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Palaeoecology and biochronology based on the rodents analysis from the Late Pleistocene/Holocene of Toll Cave (Moià, Barcelona)

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ABSTRACT

In this paper we present the chronological, environmental and climatic data obtained by analysing the remains of rodents collected from the water-screened sediments of Levels 2 and 3 of the *Sector Entrada* of Toll Cave (Moià, Barcelona), one of the caves belonging to the karstic system called the *Coves del Toll*. From these levels a total of 216 rodent remains have been recovered, corresponding to 10 rodent species. The biochronological results indicate a Late Pleistocene/Holocene chronology (<35 ka BP); Level 3 is Pleistocene (>13 ka BP), and Level 2 is probably Holocene (<13 ka BP). The palaeoclimatic and palaeoenvironmental data denote an open wet forest with lower temperatures and higher precipitation than nowadays for this region. Level 3 could be correlated with the Last Glacial Maximum (18 ka BP), while Level 2 may belong to the Preboreal period (11.5-9.5 ka BP). From a comparison of our results with the data obtained from other sites in the northeastern Iberian Peninsula with a similar chronology, we can infer two transitional phases for this period. Finally, a comparison with studies of Teixoneres Cave allows us to deduce the climatic and environmental evolution of the area around Toll Cave between the Middle Palaeolithic

RESUMEN

El presente trabajo muestra los resultados del análisis paleoecológico, paleoambiental y bioestratigráfico del estudio de los restos de roedores, obtenidos mediante el lavado y tamizado de los sedimentos pertenecientes a los niveles 2 y 3 del Sector Entrada de la cueva del Toll (Moià, Barcelona), integrada dentro del complejo kárstico de las Coves del Toll. Se han recuperado un total de 216 restos de roedores, todos ellos identificados a nivel de especie, distinguiéndose 10 especies. De los análisis biocronológicos se deduce una cronología de Pleistoceno superior final e inicios del Holoceno (<35 ka BP), siendo el Nivel 3 Pleistoceno (>13 ka BP) y el Nivel 2 posiblemente Holoceno (<13 ka BP). Por otra parte, los resultados paleoclimáticos y paleoambientales evocan un bosque abierto y húmedo y un clima más frío y con mayores precipitaciones que actualmente; siendo el Nivel 3 el más frío y húmedo, mientras que en el Nivel 2 se experimenta una mejora de las condiciones climáticas, aún siendo este nivel frío. El Nivel 3 podría corresponder a un momento alrededor del Último Máximo Glaciar (alrededor de los 18 ka BP), mientras que el Nivel 2 probablemente se asocie al Preboreal (11,5-9,5 ka BP). De la comparación de

and Upper Palaeolithic/Neolithic. It can be asserted that Neanderthals and anatomically modern humans lived in similar climatic and environmental conditions.

Keywords: Rodentia, biochronology, palaeoenvironment, palaeoclimate, Late Pleistocene/Holocene.

los resultados con otros yacimientos de similar cronología en el Noreste Peninsular podemos detectar para este período una transición en dos fases y, de la contrastación con los datos de la cueva de Teixoneres, se observa que tanto neandertales como humanos anatómicamente modernos habitaron en este entorno en condiciones paleoambientales similares.

Palabras clave: Rodentia, biocronología, paleoclima, paleoambiente, Pleistoceno superior/Holoceno.

1. INTRODUCTION

Toll Cave is located near the village of Moià, 50 km to the north of Barcelona (Fig. 1a). It is one of the caves belonging to the karstic system called the *Coves del Toll*, which forms a course of galleries more than 2 km long. Its height above sea level is about 760 metres, and its coordinates are 2°09'02"E and 41°48'25"N. This complex was formed by the drainage system of Mal torrent, which modelled the Neogene limestone (Collsuspina Formation) and configures the endokarstic landscape observed nowadays (Gómez i Costa, 2001; Rosell *et al*., 2009). Several archaeological deposits from different chronologies are contained within this complex of caves, of which Teixoneres Cave (with Middle Palaeolithic occupations and a relative chronology of 90-30 ka BP) and Toll Cave are the most representative sites (Rosell *et al*., 2010; López-García *et al*., 2012b). The current entrance to Toll Cave is located in the South Gallery (Fig. 1b). This gallery was partially excavated since the 1950s and 1970s and has revealed an important archaeo-palaeontological Holocene and Late Pleistocene sequence. The current excavation project, called *Compartint l'espai: la interacció entre Homínids i Carnívors al Nord-Est Peninsular*, was taken up in 2003, and the work has focused on three sectors of the South Gallery: *Cala C*, *Testigo M-N/34-35* and *Sector Entrada* (Rosell, 2007; Morales & Rodríguez-Hidalgo, 2010).

The *Sector Entrada* sediment package contains four levels (1 to 4) (Fig. 1c). The Holocene sediments (Level 1) have not been included in this work because they show evidence of being mixed. Level 2 has been subdivided into three sublevels: 2a, 2b and 2c. Sublevel 2b is not included in this paper because it corresponds to a negative structure dating from a recent time not related lithologically to the rest of Level 2 and only affects a little part of the sediments. Sublevels 2a and 2c are included under the generic name Level 2. This is formed by clays, gravels and sands without a clear chronological attribution due to it being an archaeologically sterile level, and it has only yielded scarce and uninformative macrofaunal remains. Finally, Level 3 and Level 4 have a similar composition, which combines carbonated and red clays. The plentiful macrofauna found in these two levels allows attributing them to the Late Pleistocene. The high presence of *Ursus spelaeus* show that they could have served as a bear den used for hibernation. These two levels also contain some remains that show cut marks and one lithic tool was found in Level 3. At present, there is no absolute dating for any of the levels of the *Sector Entrada* (Morales & Rodríguez-Hidalgo, 2010; Rodríguez-Hidalgo *et al*., 2011).

In this paper, we present the remains of rodents recovered from Levels 2-4 of the described sector. On the basis of the specific identification of these remains, the aim is to use the biochronology to provide a relative chronology for the studied levels in order to pinpoint the Pleistocene/Holocene limit more clearly. We then present the first palaeoenvironmental and palaeoclimatic reconstruction of Toll Cave, as well as an habitat characterization of the site, in order to increase our knowledge of the environment in which the first inhabitants of Toll Cave lived and to examine its faunal implications for the Pleistocene/Holocene transition in the northeast of the Iberian Peninsula.

2. MATERIAL AND METHODS

2.1. Fieldwork, sorting, systematic attribution and taphonomic remarks

Rodent remains from Toll Cave are the object of study in this paper, since these have specific ecological requirements and are more useful than other micromammals for undertaking biostratigraphic, climatic and environmental reconstructions. The rodent fossil remains used consist of teeth and fragments of disarticulated bones recovered by washing and sieving the sediment extracted from Levels 2-4 of the *Sector Entrada* in the excavation campaigns that took place from 2009 to 2011 (Fig. 2). All the sediment was washed and sieved with two superimposed meshes of 5 and 0.5 mm. The remains of rodents and other small vertebrates were sorted from the two fractions.

For the classification and specific identification of the fossils, *Olympus SZ11* and *Olympus SZ40* binocular

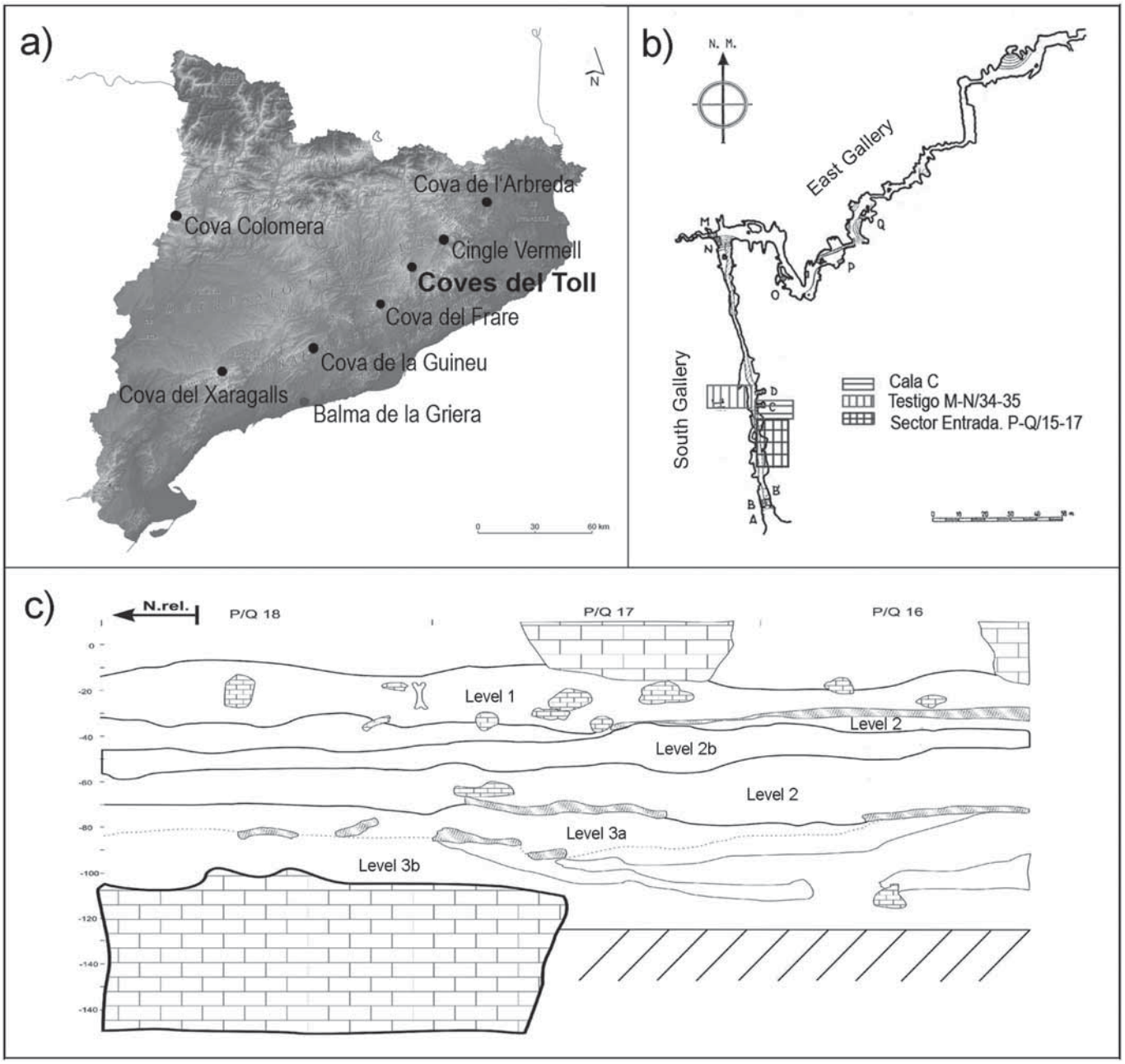

Figure 1. a) Location of Toll Cave and the sites with close chronology (35 ka BP-beginning of the Holocene) with small-mammal studies in Catalonia. **b)** Plan of Toll Cave for the three sectors currently under excavation in Galería Sur. **c)** Sector Entrada stratigraphic sequence (Morales & Rodríguez-Hidalgo, 2010).

microscopes were used, with a magnification of x20-30 and following the criteria of López-García (2011) and Gosàlbez i Noguera (1987). Specific identification relied mainly on the best diagnostic elements: isolated teeth for Murinae and Glirinae, and first lower molars (m1) for Arvicolinae. The remains were counted (NISP) and grouped using the minimum number of individuals (MNI) method, determined by counting the most highly represented diagnostic element, taking into account laterality, for each species at each level (see López-García, 2011). The photographs of the fossils were taken with an Environmental Scanning Electron Microscope (ESEM) available from the *Servei de Microscopia* of the *Servei de Recursos Científics i Tècnics* of the *Universitat Rovira i Virgili.* Although a complete taphonomic study has not been performed in Toll Cave and at present the remains are poor in number, some preliminary remarks can be done. The light to moderate digestion seen in microtine teeth, with rounding of the triangles, indicates that the bones were probably accumulated by an avian predator (*sensu* Andrews, 1990), most likely opportunistic predators.

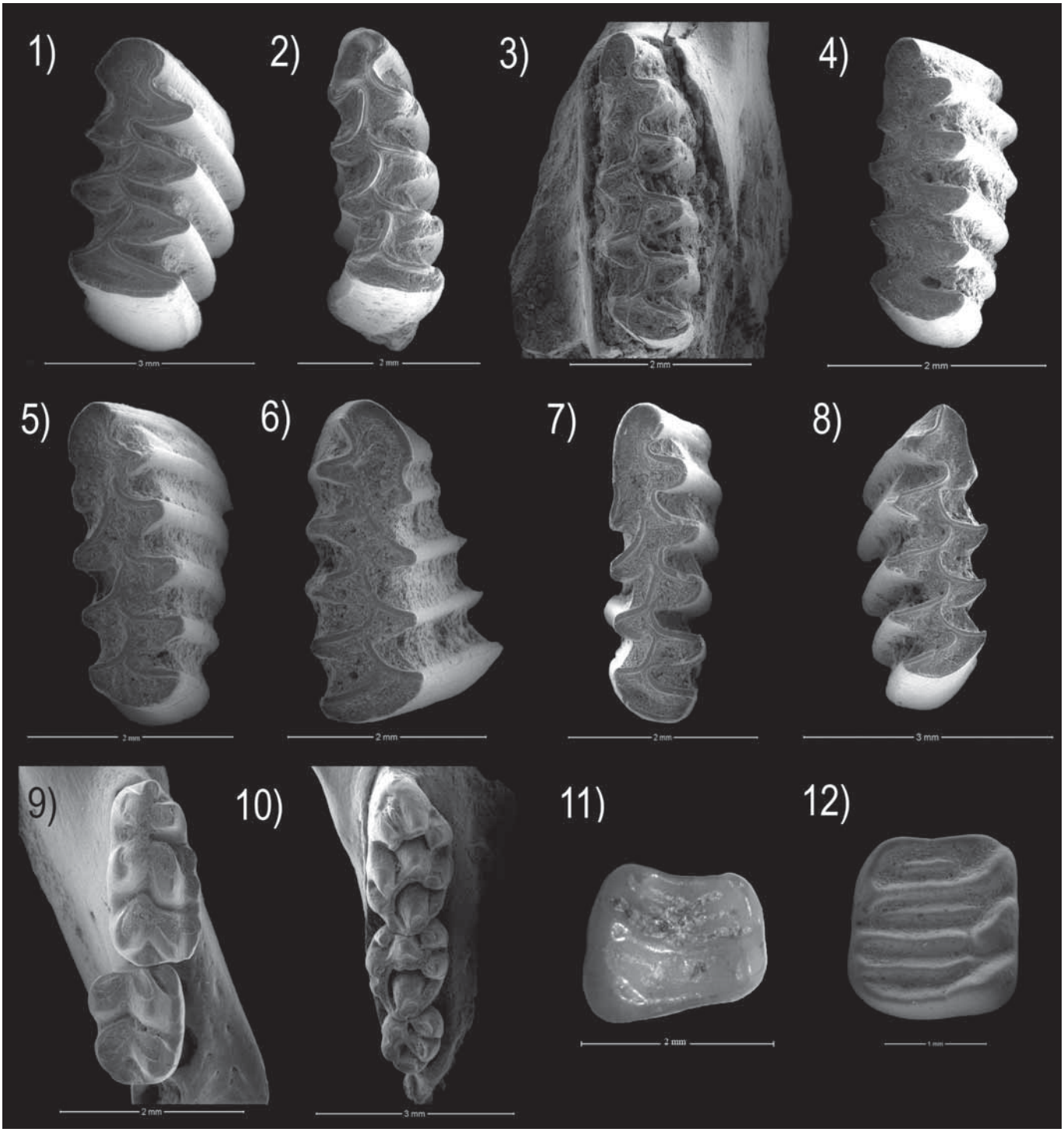

Figure 2. Molars of the rodents identified from Toll Cave in occlusal view: **1)** m1 left *Arvicola sapidus*; **2)** m1 left *Chionomys nivalis*; **3)** m1 left *Microtus arvalis*; **4)** 1 left *Microtus agrestis*; **5)** m1 left *M. (Terricola) duodecimcostatus*; **6)** m1 right *M. (Terricola) duodecimcostatus*; **7)** m1 left *M. (Terricola) gerbei*; **8)** m1 right *M. (Iberomys) cabrerae*; **9)** Right mandible with m1 and m2 *Apodemus sylvaticus*; **10)** Right maxilla with M1-M3 *Apodemus sylvaticus*; **11)** m2 right *Eliomys quercinus*; **12)** m1 right *Glis glis.* 1), 8), 10) scale 3 mm; 2-7), 9), 11) scale 2 mm; 12) scale 1 mm.

2.2. Climatic reconstruction

Climatic conditions prevailing during the formation of the Toll Cave assemblages have been inferred from the rodent taxa using a quantitative and a qualitative method. The former involves assigning each taxon to one of four chorotypes according to its recent climatic requirements and geographical distribution. Starting from the chorotypes pre-established for small mammal faunas in Catalonia by López *et al.* (2006) and Sans-Fuentes & Ventura (2000), we have differentiated the following chorotypes: *chorotype 1* includes species with mid-European requirements, with low mean summer temperatures (lower than 20 ºC), mean annual temperatures (MAT) lower than 10-12 ºC and mean annual precipitation (MAP) higher than 800 mm, and with a present distribution in Catalonia that includes the Pyrenees, a small part of the eastern Pre-Pyrenees and foothills lying more than 800 m above sea level; *chorotype 2* includes mid-European species tolerant of Mediterranean conditions, which need a high precipitation level (MAP higher than 600 mm) and with a broader distribution in Catalonia than those of chorotype 1, extending through more southern and eastern territories; *chorotype 3* includes Mediterranean species, and implies moderate temperatures (MAT higher than 5º C) and humid conditions (MAP lower than 1000 mm); *chorotype group 4* includes generalist species with a wide distribution (*Eliomys quercinus*, *Apodemus sylvaticus*) or species with a particular habitat (*Arvicola sapidus*), which in general provide little climatic information.

With a similar purpose, the Mutual Climatic Range (MCR) method was also used, allowing us to obtain climatic information from qualitative data. The aim of this method is to find the present geographical region that exhibits the same species assemblage as that documented in a given stratigraphical level through the intersection obtained from the overlap of current species distribution maps (López-García *et al.*, 2012b). The current climatic conditions of the intersected area are used to infer past conditions. This method, initially developed for assemblages containing extant reptile and amphibian taxa (Blain, 2009), has been adapted recently for Late Pleistocene small mammal assemblages (Lopéz-García, 2011). The climatic parameters were inferred using the data found in the climatic maps established by Font-Tullot (2000) and species distribution maps by Palomo & Gisbert (2005). The results were compared to the present climatic and precipitation index for Toll Cave provided by Ninyerola *et al*. (2003).

2.3. Environmental reconstruction

Environment in the surroundings of Toll Cave was reconstructed using the Habitat Weightings Method, a modified version of the methods established by Evans *et al*. (1981) and Andrews (2006). It is based on the distribution of each rodent taxon in the habitat(s) where it is possible to find it at present. For the Iberian Peninsula five main habitat types are considered: *open dry*: meadows with seasonal change; *open humid*: evergreen meadows with dense pastures and suitable topsoil; *woodland*: mature forest including woodland margins and forest patches, with moderate ground cover; *rocky*: areas with suitable rocky or stony substratum; *water*: areas along streams, lakes and ponds. Each species is given a maximum score of 1.00 that is divided up according to its habitat preferences, if it occupies more than one type. The habitat distribution is determined from the habitat characteristics of each species given in Palomo & Gisbert (2007).

3. RESULTS

3.1. Level 4

Level 4 represents the oldest chronological level and is thus the level that has been excavated least. In this study we have only found a total of 8 remains, which represent a minimum number of 6 rodents (Table 1). The identified rodent species are: *Arvicola sapidus*, *Microtus arvalis-agrestis*, *Chionomys nivalis*, *Microtus (Terricola) duodecimcostatus* and *Apodemus sylvaticus*. The number of remains is too low to undertake interpretations.

3.2. Level 3

From Level 3 a total of 84 fragments have been recovered, with the MNI estimated at 41 (Table 1). Eight taxa have been identified: *Microtus arvalis*, *Microtus agrestis*, *Chionomys nivalis*, *M. (T.) duodecimcostatus*, *M. (I.) cabrerae*, *Apodemus sylvaticus*, *Eliomys quercinus* and *Glis glis*. *M. (T.) duodecimcostatus* is the predominant species in this level (46.34%). Even so, two other species have an important representation: *Microtus arvalis* (17.07%) and *Microtus agrestis* (17.07%). Chorotype 3, consisting of Mediterranean species, is the best represented group in this assemblage (51%), though the presence of mid-European species chorotypes have also an important presence: chorotype 1 (20%) and chorotype 2 (21%). The chorotype pattern revealed by the rodent assemblage of Level 3 has to do on the one hand with the significant presence of *M. (T.) duodecimcostatus* and on the other hand with that of *Microtus arvalis*, *Chionomys nivalis* and *Microtus agrestis*.

The rodents represented in Level 3 are currently found together only at two sites: the north of Aragon and the northeast of Catalonia, both located in the Pyrenees. Climatic parameters of these two areas compared to available present

Table 1. Number of identified specimens (NISP), minimum number of individuals (MNI) and the percentage of the MNI (%) for Levels 2-4 of Toll Cave and the distribution of the species by chorotypes and habitat. C1: chorotype 1; C2: chorotype 2; C3: chorotype 3; C4: chorotype 4; (g): generalist species; OD: open dry; OH: open humid; W: woodland; R: rocky; WA: water.

	Level 2			Level 3			Level 4			Chorotypes				Habitat				
	NISP	MNI	%	NISP	MNI	%	NISP	MNI	%	C1	C2	C3	C4	OD	OH	W	R	WA
Arvicola sapidus	-	-	-	-	-	-	2	1	16.67				X					1
Microtus arvalis	1	1	1.41	13	7	17.07	-	-	-	X				0.5		0.5		
Microtus agrestis	3	2	2.82	14	7	17.07	-	-	-		X				0.5	0.5		
Microtus arvalis-agrestis	-	-	-	4	2	4.88	1	1	16.67									
Chionomys nivalis	-	-	-	2	1	2.44	1	1	16.67	X							1	
M. (Terricola) duodecimcostatus	106	61	85.92	36	19	46.34	1	1	16.67			X			0.25	0.5	0.25	
M. (Terricola) gerbei	2	2	2.82	-	-	-	-	-	-	X					0.5	0.5		
M. (Iberomys) cabrerae	4	3	4.23	2	1	2.44	-	-	-			X			0.5	0.5		
Apodemus sylvaticus	8	2	2.82	10	1	2.44	3	2	33.33				X (g)			1		
Eliomys quercinus	-	-	-	2	2	4.88	-	-	-				X (g)			0.5	0.5	
Glis glis	-	-	-	1	1	2.44	-	-	-		X					1		
Total	124	71	100	84	41	100	8	6	100									

climatic data for Moià enable to infer for this level a MAT 2-3 ºC lower than today's and similar lower values for the mean temperature of coldest month (MTC) and the mean temperature of warmest month (MTW). In addition, the estimated rainfall for this level is substantially higher than that today's, the inferred MAP doubling its current recent values, with rainfall levels in summer (JJA) and winter (DJF)100 mm higher (Table 2).

As for the environmental reconstruction, the rodent species in Level 3 indicate for the surroundings of Toll Cave an important representation of forest (51 %) and meadow (32 %), with a notable presence of wet meadows (23 %) and rocky areas (17%) (Fig. 3).

Table 2. Present climatic data from Moià (Ninyerola *et al.*, 2003) and the data obtained by the MCR method for Level 3 and Level 2 of Toll Cave. n: number of intersection points obtained; Mean: average values obtained; Max: maximum values obtained; Min: minimum values obtained; SD: standard deviation; MAT: mean annual temperature; MTC: mean temperature of coldest month; MTW: mean temperature of warmest month; MAP: mean annual precipitation; DJF: mean precipitation of winter months; JJA: mean precipitation of summer months. Temperature data in degrees centigrade (ºC) and precipitation data in millimetres (mm).

	Present data in Moià	Level 3					Level 2				
		n	Mean	Max.	Min.	SD	n	Mean	Max.	Min.	SD
MAT	11-12	2	8,5	10	7	±2,12	13	9,77	13	6	±2,68
MTC	3-4	2	1	1	1	±0,00	13	3,62	6	1	±1,80
MTW	20-21	2	17,5	18	17	±0,71	13	18,85	22	15	±1,95
MAP	650-700	2	1375	1500	1250	±176,78	13	1226	1750	500	±393,50
DJF	30-40	2	186	244	129	±81,32	13	227	370	177	±48,60
JJA	30-40	2	167	197	138	±41,72	13	148	230	94	±41,81

3.3. Level 2

Level 2 includes a total of 124 remains that represent a MNI of 71. These are from the following taxa: *Microtus arvalis*, *Microtus agrestis*, *M. (T.) duodecimcostatus*, *M. (Terricola) gerbei*, *M. (Iberomys) cabrerae* and *Apodemus sylvaticus* (Table 1). *M. (T.) duodecimcostatus* is entirely predominant, exceeding the representation shown in Level 3, with a percentage of over 85% of the total sample by contrast with the representation of 1-5% shown by the other species detected.

Accordingly, a clear predominance of Mediterranean species (chorotype 3) is evident in this level, since the best-represented species, *M. (T.) duodecimcostatus* and

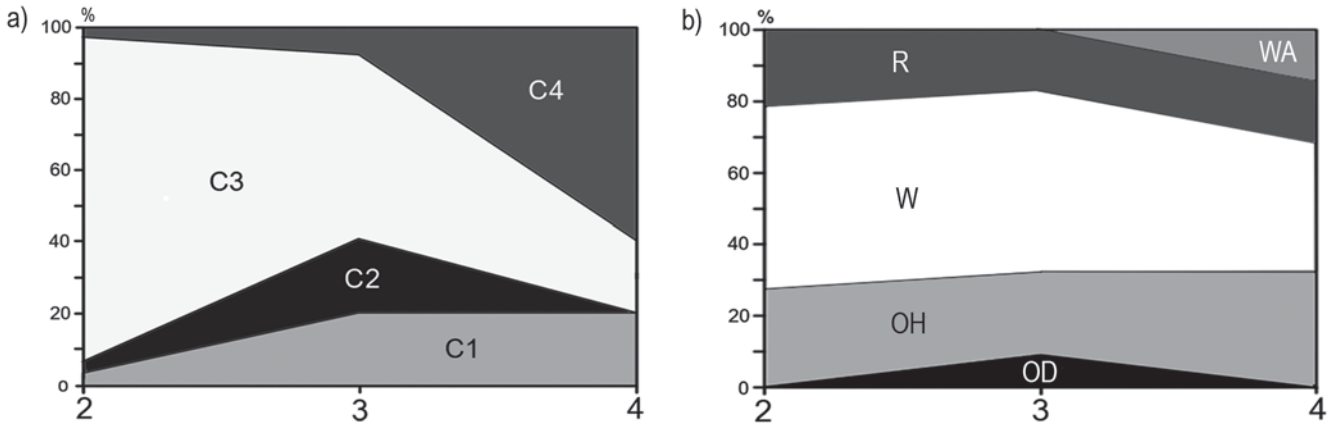

Figure 3. Distribution by chorotype (a) and habitat (b) for Levels 2-4 of Toll Cave. C1: chorotype 1; C2: chorotype 2; C3: chorotype 3; C4: chorotype 4; OD: open dry; OH: open humid; W: woodland; R: rocky; WA: water.

M. (Iberomys) cabrerae, are typically of Mediterranean distribution. Furthermore, chorotypes 1 and 2 undergo a decline, with a reduction in mid-European species such as *Microtus arvalis* and *Microtus agrestis* and the disappearance of *Chionomys nivalis.*

The MCR method locates the corresponding current rodent assemblage in the north of the Iberian Peninsula, in regions associated with the Pyrenees and the Pre-Pyrenees, and more precisely in the north of the Basque Country. For this level too, lower temperatures and higher precipitation than today can be inferred. The results obtained for climate estimation show an MAT approximately 1-2 ºC colder than at present. Similarly, the MTW is 2 ºC lower than nowadays, while the MTC is similar to current average values in the area. Estimated rainfall values are higher than at present, and similarity to Level 3, it doubles the current MAP, being 200 mm more for DJF and 100 mm more for JJA. Level 2 would thus be associated with a less cold and less humid period than Level 3, but still with a significantly colder climate and higher rainfall than at present (Table 2).

Using the habitat weightings method, a clear predominance of forest areas (51%) can be inferred for this level too, along with an important presence of wet meadows (26%) and rocky areas (22%) (Fig. 3). These results are directly linked to the predominance of *M. (T.) duodecimcostatus.*

4. DISCUSSION

4.1. Biochronology

From a biochronological point of view, the most relevant taxa identified from Toll Cave are *M. (Iberomys) cabrerae*, *Chionomys nivalis* and *Glis glis.* These three rodents are extant species already present in Spanish Late Pleistocene assemblages. *M. (Iberomys) cabrerae* is an endemic vole, descendant to the Middle Pleistocene fossil species *M.* (*Iberomys*) *brecciensis* (see López-García, 2011). It makes its first appearance in the Iberian Peninsula in the early Late Pleistocene, its earliest record found in the site of Camino Cave (Madrid), dated to around 98 ka BP (Arsuaga *et al*., 2010). Currently, this species is absent in Catalonia due to the anthropogenic pressure associated with the development of the Neolithic period and the resulting disappearance of wet soils, the preferred habitat of this species (López-García *et al*., 2012c). In Catalonia, the earliest record of this rodent, based on absolute dating, is located in Level O of the Abric Romaní, with a chronology of 58.8-56.8 ka BP, and it is found throughout the Late Pleistocene in almost all studied sites from 60 ka BP to the Holocene (López-García, 2011).

The Snow Vole (*Chionomys nivalis*) appears in the Iberian Peninsula during the Late Pleistocene. Its first record is also from Camino Cave, dated to 98 ka BP (Arsuaga *et al*., 2010). During the Late Pleistocene it was widely distributed in Iberia, whereas nowadays it has become a relict, restricted to small population nuclei, in Catalonia limited to the Pyrenees and the Pre-Pyrenees (Palomo & Gisbert, 2007). There are only five sites in Catalonia where fossils of this rodent have been recovered (Cova 120, Cova de l'Arbreda, Cova Colomera, Teixoneres Cave and Cova dels Xaragalls) (Alcalde & Brunet-Lecomte, 1985; Alcalde, 1986; López-García *et al.*, 2010, 2012a, 2012b). This records are mainly from MIS 3 deposits (60-24 ka BP), though its fossils are also present in the Holocene levels, but becoming increasingly rare, as in Cova Colomera (López-García *et al*., 2010). Cova dels Xaragalls is the Catalan site with the earliest record of the species, with an absolute dating of 45.12-48.24 ka BP (López-García *et al*., 2012a).

Finally, *Glis glis* is a dormouse species which is present in the archaeological record during the Latest Pleistocene (40-10 ka BP) in the north and the northeast of Iberia (Fig. 4). The first data documented in the Iberian Peninsula for this taxon are dated to around 40 ka BP, at sites such as Gabasa or Cova d'Olopte B. However, the citations increase through to 20 ka BP, as in the case of Cova de l'Arbreda, Riera, Mirón, Pendo and Rascaño (López-García, 2011).

