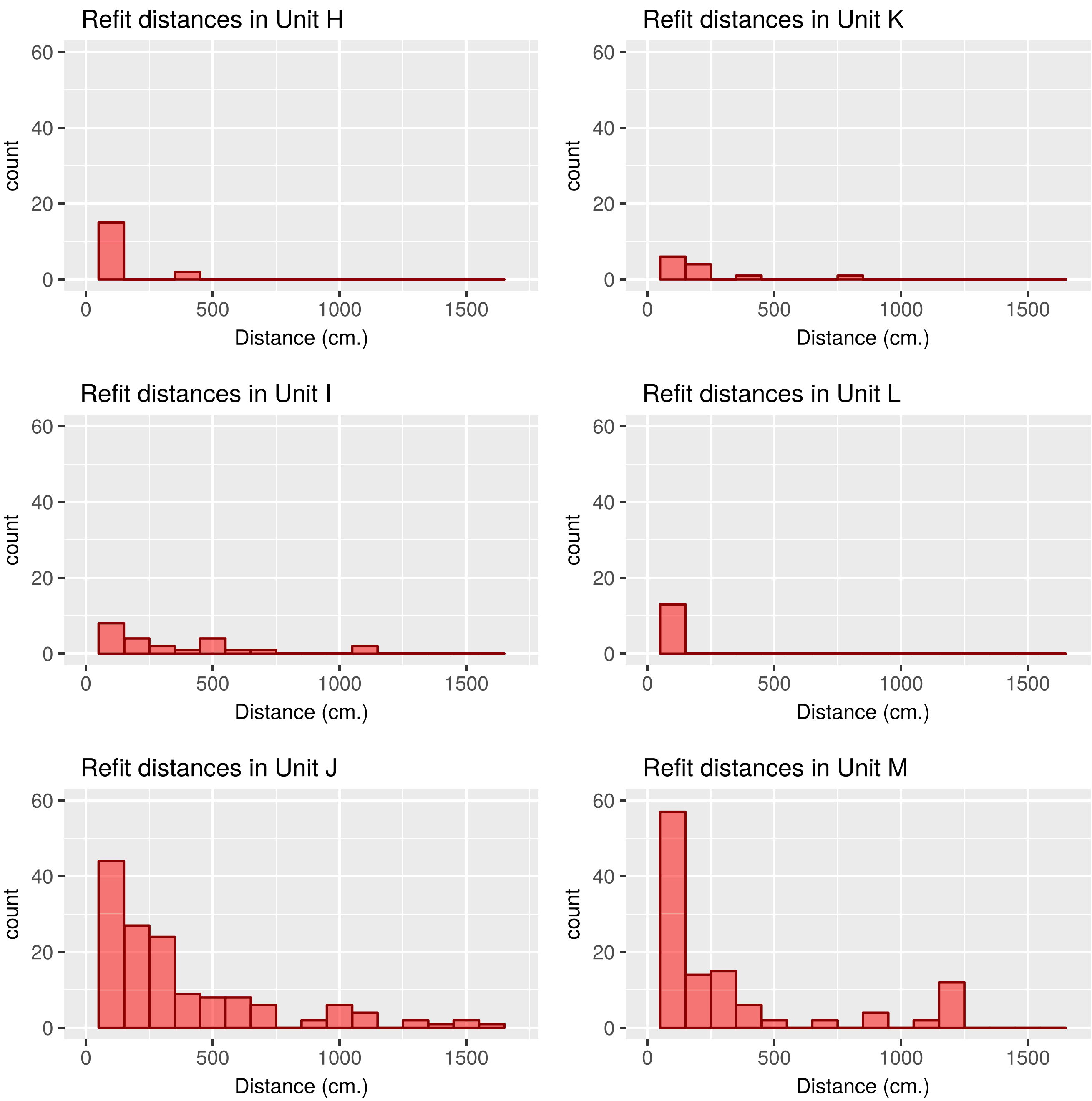

Fig. 6 Distances between the refitted elements

vertebrae, ribs and limb bone ends as the result of a systematic and deliberate destruction during consumption and cleaning activities, which could include crushing, boiling and burning. Marín et al. (2017) also used the statistically significant correlation between %MAU in unit M and bone mineral density to show the importance of post-depositional processes in the differential preservation of bones at this site. They concluded that there are similarities between the Abric Romaní assemblages and those generated by the Hadza, which, according to them, fit the unconstrained model described by Faith and Gordon (2007).

