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RESEARCH

Mixed sites: assessing carnivore, Neanderthal, and abiotic agency at Buena Pinta Cave (Pinilla del Valle, Madrid, Spain)

Clara Mielgo[1,2] · **Rosa Huguet**[1,2,3] · **Abel Moclán**[4,5] · **David M. Martín-Perea**[1,5,6] · **César Laplana**[7,8] · **Belén Márquez**[8] · **Juan Luis Arsuaga**[6,9] · **Alfredo Pérez-González**[5] · **Enrique Baquedano**[5,8]

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Abstract
Understanding taphonomic processes is essential for reconstructing past environmental dynamics and interpreting mixed sites, where successive occupations by different biological agents have occurred and, in many cases, have been modified by post-depositional processes. Such is the case in the western part of Buena Pinta Cave (Pinilla del Valle, Madrid). In this study, three Units with different taphonomic histories were analysed. Unit 32 A contains fossil remains that were incorporated by low-energy water currents during the cave's opening. Unit 23 shows an accumulation of bone remains that were resedimented and reworked by a high-energy current, which illustrates how post-depositional processes can create an assemblage with asynchronous taphocoenoses embedded in the same geological event. Finally, Unit 2/3 contains a bone assemblage that was primarily produced by hyenas, although it may also have been used sporadically by Neanderthals and other small carnivores. These findings provide a reference for comparison and evaluation of other archaeo-palaeontological sites with similar problems in caves and mixed sites.

Keywords Taphonomy · Hyaenids · Fluvial deposits · Pleistocene · Middle Palaeolithic

Introduction

During the European Pleistocene, carnivores and hominins were the primary agents responsible for accumulating large faunal assemblages in caves and shelters. These agents transported entire or partial carcasses of their prey to safe areas or living spaces, for later consumption. The characteristics of these fossil accumulations and the main biostratinomic agents involved in their formation allow for the proposal of different models of Pleistocene deposits (Hussain et al. 2022). These include: deposits generated by carnivores with minimal or no anthropogenic evidence (e.g., Rueda i Torres 1993; Marchal et al. 2009; Cuenca-Bescos and Río 2010; Rodríguez-Hidalgo et al. 2010; Diedrich 2012a); deposits accumulated by hominins with limited carnivore intervention (e.g., Rosell et al. 2012a, b; Marín et al. 2019; Moclán et al. 2021); and sites that we have designated as'mixed', where hominin and carnivore activities converge, showing varying degrees of spatial interaction (e.g., Blasco 1997; Yravedra 2007, 2010; Zilhao et al. 2010; Arceredillo Alonso et al. 2013; Fernández-Laso et al. 2015; Sanchís et al. 2019; Sánchez-Romero et al. 2020; Zilio et al. 2021).

✉ Clara Mielgo
cmielgo@iphes.cat; clamivi027@gmail.com

1 IPHES-CERCA, Institut Català de Paleoecologia Humana I Evolució Social, Tarragona, Spain

2 Departament d'Història I Història de L'Art, University Rovira I Virgili, Tarragona, Spain

3 Unit Associated With CSIC, Departamento de Paleobiología, Museo Nacional de Ciencias Naturales, Madrid, Spain

4 PALEVOPRIM lab, UMR 7262 CNRS and Université de Poitiers, Poitiers, France

5 Institute of Evolution in Africa, Madrid, Spain

6 Department of Geodynamics, Stratigraphy and Palaeontology, Faculty of Geology, Complutense University of Madrid, Madrid, Spain

7 ARQUEOPALEO Group, Department of Geodynamics, Stratigraphy and Palaeontology, Faculty of Geology, University of Alcalá, Alcalá de Henares, Spain

8 Museo Arqueológico y Paleontológico de La Comunidad de Madrid, Alcalá de Henares, Spain

9 UCM-ISCIII Research Centre for Human Evolution and Behaviour, Madrid, Spain

So-called mixed sites may represent alternating sequences of occupation by biological agents over time, separated by stratigraphic gaps. Alternatively, they may form palimpsests due to the mixing of an indeterminate number of anthropogenic and carnivore occupations in a single space (Bailey 2007; Lucas 2005, 2012). However, it is essential to consider the impact of fossil-diagenetic processes, such as sediment movement or water flow, which can displace materials from their original position of abandonment (Voorhies 1969; Behrensmeyer 1990; Enloe 2006; Goldberg and MacPhail 2006; Domínguez-Rodrigo et al. 2014) and contribute to the formation of mixed associations.

Among these fossil-diagenetic processes, hydraulic activity has been widely recognized as one of the most influential post-depositional agents in shaping and modifying archaeological and palaeontological assemblages (Voorhies 1969; Behrensmeyer 1975, 1982, 1988; Schiffer 1987; Petraglia and Nash 1987; Petraglia and Potts 1994; Coard and Dennell 1995; Coard 1999, among others). The effect of hydraulic flows can generate a great variety of patterns, from rearranged autochthonous or para-autochthonous assemblages to biased or fully transported allochthonous assemblages (Badgley 1986a; Behrensmeyer 1988; Rogers et al. 2007; Domínguez-Rodrigo et al. 2014). Consequently, remains from different biological entities or from different time periods may be uncovered, which may point to misleading associations and interpretations of the archaeological assemblages.

In mixed sites, physical factors, such as hydraulic processes, often act upon remains originally deposited by humans or carnivores, transforming them into"bioclasts"—skeletal elements that behave like sedimentary particles (e.g., Behrensmeyer 1975; Shipman 1981; Rogers and Kidwell 2007). The transport and deposition of bioclasts depend on their size, shape, and density, which influence their interaction with the sedimentary matrix. As a result, bones and teeth may be eroded, transported, and redeposited, forming concentrated deposits.

One example of such deposits is the"bone bed"or macrofossil bed, characterized by skeletal remains from at least two individuals, where most bioclasts measure less than 5 cm and often exhibit rounding that can obscure their identification (Rogers et al. 2007). When associated with hydraulic activity, these deposits are typically interpreted as attritional accumulations formed over time, as a result of the inclusion and transportation of bones and teeth from numerous animals are included and transported within the water flow. Such concentrations may obscure the original depositional patterns of human and carnivore activity, complicating the interpretation of site formation processes.

Buena Pinta Cave, in Pinilla del Valle (Madrid), has been interpreted as a hyena den (Huguet et al. 2010; Baquedano et al. 2012, 2016) with occasional anthropogenic activity (Baquedano et al. 2012, 2016). These studies indicate that the anthropic activity in question would have been concentrated mainly in the western part of the site, given the presence of lithic remains and the apparent anthropic fracturing in some bone remains found in this area. Nevertheless, a recent study on the spatial distribution of the western area (Mielgo et al. 2024) has revealed a more complex taphonomic history than was originally thought for this sector of the site.

From the archaeo-stratigraphic and spatial analyses based on taphonomic analysis of the faunal remains from the western part of the site, three distinct units have been identified: Unit 32 A, Unit 23, and Unit 2/3 (Mielgo et al. 2024). This paper presents an extensive zooarchaeological and taphonomic analysis of the fossil remains from the three identified Units. The main objective is to analyse and compare the taphonomic characteristics of the remains from each Unit in order to assess the context in which each faunal accumulation was formed, establish their functionality and interpret the taphonomic differences between the Units.

Understanding these dynamics in mixed sites, where remains initially deposited by biological agents, whether through human or carnivore activity, are later modified by post-depositional processes such as hydraulic flows, is essential for establishing a robust framework to accurately reconstruct taphonomic histories and distinguish original accumulations from secondary alterations.

Buena pinta cave

Buena Pinta Cave was discovered in 2003. Since that time, fieldwork has been conducted on an ongoing basis, with the exception of 2020 and 2021 due to the COVID- 19 pandemic. Buena Pinta Cave is part of the Calvero de la Higuera archaeo-palaeontological site complex (Fig. 1A), in Pinilla del Valle (1114 m a.s.l.), and is located in the upper reaches of the Lozoya River valley in the Sierra de Guadarrama (Central System), approximately 55 km north of Madrid (Pérez-González et al. 2010; Huguet et al. 2010; Arsuaga et al. 2010, 2012; Baquedano et al. 2012, 2016, 2021, 2023; Márquez et al. 2013, 2016, 2017; Abrunhosa 2020; Laplana et al. 2015a; Arriaza et al. 2017; Moclán et al. 2018, 2020, 2021).

The cave and shelter sites at this site (Fig. 1B), occupied by Neanderthals during Marine Isotope Stage (MIS) 5, 4 and 3, are associated with cavities that developed in Upper Cretaceous dolomitic rocks (Pérez-González et al. 2010).

Buena Pinta Cave (Fig. 1D) is a phreatic cavity, with a complex stratigraphy which is currently being studied. Two main sedimentary deposits can be distinguished (Baquedano et al. 2021). In the upper part of the cave, a Holocene deposit was identified that blocked the entrance

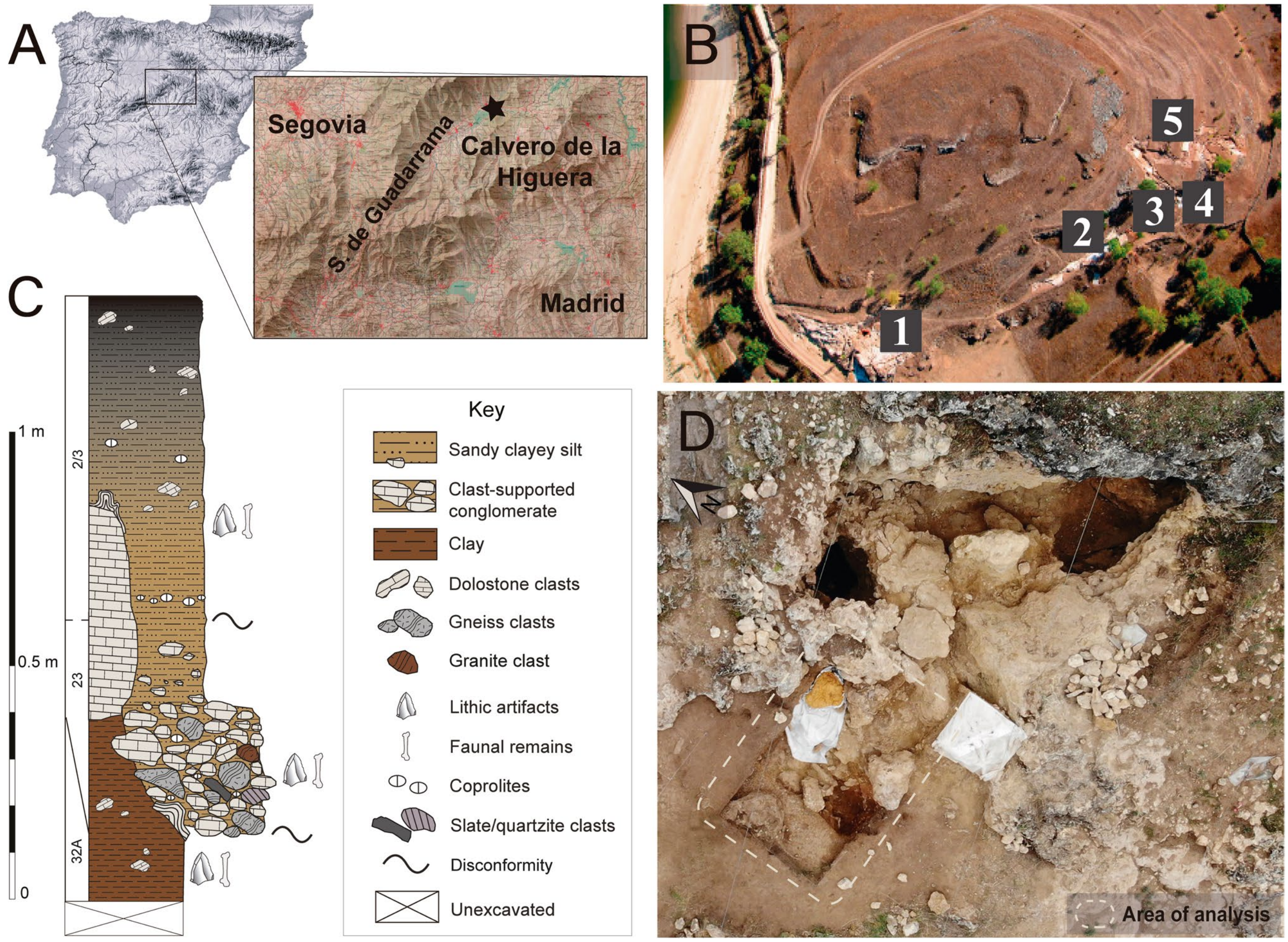


Fig. 1 Location of Calvero de la Higuera. A: Location of the sites on the map of the Iberian Peninsula. B: Orthophoto of the group of sites in the Calvero de la Higuera complex: 1. Camino Cave; 2. Navalmaíllo Rockshelter; 3. Buena Pinta Cave; 4. Des-Cubierta Cave. C: Stratigraphic column of the western area. D: Aerial view of the sites, showing the area of analysis ©Javier Trueba (Madrid Scientific Films)

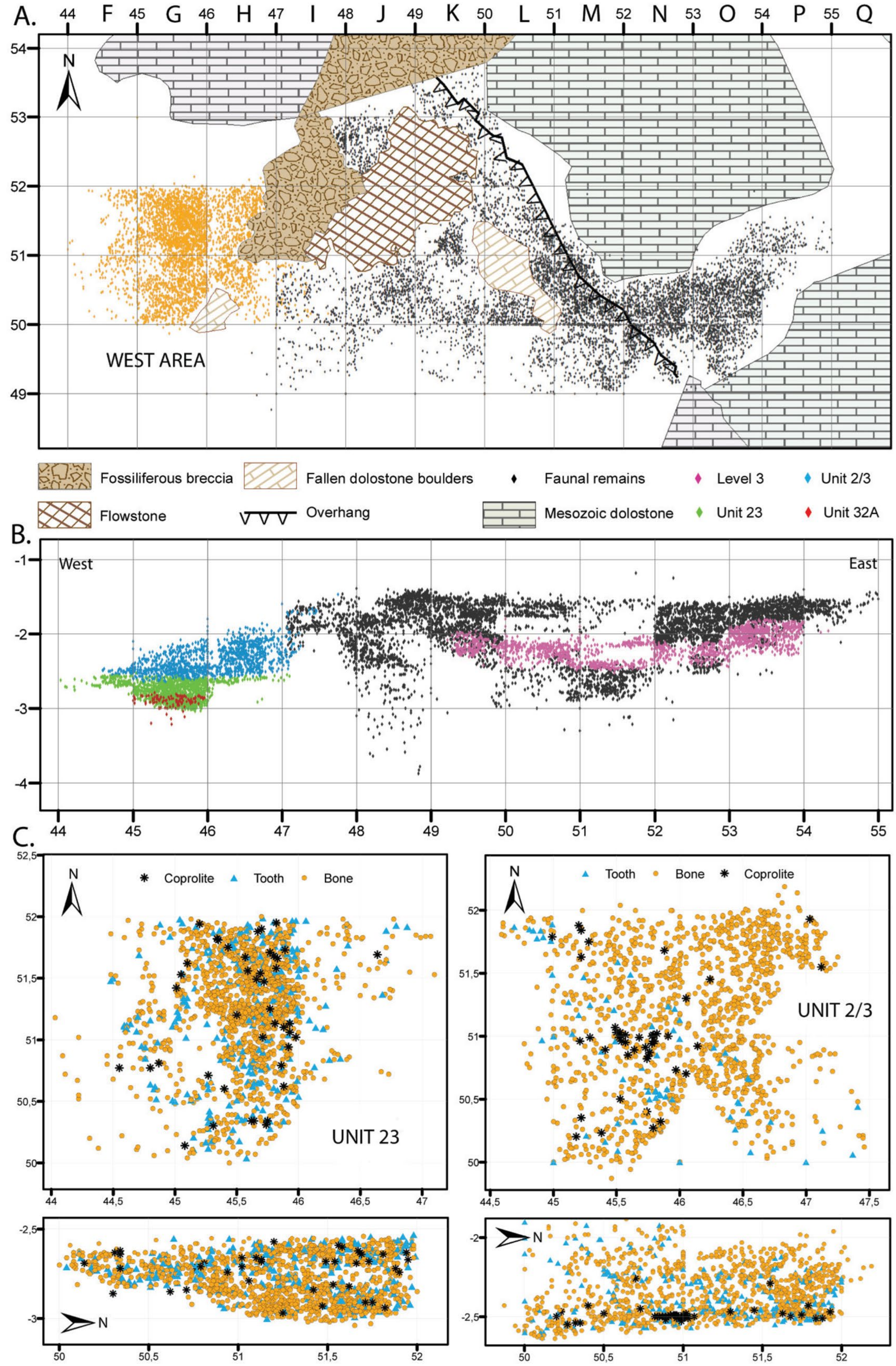
to the gallery. This deposit was approximately 1.80 m thick and yielded the remains of a Bronze Age burial. Conversely, several Upper Pleistocene levels have been identified in the lower part of the sequence. Level 3 has been dated by TL at 63.4 ± 5.5 ka BP (Pérez-González et al. 2010), placing it in MIS 4. This is supported by the presence of remains of *Ochotona* cf. *pusilla* (Laplana et al. 2009, 2015a, 2016), a biomarker taxon of cold climate.