Further insight may be obtained comparing the assemblage of Toll Cave with that of the nearby Teixoneres Cave. Analysis of the respective species lists shows the presence of two rodents, *Pliomys lenki* and *Hystrix* sp., documented in Teixoneres Cave but not in Toll Cave. Both are extinct species that became extinct from the Iberian Peninsula during the Late Pleistocene (López-García, 2011; López-García *et al.*, 2012b). *Pliomys lenki* is an extinct vole occupied the whole of the Iberian Peninsula during the first part of the Late Pleistocene, replacing the species *Pliomys episcopalis*. It became relict in northern Iberia during the Latest Pleistocene, since 35 ka BP, and finally disappeared around 13 ka BP (Sesé & Sevilla, 1996; López-García, 2011). The last record of this species in northeastern Iberia is from the Ermitons cave deposits dated approximately 36.4 ka BP (Alcalde, 1986), while in the north it persisted until the beginning of MIS 2 (24-10 ka BP), being recorded for last time in El Mirón Cave at 12.4 ka BP (Cuenca-Bescós *et al*., 2010).

Porcupine remains (*Hystrix* sp.) are well represented in Middle Pleistocene Iberian localities (Cuenca-Bescós *et al*., 1999), but during the Late Pleistocene its records become restricted to the north of the Iberian Peninsula, lasting until the end of MIS 4 (71-60 ka BP) (López-García, 2011; López-García *et al*., 2012b). The last records of this genus in Catalonia are from the earliest MIS 4-5 (> 60 ka BP) deposits from several sites, such as Cova d'Olopte B, Cova del Muscle and Cova del Gegant (López-García, 2011).

The presence of typical Late Pleistocene species that appear in the Iberian Peninsula from 90 ka BP, such as *M. (I.) cabrerae* or *Chionomys nivalis*, thus suggests a Late Pleistocene or more recent chronology for the Toll Cave sequence. Thus, considering the absence of these two rodents in Toll Cave and their last records are 60 ka BP for *Hystrix* sp. and 35 ka BP for *Pliomys lenki*, we can concluded that the analysed sequence is younger than 35 ka BP. The abundance of *Glis glis* and *Chionomys nivalis*, which first appear during the second half of the Late Pleistocene, seems to support these interpretations (Fig. 4).

Within the stratigraphic sequence of *Sector Entrada*, a number of differences between Level 3 and Level 2 can be detected. The most notable point is in Level 3 the presence of *Chionomys nivalis*, a vole species currently only found in mountain ranges and with clear preferences for cold temperatures; while in Level 2 this species is absent and there is a predominance of *M. (T.) duodecimcostatus*, a Mediterranean species that implies a climatic improvement and could indicate a Holocene date for this level. Indeed, Level 2 is likely to be younger than 13 ka BP (Fig. 4), since *C. nivalis* became relict in the Iberia Peninsula after this date. Its distribution since then became restricted to the present isolated areas, that in the case of Catalonia are located in the Pyrenees (Arribas, 2004; Pérez Aranda, 2009).

In short, the analysed levels belong probably to a chronology more recent than 35 ka BP, given the presence of typical species from the Late Pleistocene/Holocene such as *M. (I.) cabrerae*, *Chionomys nivalis* and *Glis glis* in conjunction with the absence of *Pliomys lenki* and *Hystrix* sp. Furthermore, the presence of *Chionomys nivalis* in Level 3 and its absence in Level 2 may imply a chronology older than 13 ka BP for the former and more recent than 13 ka BP for the latter.

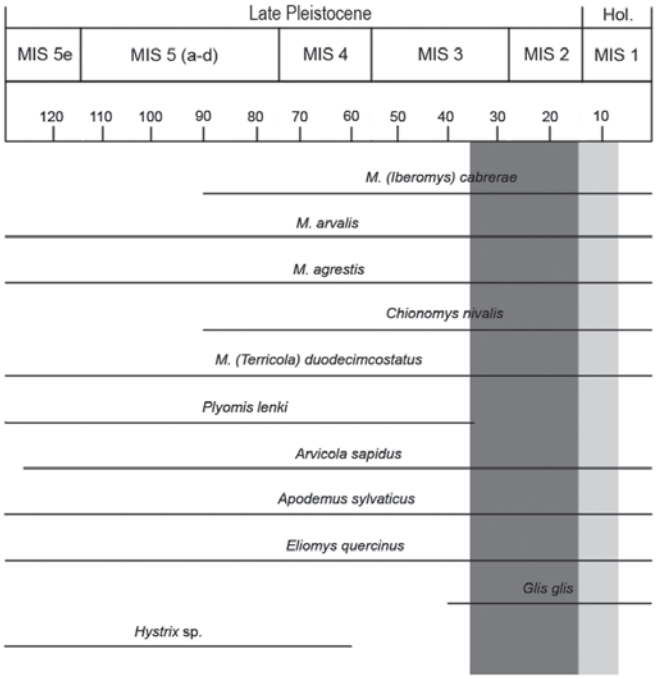

Figure 4. Range chart of the species recorded in Toll Cave and the possible chronological position of Level 3 and Level 2. MIS: Marine Isotope Stage; Hol.: Holocene.

4.2. Palaeoenvironmental approach

Without absolute dates it is difficult to establish a correlation between the studied levels of Toll Cave and the climatic events of the latest Pleistocene (40-10 ka BP) and the beginnings of the Holocene (<10 ka BP). However, the climatic results obtained and the established biochronological interpretation yield insights into which could be the climatic events associated to these two levels.

If we consider the relative chronology obtained from the rodent association of 35-13 ka BP for Level 3, the cold and wet conditions detected could be associated probably with some of the coldest peaks of the end of the Pleistocene such as Heinrich Event 3 (28-26 ka BP), Heinrich Event 2 (22.6-20.3 ka BP) or Heinrich Event 1 (15.4-13 ka BP) or also the Last Glacial Maximum (24-16.5 ka BP) (Sánchez-Goñi & d'Errico, 2005) (Fig. 5). The results obtained by rodents analysis shows that the most probably option is that this level belongs to the Last Glacial Maximum (around 18 ka BP). Whatever the case, it would be some time around these episodes, because even though the level is cold and humid, the identified association is not considered to reside at the peak of any of these events due to the marked presence of Mediterranean species such as *M. (T.) duodecimcostatus.*

Level 2, with a chronology that is likely to be more recent than 13 ka BP, seems rather to be an interstadial phase from the end of the Pleistocene, such as the Bölling/Alleröd period (15-13 ka BP), or one of the first cold phases from the Holocene, such as the Preboreal/Boreal (11.5-9.5 ka BP) (Uriarte, 2003; Sánchez-Goñi & d'Errico, 2005) (Fig. 5). Considering the dominance of *T. duodecimcostatus* in the Level 2 together with the absence of mid-European species, such as *Chionomys nivalis*, allow us to tentatively correlated this level with the first phase of the Holocene, the Preboreal (ca. 11.5-9.5 ka BP) (Uriarte, 2003).

4.3. Toll Cave and the northeastern Iberian Peninsula during the Late Pleistocene/Holocene transition

The Late Pleistocene/Holocene is represented in the northeastern region of the Iberian Peninsula by several localities, six of which have a close age to the Sector Entrada sequence of Toll Cave: Cova dels Xaragalls (48.24-13.72 ±0.09 ka BP), Cova de l'Arbreda (39.9-17.3 ka BP), Balma de la Griera (21.25 ±0.35 ka BP), Cova Colomera (13-3 ka BP), Cingle Vermell (9.76 ±0.16 ka BP) and Cova de la Guineu (9.8 ±0.8 ka BP) (Alcalde & Brunet-Lecomte, 1985; Alcalde, 1986; López-García *et al.,* 2010; 2012a; López-García, 2011). These Catalan sites cover the entire Upper Palaeolithic (35-10 ka BP) and include the first *Homo sapiens* occupations in this territory.

According to the available data, the rodent species present in northeastern Iberia Peninsula during the Late Pleistocene were predominantly mid-European taxa with ecological preference for cold environmental conditions (*M. arvalis* and *M. agrestis*), humid meadows (*M. agrestis* and *M. (T.) gerbei*) or open forests (*A. sylvaticus* and *E. quercinus*) (Alcalde, 1986; López-García, 2011). Assemblages with such characteristics have been described in levels C4-C1 of Cova dels Xaragalls (48.2-13.7 ka BP) (López-García, 2012a), in Level III of Balma de la Griera (21.2 ka BP) (Nadal, 2000) and in the oldest levels

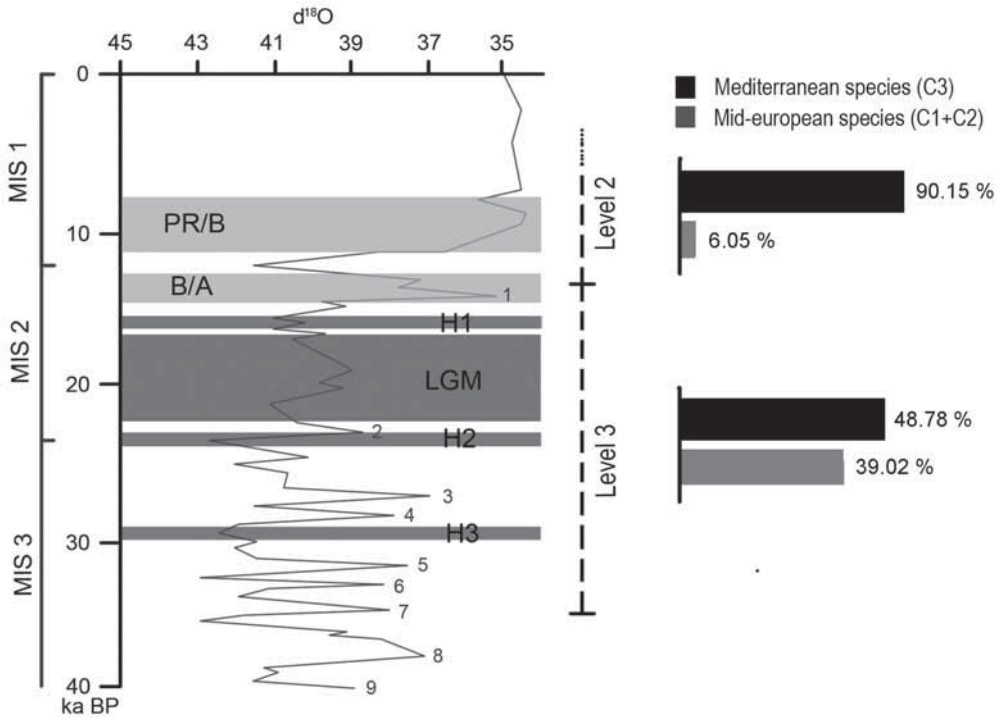

Figure 5. Latest Pleistocene-Holocene oxygen isotope curve with the location of the possible climatic episodes which could be associated with Level 3 and Level 2. Right, comparison by levels of Mediterranean species (chorotype 3) and mid-European species (chorotypes 1 and 2). The discontinuous lines show the biocronology established by the rodent assemblage. MIS: Marine Isotope Stage; PR/B: Preboreal/Boreal; B/A: Bölling/Alleröd; H: Heinrich Event; LGM: Last Glacial Maximum.

of Cova de l'Arbreda (39.9-17.3 ka BP) (Alcalde, 1986; López-García, 2011).

Of all these localities, Cova de l'Arbreda shows important similarities with Toll Cave. Its Late Pleistocene levels (39.9-17.32 ka BP) present a clear predominance of rodent species associated with open humid conditions (*M. arvalis*, *M. agrestis* and *M. (T.) duodecimcostatus*), whereas species associated with forest conditions are present in much lower proportions (*A. sylvaticus*, *G. glis* and *E. quercinus*). The association is also characterized by a strong representation of mid-European species (*M. arvalis* and *M. agrestis*), meaning cold conditions and open landscapes. These rigorous conditions increase from the Aurignacian Level or Level G (22.5 ka BP) to Indeterminate Palaeolithic Level (<17 ka BP), when a clear decrease in the temperature is inferred, as well as an increase of continental species representation in the assemblages (Alcalde & Brunet-Lecomte, 1985; Alcalde, 1986). The end of the stratigraphic sequence shows the beginning of a decrease in mid-European species (*M. agrestis* and *M. arvalis*) and a higher representation of Mediterranean taxa, such as *M. (T.) duodecimcostatus*, and in rodents linked to forest habitats. These faunal changes indicate a slight increase in temperature and moisture (Alcalde & Brunet-Lecomte, 1985; Nadal *et al*., 2002).

The transition from the Pleistocene to the climatic improvement related to the beginnings of the Holocene thus features an increase in species with warmer requirements (i.e., Mediterranean taxa) and species from forest biotopes, to the detriment of species associated with open habitats and cold environments. A similar change is detected in the Balma de la Griera sequence, where the fauna suggests a change from the Gravettian level or Level III (21.25 ka BP), with a fairly cold climate and an open landscape to a forested and temperate environment similar to nowadays during the formation of Level II (corresponding to an Epipalaeolithic occupation during the earliest Holocene) (Nadal, 2000). These faunal changes related to this transitional environment are also observed in the microfaunal association identified at Cingle Vermell (9.76 ka BP) (Alcalde & Brunet-Lecomte, 1985; Alcalde, 1986).

