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A multiproxy reconstruction of the palaeoenvironment and palaeoclimate of the Late Pleistocene in northeastern Iberia: Cova dels Xaragalls, Vimbodí-Poblet, Paratge Natural de Poblet, Catalonia				
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Abstract

The Cova dels Xaragalls is a small open karst system, located in the municipality of Vimbodí-Poblet (Tarragona, Catalonia, NE Spain). It is an important Holocene archaeological site that was inspected in the 1970s but from which little has been published. New excavations starting in 2008 have exposed a deep Late Pleistocene stratigraphical sequence. In this paper, we present for the first time palaeoenvironmental and palaeoclimatic reconstructions of this Late Pleistocene succession on the basis of both the small-vertebrate assemblages and the charcoals. Results from the small-vertebrate associations along the sequence indicate that the landscape had open-woodland habitats in the vicinity of the Cova del Xaragalls, with wet points in the surrounding area. Woodland habitats were dominant throughout the sequence, as evidenced by the abundance of the species *Apodemus sylvaticus*, but were better developed during warm periods (layers C5 and C8), whereas during cold periods (layers C4 and C3) the environment was slightly more humid in response to higher mean annual precipitation and the opening of the landscape. The charcoal analysis indicates that the woodland surrounding the cave was composed mainly of *Pinus* (more than 90% was identified as *Pinus*), but that during the cold period (C3–C4) it incorporated some *Quercus ilex/coccifera* and *Angiosperm indet.*, probably linked with greater precipitation. Comparisons are made with other long palaeoenvironmental sequences from the northeastern Iberian Peninsula and with global marine isotopic curves, providing a scenario for the palaeoclimatic and palaeoenvironmental changes that occurred during the Late Pleistocene in the woodland areas surrounding the Cova dels Xaragalls.

1. Introduction

There are many studied sites in the Iberian Peninsula relating to the Late Pleistocene. Only a few of them, however, have long sequences yielding small vertebrates that have been investigated. Only four sites in Spain meet these criteria (Fig. 1): the El Portalón site in Atapuerca, Burgos (López-García *et al.* 2010a); the Arbreda cave and the Abric Romaní in Catalonia (Alcalde 1986, 1987; Alcalde & Galobart 2002; López-García 2008; López-García & Cuenca-Bescós 2010; Burjachs *et al.* 2011); and the El Mirón cave in Cantabria (Cuenca-Bescós *et al.* 2008, 2009). The small-vertebrate studies of these long sequences have allowed accurate palaeoenvironmental and palaeoclimatic reconstructions of the Iberian Late Pleistocene for the above-mentioned sites. To these we can now add the eight-layer *in situ* Late Pleistocene sequence of the Cova dels Xaragalls, which contains abundant small-vertebrate faunas, charcoal and a few large-mammal remains. This new site allows us to integrate our study with previously published data in order to increase knowledge about the environmental and climatic conditions of the Late Pleistocene in the Iberian Peninsula. The Cova dels Xaragalls is located in the Poblet forest, a natural reserve that today has a high faunal and floral diversity in a relatively confined space (about 2200 ha). Taking into account the context of small-vertebrate studies in Spain and the background of the Cova dels Xaragalls, the aims of this paper are: (i) to ascertain the floral and faunal composition of the Poblet forest during the Late Pleistocene in order to determine the changes in the forest in the last 60 000 years; and (ii) to reconstruct the palaeoenvironment and palaeoclimate of the Late Pleistocene sequence of the Cova dels Xaragalls by means of the small-vertebrate assemblage and to compare our results with the other sequences from the Iberian Peninsula in order to establish a general view of the changes occurring during Marine Isotope Stage 3 (MIS3) in Spain.

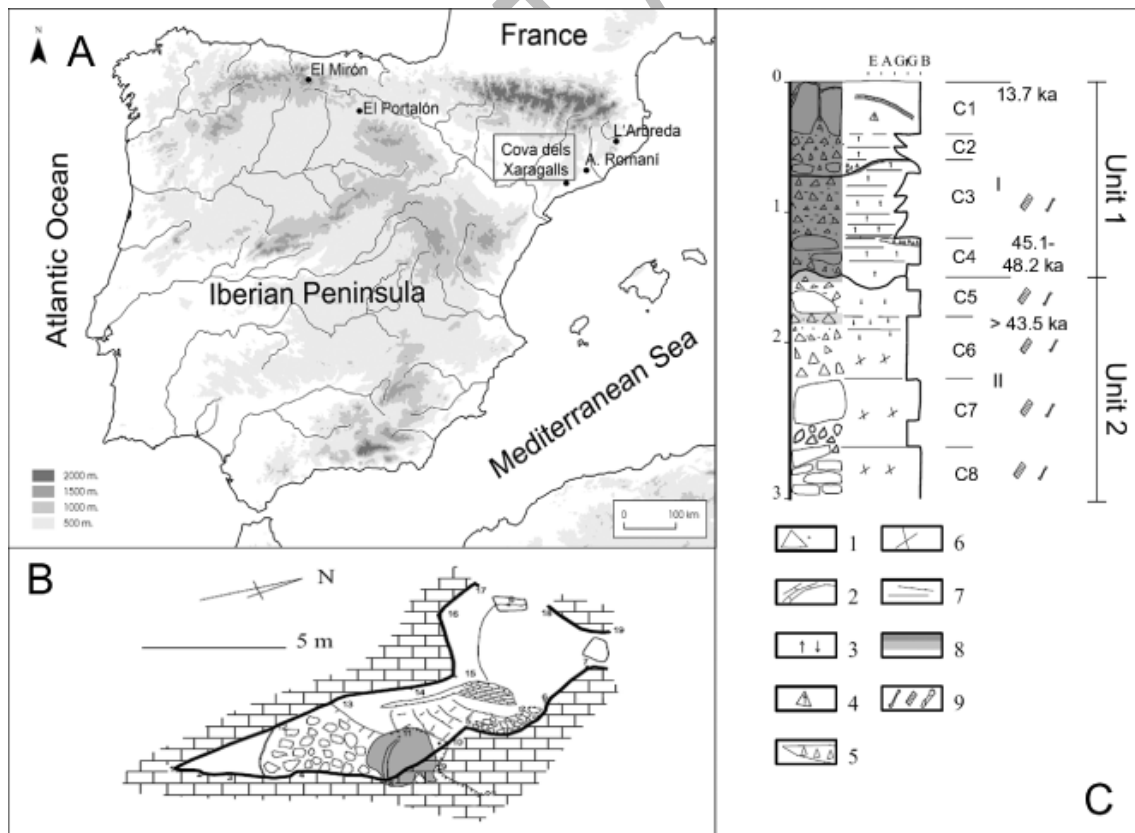


Figure 1.

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A. Location of the Cova dels Xaragalls and the other sites mentioned in this paper in the Iberian Peninsula. B. Topographical map of the Sala Gran of the Cova dels Xaragalls; grey indicates the sampled section. C. Stratigraphy of the sampled section in the Sala Gran of the Cova dels Xaragalls. 1 = angular limestone gravel and sands; 2 = stalagmite; 3 = normal and reverse gradation; 4 = vertical clast; 5 = channel filled with gravel; 6 = massive internal stratification; 7 = horizontal stratification; 8 = filled structure; half-filled and open; 9 = bones and charcoal.

The Cova dels Xaragalls site

Also known by other names, such as 'Nerola', 'Assedegats' and 'Aixeregalls', the Cova dels Xaragalls has been the subject of numerous studies on recent prehistory (Abad & Alonso 1972; Vilaseca 1973; Carreras 2002). Over the years, the site has undergone numerous clandestine excavations, which have destroyed much of the sedimentary deposits inside the cave. There are reports of the discovery of pottery remains (Vilaseca 1973) and other elements that show the occupation of the cave during the Chalcolithic and Bronze Age (Abad & Alonso 1972). Furthermore, the presence of human remains from these periods indicates the practice of burials within the cave (Carreras 2002). Most of these remains were found in the vestibule of the cave.

The Cova dels Xaragalls is a small open karstic system composed of Mesozoic limestone that has been tectonically fractured and folded. Its UTM coordinates are X0337448, Y548127, and it is located in the municipality of Vimbodí-Poblet at 590 m a.s.l. (Fig. 1). The limestone outcrop of the cave is a slip deposit formed by gravity on a slope composed of Palaeozoic shists, constituting an isolated rocky mass (Pujades Ferrer 1985). The cave is located on the right bank of the headwaters of the River Sec. Current access to the cave is through an artificial entrance, and there are two main deposit sequences: at the entrance, only Holocene deposits are found, while in the 'Sala Gran' gallery, at the end of the cave system, is the Pleistocene sequence. Our work has sought to document the findings in the deposits of the 'Sala Gran' (Fig. 1). The 'Sala Gran' is a subhorizontal conduit produced by the phreatic evolution of an extensional plane (Palau & Pallisé 2006). The 'Sala Gran' was apparently discovered by Vilaseca (1973), but there is no evidence of any archaeo-palaeontological remains having been recovered from this survey. Together with sediments entering the cave through fissure openings, the mechanical fragmentation of the walls and ceiling of the cave is the main origin of the sedimentary components that contain the fossil remains from the 'Sala Gran'. In the stratigraphic profile, we identify two sedimentary units (Fig. 1). Unit 1 is composed of gravel and blocks with a clastic support, poorly organized to stratified, and a structure filled with red sandy clays with fossil remains. This unit contains layers C1 to C4. Layers C1 and C2 are sterile, without fossil remains. Layer C1 is a speleothem that covers blocks and semi-filled gravel. Two samples have been obtained from this speleothem, and sample 2 has been dated by the U/Th method to $13\,723 \pm 99$ years. *Pinus*-type *sylvestris* charcoal from layer C4 has been dated by ^{14}C AMS to 45 120–48 240 cal. a BP (UGAMS-8123) (Table 1). Unit 2 is composed of gravel, limestone rocks with clastic support, and lithostratigraphic units with coarsening grains. This unit contains the lithostratigraphic layers C5 to C8. An undetermined charcoal fragment from layer C6 has been dated, providing an age outside the range of the ^{14}C method, which may mean that it is older than 43 500 years (Table 1) (Vallverdú *et al.* [in press](#)).

Table 1. Absolute ages of the outcrop of the Sala Gran of the Cova dels Xaragalls

Laboratory	Sample data	Sample	Method	Age (a)	Comments
Berkley	CX09_L2_C1	Stalagmite	Uranium series	13 723±99	$^{230}\text{Th}/^{234}\text{U}$ 0.1184±0.00080734
UGAMS-8123	CX09_J3_C4	Charcoal (<i>Pinus sylvestris</i>)	^{14}C AMS	43 710±210	45 120-48 240 cal. a BP
Beta-273967	CX09_J4_C6	Undetermined charcoal	^{14}C AMS	>43 500-∞	Low ^{14}C activity

Material and methods

Small-vertebrate sorting and palaeontological study

The small-vertebrate fossil remains used for this study consist mainly of disarticulated bone fragments and isolated teeth collected by water-screening. Sediments were recovered from a surface of approximately 1 m² along the stratigraphic sequence and divided into six samples in accordance with the lithostratigraphy, from level 8 at the bottom to level 3 at the top. All the sediment was water-screened using superimposed 5- and 0.5-mm mesh screens, and bagged by layer. The fossils were processed, sorted and classified at the Institut de Paleoecologia Humana y Evolució Social of the University Rovira i Virgili (Tarragona, Spain). This assemblage includes a total of 670 fragments that correspond to a minimum number of 265 small vertebrates, representing at least 25 taxa (Table 2; Figs 2, 3). The fragments were identified following the general criteria given by Furió (2007) for insectivores, by López-García *et al.* (2009) for bats, by Van der Meulen (1973) and Cuenca-Bescós *et al.* (2010) for rodents, and mainly by Bailon (1991, 1999), Sanchíz (1984), Sanchíz *et al.* (2002), Blain (2005, 2009) and Szyndlar (1984) for the herpetofauna. The specific attribution of this material rests principally on the best diagnostic elements: humerus, ilium, scapula and sacrum for anurans; skull bones and jaws for lizards, and vertebrae for snakes; mandibles, maxilla and isolated teeth for shrews; isolated teeth and humerus for the Talpidae; isolated teeth and mandibles for bats; first lower molars for the Arvicolinae; and isolated teeth for *Apodemus sylvaticus* and *Eliomys quercinus*. Moreover, the fossils were grouped using the minimum-number-of-individuals (MNI) method, by means of which we determine the sample (i.e. from each level) by counting the best diagnostic elements, taking into account, whenever possible, side and (for amphibians) sex.

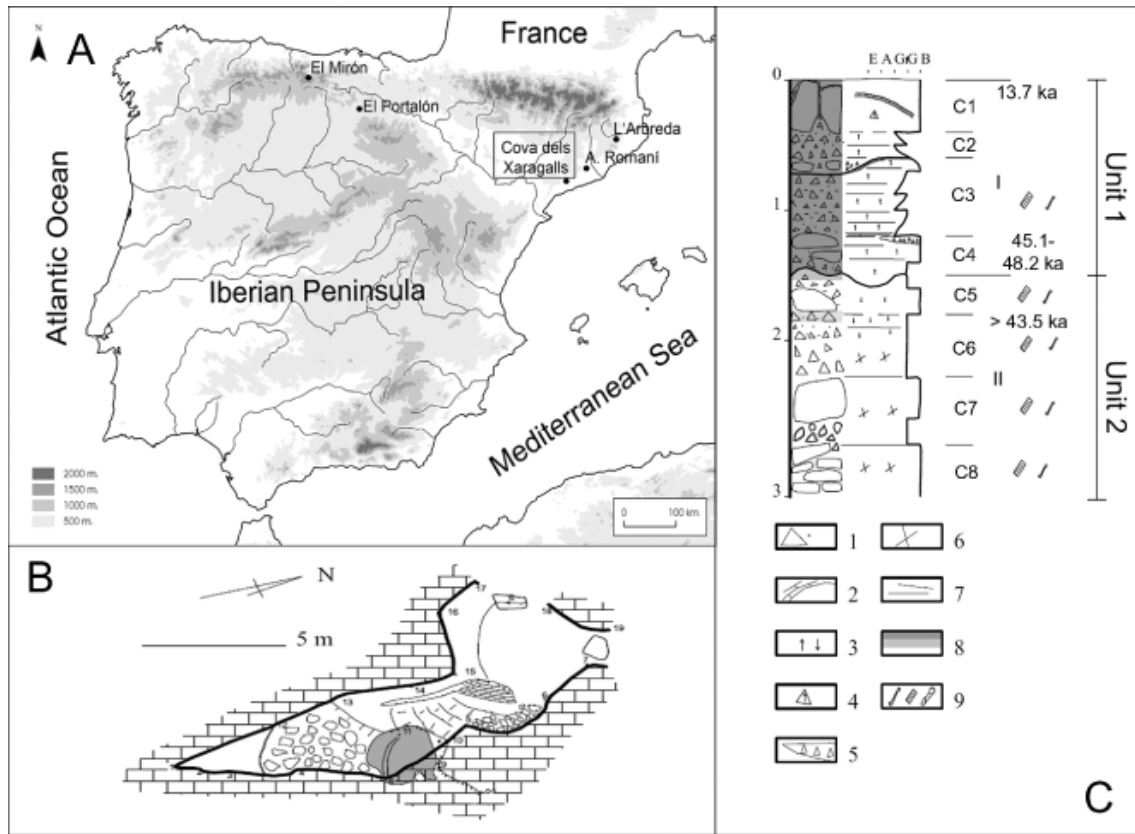


Figure 2.