The zooarchaeological and taphonomic analysis of part of the macrofaunal fossil assemblage from level 3 (see Fig. 2B) and the presence of numerous coprolites has served to interpret this level as a hyena den (Huguet et al. 2010; Baquedano et al. 2012, 2016). However, indirect evidence of the presence of hominins at the site has been identified, including some lithic industry remains and several molars attributed to *Homo neanderthalensis* recovered in level 3 (Baquedano et al. 2010; Huguet et al. 2010).

Most of the lithic remains recovered are concentrated in the western sector of the site. They are mainly knapped on quartz and include unretouched flakes and fragments (Baquedano et al. 2012). Among the retouched pieces, denticulates are the most prevalent, and the cores are knapped unifacially, bifacially or trifacially according to generally unipolar longitudinal knapping.

A spatial analysis of the remains has revealed that the assemblage in the western part of the Buena Pinta Cave (Fig. 2A) is the result of multiple events, resulting in three distinct deposits (Mielgo et al. 2024). These levels have been correlated with the new geological observations, thus integrating them into the updated stratigraphic study of this deposit (Fig. 1C).

Thus, from bottom to top, the Units in the western area are (Fig. 2B):


A.
WEST AREA
Fossiliferous breccia
Fallen dolostone boulders
Faunal remains
Level 3
Unit 2/3
Flowstone
Overhang
Mesozoic dolostone
Unit 23
Unit 32A
B.
West
East
C.
Coprolite
Tooth
Bone
UNIT 23
UNIT 2/3

◂**Fig. 2** **A** Plan of Buena Pinta Cave, with the faunal remains coordenated between 2003 and 2019. **B** XZ section of the archaeological faunal remains. The levels mentioned in the text are presented in colour. **C** Plan and YZ section of the remains treated in this work, collected in Units 23 (left) and 2/3 (right)

I. Unit 32 A: This is a 30 cm thick reddish-brown clay deposit, with sparse, very small, degraded dolostone boulders. It is located between 50 m and 50.8 m Y, from elevation − 2.8 m to the deepest area of the sector.
II. Unit 23 is a heterolithic conglomerate with a silty matrix, almost 70 cm thick. Towards the base of the Unit, it contains abundant very small and small-sized dolostone boulders, sub-rounded and sub-angular, alongside less abundant gneiss, granite, slate and quartzite small boulders, sub-rounded and rounded. The provenance of these boulders is diverse, originating from both local and distant outcrops. Unit 23 discomfomably overlies Unit 32 A, over an erosive but diffuse contact.
III. Unit 2/3 is a silty deposit with scarce dolostone very small boulders, paraconformably overlying Unit 23. The paraconformity was identified through taphonomic spatial analyses at a depth of 2.55 m. An Ap horizon has developed in the uppermost 20 cm of the deposit.

Materials and methods

Materials

In this study, a total of 2912 faunal remains were analysed, of which 119 belong to Unit 32 A. In Unit 23, 1520 faunal remains were counted, and finally, in Unit 2/3, 1273 faunal remains were identified (Fig. 2C). In addition to the faunal remains, coprolites and lithic industry remains have also been found (Mielgo et al. 2024).

The material has been collected throughout the 2009–2019 excavation campaigns. A 1 m^2 grid system was employed, whereby all faunal remains longer than 2 cm along their major axis were mapped. Additionally, identifiable smaller remains of taphonomic and/or palaeontological interest (e.g. bone flakes, teeth) were also recorded.

Methods

The remains were measured in millimeters using a digital caliper. Identification at the anatomical and taxonomic levels was carried out whenever possible, utilizing resources such as comparative manuals like Pales and Lambert (1971), Schimd (1972), Hillson (2005), among others, along with the anatomical reference collection housed at the Institut Català de Paleoecologia Humana i Evolució Social (IPHES).

The categorisation of body size was based on five weight sizes: very large (> 800 kg, e.g. *Stephanorhinus hemitoechus*), large (200–800 kg, e.g. Bos/Bison), medium (50–200 kg, e.g. *Cervus elaphus, Crocuta crocuta),* small (10–50 kg, e.g. *Capreolus capreolus, Canis lupus*), and very small (< 10 kg, e.g. *Marmota marmota, Vulpes vulpes*). It is important to note that animals of the same species may be categorised differently according to their size, particularly when considering immature individuals.

Three age groups were considered: immature (including perinatal and juvenile), adult and senile. This classification was based on the degree of epiphyseal fusion of the long bones, cortical development, growth of dental crowns, identification of deciduous or permanent teeth and wear of occlusal surfaces (e.g., Klein and Cruz-Uribe 1984; Barone 1986; Stiner 1994).

After estimating the age at death, statistical analyses were performed using Triangle 2.0 software (Weaver et al. 2011) following the model proposed by Discamps and Costamagno (2015). Due to the small sample size in the analyzed assemblage, we adopted the general model proposed by these authors. However, the application of 95% confidence intervals from Triangle 2.0 enhances the comparison of taxonomic differences. Additionally, we conducted an analysis by size classes, acknowledging a potential bias stemming from the distribution of individuals of the same species across different age groups. Despite this limitation, we consider this approach valuable at an exploratory level, as it complements the species-based analysis by highlighting the significant contribution of immature individuals from certain species to the assemblage.

The quantification of the remains was conducted using the number of remains (NR), the number of identified specimens (NISP), the minimum number of elements (MNE) and the minimum number of individuals (MNI). The calculations were carried out following the guidelines set out by Lyman (1994, 2008), Klein and Cruz-Uribe (1984), Brain (1969), Pickering (2002) and Yravedra and Domínguez-Rodrigo (2009). The NISP has been calculated from the total number of specimens attributable to a specific region of the skeleton (e.g. a humerus fragment or an isolated tooth). The term NISPs is employed when the calculation is based on weight groups, as outlined by Moclán et al. (2021). Furthermore, the standardised version of minimum animal Units (%MAU) has also been calculated (Binford 1978, 1984).

Analysis of the bone surfaces was performed with a Euromex StereoBlue SB.1902-P binocular microscope, with magnifications ranging from 6.7x to 45x. In cases where more detailed analysis was required and for taking photographs of bone surface modifications, a HIROX KH- 8700 digital microscope was used.

The analysis of weathering has been conducted with consideration of the grades proposed by Behrensmeyer (1978). Rounding and polishing have been grouped into three different grades, as proposed by Bouchud (1974), Shipman and Rose (1983) and Cáceres (2002): 1) Those features that can be observed microscopically, 2) those that can be observed macroscopically, and 3) those that significantly affect the whole bone.

Other biostratinomic and diagenetic alterations, such as trampling (Behrensmeyer et al. 1986; Olsen and Shipman 1988), biochemical alterations (Morlan 1980; Andrews 1995; Domínguez-Rodrigo and Barba 2006; Backwell et al. 2012), or micromammalian gnawing (Laudet and Fosse 2001; Pickering et al. 2013) have been documented based on their presence/absence. The presence or absence of calcareous and carbonate concretions and manganese oxides has also been considered (Courty et al. 1989; Coard 1999), with up to five degrees of oxidation according to Moclán (2023) considered.

A 6-grade scale (Moclán et al. 2021) was used to determine the level of cortical preservation on bone surfaces, where 0 represents 0%, 1 represents 1–25%, 2 represents 25–50%, 3 represents 50–75%, 4 represents 75–99%, and 5 represents 100% cortical preservation. Anthropogenic alterations (i.e., cut marks and percussion marks) were identified (Potts and Shipman 1981; Blumenschine and Selvaggio 1988; Blumenschine 1995; Galán and Domínguez-Rodrigo 2013). Thermal alterations were classified according to the degree of coloration, distinguishing between unburnt (grade 0), brown (grade 1), black (grade 2), grey (grade 3) and white (grade 4) remains, following the classification system proposed by (Stiner et al. 1995; Cáceres 2002 modified by Moclán 2023).

Carnivore activity was determined by the presence of pits, punctures, scores and furrowing, as well as the presence of digested remains (Haynes 1980, 1983; Binford 1981; Selvaggio 1994; Pickering 2001). All those scores and pits that presented a morphology that allowed their measurement in remains with good preservation of the cortical were measured and the dimensions were compared with experimental models (Domínguez-Rodrigo and Piqueras 2003; Andrés et al. 2012; Rodríguez-Hidalgo et al. 2013; Saladié et al. 2013b, a) to determine the type of carnivore involved.

The analysis of long bone fractures was carried out following the method proposed by Bunn (1982) and Villa and Mahieu (1991). Whenever possible, long bone fragments were also analysed for fracture type (Lyman 1994; Outram 2001) and fracture surface (Pickering et al. 2005; Alcántara García et al. 2006). The notches have been identified and classified using the typology proposed by Capaldo and Blumenschine (1994), modified by Pickering and Egeland (2006) and Galán et al. (2009): Type A (Complete notches): Two inflection points on the cortical surface and a scar on the internal face, both retaining their inflection points; Type B (Incomplete notches): Missing one inflection point, making it unclear where the notch begins or ends; Type C (Overlapping notches): Two or more consecutive, overlapping notches; Type D (Opposite notches): Two notches facing each other on opposing fracture planes; Type E (Micronotches): Notches shorter than 1 cm.

To ascertain whether the assemblage was subjected to any bias before burial, the geometric shape of the bone remains was analysed by taking into account the ratios between the length of bones (D1), width (D2) and maximum thickness (D3). The measurements were used to categorise each remains as flat, cubic, or elongated, in accordance with the diagrams of Flinn (1978). Similarly, to ascertain the degree of integrity of the assemblage, a correspondence analysis was conducted following the methodology proposed by Domínguez-Rodrigo et al. (2014) and Organista et al. (2017). Information from the non-transported assemblage of Navalmaíllo rockshelter (Moclán et al. 2021) has been included in this analysis due to its proximity.

Finally, three-dimensional models were constructed using ArcMap 10.5 for the spatial taphonomic analysis. All materials were recorded as individualised elements in a three-dimensional diagram representing the deposit, with Cartesian coordinates employed to delineate their spatial relationships.

Results

Unit 32 A

Quantification and sample characteristics

A total of 119 remains were counted, of which 12.6% (15 NR) were ascribed to a taxon (Table 1). Ungulates accounted for 66.7% of the NISP, including *Stephanorhinus hemitoechus*, Bos/Bison, *Cervus elaphus, Dama dama* and *Capreolus capreolus*. The identification of large bovids was limited to the subfamily level (i.e. Bovinae), with both genera present in the Lozoya Valley during the Upper Pleistocene (Galindo-Pellicena et al. 2019). Among the carnivores, only *Felis silvestris* and an undetermined mustelid were identified. The remaining 20% of NISP is comprised of indeterminate birds and hedgehogs.

77.3% (92 NR) of the faunal remains have been assigned to a weight size. Considering both NR and NISPs (Table 1), medium (30% NISPs) and small (26% NISPs) size animals predominate, although all sizes are represented in Unit 32 A.

A total of 11 individuals have been recorded (Table 1). The highest MNI values are observed for bovines and fallow deer, with two individuals each. The MNE and %MAU values for ungulates (Supplementary File 1) demonstrate a low

Table 1 NR, NISP, MNE and MNI values for each taxon and weight group of the faunal sample from Unit 32 A

		NR	%NR	NISP	%NISP	MNE	%MNE	MNI	%MNI	Inmature	Adult	Senile
S. hemitoechus		1	6.67	1	6.67	1	7.14	1	9.09		1	
Bos/Bison		4	26.67	4	26.67	4	28.57	2	18.18	1	1	
Cervus elaphus		2	13.33	2	13.33	2	14.29	1	9.09		1	
Dama dama		2	13.33	2	13.33	2	14.29	2	18.18		2	
Capreolus capreolus		1	6.67	1	6.67	1	7.14	1	9.09		1	
Erinaceus sp.		1	6.67	1	6.67	1	7.14	1	9.09		1	
Birds		2	13.33	2	13.33	1	7.14	1	9.09		1	
Felis silvestris		1	6.67	1	6.67	1	7.14	1	9.09		1	
Mustelidae		1	6.67	1	6.67	1	7.14	1	9.09		1	
Total		**15**	**100**	**15**	**100**	**14**	**100**	**11**	**100**	**1**	**10**	**0**
Very small	(0–10 kg)	10	8.40	5	10.0	5	10.0	4	36.36		4	
Small	(10–50 kg)	30	25.21	13	26.0	13	26.0	1	9.09		1	
Medium	(50–200 kg)	32	26.89	15	30.0	15	30.0	4	36.36	1	3	
Large	(200–800 kg)	18	15.13	8	16.0	8	16.0	1	9.09		1	
Very large	(> 800 kg)	2	1.68	2	4.0	2	4.0	1	9.09		1	
Total		**92**	**77.31**	**43**	**86**	**43**	**86**	**11**	**100**	**1**	**10**	**0**
Indet		27	22.69	7	14	7	14					
Total		**119**	**100**	**50**	**100**	**50**	**100**					

representation of the axial skeleton. The cranial section is the best represented, followed by the appendicular elements.

Upon analysis of the sample by weight size, it becomes evident that the MNE and %MAU exhibit a comparable pattern in the very large, large, and medium size groups. The cranial skeleton is observed to prevail, although axial and appendicular elements are observed to be somewhat more represented than in the taxon analysis (Fig. 3, Supplementary File 2). However, the disproportionate representation of the cranial skeleton is largely due to the presence of isolated teeth rather than complete dental series or skull and jaw remains per se. The appendicular skeleton predominates in the small size, followed by the cranial skeleton and, lastly, the axial skeleton.

Taphonomic modifications

48.7% of the faunal remains have poor cortical preservation (grades 0, 1 and 2), while the remaining sample has better preservation (Supplementary File 3). Only 10% of

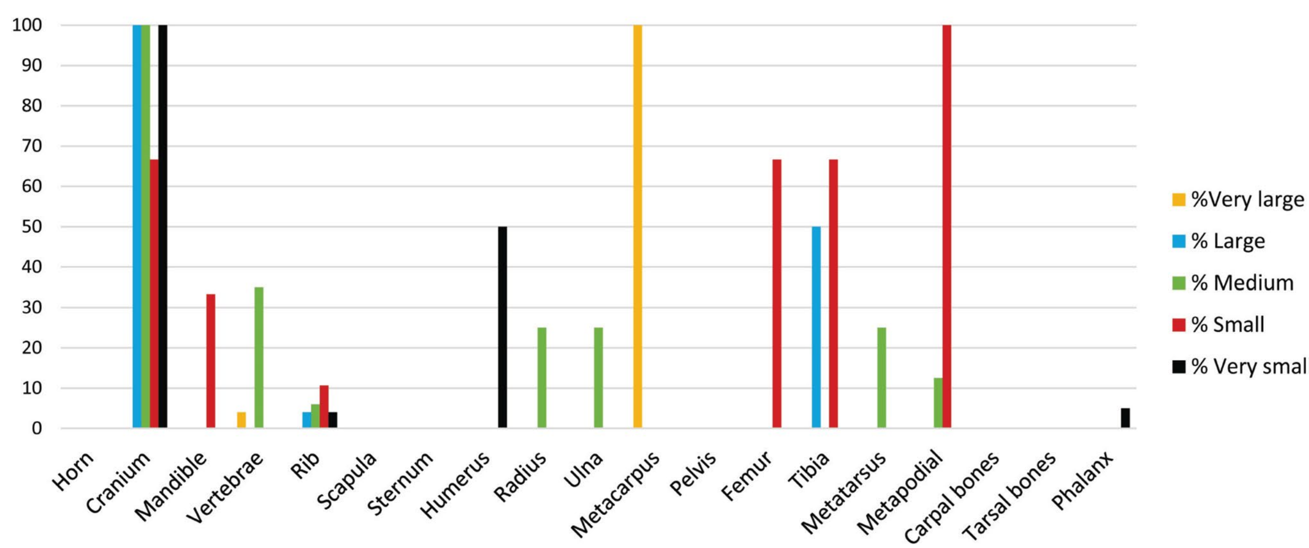


Fig. 3 %MAU of the different weight sizes of Unit 32 A

the sample shows stage 1–2 weathering. Approximately 70% of the specimens exhibited manganese oxide alteration, with most of these occurrences occurring in isolation. Additionally, 60.5% of the specimens show concretions, and biochemical marks were observed in 51.3% of the sample, while trampling was observed in 1.7%.

A total of 54 remains (45.4%) show alterations related to carnivore activity. In these, pits, scores, and punctures have been documented in 9.2% (n = 11) of the sample, nibbling in 32.8% (n = 45), dissolution from contact with salivary enzymes resulting from sucking in 9.2% (n = 11) and from gastric acids in 13.5% (n = 16). Among the digested remains, bones of different weight sizes groups were identified: small-sized (n = 2), medium-sized (n = 5), and large-sized (n = 2). In addition, a certain uniformity in the size of the remains was observed, with all the digested remains being less than 4 cm in length. Carnivore activity is concentrated in the appendicular skeleton (n = 23), followed by the axial (n = 15) and cranial (n = 2), in rhinoceros, bovine and avian remains (Supplementary File 3). The high alteration of the bone cortex has allowed only two pit measurements, one of 0.3 mm and the other of 0.5 mm diameter.

The only evidence of anthropogenic action is a percussion mark associated with a patch of microstriations, a feature typically associated with the use of anvils during the bone fracturing process (Pickering and Egeland 2006). This mark is located on the diaphysis of a long bone from a medium-sized animal, representing 3.1% of the medium-sized remains and 2.5% when considering only those with well-preserved cortical surfaces.

51.3% of the remains show water-related modifications (Supplementary File 3). Among these alteration processes, rounding (46.2%) and polishing (28.6%) predominate. The first stages are the most abundant, although 16.4% of the rounded remains and 8.8% of the polished remains reach the highest degree of alteration (Table 2).

The only remains exhibiting evidence of anthropogenic activity are those that have been rounded to grade 2. Similarly, among the bones that have been altered by carnivores, 60.4% exhibit evidence of rounding, while 35.9% display polish to grades 1 and 2.

Bone fragmentation

A total of 69% of the remains are less than 3 cm in length. 12 diaphysis fragments (10.1% of the sample) exhibited a fracture type and pattern indicative of fresh fracturing. Two E-type notches were observed on two diaphyseal fragments from medium-sized animals. Dry and diagenetic fractures were also observed. Furthermore, 64.5% of the diaphyses exhibit less than 25% of the original length and less than 50% of the original circumference.

The geometric shape analysis reveals a diverse range of forms, including examples of elongated, cubic, and planar-shaped remains (Supplementary File 7 A).

Unit 23

Quantification and sample characteristics

At this Unit, 1520 faunal remains have been recorded, of which 26.1% (n = 397) have been taxonomically identified (Table 3). In terms of NISP, ungulates account for 51.9% of the sample and carnivores 17% (see Table 3). The presence of two remains of Proboscidea is noteworthy, as they are the only remains of these animals in the Pinilla del Valle sites.

Eighty-one percent of the specimens and 91.7% of the NISPs have been ascribed to one of the weight sizes (Table 3). Among them, animals of medium size (33.8% NISPs) and very small size (20.3% NISPs) predominate.

Cervids have the highest NISP values, especially *Cervus elaphus* and *Dama dama*, with 13 and 10 individuals respectively. These species are notable for their abundance of immature animals (Table 3). They are followed by bovines (6) and roe deer (5), while the remaining ungulates are represented by 1 or 2 individuals. The mesofauna taxa are represented by a single individual, except in the case of turtles (2). Among the carnivores, *Crocuta crocuta* stands out with 3 individuals, 2 of which are immature.

The taxa with the highest number of individuals (i.e. bovines, *Cervus elaphus, Dama dama* and *Crocuta crocuta*) show attritional mortality patterns (Fig. 4A). In terms of weight sizes, most of the individuals are adults (Table 3), except for the small-sized animals with 15 immature individuals and 9 adults. When examining mortality patterns according to weight categories (Fig. 4B), it can be observed that while the medium, large and very large sizes are situated

Table 2 Number of remains according to their degree of rounding and polishing by dimensions. In brackets the % based on the total number of rounded or polished remains

	Rounding			Polishing		
Unit	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3
32 A	27 (49.09%)	19 (34.54%)	9 (16.36%)	20 (58.82%)	11 (32.35%)	3 (8.82%)

Table 3 NR, NISP, MNE and MNI values for each taxon and weight group of the faunal sample from Unit 23

		NR	%	NISP	%NISP	MNE	%MNE	MNI	%MNI	Inmature	Adult	Senile
Proboscidea		2	0.50	2	0.5	1	0.39	1	1.45		1	
Stephanorhinus hemitoechus		6	1.51	6	1.5	5	1.93	2	2.90	1	1	
Bos/Bison		74	18.64	74	18.8	68	26.25	6	8.70	2	4	
Equus ferus		1	0.25	1	0.3	1	0.39	1	1.45		1	
Equus hydruntinus		1	0.25	1	0.3	1	0.39	1	1.45		1	
***Equus* sp.**		12	3.02	12	3.1	12	4.63	2	2.90	1	1	
Cervus elaphus		61	15.37	61	15.5	51	19.69	13	18.84	7	6	
Dama dama		26	6.55	26	6.6	26	10.04	10	14.49	5	5	
Cervidae		6	1.51	6	1.5	6	2.32	1	1.45		1	
Sus scrofa		1	0.25	1	0.3	1	0.39	1	1.45		1	
***Capra* sp.**		4	1.01	4	1.0	4	1.54	1	1.45		1	
Capreolus capreolus		8	2.02	8	2.0	9	3.47	5	7.25	2	3	
Rupicapra rupicapra		2	0.50	2	0.5	2	0.77	2	2.90	1	1	
Marmota marmota		1	0.25	1	0.3	1	0.39	1	1.45	1		
Oryctolagus cuniculus		1	0.25	1	0.3	1	0.39	1	1.45		1	
Testudines indet		120	30.23	118	30.0	3	1.16	2	2.90	1	1	
Birds		4	1.01	2	0.5	2	0.77	1	1.45		1	
Ursus arctos		2	0.50	2	0.5	2	0.77	1	1.45		1	
Crocuta crocuta		22	5.54	22	5.6	22	8.49	3	4.35	2	1	
Panthera pardus		10	2.52	10	2.5	10	3.86	2	2.90	1	1	
Canis lupus		3	0.76	3	0.8	3	1.16	2	2.90	1	1	
***Cuon* sp.**		1	0.25	1	0.3	1	0.39	1	1.45		1	
Felis sylvestris		1	0.25	1	0.3	1	0.39	1	1.45		1	
Vulpes vulpes		7	1.76	7	1.8	7	2.70	2	2.90		2	
Martes foina		1	0.25	1	0.3	1	0.39	1	1.45		1	
Mustelidae		3	0.76	3	0.8	3	1.16	2	2.90		2	
Canidae indet		1	0.25	1	0.3	1	0.39	1	1.45		1	
Carnivora indet		16	4.03	16	4.1	14	5.41	2	2.90	1	1	
Total		**397**	**100**	**393**	**100**	**259**	**100**	**69**	**100**	**26**	**43**	**0**
Very small	(0–10 kg)	173	11.38	154	20.32	37	8.73	16	23.19	7	9	
Small	(10–50 kg)	371	24.41	144	19.00	75	17.69	24	34.78	15	9	
Medium	(50–200 kg)	391	25.72	256	33.77	148	34.91	19	27.54	3	16	
Large	(200–800 kg)	238	15.66	107	14.12	81	19.10	8	11.59	1	7	
Very large	(> 800 kg)	58	3.82	34	4.49	31	7.31	2	2.90		2	
Total		**1231**	**80.99**	**695**	**91.69**	**372**	**87.74**	**69**	**100**	**26**	**43**	**0**
Indet		289	19.01	63	8.31	52	12.26					
Total		**1520**	**100**	**758**	**100**	**424**	**100**					

within the adult-dominated area, the small size falls within the catastrophic zone. This bias stems from the high proportion of immature individuals classified as small-sized based on their weight. However, when analysed by taxon, the average values remain within the JPO space.

MNE and %MAU values show widely varying values (Supplementary File 4a, 4b and 5). Proboscidea, *Stephanorhinus hemitoechus, Equus ferus, Equus hydruntinus* and *Sus scrofa* are represented only by the cranial section due, in most cases, to the presence of isolated teeth. In the remaining ungulates (Fig. 5), the cranial section is also the best represented, followed by the appendicular skeleton (with a predominance of metapodials and humeri) and, finally, the axial skeleton. Among carnivores, the same pattern is observed, although, among the appendicular elements, compact bones are more abundant than long bones (Supplementary File 4b). Finally, among the mesofauna, the abundance of remains identified as plates forming part of the turtle carapace (n = 116) is noteworthy, although if the carapace is considered as a single element formed by the different plates, it represents a total MNE of 2.

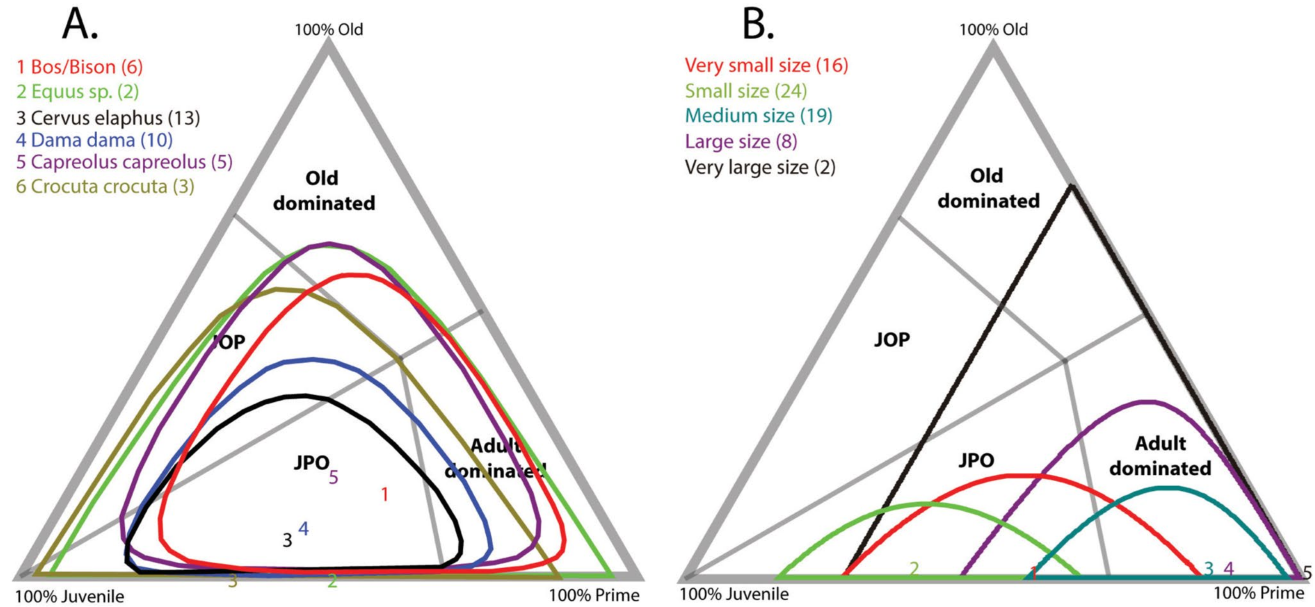


Fig. 4 Ternary graph showing age at death (95%CIs) for main taxa (**A**) and weight sizes (**B**) at Unit 23

When analysed by size and weight of the animals (Supplementary File 6), the cranial section is again the most abundant, followed by the appendicular elements and the axial skeleton at all sizes.

Taphonomic modifications

41.4% of the faunal remains have good cortical preservation (grades 3, 4 and 5) (Table 4) and 17.4% correspond to dental pieces.

A total of 9.1% of the sample is weathered, with no discernible concentration within the excavated area (Fig. 6). All the sizes present, to a greater or lesser extent, fractures, and cracks typical of stages 1 and 2, while only the large, medium, and small sizes also present the alterations typical of stages 3 and 4. 78% of the sample (n = 1186) has been affected by manganese oxides, 58.5% (Table 4) by calcareous concretions, and 7% by trampling. Biochemical marks were also observed in 60.2% of the sample, with these marks being rounded in 26 remains (Supplementary File 8 M).

Evidence of modifications attributed to carnivore activity was observed on 29.5% (n = 449) of the remains. Pits, scores, and punctures were documented in 7% (n = 107) of the sample (Table 4), while loss of bone tissue due to furrowing was observed in 21% (n = 319). These modifications affect a wide range of animals, including small, medium, and large animals, as well as taxa such as bovines and deer (Supplementary File 9). To a lesser extent, these modifications have been observed in turtle, bird, bear, leopard, and mustelid specimens (Supplementary Files 9 and 10).

Tooth marks were measured on 107 well-preserved remains. In these instances, the diameter of the pits ranged from 0.3 to 8 mm, while the scores exhibited dimensions of 1–28 mm in length and 0.3–7.3 mm in width. The recorded dimensions of pits and scores in both epiphyses and diaphyses are in agreement with experimental models for different carnivores (Supplementary File 11). However, the width of the scores is consistent with the model generated by large carnivores.

Similarly, gnawing (3.4%, n = 52) is observed in all weight sizes, with a prevalence below 5.5%. In contrast, digested remains (9.7%, n = 147) are concentrated, from largest to smallest, in small, medium, and large sizes. The specimens that had been digested ranged in size from 15 to 65 mm, with 16 of them being larger than 40 mm in length.

Two additional specimens exhibited rodent scores Anthropic action has been documented in 0.5% of the sample in the form of cut marks (Supplementary File 8G and 8H) and percussion marks (0.6%) (Table 4). A total of seven remains with cut marks have been identified. These include one large-sized diaphysis fragment with a scraping, one indeterminate very large-sized remains with one incision, two large-sized diaphysis fragments with two and four incisions, one large-sized epiphysis fragment with one incision, one large-sized axial remains with four incisions, and one medium-sized diaphysis fragment with two incisions. Conversely, the percussion marks are concentrated on medium-sized bones, two of which are deer (Table 4 and Supplementary File 9). Furthermore, three grade 1 burnt bones have been identified.

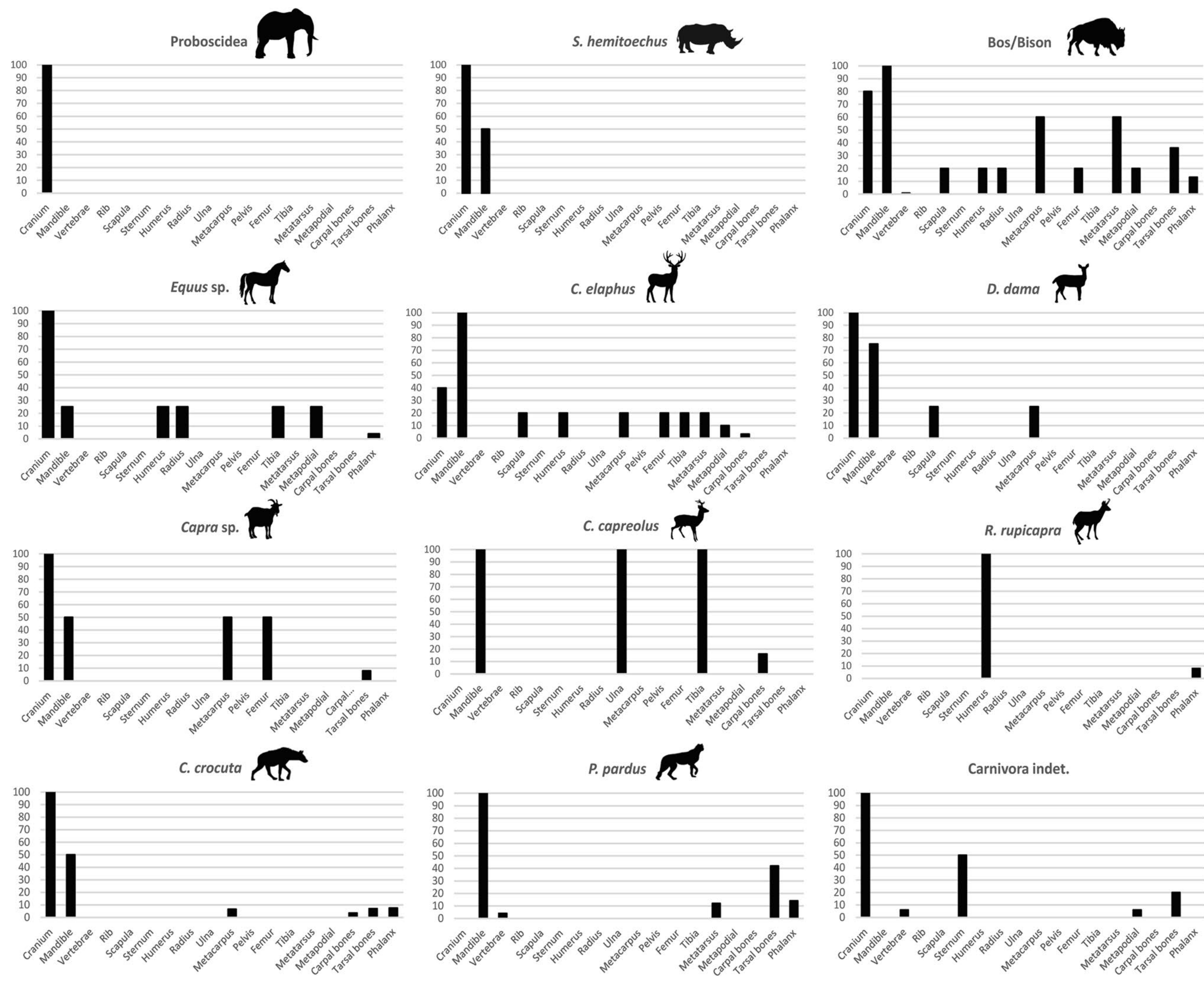


Fig. 5 %MAU values for the main ungulates and carnivores at Unit 23

As shown in Table 4, 63.2% of the remains have been subjected to water-related modifications. Among the various alteration processes, rounding and polishing have affected 48.7% and 34.1% of the sample, respectively. In both cases, more than 37% of the altered specimens are modified to grades 2 and 3 (Table 5).

Most of the remains with anthropogenic alterations (71.4% of the remains with cut marks and 75% of the bones with percussion marks) show evidence of rounding and polishing in grades 1 and 2. On the other hand, among the remains in which alterations produced by carnivores have been identified, 61.7% have evidence of rounding in grades 1, 2 and 3, and 30.5% are polished.

The spatial taphonomic analysis does not reveal any discernible groupings based on the different taphonomic processes that modified the bones (Fig. 6). Furthermore, the overlap in the spatial distribution of all degrees of alteration is also evidence of a heterogeneous assemblage.

Bone fracturing, shape, and composition

A total of 55.2% of the remains were less than 3 cm long, with 30% being between 3 and 5 cm. The study of the fracture patterns in the diaphyses revealed that 91% of them were freshly fractured, a type of fracture identified especially in femurs and radii. Additionally, dry and diagenetic fractures were observed.

Twenty-five remains (1.7%) accumulated 32 notches in total (Fig. 7). 8 are of type A (25%), 3 are of type B (9%), 4 are of type C (12%), 4 are of type D (13%) and 13 are of type E (41%). All weight categories, except the very small, exhibit notches (Fig. 6). The large animals exhibited 66.7% of type E, while the medium-sized animals

Table 4 Results of taphonomic analyses by weight size carried out at Unit 23

	Very large		Large		Medium		Small		Very small		Indet		Total	
Good surface preservation	22	37.9%	75	31.5%	166	42.5%	169	45.6%	144	83.2%	53	18.9%	629	41.4%
Bad surface preservation	17	29.3%	109	45.8%	147	37.6%	173	46.6%	16	9.2%	164	58.4%	626	41.2%
Weathering	11	19.0%	44	18.5%	33	8.4%	20	5.4%	1	0.6%	30	10.7%	139	9.1%
Manganese oxides	40	69.0%	197	82.8%	306	78.3%	283	76.3%	145	83.8%	215	76.5%	1186	78.0%
Water	27	46.6%	100	42.0%	163	41.7%	138	37.2%	19	11.0%	70	24.9%	517	34.0%
Rounding	36	62.1%	153	64.3%	197	50.4%	179	48.2%	30	17.3%	145	51.6%	740	48.7%
Polishing	27	46.6%	98	41.2%	151	38.6%	132	35.6%	28	16.2%	82	29.2%	518	34.1%
Concretion	41	70.7%	160	67.2%	251	64.2%	229	61.7%	45	26.0%	163	58.0%	889	58.5%
Trampling	7	12.1%	18	7.6%	36	9.2%	30	8.1%	6	3.5%	9	3.2%	106	7.0%
Biochemical marks	40	69.0%	151	63.4%	260	66.5%	223	60.1%	132	76.3%	109	38.8%	915	60.2%
Rodent gnawing	0		2	0.8%	0		0		0		0		2	0.1%
Burned bones	0		0		0		1	0.3%	0		2	0.7%	3	0.2%
Cut marks	1	1.7%	5	2.1%	1	0.3%	0		0		0		7	0.5%
Percusion marks	0		2	0.8%	4	1.0%	1	0.3%	0		1	0.4%	8	0.5%
Notch	3	5.2%	7	2.9%	9	2.3%	6	1.6%	0		1	0.4%	26	1.7%
Pits	0		14	5.9%	6	1.5%	17	4.6%	3	1.7%	3	1.1%	43	2.8%
Scores	2	3.4%	13	5.5%	12	3.1%	21	5.7%	8	4.6%	6	2.1%	62	4.1%
Punctures	0		0		0		1	0.3%	0		0		1	0.1%
Furrowing	9	15.5%	58	24.4%	75	19.2%	101	27.2%	13	7.5%	63	22.4%	319	21.0%
Gnawing	1	1.7%	13	5.5%	16	4.1%	11	3.0%	2	1.2%	9	3.2%	52	3.4%
Digested bones	1	1.7%	15	6.3%	29	7.4%	59	15.9%	0		43	15.3%	147	9.7%

exhibited 60% of type A. In the small animals, type D and E each accounted for 37.5% of the total. At the taxonomic level, 1 rest is bovine and 4 are deer.

A total of 593 diaphysis fragments (39% of the sample) were counted in the assemblage. Given the intensity of fracturing in the set, 59.7% (n = 145) of the diaphyses of small-sized animals are less than 25% of their original length and circumference, as well as 75.4% (n = 138) of medium-sized animals, 80.3% (n = 94) of large-sized animals and 74.1% (n = 20) of very large-sized animals. In contrast, in the case of the very small size, there is no diaphysis with these characteristics and 56.5% (n = 13) maintain their full circumference and almost the entire original length. Additionally, seven cylinders have also been documented (3 of which correspond to small sized adults, 3 to small sized immature individuals, and 1 to a large sized adult), and 2 complete metacarpals of medium and large size.

Cubic and flat shapes are the most abundant (Supplementary File 7), although a certain variety of shapes is observed, including also elongated remains. When not only shape but also composition is taken into account, the correspondence analysis (Fig. 8) with the comparative frame of reference suggests that the assemblage presents intermediate characteristics between the non-transported and water-transported assemblages.

Unit 2/3

Quantification and sample characteristics

A total of 1273 faunal remains have been recovered at this Unit, with 27.8% (n = 315) identified taxonomically (Table 6). The ungulates constitute 64.1% of the NISP, while the carnivores account for 16.2% of the NISP. Additionally, mesofauna species are present (see Table 6). A minimum of 58 individuals have been recorded (Table 6). Of these, 68.9% were adults, 27.6% were immature individuals, and 3.5% corresponded to two senile individuals.

The assemblage is dominated by *Cervus elaphus*, with a minimum number of individuals (MNI) of 7, followed by hedgehogs (6), as well as *Dama dama, Capreolus capreolus*, and *Oryctolagus cuniculus*, each with 3 adult and 1 immature individual. Two individuals exhibiting signs of advanced age have been identified, one bovine and one *Capra* sp., in addition to a perinatal individual of an indeterminate cervid. Regarding carnivores, the highest values were observed in *Vulpes vulpes* (3), followed by *Crocuta crocuta*, Mustelidae, and indeterminate Carnivora specimens (Table 6).

A total of 996 specimens (78.2% of the sample) were classified according to weight size. The most abundant size group was medium-sized animals (27.7% of the total), followed by small-sized animals (23.4%). Adults are the most

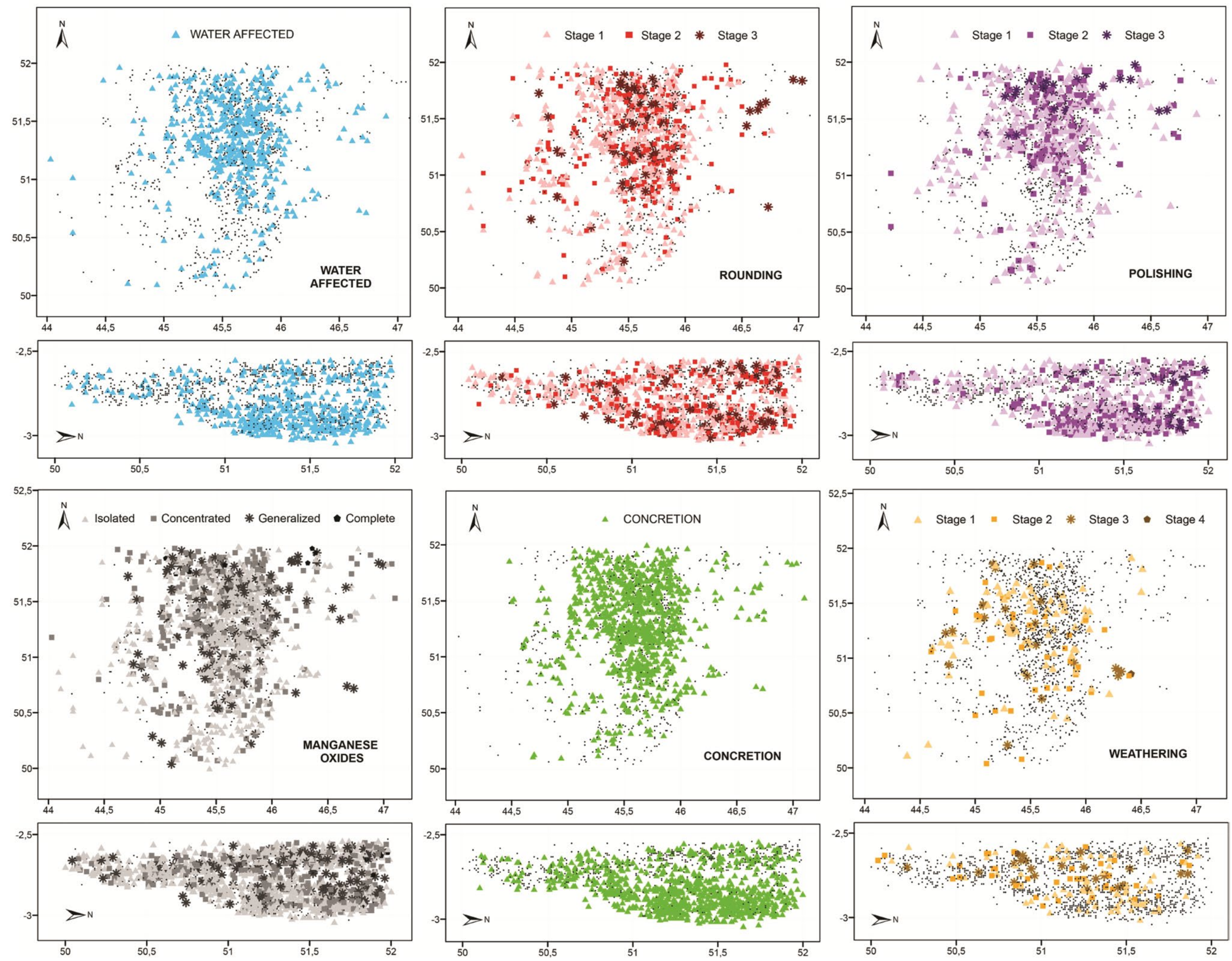


Fig. 6 Spatial distribution of all skeletal remains from Unit 23 (see Fig. 2C). All images show the spatial distribution of each bone specimen according to taphonomic variables in plan (top) and in YZ section (bottom)

Table 5 Number of remains according to their degree of rounding and polishing by dimensions. In brackets the % based on the total number of rounded or polished remains

	Rounding			Polishing		
Unit	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3
23	281 (57.94%)	152 (31.34%)	52 (10.72%)	247 (62.06%)	125 (31.41%)	26 (6.53%)

prevalent across all size groups, except for small-sized animals (Table 6).

Most taxa and weight-size groups exhibit a catastrophic mortality pattern (Supplementary Files 12 A, 12B, 12C, and 12D). In contrast, Cervidae, *Meles meles*, and the small-sized group follow an attritional pattern (Supplementary Files 12B, 12 C, and 12D). However, categorizing *Meles meles* this way based on a single immature individual may be an overinterpretation.

The values of MNE and %MAU (Fig. 9, Supplementary File 13a) for the identified ungulates indicate a significant disproportion among different skeletal sections. The best-represented elements are the skulls and mandibles (due to the high number of isolated teeth), followed by the appendicular skeletal elements. The axial skeleton is barely represented, except for *Cervus elaphus*, where the coxal and scapula have low values. Among the carnivores (Supplementary File 13b), the cranial section is the most prevalent, while

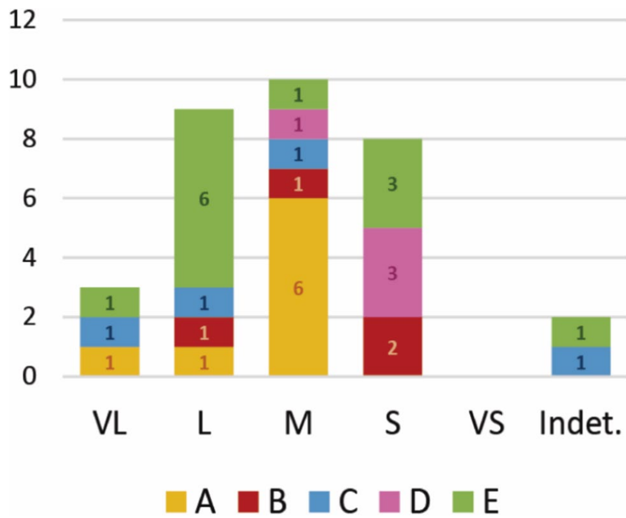


Fig. 7 Cumulative bar chart with the number of notches for each type using the typology (**A**, **B**, **C**, **D**, **E**) proposed by Capaldo and Blumenschine (1994), modified by Pickering and Egeland (2006) and Galán et al. (2009), analysed according to weight size (VL: very large, L: large, M: medium, S: small, VS: very small)

the rest of the skeletal elements are very scarce. However, compact bones have been documented in almost all species.

The same pattern was observed with respect to body size (Supplementary File 14 and 15). The high %MAU values for the cranial skeleton are largely due to the presence of isolated teeth rather than complete dental series or remains of mandibles or maxillary bones, as seen in Supplementary File 14. On the other hand, the appendicular elements reach medium–high values, and the axial elements are somewhat better represented.

Taphonomic modifications

57.3% of the faunal remains exhibit good cortical preservation (grades 3, 4, and 5), while 24.7% show poorer preservation (Table 7). The remaining 18% of the remains consist of dental pieces.

Biochemical marks were identified in 69.9% of the sample. Additionally, weathering (16.3%), manganese oxides (83%), and concretions (22.1%) have been observed. 13 specimens have calcareous concretions (Supplementary File 20 A), detached from the fossiliferous breccia (Fig. 2A) and incorporated into the level in the same area.

The activity of carnivores has been documented in 41% of the sample (n = 522). These modifications affect all ungulates and taxa weighing less than 10 kg (Supplementary File 16), with the exception of *Equus ferus* and *Sus scrofa*, which are represented only by dental remains, and *Lepus* sp. These modifications have also been observed in carnivore remains, such as hyena, leopard, fox, and badger (Supplementary Files 17 and 18), albeit to a lesser extent.

Tooth marks were observed in 20.4% of the remains (n = 260, Table 7), with the greatest prevalence on carpal/tarsal bones (n = 61), phalanges (n = 52), and ribs (n = 49). However, humerus (n = 36) and femur (n = 36) remains with these alterations were also abundant (Supplementary File 18 and Supplementary File 19 G, H, I, K). Among the modifications observed in the carcasses of animals consumed by carnivores, the loss of bone tissue due to furrowing is noteworthy. This was observed in 34.1% of the sample (n = 434), affecting all size categories in more than 26% of the total in each case. Gnawing was observed in

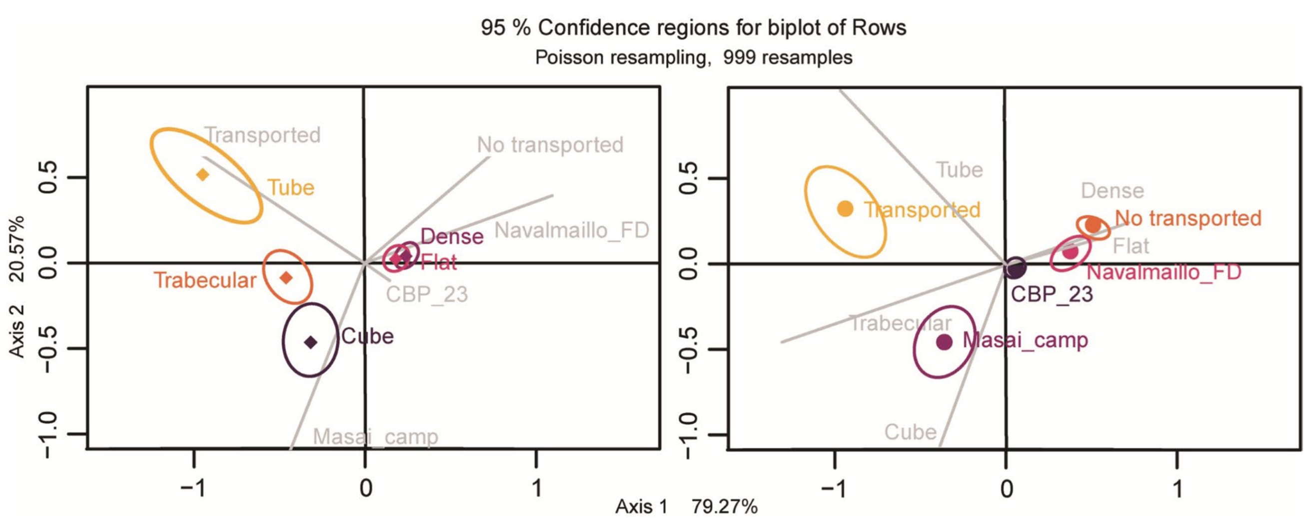


Fig. 8 Correspondence analysis comparing the shape and composition of the skeletal remains from Unit 23 (CBP_23) with those from different water transport models (Domínguez-Rodrigo et al. 2014; Organista 2017; Organista et al. 2017; Moclán et al. 2021). Ellipses indicate 95%CIs. Left, distribution of different bone types; right, distribution of sites with models included

Table 6 NR, NISP, MNE and MNI values for each taxon and weight group of the faunal sample from Unit 2/3

		NR	%NR	NISP	%NISP	MNE	%MNE	MNI	%MNI	Inmature	Adult	Senile
Stephanorhinus hemitoechus		8	2.54	8	2.54	6	2.17	2	3.45	1	1	
Bos/Bison		45	14.29	45	14.29	34	12.32	3	5.17		2	1
Equus ferus		3	0.95	3	0.95	3	1.09	2	3.45	1	1	
***Equus* sp.**		16	5.08	16	5.08	13	4.71	1	1.72		1	
Cervus elaphus		81	25.71	81	25.71	66	23.91	7	12.07	3	4	
Dama dama		14	4.44	14	4.44	12	4.35	4	6.90	1	3	
Cervidae		8	2.54	8	2.54	10	3.62	3	5.17	2	1	
Sus scrofa		1	0.32	1	0.32	1	0.36	1	1.72		1	
***Capra* sp.**		4	1.27	4	1.27	4	1.45	2	3.45	1		1
Capreolus capreolus		18	5.71	18	5.71	18	6.52	4	6.90	1	3	
Rupicapra rupicapra		4	1.27	4	1.27	4	1.45	1	1.72		1	
Castor fiber		4	1.27	4	1.27	3	1.09	1	1.72		1	
Marmota marmota		3	0.95	3	0.95	2	0.72	1	1.72		1	
Erinaceidae		10	3.17	10	3.17	10	3.62	6	10.34		6	
Oryctolagus cuniculus		17	5.40	17	5.40	15	5.43	4	6.90	1	3	
***Lepus* sp.**		1	0.32	1	0.32	1	0.36	1	1.72		1	
Testudines indet		26	8.25	26	8.25	26	9.42	1	1.72		1	
Grus grus		1	0.32	1	0.32	1	0.36	1	1.72		1	
Crocuta crocuta		13	4.13	13	4.13	12	4.35	2	3.45	1	1	
Panthera pardus		4	1.27	4	1.27	4	1.45	1	1.72		1	
Canis lupus		1	0.32	1	0.32	1	0.36	1	1.72		1	
Vulpes vulpes		12	3.81	12	3.81	11	3.99	3	5.17	1	2	
Meles meles		1	0.32	1	0.32	1	0.36	1	1.72	1		
Mustelidae		6	1.90	6	1.90	6	2.17	2	3.45	1	1	
Canidae indet		1	0.32	1	0.32	1	0.36	1	1.72		1	
Carnivora indet		13	4.13	13	4.13	11	3.99	2	3.45	1	1	
Total		**315**	**100**	**315**	**100**	**276**	**100**	**58**	**100**	**16**	**40**	**2**
Very small	(0–10 kg)	123	9.66	108	14.50	85	19.81	23	39.66	6	17	
Small	(10–50 kg)	298	23.41	208	27.92	122	28.44	16	27.59	8	7	1
Medium	(50–200 kg)	353	27.73	234	31.41	119	27.74	12	20.69	1	11	
Large	(200–800 kg)	202	15.87	134	17.99	63	14.69	6	10.34	1	4	1
Very large	(> 800 kg)	20	1.57	17	2.28	15	3.50	1	1.72		1	
Total		**996**	**78.24**	**701**	**94.09**	**404**	**94.17**	**58**	**100**	**16**	**40**	**2**
Indet		277	21.76	44	5.91	25	5.83					
Total		**1273**	**100**	**745**	**100**	**429**	**100**					

7.2% of the sample (n = 92), with the majority of instances occurring in large and medium-sized specimens (Table 7).

The analysis of the dimensions of pits and scores present in 185 remains of long bones with good cortical preservation (Fig. 10) has revealed variations depending on the location of the marks. The size of the pits in the epiphyses matches that of experimental models of medium-small carnivores (wolf, fox, lynx), while the scores overlap with those of humans, wolves, and lions. Conversely, the sizes of the pits recorded in the diaphyses mainly coincide with those of medium-large carnivores (bear, lion, and hyenids), and the scores even exceed the highest experimental intervals (Fig. 10).

161 specimens (12.6%) have been digested (Supplementary File 19 C, F, J, L). This alteration is primarily concentrated in medium and large weight sizes, although it affects all sizes and includes bovines, deer, fallow deer, goats, ibexes, leopards, and unidentified canids. The size of the remains exhibiting this alteration ranges from 12 to 63 mm, with 22 specimens larger than 40 mm.

Finally, among the alterations related to carnivore activity, it is worth noting the presence of four bones on which small cavities are observed on the bone surface, along with some patches of unaltered cortical bone (Supplementary File 20). This type of alteration has been described by Fernández-Jalvo and Andrews (2016:245) in the sediments

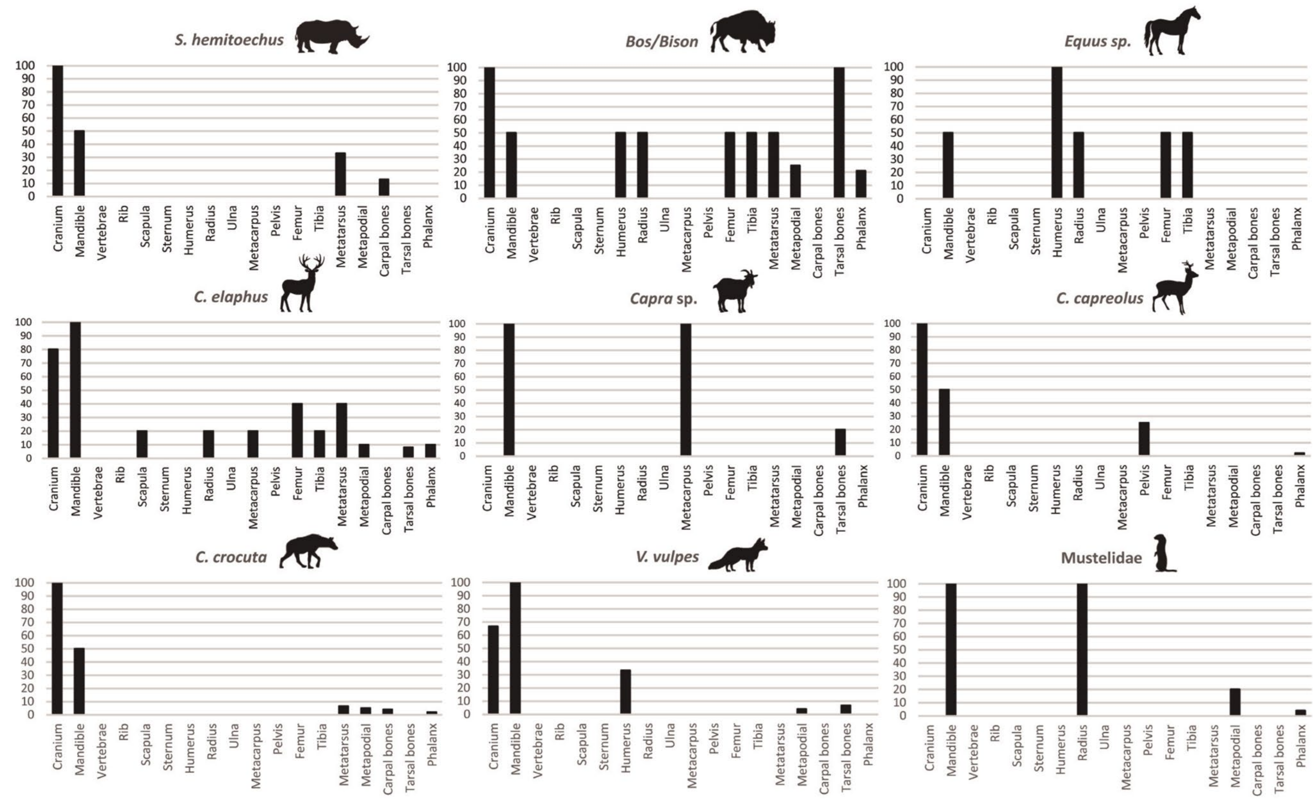


Fig. 9 %MAU values for the main ungulates and carnivores from Unit 2/3

Table 7 Results of taphonomic analyses by weight size conducted in Unit 2/3

	Very large		Large		Medium		Small		Very small		Indet		Total	
Good surface preservation	7	35%	95	47%	273	77.3%	158	53%	116	94.3%	81	29.2%	730	57.3%
Bad surface preservation	5	25%	60	29.7%	87	24.6%	63	21.1%	10	8.1%	89	32.1%	314	24.7%
Weathering	2	10%	36	17.8%	89	25.2%	35	11.7%	4	3.3%	41	14.8%	207	16.3%
Manganese oxides	19	95%	172	85.1%	339	96.0%	227	76.2%	110	89.4%	189	68.2%	1056	83%
Water	3	15%	50	24.8%	88	24.9%	34	11.4%	11	8.9%	36	13%	222	17.4%
Rounding	11	55%	104	51.5%	178	50.4%	85	28.5%	31	25.2%	101	36.5%	510	40.1%
Polishing	3	15%	41	20.3%	73	20.7%	29	9.7%	16	13%	30	10.8%	192	15.1%
Concretion	10	50%	75	37.1%	97	27.5%	33	11.1%	21	17.1%	45	16.2%	281	22.1%
Trampling	2	10%	31	15.3%	63	17.8%	25	8.4%	4	3.3%	8	2.9%	133	10.4%
Biochemical marks	12	60%	138	68.3%	324	91.8%	205	68.8%	94	76.4%	117	42.2%	890	69.9%
Rodent gnawing	0		0		7	2.0%	4	1.3%	0		1	0.4%	12	0.9%
Burned bones	0		0		9	2.5%	3	1%	2	1.6%	3	1.1%	17	1.3%
Cut marks	0		0		2	0.6%	0		0		0		2	0.2%
Percusion marks	0		2	1.0%	1	0.3%	0		0		0		3	0.2%
Notch	0		6	3%	16	4.5%	14	4.7%	1	0.8%	0		37	2.9%
Pits	2	10%	18	8.9%	31	8.8%	24	8.1%	12	9.8%	19	6.9%	106	8.3%
Scores	2	10%	20	9.9%	45	12.7%	38	12.8%	18	14.6%	21	7.6%	144	11.3%
Punctures	0		0		2	0.6%	4	1.3%	2	1.6%	2	0.7%	10	0.8%
Furrowing	7	35%	80	39.6%	107	30.3%	80	26.8%	44	35.8%	116	41.9%	434	34.1%
Gnawing	1	5%	27	13.4%	34	9.6%	10	3.4%	3	2.4%	17	6.1%	92	7.2%
Digested bones	1	5%	11	5.4%	39	11.0%	40	13.4%	4	3.3%	66	23.8%	161	12.6%

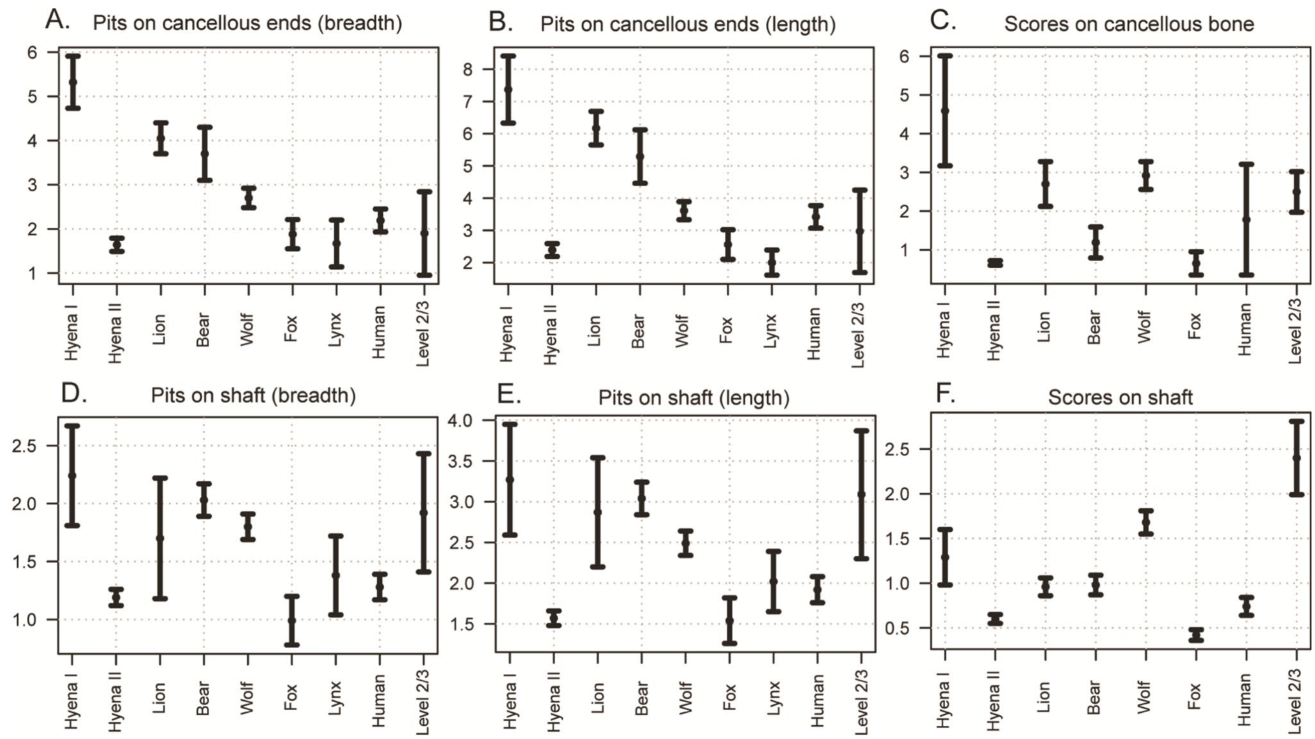


Fig. 10 Means and 95% confidence intervals for the dimensions of pits and scores generated by carnivores in remains belonging to Unit 2/3 of the Buena Pinta Cave compared with those of two experimental hyena models (Domínguez-Rodrigo and Piqueras 2003; Andrés et al. 2012), wolves, lions, and foxes (Andrés et al. 2012), lynxes (Rodríguez-Hidalgo et al. 2013), bears, and humans (Saladié et al. 2013a, b)

of spotted hyena (*Crocuta crocuta*) dens, where the corrosion of bone remains is the result of the action of urine and organic acids from excrement.

Anthropogenic action, observable in the form of cut and percussion marks, has been present in 0.16% and 0.24% of the accumulation, respectively (Table 7). While cut marks are exclusively observed on the diaphyses of medium-sized animals (n = 2), percussion marks are distributed among large and medium-sized animals. The cut marks are incisions located on an indeterminate diaphysis and on a humerus. Additionally, 1.3% of the remains are burned at grade 1 (n = 13) and grade 2 (n = 4).

Trampling was observed in 10.4% of the sample, while rodent marks were identified in 0.9%. 222 specimens (17.4%) exhibited modifications related to water (Fig. 11). Among these alteration processes, rounding (16.6%) and polishing (9.2%) have been documented (Fig. 11). 50% of bones with cut marks and 60% of those with percussion marks show evidence of rounding and polishing, particularly at grade 2. This is also observed in burned remains (Supplementary File 19B). In the case of specimens with alterations produced by carnivores, 25.4% of them are rounded, and 16.4% are polished due to water action.

The spatial taphonomic analysis does not reveal any clustering based on different abrasive processes (water, rounding, and polishing) that modified the bones (Fig. 11). Conversely, remains exhibiting more advanced degrees of manganese oxide and weathering, as well as the presence of concretions, appear to concentrate in the eastern part of the excavated area (Fig. 11). However, this may be due to the proximity of this area to large blocks (Fig. 2A).

Bone fracturing, shape, and composition

A total of 50.4% of the remains exhibited a length of less than 3 cm, while 32.1% were between 3 and 5 cm. The study of fracture patterns in the diaphyses revealed that 79.3% of the bones were fractured when fresh, especially identified in tibiae, humeri, and radius. The most prevalent fracture type is longitudinal, accounting for 63.6% of cases. Transverse fractures represent 21.4% of cases, while oblique fractures account for 15%.

66.1% of the diaphyses (n = 144) preserve less than 25% of the original bone length and circumference. Only 11 diaphysis fragments retain more than 50% of the circumference, and 6 retain it completely. Finally, 2 remains (0.9%) conserve almost the entire original bone length, but both have less than half of the original circumference.

In total, 458 diaphysis fragments have been counted (35.9% of the sample). It was found that 45.3% of the

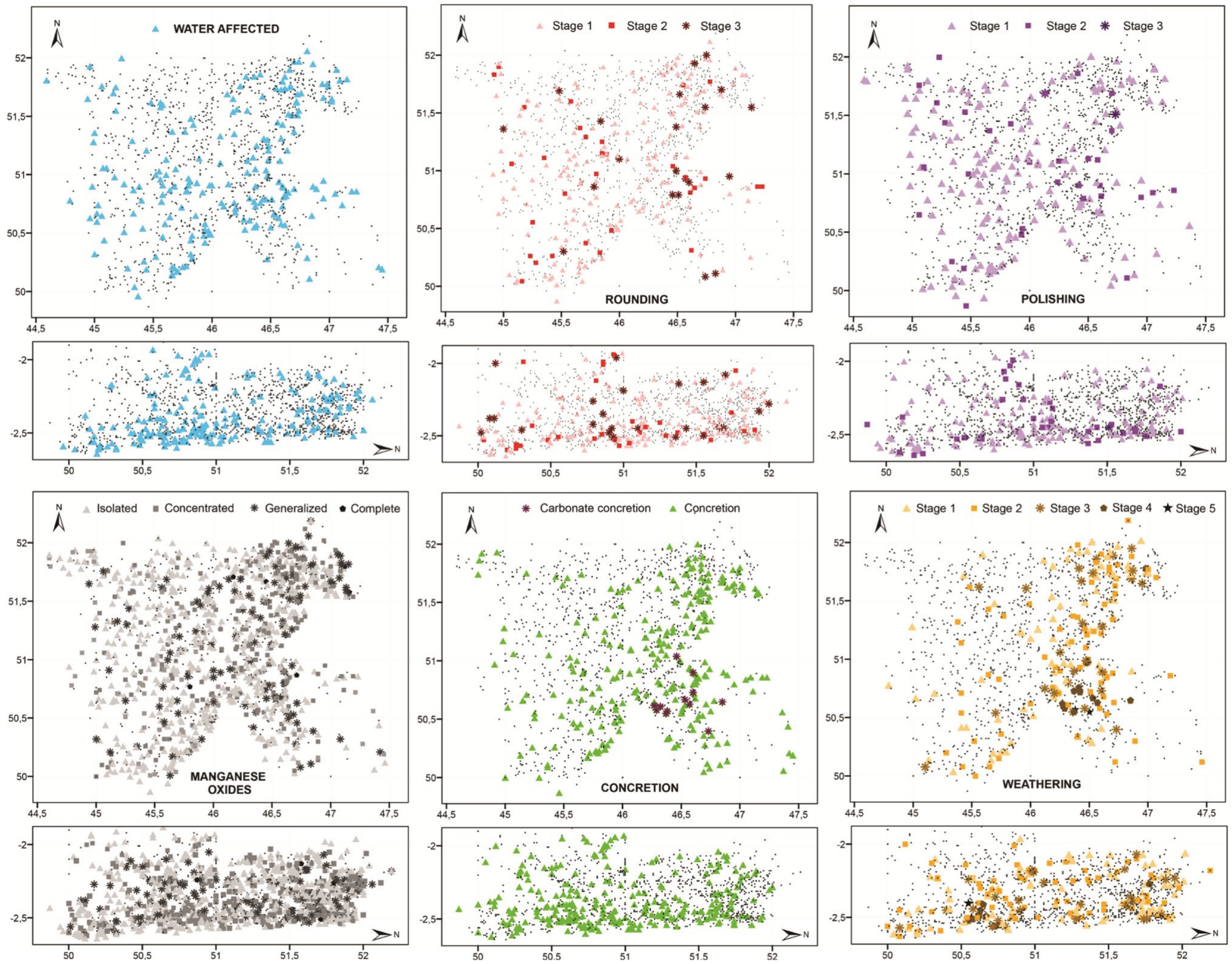


Fig. 11 Spatial distribution of all skeletal remains from Unit 2/3 (see Fig. 2C). All images show the spatial distribution of each bone specimen according to taphonomic variables in plan (top) and in YZ section (bottom)

diaphyses from small-sized animals were less than 25% of their original length and circumference, as were 68.6% of those from medium-sized animals and 69.8% of those from large-sized animals. On the other hand, 64.1% of the diaphyses from very small-sized animals maintain their complete circumference and almost complete original length. A total of 11 cylinders were documented, comprising 4 from very small-sized animals (3 from adult individuals and 1 from an immature individual), 6 from medium-sized animals (1 from an adult individual and 5 from immature individuals), and 1 from a large-sized animal (an immature individual). Only two complete hare metatarsals were preserved.

A total of 28 notches on 27 remains have been counted (2.1% NR), of which 11 were type A notches (39.3%), 11 were type C notches (39.3%), and 6 were type E notches (21.4%). Notches are present in all size categories except for the very large one (Supplementary File 21), with the majority found in small and medium-sized animals. At the taxonomic level, only 4 remains have been identified. Among them, 1 was from a bovine (type E notch), and 3 were from deer (type A notch).

Cubic forms are the most prevalent, although there is a variety of shapes with flat and some elongated remains (Supplementary File 7 C). A correspondence analysis of the shape and composition of the remains (Fig. 12) indicates that Unit 2/3 exhibits attributes that place it between non-transported assemblages and those transported by hydraulic processes.

Discussion

The taphonomic studies, in conjunction with the geological analyses, facilitated the archaeological stratigraphic reorganization of what was initially referred to in the field as"Level 23"into three distinct Units: Unit 2/3, Unit 23, and

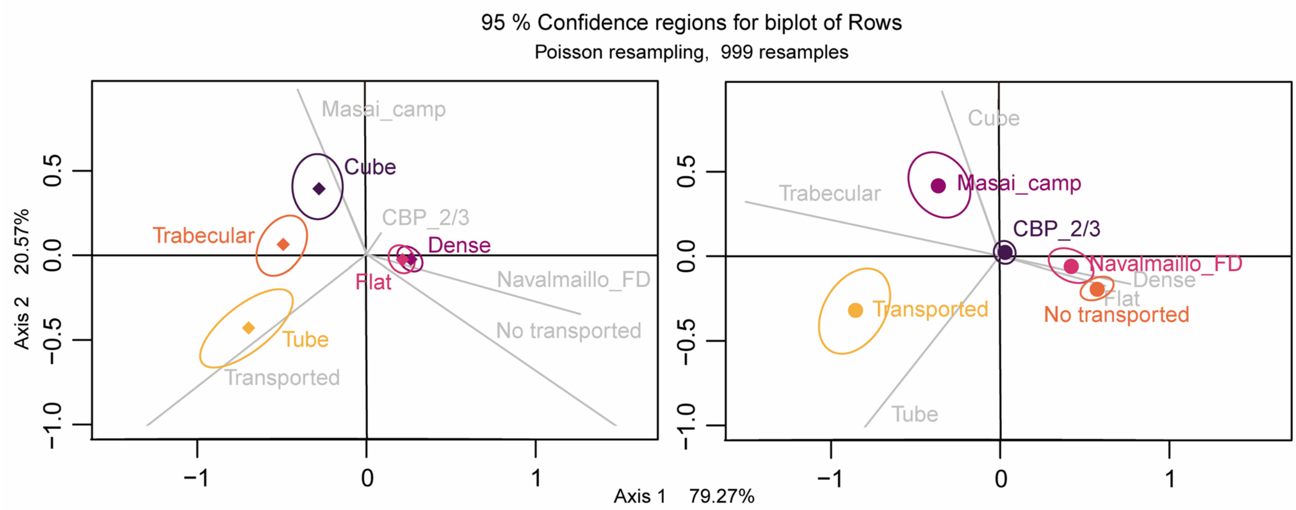


Fig. 12 Correspondence analysis comparing the shape and composition of the skeletal remains from Unit 2/3 (CBP_2/3) with those from different water transport models (Domínguez-Rodrigo et al. 2014; Organista 2017; Organista et al. 2017; Moclán et al. 2021). Ellipses indicate 95%CIs. Left, distribution of different bone types; right, distribution of sites with models included

Unit 32 A (Mielgo et al. 2024). Once again, the taphonomic studies allow for the identification of the various agents and formation processes that acted upon the recovered remains, thereby revealing the origin of each of these assemblages, now individually identifiable. This aligns with the concept of the'taphonomic mode', as defined by Behrensmeyer and Hook (1992), which refers to a set of fossil occurrences resulting from similar physical, chemical, and biological processes.

Unit 32 A

The faunal assemblage from Unit 32 A exhibits the lowest quantity of remains (n = 119). Although the sample size is small, there appears to be a certain variety of taxa and sizes, with all weight categories represented. However, given the limited number of remains recovered from this unit, we will focus our discussion on the most prominent alterations observed, as these provide the most meaningful insights into the taphonomic processes at play. Other alterations, while present, are less representative due to their low frequency and limited interpretive value in this context.

It is a highly fragmented and fresh-fractured sample, potentially related to carnivore activity as there is minimal anthropogenic evidence. However, there is a contrasting high percentage of carnivore activity (45.4% NR) affecting all size categories and taxa such as rhinoceros, bovids, and birds. Based on the size of the animals and the size of the specimens, medium-small carnivores could have generated the observed alterations. The remains of animals weighing less than 10 kg also exhibited evidence of carnivore consumption, potentially contributed by small carnivores. It can be concluded that a variety of carnivores of different sizes were involved in the process of modifying the assemblage.

51.3% of the remains show rounding and polishing related to water action. This particularly affects animals of small, medium, and large sizes, the sole specimen with anthropogenic activity, and 60.4% of those modified by carnivores. The increase in the degree of modification by rounding and polishing resulting from water action could suggest that these remains have been incorporated into the level by currents with sufficient energy to transport them. The same would apply to very large-sized animals, such as the rhinoceros, as the higher density of their remains results in less intense modifications.

Furthermore, medium and large-sized animals are primarily represented by isolated teeth, which are easily transported by hydraulic flows. In medium-sized animals, cranial and axial remains are also present, being less dense and more porous elements, along with remains of long bones that may have been carried by currents with higher energy (Voorhies 1969; Schick 1987; Domínguez-Rodrigo et al. 2014). Following the same idea, the smaller size and weight of elements from small-sized animals facilitate their transport and, consequently, their presence in the assemblage.

Conversely, the lower degree of rounding (20%) and polishing (20%) observed in very small-sized animals suggests a different taphonomic history. It is possible that some of the remains were transported, but in those that show no evidence of rounding or polishing and also have better cortical preservation, their accumulation process could be related to natural death in the nearby environment or by the action of other predators.

In light of the aforementioned considerations, we propose that the bone accumulation found in Unit 32 A of Buena Pinta Cave is of secondary position. The faunal remains recovered from animals of varying sizes would have been transported into the cave by medium to high-energy water flows at a later time, following consumption and abandonment of these remains by carnivores in the vicinity of the cavity. As the current entered the cave, its energy diminished, resulting in the gradual deposition of the remains within the cave. This was accompanied by the formation of a sedimentary matrix, as the suspended clays settled. Upon entering the cave, the humid conditions would facilitate the formation of manganese oxides and concretions on the remains.

Unit 23

The faunal assemblage from Unit 23 boasts the greatest number of faunal remains ($n = 1520$) among the three Units. It exhibits a wide taxonomic variety, with deer and bovids being predominant, and noteworthy are two proboscidean tusk fragments, the only remains of this taxon identified in Calvero de la Higuera. Additionally, numerous individuals (MNI = 69) are present, of which 37.7% are immature.

The abundance of fragmented bones, with specimens predominantly smaller than 3 cm, could be related to prolonged exposure to various destructive taphonomic processes (anthropogenic or carnivore-induced fracturing, weathering, etc.). In this regard, the scarce complete remains are mainly represented by isolated teeth, which are skeletal elements with high structural density (Lyman 1994). Given the high percentage of documented carnivore activity (41.1%), it is likely that a significant portion of the assemblage would be fractured during carcass consumption. However, some long bones could have been processed by Neanderthals, as evidenced by the 7 remains with cut marks, and fractured by them as indicated by the 8 remains with percussion marks.

9% of the sample is weathered, indicating that the assemblage contains bone remains with different taphonomic histories. One potential explanation is that the altered specimens were transported before burial, suggesting they have been re-sedimented (Fernández-López 1991, 2000). An alternative hypothesis is that these specimens were exhumed due to the erosion of older sediments and added to the current level, representing evidence of reworking in that case (Fernández-López 1991, 2000).

The high percentage of the sample modified by rounding and polishing, with the highest percentages with alteration degrees 2 and 3 accumulated (Table 8) across the entire western zone of the site, is consistent with the action of high-energy currents. Abrasion is also a useful relative measure of transport distance and/or exposure duration to hydraulic processes (see Eberth et al. 2007). Consequently, it can be postulated that once the bone remains were incorporated into the water flow, some of them were exposed for an extended period to the abrasive action of hydraulic currents and transported sediment particles (Behrensmeyer 1991), resulting in more intense modification of these remains.

Likewise, the presence of abrasion on the fracture surface, along with cut marks, percussion marks, and rounded tooth marks, indicates that the remains have been resedimented and reworked from other areas and subsequently incorporated into the studied level. Furthermore, transverse fractures typically occur after the burial phase (Alcalá and Martín Escorza 1988, 1998). Consequently, diagenetic fractures may be attributed to the lithostatic load of sediments on the bones or to the contraction and expansion movements of surrounding sediments during wet and dry seasons (Gustavson 1991).

The majority of the remains exhibiting biochemical alterations linked to edaphic processes were subsequently altered following deposition. However, in some specimens, the edges of root marks exhibit a rounded morphology, which may be indicative of water action. Consequently, it is possible that they were incorporated into the level through the erosion of previous deposits along the course of the stream, thereby providing further evidence of reworking.

The spatial analysis of taphonomic processes does not reveal any groupings based on different types of bone alteration (Fig. 8). Similarly, the spatial overlap of all degrees of alteration indicates a differential modification of the materials (Fig. 8). This result indicates that Unit 23 was significantly modified by water in terms of resedimentation.

The transport and dispersion of bone remains by river activity have been a topic of great interest among archaeologists, palaeontologists, and taphonomists seeking to understand site formation processes. A multitude of modern studies have been conducted with the objective of detecting any alterations that may have been caused by water in a given

Table 8 Number of remains according to their degree of rounding and polishing by Units. In parentheses, the percentage is calculated based on the total number of rounded or polished remains of each degree

	Rounding			Polishing		
Unit	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3
2/3	162 (34.47%)	31 (15.35%)	11 (15.28%)	87 (24.58%)	27 (16.56%)	2 (6.45%)
23	281 (59.79%)	152 (75.25%)	52 (72.22%)	247 (69.77%)	125 (76.69%)	26 (83.87%)
32 A	27 (5.74%)	19 (9.41%)	9 (12.5%)	20 (5.65%)	11 (6.75%)	3 (9.68%)

assemblage (e.g., Isaac 1967; Voorhies 1969; Dodson 1973; Wolff 1973; Behrensmeyer 1975, 1982; Boaz and Behrensmeyer 1976; Gifford and Behrensmeyer 1977; Korth 1979; Badgley and Behrensmeyer 1980; Hanson 1980; Frostick and Reid 1983; Schick 1984, 1987; Badgley 1986a, b; Argast et al. 1987; Petraglia and Nash 1987; Petraglia and Potts 1994; Coard and Dennell 1995; Trapani 1998; Coard 1999; Domínguez-Rodrigo et al. 2014). However, most of these studies have been conducted on low-density turbidity currents with relatively low energy, where there is selection by size, shape, and composition of remains that tend to be transported by saltation or flotation (Dabrio and Hernando 2003; Colombo 2010).

The type of energy under which comparisons are made is of significant importance, as it determines the manner in which transport takes place. Transport occurs when there is a field of forces, a transporting agent (such as a fluid), and materials ready to be moved. It is an intermediate stage between erosion and sedimentation, occurring simultaneously and in alternation with them in space and time (Dabrio and Hernando 2003: 78). The materials transported can exhibit a wide range of grain sizes and may be transported in suspension, by saltation, or by traction (sliding or rolling/rotation).

It is generally accepted that as the energy available for transport increases, a particular particle has greater potential for being transported over greater distances (Dabrio and Hernando 2003). With higher energy, there are greater possibilities of transporting larger sizes, so the grain size diversity can be very large and the selection poor or inadequate. Consequently, in contrast to the initial presentation of experimental works, which indicated that lower energy levels result in material selection, the remains at Unit 23 encompass a diverse range of shapes and compositions. This may be the reason why, when conducting multiple correspondence analysis (Fig. 7) of this Unit of the site against different water transport models (Domínguez-Rodrigo et al. 2014; Organista 2017; Organista et al. 2017), Unit 23 appears to be more closely associated with untransported sites, such as the neighbouring Navalmaíllo rockshelter (Moclán et al. 2021), than with those affected by hydraulic flows.

Similarly, if the preservation of the denser elements that are above the threshold for transportability by water currents is examined, it appears that Unit 23 has undergone less sorting (Behrensmeyer 1988). The skeletal elements identified in the studied assemblage are predominantly those belonging to Voorhies (1969) groups I (highlighting long bones) and III (primarily isolated teeth and compact bones). This indicates the presence of remains that are more resistant to transport, in addition to others with low susceptibility to being transported by water currents (Behrensmeyer 1975). However, the very high ratio between teeth and vertebrae (18.2) contrasts this, supporting the idea of a high degree of hydrodynamic sorting. This could indicate the marked influence of water currents on the remains, differentially affecting them based on their characteristics. However, the possibility that the original assemblage was biased by another agent cannot be ruled out.

While density-mediated attrition or consumption by carnivores could have reduced the number of vertebrae and other spongy bones before hydraulic processes acted, the dominant role of mechanical damage, rounding, and polishing on a substantial proportion of the vertebrae indicates that many survived to be transported and affected by water. Further, the evidence suggests a complex interplay of pre-transport destruction and post-transport hydrodynamic sorting.

Previous studies of this Unit (Mielgo et al. 2024) have identified the presence of numerous rounded pebbles, some of which are made of raw materials originating several kilometres upstream, and two fragments of proboscidean tusk, these being the only elements of this taxon found in the Pinilla del Valle sites. Similarly, part of the lithic industry and pebbles larger than 5 cm show evidence of abrasion and polish caused by water action (Mielgo et al. 2024). Simultaneously, the pebbles and archaeological remains (lithics and fauna) exhibit similar spatial distribution patterns among themselves, the mixture of these, and the heterogeneity of rock raw materials. These results, in conjunction with the high density of bone remains and their taphonomic alterations, suggest the identification of Unit 23 as a"*bonebed*"(Behrensmeyer 1991; Rogers et al. 2007). In this context, the bone elements, understood as'bioclasts'(e.g., Behrensmeyer 1975; Shipman 1981; Rogers and Kidwell 2007), were transported and deposited alongside other sedimentary particles.

The analysed sample from this unit fulfils all the characteristics of macrofossil beds, except perhaps in the mortality pattern. While the taxon analysis (Fig. 4A) indicates an attritional profile, if one observes the graph by weight size (Fig. 4B), the midpoint of medium, large, and very large size falls within the area of a catastrophic profile. However, some carnivores selectively kill juvenile prey (e.g., Kruuk 1972; Haber et al. 1976). Therefore, when the agent of mortality has been a carnivore, the transported bone assemblages may reflect a relatively high proportion of juvenile remains, as opposed to non-biological or anthropogenic mortality causes (Badgley 1986a).

Along these lines, the abundance of remains with modifications generated by carnivores and the presence of anthropogenic activity with rounding derived from water action suggest that the remains come from several previously altered and biased taphocoenoses, mainly because of these biological agents. It is proposed that bones and teeth, as well as lithic industry and coprolites, from different focal areas, have been introduced into the hydraulic flow as the high-energy stream eroded the landscape upstream, several kilometres away. However, it is acknowledged that, given the tendency of bones to disperse over time based on the differential transport from their respective places of origin and in relation to selection behaviours (i.e., the original accumulating agents or the current), not all materials that leave the source area will be accumulated, and more materials may arrive than initially left (Dabrio and Hernando 2003).

The works of Eberth (1990), Rogers (1995), and Rogers and Kidwell (2000) have previously proposed the existence of skeletal element concentrations preserved within ancient river channels. These accumulations are thought to originate from pre-existing concentrated sources, likely resulting from initial biological processes, such as predator activity, which were subsequently transported and redeposited.

In summary, Unit 23 is a hydraulic origin concentration in which the bone remains or bioclasts have been accumulated as another sedimentary particle. This deposit would result from the erosion of various initial biological accumulations (mainly linked to carnivore activity and, secondarily, to hominins), their transport, and deposition from multiple source areas. This concentration could have originated from various processes, including obstruction by blocks or walls acting as barriers and/or rapid deceleration of the flow, which would result in reduced hydraulic competence and material deposition. The team of geologists is currently engaged in further studies to elucidate this issue.

Unit 2/3

The faunal assemblage recovered from Unit 2/3 exhibits a wide anatomical and taxonomic variety. While cervids and bovids are the most common, there is a great diversity of herbivores and carnivores, as well as the presence of animals of all weight classes. The MNI is predominantly composed of adult individuals, although two senile individuals and a perinatal cervid are notable exceptions. This allows for a seasonal approximation to the time of death of this individual.

Currently, deer births typically occur in May (García et al. 2006; Carranza 2011). However, several factors can lead to variations in foetal development and birth timing (see Guiness et al. 1978; Asher et al. 2005; Carranza 2011). In light of these considerations, along with the individual's developmental stage, it can be estimated that it died during the spring months (April–May). The absence of any evidence of rounding or other transport-related alterations indicates that at least during these periods, the cave was in use.

At the skeletal level, cranial sections are most prevalent, particularly isolated dental pieces, followed by appendicular, and finally axial sections. The ratio of teeth to vertebrae of 9.60 suggests that the bone assemblage has been subjected to a high degree of selection. However, selective loss or low survival of low-density bones may result from factors such as water transport or consumption by carnivores. These predators tend to consume less dense bones because they are easier to break and contain more fat (e.g., Cruz-Uribe 1991; Marean and Spencer 1991; Marean et al. 1992; Blumenschine and Marean 1993). Taking this into account along with the representation of bone elements (%MAU), in all weight classes, the axial skeleton is underrepresented, in favour of isolated teeth and long bones.

In large, medium, and small-sized animals, percussion marks have been observed, and in medium-sized animals, cut marks have been documented in two specimens. Notches have also been recorded, although given their typology (essentially type A and C), it is not possible to attribute them exclusively to one agent. Furthermore, the high percentage of bone remains with tooth marks found in all three weight groups, along with their measurements and other alterations such as furrowing, gnawing and digestion, provides evidence of intense activity by medium to large-sized carnivores on these animals. A total of 17 burnt bones have been identified within the assemblage, of which four exhibit tooth marks. It is not possible to definitively attribute the origin of these remains to anthropogenic causes due to the absence of hearths and limited anthropogenic activity, or to natural causes.

On the other hand, very small-sized animals (i.e., lagomorphs, turtles, beavers, groundhogs, and hedgehogs) are well represented in skeletal terms. It is possible that these remains were introduced by carnivores, as there are specimens with clear evidence of tooth marks. Additionally, the dimensions of the pits and scores suggest they would have been contributed by small carnivores. However, there are two turtle remains with evidence of digestion, indicating they must have been consumed by a medium to large-sized carnivore capable of digesting remains between 2 and 4 cm, such as wolves or hyenas (Esteban-Nadal et al. 2010; Fosse et al. 1998).

The majority of bones (84.7%) exhibit weathering stage 0. This indicates that the bones were buried relatively quickly after the animals'death (Behrensmeyer 1978; Andrews 1995). However, at the base of the sedimentary sequence, there is a concentration of specimens exhibiting weathering stages 3 and 4, which suggests a different taphonomic history and a longer period of subaerial exposure (Fig. 12).

There is no evidence of significant abrasion resulting from the transport of bones by water currents. The surfaces affected by water and polishing are scarce and, when present, show non-severe development. This occurs in 17.4% and 9% of specimens, respectively. This indicates that rather than being transported from a distant source area, polished bones were likely the result of physical modification in situ, due to slow abrasion by water circulation within the sedimentary matrix (Thompson et al. 2011) or their resedimentation from a nearby area.

The assemblage also exhibits a paucity of rounded specimens (16.6% of the sample). Furthermore, 25.4% of the carnivore-altered remains are rounded, while 16.35% are polished. This is consistent with the hypothesis that water resedimentation and slight reorganization of the materials occurred, with insufficient energy to significantly modify the original spatial properties of the assemblage. Furthermore, 50% of the bones with cut marks and 60% of those with percussion marks are rounded and polished. This, along with the presence of lithic artifacts showing water patination (Mielgo et al. 2024), could suggest that they were integrated into the level in a near-autochthonous position by low-energy runoff with minimal involvement, as a cause of bone aggregation or reordering of the original assemblage.

The results of the spatial taphonomic analysis indicate that there were no significant differences in the degree of bone modification by post-depositional processes (Fig. 12). This suggests that Unit 2/3 was not significantly modified by water, but rather that the chemical and physical modification of bones was likely due to water circulation in a sedimentary matrix that slowly resedimented and abraded the autochthonous bone (Thompson et al. 2011) to mild degrees. Furthermore, the presence of specimens of all shapes and compositions analysed in the multiple correspondence analysis (Fig. 10) indicates that Unit 2/3 did not undergo any significant hydraulic transport.

Figure 11 illustrates the activity of small carnivores on the epiphyses of the remains, while tooth marks left by medium to large-sized carnivores have been identified on the diaphyses. It is well documented that hyenas consume bones almost entirely, with a particular preference for those parts with high-fat content, such as the epiphyses (Bartram and Villa 1998; Fosse et al. 1998). If these parts are consumed and therefore not integrated into the record, it is not possible to identify tooth marks on them. Nevertheless, the presence of tooth marks on the epiphyses of metapodials, which are not typically consumed by hyenas (Bartram and Villa 1998; Fosse et al. 1998), could indicate gnawing by immature hyenas or secondary access to these remains by small-sized carnivores.

Given the diversity of carnivorous species present in the assemblage, it can be reasonably assumed that interspecific competition for food would have been a common occurrence. It is possible that any of these species could have been scavengers. However, given the large body size of the prey, the dimensions of the punctures and scores, and the size of the digested remains, the most likely species to have contributed to the deer, equid, and large bovids are hyenas. To ascertain whether they are the accumulating agent, an analogy was made by comparing the results obtained with the reference frameworks proposed by Cruz-Uribe (1991), Pickering (2002), and Kuhn et al. (2010).

The scarcity of remains of immature carnivores in the analysed sample precludes the possibility that the site was primarily used as a den (East et al. 1989; Dusseldorp 2011). However, this could have been an occasional function. An alternative hypothesis is that the site was used as a lair (Brain 1980), given that Unit 2/3 aligns with characteristic features such as substantial accumulations of coprolites, abundant furrowing (Stiner 2004: 771), and a high percentage of carnivores/ungulates.

The presence of carnivore remains is relatively common in hyena accumulations (Cruz-Uribe 1991). In the studied Unit, carnivore remains account for 16.2% of NISP, with hyenid remains being the most abundant. This prevalence of hyenas is characteristic of most dens belonging to this taxon during the European Upper Pleistocene (Fosse et al. 1998; Diedrich 2011b, 2012b).

A significant proportion of the taxa present in the faunal assemblage of Unit 2/3 align with the pattern described in modern studies of African spotted hyenas (Sutcliffe 1970; Scott and Klein 1981). Large bovids, equids, and rhinoceroses were common prey for hyenas, as evidenced by their presence in several Upper Pleistocene sites (Villa and Bartram 1996; Diedrich 2011a, 2011b; Dusseldorp 2011, 2013). In this case, bovines and deer are the most abundant taxa in the entire assemblage, representing a significant proportion of the taxonomic variety. Frank (1994) and Stiner (2004) propose that the presence of other carnivore species in dens is a consequence of hyena predation on these, which is corroborated by the presence of tooth marks and digestion in animals such as leopards or hyenas in the analysed sample. Furthermore, the practice of scavenging and the importation of feline carcasses by hyenas has been documented in other sites, including the caves of Perick (Diedrich 2009), Camino (Arsuaga et al. 2010), and Pinarillo (Arribas et al. 2008).

Hyenas transport bones to their dens and fracture them to consume the marrow. As a result, they generate highly fragmented assemblages. In Unit 2/3, numerous bone fragments and splinters are present (predominance of remains less than 5 cm), which could be linked to hyenas'ability to fracture bones, as well as the production of cylinders (n = 8). However, the presence of cylinders is also related to competition for carcass consumption or the level of hunger in wild hyenas (Prendergast and Domínguez-Rodrigo 2008; Sardella and Petrucci 2012; Kruuk 1972). Likewise, their abundance may vary in periods of low competition, such as in Western Europe during the Pleistocene (Rodríguez and Mateos 2018). Additionally, the abundance of high-density elements (17.2% of the total MNE), metapodials, and compact bones suggests that these were accumulated by hyenas (Potts et al. 1988; Cruz-Uribe 1991; Pickering 2002; Kuhn et al. 2010; Stewart et al. 2021). Moreover, it has been demonstrated that spotted hyenas carry cranial remains of large ungulates to their dens (Kuhn et al. 2010), which could justify the high quantity of isolated teeth.

The bone assemblage of Unit 2/3 is significantly altered by furrowing, scores, pits, and digestive acids. Furrowing, in particular, is a notable feature, observed in 34.1% of the sample. In modern dens, this type of alteration ranges from 22–100%, whereas in fossil carnivore assemblages, the frequency tends to be lower (5–30%) (Cruz-Uribe 1991; Tappen et al. 2002). In contrast, the localised deposition of excrement in latrines is another ethological characteristic common to all extant hyena species (Brain 1981; Kruuk 1972). In Unit 2/3, 39 coprolites have been recorded, with the majority exhibiting characteristics typical of hyenas (Huguet et al. 2010).

Concerning the remains of very small-sized animals bearing tooth marks or furrowing, when hyenas consume small animals, they are almost completely destroyed (Bartram and Villa 1998; Fosse et al. 1998). Therefore, it is proposed that the presence of these prey items is related to the consumption by small carnivores. However, the two digested turtle remains could have been consumed by medium-sized canids or hyenas.

In addition to the few alterations directly attributable to hominins, 134 lithic pieces have been recorded in this level, partially altered by water action (Mielgo et al. 2024), and there are no hearths. The co-occurrence of these evidences is frequently employed to assess the likelihood of hominin activity in archaeological assemblages (Stiner 1991). However, Villa and Soressi (2000) emphasise the role of post-depositional processes in the fortuitous generation of some accumulations in places occupied by carnivores. Several examples in the vicinity of the Central System include sites such as Búho and Zarzamora caves, where 3 lithic remains were found within a carnivore accumulation (Sala et al. 2009, 2011); Portalón del Tejadilla, featuring Mousterian industry in a hyena den (Sanz et al. 2015; Sala et al. 2020), or, also in Pinilla del Valle, the Camino Cave with 105 lithic pieces (Arsuaga et al. 2012), and level 3 of the Buena Pinta Cave itself, containing some industry pieces (Huguet et al. 2010).

Other fossil accumulations attributed to carnivores with some anthropogenic evidence, either through bone remains or traces of their activity, include Les Auzières 2 and Bois Roche (France) (Villa and Soressi 2000; Marchal et al. 2009; Villa et al. 2010), Geula Cave (Israel) (Monchot 2005), Westeregeln (Germany) (Diedrich 2012a), Zourah Cave (Morocco) (Monchot and Aouraghe 2009), Akhalkalaki (Georgia) (Tappen et al. 2002), Buzdujeni 1 (Moldova) (Croitor and Burlacu 2020), Moros de Gabasa (Spain) (Blasco 1997), level D of Arlanpe Cave (Spain) (Arceredillo Alonso et al. 2013), or the Sala de los Huesos (Spain) (Rodríguez-Hidalgo et al. 2010), among others.

In all of the examples, the presence of lithic tools is combined with limited anthropic activity, often limited to a couple of remains with direct evidence. The lithic material may have been incidentally incorporated due to post-depositional processes, such as gravitational movements or water flows, or even ephemeral occupation by hominins. In the case of Unit 2/3 of the Buena Pinta Cave, the results of the taphonomic analysis suggest that the fossil remains altered by hominins and the lithic industry have been accumulated independently, resulting from a fortuitous stratigraphic association derived from a mixture of autochthonous and para-autochthonous materials due to the passage of water runoff. Nevertheless, the discovery of artefacts and hominin fossils in the vicinity of the Buena Pinta Cave and neighbouring sites (Baquedano et al. 2012) suggests that Neanderthals may have been more prevalent in the environment than reflected in the studied level.

Upon comprehensive analysis of the data, it can be concluded that at least two distinct origins can be identified in Unit 2/3 of the western area of the Buena Pinta Cave. Most of the assemblage was accumulated in situ by hyenas. Meanwhile, the remains exhibiting evidence of anthropic activity and lithic industry could be in a para-autochthonous position (Fernández-López 1990) following transportation by gravitational movements or water currents, which would in turn wash the carnivore assemblage and resediment part of the sample. Nevertheless, the possibility of occasional in situ anthropic occupation cannot be entirely discounted.

General interpretations

The assemblage recovered from Unit 32 A is composed of resedimented remains. In Unit 23, materials originating from both within and outside the karst system were recovered, forming an allochthonous package with bioclasts reworked from older deposits eroded by a high-energy hydraulic flow. Conversely, most of the elements in Unit 2/3 are autochthonous, accumulated by hyenas or para-autochthonous, and resedimented by low-energy runoff.

The three analysed assemblages can be defined as mixed (sensu Fernández-López 2000), as they are formed by elements corresponding to biological entities from different environments. Moreover, they can be considered condensed (Fernández-López 2000) as they originated from the gradual incorporation of remains corresponding to temporally successive biological entities. However, the only taxonomic evidence recorded indicating significant faunal changes between the three fossiliferous levels is the presence of proboscideans in Unit 23. While only two remains are identified, their significance lies in the fact that they are not only the sole evidence of proboscideans within Buena Pinta Cave but also across the entire Calvero de la Higuera site complex and its surroundings. This characteristic may serve as a key indicator of external provenance, supporting the hypothesis that part of Unit 23 was likely transported from another location outside of Calvero de la Higuera, highlighting its unique taphonomic history.

Based on the definition of'taphonomic mode'by Behrensmeyer and Hook (1992), the differences observed among the identified Units in the western area of Buena Pinta Cave (Table 9) have allowed for the identification of three distinct taphonomic modes: endokarstic, fluvial (or influenced by hydraulic currents), and carnivore den/lair.

Despite the presence of other archaeological sites in the vicinity with taphonomic studies, such as the Navalmaillo Rockshelter (Moclán et al. 2018, 2020, 2021), Des-Cubierta Cave (Huguet et al. 2010; Baquedano et al. 2023), and Camino Cave (Arsuaga et al. 2010, 2012; Jiménez et al. 2024), the taphonomic modes documented in Units 32 A and 23 of Buena Pinta Cave appear to be unique. None of the nearby sites exhibit similar patterns of formation processes or assemblage characteristics. However, as not all stratigraphic levels at these sites have been thoroughly studied and excavations are ongoing, future research may reveal comparable taphonomic histories within the Calvero de la Higuera archaeo-palaeontological site complex. In contrast, the carnivore den/lair taphonomic mode identified in Unit 2/3 of Buena Pinta Cave shows similarities to other levels at the same site, such as Level 3 (Huguet et al. 2010), as well as to Camino Cave, where carnivore accumulations have also been documented.

Conclusions

Understanding the taphonomic processes that influence archaeological site formation and assemblage composition is essential for interpreting mixed sites, where occupation sequences by different biological agents alternate and are frequently modified by post-depositional processes. This is the case in the western zone of Buena Pinta Cave.

The three Units analysed consist of remains that were affected by various biostratinomic and fossil-diagenetic processes, resulting in distinct taphonomic histories. Unit 32 A is characterized as an endokarstic level with some fossil remains incorporated by water currents related to the cave's initial opening to the exterior.

Unit 23 presents an accumulation of bone remains that have been resedimented and reworked by the action of transportation from a high-energy current, acting as bioclasts alongside other sedimentary particles. This serves as an example of how post-depositional processes can disrupt the dynamic links governing the structure of a bone assemblage, creating an aggregate of elements that are contemporaneous only in a geological sense, as they have lost their original context.

Finally, the bone accumulation in Unit 2/3 was primarily produced by hyenas, although occasional use of the site by hominins in the vicinity cannot be ruled out, with secondary access to the remains by small-sized carnivores.

Overall, the findings of this study provide new data that offer a reference framework for comparing and evaluating other local and regional archaeo-paleontological sites presenting faunal associations and similar issues in caves and mixed deposits.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12520-025-02214-6.

Table 9 Characteristics of the three recognized taphonomic modes in the western area of Buena Pinta Cave

		Unit 32 A	Unit 23	Unit 2/3
Number of specimens		119	1520	1273
Fragmentation		High	High	High
Index isolated teeth/vertebrae		6.67	18.17	9.6
Most represented taxa		Bovids	*C. elaphus* and bovids	*C. elaphus* and bovids
Most represented size		Medium size	Medium size	Medium size
% NISP carnivores		13.33%	17%	16.19%
Anthropic modifications	Cut marks	0	0.46%	0.16%
	Percussion marks	0.84%	0.53%	0.24%
Carnivore modifications		45%	41.1%	74.4%
Rounding		46.22	48.7%	16.6%
Polishing		28.57	34.1%	9.2%
Water affected		51.26%	63.22%	17.4%
Main agent		**Low-energy flow**	**High-energy water flow**	**Hyaenids**

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Author contribution C.M. analysed the faunal material and the data, and wrote the original draft. A.M. and R.H. has actively participated in the writing and revision of the article and data analysis. D.M.P. and A.P.G. provide geological data. E.B., A.P.G. and J.L.A. supervised the project. All authors discussed the results and contributed to the final manuscript. All authors approved the final version of the manuscript and agree to be held accountable for the content therein.

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Declarations

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