Thus, a generalised pattern is observed in rodent taxa replacement during the Pleistocene/Holocene transition in the northeastern Iberia, recorded in various localities covering this interval. Starting from an initial scenario in which mid-European species with cold requirements and open habitat preferences prevail (*M. arvalis*, *M. agrestis* and *C. nivalis*); the end of the Pleistocene and the beginning of the Holocene is characterized by an increase in taxa of Mediterranean character (*M. (T.) duodecimcostatus* and *M. (I.) cabrerae*) and liked to forest habitats (*A. sylvaticus* and *E. quercinus*), together with a decrease in mid-European species. Toll Cave fits well with this transitional pattern, but considering the relevant representation of *M. (T.) duodecimcostatus*, Level 3 would fit in a late stage of the initial conditions of this scenario, whereas Level 2 with those related to those of the earliest Holocene.

Considering the proximity of Teixoneres Cave, by correlating its Late Pleistocene sequence with that of Toll Cave, a wider temporal view may be obtained concerning environmental changes that took place in the region of Moià during the neanderthal/modern human replacement. In Teixoneres Cave, both Levels III (90-60 ka BP) and Level II (60-30 ka BP) assemblages indicate colder and more humid conditions than today developed in an open woodland landscape. These two levels differ in that yet a relatively warm and wet phase for Level III can be differentiated from a cold and dry phase for Level II. Both levels have provided Mousterian industry and other evidence of Neanderthal occupations, such as cut marks (López-García *et al*., 2012b).

According to their small mammal content, both localities present lower temperatures and higher precipitations than today. Level 3 and Level 2 in Toll Cave are of a more recent age and indicate a milder climate than Teixoneres Cave, though slightly colder and with higher rainfall values. Forests were still the predominant feature of the habitat during the Pleistocene/Holocene transition, but probably less dense that in the period represent by levels of Teixoneres Cave. Thus it seems that both the neanderthal and modern human populations that inhabited this area during the Late Pleistocene and earliest Holocene lived under similar climatic and environmental conditions, with no evidences of a relevant change that might be related to the replacement of *H. neanderthalensis* by *H. sapiens* (Fig. 6).

5. CONCLUSIONS

In this study of the rodents from Level 2, Level 3 and Level 4 of *Sector Entrada* of Toll Cave, a total of 216 remains have been collected, and these correspond to ten rodent taxa. The studied levels are chronologically located probably between the Latest Pleistocene and the beginnings of the Holocene (<35 ka BP), given the presence of typical species from the Late Pleistocene/Holocene (*M. (I.) cabrerae*, *C. nivalis* and *G. glis*) in addition with the absence of *P. lenki* and *Hystrix* sp. Furthermore, the presence of *C. nivalis* in Level 3 and its absence in Level 2 could indicated chronology older than 13 ka BP for the former and younger than 13 ka BP for the latter. Both levels denote a landscape dominated by an open wet forest with lower temperatures (between -3 ºC and -2 ºC) and higher rainfall (between +700 and +600 mm) than nowadays for this region, Level 3 being the colder and wetter. Thus, the transition between Level 3 and Level 2 shows an improvement in the weather conditions though in latter recent climatic values are not attained, temperatures remaining below recent values.

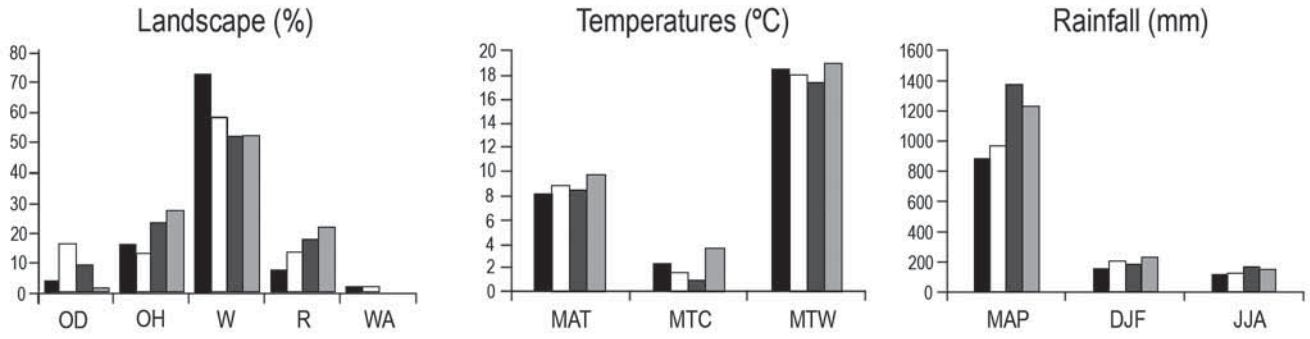

Figure 6. Environmental and climatic comparison between levels 2-3 from Toll Cave (black/white) and levels II-III from Teixoneres Cave (dark gray/light gray). In each category is represent from left to the right: Level 2 and Level 3 from Toll Cave and Level II and Level III from Teixoneres Cave. OD: open dry; OH: open humid; W: woodland; R: rocky; WA: water; MAT: mean annual temperature; MTW: mean temperature of warmest month; MTC: mean temperature of coldest month; MAP: mean annual precipitation; DJF: mean precipitation of winter months; JJA: mean precipitation of summer months. Environmental data in percentage (%), temperature data in degrees centigrade (ºC) and precipitation data in millimetres (mm).

According to the available data from other Late Pleistocene and early Holocene sites from the northeast of the Iberian Peninsula, the Late Pleistocene/Holocene transition is characterized by an early phase in which mid-European and open forest species dominated in the rodent assemblages to a later phase during the latest Pleistocene/early Holocene in which the representation of Mediterranean and typical forest species become more frequent accompanied with a notable decrease in the representation of mid-European species. The two assemblages from Toll Cave described in this paper seem to fit well with the end of the early phase (Level 3) and the later phase (Level 2). Finally, juxtaposing the results from Toll Cave with the data from Teixoneres Cave provides insights into the climatic and environmental evolution around Toll Cave between the Middle Palaeolithic and the Upper Palaeolithic/Neolithic and justifies the assertion that Neanderthals and anatomically modern humans lived in similar climatic and environmental conditions.

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