However, Marín et al. (2017) failed to consider several aspects that could significantly alter their results. First, they attempted to assess the skeletal profiles of whole assemblages by using only the bones that have been identified at the anatomical level and that are classified by size. Considering the low degree of identification in all of the assemblages, a significant number of bones (mostly mid-shafts) are not included in their statistical tests. In addition, and following the methods proposed by Faith and Gordon (2007), low-survival bones must also be excluded from tests to prevent any bias caused by the possible visits of carnivores to the assemblages and

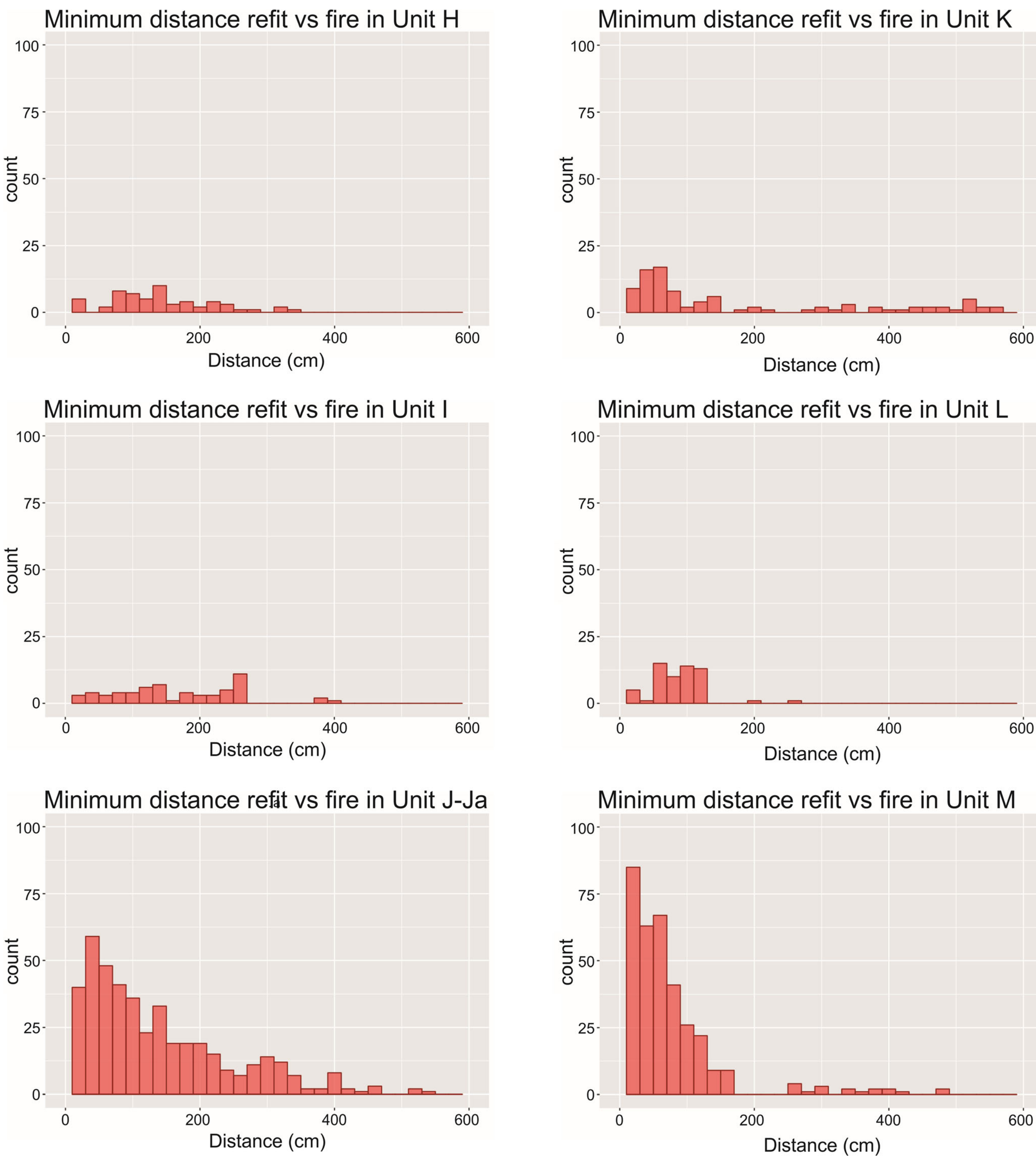

Fig. 7 Distances of every single refit to its closer hearth

other differential preservation phenomena. These exclusions mainly affect thin-cortical bones, corresponding to those with a low-density (axial bones, both girdles and long-bone ends) and compact bones (carpal, tarsal and phalanges). Therefore, the observed diversity comes only from limb bones but always obviating the axial skeleton. A way to minimise this issue is to analyse the assemblages using the categories of bones and class size. Figure 8 shows a similar composition of the assemblages in which the lack of axial elements is significant.

On the other hand, the generalised lack of axial bones and limb ends at Abric Romaní cannot be explained only by anthropogenic causes (crushing, boiling and burning) and—especially

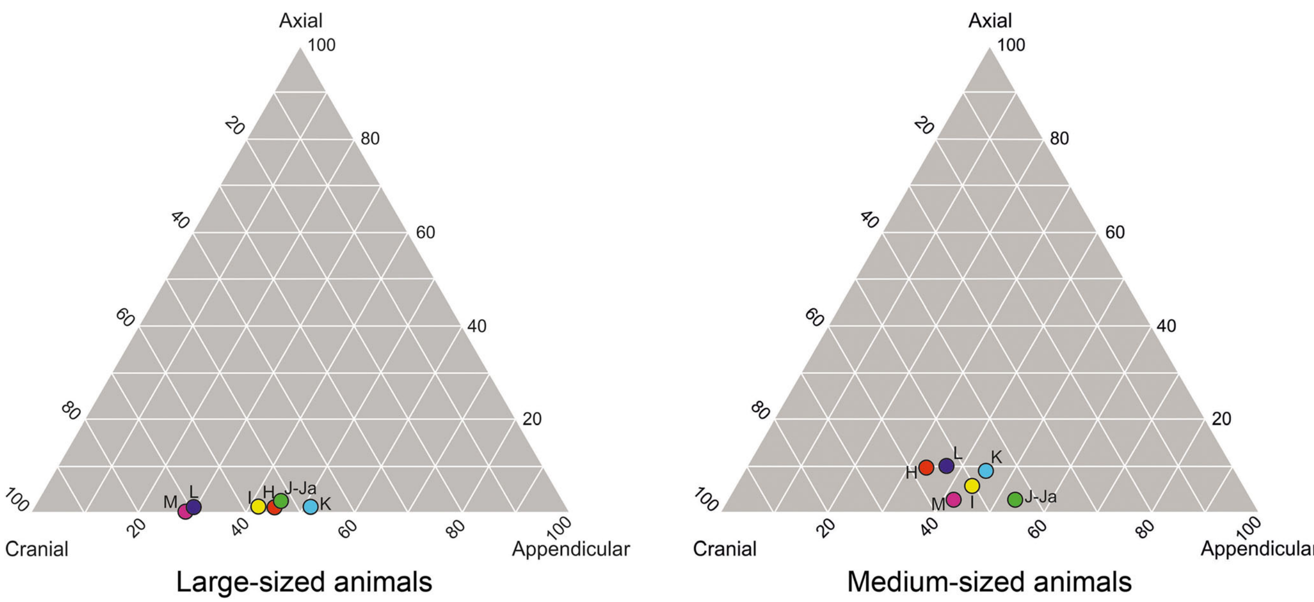

Fig. 8 Ternary plots showing the main anatomical elements (%SR) clustered by the main segments: cranial, axial and appendicular skeleton

in the case of unit M—post-depositional processes. The lithology and sedimentary characteristics do not differ excessively between the stratigraphic units. Therefore, the ability of different post-depositional agents at level M to produce significant phenomena of differential preservation by the mineral density of the bones must be identified by other methods as well, such as important chemical attacks on the surface of the bones. Alternatively, the destruction and total disappearance of this quantity of axial and end bones of large- and medium-sized animals (i.e. horses, red deer and aurochs) to the hearths would be a slow process, one that requires a significant amount of time and calorific intensity (Costamagno et al. 1999). In other words, there may be more evidence, including at the micromorphological level, from important amounts of burned bones in the thin sections. In this respect, the number of burned bones in these assemblages is not high and is mainly represented in the different degrees of thermal alteration among which the medium and slow degrees are the most common (Rosell et al. 2012a, b, c; Modolo and Rosell 2017). Only in units K, L and M do these indices slightly exceed 50% (Fernández-Laso 2010).

Finally, the tests used by Marín et al. (2017) show a significant overlap between the unconstrained and bulk models (transport of high-utility elements). Therefore, from this perspective, the initial hypothesis cannot be completely discarded, and the idea of homogeneity between assemblages should still be considered. However, the diversity between the stratigraphic units comes from the bone refits, mainly from those of a long distance, hence connecting different hearths (or areas of hearths). Except for a few specific cases, the conjoined fragments are located on hearths or within their areas of influence. These conditions are very clear in units H, I, L and M, supporting Vaquero and Pastó (2001)'s assertion about the structuration of these human groups (and their activities) around hearths. These hearth areas are separated by free zones without hearths and bone refits. In this respect, the bone refit areas in level M, where five distinct and roughly equidistant areas have been identified, are remarkable (Vaquero et al. 2017).

Unit K presents an exceptional situation because the bone refits are scarce and mostly local. Only one refit connects the two hearths at the centre of the rock shelter. However, there is a significant isolated area with bone refits outside of the rock shelter (at the northern corner) that is completely disconnected from the hearth areas. This situation is not observed for the other archaeological units. The involved remains, however, do not show taphonomic modifications that are distinct from those observed for the rest of the assemblage, such as a higher intensity of carnivore damage or rounded edges related to hydric transport. Therefore, their presence in this area is difficult to explain by processes other than anthropogenic ones. A possible parallel may be the site of Gatecliff Shelter (USA), where Thomas (1983) observes the presence of a toss area outside the rock shelter that is composed of the largest items related to a central hearth and that is far from the drop area. According to Thomas (1983), the principal domestic activities seem to have been carried out inside the rock shelter, so any unwanted elements were systematically thrown outside. This area of unit K may have had similar activity.

Unit J–Ja shows the most complexity. It contains the greatest quantity of faunal remains and hearths, which seem to correspond to an environment with more occupational intensity and events. This quantity of items makes it difficult to define empty zones outside the hearths' areas of influence, which are mainly in central areas and those close to the walls. However, there are empty zones outside of the rock shelter beyond the accumulation of the fallen blocks of the roof that delimit the used area.

There are numerous faunal refits in unit J–Ja. However, they do not differ percentagewise from the number identified in other units. In general, long-distance refits show significant connections between the hearths, and some are located in different areas. Most connect the areas located along all the central zone of the rock shelter. Hence, a preferential EW direction of these refits can be observed, which could be interpreted as the result of some movements of the materials following the slope of the rock shelter and that was first produced by human trampling or natural/gravitational processes. However, this phenomenon should affect all of the recovered items, selecting them by sizes. The lithic refits show both N-S and E-W refits, some of which are arranged opposite the slope (Vaquero et al. 2012). In addition, it is necessary to note three cases in which connections between the areas closer to the wall and the central zones (N-S direction) can be identified. Two of them avoid the stalagmitic formation located at squares R–S/50–51–52, which is very difficult to explain without seeing them as intentional.

Several alternative hypotheses to the anthropogenic one have been proposed and tested to explain the primary motivation for the long-distance movements of these bones. The first hypothesis considers the role played by carnivores as the usual scavengers of anthropogenic assemblages. The waste left by humans in their abandoned campsites has always attracted these animals. Many researchers have tested the activities conducted by scavengers both in nature and experimentally (Isaac 1983; Binford et al. 1988; Marean and Bertino 1994; Blumenschine 1995; Camarós et al. 2013). All of these authors agree that these animals prefer epiphyses and vertebral bodies, which usually retain nutrients, mainly fat, after human consumption. Thus, carnivore activities could account for the disappearance of some elements, such as spongy tissues, because the carnivores eating them or—especially in the case of heavier or larger bones—by the carnivore transporting the bones to other places outside the site. The difficulty here lies in the scarce taphonomic signal that these activities leave in the archaeological record. In the case of Abric Romaní, carnivore marauding has been detected in all of the archaeological units by some tooth marks and/or isolated coprolites over the hearths (Rosell et al. 2012b). However, this could partially explain the lack of some bones but not the movements between hearths and their areas of influence.

Another alternative hypothesis is related to unintentional movements caused by human trampling. Yellen (1977) examines this possibility, identifying a significant dispersion of hearths and their associated materials. However, the hearths in Abric Romaní are usually well defined, and the materials (including long-distance refits) are clustered around the hearths and are not scattered about randomly. The 3D position of the bones also refutes a third hypothesis that indicates that bones could be moved by postdepositional processes such as hydric transport or gravity. In this respect, Rosell et al. (2012a, c) state that most of the burned bones in unit J–Ja are placed on hearths (the assemblage with more items), and this could be extended to the other units (Fernández-Laso 2010; Rosell et al. 2012a; Modolo and Rosell 2017). In the same way, no selection by size is observed by these authors, as would be expected in the case of hydric and gravitational movements.

At this point, only anthropogenic and intentional processes can explain the movements of the faunal remains between the hearths. However, the theory regarding the use of these bones as raw materials for making bone tools or retouchers must be abandoned because these kinds of elements have not been identified in the studied assemblages: only one possibly pointed object made from an auroch mandible in unit J–Ja has been recognised (Rosell et al. 2012c). In addition, fresh bone breaks are observed on many of these refits, which could indicate that the bones were moved when they still contained nutrients (Fernández-Laso 2010). A prime example is found in unit M, where one refitted tibia of a red deer is composed of 11 fragments (Fernández-Laso 2010; Vaquero et al. 2017). Nine of these fragments are located in the areas of influence of two hearths from the west area of the site (squares R-S/41–42 and P/44), and the other two are located in the main accumulation of the east side of the site (squares O/52–53). Both areas are separated by more than 10 m. All the refitted items show evidence of green fractures. Except for two unburned fragments located at the R–S/41–42 hearth-related accumulation, the rest show different degrees of burning damage, meaning that the thermo-alteration processes occurred after the fragments were first displaced. From this perspective, the movements seem to have occurred when the bones still contained nutrients; therefore, they could be related to nutritional purposes. On the contrary, the limited lifespan of meat, fat and marrow, as well as the complete absence of the use of bones as raw materials, seems to reject the possibility that the bone movements are linked to the processes of reusing or recycling.

Long-distance refits could also be considered as evidence of the contemporary coexistence of two (or more) activity areas in some units. This circumstance is clearly evident in units I, J–Ja, M and—to a lesser extent—K. However, units H and L seem to be formed by disconnected and (probably) non-contemporaneous activity areas. All these data imply at least two different occupational models at Abric Romaní: (1) the simple model, which is represented by those units with isolated activity areas (units H and L), and (2) the complex model, which is primarily defined by a significant number of refits between the areas (units J–Ja, M and—to a lesser extent—I). Obviously, both models are not exclusive and could coexist in the same stratigraphic unit. Considering the palimpsest characteristics of all of the units, it is possible that some isolated activity areas typical of the simple model could overlap with the occupations of the complex model and hence be hidden inside the most intense occupations. An example could be unit K, where only one refit connecting the two hearths at the centre area is identified, while the rest of the hearths are completely isolated. These conditions add more complexity to the identified models and allow for a significant issue to be raised, one that should be investigated in the future: these complex models may be the result of the replication of multiple simple models or, conversely, both models may have evolved in parallel directions without the chance to converge. From this perspective, the data obtained by the method proposed here must be aligned with the results of lithic refits. Although the mobility of many lithic artefacts in Abric Romaní seem to be affected by several processes of recycling and reuse, the directions marked by these objects could reinforce the faunal results and help understand the development of the occupational patterns at the site. This data confrontation has been tested recently in unit M (Vaquero et al. 2017), and the results show clear intentional and nonrandom movements of both materials but with different patterns. The main differences have been explained by the major durability of the lithic remains and the possibility that they were reused and recycled. Even so, Vaquero et al. do not see excessively random movements in both short- and long-distance lithic refits. On the contrary, the lithic artefacts seem to have been intentionally moved to specific places, reinforcing the high resolution of this stratigraphic unit and the validity of the spatial studies at this site.

At this point, the diversity observed from the lithic and faunal refits may answer other questions related to the formation processes of the site, such as the durability of the human occupations and the main influences that the physical and topographic characteristics had over the respective floors (presence of large blocks, flat zones, flooded areas, etc.). Together, these points can allow for more accurate data to be obtained and to aid in the research of the composition of the human groups in terms of their numbers, their intrasite organisational patterns and their evolution over time.

Conclusions

The well-preserved anthropogenic assemblages at Abric Romaní provide the high-resolution properties required to carry out studies on human groups' lifestyles at the end of the Middle Palaeolithic and their ability to manage dwelling spaces. From this perspective, the taphonomy shows relatively similar subsistence strategies and processing patterns for all of the assemblages, which focus mainly on the transport of limbs and heads of large- and medium-sized ungulates (horses, red deer and aurochs).This apparent homogeneity could reflect the persistence of a cultural tradition over time. Nevertheless, some changes can be detected in the occupational patterns. Most archaeological items are located in the areas of influence around hearth-related accumulations, reinforcing the hypothesis developed by Vaquero and Pastó (2001) for this site based on the drop or toss ethnographic model of Binford (1978). According to this idea, hearths represent the centre of the core domestic activities and may be interpreted as the product of a social unit. Most of the faunal refits, both those that are local and long distance, are found inside these hearth-accumulation areas, indicating the intentionality of their displacements. In this respect, no significant movement of archaeological items produced by carnivores or post-depositional processes, such as the accumulations of selected materials by size caused by hydric transport or gravity, can be identified. Instead, the lack of evidence related to the reuse and recycling of these bones implies that nutritional purposes may be the main motivation behind these movements.

Regarding the occupational patterns developed at this site, the specific analyses of the faunal refits allow for a higher diversity between the assemblages than is shown by taphonomic studies alone. These results indicate two possible models: (1) the simple model, which is represented by isolated hearths and dominated by local faunal refits (units H, L and—to a lesser extent—K) and (2) the complex model, in which several hearth-related accumulations are connected by long-distance faunal refits (units I, J–Ja and M). These differences could be linked to the composition of the human groups, the number of social units in each occupational event and, probably, to the function and durability of the occupations. From this perspective, the major spatial requirements needed for the complex model could be related to the presence of large groups or several social units using the rock shelter at the same time. In contrast, the units of the simple model could be the result of the rock shelter being used by several small social units that did not significant spatial requirements and that did so at different time periods.

Considering the palimpsest character of the assemblages, these models are not exclusive, and both could have developed in the same stratigraphic unit at different times. Thus, occupations belonging to the simple model could be masked by the greater intensity of events related to the complex model. In this scenario, a taphonomy could not differentiate between the two models because the subsistence strategies would be similar. This should be further investigated.

In summary, studies of faunal refits can contribute to the knowledge of occupational patterns at archaeological sites. This technique is especially advantageous at high-resolution sites like Abric Romaní, where the faunal refits allow for several features related to the social composition of human groups and the durability of their occupations to be assessed to a certain degree of certainty. These results, however, must be checked against other elements of the record, such as lithics or hearths, which provide information key to making accurate assessments about how Middle Palaeolithic human communities functioned in the region and evolved over time.

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