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Some small mammals from the Cova dels Xaragalls. A. Right mandible *Neomys fodiens* (lingual and posterior views) from layer C7. B. Left mandible *Plecotus* gr. *auritus-austriacus* (occlusal and buccal views) from layer C5. C. Left mandible *Nyctalus lasiopterus* (occlusal and buccal views) from layer C6. D. First lower left molar (m1) *Arvicola sapidus* (occlusal view) from layer C5. E. Left m1 *Microtus* (*Terricola*) *duodecimcostatus* (occlusal view) from layer C6. F. Right m1 *Microtus* (*Iberomys*) *cabreræ* (occlusal view) from layer C6. G. Left m1 *Chionomys nivalis* (occlusal view) from layer C4.

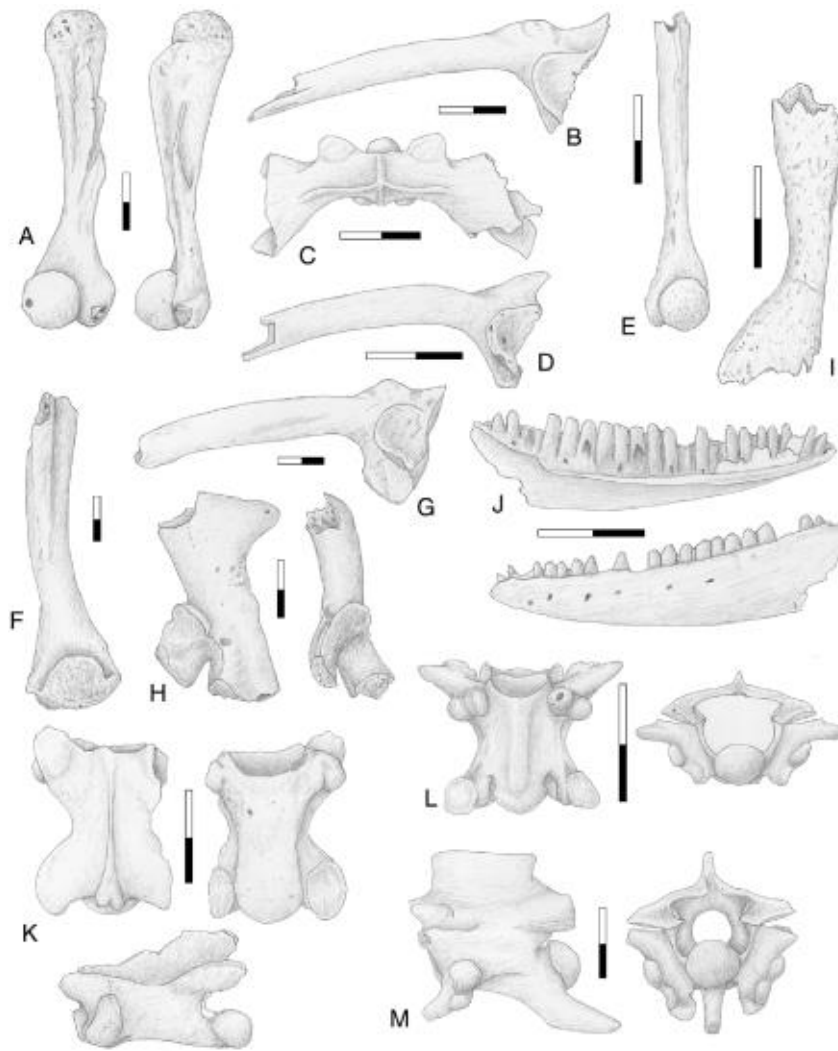


Figure 3.

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Amphibians and squamate reptiles from the Cova dels Xaragalls. A–C. *Alytes obstetricians*. A. Right humerus (ventral and posterior views) from layer C6. B. Left ilium (lateral view) from layer C7. C. Sacrum (dorsal view) from layer C7. D and E. *Pelodytes cf. punctatus*. D. Left ilium (lateral view) from layer C8. E. Left humerus of female (ventral view) from layer C6. F–H. *Bufo calamita*. F. Left humerus of female (ventral view) from layer C6. G. Left ilium (lateral view) from layer C8. H. Right scapula (dorsal and posterior views) from layer C6. I and J. Lacertidae indet. I. Frontal (dorsal view) from layer C4. J. Dentary (lingual and lateral views) from layer C4. K. *Anguis fragilis*, trunk vertebra (dorsal, ventral and left lateral views) from layer C4. L. *Coronella girondica*, trunk vertebra (ventral and posterior views) from layer C8. M. *Vipera cf. latasti*, anterior trunk vertebra (left lateral and posterior views) from layer C4. All scales = 2 mm.

Table 2. The number of identified specimens (NISP), the minimum number of individuals (MNI) and the percentage of the MNI (%) for the small vertebrates from the Cova dels Xaragalls, by layer (C8–C3)

	NIS P	MN I	%	NIS P	MN I	%	NIS P	MN I	%	NIS P	MN I	%	NIS P	MN I	%	NIS P	MN I	%
Taxa/Layers	C3			C4			C5			C6			C7			C8		
Anura																		
<i>Alytes obstetricans</i>	1	1	6.7	1	1	2.8	0	0	0.0	5	2	1.8	8	2	3.8	3	1	2.7
<i>Pelodytes cf. punctatus</i>	0	0	0.0	2	0	0.0	1	1	7.1	1	1	0.9	1	1	1.9	1	1	2.7
<i>Bufo calamita</i>	1	1	6.7	7	1	2.8	0	0	0.0	8	1	0.9	2	1	1.9	11	1	2.7
Squamata																		
Lacertidae indet.	0	0	0.0	11	1	2.8	0	0	0.0	7	1	0.9	6	2	3.8	3	1	2.7
<i>Anguis fragilis</i>	1	1	6.7	1	1	2.8	0	0	0.0	3	1	0.9	6	1	1.9	1	1	2.7
Serpentes																		
<i>Coronella girondica</i>	0	0	0.0	9	1	2.8	2	1	7.1	18	1	0.9	7	1	1.9	7	1	2.7
<i>Vipera cf. latasti</i>	0	0	0.0	2	1	2.8	0	0	0.0	2	1	0.9	0	0	0.0	0	0	0.0
Rodentia																		
<i>Arvicola sapidus</i>	0	0	0.0	0	0	0.0	2	1	7.1	1	1	0.9	0	0	0.0	0	0	0.0
<i>Microtus agrestis</i>	2	2	13.3	2	2	5.6	0	0	0.0	2	2	1.8	2	2	3.8	0	0	0.0
<i>Microtus arvalis</i>	0	0	0.0	7	4	11.1	1	1	7.1	3	2	1.8	0	0	0.0	2	1	2.7
<i>M. (Iberomys) cabrerae</i>	0	0	0.0	1	1	2.8	0	0	0.0	4	3	2.7	1	1	1.9	4	2	5.4
<i>Chionomys nivalis</i>	1	1	6.7	3	2	5.6	0	0	0.0	2	1	0.9	0	0	0.0	0	0	0.0
<i>M. (T.) duodecimcostatus</i>	1	1	6.7	3	2	5.6	1	1	7.1	8	7	6.3	0	0	0.0	6	4	10.8

	NIS P	MN I	%	NIS P	MN I	%	NIS P	MN I	%	NIS P	MN I	%	NIS P	MN I	%	NIS P	MN I	%
<i>Apodemus sylvaticus</i>	18	6	40.0	44	14	38.9	25	7	50.0	191	69	62.2	93	33	63.5	31	18	48.6
<i>Eliomys quercinus</i>	1	1	6.7	4	3	8.3	2	1	7.1	17	6	5.4	7	3	5.8	2	2	5.4
Insectivora																		
<i>Sorex sp.</i>	0	0	0.0	0	0	0.0	0	0	0.0	7	3	2.7	1	1	1.9	0	0	0.0
<i>Sorex minutus</i>	0	0	0.0	0	0	0.0	0	0	0.0	4	3	2.7	0	0	0.0	1	1	2.7
<i>Neomys fodiens</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	2	1	1.9	0	0	0.0
<i>Crocidura russula</i>	0	0	0.0	0	0	0.0	0	0	0.0	2	1	0.9	1	1	1.9	1	1	2.7
<i>Talpa europaea</i>	0	0	0.0	2	1	2.8	0	0	0.0	0	0	0.0	1	1	1.9	0	0	0.0
Chiroptera																		
<i>Myotis nattereri</i>	0	0	0.0	0	0	0.0	0	0	0.0	6	3	2.7	0	0	0.0	0	0	0.0
<i>R. euryale-mehelyi</i>	0	0	0.0	2	1	2.8	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>P. auritus-austriacus</i>	0	0	0.0	0	0	0.0	1	1	7.1	1	1	0.9	1	1	1.9	2	2	5.4
<i>Miniopterus schreibersii</i>	1	1	6.7	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Nyctalus lasiopterus</i>	0	0	0.0	0	0	0.0	0	0	0.0	1	1	0.9	0	0	0.0	0	0	0.0
Total	27	15	100	101	36	100	35	14	100	293	111	100	139	52	100	75	37	100

Palaeoenvironmental reconstruction

In order to reconstruct the palaeoenvironment at the Cova dels Xaragalls, we used the method of habitat weightings (see Evans *et al.* 1981; Andrews 2006), distributing each small-vertebrate taxon in the habitat(s) where it can be found at present in the Iberian Peninsula. Habitats were divided into five types (in accordance with Cuenca-Bescós *et al.*

2005, 2009; Blain *et al.* 2008; López-García *et al.* 2010a, 2011a; Rodríguez *et al.* 2011): open land in which dry and wet meadows are distinguished, woodland and woodland-margin areas, rocky areas and areas surrounding water. These types are detailed as follows (Tables 3, 4) – open dry: meadows under seasonal climate change; open humid: evergreen meadows with dense pastures and suitable topsoil; woodland: mature forest including woodland margins and forest patches, with moderate ground cover; water: areas along streams, lakes and ponds; rocky: areas with a suitable rocky or stony substratum. The ‘Ch1&Ch2’ and ‘Ch3’ curves were obtained from the percentage representation of the MNI by means of the classification of our taxa according to chorotypes established previously by Sans Fuentes & Ventura (2000) and López-García *et al.* (2010b). These chorotypes are detailed as follows (Tables 3, 4) – chorotype 1: includes species with mid-European requirements, with mean summer temperatures lower than 20°C, mean annual temperatures (MAT) between 10°C and 12°C, and mean annual precipitation (MAP) higher than 800 mm; chorotype 2: includes mid-European species tolerant of Mediterranean conditions, with a broader distribution in Catalonia than species of chorotype 1, with MAP higher than 600 mm; chorotype 3: includes non-strictly Mediterranean species and strictly Mediterranean species, with a broad distribution in Catalonia and without very strict requirements.

Table 3. Small-vertebrate distribution by habitat and by chorotype. OD = open dry; OH = open humid; Wo = woodland/woodland-edge; Ro = rocky; Wa = water; Ch1 = chorotype 1; Ch2 = chorotype 2; Ch3 = chorotype 3; (g) = generalist; (m) = Mediterranean requirements x represents the relationship between chorotypes and taxa

	OD	OH	Wo	R	W	Ch1	Ch2	Ch3
<i>Alytes obstetricans</i>		0.6	0.2		0.2			x (g)
<i>Pelodytes cf. punctatus</i>	0.5		0.2	0.1	0.2			x (g)
<i>Bufo calamita</i>	0.75			0.25				x (g)
Lacertidae indet.	0.25	0.25	0.25	0.25				x (g)
<i>Anguis fragilis</i>		0.25	0.75				x	
<i>Coronella girondica</i>	0.25	0.25	0.25	0.25				x (g)
<i>Vipera cf. latasti</i>	0.375		0.25	0.375				x (m)
<i>Arvicola sapidus</i>					1			
<i>Microtus agrestis</i>		0.5	0.5				x	
<i>Microtus arvalis</i>	0.5		0.5			x		
<i>M. (Iberomys) cabrerae</i>		0.5	0.5					x (m)
<i>Chionomys nivalis</i>				1		x		
<i>M. (T.) duodecimcostatus</i>		0.5	0.5					x (m)

	OD	OH	Wo	R	W	Ch1	Ch2	Ch3
<i>Apodemus sylvaticus</i>			1					x (g)
<i>Eliomys quercinus</i>			0.5	0.5				x (g)
<i>Sorex sp.</i>		0.5	0.5			x		
<i>Sorex minutus</i>		0.5	0.5			x		
<i>Neomys fodiens</i>		0.25			0.75	x		
<i>Crocidura russula</i>	0.5		0.5					x (m)
<i>Talpa europaea</i>		0.5	0.5				x	
<i>Myotis nattereri</i>	0.25	0.25	0.5					x (g)
<i>R. euryale-mehelyi</i>			0.75	0.25				x (m)
<i>P. auritus-austriacus</i>			0.75	0.25				x (g)
<i>Miniopterus schreibersii</i>				1				x (m)
<i>Nyctalus lasiopterus</i>			1					x (g)

Table 4. Percentages obtained by means of MNI for the layers of the Cova dels Xaragalls. Percentage representation of micro-vertebrate taxa associated with open dry meadows (O. Dry); open humid meadows (O. Humid); Woodland: woodland environments (Woodland); rocky meadows (Rocky) and meadows beside running water (Water). Ch1&Ch2 = percentage representation of small-vertebrate taxa associated with mid-European requirements; Ch3 = percentage representation of small-vertebrate taxa associated with Mediterranean requirements

	C3	C4	C5	C6	C7	C8
O. Dry	11.0	10.0	8.0	4.0	5.0	8.0
O. Humid	15.0	12.0	5.0	10.0	9.0	13.0
Woodland	56.0	66.0	72.0	79.0	78.0	72.0
Rocky	17.0	11.0	7.0	5.0	5.0	6.0
Water	1.0	1.0	8.0	2.0	3.0	1.0
Ch1&Ch2	26.4	27.8	7.1	10.8	11.4	8.1
Ch3	13.4	16.8	14.2	12.6	11.4	29.7

Palaeoclimatic reconstruction

Climatically, the Iberian Peninsula can be considered a mini-continent owing to its large latitudinal range (between the parallels 36° and 44°N), its geographical position between Atlantic (temperate-cold) and African-Mediterranean (temperate-warm or subtropical) influences, and its complex orography. The Iberian Peninsula is one of the most mountainous areas of Europe, and these mountains play a major role in the characterization of its climatic diversity. Thus, climatic conditions may change abruptly over a few hundred kilometres, from the mildness of the seashore to the harshness of coastal mountain summits, resulting in a great variety of climates. As a result, diverse small-vertebrate assemblages with opposing climatic requirements may coexist over a short distance and time, allowing taxonomic change in a fossil locality to be correlated with climate change. In order to assess the palaeoclimatic changes through the Cova dels Xaragalls sequence, we evaluate the current distribution of all the taxa occurring in each level, permitting us to calculate the potential palaeoclimatic conditions (mutual climatic range method (MCR), modified from Blain *et al.* 2009). On the basis of the distribution of the extant Iberian fauna, we simply identify the geographical region where all the species present in a stratigraphical level currently live. Because our sources for the distribution of the small-vertebrate taxa (Pleguezuelos *et al.* 2004; Palombo & Gisbert 2005) are based on a 10 × 10 km² UTM network, climatic data are resolved to 10 × 10 km² UTM squares. Careful attention is paid to ensure that the real current distribution of each species corresponds to the potential ecological/climatic distribution and has not been strongly affected by other limiting or perturbing parameters such as urban development, human impact on the landscape, predation, competition with other species, etc. Several climatic factors are estimated: MAT, MAP, and the mean precipitation for summer (June, July and August = JJA), using various climatic maps of Spain (Font-Tullot 2000) and data provided by the network of Catalanian meteorological research stations over a period of 30 years. From this region we can estimate the climatic parameters and compare them with the weather station in Vimbodí-Poblet (current data from Ninyerola *et al.* 2003). Vimbodí-Poblet has a MAT of 13.4°C (weather station at 490 m a.s.l.). The MAP is 629 mm, and JJA is 99 mm (Ninyerola *et al.* 2003).

Small-vertebrate assemblage from Cova dels Xaragalls

There are at least 25 species of small vertebrates in the Cova dels Xaragalls (Table 2): 3 amphibians, 4 squamates, 5 insectivores, 5 bats and 8 rodents.

Small mammals

The small-mammal distribution in the Cova dels Xaragalls is characterized by the abundance throughout the whole sequence of *Apodemus sylvaticus*. The Mediterranean taxa such as *Microtus (Iberomys) cabreræ* and *Microtus (Terricola) duodecimcostatus* seem to have a distribution throughout the sequence but are more abundant in levels C6 and C8. The mid-European taxa such as *Microtus arvalis* and *Chionomys nivalis* are present in almost all layers, but their representation is more important in levels C4 and C3 (Fig. 4). From a quantitative point of view, the wood mouse (*Apodemus sylvaticus*) is very well represented throughout the Cova dels Xaragalls sequence, often accounting for more than 50% of the total in each sample. Among the fossil material analysed here, *A. sylvaticus* corresponds to 342 remains (i.e. 51%) and 147 individuals (i.e. 55.4%). The presence of *A. sylvaticus* in Late Pleistocene sites is common, but this great abundance is rare in Late Pleistocene cave localities (see, for example, Sesé 1994, 2005; Pokines 1998; Cuenca-Bescós *et al.* 2008, 2009; López-García 2008; López-García *et al.* 2011b), because during these generally cold periods the dominant species are normally associated with open

environments. However, *A. sylvaticus* is today a very abundant species throughout Spain. It is a generalist species, but its greatest abundance is currently reported to be in woodland/edge-woodland habitats (Palombo & Gisbert [2005](#)). On the other hand, except for *Microtus arvalis*, *Microtus agrestis*, *Microtus (Iberomys) cabreræ*, *Chionomys nivalis*, *Sorex* sp., *Neomys fodiens* and *Nyctalus lasiopterus*, all the small-mammal taxa represented in the Late Pleistocene layers of Cova dels Xaragalls are currently found in the vicinity of the cave (Poblet forest). Nowadays, 24 small-mammal species live in this part of the Poblet forest, among them insectivores, bats and rodents (Flaquer *et al.* [2009](#); Freixas *et al.* [2010](#)). Including bats, despite the fragility of their bones, as well as species linked with anthropization (such as *Rattus* and *Mus*), the Cova dels Xaragalls small-mammal assemblage corresponds to 75% of the current small-mammal fauna in the Poblet forest.

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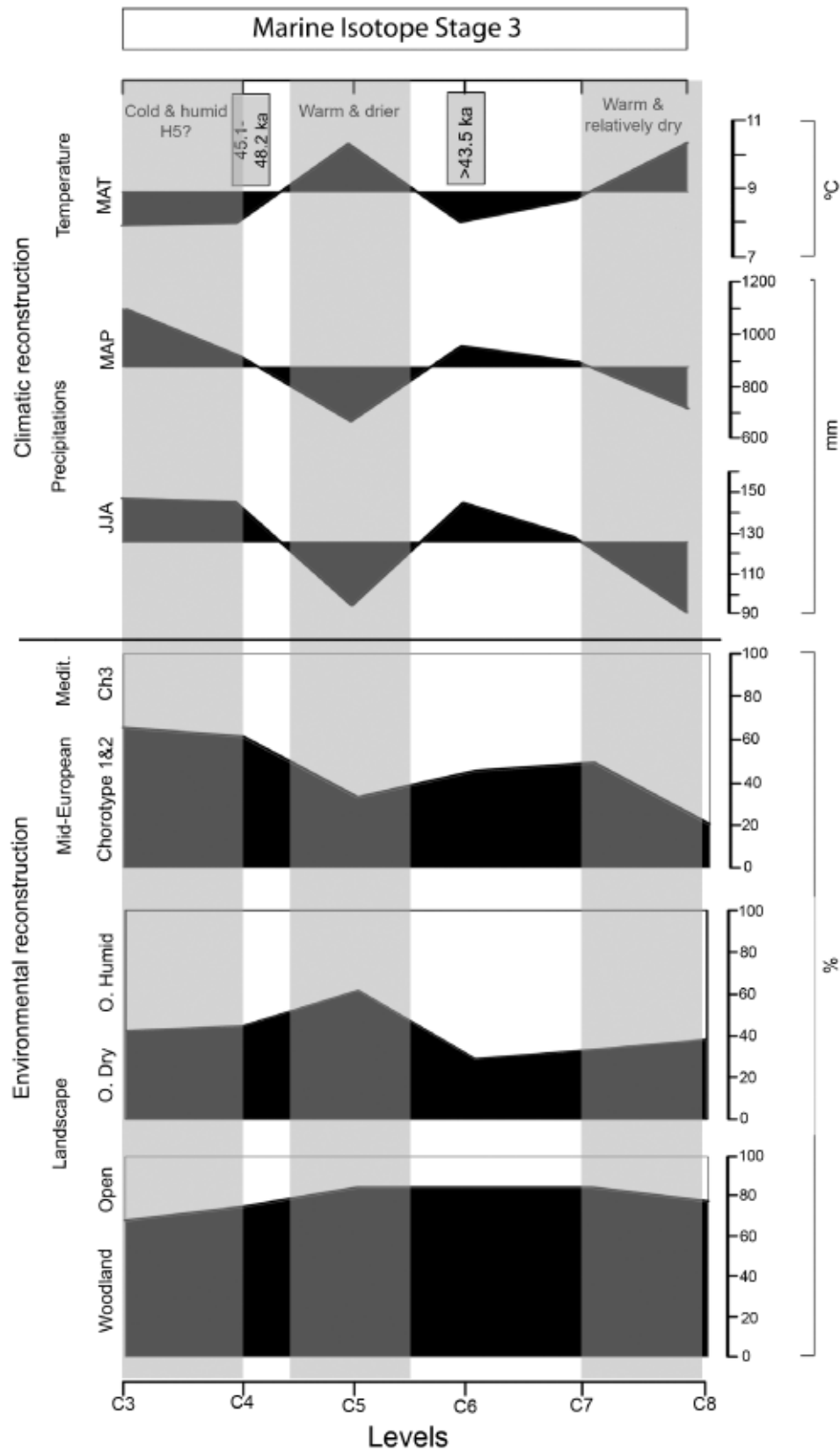


Figure 4.

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Proposed correlation of climatic and environmental data for the Cova dels Xaragalls. From top to bottom: mean annual temperature (MAT); mean annual precipitation (MAP); summer precipitation (JJA); representation of the small vertebrates associated with Mediterranean (Ch3) and mid-European (Ch1&2) requirements; representation of the small vertebrates associated with open dry and open humid environments; representation of the small vertebrates associated with woodland and open meadows. The separation line of the curves represents the average values obtained for each layer of the Cova dels Xaragalls.

Amphibians and squamate reptiles

As far as the herpetile assemblage is concerned, the richness in terms of the number of remains and the number of species is relatively low in the whole sequence (Table 2). No major difference can be seen between the various layers of the Cova dels Xaragalls; noteworthy is that layers C3 and C5 are very poor in number of remains. Apart from *Bufo calamita*, all the species that occur show a reasonably strong affinity for woodland edges and consequently may come from the local environment surrounding the cave. *B. calamita*, together with *P. punctatus*, lacertids and snakes, is linked with rocky or stony substrates, which are well represented today in the vicinity of the cave. All the species can be found today in the study area.

Small-vertebrate taphonomy

A total of 2181 skeletal elements from levels C4, C6, C7 and C8 of the Cova dels Xaragalls have been studied, amongst which there are micro-vertebrate elements identified to the genus or species level. The alterations caused by digestion found in incisors, molars and femurs from all the studied layers indicate that the accumulation of micro-mammals is associated with predation. As regards the amphibians and reptiles, signs of digestion have been found on a cervical vertebra of *Coronella girondica* from level C4 and on a radius-ulna of *Alytes* from level C8, suggesting that these remains might have their origin in predation. By contrast, no signs of digestion have been found in the amphibians and reptiles of levels C6 and C7. It is possible that these individuals might have used the cave as a place of hibernation or aestivation. Recent investigations in small-vertebrate taphonomy have suggested the need to examine whether the degrees of digestion of the various elements studied from a single layer are homogeneous, in order to ascertain the contribution made by various predators within a single micro-vertebrate assemblage (Bennàsar 2010). In the case of the layers making up the Cova dels Xaragalls, a high degree of taphonomic homogeneity is observed, which would suggest that the contribution of micro-mammals can be attributed mainly to the activity of a single predator in each of the levels. In general, the percentages of alteration in incisors, molars and femurs in layers C4, C6, C7 and C8 are very similar. However, there is a slight decrease in the percentages of digestion for the molars of layers C6 and C7. This is due to a slight preferential disappearance of arvicolid molars in these layers, which could be connected with the activity of the predator. Accordingly, in these levels there are greater numbers of teeth from *Apodemus*. These teeth are more resistant to the effects of gastric juices, explaining the decrease in the percentages of digestion (Fig. 5). The percentage of incisors, molars and femurs showing signs of digestion and the degree of alteration observed suggest that the predator of layers C4, C6, C7 and C8 would have been a nocturnal bird of prey similar to a little owl (*Athene noctua*) (Fig. 5). The little owl identified in the layers from C4 to C8 is a small nocturnal bird of prey that can be found in all open or semi-open terrains such as scrubland and grassland or in rocky areas. It avoids thick forest (König *et al.* 1999). This species of owl is considered an opportunist, feeding on reptiles, amphibians and micro-mammals, with its consumption generally increasing during the winter (Delibes *et al.* 1983). It nests alone, in

any hollow or crack in the rocks that is available. As observed in the course of the study, in all the samples there is a predominance of murids (of the genus *Apodemus*) among the rodents. However, the predator identified does not generally use criteria of preference to select the taxa that it consumes and that are thus represented in each of these assemblages. Accordingly, it can be affirmed that the taxa represented are a reflection of the community that lived there at the time. Palaeoecological interpretations based on the relative abundances of the micro-mammal taxa thus provide a reliable indication of the habitat of prey consumed by the predator in question.

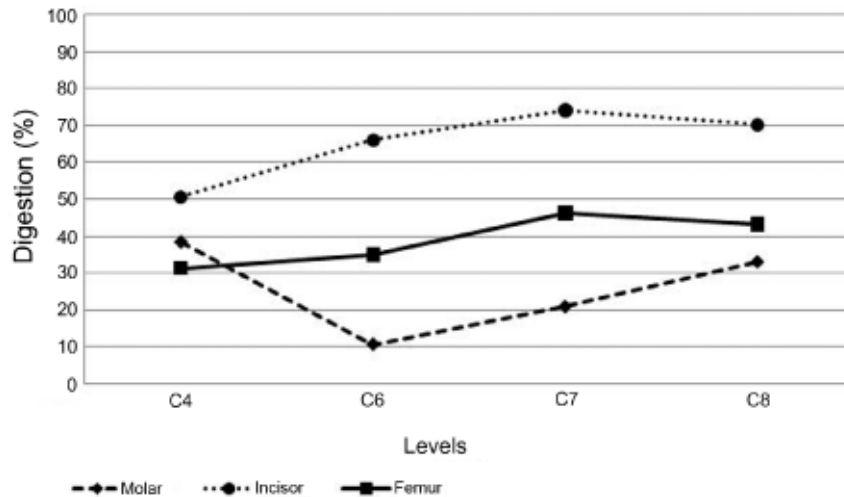


Figure 5.

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Percentage of digestion for the elements studied from the levels of the Cova dels Xaragalls.

Other vertebrates from the Cova dels Xaragalls

In addition to small mammals, anurans and reptiles, certain other vertebrates were documented in the course of the study. These correspond to a few remains (18 bony remains) and comprise rabbits (*Oryctolagus cuniculus*), birds (indeterminate birds) and wild boar (*Sus scrofa*). These vertebrates from the sample were recovered during the water-screening sessions. Their origin may have been intrusive (natural death) or exogenous (supplied by predators). Although rabbit and wild boar are currently abundant in the Poblet forest and both species are normally linked to open forest environments, the scarcity of the remains recovered from the Cova dels Xaragalls prevents us from making any interpretation.

The charcoal from the Cova dels Xaragalls

A total of 202 charcoal fragments, derived from the water-screening of the sediments from the Sala Gran, have been analysed and quantified. *Pinus*-type *sylvestris* is the best-represented taxon in all the sequence of the Cova dels Xaragalls, with almost 75% of the fragments analysed corresponding to this taxon. Also remarkable is a fragment of *Quercus ilex/coccifera* from layer C4 and a fragment of indeterminate angiosperm from layer C3 (Table 5). The charcoal studied probably has a natural origin, given that there is no evidence of a predetermined structure or a bonfire. In addition, although the low diversity in the woodland could result in low variability of the charcoal assemblage regardless of

whether the fires were natural or anthropogenic, the natural vegetation of this period in other Late Pleistocene sites in northeastern Iberia is characterized by a low degree of variability (Allué 2002). In the Late Pleistocene, pine is the most highly represented taxon in the charcoal records, because it is well adapted to the harsher conditions of this period (Carrión *et al.* 2000; Allué 2002). Today, *Pinus sylvestris* grows at altitudes of between 1000 and 1800 m a.s.l. In the Late Pleistocene, by contrast, the record of *Pinus*-type *sylvestris* extends from high altitudes to the coast (Allué 2002). The vegetation of this period consists of small areas of forest integrated in pine formations, forming 40–70% of the total forest mass in southern Europe (Bennett *et al.* 1991). To sum up, the charcoal analysis allows us to draw the following conclusions: (i) the composition of the Poblet forest during the Late Pleistocene was different from today – while today the forest is made up of a high diversity of tree taxa such as *Pinus halepensis*, *P. sylvestris*, *Quercus ilex*, *Q. pyrenaica* and *Ulmus* sp. among others, during the Late Pleistocene there was a clear predominance of *Pinus*-type *sylvestris*; (ii) the preponderance of Scots pine suggests that the climate during this period was colder than today and that the landscape was dominated by open forest formations.

Table 5. Results of charcoal analysis from the Cova dels Xaragalls

Taxon	Number of fragments						Total	
	C3	C4	C5	C6	C7	C8	n	%
<i>Pinus</i> type <i>sylvestris</i>	8	23	35	41	21	25	153	75.7
<i>Pinus</i> sp.	–	3	2	3	2	4	14	6.93
<i>Quercus ilex/coccifera</i>	–	1	–	–	–	–	1	0.49
Indeterminate angiosperm	1	–	–	–	–	–	1	0.49
Indeterminate conifers	1	7	–	6	1	2	17	8.41
Indeterminate	1	–	–	8	2	4	15	7.42
Cortex	–	1	–	–	–	–	1	0.49
Total	11	35	37	58	26	35	202	100

Palaeoclimatic and palaeoenvironmental reconstructions

Palaeoclimatic reconstruction

The MAT in the layers of the Cova dels Xaragalls (C8–C3) varies between –5.5 and –2.9°C with respect to the current mean ($MAT_{Vimbodí-Poblet} = 13.4^{\circ}\text{C}$; recent data from Ninyerola *et al.* 2003). In layers C6, C4 and C3, MAT is between 5.5 and 4.7°C lower than at present, reaching its lowest levels in layer C3 ($MAT_{C3} = 7.9^{\circ}\text{C}$). In layers C8 and C5, MAT is 3 and 2.9°C lower, which is still lower than at present but higher than for the other layers, with the highest value reached in layer C8 ($MAT_{C8} = 10.5^{\circ}\text{C}$) (Table 6; Fig. 4). Furthermore, MAP (664–1092 mm) and the mean summer precipitation (JJA: 89–147 mm), with the exception of the JJA precipitation for layers C8 (JJA = 89 mm) and C5 (JJA = 94 mm), are

higher in the layers of the Cova dels Xaragalls than currently observed at the Vimbodí-Poblet station (MAP = 629 mm; JJA = 99 mm; recent data from Ninyerola *et al.* 2003). As can be observed in Fig. 5, the figure for JJA follows the tendency of MAP and is opposite to MAT. It can thus be seen that MAP and JJA increase during cold periods, whereas during mild periods they decrease.

