



USING SMALL MAMMALS TO RECONSTRUCT THE CLIMATIC CONTEXT OF THE LATE PLEISTOCENE LAGAR VELHO ROCKSHELTER (LEIRIA, PORTUGAL).

Juan Manuel López-García^{1,2}, Carlos Pimenta³, Ana Cristina Araújo^{3,4,5}, Ana Maria Costa^{3,4,6},
Montserrat Sanz^{5,7}, Joan Daura^{5,7}

¹ Institut Català de Paleoeologia Humana i Evolució Social (IPHES-CERCA), Campus Sescelades URV, Tarragona, Spain.

² Universitat Rovira i Virgili, Departament d'Història i Història de l'Art, Tarragona, Spain.

³ Laboratório de Arqueociências (LARC)-DGPC, Lisboa, Portugal.

⁴ InBIO, and CIBIO, University of Porto, Portugal.

⁵ UNIARQ-Centro de Arqueologia da Universidade de Lisboa, Universidade de Lisboa, Lisboa, Portugal.

⁶ IDL, Instituto Dom Luiz, Universidade de Lisboa, Lisboa, Portugal.

⁷ Grup de Recerca del Quaternari, GRQ-SERP, Department of History and Archaeology, University of Barcelona, Barcelona, Spain.

Corresponding author: Juan Manuel López-García <jmlopez@iphes.cat>

ABSTRACT: To reconstruct the climatic conditions of the Lagar Velho rockshelter during the late Pleistocene, we applied the bioclimatic model to the rodent assemblages, mainly composed of the vole species *Arvicola sapidus*, *Microtus arvalis*, *Microtus agrestis*, *Microtus (Terricola) lusitanicus* and *Microtus (Iberomys) cabreræ* and the field mouse *Apodemus sylvaticus*. Based on the distribution of these species by layers and percentages, considering different climate-types, and applying a series of functions, it was possible to estimate the mean annual temperature (MAT), the mean temperature of the coldest month (MTC), the mean temperature of the warmest month (MTW) and the mean annual precipitation (MAP). For comparative purposes, the resulting parameters were compared with climate data obtained for the last 30 years from nearby meteorological stations in order to attain averages and observe climatic fluctuations. The climatic parameters were then compared with the Köppen-Geiger classification in order to contrast our data with the current climate-types. Finally, we combined the results with chronological and environmental information to produce a climate framework within Marine Isotope Stage 2 (MIS 2).

Keywords: Bioclimatic model, Köppen-Geiger classification, Marine Isotope Stage 2, Heinrich events, Last Glacial Maximum, Iberian Peninsula.

1. INTRODUCTION

Marine Isotope Stage 2 (MIS 2; ca. 29 to 14.9 kyr B.P.) corresponds to the last portion of the most recent glaciation (Ishiwa et al., 2019). In the Iberian Peninsula, the pollen spectra for MIS 2 suggest in general an open landscape dominated by semi-arid vegetation (Fletcher & Sanchez-Goñi, 2008). This stage includes the Last Glacial Maximum (LGM, ca. 27-17 kyr B.P.), when the ice sheets reached their greatest volume (Hein et al., 2010; Ishiwa et al., 2019, among others). It also includes the most recent Heinrich events, which produced the IRD (ice-rafted debris) layers observed in marine sediment cores from the north Atlantic, notably Heinrich Event 3 (H3; ca. 31-29 kyr B.P.), which caused the collapse of the northern hemisphere ice shelves and the consequent release of a prodigious volume of icebergs (Bond & Lotti, 1995; Hemming, 2004, among others). Pollen studies have shown that LGM was characterized by humid conditions in southwestern Europe, allowing

the development of arboreal vegetation, a factor that further distinguishes it from the MIS 2 Heinrich events, during which there was a notable predominance of semi-arid vegetation (Fletcher & Sánchez-Goñi, 2008; Kageyama et al., 2005; Peyron et al., 1998). Likewise, faunal assemblages (small and large mammals) shows for the LGM in the Iberian Peninsula the presence of numerous temperate taxa, such as *Cervus elaphus*, *Capreolus capreolus* or *Vulpes vulpes* (Sommer & Nadachowski, 2006). Indicating that Iberia acts as glacial refugia for the temperate species.

In the light of this brief environmental characterization, the present study applies a bioclimatic model (following Hernández-Fernández, 2001a, 2001b) to the analysis of the rodent assemblages of the Lagar Velho rockshelter, located in the Lapedo Valley (Leiria, Portugal). The aim is to infer various climatic parameters, which will be further compared with the present climatic data, taking into account the available studies of the LGM and H3 small-vertebrate assemblages.

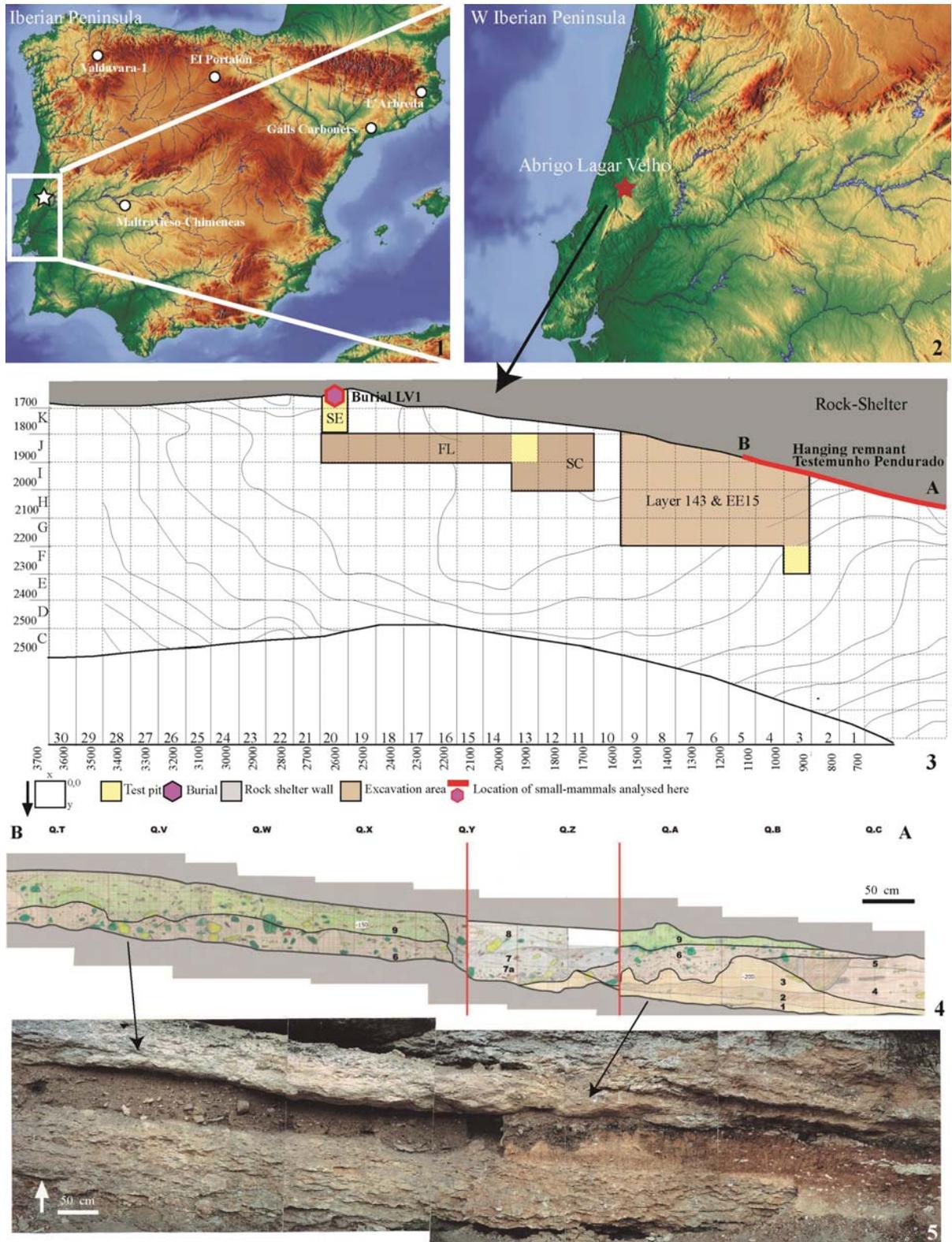


Fig. 1 - 1 and 2: Location of the main sites mentioned in the Iberian Peninsula, including the Lagar Velho rockshelter (2). 3: Plan of the Lagar Velho rockshelter showing the location of LV1 burial. 4 and 5: The Hanging Remnant (TP) with the position of TP06 and TP09 (courtesy of João Zilhão).

2. THE LAGAR VELHO SITE AND THE LAPEDO CHILD

The Lagar Velho rockshelter (Abrigo do Lagar Velho-ALV; 30°45'25"N; 8°43'58"W) is located in the Lapedo Valley in the municipality of Leiria, about 135 km north of Lisbon (Fig. 1.1, 1.2), on the left bank of the Caranguejeira stream. It was first discovered and excavated in late 1998, soon after the identification of the LV1 infant burial (Duarte et al., 1999). The top two/three metres of sediment overlying the burial had previously been removed by the shelter-owner by mechanical means; all that survived was a profile trapped inside a recess in the back wall of the shelter and labelled "Hanging Remnant" (Testemunho Pendurado / TP in Portuguese; henceforth TP; Fig. 1). On the one hand, levels TP09 and TP06 (see Fig. 1), which contain the small-mammal remains analysed in the present study, are included in the upper slope deposits (us), defined during the 1998 and 1999 investigations (Angelucci, 2002 in Zilhão & Trinkaus, 2002). The us sedimentary complex preserves traces derived from archaeological occupations that took place at ALV between the terminal Gravettian (level TP06) and the middle Solutrean (level TP09) (Zilhão & Almeida, 2002). These units are in general characterized by a coarse sedimentary component of angular limestone slabs originating from the shelter wall, and by a finer component of sandy silts and clayey silts rich in anthropogenic remains (Angelucci, 2002). Registered in the lower part of the us complex, level TP06 (Fig. 1.4) is characterized by sandy, dark brown-grey sediment with limestone clasts, with a maximum thickness of ca. 30 cm. It contains a much higher amount of archaeological remains than the overlying level TP09. Radiocarbon dating suggests that it was deposited between 25976-24955 cal yr B.P. (using the most consistent ^{14}C date of 21180 ± 240 B.P.; Pettitt et al., 2002; Tab. 7-4). Level TP09 (Fig. 1.5) is chaotically arranged in terms of its inclination and orientation. It comprises numerous limestone blocks and platelets of various dimensions, detached from the shelter wall by mechanical or cryogenic action. It has a maximum thickness of approx. 18 cm. The finer component consists of thin sands of a light cream colour, sometimes whitish, especially at the top in contact with the limestone, indicating some later carbonation of this deposit. Charcoal appears in large amounts and is ubiquitously distributed; faunal remains, also very numerous, show a relatively poor state of conservation. This unit is ^{14}C dated to 20200 ± 180 (Pettitt et al., 2002, Table 7-4), i.e. 24906-23877 cal yr B.P., 95% confidence (Tab. 1; Fig. S1).

On the other hand, the upper fine gravel and sand complex (gs) analysed in the framework of the present study was identified immediately under the artificial surface created after the bulldozer terracing and corresponds to the sedimentary layer where the infant was buried (Fig. 1.3). The burial was a single episode involving a complex and careful ritual (Duarte, 2002; Zilhão, 2005). The small mammal recovered in this sedimentary unit was not directly related to the burial, but to the sediments that accumulated in the level where the grave was opened. Radiocarbon dating of the burial has provided four ^{14}C dates from remains accompanying the

	Lab. Code	^{14}C age B.P.	Mean Calendar Age 2 σ cal yr B.P.	2 σ cal yr B.P.
TP09	OxA-8418	20220 \pm 180	24332 \pm 251	23877 - 24906
TP06	OxA-8420	21180 \pm 240	25483 \pm 258	24955 - 25976
	Sac-1561	21380 \pm 810	25687 \pm 889	23995 - 27433
	OxA-8419	22180 \pm 180	26442 \pm 245	26017 - 26971
	OxA-8422	23920 \pm 220	28025 \pm 219	27637 - 28485
Child Burial	OxA-8423	24520 \pm 240	28550 \pm 269	27982 - 29077
	OxA-8421	24660 \pm 260	28714 \pm 295	28119 - 29332
	GrA-13310	24860 \pm 200	28924 \pm 229	28494 - 29407
bs complex/tc complex interface	OxA-10849	27100 \pm 100	31100 \pm 90	30915 - 31278

Tab. 1 - Radiocarbon results for TP06, TP09 and Child's Burial sediments modified from Pettitt et al. (2002) and calibrated using OxCal 4.2.4 software (Bronk Ramsey, 2009) and the Intcal'13 curve (Reimer et al. 2013).

burial, giving a range between 27637-29407 cal yr B.P. (Pettitt et al., 2002; Zilhão & Almeida, 2002) (Tab. 1; Fig. S1). Another ^{14}C sample from the bs/tc complex interface, i.e. around 1m below the sepulchre, gives a range between 31278-30191 cal yr B.P. (Tab. 1; Fig. S1). Therefore, the small mammals date to between the burial event (ca. 29.4-27.6 kyr B.P.) and the age obtained for the underlying layer (ca. 31 kyr B.P.).

3. MATERIAL AND METHODS

3.1. Small-mammal sorting, palaeontological and taphonomic studies and palaeoenvironmental reconstruction

The small-mammal fossil remains used in this study come from layers TP06, TP09 and from the sediments where the LV1 child was buried, in the upper gs complex. The assemblage consists of disarticulated bone fragments collected in a very small volume of sediments (ca. 1 m³), although this is extremely rich in faunal remains. Sediments from the TP layers were water-sieved through a 2.5 mm mesh in the field (Moreno-García & Pimenta, 2002), whereas the sediments from the child burial were water-sieved through a 1.5mm mesh in the laboratory (Moreno-García, 2002). A preliminary small-mammal list was published by Moreno-García & Pimenta (2002), and a revision was recently undertaken in January 2020 at the Laboratório de Arqueociências (LARC) in Lisbon, during a short stay by the corresponding author. The assemblage under study is small and includes a total of 135 identified remains, corresponding to a minimum number of 75 individuals belonging to 11 different taxa (Tab. 2; Fig. 2). The fragments were identified at LARC following the general criteria of systematic palaeontology (Appendix S1). Specific identification was based principally on the best diagnostic elements, such as mandible and maxilla for shrews and hedgehogs; first lower molars for the subfamily Arvicolinae; and mandibles and maxilla for the subfamily Murinae. Specimens were grouped using the minimum number of individuals (MNI) method, determined by counting the most diagnostic element of each species by layers. Following Andrews (1990) and Fernández-Jalvo et al. (2016), alterations caused by digestion in the first lower molars of the arvicoline rodent species were observed, but a probable bias in the methodology of collecting the samples

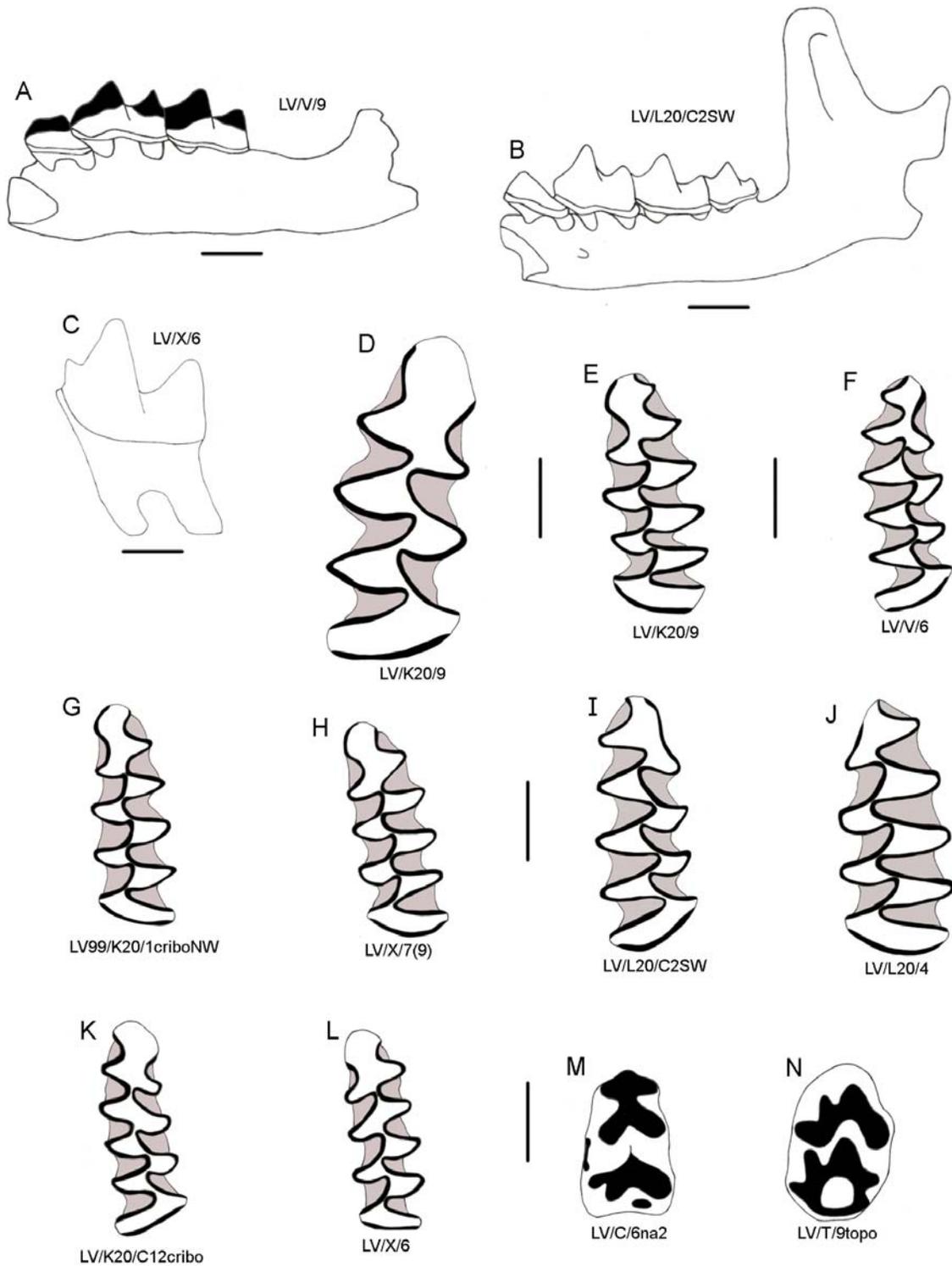


Fig. 2 - Some small-mammal material identified from the studied levels of Lagar Velho. A. left mandible *Sorex* sp. (buccal view); B. left mandible *Crocidura* cf. *suaveolens* (buccal view); C. left m2 *Talpa* cf. *occidentalis* (buccal view); D. right m1 *Arvicola sapidus* (occlusal view); E and F. left and right m1 *Microtus agrestis* (occlusal view); G and H. two left m1 *Microtus arvalis* (occlusal view); I and J. right and left m1 *Microtus (Iberomys) cabrerai* (occlusal view); K and L. right and left m1 *Microtus (Terricola) lusitanicus* (occlusal view); M and N. left m1 and M1 *Apodemus sylvaticus* (occlusal view). Scales 1 mm.

	TP09			TP06			Underlying the Child Burial		
	NISP	MNI	%	NISP	MNI	%	NISP	MNI	%
<i>Erinaceus</i> sp.	0	0	0.00	0	0	0.00	1	1	6.67
<i>Talpa occidentalis</i>	2	1	2.94	4	1	3.85	0	0	0.00
<i>Crocidura</i> cf. <i>C. suaveolens</i>	2	1	2.94	1	1	3.85	2	1	6.67
<i>Sorex</i> sp. (cf. <i>granarius</i>)	3	1	2.94	0	0	0.00	0	0	0.00
<i>Arvicola sapidus</i>	6	4	11.76	7	4	15.38	7	5	33.33
<i>Microtus agrestis</i>	21	12	35.29	11	7	26.92	2	1	6.67
<i>Microtus arvalis</i>	4	3	8.82	0	0	0.00	2	1	6.67
<i>M. arvalis-agrestis</i>	0	0	0.00	1	1	3.85	0	0	0.00
<i>M. (Iberomys) cabreræ</i>	2	1	2.94	1	1	3.85	1	1	6.67
<i>M. (Terricola) lusitanicus</i>	8	5	14.71	14	8	30.77	5	3	20.00
<i>Apodemus sylvaticus</i>	14	6	17.65	9	3	11.54	5	2	13.33
Total	62	34	100	48	26	100	25	15	100

Tab. 2 - Representation of the small-mammal material identified from the Lagar Velho rockshelter. NISP is the number of identified specimens; MNI is the minimum number of individuals; and % is the percentage of MNI.

precluded a quantitative taphonomic interpretation. This is because the screen meshes both of 2.5 mm used for the TP layers and of 1.5 mm used for the child burial were too large to recover certain small microvertebrate elements considered relevant to this research. This comes to light through the absence of isolated teeth belonging to small taxa such as *A. sylvaticus* or *S. cf. granarius* (Appendix S1). Finally, the application of quantitative palaeoenvironmental methods such as habitat weightings (see Evans et al., 1981; Andrews, 2006) was also ruled out by the methodological bias of the sample collecting. However, we took into account the current habitat preferences of the identified species for our interpretation and discussion, using the published works of Palomo et al. (2007) and Bencatel et al. (2017).

3.2. Palaeoclimatic reconstruction

Considering the bias recovering the small-mammal and the low number of small mammals remains recovered, quantitative methods have been avoided. Then we used a method for the obtention of climatic parameters based on the faunal list. After that, to reconstruct the climatic conditions at ALV during the above-mentioned human occupations we used the bioclimatic model (Hernández-Fernández, 2001a and b). This method is based on the hypothesis that a significant correlation exists between climate and mammal communities. The rodent assemblage from the three analysed layers at ALV corresponds to four of the ten climatic types described by Hernández-Fernández (2001a and b), Hernández-Fernández & Peláez-Campomanes (2005) and Hernández-Fernández et al. (2007): IV, subtropical with winter rains and summer droughts; VI, typical temperate; VII, arid temperate; and VIII, cold temperate (boreal). The assemblages were analysed using the climatic restriction index ($CRI_i = 1/n$, where “n” is the number of climatic zones where the species are represented and “i” is the climatic zone where the species appears) (Table 3). The bioclimatic component (BC; representation, by level, of each of the four represented climates) was then calculated using the following formula: $BC_i = (\sum CRI_i) \times 100/S$, where S is the number of species per unit of each site (Tab. 3). From BC, a mathematical model was elaborated using a multiple linear

	TP09			
	IV	VI	VII	VIII
<i>Arvicola sapidus</i>	0.5		0.5	
<i>Microtus agrestis</i>		0.5		0.5
<i>Microtus arvalis</i>			1	
<i>M. (Iberomys) cabreræ</i>	1			
<i>M. (Terricola) lusitanicus</i>	1			
<i>Apodemus sylvaticus</i>	0.5	0.5		
Σ CRI	3	2	0.5	0.5
Bc_i=(Σ CRI_i)100/S	50	33.3	8.3	8.3

	TP06			
	IV	VI	VII	VIII
<i>Arvicola sapidus</i>	0.5		0.5	
<i>Microtus agrestis</i>		0.5		0.5
<i>M. (Iberomys) cabreræ</i>	1			
<i>M. (Terricola) lusitanicus</i>	1			
<i>Apodemus sylvaticus</i>	0.5	0.5		
Σ CRI	3	1	0.5	0.5
Bc_i=(Σ CRI_i)100/S	60	20	10	10

	Underlying Child Burial			
	IV	VI	VII	VIII
<i>Arvicola sapidus</i>	0.5		0.5	
<i>Microtus agrestis</i>		0.5		0.5
<i>Microtus arvalis</i>			1	
<i>M. (Iberomys) cabreræ</i>	1			
<i>M. (Terricola) lusitanicus</i>	1			
<i>Apodemus sylvaticus</i>	0.5	0.5		
Σ CRI	3	2	0.5	0.5
Bc_i=(Σ CRI_i)100/S	50	33.3	8.3	8.3

Tab. 3 - Distribution of the rodent species identified from the different analysed sites according to their climate preferences, in accordance with Hernández-Fernández (2001b) and Hernández-Fernández et al. (2007). IV subtropical with winter rains and summer droughts; VI typical temperate; VII arid-temperate; VIII cold-temperate (boreal). CRI: climatic restriction index; Bc: bioclimatic component.

regression (Hernández-Fernández & Peláez-Campomanes, 2005). By means of a series of functions, this yielded estimates for the mean annual temperature (MAT), the mean temperature of the coldest month (MTC), the mean temperature of the warmest month (MTW) and the mean annual precipitation (MAP) (Table S1). A comparison was drawn with 30-year climatic data (from Climate-Data.org) from the meteorological station of Leiria (Leiria, Portugal), located at 36 m above sea level (a.s.l.), with MAT=15.9°C, MTW=21.1°C, MTC=10.8°C and MAP=790 mm. To place our data in a global context, we used the Köppen-Geiger climatic classification (Köppen & Geiger, 1936), with updates according to Peel et al. (2007) and Beck et al. (2018). This classification is based on mean annual and monthly temperatures and precipitation, using the native vegetation to determine the climate types.

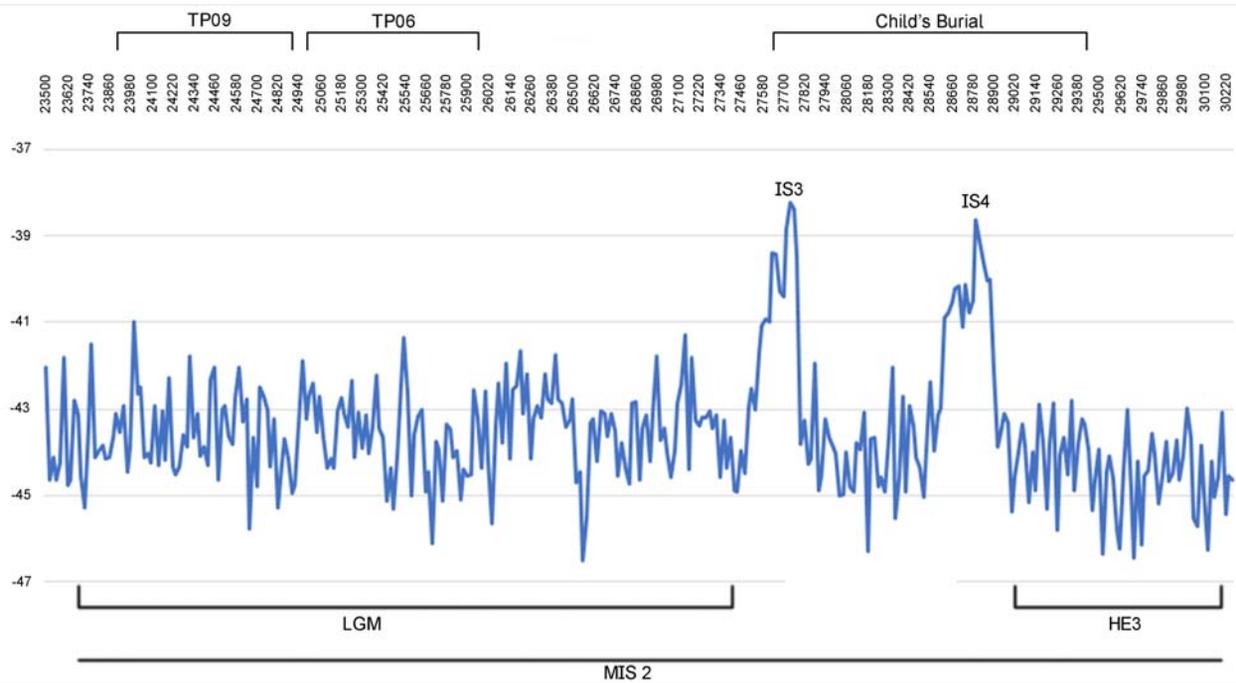


Fig. 3 - Chronological position of the studied levels of Lagar Velho (x axis) in relation to the benthic ¹⁸O (y axis) isotope curve (modified from Lisiecki & Raymo, 2005).

4. RESULTS AND DISCUSSION

4.1. The small-mammal composition of the Lagar Velho rockshelter and some palaeoenvironmental remarks

The small-mammal remains recovered from the different layers of the Lagar Velho site are scarce, but the number of identified species is relatively high, with at least ten taxa. From the point of view of the presence / absence of species, the small-mammal composition is very constant, with the three studied layers showing few differences (Tab. 2). *Erinaceus* sp. is present in the upper part of the gs complex where the child was buried, whereas *Talpa occidentalis* and *Sorex* sp. are absent. In level TP06 *Erinaceus* sp., *Microtus arvalis*

and also *Sorex* sp. are absent, whereas in TP09 the only absent species is *Erinaceus* sp. (Tab. 2). From a quantitative point of view (although this should be taken with caution due to the scarcity of remains), the sediment excavated in the upper gs complex possesses the greatest representation of the small-mammal assemblage (Tab. 2), with *Arvicola sapidus*, *Microtus (Terricola) lusitanicus* and *Apodemus sylvaticus* being identified. These three species are widely distributed nowadays in Portugal, and their relative abundance indicates an open forest and relatively humid conditions with stable water courses surrounding the site (Paupério et al., 2017). *Arvicola sapidus*, *Microtus (Terricola) lusitanicus*, *Microtus agrestis* and *Apodemus sylvaticus*, identified in layer TP06, represent almost 85% of the small-mammal assemblage (Tab. 2). Of these four species, *Microtus agrestis* occurs almost exclusively in the north and centre-north of Portugal (Paupério et al., 2017), but it is also widely distributed in the northern part of the Iberian Peninsula from Galicia to the Pyrenees (Palomo et al., 2007). Their relative abundance in TP06 indicates open forest with relatively humid conditions and stable water courses in the vicinity of the site. The dominant species in TP09 are the same as in TP06, representing almost 80% of the small-mammal assemblage, although unlike in the previous layer *Microtus arvalis* is represented (Tab. 2). *Microtus arvalis* is currently found in the extreme northeast of Portugal (Paupério et al., 2017) and may indicate drier conditions during the accumulation of layer TP09.

	TP09	TP06	Underlying Child Burial	r2	SE
MAT	13.31	13.34	13.31	0.93	3.637
ΔMAT	-2.59	-2.56	-2.59		
MTW	22.69	24.24	22.69	0.746	4.754
ΔMTW	1.59	3.14	1.59		
MTC	4.69	2.94	4.69	0.932	5.081
ΔMTC	-6.11	-7.86	-6.11		
MAP	664.02	302.71	664.02	0.746	470.615
ΔMAP	-125.98	-487.30	-125.98		

Tab. 4 - Relation of temperatures and precipitation for the different studied layers; MAT, mean annual temperature; MTW, mean temperature of warmest month; MTC, mean temperature of coldest month; MAP, mean annual precipitation; present-day values from the Leiria meteorological station; Δ: difference between the values obtained by analysing rodents from the different sites and the present-day mean.

Other proxy studies conducted on the archaeological remains, e.g. studies of the archaeobotanical and other vertebrate taxa, indicate the following: 1) that the

charcoal documented in the child burial shows a lower degree of preservation, but there are specimens belong to *Pinus sylvestris* s.l. (Queiroz, 2002); 2) that analysis of the pollen recovered from the excavation pit under the child burial does not provide a basis for palaeovegetation and palaeoenvironmental reconstruction (Queiroz et al., 2002); and 3) that *Oryctolagus cuniculus* represents more than 85% of the faunal assemblage identified in the burial (Moreno-García, 2002). For layers TP06 and TP09, however, the presence/absence of certain types of charcoal reflects both the local vegetation and the choices of the human groups. No major differences were detected between layers and samples. The species *Pinus sylvestris*, *Erica arborea*, *Cytisus scoparius* and *Ulex* sp. represent at least 80% of the total assemblage. The scots pine is the dominant arboreal taxon, indicating an open, forested landscape without evidence of Mediterranean-type vegetation (Queiroz et al., 2002). This pattern partially coincides with our small-mammal data, where open forest is well represented in both TP layers by *Apodemus sylvaticus* and *Microtus (Terricola) lusitanicus*. In addition, the large-mammal assemblage identified in TP06 shows a predominance of horse (*Equus* sp.), followed by red deer (*Cervus elaphus*) and hare (*Lepus* sp.), indicating the occurrence of more open spaces of a grassland type. The abundance of the above-mentioned species in TP09 is accompanied by an increase in wild boar, the occurrence of roe deer and lynx, and a decline in hare relative to TP06. These data suggest an increase in forest cover compared to the fauna recovered from the sediments underlying the burial grave (Moreno-García & Pimenta, 2002). The large-mammal data for the TP units coincide with a slight increase in the representation of small-mammal species associated with forest requirements, such as *Apodemus sylvaticus*, from layer TP06 (where this species represents 11.5% of the small-mammal assemblage) to layer TP09 (where it represents 14.7% of the small-mammal assemblage). Statistically, application of the chi-square test to the small-mammal taxa represented in both units and the MNI shows there to be no significant differences in the small-mammal composition between TP09 and TP06, yielding the same probability p (same) = 0.7998.

4.2. Palaeoclimatic reconstruction

The ^{14}C results obtained for the two TP units and the child burial (Zilhão & Almeida, 2002) suggest that the burial may have occurred between Heinrich Event 3 (HE 3) and Interstadial 4 (IS 4), and TP06 and TP09 during the Last Glacial Maximum (LGM) (Fig. 3).

Using the rodent assemblage to compare the Lagar Velho data with current climatic data (Tab. 4), the bioclimatic model points to conditions that were cooler (ΔMAT between -2.58°C and -2.56°C) and dryer (ΔMAP between -488 mm and -126 mm) for all studied layers. The thermal gradient between summer and winter was higher than at present (ΔMTW between $+1.58^\circ\text{C}$ and $+2.65^\circ\text{C}$; ΔMTC between -7.87°C and -6.12°C), providing a more continental-temperate climate (warm summers, very cold winters and low rainfall) than present-day conditions, which are characterised as Mediterranean

an oceanic (mild summers and mild, rainy winters). Indeed, in terms of the Köppen-Geiger climatic classification (modified from Peel et al., 2007 and Beck et al., 2018), the current climate at Leiria is considered Csb (Mediterranean oceanic), with MTW values not exceeding 22°C and MTC above 0°C , whereas the climate projected from the ALV rodent assemblage shows a Dfa climate (continental temperate), with MTW values above 22°C and MTC below 0°C . These data may explain the coexistence of species with different ecological requirements that do not have an analogous distribution nowadays, according to Sans-Fuentes & Ventura (2000) and López-García et al. (2010a). Species with mid-European requirements such as *Microtus arvalis* and *M. agrestis* appear together with species of strictly Mediterranean requirements such as *M. (Iberomys) cabreræ*. Although the anthracological studies of layers TP06 and TP09 (Queiroz et al., 2002) have shown no evidence of Mediterranean species among the charcoal samples, the small-mammal assemblage points to the presence of Mediterranean species such as the taxon *M. (Iberomys) cabreræ* (Tab. 2), albeit in low numbers.

4.3. Lagar Velho in the context of the Iberian MIS 2

The discovery at the time of an Upper Palaeolithic (late Pleistocene) burial, highlighted the importance of the Lagar Velho rockshelter, which represented the evidence of the presence of modern humans in southern Iberia during the MIS 2 (Duarte et al., 1999).

Chronologically similar, there are other MIS 2 sites in the Iberian Peninsula where H3 and LGM have been detected on the basis of small-vertebrate studies. For H3 we found the Galls Carboners site located at Mont-Ral (Tarragona, northeastern Iberia) (López-García et al., 2014), whereas for LGM we found various sites: layers C and B of l'Arbreda cave in Serinyà (Girona, northeastern Iberia) (López-García et al., 2015); Maltravieso-Chimeneas cave in Cáceres (Extremadura, western Iberia) (Bañuls-Cardona et al., 2012); layer P1 of El Portalón cave at Sierra de Atapuerca (Burgos, northern Iberia) (López-García et al., 2010b) and the Lower Unit of Valdavara-1 cave in Becerreá (Lugo, northwestern Iberia) (López-García et al., 2011).

As expounded above, the scarcity of small-mammal remains may make climatic interpretations and correlations difficult. Nonetheless, the qualitative climatic data obtained from the rodent association indicate that the underlying burial may have happened during a cool period, as is indicated by a lower MAT (-2.58°C) than at present. However, the conditions are a little milder than those detected for H3 in the Galls Carboners site, where the MAT was 3.72°C lower than nowadays (Fig. 4) (López-García et al., 2014).

The interpretation of layers TP06 and TP09, situated chronologically within LGM (Fig. 3), and their comparison with other sites of similar chronology seem more plausible. In general, all sites with small-vertebrate studies attributed to LGM are associated with cold climatic fluctuations characterized by MAT lower than at present (Fig. 4). However, those sites located in central-north and northwestern Iberia with a greater oceanic and continental influence, such as El Portalón-

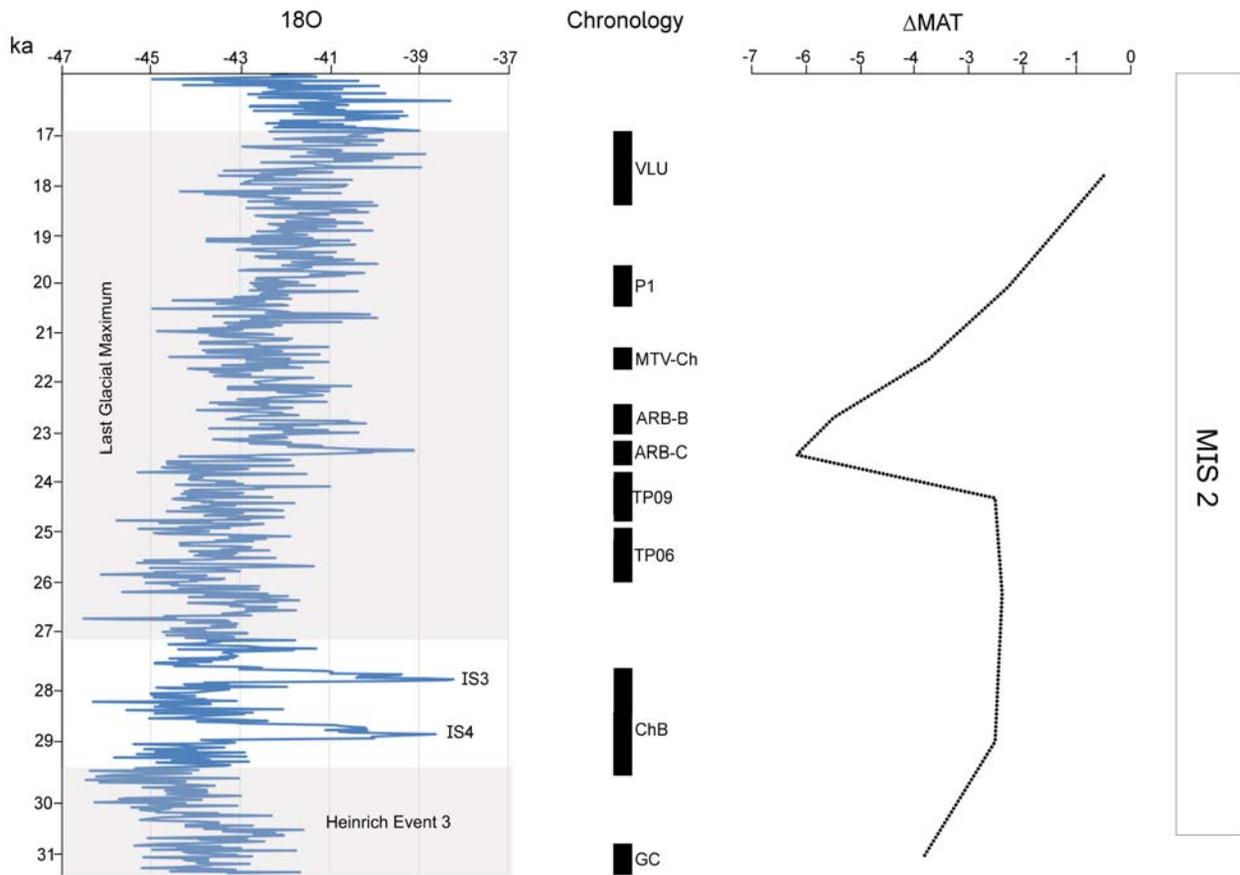


Fig. 4 - Comparison of the benthic ^{18}O isotope curve (modified from Lisiecki & Raymo, 2005) from 32 to 16 ka with the absolute dating range of the analysed sites and the difference (Δ) with respect to the present-day mean annual temperature (MAT) obtained on the basis of the rodent assemblages of various sites. GC: Galls Carboners; ARB: l'Arbreda cave; MTV-Ch: Maltravieso-Chimeneas; P1: El Portalón; VLU: Valdavara-1 lower unit; and ChB, TP06 and TP09: the levels of Lagar Velho studied in the present manuscript.

P1 and Valdavara-1-LU, have an MAT that is more similar to present-day values in the area in comparison with other sites which also fall within LGM, such as our studied layers, Maltravieso-Chimeneas and l'Arbreda cave layers C and B (Fig. 4). We also found differences among these sites. Whereas in Maltravieso-Chimeneas and Lagar Velho TP06 and TP09, the MAT is very similar, in l'Arbreda cave it is substantially lower (Fig. 4). These differences can be explained by the small-mammal associations. According to Sans-Fuentes & Ventura (2000) and López-García et al. (2010a), the small-mammal associations of the LGM layers of l'Arbreda cave are dominated by species with mid-European requirements such as *Microtus arvalis* and *Microtus agrestis*, along with an abundant representation of *Microtus oeconomus* and a lower representation of *Apodemus sylvaticus* (López-García et al., 2015). By contrast, the small-mammal association of Maltravieso-Chimeneas is very similar to levels TP06 and TP09 of Lagar Velho, represented by a combined association of species with mid-European requirements, such as *Microtus arvalis* and *Microtus agrestis*, with others with Mediterranean requirements, such as *Microtus*

(*Iberomys cabreræ*, together with a relative abundance of *Apodemus sylvaticus* (Bañuls-Cardona et al., 2012).

5. CONCLUSIONS

Our review of the small-mammal material from the Lagar Velho rockshelter leads to the following conclusions:

The species *Microtus (Terricola) lusitanicus* was identified during the present study, thus refining the previous identification placed within the duodecimcostatus-lusitanicus group. Likewise, *Microtus arvalis* and *Microtus agrestis* were recognized both species being present in the reviewed layers. Finally, *Microtus (Iberomys) cabreræ*, which had not previously been identified, is added to the taxonomic list.

From a taphonomic point of view, although certain degrees of digestion were observed, especially in arvicoline molars, a probable methodological bias in the recovery of the samples, which saw the sediments from the TP layers water-sieved through a 2.5 mm mesh in the field and the sediments underlying the child burial water-sieved through a 1.5 mm mesh in the laboratory,

precludes a taphonomic interpretation of the association.

This bias could be also affected the representation in the studied small mammals community.

The same can be argued regarding the application of quantitative methods to an environmental reconstruction. The small-mammal assemblage suggests the presence of an open forest in the vicinity of the rockshelter, which is consistent with the data previously published based on charcoal and large mammals.

Although it has been taken with caution, the application of the qualitative method of the bioclimatic model to the rodent assemblage shows the different layers analysed at the Lagar Velho rockshelter to have a cooler and relatively drier climate than nowadays, marked by more rigorous winter temperatures and slightly milder summer temperatures.

In the light of the chronological position of the Lagar Velho rockshelter (considering the small-mammal association of the studied layers), it can be seen that layers TP06 and TP09 present similar micromammal compositions to all the other sites with small-vertebrate studies that fall within LGM, reflecting cold climatic fluctuations and mean annual temperatures lower than at present.

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REFERENCES

- Andrews P. (1990) - Owls, Caves and Fossils. Predation, Preservation and Accumulation of Small Mammal Bones in Caves, with an analysis of the Pleistocene Cave Faunas from Westbury-sub-Mendip, Somerset, UK. The University Chicago Press, London, pp. 239.
- Andrews, P. (2006) - Taphonomic effects of faunal impoverishment and faunal mixing. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 241, 572-589.
- Angelucci D. (2002) - The Geochronological context. in: Zilhão J., Trinkaus E. (Eds.), *Portrait of the artist as a child. The Gravettian human skeleton from the Abrigo do Lagar velho and its archeological context.* IPA (Trabalhos de Arqueologia, 22), Lisbon, 58-91.
- Bañuls-Cardona S., López-García J.M., Blain H.-A., Canals A. (2012) - Climate and landscape during the Last Glacial Maximum in southwestern Iberia: The small vertebrate association from the Sala de las Chimeneas, Maltravieso, Extremadura. *C.R. Palevol* 11, 31-40.
- Beck H. E., Zimmermann N.E. McVicar T.R., Vegopoulou N., Berg A., Wood E.F. (2018) - Present and future Köppen-Geiger climate classification maps at 1-km resolution. *Sci. Data.*, 5, 180214.
- Bencatel J., Álvares F., Moura A. E. Barbosa A.M. (Eds.). (2017) - *Atlas de Mamíferos de Portugal.* Universidade de Évora, Portugal, pp. 271.
- Bond G.C., Lotti R. (1995) - Iceberg Discharges into the North Atlantic on Millennial Time Scales During the Last Glaciation. *Science*, 267,1005-1010.
- Bronk Ramsey C. (2009) - Bayesian analysis of radiocarbon dates. *Radiocarbon*, 51, 337-360.
- Duarte C. (2002) - The burial Taphonomy and ritual. in: Zilhão J., Trinkaus E. (Eds.), *Portrait of the artist as a child. The Gravettian human skeleton from the Abrigo do Lagar velho and its archeological context.* IPA (Trabalhos de Arqueologia, 22), Lisbon, 187-201.
- Duarte C., Maurício J., Pettitt P.B., Souto P., Trinkaus E., van der Plicht H., Zilhão J. (1999) - The upper early Paleolithic human skeleton from the Abrigo do Lagar Velho (Portugal) and modern human emergence in Iberia. *Proc. Natl. Acad. Sci. USA* 96, 7604-7609.
- Evans E.M.N., Van Couvering J.A.H., Andrews P. (1981) - Palaeoecology of Miocene Sites in Western Kenya. *J. Hum. Evol.*, 10, 99-116.
- Fernández-Jalvo Y., Andrews P., Denys C., Sesé C., Stoetzel E., Martín-Monfort D., Pesquero D. (2016) - Taphonomy for taxonomists: implications of predation in small mammal studies. *Quat. Sci. Rev.*, 139, 138-157.
- Fletcher W., Sánchez-Goñi M.A. (2008) - Orbital and sub-orbital scale climate impacts on vegetation of the western Mediterranean basin over the last 48 000 years. *Quat. Res.*, 70, 451-464.
- Hein A.S, Hulton N. R.J., Dunai T.J., Sugden D.E., Kaplan M.R., Xu S. (2010) - The chronology of the Last Glacial Maximum and deglacial events in central Argentine Patagonia. *Quat. Sci. Rev.*, 29, 1212-1220.
- Hemming S.R. (2004) - Heinrich events: Massive late Pleistocene detritus layers of the North Atlantic and their global climate imprint. *Rev. Geophys.*, 42, RG1005, pp 43.
- Hernández-Fernández M., (2001a) - Bioclimatic discriminant capacity of terrestrial mammal faunas. *Glob. Ecol. Biogeogr.*, 10, 189-204.
- Hernández-Fernández M. (2001b) - Análisis paleoecológico y paleoclimático de las sucesiones de mamíferos del Plio-Pleistoceno ibérico. PhD Thesis. Universidad Complutense de Madrid, Madrid, 379.
- Hernández-Fernández M., Peláez-Campomanes P. (2005) - Quantitative palaeoclimatic inference based on mammal faunas. *Glob. Ecol. Biogeogr.*, 14, 39-56.
- Hernández-Fernández M., Álvarez-Sierra M.A., Peláez-Campomanes P. (2007) - Bioclimatic analysis of rodent palaeofaunas reveals severe climatic chan-

- ges in Southwestern Europe during the Pliocene-Pleistocene. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 251, 500-526.
- Ishiwa T., Yokoyama Y., Okuno J., Obrochta S., Uehara K., Ikehara M., Miyairi Y. (2019) - A sea-level plateau preceding the Marine Isotope Stage 2 minima revealed by Australian sediments. *Sci. Rep.*, 9, 6449.
- Kageyama M., Combourieu Nebout N., Sepulchre P., Peyron O., Krinner G., Ramstein G., Cazet J.-P. (2005) - The Last Glacial Maximum and Heinrich Event 1 in terms of climate and vegetation around the Alboran Sea: a preliminary model-data comparison. *C.R. Geoscience*, 337, 983-992.
- Köppen W., Geiger R. (1936) - *Handbuch der Klimatologie*. Hansebok, