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Zooarchaeological and Taphonomic perspectives of Leporid accumulations: a case study of Unit 2 of the Cova del Coll Verdaguer site (Cervelló, Barcelona, Iberian Peninsula)

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Abstract

Leporid remains are abundant in many Upper Pleistocene sites on the Iberian Peninsula. Various factors contribute to their accumulation, such as human activity, animal predation and natural rabbit burrows. These remains, therefore, provide valuable insights into human subsistence strategies, site habitation patterns, and the demographic trends of the taxon.

This study focuses on the leporid remains from Cova del Coll Verdaguer, a karstic site dated to 34-90 cal ka yrs BP, which also contains Mousterian stone tools and a rich assemblage of faunal remains. The accumulation of the vertebrate remains can be attributed to several agents, including hyenas, medium-sized carnivores, and humans. Additionally, brown bears used the cave for hibernation and birthing their cubs.

Here, we examined the zooarchaeological and taphonomic aspects concerning 2421 leporid remains from Unit 2, the age range in 41-43 ka cal BP, deposited in the Sala Sal de Llop chamber of the site. The primary objective of this research is to identify the taphonomic signatures generated by various agents (i.e., humans, and terrestrial carnivores), alongside paleoenvironmental information. The investigation was conducted through the analysis essentially of anatomical representation, age-at-death, breakage patterns, tooth marks, digestion marks, burning, manganese oxide pigmentation, and concretion.

The findings suggest a high frequency of appendicular elements, especially distal ones, followed by axial and innominate bones. In addition, leporid remains demonstrated a substantial quantity of tooth marks. Through detailed analysis, medium-sized terrestrial carnivores emerge as the primary agents responsible for the accumulation and subsequent modification of leporid remains. This interpretation is supported by the presence of characteristic damage patterns consistent with carnivore consumption and processing behaviours. Thus, the identified taphonomic signatures not only provide insights into carnivore foraging strategies but also contribute to our understanding of predator-prey interactions and ecosystem dynamics in past environments.

Keyword: Upper Pleistocene, Leporidae, Taphonomy, Medium-sized carnivores

Index

Contents

Index of figures

Index of tables

1. Introduction

1.1 Conceptual and theoretical framework

Zooarchaeology is a specialized discipline within archaeology focused on the analysis and interpretation of faunal remains such as bones, teeth, and other animal parts recovered from archaeological contexts (Gifford-Gonzalez, 2002; Reitz, 2008; Broughton, 2015; Gifford-Gonzalez, 2018;). This discipline involves a systematic approach to analysing and interpreting faunal remains to elucidate past human-animal interactions, subsistence strategies, and cultural practices. By examining these remains, zooarchaeologists reconstruct historical environments, dietary patterns, and economic activities, providing valuable insights into how ancient societies utilized and interacted with their surrounding fauna (Landon, 2005; Bartosiewicz, 2014; Linseele, 2018; Wolverton and Nagaoka, 2018). In particular, the investigation of leporid accumulations which refers to the study of rabbit and hare remains serves to uncover patterns of exploitation, including hunting practices and dietary preferences, within past societies. This analysis can reveal important information about the role of leporids in prehistoric diets and subsistence strategies, contributing to our understanding of how different communities adapted to their environments (Stiner, 1994; Banks et al., 1999; Hockett, 1999; Cochard, 2004b; Jones, 2006; Lloveras et al., 2016; Albarella et al., 2017).

Complementing zooarchaeological studies is taphonomy, the scientific investigation of the processes that affect organic remains from their initial deposition to their recovery (Bartosiewicz, 2001, 2008). Taphonomy explores a range of factors that influence the origin, preservation, modification, and destruction of animal remains within archaeological or palaeontological contexts. Taphonomic research has shown that faunal assemblages often result from the combined activities of both human and non-human agents, including terrestrial carnivores, raptors, etc. (Binford, 1981; Shipman and Rose, 1983; Wing et al., 1987; Lyman, 1994; Tortosa et al., 2002). By examining bone surface modifications and patterns of skeletal fragmentation, it is possible to differentiate between carnivore predation, scavenging, and other post-depositional processes, thus providing insights into past ecological dynamics and human-carnivore interactions (Behrensmeyer, 1978a; Lyman, 1994; Stiner, 1994; Fisher, 1995; Esteban-Nadal, 2012; Saladié et al., 2014; Fernandez-Jalvo and Andrews, 2016). Understanding these taphonomic processes is crucial for accurately interpreting the archaeological record and reconstructing past environments and behaviours (Fernández-Jalvo and Andrews, 2016a). By synthesizing insights from both zooarchaeology and taphonomy, researchers can attain a nuanced understanding of faunal assemblages and the diverse factors that have influenced their formation and preservation over time.

The presence of leporids (rabbits and hares) in the archaeological record is well-established, with documented occurrences in both anthropogenic deposits and non-anthropogenic spanning from the Middle Palaeolithic to the Mesolithic in the Iberian Peninsula (Hockett, 1991; Sanchis, 2000; Hockett and Haws, 2002; Tortosa et al., 2002; Cochard, 2004a, 2004b; Cochard et al., 2012; Lloveras et al., 2008, 2009, 2011, 2016; Blasco and Fernández Peris, 2012a, 2012b; Rosado-Méndez et al., 2015; Arriaza et al., 2017; Martínez-Polanco et al., 2017; Pelletier et al., 2020). The frequent presence of these small mammals in various archaeological contexts highlights their role and importance within past human subsistence strategies.

Leporid remains in archaeological sites are crucial for understanding past ecological dynamics, as rabbits and hares served as vital food sources for both humans (Hockett and Bicho, 2000; Hockett and Haws, 2002; Tortosa et al., 2002; Pérez-Ripoll, M., 2004; Fa et al., 2013) and non-human predators (Delibes and Hiraldo, 1981; Rosado-Méndez et al., 2015). For humans, leporids have been a valuable resource throughout history, providing essential sustenance. Similarly, non-human predators, including terrestrial carnivores and raptors, rely on leporids as a primary food source.

A predator in archaeozoology refers to animals that actively hunt and consume other animals. Evidence of predation is detected through various methods: examining taphonomic modifications on bones, performing quantitative analyses of predator-prey relationships, conducting microscopic analysis of bone surfaces, and analysing coprolites (fossilized feces) (Binford, 1981; Lyman, 1994; Chin, 2002; Reitz and Wing, 2008; Mittelbach and McGill, 2019). These approaches collectively aid in reconstructing past ecological dynamics and understanding predator-prey interactions. Predatory animals such as carnivores and raptors frequently visit caves and rock shelters, where they leave behind the remains of their prey, often along with pellets or scats (Andrews, 1990b; M. C. Stiner, 1991; James, 1992; Williams et al., 2012). This contributes to the archaeological record by adding layers of information about predator behaviour and the ecological interaction s of the past (M. C. Stiner, 1990; Lyman, 1994; Reitz and Wing, 2008).

In the analysis of leporid remains, particular attention has been given to distinguishing those modified by human activity. Key methodologies include the examination of cut marks, which are indicative of butchering practices, and the analysis of bone breakage patterns, which suggest deliberate processing for marrow extraction (Hockett and Haws, 2002; Pérez-Ripoll, M., 2004). In contrast, leporid remains altered by non-human predators, such as coyotes, can be identified through distinct diagnostic features. These include characteristic tooth marks associated with feeding behaviour, irregular bone fractures typical of predator-induced damage, and digestive modifications such as enamel pitting (Schmitt and Juell, 1994; Armstrong, 2016).

Fox predation results in unique bone modification patterns that can be reliably distinguished from those of other predators. The tooth marks and bone alterations characteristic of fox activity have been well documented (Lloveras et al., 2012). Similarly, the Iberian lynx (*Lynx pardinus*) leaves distinctive patterns of bone modification. Research has identified specific tooth marks and bone alterations unique to lynx predation (Rodríguez-Hidalgo et al., 2013; Lloveras et al., 2018).

Golden Eagles (*Aquila chrysaetos*) produce notable bone breakage patterns and digestion-related alterations, providing a clear set of diagnostic features for their predation on leporids (Hockett, 1996; Lloveras et al., 2009; Cochard et al., 2012). Similarly, the Spanish Imperial Eagle (*Aquila adalberti*) exhibits specific breakage patterns and digestive modifications that can be used as reliable indicators of its predatory behaviour (Lloveras et al., 2008). The Eagle Owl (*Bubo bubo*) provides additional evidence of predation through the analysis of pellet and scat remains, offering further markers for the identification of predator activity (Sanchis, 2000; Cochard, 2004a; Lloveras et al., 2009). Other raptors contribute further insights into avian-specific bone modifications and accumulation patterns, enhancing our understanding of raptor-induced taphonomic signatures. These analyses collectively aid in accurately attributing leporid remains to specific predators and distinguishing them from those modified by humans (Hockett, 1989, 1991, 1995; Cruz-Uribe and Klein, 1998). The establishment of a comprehensive dataset of neo-taphonomic evidence has been crucial in this endeavour.

Another, type of accumulation can happen without predators. Rabbits, due to their burrowing habits and limited mobility, often create colonies and dig tunnels in sandy sediments. In these conditions, they can get trapped and die, which helps preserve their bones in an anatomically connected state (Stahl, 1996). Leporids, being burrowing animals, create extensive networks of burrows where they establish colonies and raise their young. These burrows, often in sandy environments, are prone to collapse, trapping and killing the rabbits inside (Stahl, 1996). The presence of rabbit burrows in an archaeological setting can complicate the interpretation of the assemblage due to potential disturbances of the archaeological context (Stahl, 1996; Cochard, 2004a, 2004b). Analysing sediment characteristics, spatial distribution patterns, identifying bones in anatomical connection, and studying other post-depositional agents that could affect bones before or during burial are crucial steps in distinguishing these accumulations from those influenced by other agents (Cochard, 2004a; Pelletier et al., 2015, 2016). Intensive excavation techniques are essential for recognizing sediment alterations associated with burrow formation. Apart from burrows, leporids can be naturally introduced into a site through other means such as natural traps (Cochard, 2004a). Remains that accumulate naturally, without alteration by predators or other post-depositional processes, may be discovered intact and in anatomical connection during excavation efforts (Pavao and Stahl, 1999). However, finding such connections is rare due to the myriads of post-mortem processes that can affect bone preservation (Oliver and Graham, 1994).

In the case of leporid accumulations at the Cova del Coll Verdaguer site, the application of taphonomic and zooarchaeological methodologies provides a robust framework for interpreting the complexities of both carnivore activities and human hunting practices within the prehistoric context of the Garraf Massif in the Iberian Peninsula (Sanz et al., 2016; Gabucio et al., 2024). By comparing our findings with actualistic data concerning the modification of leporid remains by various predators (e.g. Hockett, 1991, 1996; Hockett and Haws, 2002; Lloveras et al., 2008a, 2008b, 2009, 2018, 2020; Rodríguez-Hidalgo et al., 2013), alongside previous archaeological studies, we aim to distinguish the primary agents responsible for leporid accumulations in Unit 2 of the Cova del Coll Verdaguer site. This comparative approach will facilitate a clearer understanding of the roles played by different predators and human activities in shaping the faunal assemblages at the site.

1.2 Objectives

This study aims to identify the key agents responsible for the accumulation of leporid remains form Unit 2 of the Sala Sal de Llop chamber at Cova del Coll Verdaguer. This involves analysing damage inflicted by humans, carnivores, raptors, and rabbit burrows. To achieve this, we examined over 2,421 leporid remains recovered from Unit 2 at the Cova del Coll Verdaguer site. The analysis includes anatomical representation, abundance measurements, and age-at-death. We also identified taphonomic signatures to understand the processes involved in the remains' accumulation and modification, focusing on both breakage pattern and surface alterations. By achieving this aim, we pretend to contribute significantly to understanding of past predator-prey interaction and broader ecosystem dynamics within the study area.

2. Cova del Coll Verdaguer

2.1 Geographic location

Cova del Coll Verdaguer (coordinates: 41°23'35.0800"N, 1°54'39.8100"E, 448 meters above sea level) is situated in the municipality of Cervelló, within the comarca of Baix Llobregat (province of Barcelona) (Figure 1. A-C). It is located in a wooded area on the outskirts of the urban centre and very close to the pass known as Coll Verdaguer, which gives the cave its name. In the mountainous region that constitutes the Garraf karst massif, approximately 30 km southwest of Barcelona, in the northeastern Iberian Peninsula (Figure 1. A-C). The site is influenced by the headwaters of the Vallirana and Sant Ponç Rafamans streams, which ultimately flow into the Llobregat River, either directly or indirectly. This landscape is typically Mediterranean, marked by narrow, steep, and highly inaccessible valleys, featuring the unique characteristics of the limestone hills of the Mesozoic Garraf massif (Daura et al., 2010). The cave is about 15 km from the current coastline, and the region's drainage basin is now confined to the Sant Ponç dry valley, a tributary of the Rafamans creek (Daura et al., 2014).

Today, the region encompasses meso- and thermo-Mediterranean environments, primarily consisting of Mediterranean maquis shrubland with a high density of evergreen shrubs, and forests with sclerophyll vegetation that can withstand the dry season (Daura et al., 2014). To the south lies the corridor shaped by the upper Vallirana stream, significantly altered by the N-340 road from Barcelona to Valencia. This stream's hydrological network is intricate, with numerous gullies and tributaries contributing to it. It is one of the major waterways in the Garraf-Ordal massif, flowing from its western boundary to the Llobregat River (Sanz, 2013).

2.2 Geology of the site

The massif constitutes a low relief, intensely karstified, mountain range that rises to a height of close to 600 m. A simple five-stage geomorphological model of the evolution of the Garraf karstification has been proposed between the Miocene and the Holocene (Daura et al., 2014). The karstification of the Garraf massif is highly local and concentrated in the fractured carbonate rocks. The main karst features include dolines, shafts and caves (Daura et al., 2014). From a geological point of view, the limestone massif is affected by an antiform (Bartrina et al., 1992), and a series of fractures trending predominantly northeast to southwest run across the entire massif (Guimerà, 1988).

The stratigraphy of the Cova del Coll Verdaguer consists of three main geological units of Mesozoic carbonate rocks. The sequence begins with the Buntsandstein Formation characterised by its sandstones and marls. This is overlain by the Muschelkalk Limestones, which are separated by a 50-meter fault visible from the Vallirana valley. The uppermost unit comprises the Keuper Dolomites and Breccias, which include black dolomites with breccias from the Lower Cretaceous period resting upon the Keuper limestones. These geological units collectively form the karstic massif, which is formed by these units features the highest peaks in the area, such as Puig de les Agulles and Puig Bernat. The arrangement and interaction of these units significantly influence the geological structure and karstic landscape, providing a foundation for the cave's formation and shaping the surrounding topography (Sanz, 2013).

2.3 Site description

The Cova del Coll Verdaguer is situated in a small depression that functions as a natural water conduit. Over time, this water, through infiltration and various geological processes, has sculpted the cave, which is relatively recent in geological terms. Erosion and lithogenic processes have resulted in two distinct chambers within the cave, largely due to a historic collapse of the cave’s ceiling (Sanz, 2013). Mining activities led to the discovery of the previously inaccessible cave (Llopis, 1941), which had been sealed by sediments. Unfortunately, the mining caused damage by fracturing and removing part of the stalagmitic flow and many speleothems. Evidence of the large debris pile left by the miners remains visible outside the cave.

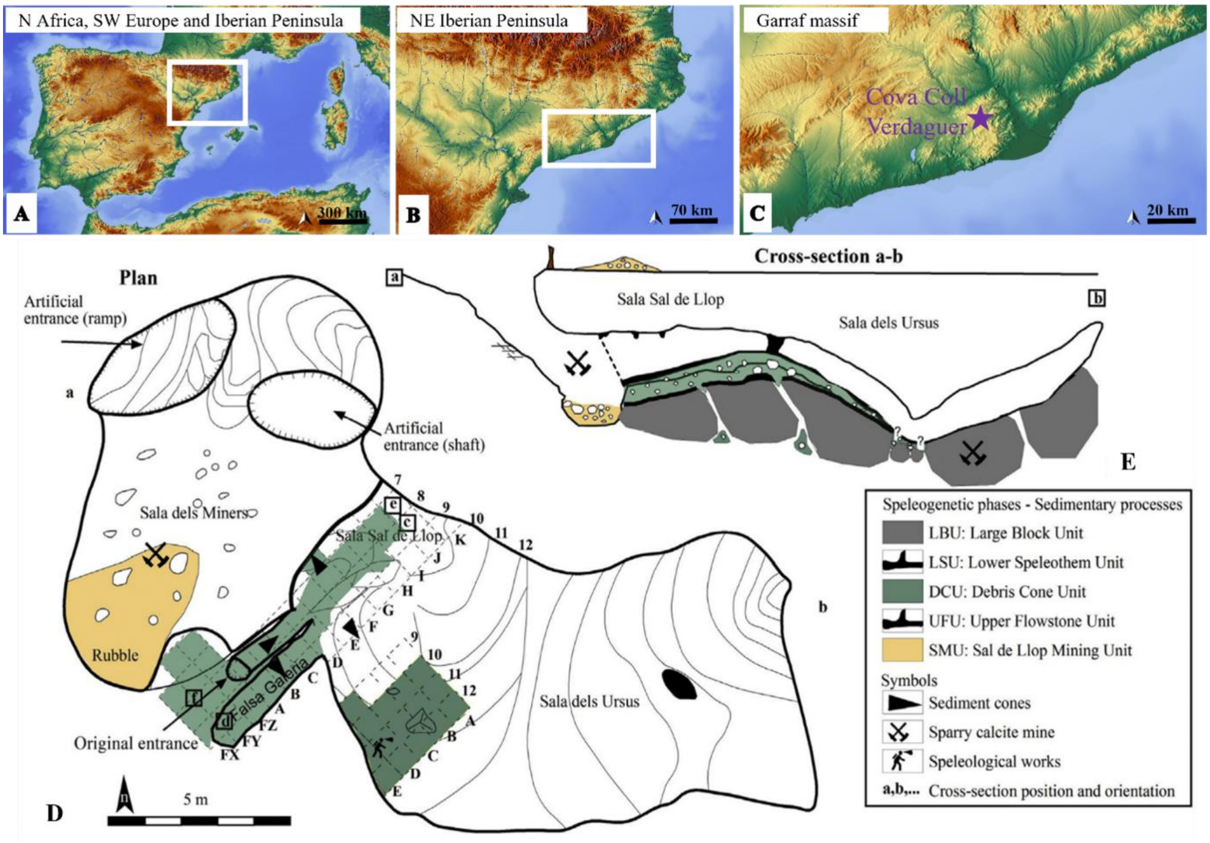

Figure 1. A-C: Map showing the location of the cave of the Cova del Coll Verdaguer site, in map extracted from Open Street Map (CC BY-SA). Open Street Map© licensed under ODdL 1.0 (https://www.openstreetmap.org/copyright) by the Open Street Map Foundation (OSMF). ©Open Street Map contributors (https://www.openstreetmap.org). The license terms can be found on the following link: https://creativecommons.org/licenses/by-sa/2.0/es/ (accessed on 25 May 2023). D-E: Plan site and cross-section indicating distinct areas (modified from Gabucio et al., 2024).

The cave features three primary entrances. On the northwest side, two artificial entrances, a ramp and a shaft, were created during the extraction of sparry calcite (Daura et al., 2017). The original cave entrance, which had been obstructed by a debris cone, was reopened during recent fieldwork (see Figures 2. A-C).

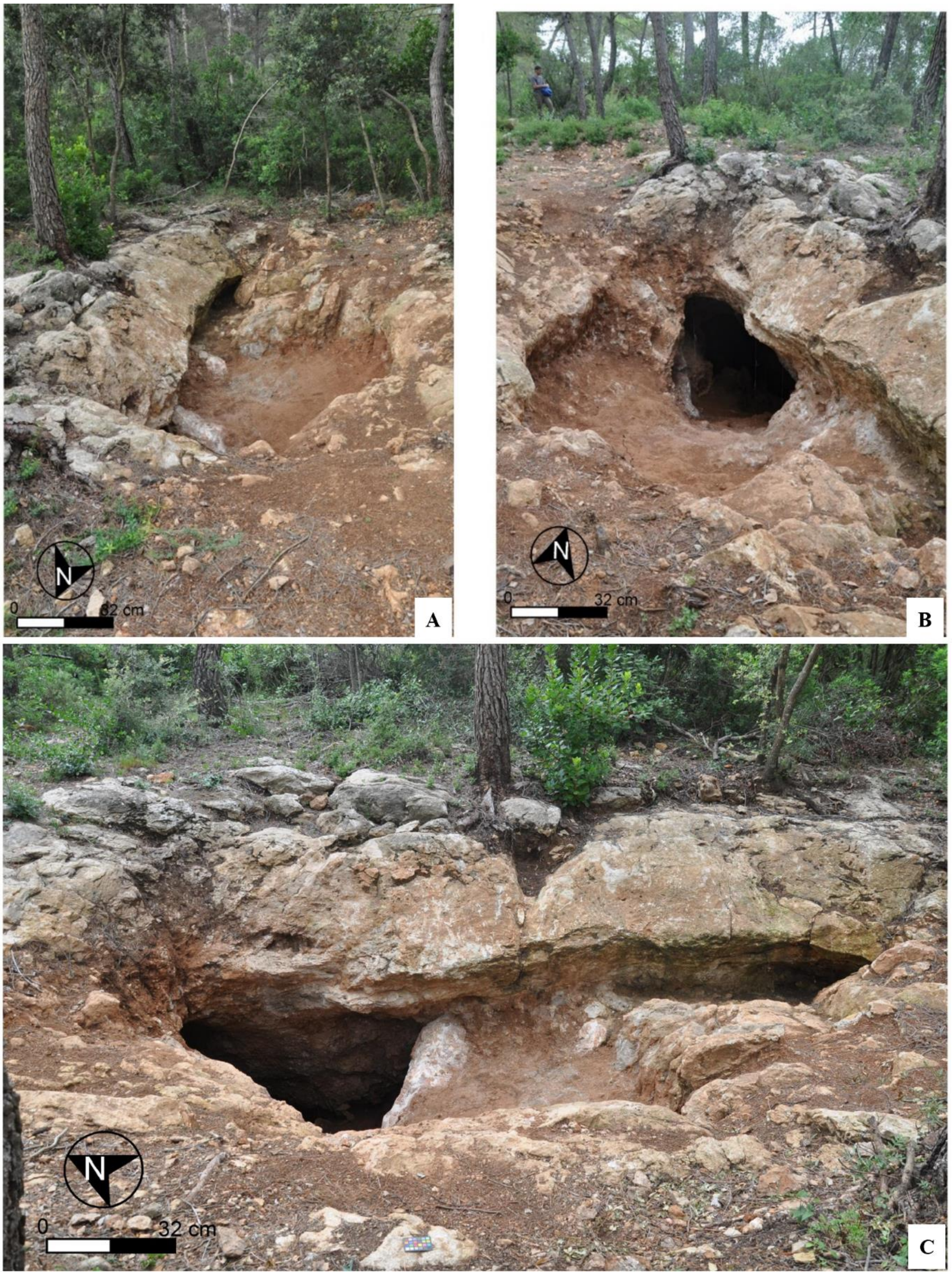

Figure 2. A-C: Original entrance completely sealed by Pleistocene cone-debris and re-opened during the current phase of fieldworks (modified from Daura et al. 2017).

The cave consists of three main chambers (see Figures 1. D-E). One of these, called Sala dels Miners, was artificially formed through quarrying activities. The other two, Sala Sal de Llop and Sala dels Ursus, remain in their natural state. Sala Sal de Llop is positioned near the cave's original entrance, whereas Sala dels Ursus is found in the deeper, darker part of the cave. The cave sequence is characterized by five main units, arranged from bottom to top: the Large Block Unit (LBU), Lower Speleothem Unit (LSU), Debris Cone Unit (DCU), Upper Flowstone Unit (UFU), and Sal de Llop Mining Unit (SMU). Archaeological layers within the cave have been classified into three distinct episodes, identified as Units 1 to 3 (refer to Figures 3. A-C).

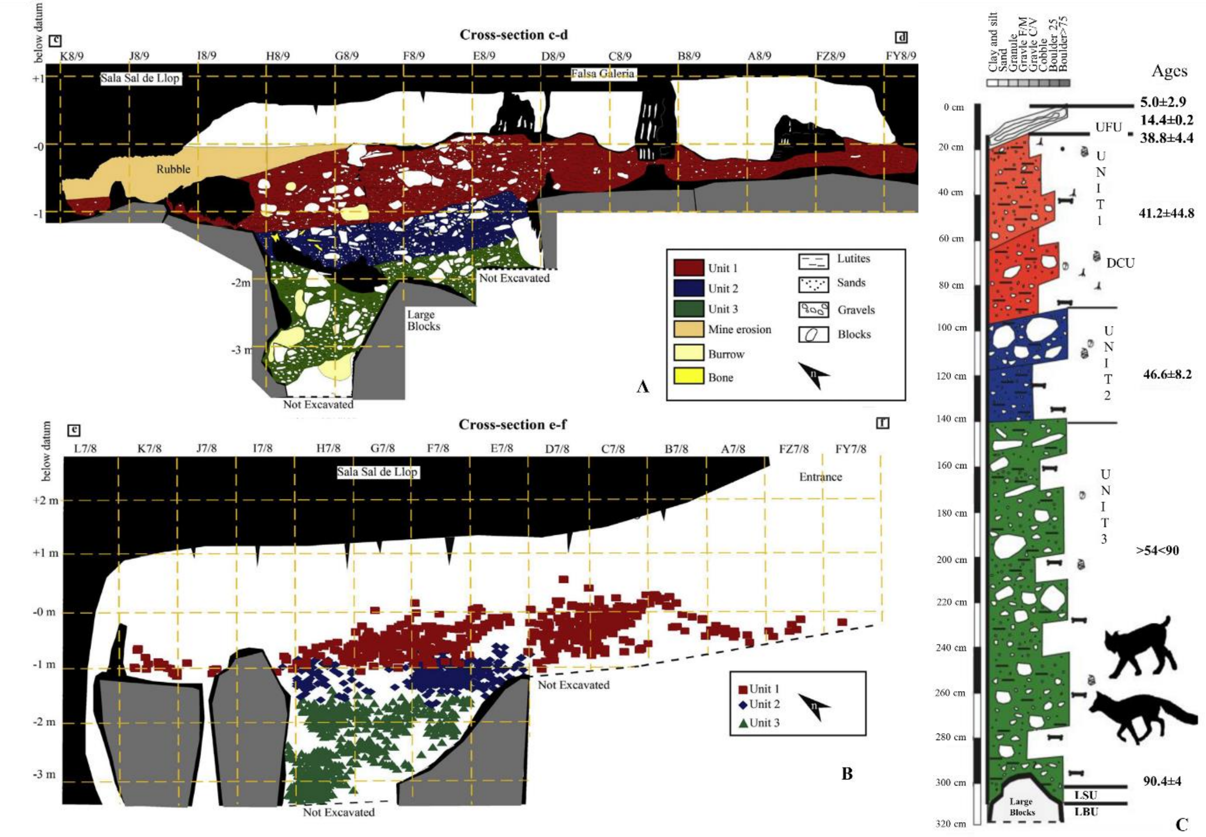

Figure 3. A-B: North-South cross-section showing three main stratigraphic units and archaeological artefacts plotted and grouped according to distribution in three main units (the position and orientation of the cross-sections are marked in the figure 1). C: Stratigraphic column showing the main features (modified from Gabucio etal., 2024).

The archaeological setting of the site is defined by lithic tools typical of Mousterian technologies, suggesting occasional and transient visits by Neanderthals (Daura et al., 2017) most of them correspond to Unit 2 and the boundary between Units 1 and 2. The faunal assemblages studied from Cova del Coll Verdaguer predominantly represents a carnivore den, with the primary activity associated with hyenids and lacks signs of human activity, pointing to carnivores as the principal contributors to the accumulation process (Sanz and Daura, 2018). Taphonomic clues and the presence of coprolites indicate that hyenas were primarily responsible for gathering ungulate remains, despite the absence of hyena skeletal remains (Sanz and Daura, 2018). Brown bears also utilized the Sala dels Ursus for hibernation and birthing purposes, this resulted in the deposition of both immature and adult remains, which accumulated as a consequence of natural mortality processes occurring within the cave (Sanz, 2013; Sanz et al., 2016; Daura et al., 2017; Sanz and Daura, 2018). Furthermore, smaller carnivores such as lynxes and foxes also played a role in the accumulation of faunal remains especially leporid remains which were correspond mostly to a non-ingested assemblage, supported by the discovery of their skeletal remains and coprolites (Sanz et al., 2016; Gabucio et al., 2024). The discovery of these remains underscores the role of these predators in the cave's palaeoecological system, reflecting their dietary habits and interaction with the cave environment.

2.3.1 Sala Sal de Llop chamber

The Sala Sal de Llop has a sedimentary sequence averaging 1.8 meters thick at the stratigraphy that was deposited within a relatively short period during Marine Isotope Stage (MIS) 3. While the infill is largely uniform in terms of clast size, matrix abundance, and colour, distinct layers are identified by discontinuities, though these do not correspond to specific chronological events. Therefore, the layers are grouped into three main depositional episodes (Units 1 to 3). A flowstone layer at the top, dated using U-Th disequilibrium methods, indicates that the deposit is at least approximately 38.4 cal BP. The ages obtained by thermoluminescence (TL) dating of sediment (Unit 2) provide a range for the deposit between 41-43 ka cal PB (Daura et al., 2017). Beneath the basal blocks of Sala Sal de Llop lies a narrow passageway known as Sector Meandre (SM). This conduit has yielded numerous loose remnants that were accumulated from the base of sedimentary filling of Sala Sal de Llop, i.e. Unit 3.

In the Sala Sal del Llop chamber, Unit 1 is the most recent layer, heavily impacted by mining and modern archaeology, featuring calcite remnants and excavation artifacts. Unit 2, beneath Unit 1, contains older sediments with less mining disturbance, including faunal remains (Table 1) and potential artifacts, offering insights into past sedimentation and human activities. Unit 3 is the deepest and oldest layer, primarily consisting of well-preserved natural deposits with significant faunal remains and sporadic artifacts, crucial for understanding the cave's long-term geological history and environmental changes (Sanz, 2013).

Table 1. Faunal species represented within Unit 2 in Cova del Coll Verdaguer (extracted and modified from Daura et al., 2017)

	NISP	MNI
Mammalia Carnivora		
Lynx pardinus	13	1
Ursus arctos	15	5
Vulpes vulpes	3	1
Meles meles	1	1
Perissodactyla		
Equus caballus	51	3
Capra pyrenaica	22	3
Capreolus capreolus	6	1
cf. Cervidae/Caprinae	14	
Cervus elaphus	67	5
Ungulates per body size		
Small	71	
Medium	118	

Large	1	
Lagomorpha		
Leporidae*	2421	40
Soricoforma		
Talpa europaea	2	1
Crocidura russula	1	1
Rodentia		
Arvicola sapidus	2	1
Iberomys cabrerae	12	10
Microtus arvalis	9	5
Microtus agrestis	4	3
M. arvalis-agrestis	1	1
Microtus (Terricola) duodecimcostatus	5	3
Apodemus sylvaticus	11	4
Eliomys quercinus	2	1
Sciurus vulgaris	1	1
Aves		
Alectoris cf. rufa	1	1
Columba livia/C. oenas	1	1
Gastropoda		
Galba truncatula		2
Abida polyodon		10
Discus rotundatus		7
Sphincterochlia af. baetica		5
Suboestophora tarraconensis		2
Xerocrassa penchinati		94
Cepea nemoralis		44
Pseudotaecha splendida		261
Theba pisana		424

*Leporids were not analysed all of the subunits within Unit 2, however, this study includes most of the leporid remains from this unit

3. Materials and methods

3.1 Materials

The faunal assemblage analysed comprises a total of 2,421 leporid remains recovered from Unit 2 of the Sala Sal de Llop chamber, specifically from subunits IIIg, IIIg/2, IVb, IVb/c, IVd, IVf, IVf/2, IVg, IVh, and IVj. It is important to note that not all subunits within unit 2 were analysed in this study. Thus, subunits IIIe, IVc, IVe have not yet been analysed. However, this study includes most of the leporid remains from the unit.

Of these remains, 2,365 were recovered using 1 m² units of provenance, indicating they were bagged as discrete units by subunit and square level. Additionally, 56 remains were piece-plotted, meaning they were recovered and recorded with specific data on subunit, square level, and 3D coordinates. This comprehensive recording method ensures that each piece-plotted remain is associated with precise spatial and contextual information. This study encompasses leporid remains from Unit 2 of the Cova de Coll Verdaguer (Cervelló, Barcelona). In analysing these remains, considering anatomical identification, age-at-death, and structural and/or surface modifications, the data were integrated into a database that enabled comparisons related to human behaviour, other predators, and site formation processes.

3.2 Methods

To study the various assemblages included in this work, Zooarchaeological analysis methods were applied, following the methodological approaches of Binford (1981) and Brain (1981). Additionally, Taphonomy has been utilized to understand the history of the studied fossils, both pre- and post-depositional burial (e.g., Andrews, 1990; Lyman, 1994; Scott, 2000). Given that the assemblages involve accumulations of leporids, taphonomy is essential for identifying the processes and agents that have altered the fossil remains (Stiner, 1994; Fisher, 1995; Reitz and Wing, 2008).

3.2.1 Anatomical identification and abundance measurements of anatomical representation

Examining faunal remains and identifying their anatomical representation is crucial, as it facilitates the accurate quantification of skeletal elements, aiding in the precise quantification of both elements and specimens. Detailed anatomical analysis also helps identify butchery patterns, predator activity, and post-depositional changes, providing insights into past human behaviours and environmental conditions.

Comprehensive analyses were conducted to determine the specific anatomical elements present within the assemblage. This involved meticulous examination and classification based on morphological characteristics, utilizing comparative anatomy atlases (Barone, 1976; Grayson, 1984; Lyman, 1994, 2008b, 2008a; Hillson, 2005; Wing, 2008; Gifford-Gonzalez, 2018) and through direct comparison to the reference collections from the *Institut Català de Paleocologia Humana i Evolució Social* (IPHES-CERCA) in Tarragona for indicating elements, sides (right or left), portions and faces.

Generally, bones can be classified into three principal categories based on their structure and function:

- Long Bones: They are composed of a diaphyseal cylinder, two metaphyses, and two epiphyses at each end. They have a well-developed medullary cavity and correspond to the limbs of animals (except for the carpals and tarsals). This category includes all remains that could belong to stylopods (humerus, femur), zeugopods (radius, ulna, tibia/tibiotarsus, fibula), metapods (metacarpal/carpometacarpus and metatarsal/tarsometatarsus), and acropods (phalanges).
- Flat Bones: They have almost no medullary cavity and belong to the so-called axial skeleton (vertebrae and ribs), skull (cranium and mandible), and girdles (scapula and pelvis).- Articular Bones: Composed of basipods (carpals and tarsals) and patella. They do not have a medullary cavity and are formed by dense and compact spongy tissue.

In regard to the portions, each bone is divided into specific portions, numbered from the closest to the mouth to the furthest away, following the criteria of anatomical definition described in Palaeontology (Figure 4). Each bone is, in turn, composed of four faces, which together form the anatomical element and allow for its identification with a higher level of precision (Schmidt, 1972):

- Anterior, cranial, or dorsal.
- Posterior, caudal, or palmar/plantar.
- Exterior or lateral.
- Interior or medial.

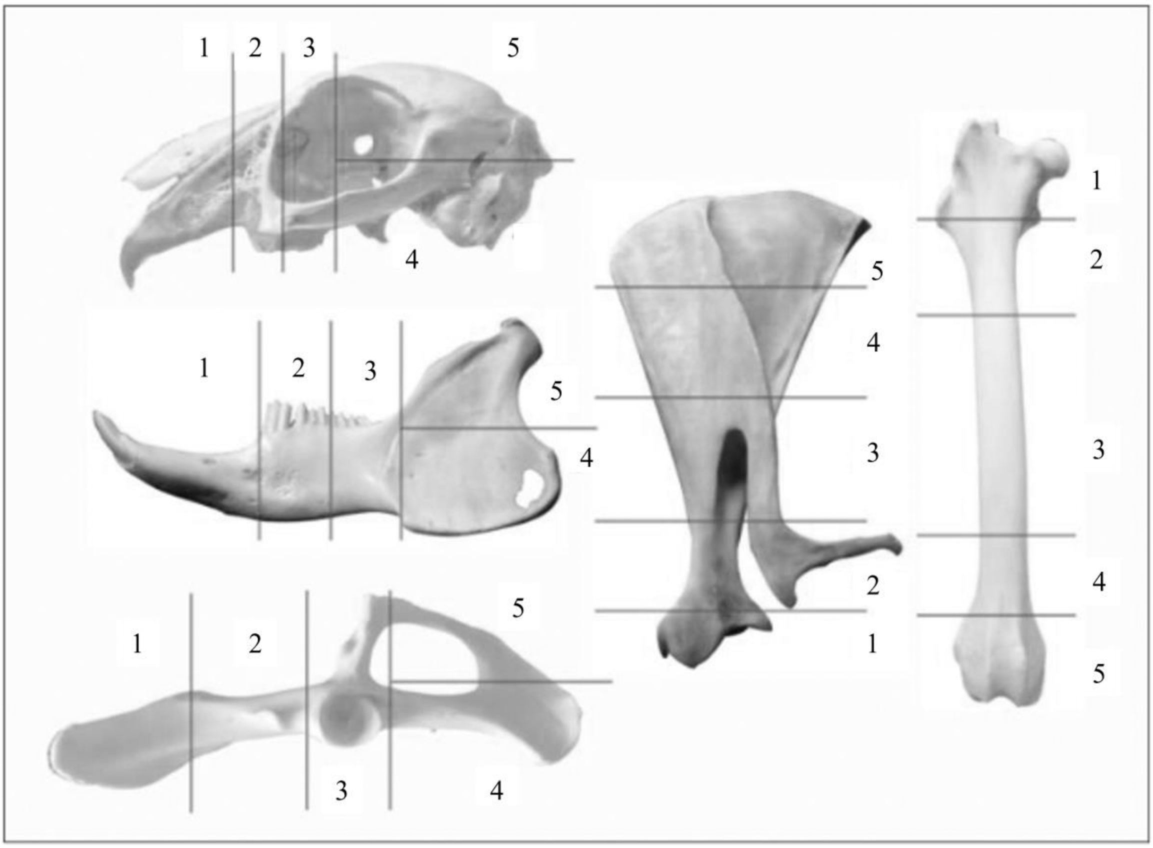

Figure 4. The portions of different elements of leporids (Modified from Rufà, 2017)

This classification helps to a better quantification of the elements, of the individuals as well as to the localization of taphonomic alterations.

The proportions of skeletal elements in leporid remains have been evaluated using several indices (Lloveras et al., 2008; Rodríguez-Hidalgo et al., 2013, 2020). These include:

- Proportions between postcranial and cranial elements:
  - PCRT/CR: the total number of postcranial elements was compared with the total number of cranial elements (cranium, mandibles, maxillae and teeth).
  - PCRLB/CR: the total number of long bones (humeri, radii, ulnae, femora and tibiae) was compared to cranial elements (cranium, mandibles, maxillae and teeth).
- The loss of distal elements was assessed applying the following indexes:
  - AUT/ZE: the number of elements corresponding to the autopodium (metapodials, carpals, tarsals, phalanges, calcanei and astragals) compared to

    - elements corresponding to the zygopodia and stylopodia (tibiae, radii, ulnae, humeri, femora and patellae).
    - Z/E: the number of elements corresponding to the zygopodia (tibiae, radii and ulnae) compared to elements corresponding to the stylopodia (femora and humeri).
- The proportion between elements from the anterior and posterior extremities was assessed applying the following index:
    - AN/PO—the number of elements corresponding to the anterior extremities or forelimbs (humeri, radii, ulnae and metacarpals) compared to elements corresponding to the posterior extremities or hind limbs (femora, tibiae and metatarsals).

These indexes are useful to detect different predators' participation (including human), since different parts may be better represented than others depending on the behaviour of each predator (Cochard, 2004a, 2004b).

3.2.2 Age at Death

In zooarchaeology, understanding the age at death of animals is crucial for discerning patterns of mortality, which reveal acquisition strategies and behaviours of both human and non-human predators (Marean and Spencer, 1991; Steele and Weaver, 2002; Fernandez, 2009; Pelletier et al., 2015, 2016). Factors influencing age distributions include predator size, capture season, geographical location (e.g., Cochard, 2004b; Lloveras et al., 2012) and the presence of various accumulation agents such as foxes and eagle owls, which exhibit similar mortality profiles. These studies help exclude predators that primarily target adult individuals, such as medium to large carnivores (e.g., badgers, dholes, lynx), large raptors (e.g., eagles, vultures), and humans (Cochard, 2004b; Cochard et al., 2012; Hockett, 1991; Lloveras, 2011; Lloveras et al., 2011, 2014, 2016; Pelletier et al., 2016). Age structure analysis is also instrumental in identifying or ruling out potential predator species known to prey on rabbits and assessing natural attritional mortality. This study employs ternary diagrams adapted from Stiner (M. C. Stiner, 1990).

The method used in Zooarchaeology for estimating the age of individuals is based on the degree of epiphyseal fusion of the bones, the degree of ossification of their cortical tissue, and especially on dental growth and wear patterns (Hillson, 2005). In leporids, dentition does not provide clear information regarding the age of individuals, as they have continuously growing teeth and only provide data when they are still developing, during the first few months of life. Therefore, it is only possible to estimate age based on the degree of bone ossification and epiphyseal fusion.

In this work, ages have been distinguished following the criteria indicated in Table 2 (Cochard, 2004a; Jones, 2006; Rufà, 2017), creating different age at death categories based on the epiphyseal fusion of long bones: perinatal (less than 3 months), infantile (3 to 5 months), juvenile (5 to 9 months), and adult (more than 9/10 months). Sometimes we can use combined categories (for instance INFANTILE/JUVENILE), when if it is not possible to specify a single category.

Table 2. Degree of ossification of epiphyses in leporid bones and age at death categories.

AGE CATEGORY	AGE	ELEMENT
PERINATAL: < 3 months	< 2 months	Unfused distal humerus
	< 3 months	Unfused proximal radius
INFANTILE: 3-5 months	< 5 months	Unfused ulna (proximal and distal) Unfused femur (proximal and distal) Unfused tibia (proximal and distal)
JUVENILE: 5-9 months	5-9 months	Humerus: distal fused, proximal unfused Radius: proximal fused, distal unfused Femur: proximal fused, distal unfused Tibia: distal fused, proximal unfused Ulna: proximal fused, distal unfused
ADULT: > 9 months	9 months	All the epiphyses of long bones fused

3.2.3 Quantification

Quantifying remains within an assemblage is essential for counting the specimens in the sample and identifying potential biases in skeletal part representation. Various techniques for quantifying a faunal assemblage provide specific information that aids in organizing and analysing the record at different levels. The combined use of several quantification indexes also makes it possible to reduce the limitations of each of them and to make a more accurate assessment of the whole.

In this work we have used four main types of abundance measurements to quantify fossil remains: the Number of Identified Specimens (NISP), the Minimum Number of Elements (MNE), Minimum Number of Individuals (MNI) (Lyman, 1994) and the Relative Abundance (%RA) (Lloveras et al., 2008).

3.2.3.1 The Number of identified Specimens

The NISP is the Number of Identified Specimens (Wing et al., 1987) that provide basic method for comparing skeletal composition and taxonomic distribution in archaeological or paleontological studies (Payne, 1972; Casteel, 1976; Grayson, 1978, 1984; Watson, 1979; Lyman, 1994; Domínguez-Rodrigo, 2012; Richards and Britton, 2019;). It counts all bone and dental fragments identified taxonomically and/or anatomically, and was first used in zooarchaeology (Lyman, 1994; Reitz, 2008). In order to facilitate comparison of the NISP provided by the various skeletal elements, it is possible to calculate the %NISP.

3.2.3.2 Minimal Number of Elements

Minimal Number of Elements, as defined by Bunn (1986), represents the minimum number of original skeletal elements necessary to account for identifiable fragmented samples within an assemblage. Various methodologies exist for estimating MNE, involving the quantification of all bone fragments regardless of their degree of fragmentation (Bunn, H.T., Kroll, 1986). Given its interpretative nature, a thorough explanation of the estimation process is recommended. In this work, all available identification information (portion, side, landmark, face and age) was used to calculate the MNE of the different elements. The %MNE (standardized value of the MNE according to the total number of elements identified in the assemblage) and the MNEe (Minimum Number of Expected Elements, i.e. the product of the NMI by the number of times each element is repeated in a complete skeleton) have also been calculated.

MNE is crucial for estimating the number of individual animals represented in the faunal assemblages, helping to reconstruct the composition of the faunal assemblage by providing a more accurate estimate of animal numbers and reducing potential biases that can arise from simply counting the number of fragments (Number of Identified Specimens - NISP) (Grayson, 1984; Lyman, 1994; Reitz and Wing, 2008).

3.2.3.3 The Minimal Number of Individuals

The Minimum Number of Individuals (MNI) is defined as the smallest number of individual animals required to account for an analytically specified set of identified faunal specimens (Lyman, 1994). To compute the MNI, the calculation considers the laterality, size, morphology, and age of the most commonly represented skeletal elements within a taxon (Lyman, 1994, 2008c). This approach is pivotal in several aspects of zooarchaeological research. Firstly, MNI provides a reliable metric for assessing the demographic composition and size of ancient animal populations. It aids in reconstructing subsistence strategies and understanding hunting practices, resource utilization patterns, and ecological interactions. Moreover, MNI analysis allows for the identification of taphonomic biases and helps differentiate between primary deposits and accumulations resulting from secondary processes, thereby contributing to the interpretation of site formation processes (Stiner, 1994).

3.2.3.4 The Relative Abundance

The Relative Abundance (%RA) allows for determining if there are biases in the representation of the different skeletal elements. It is based on the best-represented anatomical elements in the assemblage (Lloveras et al., 2008). It is calculated by combining the MNE and the MNEe using the following formula:

$$\%\mathrm{RA} = \frac{(\mathrm{MNE} \times 100)}{\mathrm{MNEe}}$$

3.2.4 Breakage pattern

Archaeological sites often reveal bone assemblages that exhibit significant fragmentation, attributable to a variety of taphonomic factors encompassing both biological and physical processes (Behrensmeyer, 1978a; Binford, 1981; Lyman, 1994). Villa and Mahieu (1991) developed a key framework for analysing bone fractures, classifying them into green-bone fractures (from fresh, pliable bones) and dry-bone fractures (from brittle, weathered bones). This classification helps distinguish between breakage from early butchery versus later natural processes. They also identified impact fractures, caused by high-energy impacts like hammering, which indicate activities such as bone smashing or tool production.

Lyman (1994) expands on this by discussing how these breakage patterns can be used to interpret site formation processes and subsistence strategies. According to Lyman, the presence of specific fracture types can reveal information about how bones were processed and the extent of human involvement. For instance, systematic breakage patterns consistent with marrow extraction or tool-making activities can indicate deliberate human behaviour rather than random or natural breakage.

This comprehensive approach to analysing bone breakage patterns involves both macroscopic and quantitative methods. By examining fracture types, locations, and frequencies, researchers can infer subsistence strategies, site formation processes, and cultural practices. Integrating these insights helps archaeologists reconstruct detailed aspects of past human behaviours and interactions with their environment, thereby providing a richer understanding of bone assemblages at archaeological sites (Gifford-Gonzalez, 1991a; Villa and Mahieu, 1991; Lyman, 1994; Domínguez-Rodrigo, 1999).

Carnivores affect bone fragmentation in distinctive ways. They leave gnaw marks from chewing bones to access marrow, which are irregular compared to human tool marks. Carnivores also cause extensive bone fragmentation through high-force impacts to break bones open, leading to crushed or splintered fragments. Additionally, they may create pit and percussion marks from their attempts to break bones. Identifying these patterns helps differentiate carnivore activity from human-induced modifications and provides insights into past predator behaviours and ecological interactions (Behrensmeyer, 1978a; Lyman, 1994; Todd and Rapson, 1988).

The breakage pattern was assessed by analysing the completeness of bone elements, including the percentage of intact specimens, as well as the preserved proportions of circumference (C1-C3) and length (L1-L4) which has attribute states for bone circumference (Bunn, 1983) as follows:

- Less than half of the original circumference (C1)
- More than half of the circumference present in at least part of the bone length (C2)
- Complete circumference in at least a portion of the bone length (C3)

Shaft length is categorized based on (Bunn, 1983) as follows:

- Less than one-fourth of the original length (length here refers only to the shafts, excluding the articular ends) (L1)
- Between one-fourth and one-half of the original length (L2)
- Between one-half and three-fourths of the original length (L3)
- More than three-fourths of the original length, which is essentially a complete or nearly complete shaft (L4)

Additionally, the examination focused on the fracture outline, angle, and edges of long bones (Villa and Mahieu, 1991) as follows:

- Outline: including transverse which describing fractures that are straight and transverse to the bone long axis; curved that is spiral fractures or portions of spiral fractures combined with V-shaped; longitudinal which includes fractures that have a straight morphology but are diagonal, and fractures with a stepped outline.

- Edge: refers to the aspect or texture of the fracture margin of smooth or jagged.

- Angle: This refers to the angle created between the fracture surface and the cortical surface of the bone. Green bone fractures are typically linked to obtuse or acute angles, whereas right angles are more commonly associated with fractures in dry or permineralized bones. The observed attribute states are as follows: 1) oblique (i.e. obtuse or acute); 2) right; 3) oblique and right (for fractures that have variable angles).

However, the thin cortical layer of leporid bones sometimes complicates the application of the criteria proposed by Villa and Mahieu (1991).

The presence of notches, and their features, were recorded (Capaldo and Blumenschine, 1994). Analysing notch shapes and their distributions might help differentiate between dynamic and static loading, including those caused by carnivores (Domínguez-Rodrigo et al., 2007). The distribution of notch types was identified according to the following classification (modified from Capaldo and Blumenschine (1994)):

- Complete notches have two inflection points on the cortical surface and a non-overlapping negative flake scar.
- Double opposing complete notches are two complete notches that appear on opposite sides of a fragment and result from two opposing loading points.
- Incomplete notches are missing one of the inflection points.
- Double overlapping notches have negative flake scars that overlap with an adjacent notch. The shape of both notches has to be visible from both the cortical and the medullary surfaces.
- Inverse notches have double scars, one emanating from the cortical surface and the other from the medullary surface.
- Micro notches (<1 cm)

Shaft cylinders were also documented in the study (Rodríguez-Hidalgo et al., 2020). In the analysis of long shaft cylinders, a classification was established distinguishing between two categories: “tubes” and “fake tubes.” The term “tubes” refers to middle shaft portions characterized by snapped ends, which are indicative of marrow extraction processes. Conversely, “fake tubes” are similar in form but exhibit traits of dry breakage rather than consumption (Rodríguez-Hidalgo et al., 2020). For this study, only long bones containing a substantial amount of marrow, specifically the humerus, tibia, and femur, were subjected to analysis.

All elements were categorized into various breakage types based on the classification system established by Lloveras et al. (2008b) (Table 3) and this system has been subsequently utilized by multiple studies (Lloveras et al., 2008, 2009, 2014; Rodríguez-Hidalgo et al., 2013, 2020; Pelletier et al., 2015, 2016; Gabucio et al., 2024). Breakage categories varied depending on bone type:

Table 3. Breakage categories of leporids

No.	Elements	Breakage zone	Abbreviation
1	Long bone, metacarpal, metatarsal, phalange, and rib	Complete	C
		Proximal epiphysis	PE
		Proximal epiphysis + shaft	PES
		Shaft	S
		Shaft + distal epiphysis	SDE
		Distal epiphysis	DE
2	Mandible	Complete	C
		Incisive part	IP
		Mandible body + incisive part	MBI
		Mandible body	MB
		Mandible body + branch	MBB
		Condylary process	CP
3	Cranium	Complete	C
		Incisive bone	IB
		Incisive bone + maxilla	IBM
		Maxilla	M
		Zygomatic arch	ZA
		Neurocranium	NC
4	Innominate	Complete	C
		Acetabulum	A
		Acetabulum + ischium	AIS
		Acetabulum + ischium + illium	AISIL
		Acetabulum + illium	AIL
		Ischium	IS
		Illium	IL
5	Scapula	Complete	C
		Glenoid cavity	GC
		Glenoid cavity + neck	GCN
		Neck + fossa	NF
		Fossa	F
6	Vertebrae	Complete	C
		Vertebral body	VB
		Vertebral epiphysis	VE
		Spinous process	SP
7	Patella, carpal, tarsal, calcaneum, astragulus (talus), and teeth	Complete	C
		Fragment	F

3.2.5 Damage to bone surface

All the remains were analysed both macroscopically and microscopically. For this second phase of the taphonomic analysis, an Olympus SZ1144TR stereoscopic microscope was used for identification the presence of taphonomic alteration on bones including cut marks, burning, furrowing, puncture, granulated edge, pits, imprints, score, digestion, weathering, root, trampling, rounding, polishing, fissure, chemical corrosion, dissolution, manganese, and concretion. A HIROX KH-8700 Digital Microscope (low range, 35x and 50x) were used for measuring the toothmarks on bones and obtaining photo of those toothmarks. The Sensofar S-Neox 3D Optical Profiler (SSN09000), which has confocal, focus variation and interferometry technology, along with the SensoView 1.9 software for data processing was used for obtaining high magnification figure of trampling marks, also measuring the profile of striae to distinguish those trampling which have very close to the morphology of cut marks when observed by naked eyes.

In this study, all modifications to bone specimens were quantified in terms of their absence or presence on each specimen. also noting the presence of the alteration in specific portion and faces of bones. In reference to toothmarks, the number of modifications, type, location and measurements have been noted Additionally, in the case of post-depositional alterations, four categories were used depending on the distribution of the modifications as followed: isolated, concentrated, dispersed and generalized.

3.2.5.1 Human alterations

a) Cut marks

Cut marks on bones, indicative of human activity, result from accidental tool contact during prey processing. These elongated, linear striations have a "V"-shaped cross-section and show longitudinal micro-striations (Binford, 1981; Shipman and Rose, 1983; Marean and Spencer, 1991). Within cut marks, four general types can be differentiated (Binford, 1981; Shipman and Rose, 1983):

- Incisions are fine striations from tool edges on bones, varying in orientation and shape.
- Sawing marks are short, deep “zigzag” patterns from repeated cutting, usually transverse or oblique.
- Chop marks are deep, wide, and short, resulting from forceful strikes, typically linked to butchering.

These marks indicate different activities in prey processing; for instance, chop marks are associated with butchering, while incisions can suggest various tasks depending on their specific characteristics. Although cut marks can be found on the bones of small animals, their frequency is usually lower than on larger animals. This is mainly because the size of small animals allows them to be processed easily with hands and mouth, without the need for tools (Blasco and Fernández Peris, 2012). Therefore, the lack of cut marks on bones does not rule out the possibility that the animals were placed at a site due to human activities.

b) Human toothmarks

Humans, like carnivores, leave distinct marks on bones during meat consumption, including bite marks and fractures. Research, informed by ethnographic studies (Weisler and Gargett, 1993; Landt, 2004, 2007), aims to differentiate human-induced marks from those made by carnivores (Pérez-Ripoll, 2004). However, distinguishing between these marks is challenging due to similarities in bone modifications, such as depressions and grooves, and variations in how small versus large prey bones react to processing (Landt, 2004, 2007).

c) Human breakage of small prey

Humans and carnivores both leave distinctive marks on bones, such as bite marks and fractures, during meat consumption. Ethnographic studies (Weisler and Gargett, 1993; Landt, 2004, 2007) and extensive research (Laroulandie, 2000, 2001, 2005a; Pérez Ripoll, 2005; Lupo and Schmitt, 2005; Martínez, 2009; Fernández-Jalvo and Andrews, 2011; Sanchis, 2012) have aimed to differentiate these human-induced marks from those caused by carnivores. However, distinguishing between these marks is complex due to similarities in bone modifications, such as depressions, perforations, grooves, notches, and crenulated edges. Additionally, small prey bones react differently to processing compared to larger bones, further complicating mark identification.

d) Burning

Burnt bones found in archaeological contexts can result from both anthropogenic and natural factors (Shipman et al., 1984; Nicholson, 1993). Within zooarchaeology, such bones are often associated with deliberate human activities like cooking, waste disposal, or ritual practices (Stiner, 1995). However, accidental burning can also occur as an unintended consequence of human actions, such as during hearth maintenance (Lyman, 1994). Additionally, natural events like wildfires may cause bone burning independently of human activity (Buikstra and Swegle, 1989). The coloration of bones due to fire exposure depends on variables such as temperature, duration, soil chemistry, bone density, and whether the bone was in direct contact with flames. Researchers have identified a sequence of colour changes, from lighter tones to brown, then to black as carbonization occurs, and finally to white as organic materials are completely consumed (Cáceres, 2002). As burning progresses, bones become rougher and more prone to cracking due to the loss of organic matter and subsequent weakening of their internal structure (Shipman et al., 1984).

Despite the numerous existing studies on bone properties in burning processes, in this work, microscopic evaluations based on the degrees of coloration of the remains have been used following the criteria established by Stiner et al. (1995):

Table 4. Burning damage categories based on macroscopic appearance and colour established by Stiner et al. (1995).

Burned colour code	Descriptions
Grade 0	No burned (cream/tan)
Grade 1	Bone surface slightly burned; localized and less than half carbonized
Grade 2	The bone presents slightly burned; more than half carbonized
Grade 3	The bone is fully carbonized (completely black colour)
Grade 4	The bone is localized less than half calcined (more black than white)
Grade 5	The bone is more than half calcined, (more white than black)
Grade 6	The bone is fully calcined (completely white)

3.2.5.2 Modifications generated by carnivores

Surface modifications produced by carnivores can be categorized into physical (bites, scratches, and fractures) and chemical (gastric acids and salivary enzymes) types, which can occur independently or simultaneously (Gifford-Gonzalez, 2018b). Marks shape (ratio of major axis to minor of mark) and size (area in millimetres) can be different due to the type of carnivores (Fernández-Jalvo and Andrews, 2011). Modifications generated by carnivores in this study include toothmarks and digestion marks.

a. Tooth marks

Physical modifications result from the contact of teeth with bones, aiming to consume the meat, break the bone and/or access the nutrients inside (Delaney-Rivera et al., 2009). Numerous studies have aimed to differentiate between predators based on the characteristics and dimensions of their bites (Binford, 1981, Domínguez-Rodrigo et al., 2009; Andrés et al., 2012). However, research on the tooth marks of small carnivores remains limited and under-analysed (Aramendi et al., 2017; Courtenay et al., 2021, 2023). Moreover, these studies primarily focus on large mammal bones, leaving it uncertain whether the same predators would produce similar modifications on smaller animals (Haynes, 1983; Yravedra et al., 2022 Courtenay et al., 2023).

Tooth marks on bone resulting from carnivores have been described by several authors (Binford, 1981; Bunn, 1981; Shipman, 1983; Fisher, 1995; Selvaggio and Wilder, 2001;) and among the documented mechanical alterations are (Binford, 1981):

- Pits: These are small circular or oval indentations on the bone surface. They originate from the pressure exerted by the cusps of the molars when they encounter the bone surface, and in some cases, they can cause collapse of the bone cortex. They are typically found in the harder portions of the bone, with the shafts being where they are best documented.
- Punctures: These are deep depressions commonly found on the shafts of long bones when pressure is exerted with the teeth. The pressure causes total bone collapse, creating holes with generally rounded morphologies
- Score: These are streaks of variable length, width, and depth, but with rough, and irregular bottoms and U-shaped sections. They are produced by the dragging of teeth on the bone surface when they come into contact. Although they can have other arrangements, they are typically found transverse to the longitudinal axis of the bone.
- Imprints: Imprints are deep depressions left by molars or a series of teeth when pressure is exerted on the bone, forming the negative of one or more tooth cusps. They are documented in portions where the bone is more porous, such as epiphyses or metaphysis, as well as the coxae and vertebral bodies.

To accurately analyse tooth marks on faunal remains, a detailed examination and measurement process is essential (Marean and Spencer, 1991; Blumenschine et al., 1996). This involves identifying the specific characteristics of the marks and quantifying their dimensions. In this work, for precise measurement, a HIROX-microscope was employed to capture the dimensions of the marks accurately. The focus of the measurements was on two key aspects: the length and breadth of the tooth pits and punctures, on the one hand, and of the scores, on the other hand. Length refers to the maximum dimension of the mark, while breadth measures the dimension perpendicular to the length (Andrés et al., 2012). Regarding the comparison to the actualistic study and the previous work of Unit 2, only measurements of pits and punctures were used for the statistic calculation.

b. Furrowing marks and crenulated edge

- Furrowing marks: The loss of cancellous tissue due to the chewing of epiphyses results in a distinct pattern of furrowing, characterized by the removal of trabecular bone through repetitive masticatory actions (Haynes, 1980a, 1983; Brain, 1981). This furrowing is indicative of the gnawing behaviour of certain animals, which systematically erode the cancellous bone within the epiphyseal regions. This process creates a series of parallel, striated grooves or furrows on the bone surface, reflecting the intense mechanical forces exerted during feeding.

- Crenulated edges: refers to a distinctive rough, pitted texture found on bone surfaces. Crenulated edges occur when the applied masticatory forces exceed the mechanical threshold of bone density and strength, resulting in the formation of notched or serrated margins along the bone tissue (Maguire et al., 1980; Binford, 1981). This texture is indicative of carnivore activity, as described by Binford (1981). These crenulated edges are crucial for archaeologists in distinguishing carnivore modifications from other types of bone damage such as those caused by human activities or natural processes.

c. Digestion marks

Digestion marks on bone surfaces result from both chemical and mechanical processes within the digestive tract. These marks, including corrosion pits, surface erosion, and grooves, are caused by acidic digestive fluids and mechanical actions such as grinding and crushing (Sutcliffe, 1970; Gifford-Gonzalez, 1991b; Fernandez-Jalvo and Andrews, 1992). The extent and type of damage are influenced by the bone's composition, the animal's digestive efficiency, and the duration of bone exposure within the digestive system. Regarding leporid faunal investigation, this modification further develops by Lloveras et al., (2008a, 2008b), advanced the methodology by incorporating microscopy and quantitative analysis to improve the precision of identifying digestion damage and differentiating it from other taphonomic effects.

In this study, regarding leporid remains, the digestion was observed and graded according to the degree of digestion described by Lloveras et al., (2014) as follow:

Table 5. Description of the grades of digestion damage on leporid bones

0/Null	No traces observed
1/Light	The surface of the bone is slightly altered. Digestion is concentrated in a particular area of the bone with concentrated in a particular area of the bone with presence of pitting caused by digestion enzymes. Less than 25% of the surface of the bone has been affected by alteration. Edges may be slightly rounded.
2/Moderate	Between 25% and 75% of the surface of the bone is affected and the digestion is more advanced than in the previous category. Effects of pitting increase. Bone destruction may have occurred, but it is very localized. Possible splitting and rounding of edges.

3/Heavy	The entire surface of the bone is affected. Extensive pitting with presence of small holes that become visible in the bone surface. Advanced bone destruction affecting more than 50% of the bone. Extensive rounding of edges. Possible splitting and cracking.
4/Extreme	Important bone destruction has affected the entire surface of the bone. The bone structure has been destroyed by corrosion. Strong rounding of edges. Identification of the bone element is difficult.

Five degrees of digestion were observed as: null (grade 0), light (grade 1), moderate (grade 2), heavy (grade 3), and extreme (grade 4). The same degree of digestion was applied on both bones and teeth from Lloveras et al., 2014.

The extent of digestion in prey remains is influenced by several factors beyond predator species (Marean and Spencer, 1991). A predator's hunger level significantly affects digestion, as a very hungry predator retains food longer, leading to more extensive digestion (Andrews, 1990a). The ingestion of remains appears different affecting graded due to various predators. Mammalian carnivores cause intense pitting and rounding of bone ends due to their saliva, which creates small depressions on chewed bones. In contrast, raptors produce varying degrees of corrosion through gastric acids; diurnal raptors and mammalian carnivores generally cause more severe erosion with softened edges and porous surfaces, while nocturnal raptors cause less intense damage (Dodson and Wexlar, 1979; Brain, 1981; Marean and Spencer, 1991).

3.2.5.3 Modifications generated by raptors

The study of bone accumulations resulting from raptor activity provides crucial insights into identifying the responsible taxa based on their distinctive behaviours and associated taphonomic signatures. In contrast to larger prey, where differential transport patterns are more apparent, small prey such as leporids (rabbits) display unique characteristics in their accumulations due to their smaller size and the specific handling methods of predators.

Raptors, along with small mammalian carnivores, are primary consumers of small prey. Their consumption patterns are characterized by a low frequency of axial remains and a tendency to target the abdominal and ano-genital regions first to access the entrails. Consequently, vertebrae and ribs are often destroyed or absent in many assemblages. The presence of pellets is a significant indicator of raptor-generated accumulations. Notable raptor predators of leporids in the studied regions include eagles, owls, and hawks. To differentiate between taxa responsible for these accumulations, researchers have employed both observational and experimental approaches to identify distinctive taphonomic signatures left by raptors (Hockett, 1991, 1996; Cochard, 2004a; Lloveras et al., 2008, 2009; Rodríguez-Hidalgo et al., 2013). These include analysing bone surface modifications such as pitting and rounding, which are typical of raptor predation. Studies of raptor pellets reveal how prey remains are processed, indicating patterns of digestion. Controlled feeding experiments and simulations help document these changes, while comparative taphonomic analysis distinguishes raptor effects from those of other predators. Microscopic techniques, such as scanning electron microscopy (SEM) and optical microscopy, provide detailed views of bone damage.

3.2.5.4 Rodents marks

Research by various scholars has examined the impact of rodent activity on bones, with a particular focus on the Hystrix genus (Brain, 1981). Both large and small rodents modify bones through gnawing, but their effects can differ. Small rodents create grooves that match their dental characteristics, and these grooves' dimensions and shapes can help identify the responsible animals, though the wide range in rodent incisor shapes and sizes complicates precise identification (Shipman and Rose, 1983; Pokines et al., 2017).

Rodents may gnaw on dry bones for various purposes, including the maintenance and sharpening of their continuously growing maxillary and mandibular incisors (Kibii, 2009; Pokines, 2013). This gnawing behaviour also extends to hard inorganic materials encountered in their environment (Pokines, 2015). Additionally, rodents may engage in bone gnawing to obtain essential mineral salts (Coventry, 1940; Duthie and Skinner, 1986). The distinctive marks resulting from rodent gnawing on dry bones are typically shallow, parallel striations that tend to coalesce as the gnawing action continues at the same location (Fernández-Jalvo and Andrews, 2016b).

Large rodents, such as those from the Hystrix genus, have a more pronounced impact. Their gnawing can produce marks similar to those made by carnivores, especially on trabecular tissue, characterized by radial or parallel striations (Maguire et al., 1980). More commonly, large rodent marks are found on cortical tissue and long bones, with transverse gnaw marks on shafts and fractured edges (Haglund and Sorg, 1996; Pokines, 2013).

Additionally, large rodents can accumulate significant quantities of bones inside cavities (Brain, 1981). They primarily act on dry bones, suggesting that numerous marks indicate a slow burial process. Evidence of rodent gnawing in archaeological assemblages implies that bones were exposed to weathering before being buried by sediment, indicating a prolonged period of exposure (Brain, 1969).

3.2.5.5 Natural death (burrow)

It is important to recognize that in archaeological assemblages, the composition of faunal remains can be influenced by various natural processes beyond just predator activity. One such process is bioturbation, which includes both ancient and recent disturbances that occur independently of predators (Lyman, 1994; Stahl, 1996). In addition to bioturbation, identifying leporid remains in archaeological sites where these animals died within their burrows, or "warrens," is crucial for understanding their behavioural and environmental contexts. When these animals die within their warrens, their remains display unique characteristics that distinguish them from those affected by other processes or predators (Pelletier et al., 2016) such as:

- The lack of human and non-human predation evidence.
- The presence of numerous infants remains indicate that leporids likely died within the warren, as they rarely exit it.
- High proportions of young individuals and dry bone breaks from trampling, rather than predation, are additional indicators.

Leporid bones from warrens typically show fragmentation patterns due to compression within the burrow system and may retain anatomical connections, unlike the dispersed and fragmented remains found in predator-affected assemblages (Stahl, 1996).

3.2.5.6 Geological alterations

In taphonomic analysis, understanding geological modifications is crucial for interpreting bone assemblages. These modifications arise from various environmental and geological processes that impact bone preservation and alteration. The geological alteration analysed in this study included:

a. Trampling

Occurs when bones are exposed on the surface and abraded by the movement of living beings, causing fine, superficial incisions. Unlike cut marks, trampling marks have a flat bottom and are disorderly on the bone surface. These marks tend to be oriented transversely to the bone's longitudinal axis (Andrews and Cook, 1985; Behrensmeyer et al., 1986; Fernandez-Jalvo and Andrews, 2016). Trampling can occur on both surface and buried bones, and can even create notches on fracture edges, particularly where oblique angles exist (Blasco, 2008). Trampling marks can be similar to cut marks, presenting equifinality problems, prompting studies to differentiate between these types (Behrensmeyer et al., 1986; Domínguez-Rodrigo et al., 2009).

b. Roots

Roots can significantly alter bone surfaces through processes known as root-induced modifications. As roots grow through or interact with bones, they can leave distinct marks or patterns on the bone surface. These marks result from both physical pressure and chemical alterations caused by the roots. Physically, as roots penetrate and move through the soil, they can create grooves, indentations, or abrasions on the bone surface. Chemically, roots can leach organic compounds from the bone, leading to additional surface alterations such as rounding or erosion. The resultant patterns are often characterized by irregular, rounded grooves or pits, which can help distinguish root-induced modifications from other types of taphonomic changes (Behrensmeyer, 1978a; Fernandez-Jalvo and Andrews, 2016). The branched grooves are varying depth which can lead to vermiculation that characterised by “U-shape” grooves on bones surfaces. These marks are critical for identifying post-depositional alterations and understanding the interaction between vegetation and bone remains (Binford, 1981; Fernandez-Jalvo and Andrews, 1992).

c. Rounding and polishing

Currents moving remains can result in modifications like trampling and more pronounced rounding and polishing. This occurs due to sedimentary particles eroding or abrading the bone surface during water movement (Behrensmeyer, 1978b; Gifford-Gonzalez et al., 1985; Fisher, 1995; Fernández-Jalvo and Andrews, 2016a). The degree of rounding and polishing depends on factors such as sediment grain size, bone condition (fresh, dry, weathered), and physicochemical properties (bone type and fossilization state). Cáceres (2002) established degrees (0-4) of rounding and polishing used to assess these modifications as follows:

Table 6. the rounding and polishing grades according to Cáceres et al. (2002)

Grades	Description
0/ No Rounding or Polishing	The bone surface is completely unmodified with no evidence of rounding or polishing.
1/ Slight Rounding and Polishing	Minimal rounding of edges and slight polishing, generally just beginning to appear.
2/ Moderate Rounding and Polishing	Noticeable rounding of bone edges and moderate polishing on surfaces; the texture of the bone surface starts to change.
3/ Heavy Rounding and Polishing	Significant rounding of edges and extensive polishing; the bone surface appears smooth and rounded.
4/ Extreme Rounding and Polishing	Severe rounding and polishing; bone surfaces are highly smoothed, often with a glassy appearance

The classification ranges from 0, indicating no visible rounding or polishing, to 4, representing bones that have been extensively rounded and polished, often losing much of their original surface texture.

d. Weathering:

Exposure to atmospheric agents causes modifications in bones known as weathering. During the sedimentary formation process, bones undergo prolonged exposure to atmospheric agents, which subjects them to various weathering processes including changes in humidity, temperature fluctuations, and sun exposure. Weathering involves the decomposition and destruction of bones and is a natural process in which nutrients are recycled in and on soils (Behrensmeyer, 1978b). This process results in a series of cracks and exfoliations on the bone surface. Behrensmeyer (1978b) proposed stages (0-5) to classify the degree of weathering in bones as follows:

Table 7. Five stages of weathering classified by Behrensmeyer, 1978

Stages	Descriptions
0/ No Weathering	No Weathering/ Bones are intact with no visible signs of alteration.
1/ Initial Weathering	Surface shows fine cracks or fissures; beginning of roughening.
2/ Moderate Weathering	Extensive cracking and surface loss; significant fragmentation and rough texture.
3/ Advanced Weathering	Increased number and depth of cracks; noticeable flaking and erosion.

4/ Severe Weathering	Heavy erosion and fragmentation; major loss of bone material and structural integrity.
5/ Extreme Weathering	Extreme degradation: bone reduced to fragments or powder, with extensive surface loss.

The presence or absence of weathering can provide insights into the duration of bone exposure on the surface before burial and accumulation. In covered spaces like cavities, weathering may indicate an accumulation transported from outside or the existence in the past of an entrance of light that is hidden today (Behrensmeyer, 1978a; Rodríguez-Hidalgo et al., 2015; Fernandez-Jalvo and Andrews, 2016).

e. Manganese oxidation pigmentation

The precipitation of oxides on bones results in various colorations. Iron-rich, oxygenated soils cause a reddish hue, while exposure to freshly oxygenated water encourages the formation of manganese dioxide crystals, staining bones black. Manganese deposition is linked to constant humidity or waterlogged conditions, neutral pH, anaerobic environments, and bacterial activity. Such coloration is common in karst systems, where manganese coatings occur inside caves due to the insolubility of manganese oxide (López-González et al., 2006; Fernández-Jalvo and Andrews, 2016).

f. Concretion:

In humid environments, bones can also undergo modifications like concretions or cementations. These occur due to sediment expansion and compaction from humidity changes, potentially covering bones entirely or partially with a sedimentary matrix. Additionally, cemented bones may result from high carbonate presence in water (Macphail et al., 1990; Rodríguez-Hidalgo et al., 2015; Fernández-Jalvo and Andrews, 2016a).

Humidity changes can generate cracks on the cortical surface of bones due to expansion and contraction, sometimes leading to diagenetic fractures. Pressure from sediment can also cause fractures, resulting in bone crushing and deformation (Shipman, 1981; Rodríguez-Hidalgo et al., 2015; Fernández-Jalvo and Andrews, 2016a).

4. Results

4.1 Anatomical representation

In the analysis of the remains from Unit 2, a total of 2421 leporid remains were considered (Table 8). Of these, 1828 (75.51%) bones, 83 pieces containing bone and teeth (16.27%), and 510 isolated teeth (27.90%) were identified to skeletal element. Table 8 shows the anatomical composition of leporid assemblage. The entire skeleton was represented – isolated teeth (NISP=609), phalanges (NISP=528), metatarsals (NISP=244), vertebrae (NISP=157) are the most frequent elements according to NISP. Regarding the presence by Minimum Number of Elements (MNE), phalanges (19.70%), upper molars (11.65%) and metatarsals (9.71%) were the most represented.

Table 8. Anatomical representation of the leporid remains from Unit 2, Cova del Coll Verdaguer.

Unit 2	**Leporidae (MNI=40)**				
	NISP	**%NISP**	**MNE**	**%MNE**	**%RA**
Cranium	73	3.02	14	0.58	35.00
Mandible	71	2.93	26	1.07	32.50
Incisor	184	7.60	184	7.60	76.67
Upper Molar	282	11.65	282	11.65	58.75
Lower Molar	143	5.91	143	5.91	35.75
Atlas	3	0.12	3	0.12	7.50
Axis	2	0.08	2	0.08	5.00
Vertebra	157	6.48	62	2.56	3.78
Rib	124	5.12	45	1.86	4.02
Scapula	38	1.57	33	1.36	41.25
Humerus	46	1.90	33	1.36	41.25
Radius	61	2.52	32	1.32	40.00
Ulna	56	2.31	38	1.57	47.50
Innominate	83	3.43	25	1.03	62.50
Femur	44	1.82	19	0.78	23.75
Patella	8	0.33	8	0.33	10.00
Tibia	72	2.97	24	0.99	30.00
Fíbula	0	0.00	0	0.00	0.00
Carpal/tarsal	13	0.54	13	0.54	1.35
Astragalus	17	0.70	17	0.70	21.25
Calcaneum	51	2.11	51	2.11	63.75
Metacarpal	120	4.96	118	4.87	29.50
Metatarsal	244	10.08	235	9.71	58.75
Metapodial	1	0.04	1	0.04	0.13
Phalanges	528	21.81	477	19.70	19.88

Relative abundance of skeletal elements (%RA) is shown in Table 8 and Figure 5. It provides valuable insights into the composition of the assemblage and highlights notable patterns in bone preservation and representation. Among the recovered remains, isolated teeth emerge as the most abundant and well-represented, exhibiting the highest percentages in the assemblage. This prominence underscores their relative resistance of teeth to taphonomic processes of being preserved intact or in fragments compared to other skeletal materials. Innominate, calcaneum and metatarsal are also very abundant.

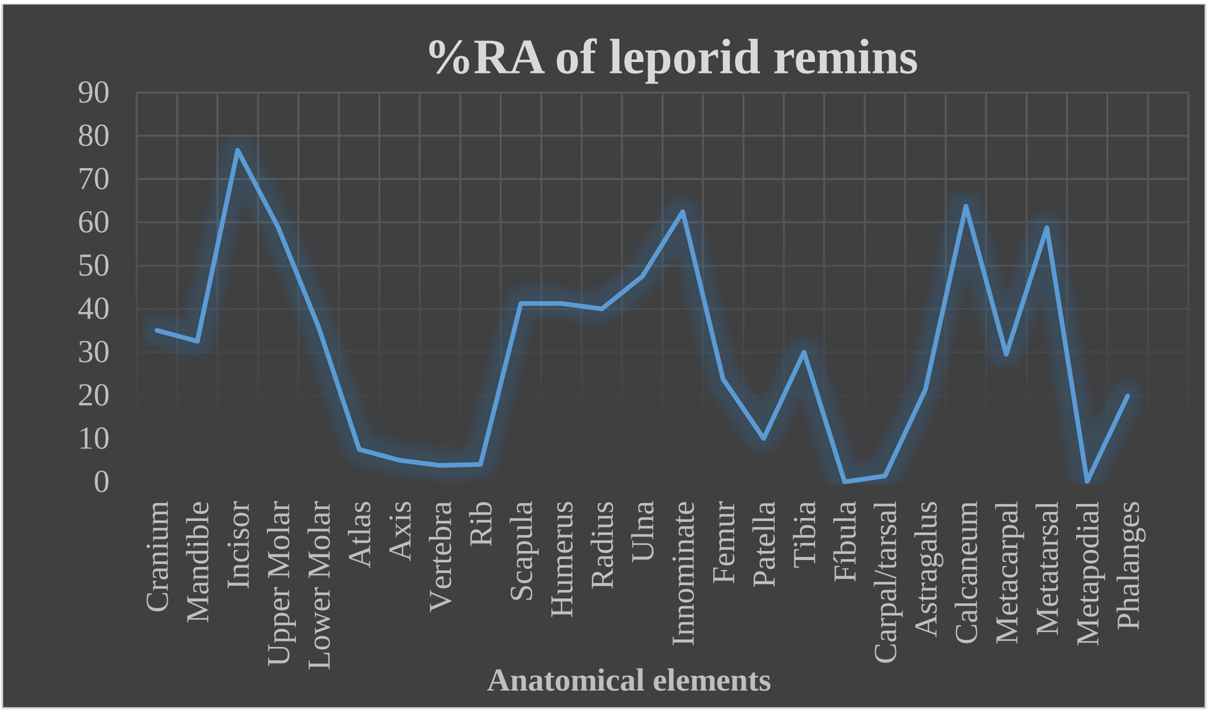

Figure 5. Relative abundance of different parts of the skeleton

Long bones also feature prominently in the assemblage, with notable representation observed in elements such as the humerus, ulna, and femur. These elements, essential for limb structure and mobility, often exhibit robustness and durability conducive to preservation. In contrast, certain skeletal elements such as carpal, tarsal, axial elements and scapula fragments are notably scarce within this assemblage (Figure. 6). Their reduced presence may reflect their anatomical characteristics, which render them more susceptible to fragmentation or destruction during deposition and subsequent burial processes.

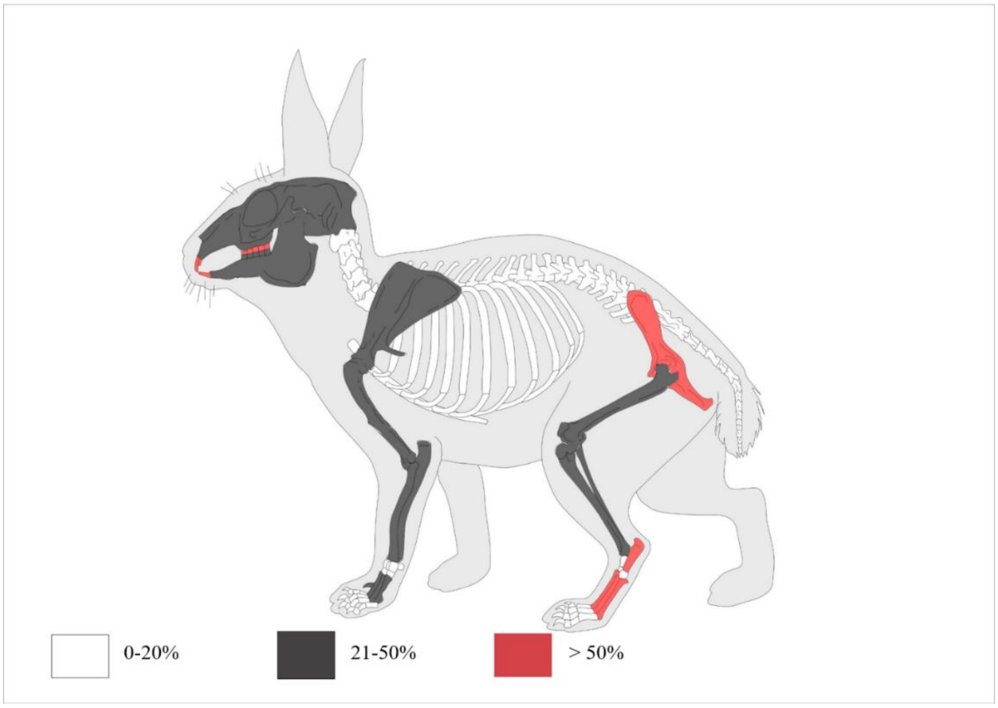

Figure 6. %RA of leporid remains were group in three main categories

Relative proportion of the skeleton elements are shown in Table 9 introduces a key aspect of the study, which is the comparison of different segments of the anatomical composition of a leporid assemblages. These proportions are derived from the outcomes of specific indices used to estimate the distribution of anatomical parts within the assemblage.

Table 9. Proportions of different anatomical parts of the leporid assemblage from Unit 2, Cova del Coll Verdaguer

Indices	Result (%)	Calculation	Interpretation
PCRT/CR	210.49	Postcranial skeleton (limb elements, vertebrae and ribs) NISP compared to cranial skeleton (mandibles, maxillae and teeth) NISP.	Much more post-cranial remains than cranial remains.
PCRAP/CR	183.53	Appendicular skeleton (long bones, scapula, coxal, patella, metapodials, carpals, tarsals and phalanges) NISP compared to cranial skeleton (mandibles, maxillae and teeth) NISP.	Much more appendicular skeleton remains than cranial remains.
PCRLB/CR	193.75	Postcranial long bones (humerus, radius, ulna, femur and tibia) NISP compared to cranial elements (mandibles and maxillae) NISP.	Much more long bones than cranial remains.
HU+FM/CR+MD	62.5	Stylopodium (femur and humerus) NISP compared to cranial elements (mandible and maxillae) NISP.	A little more upper limbs than skull.
TA/MD	101.41	Tibia NISP compared to mandible NISP.	A little more tibia than mandible.
TAE/MDE	92.31	Tibia MNE compared to mandible MNE.	More tibia than mandible.
AUT/ZE	339.37	Autopodium (metapodials, carpals, tarsals and phalanges) NISP compared to zeugopodium and stylopodium (tibia, radius, ulna, humerus, femur and patella) NISP.	Much more auto-podium than zeu-gopodium and stylopodium.
Z/E	210	Zeugopodium (tibia, radius and ulna) NISP compared to stylopodium (femur and humerus) NISP.	More zygopodium than stylopodium.
AN/PO	78.61	Humerus, radius, ulna and metacarpal NISP compared to femur, tibia and metatarsal NISP.	More posterior than anterior limbs.
HU/FM	104.55	Humerus NISP compared to femur NISP.	Almost balanced.
RDU/TA	162.5	Radius and ulna NISP compared to tibia NISP.	More radius and ulna.
MCP/MTT	49.18	Metacarpal NISP compared to Metatarsal NISP.	Balanced

These indices provide a refined analysis of the %RA (relative abundance) data, emphasizing the greater representation of postcranial elements compared to cranial elements, with a particular focus on the distal appendicular bones, such as metapodials and phalanges.

4.2 Age at death

According to the epiphysis fusion pattern of long bones yielded a minimum of 40 leporid individuals based on the number and fusion state of tibias (see example in Figure. 7), humerus, ulna, and radius. Analysis of the long bones' epiphyseal fusion stages indicates the presence of perinatal (<3 months, MNI =8), infantile (3–5 months, MNI =3), juvenile-adult (5-9 months, MNI=25), juvenile (5-9 months, MNI =1) and adult (>9 months, MNI=3) individuals. Among these, the juvenile-adult individuals (5-9 months) is the most represented, followed by the perinatal individuals (<3 months).

Figure 7. The estimation of epiphyseal fusion on tibiae showing the differences in ages

4.3 Breakage pattern

The 25.93% (NISP=867) of the leporid remains are complete elements. If we add the almost complete elements, the ratio increases to 35.81% (NISP=628). In Table 10, the number and percentage of leporid remains classified by breakage category are presented.

The higher proportion of complete elements is observed between post-cranial bones, especially in phalanges and the articular bones (carpals, tarsals and patella).

The overall completeness of skeletal elements averaged 43% (refer to Table 10). This percentage varied notably depending on bone size, with smaller bones such as carpals/tarsals, patellae, molars, and phalanges exhibiting the highest completeness rates (see Table 10 and Figure 8. Detailed breakdowns (detailed in Table 10 reveal specific patterns of breakage across different bone categories:

- Cranium generally showed advanced levels of breakage, with identified fragments including parts of the maxilla (M), zygomatic arch (ZA), incisive bone (IB), and neurocranium (NC).
- Mandibles were typically represented by body fragments (MB) and incisive part (IP), although occasional recoveries included the condylar process (CP).
- Isolated teeth (89.85%) were fragmented and nearly always complete presented only 10.15%.
- Vertebrae fragments predominantly consisted of vertebral body (VB) and vertebral epiphysis (VE), whereas ribs were almost universally fragmented.
- Large fragments containing part of the acetabulum, the ischium and the ilium (AISL) were the most prevalent among innominate bones (Figure 11. A). Among small fragments, ilium pieces (IL) are the most abundant followed by ischium (IS) and acetabulum (A) fragments.
- Scapulae were consistently incomplete, with a majority of fragments comprising the glenoid cavity (63.16%).
- Limb bones (including metatarsal and metacarpal) exhibited representation across all breakage categories, although complete bones are common only among metapodials.
- Patella (100%) represented the highest preservation completeness, followed by carpal/tarsal (92.31%), astragalus (70.59%). Calcaneus (52.94%) were nearly completed.
- Phalanges showed an overall high completeness rate, with 84.47% appearing complete.

The high prevalence of ribs (98,39) and isolated teeth (89.85%) underscore the extensive breakage observed in the assemblage of leporid remains in this study.

Table 10. NISP and %NISP of leporid remains identified in Unit 2 by breakage category. Long bones and metapodial bones were classified as complete (C), proximal epiphysis (PE), proximal epiphysis + shaft (PES), shaft (S), shaft + distal epiphysis (SDE) and distal epiphysis (DE). Cranium as complete (C), incisive bone (IB), incisive bone + maxilla (IBM), maxilla (M), zygomatic arch (ZA) and neurocranium (NC). Mandible as complete (C), incisive part (IP), mandible body + incisive part (MBI), mandible body (MB), mandible body + branch (MBB) and condylar process (CP). Innominate as complete (C), acetabulum (A), acetabulum + ischium (AIS), acetabulum + ischium + ilium (AISIL), acetabulum + ilium (AIL), ischium (IS) and ilium (IL). Scapula as complete (C), glenoid cavity (GC), glenoid cavity + neck (GCN), neck + fossa (NF) and fossa (F). Vertebrae as complete (C), vertebral body (VB), vertebral epiphysis (VE) and spinous process (SP). Isolated teeth, ribs, patella, astragalus, calcaneum, carpal/tarsal and phalanges as complete (C) and fragment (F).

	C		F	
	N	%	N	%
Isolated teeth	46	10,15	407	89,85
Ribs	2	1,61	122	98,39
Patella	9	100,00	0	0,00
Astragalus	12	70,59	5	29,41
Calcaneus	27	52,94	24	47,06
Carpal/Tarsal	12	92,31	1	7,69
Phalanges	446	84,47	82	15,53

Cranium	N	%
C	2	2,74
IB	10	13,70
IBM	2	2,74
M	18	24,66
ZA	17	23,29
NC	24	32,88

Mandible	N	%
C	1	1,41
IP	21	29,58
MBI	10	14,08
MB	32	45,07
MBB	2	2,82
PC	5	7,04

	C		PE		PES		S		SDE		DE	
	N	%	N	%	N	%	N	%	N	%	N	%
Humerus	2	4,35	6	13,04	1	2,17	4	8,70	9	19,57	24	52,17
Radius	2	3,28	7	11,48	13	21,31	24	39,34	12	19,67	3	4,92
Ulna	0	0,00	20	35,71	20	35,71	7	12,50	8	14,29	1	1,79
Femur	3	6,82	21	47,73	4	9,09	8	18,18	2	4,55	6	13,64
Tibia	5	6,94	9	12,50	4	5,56	15	20,83	27	37,50	12	16,67
Metacarpal	65	54,17	3	2,5	18	15,00	0	0,00	34	28,33	0	0,00
Metatarsal	83	34,02	1	0,41	72	29,51	12	4,92	76	31,15	0	0,00
Metapodial	0	0,00	0	0	0	0,00	1	100	0	0,00	0	0,00

Innominate	N	%
C	0	0,00
A	9	10,84
AIS	8	9,64
AISIL	22	26,51
AIL	7	8,43
IS	20	24,10
IL	10	12,05
Sacrum	7	8,43

Scapula	N	%
C	0	0,00
GC	2	5,26
GCN	24	63,16
NF	9	23,68
F	3	7,89

vertebrae	N	%
C	1	0,64
VB	126	80,77
VE	10	6,41
SP	19	12,18

Figure 8. Example of complete metatarsal (from II, III, IV, and V, from left to right in order)

The fracture patterns of the humerus, femur, and tibia, bones renowned for their substantial marrow content, were examined. Regarding the length of the 35 specimens, showing different portion from the most frequent of L1 (25 specimens) follow by L2 (6 specimens), L3 (2 specimens) and L5 (2 specimens). A detailed investigation revealed that many of these bones exhibited morphotypes extending approximately halfway along their shaft length (L1+L2 = 88.57%) and spanning nearly the entire circumference (C4 = 32.25%), even though in C3 also represented similarly (C3 = 29.03%). Both green and dry fractures were observed, with green fractures being more prevalent. There are many types of fracture patterns that stand out above the rest, curved, oblique and soft fractures with 51,33 were the most represented on the fractures followed by straight (right), oblique and soft fractures with 9.73% and longitudinal, right and soft with 7.08%. This probably associated with fresh fracturing, in this case possibly due to the action of carnivores (Villa and Mahieu, 1991). Specifically, 9 fragments (25.72% of the sample) displayed V helical fractures, including 8 samples with fractures confined to the shaft, 2 PES with fractures extending into the epiphysis, and 22 SDE with fractures extending into the epiphysis. Lastly, among the 16 diaphyseal cylinders examined in this work, only 9 showed distinct green fracture characteristics, but they are typically of short length (see Figure 9. A and 9. B).

Figure 9. A: Examples of fractures on long bones; B: Examples of shaft cylinders of long bones

4.4 Damage on bone surface

4.4.1 Burning

Regarding anthropogenic factors, no bones exhibited cutmarks. However, evidence of burning was found on 5 specimens (0.21%), varying in degree as shown in Figure 10. The majority showed low grades of burning, with 38 remains classified as one in grade 2, three in grade 3 and one as grade 4. Notably, half carbonized bones (1 remain in grade2) and fully carbonized bones (one in grade 3), and half calcined (one in grade 4).

Figure 10. Burning grade on bone (femur with grade 2, phalange with grade 3 and rib with grade 4)

4.4.2 Modifications generated by carnivores

Furrowing marks on the edges were also identified in 198 specimens (Figure 11), the most represented furrowing included innominate (19.20%), tibia (12.62%), mandible (10.10%), phalange (5.55%), femur (5.05%), the other was humeri, cranium, metatarsals, metacarpals, radii, ribs, scapulae, and ulnae.

Figure 11. Showing carnivore ravaging. A: Punctures and furrowing on innominate. B: Furrowing on mandible body.

4.4.2.1 Tooth marks

Tooth marks were observed in 153 remains (6.21% of NISP). The most common form of damage was pits (54.24%) and punctures (51.63%), followed by scores (7.84%). These marks were observed in all elements (e.g., mandibles, tibia, innominate, femur, humerus, calcaneus, etc.). Pits and punctures were noted on humerus (11), femur (8), radius (11), ulna (4), innominate (27), scapula (8), tibia (6), vertebrae (6), calcaneus (12), metacarpals (4), phalanges (13), mandibles (11), astragalus (2), ribs (5). On long bones, these marks were primarily located near the proximal and distal ends (73.68%) and along the shaft (26.32%); on mandible the tooth marks mostly represented on the mandible body (81.82%); on the innominate under the acetabulum (11.11%), ischium surface (48.15%) and the ilium surface (40.71%). Many of these marks are evidently linked to carnivore activity, indicated by the presence of gnawing damage, multiple punctures, pits also imprint on the same specimen (Figure 11. A and Figure 12) and their specific locations on the bones (Andrés et al., 2012; Conybeare and Haynes, 1984).

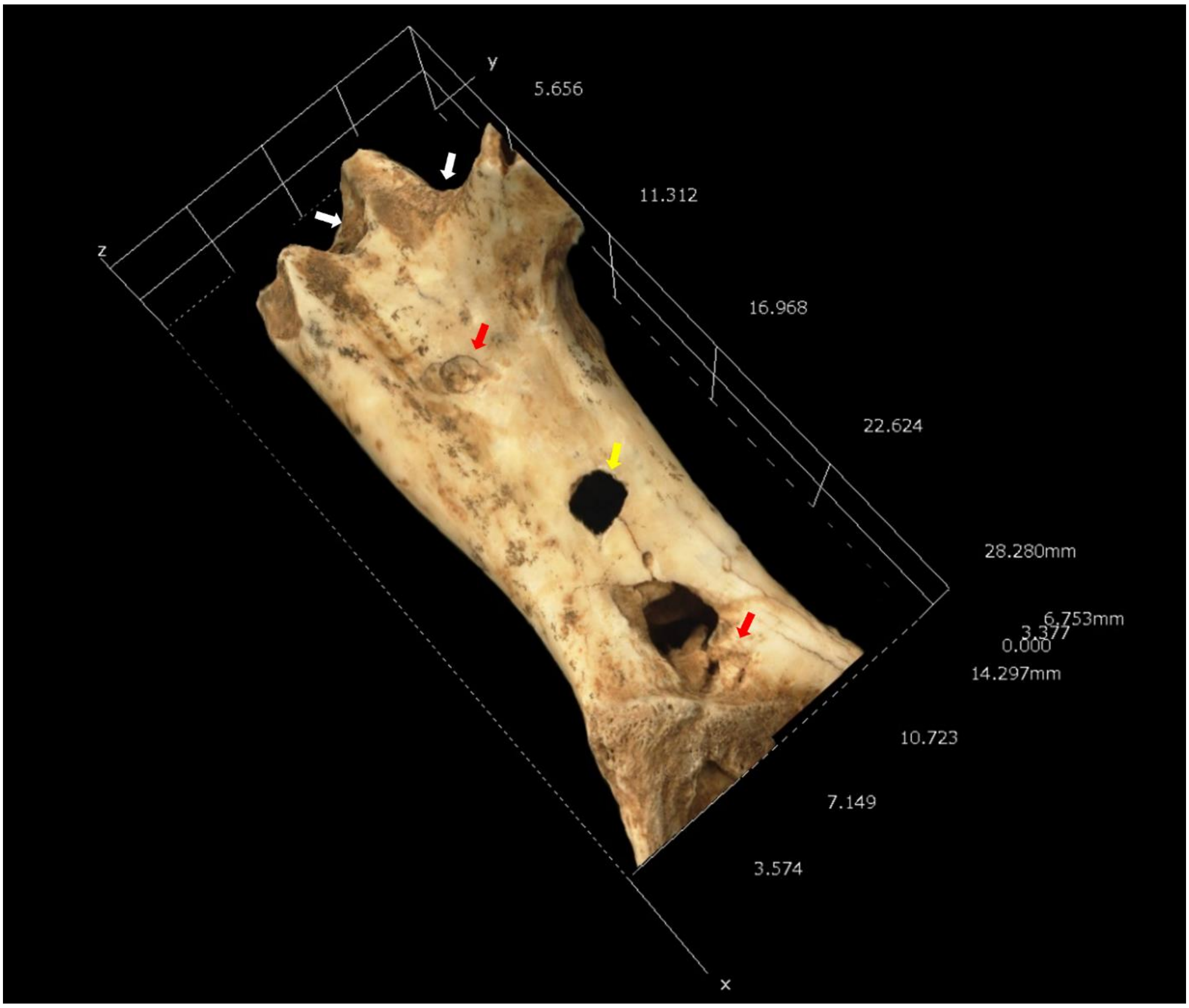

Figure 12. Innominate showing puncture (yellow arrow), imprints (red arrows) and furrowing (white arrows)

Score marks were also recorded in 12 specimens, accounting for 0.50% of the total sample. These marks were observed on a range of bones, including metatarsals, innominate bones, ulnae, femora, and calcanei (Figure 13). The distribution of these score marks appeared across different bone types and location (portion) on bones.

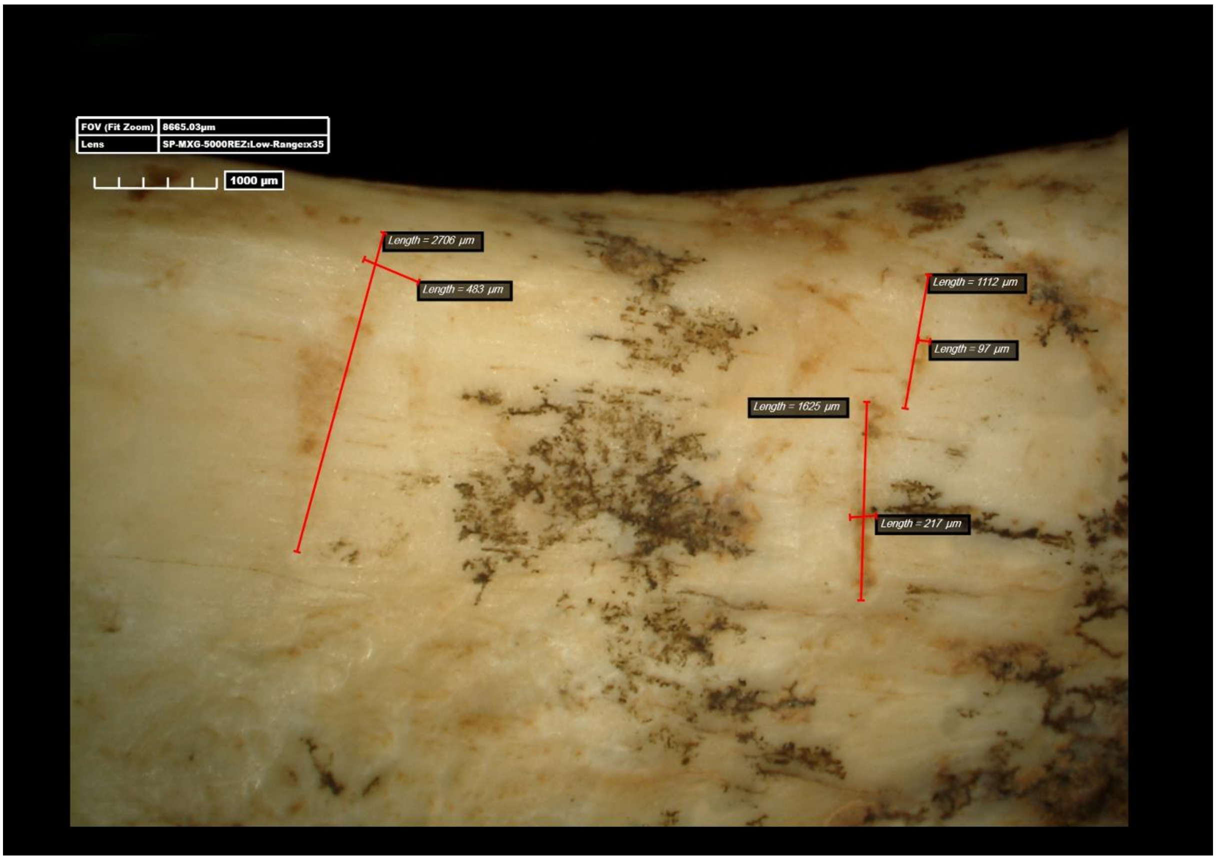

Figure 13. Score marks on innominate

The dimensions of pits and punctures, as well as scores, are detailed in Table 11 and Figure 14. On compact bone, the average size of pits and punctures is 1.46 (SD 0.69) in length and 1.17 (SD 0.63) in width, whereas on cancellous bone, the measurements are 2.21 (SD 1.42) in length and 1.68 (SD 1.02) in width. Regarding scores, the mean width is 1.76 (SD 0.11) on compact tissue and 2.35 (SD 1.09) on cancellous tissue.

Table 11. Descriptive statistics for the measurements (length and breadth) of the tooth marks (pits and punctures/scores) on different bone tissue (compact and cancellous) from leporid remains. Abbreviations: SD= standard deviation, CI= confidence interval.

Toth marks mesures (mm) on leporids	N	Min.	Max.	mean	SD	CI -95%	CI 95%
Length pit and puncture on compact bone	30	0.27	3.33	1.46	0.69	1.21	1.72
Breath pit and puncture on compact bone	30	0.18	3.33	1.17	0.63	0.93	1.40
Length pit and puncture on cancellous bone	63	0.18	7.55	2.21	1.42	1.86	2.56
Breath pit and puncture on cancellous bone	63	0.16	5.14	1.68	1.02	1.43	1.94
Length score on compact bone	2	1.68	1.84	1.76	0.11	0.75	2.78
Breath score on compact bone	2	0.79	1.21	1.00	0.30	-1.66	3.66

Length score on cancellous bone	13	0.86	3.55	2.35	1.09	1.69	3.01
Breath score on cancellous bone	13	0.10	2.14	0.73	0.68	0.32	1.14

To determine the primary accumulators of these bone assemblages, we compared the measurements of the tooth marks with data from both actualistic and archaeopaleontological studies. This comparative analysis drew upon actualistic research (Rodríguez-Hidalgo et al., 2013, 2015) and archaeological research of leporid remains from the same site (Unit 3) of Gabucio et al. (2024) by aligning the dimensions (in millimetres) and patterns of the observed tooth marks with those documented in these studies (Figure 14).

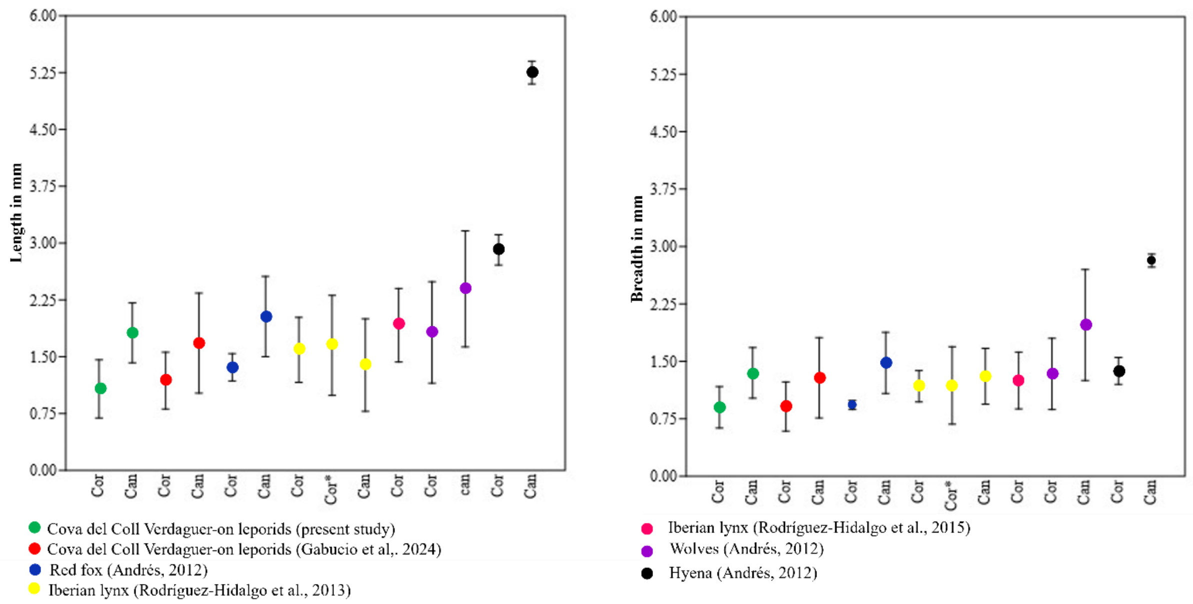

Figure 14. Comparisons of pit and puncture measurements (length and breadth in mm) caused by different carnivores. Mean and SD of the dimensions by tissue type (cortical and cancellous bone) of pits and punctures on leporids from Cova del Coll Verdaguer Unit 2, compared with pits and punctures on leporids from the Unit 3) of the same site (Gabucio et al., 2024), actualistic tooth marks generated by red fox (Andrés et al., 2012), and by lynx on leporid bones (Rodríguez-Hidalgo et al., 2013; Rodríguez-Hidalgo et al., 2015). Cor: cortical bone; Cor*: thin cortical bone; Can: cancellous bone.

Illustrations of tooth marks on leporid remains are depicted in Figures 15.A and 15.B which displayed the morphology of the tooth marks (puncture and pit) present on bone surface of different bone types.

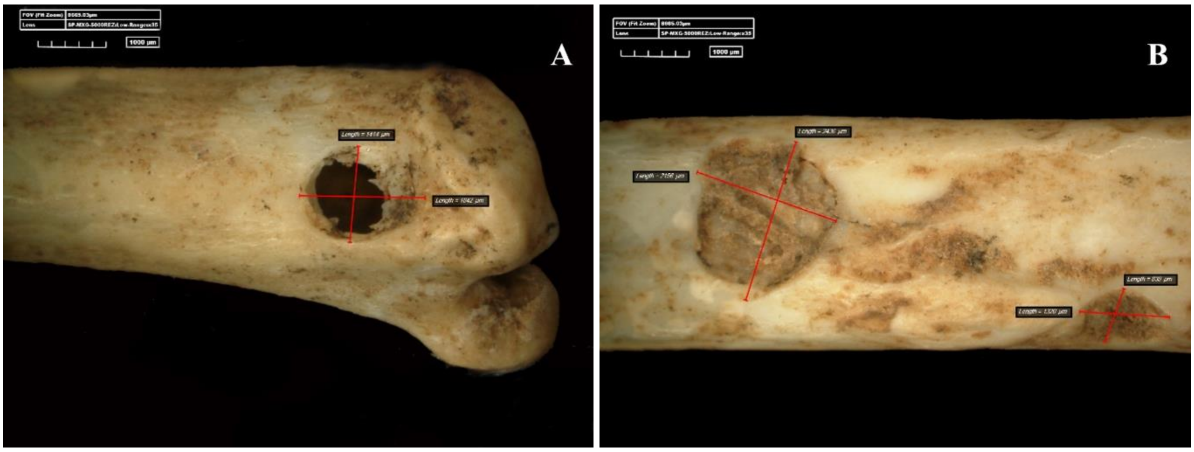

Figure 15. A: Puncture on phalange I; B: Pits on radius

4.4.1.2 Digestion

Digestion evidence was identified in 366 specimens, accounting for 15.12% of the assemblage (Figure.16), predominantly at a low degree (310 in grade 1 and 41 in grade 2), with a few remains exhibiting more severe digestion signs (13 in grade 3 and 2 in grade 4). In absolute terms, the skeletal elements most frequently showing this alteration were phalanges, metatarsals and calcaneum (61, 47 and 34 instances, representing 16.67%, 12.84% and 9,34 % of the NISP for these digested elements, respectively), regarding the degree of the digestion among those element, metatarsals and phalanges represented 91.50% and 85.25 as low grades as while calcaneum represent the grade 2 and 3 in 61.71%. In relative terms, the vertebra remains (7.65%), followed by the humerus (5.74%), metacarpals (4.37%), innominate (3.83%), and mandible (3.83%).

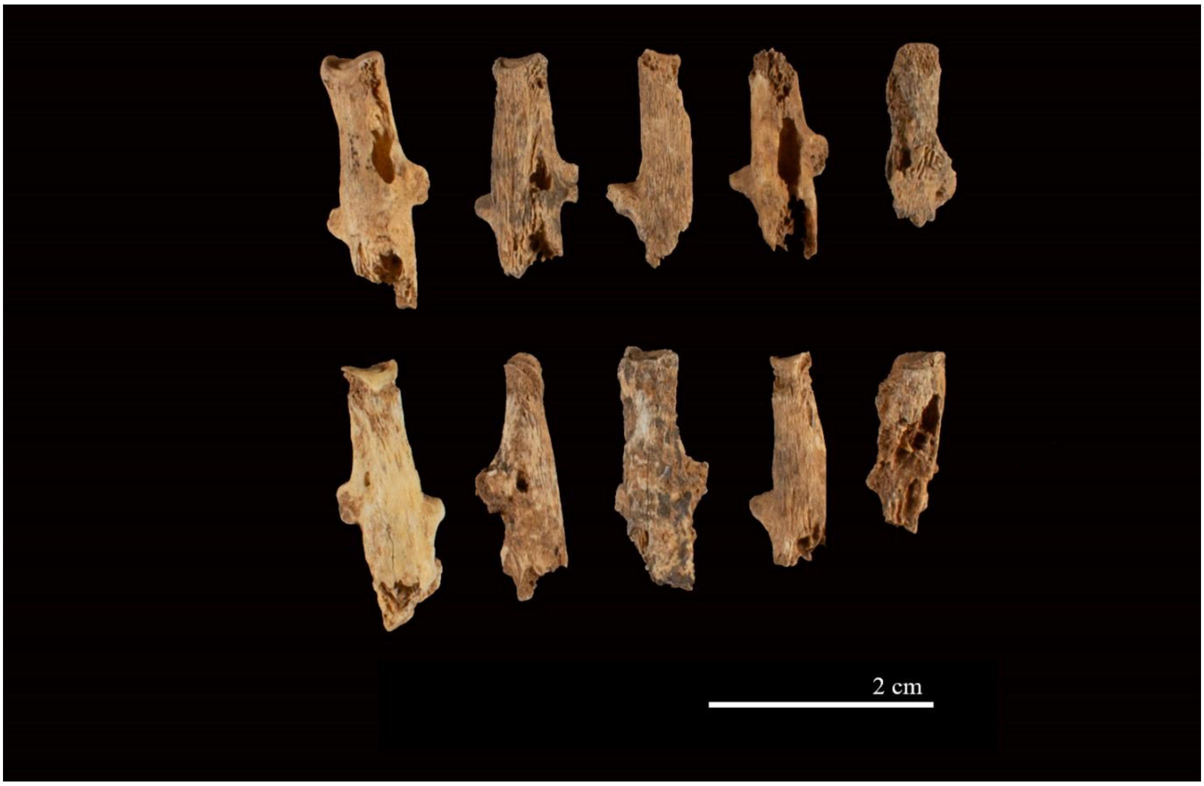

Figure 16. Some calcaneus showing different digestion grades.

4.4.3 geological alterations

Other biological alterations and also geological influences on the leporid assemblage were examined in detail. Among biological agents, the activity of plant roots was scarce. Vermiculation was observed 2.52% of the remains by representing the grooves an/or channel in irregular marks in warm-like, some of them appeared below the concretion spot and manganese which attached on the surface on bones. The rodents were noted, albeit infrequently, specifically in three remains (0.12%) (Figure 17. B) which were identified on two metatarsals, and one radius.

There were three specimens displaying corrosion, and/or staining attributable the bacteria corrosion (Figure 17. A) also possibly related to plant activity.

Figure 17. A: Bacteria corrosion on humerus; B: Rodent marks on metatarsal

Trampling marks on bones were identified in 12 specimens, representing 0.5% of the total sample. Among these, some remains were examined using an optical microscope, as illustrated in Figure 18. However, for more precise identification and differentiation of these marks from cut marks, we employed a confocal microscope.

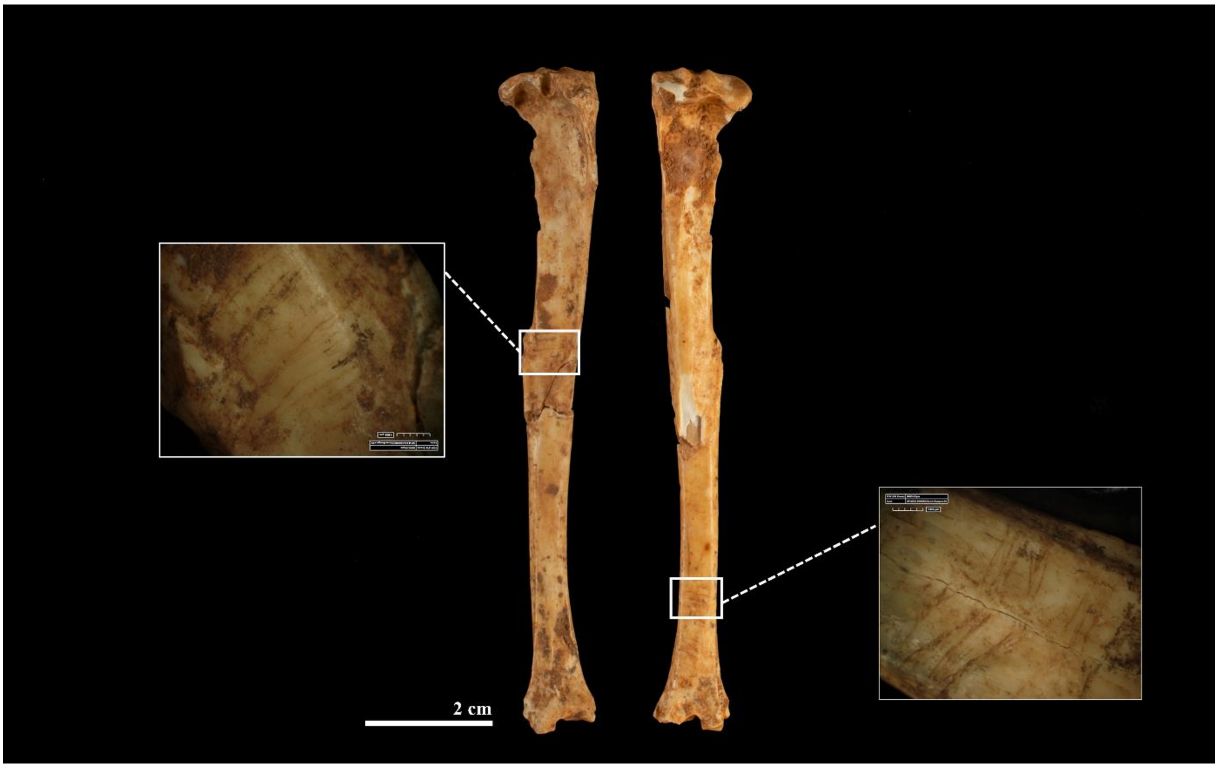

Figure 18. Trampling marks on tibia observed by stereo microscope

Advanced imaging technique from confocal microscope (Figure. 19) allowed us to distinguish finer details and confirm the nature of the marks. Notably, three specimens exhibited trampling marks that closely resembled cut marks, as shown in Figure 19. This detailed analysis underscores the importance of using high-resolution microscopy to accurately interpret the taphonomic processes affecting bone surfaces.

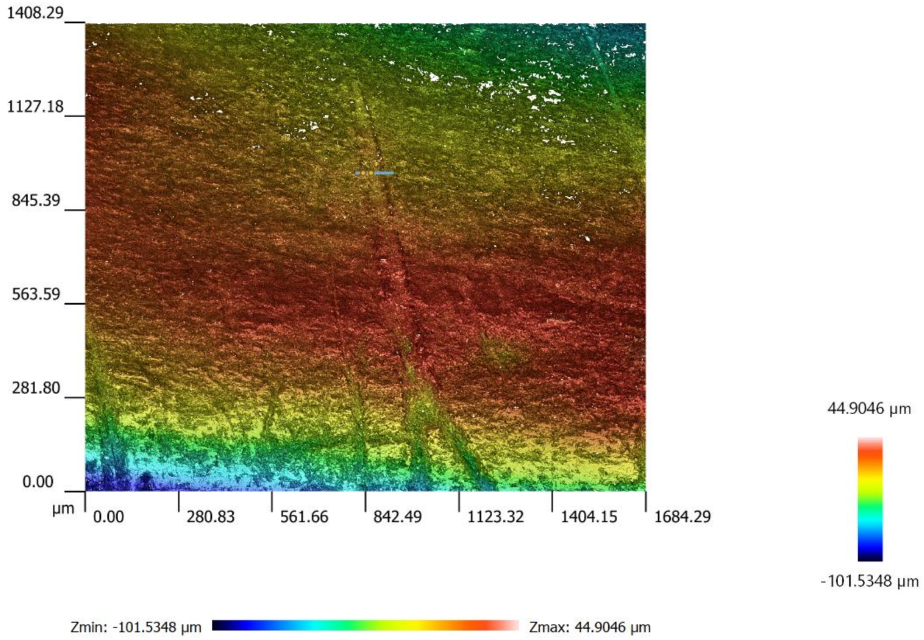

Figure 19. Trampling marks on metatarsal observed by Sensofar S-Neox 3D Optical Profiler (SSN09000) confocal microscope.

The confocal microscope with high-resolution capabilities, the detailed measurements on trampling marks was obtained (Figure. 20), by the image, it is enhancing our understanding and differentiated this alteration from the cut marks by observing the profile section of the trampling.

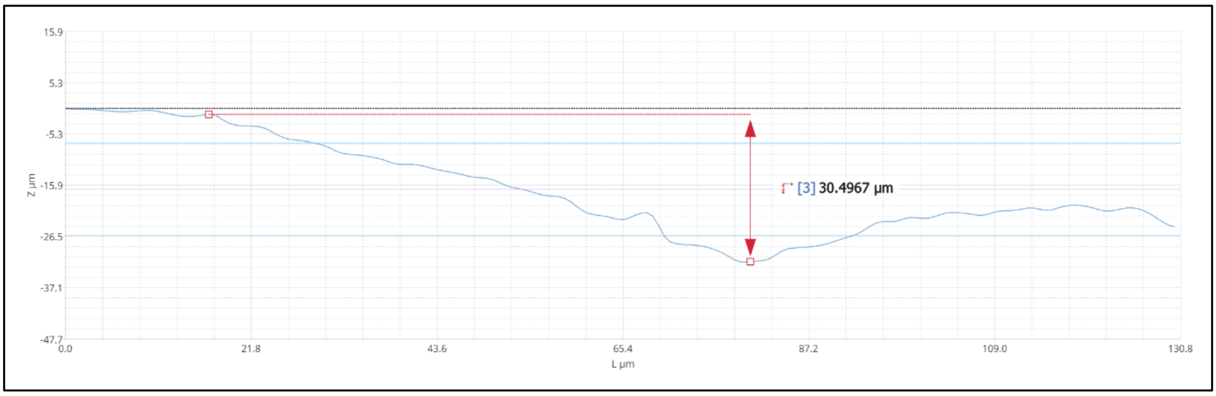

Figure 20. Profile of the section of trampling mark that was measure on confocal microscope

The most common geological alterations observed in the leporid remains are concretion, affecting 1,782 specimens (73.60%) (Figure 21: A-B); manganese oxide pigmentation, found on 1,768 specimens (73.02%); and abrasion, present on 1,010 specimens (41.71%). However, these alterations were generally minimal, with manganese oxide pigmentation appearing as isolated spots on 77.28% of the affected bones, concretion covering 74.51%, and abrasion affecting a similarly limited portion of the bone surfaces.

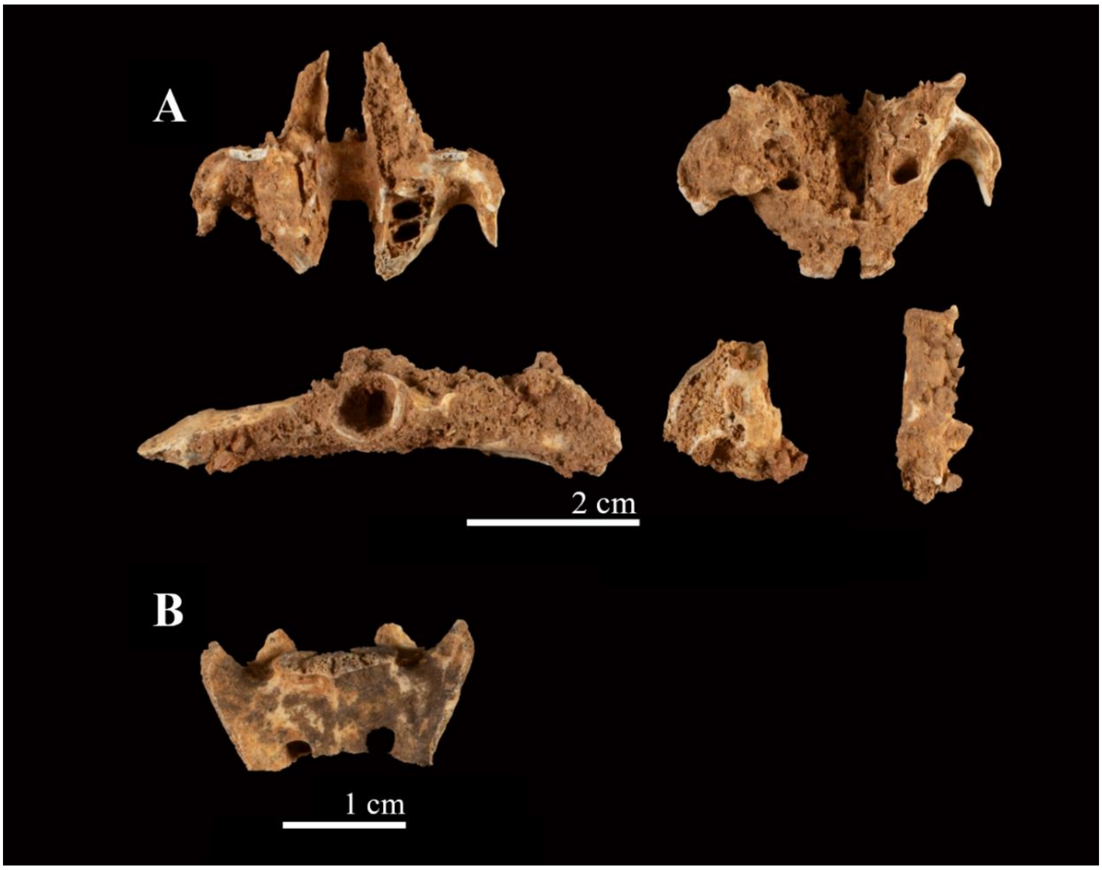

Figure 21. A: Generalized concretion on bones (maxillae, innominate, tibia, and calcaneus). B: Manganese oxide pigmentation (on sacrum).

In summary, table 12 displays the leporid remains in Unit 2 were subject to both biological and geological alterations. These modifications were distributed across the specimens, with some exhibiting significant changes from both types of alterations, while others showed only one type of alteration—either biological or geological. The extent and nature of these alterations varied, highlighting the complex taphonomic history of the remains.

Table 12. Main taphonomic modifications identified on leporid remains from Unit 2 (modified by NISP include isolated teeth).

Unit 2 Taphonomic modifications		Leporidae	
		NISP	%
Biological modifications	Crenulated edges	9	0.37
	Furrows	198	8.18
	Pits	83	3.43
	Punctures	79	3,26
	Imprints	6	0,25
	Scores	12	0,50
	Digested remains	366	15.12
	Rodent marks	3	0.12
	Plant activity	8	0.03
	Burning	5	0.21
Geological modifications	Weathering	0	0.00
	Abrasion	1010	41.71
	Manganese oxide pigmentation	1768	73.02
	Dissolution	55	2.27
	Concretion	1782	73.60

5. Discussion

The analysis of the leporid remains from Unit 2 offers valuable insights into the zooarchaeoogical and taphonomic representation of these animals within the assemblage. A total of 2421 leporid remains were analysed, providing a substantial dataset for interpreting their skeletal representation and their taphonomic alterations, which aims to identify the main predator responsible for their accumulation considering the presence of raptors, carnivores and occasional human incursions in the cave (Sanz et al., 2016).

5.1 Zooarchaeological criteria

A thorough analysis of leporid remains shows a significant predominance of cranial elements, especially isolated teeth, in terms of NISP (Number of Identified Specimens) while NME (Minimum Number of Elements) indicated phalanges were the most represented. Metatarsals are also prominently represented in both NISP and NME counts. However, when using %RA (Percentage of Relative Abundance), which accounts for the frequency of each element within a carcass, isolated teeth are succeeded by the innominate, calcaneum, and metatarsals as the most abundant elements. Consequently, this indicates that the representation of bones reflects the relative abundance and frequency of these elements in the analysed remains. The relative abundance of different skeletal elements, as detailed in Table 7, offers a nuanced view of the anatomical composition of the assemblage. By comparing cranial versus postcranial elements and long bones versus smaller fragments, the study highlights distinct preservation and representation patterns.

This pattern is consistent with previously recorded Pleistocene small mammals assemblages where these elements appear more frequently due to their durability and relative resistance to taphonomic processes and the possibly accumulated in greater quantities compared to other elements (Schmitt and Juell, 1994; Lloveras et al., 2008). Long bones, such as the humerus, ulna, and femur, are also well-represented in the assemblage, conversely, smaller bones such as carpal and tarsal fragments, and axial skeleton are notably scarce. This pattern can be attributed to a preferential consumption of long bones in detriment of small articular bones, as observed, for instance, in felid accumulations (Haynes, 1980; Hockett and Bicho, 2000; Lloveras et al., 2018). The anatomical pattern observed at Unit 2 is similar to other assemblages previously analysed, suggesting accumulation by small or medium carnivore mammals (Lloveras et al., 2008, 2014; Rodríguez-Hidalgo et al., 2020; Gabucio et al., 2024). The anatomical representation of the leporid assemblage from Unit 2 could also fit with the predator behavior of some raptors. However, the presence in Unit 2 of medium-sized terrestrial carnivore taxa (NMI= 1 adult for *Felis silvestris* and *Vulpes vulpes*, and NMI= 2 adult for *Lynx pardinus* (Gabucio, com. pers.), and coprolites probably generated by these animals (Sanz et al., 2016) suggests that terrestrial carnivores are a more probable accumulator agent than raptors.

The age distribution analysis, based on the fusion pattern of tibias, humerus, ulnae, and radius, indicates the presence of various life stages. Specifically, the assemblage includes perinatal (<3 months, MNI = 8), infantile (3–5 months, MNI = 3), juvenile or adult (5-9 months, MNI = 25), juvenile (5-9 months, MNI =1), and adult (>9 months, MNI = 3) individual. The predominance of adult and juvenile individuals (5-9 months) suggests that this age group was the most frequently present. This can be related to the age preference observed in extant Iberian lynxes when hunting leporids (Lloveras et al., 2012). In fact, terrestrial carnivores focus on adult leporid individuals (Lloveras et al., 2012; Rodríguez-Hidalgo et al., 2013). Adult and/or juvenile individuals are followed by perinatal individuals. The abundance of perinatal individuals is usually linked to natural death inside their barrows, in which case they would preserve in anatomically connected remains (Pavao and Stahl, 1999). However, in these cases, adult individuals were represented in low numbers.

In conclusion, it seems that leporid remains from Unit 2 predominantly feature post-cranial elements, phalanges and metatarsals according to MNE. While isolated teeth are most common when measured by NISP, %RA shows innominate, calcaneum, and metatarsals as the most abundant. This pattern aligns with the preservation of durable elements seen in other Pleistocene assemblages and suggests accumulation by medium-sized terrestrial carnivores, rather than raptors. Age distribution indicates a predominance of adult and juvenile individuals, consistent with the hunting preferences of extant carnivores.

5.2 Taphonomic criteria

The leporid remains from Unit 2 show that 25.92% (NISP=628) are complete, and when nearly complete elements are included, this figure rises to 35.61% (NISP=862). The completeness is notably high in post-cranial bones, particularly phalanges and articular bones (carpals, tarsals, and patellae). This fact suggests an accumulation of leporid by medium-sized predators, specifically lynxes (Javier and Palomares, 1996). This phenomenon is likely because lynxes typically do not eat the rabbit’s hind feet, which often remain intact and are left with the leporid’s skin still attached (Javier and Palomares, 1996). A similar pattern has been observed in coyotes and foxes when prey is plentiful (Schmitt and Juell, 1994; Lloveras et al., 2012).

Small bones such as carpals and tarsals exhibit the highest completeness rates, with phalanges showing an impressive 84.47% completeness. In contrast, the cranium displays significant breakage, with fragments from the maxilla, zygomatic arch, incisive bone, and neurocranium. Mandibles are mainly represented by body and incisive fragments, with some condylar process fragments. Isolated teeth are mostly fragmented, with 89.85% being fragmented and only 10.15% complete. Vertebrae fragments mainly include the vertebral body and epiphysis, while ribs are nearly all fragmented. Among innominate bones, large fragments of the acetabulum, ischium, and ilium are the most common, with ilium pieces being the most prevalent among smaller fragments. Scapulae are often incomplete, predominantly comprising glenoid cavity fragments. Limb bones are found across all breakage categories. While stylopodium and zygopodium are usually fragmented, autopodium are frequently complete. The calcaneus and astragalus exhibit high preservation rates, with 52.94% and 70.59% nearly complete, respectively.

Analysis of fracture patterns in long bones like the humerus, femur, and tibia reveals that many fractures occur along the shaft, with a significant portion spanning the entire circumference. The most common fracture types are curved, oblique, and soft fractures, indicating both fresh and dry breakage, likely due to carnivore activity (Villa and Mahieu, 1991). V-helical fractures constitute 25.72% of the sample, with some extending into the epiphysis. Out of 16 diaphyseal cylinders examined, 9 exhibit distinct green fractures, suggesting fresh breakage. Overall, the varied preservation and breakage patterns underscore significant taphonomic processes and provide insights into the formation and context of the archaeological site.

Tooth marks were present in 153 remains, accounting for 6.21% of the total NISP. The predominant types of damage were pits (54.24%) and punctures (51.63%), with scores being less common (7.84%). These marks were identified on various skeletal elements including mandibles, tibiae, innominates, femora, humeri, calcanei, and others. Regarding, pits and punctures, in long bones, tooth marks were predominantly located near the proximal and distal ends (73.68%) and, to a lesser extent, along the shaft (26.32%). The presence and distribution of these marks align with established carnivore behaviours (Andrés et al., 2012; Haynes, 1983). For mandibles, marks were concentrated on the mandible body (81.82%). On the innominate bones, marks were found under the acetabulum (11.11%), on the ischium surface (48.15%), and on the ilium surface (40.71%). The presence of those marks is comparable with those from Unit 3 within the same site and actualistic studies that suggested the accumulation by the lynxes and/or foxes (Lloveras et al., 2012; Rodríguez-Hidalgo et al., 2013, 2020a; Gabucio et al., 2024).

The nature of these tooth marks is therefore consistent with carnivore activity. Some remains of Unit 2 show gnawing damage and repeated punctures and pits on the same bones, typical of fox accumulated assemblages (Lloveras et al., 2012; Rodríguez-Hidalgo et al., 2020). Additionally, furrowing marks were identified in 198 specimens, with the highest frequency on innominates (19.20%), tibias (12.62%), mandibles (10.10%), phalanges (5.55%), and femur (5.05%). A modification further observed on humerus, crania, metatarsals, metacarpals, radius, ribs, scapulae, and ulnae (see Figure. 11). These furrows further corroborate the extensive activity of carnivores and are compatible with the activity of lynxes and foxes (Lloveras et al., 2012; Rodríguez-Hidalgo et al., 2013, 2020a; Gabucio et al., 2024).

The examining variations in tooth mark shape and size could differentiate between carnivores like felids and hyenids by analysing marks on various bone types (Selvaggio and Wilder, 2001), and also human-made tooth marks can be distinguished (Fernández-Jalvo and Andrews, 2011). Tooth mark sizes vary depending on the bone type and can be classified into small, mixed, and large categories (Andrews and Jalvo, 1997). The employment of statistical analyses to correlate tooth mark sizes with carnivore sizes, indicating that each carnivore type produces a limited range of tooth mark sizes. The dimensions of tooth marks measurement are detailed in Table 11 and Figure 14 as well as the illustration of the morphology of tooth marks in Figure. 15: A and B. These measurements are consistent with known carnivore tooth marks corresponding to the range of lynx and fox (Andrés et al., 2012; Rodríguez-Hidalgo et al., 2013; Gabucio et al., 2024), as seen in figure 11. Some outliers, indicate larger tooth marks, possibly representing a different carnivore species with large teeth so in the case of leporid remains from Unit 2 is not the case. When compared to the leporid assemblage from Unit 3, the minimum length and breadth is observed to be smaller (Gabucio et al., 2024; ML = 0.50; MW = 0.30 / present study; ML = 0.30; MW = 0.20). This fact could be attributed to the activity of cubs of medium-size carnivores as observed in Rodriguez-Hidalgo et al. (2020) which displayed the same minimum length and breadth as this study (ML = 0.30; MW = 0.20). However, no sub-adult remains of these carnivores have been recovered from unit 2 (Sanz and Daura, 2018; Gabucio com. pers.).

Digestion marks were found in 366 specimens, making up 15.12% of the total assemblage (Figure. 16). Most of these specimens exhibited low degree of digestion (grade 1), only a small number of specimens showed high degree of digestion (grade 3 and 4). Hence, the accumulation by raptors can be discarded while reinforcing the medium size carnivores as the main responsible for the accumulation, characterized by slightly digested bone assemblages (Lloveras et al., 2012; Rodríguez-Hidalgo et al., 2013). The presence of meso-carnivore coprolites containing leporid remains in Cova del Coll Verdaguer support this hypothesis (Sanz et al., 2016).

Since no cut marks were identified on the bones, direct human defleshing was not a significant factor in the modification of these bones. However, evidence of burning was observed on 5 specimens (0.21% of the assemblage), with varying degrees of thermal alteration (Figure. 10). The majority of these burned bones exhibited fully carbonized, with grade 3 (*n* = 3), although one displayed localized calcination (grade 4) and one was lightly burned (grade 2). The limited evidence of anthropogenic modifications suggests that natural processes are the most likely causes to explain the leporid accumulation. Although human activity could be responsible for these alterations, there is insufficient evidence to support intentional thermal alteration of leporids, such as through cooking practices. One possibility is that leporid remains were initially accumulated by carnivores, and subsequent thermal alteration could have occurred indirectly from heat sources, such as hearths, in the immediate sedimentary environment (Lloveras et al., 2009). This scenario would be credible in the case of Cova del Coll Verdaguer, where sporadic visits by Neanderthals have been documented.

The analysis of breakage patterns, tooth marks, furrowing, digestion evidence, and anthropogenic modifications provides a nuanced view of the taphonomic history of the leporid remains from Unit 2. The predominant role of carnivores, as indicated by tooth marks and furrowing, and the observed patterns of digestion, offer insights into the natural processes that influenced the accumulation and modification of these remains. However, we cannot rule out the possibility of leporid bones occasionally accumulated by other agents such as raptors and natural death inside the burrows themselves. The minimal anthropogenic impact, as evidenced by the absence of cutmarks and limited burning, highlights the primary role of natural agents in shaping the assemblage.

The post-depositional modifications observed in the leporid assemblage from Unit 2 provide valuable insights into the various biological and geological processes that have influenced the skeletal remains. These alterations reflect both natural and environmental factors that have shaped the assemblage over time. Among biological agents, plant root activity was noted as scarce, affecting only a few specimens. Specifically, this was observed in three remains (0.12%), including two metatarsals and one radius. The limited impact of plant roots on the assemblage suggests that root activity was not a major factor in modifying these remains, this could be due to the low light levels inside the cave, which might have restricted plant growth and, consequently, root penetration (Daura et al., 2017). Rodent activity was infrequently observed, affecting only three remains (two metatarsals and one radius). This activity, though present, represents a minor component of the taphonomic history of the assemblage. The low frequency of rodent-induced alterations further supports the notion that other factors played a more significant role in accumulating and modifying the remains. Sixty specimens exhibited signs of corrosion, and three specimens of staining attributable to chemical corrosion. These alterations indicate that chemical processes contributed to the modification of a small proportion of the remains. Chemical corrosion can significantly affect bone preservation, but in this assemblage, its impact appears to be relatively limited. Trampling was observed in 12 specimens (0.5%), with some evidence detectable through optical microscopy and others through confocal microscopy. The trampling marks, particularly those resembling cut marks, highlight the complex nature of post-depositional processes affecting the bones. The presence of trampling evidence suggests that the remains experienced very few mechanical disturbances, possibly due to animal activity or environmental factors (Behrensmeyer et al., 1986; Madgwick and Mulville, 2015).

Geological alterations included concretion, impacting 1,782 specimens (73.60%) (Table 12 and Figure. 21: A and B). Manganese oxide pigmentation, which was also prevalent, affected 1,768 specimens (73.02%), but it should be noted that 1,449 specimens represented only isolated manganese stains. Manganese oxide pigmentation likely results from soil and sediment interactions, while concretion reflects mineral deposition around the bones. These alterations are indicative of geological and chemical processes influencing the bones. The high frequency of these alterations suggests that the leporid remains were exposed to conditions conducive to manganese staining and mineralization, related to humidity conditions, which significantly impacted their preservation (Fernandez-Jalvo and Andrews, 2016; López-González et al., 2006). Abrasion was observed on leporid specimens (41.71%), primarily characterized by low-grade wear affecting small areas of bone surfaces. This pattern suggests limited exposure to mechanical disturbances, such as sediment movement, trampling, or water flow (Behrensmeyer, 1978b). Dissolution was less common but still notable, affecting 60 specimens (2.48%). These findings highlight the diverse range of biological and geological processes influencing the preservation and alteration of the leporid remains (de Ruiter and Berger, 2000; Hockett and Haws, 2002).

In summary, post-depositional modifications observed in the leporid assemblage from Unit 2 reveal a complex interplay of biological and geological factors influencing bone preservation. The limited impact of plant roots and rodent activity, coupled with the presence of chemical corrosion and trampling, indicates a range of natural processes affecting the assemblage. The predominant alterations, manganese oxide pigmentation and concretion are similar to those observed in the Leporidae remains of Unit 3 and the macrofaunal assemblage of the entire Sala Sal del Llop chamber. These alterations reflect significant geological influences on the remains and are equivalent to the recording in the previous investigation carried out in Cova del Coll Verdaguer (Sanz and Daura, 2018). In particular, the manganese oxide pigmentation in Unit 2 is more prevalent compared to Unit 3; however, it is important to note that most remains show only minimal degrees of affectation. This means that while pigmentation is present, it does not uniformly impact all specimens to the same extent. The degree of alteration across the assemblage suggests that geological processes have similarly influenced the preservation of leporid remains in both units, reinforcing the consistency of environmental and geological factors affecting the Sala Sal del Llop chamber. These findings contribute to a nuanced understanding of the taphonomic history of the leporid assemblage and provide critical context for interpreting the preservation and modification of the remains.

6. Conclusion

The study of leporid remains from Unit 2 has yielded critical insights into the zooarchaeological and taphonomic dynamics affecting these specimens. Analysing a total of 2,421 leporid bones has provided a comprehensive view of their skeletal representation and the taphonomic processes they have undergone. The data reveal a distinct predominance of cranial elements, notably isolated teeth regarding NISP, while phalanges and metatarsals prominent in the Number of Minimum Elements (NME). However, when considering the Relative Abundance (%RA), which accounts for the repetition of elements within a carcass, innominate, calcaneum, and metatarsals (in addition to isolated teeth) highlight in terms of abundance.

This anatomical distribution reflects patterns observed in other Pleistocene small mammal assemblages, where teeth and post-cranial elements are more frequently preserved due to their structural durability. The scarcity of smaller bones such as carpal and tarsal fragments and axial elements can be attributed to their preferential consumption by carnivores, similar to patterns seen in felid accumulations. The anatomical profile of Unit 2 aligns with previously analysed assemblages, suggesting that small to medium-sized carnivores are the primary agents of accumulation. The presence of medium-sized terrestrial carnivores, including lynxes, and foxes as indicated by both the bone assemblage and coprolites, further supports this hypothesis.

The age distribution analysis reveals that the assemblage includes a range of life stages: perinatal, infantile, juvenile, and adult individuals. The predominance of adult and juvenile individuals, particularly those aged 5-9 months, suggests a bias toward these age groups, which aligns with the hunting preferences of modern Iberian lynxes. This preference for certain age groups is consistent with observed predation patterns where adult and juvenile individuals are more commonly targeted. Additionally, the relatively high number of perinatal individuals (aged less than 3 months) could be related to natural deaths occurring in the burrows, which might have contributed to their presence in the assemblage.

Taphonomic analysis highlights several key features of the remains. Notably, 25.93% of the bones are complete, and when including nearly complete elements, the figure rises to 35.81%. This high degree of completeness, especially in post-cranial bones like phalanges and articular bones, fits with an accumulation by medium-sized predators such as lynxes. This pattern is consistent with observations of lynxes and other carnivores that often leave certain bone elements intact. The presence of tooth marks, predominantly pits and punctures, their measures and their location further support this interpretation, aligning with known behaviours of carnivores such as lynxes and foxes. The analysis of breakage patterns reveals that many fractures are curved, oblique, or soft, indicative of both fresh and dry breakage likely resulting from carnivore activity. The examination of furrowing marks, tooth damage, and digestion evidence reinforces the role of carnivores in shaping the assemblage. The absence of cut marks and minimal evidence of burning suggest limited human impact, with any thermal alterations likely resulting from unintentional and subsequent contact with a heat source, rather than direct human activity.

The post-depositional modifications observed in Unit 2 are primarily influenced by geological factors, with a significant presence of manganese oxide pigmentation and concretion affecting a large number of specimens. These alterations are indicative of the humidity conditions typical of karstic environments, such as those found in Cova del Coll Verdaguer. This suggests that soil and sediment interactions, driven by these humid conditions, played a crucial role in bone preservation. In contrast, the limited impact of plant roots and rodent activity indicates that biological factors were less significant in this context.

In summary, the taphonomic analysis of leporid remains from Unit 2 provides a detailed understanding of the natural processes affecting these specimens. The predominant role of medium-sized carnivores in accumulation, combined with geological and chemical alterations, offers valuable insights into the formation and context of the assemblage. These findings contribute to a broader understanding of the taphonomic history of leporid remains and underscore the complex interplay of biological and geological factors in shaping archaeological assemblages.

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