Table 6. Relationship of temperature and precipitation for the layers of the Cova dels Xaragalls. MAT = mean annual temperature; MAP = mean annual precipitation; JJA = mean summer precipitation; n = number of intersection points; Max = maximum of values obtained; Min = minimum of values obtained; Mean = mean of values obtained; SD = standard deviation of values obtained

	n	MAT				MAP				JJA			
		Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD
C3	6	10.00	6.00	7.92	1.69	1500	800	1092	322	197	93	147	55
C4	2	9.00	7.00	8.00	1.41	1000	850	925	106	197	93	145	74
C5	52	13.00	6.00	10.36	1.58	1500	400	664	204	197	71	94	27
C6	2	9.00	7.00	8.00	1.41	1000	850	950	106	197	93	145	74
C7	3	10.00	7.00	8.67	1.53	1000	850	900	87	197	93	128	60
C8	26	13.00	7.00	10.48	1.72	1000	400	729	245	197	45	89	38

Palaeoenvironmental reconstruction

The changes in representation of open dry/open humid and open/woodland taxa in the Cova dels Xaragalls sequence show a saw-like pattern of increase and decrease through the sequence (Figs 5, 6). There are two peaks in the representation of open dry environments in layers C8 and C5, coinciding in layer C5 with an increase in the representation of values for meadows besides running water. By contrast, there is also a clear peak in the increase in representation of open humid environments, coinciding with a decrease in woodland environments. On the other hand, as seen above, the predator identified in the layers of the Cova dels Xaragalls suggests the presence of various nearby ecosystems. This bird of prey is distributed over a wide range of environments, making it possible to infer a mosaic of landscapes in the Poblet forest (NE Iberian Peninsula) comprising different habitats. Such habitats might have been semi-open woodland, riverbanks, or open areas close to woodland and spacious rocky areas. Based on this predator, there have been no observable significant changes in the landscape during the formation of the layers making up the Cova dels Xaragalls. This allows us to affirm the existence of a certain degree of constancy in the landscape during its formation.

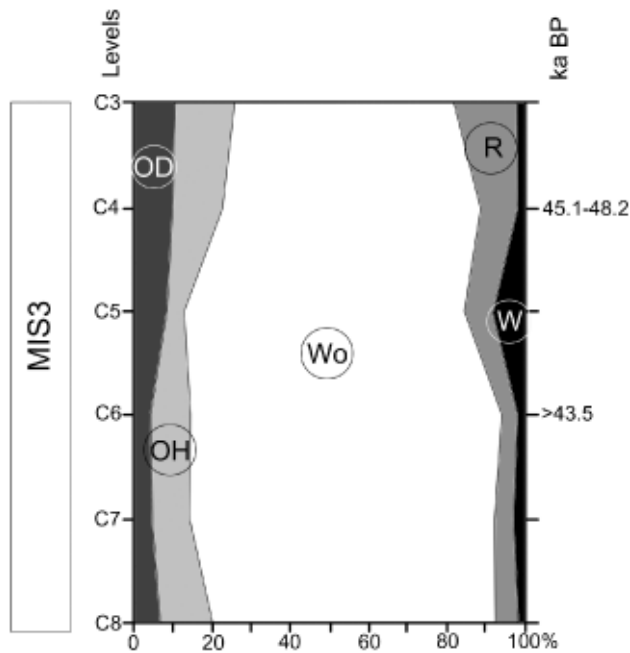


Figure 6.

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Palaeoenvironmental evolution in the Cova dels Xaragalls sequence based on the stratigraphic distribution of the habitat types. OD = open dry meadow; OH = open humid meadow; Wo = woodland/woodland-edge; R = rocky; W = water stream.

Chorotypes

The representation for Mediterranean taxa (chorotype 3) throughout the sequence is variable (Table 6; Fig. 5). An increase in the representation of these taxa is seen in layers C8 and C5, coinciding with the increase in taxa associated with open dry environments and meadows beside running water in C5 (Figs 4, 6), and with the increase in MAT and the decrease in MAP and JJA. By contrast, an increase in the representation of mid-European taxa (chorotypes 1 and 2) can be observed in layers C6 and C4–C3, coinciding in layer C3 with the fall in representation of taxa associated with woodland, and in general coinciding with an increase in the representation of taxa linked to open humid environments, a decrease in MAT and an increase in MAP and JJA precipitation.

Discussion

The environmental and climatic changes of the last 140 000 years in continental Iberia are known mainly from pollen analyses (Davis *et al.* 2003; Sánchez-Goñi & d'Errico 2005; Fletcher & Sánchez-Goñi 2008) and geomorphological studies (e.g. Gutierrez Elorza & Peña Monné 1998; Gutierrez Elorza & Sesé Martínez 2001). Changes in small-vertebrate distributions offer another proxy for studying these environmental and climatic changes. The evolution of the micro-vertebrate taxa of the Late Pleistocene sequence of the Cova dels Xaragalls does not provide fluctuations as detailed as those produced by marine or lacustrine pollen (Peyron *et al.* 1998; Pons & Reille 1988; Allen *et al.* 1999; Nimmergut *et al.* 1999; Sánchez-Goñi *et al.* 2000; Kageyama *et al.* 2005; Sánchez-Goñi & d'Errico 2005; Fletcher & Sánchez-Goñi 2008). However, they constitute an attempt to establish a correlation between the various cold events and temperate interstadials on the basis of a

non-pollen continental record, allowing us to identify several of these periods. According to pollen analyses, MIS3 is characterized by dynamics that alternate between phases of forest development and the expansion of semi-arid areas in accordance with the warming and cooling, respectively, of the marine surface temperatures. The peaks detected in the Cova dels Xaragalls sequence can be correlated with the fluctuations (interstadials and Heinrich events) produced during MIS3. Layers C8 and C5 are related to temperate climatic conditions, and layers C4–C3 are related to a cold period.

Interstadial 15 or 16

The small-vertebrate study of layer C8 establishes that this layer is climatically characterized by a relatively high MAT and a relatively low MAP, together with a high representation of Mediterranean taxa (chorotype 3) and a relatively high proportion of species linked with open humid meadows (Fig. 5). All these data, together with the dating of layer C6 to over 50 ka BP, lead us to believe that layer C8 is probably related to a warm and relatively dry period (interstadial) at the beginning of MIS3. According to the data obtained from the small vertebrates, and taking into consideration the data provided by the NorthGRIP ice core and the marine core collected from the SW Iberian margin (Sánchez-Goñi & d'Errico 2005), layer C8 of the Cova dels Xaragalls probably correlates with Interstadial 15 or 16 (IS15 or 16), dating to c. 56–59 ka BP and characterized by an increase in the temperature of the coldest months and a relative decrease in annual precipitation (Fig. 7).

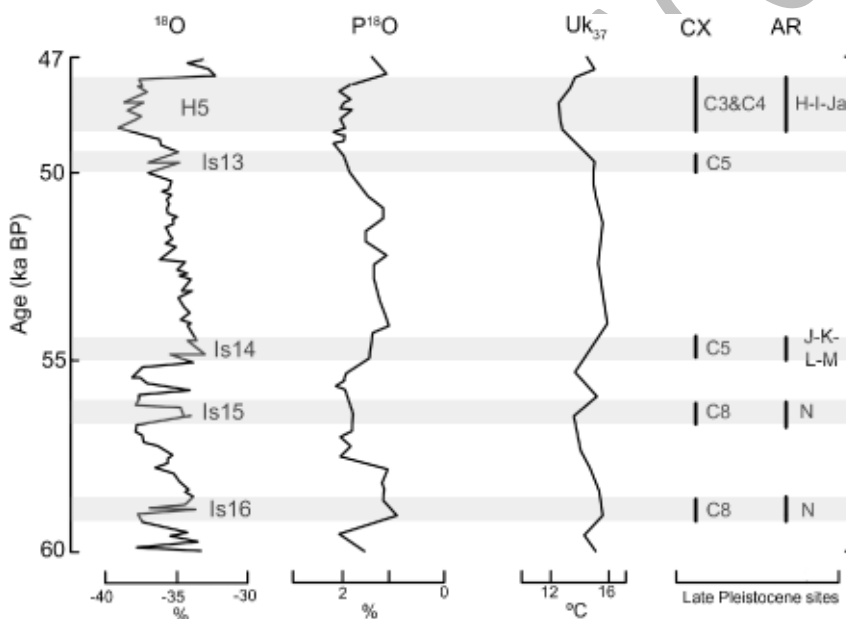


Figure 7.

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Proposed correlation of the NorthGRIP2 Isotope (^{18}O) curve, the Planktonic Isotope curve (P^{18}O), which reflects the temperatures of the ocean surface, and the quantitative variation in the annual ocean surface temperature (Uk_{37}) (modified from Sanchez-Goñi & d'Errico 2005) with the various layers of Late Pleistocene sites with small-vertebrate studies. CX = Cova dels Xaragalls (from this work); AR = Abric Romaní.

Interstadial 13 or 14

Layer C5 is climatically characterized according to the small-vertebrate analysis by a relatively high MAT and a relatively low MAP, together with a high representation of Mediterranean taxa (chorotype 3) and a high proportion of species associated with open dry meadows (Fig. 5). Taking into account that layer C5 is older than 48 ka BP, the data obtained lead us to believe that this layer probably represents a warm and dry period (interstadial) at the end of MIS3. According to the data obtained from the small vertebrates, and bearing in mind the data from the NorthGRIP ice core and the marine core collected from the SW Iberian margin (Sánchez-Goñi & d'Errico 2005), layer C5 of the Cova dels Xaragalls probably corresponds to IS13 or 14, dating to c. 50–5 ka BP and characterized by an increase in the temperature of the coldest months and a pronounced decrease in annual precipitation (Fig. 7).

Heinrich Event 5

Layers C4–C3 are climatically characterized according to the small-vertebrate study by a relatively low MAT and a relatively high MAP, together with a high representation of mid-European taxa (chorotypes 1 and 2), relatively high proportions of species representing open humid meadows, and a decrease in the percentage representation of woodland taxa (Fig. 5). Taking into account that layer C4 is dated to c. 45–48 ka BP, the data obtained lead us to believe that this layer probably represents a cold and humid period (Heinrich event) at the end of MIS3. According to the data obtained from the small vertebrates, and bearing in mind the data from the NorthGRIP ice core and the marine core collected from the SW Iberian margin (Sánchez-Goñi & d'Errico 2005), layers C4–C3 of the Cova dels Xaragalls probably correspond to Heinrich Event 5 (H5), dating to c. 47 ka BP and characterized by a decrease in the temperature of the coldest months and a relative increase in annual precipitation (Fig. 7).

Comparison with other Iberian sites

Of all the above-mentioned Late Pleistocene sites where small-vertebrate studies have been undertaken (El Portalón site, l'Arbreda cave, El Mirón cave, the Abric Romaní), the only one that resembles the Cova dels Xaragalls sequence is the Abric Romaní, as all the other sites have a chronology more recent than c. 40 ka BP. The Abric Romaní is a classical site with Neanderthal industries in a rock shelter. The site is near the town of Capellades, some 45 km to the NW of Barcelona. The shelter is carved in Quaternary travertine, and the Mousterian lithics preserved in the succession of layers provide evidence that Neanderthals occupied the site at various times within MIS3 and 4, about 70–40 ka (Carbonell 2002). This site has provided a long small-vertebrate sequence with 20 taxa and more than 500 remains (López-García 2008; López-García *et al.* 2009; Burjachs *et al.* 2011). The Abric Romaní sequence is slightly older than the Cova dels Xaragalls sequence, but they match in H5, IS14 and IS15–16. H5 is detected in layers H, I and Ja of the Abric Romaní, with an age of c. 47–49 ka BP. It is also detected in layers C3–C4 of the Cova del Xaragalls. In the Abric Romaní, H5 is climatically characterized by a decrease in temperature and an increase in precipitation (López-García & Cuenca-Bescós 2010; Burjachs *et al.* 2011), associating these layers with relatively cold and wet conditions, as is also suggested by the charcoal and pollen analyses, which show a decrease in the representation of thermophilous taxa and an increase in taxa associated with moisture (Burjachs & Julià 1994; Burjachs *et al.* 2011). IS14 is detected in the Abric Romaní in layers M, L, K and J of the Neanderthal occupation, with an age of c. 50–53 ka BP. This interstadial occurs in layer C5 of the Cova dels Xaragalls. In the Abric Romaní, IS14 is climatically characterized by an increase in temperature and a decrease in precipitation in relation to

the earlier H5 (López-García & Cuenca-Bescós 2010; Burjachs *et al.* 2011). This data endows these layers of the Abric Romaní with relatively warm and dry conditions, as is also implied by the charcoal and pollen analyses, which show an increase in taxa associated with dry environments and a relatively high representation of thermophilous taxa (Burjachs & Julià 1994; Burjachs *et al.* 2011). Finally, IS15-16 is detected in the Abric Romaní in archaeological layer N, with an age of c. 55 ka BP, whereas it is detected in the Cova dels Xaragalls in layer C8. IS15-16 is climatically characterized in the Abric Romaní by a relative increase in the temperatures and a moderate decrease in precipitation (López-García & Cuenca-Bescós 2010; Burjachs *et al.* 2011) in relation to the layers mentioned above, suggesting warm and relatively dry conditions in these layers of the Abric Romaní. Again, this is corroborated by the charcoal and pollen analyses, which reveal high values for thermophilous taxa and a relatively high representation of taxa associated with dry environments (Burjachs & Julià 1994; Burjachs *et al.* 2011).

Conclusions

The sequence of the Cova dels Xaragalls is one of the few stratigraphic series from the second half of the Late Pleistocene (c. 60 to 40 ka BP) in the Iberian Peninsula. The small-vertebrate bone remains from the Cova dels Xaragalls have been analysed and quantified. There are a total of 2181 fragments, of which 670 have been identified to genus or species level. They correspond to a minimum of 265 small-vertebrate specimens, representing at least 25 taxa, including toads, lacertids, snakes, insectivores, bats and rodents. The animal responsible for the assemblage may have been a nocturnal bird of prey similar to *Athene noctua* (little owl). Taking into account the small vertebrates and the charcoal analysed from the Cova dels Xaragalls, the composition of the Poblet forest was slightly different in the Late Pleistocene from what it is today. While nowadays the Poblet forest has a high diversity of trees, the charcoal analyses show that in the Late Pleistocene one species was predominant; regarding the small-vertebrate assemblage in the Late Pleistocene sequence, there are species with mid-European requirements that are not present today in the area of the Poblet forest. According to the small-vertebrate assemblage and the charcoal studies, the palaeoenvironment seems to have been relatively closed and varyingly humid throughout the Cova dels Xaragalls sequence. The more humid periods correspond to the cold periods (layers C4–C3), in response to higher precipitation, lower temperatures and the opening of the landscape. During the warm periods (layers C8 and C5), by contrast, open dry meadows were well developed in response to lower precipitation and higher temperatures. Finally, this study corroborates that the temperatures and precipitation during the Late Pleistocene concur with the quantitative variation in mid-European/Mediterranean small vertebrates throughout the sequence.

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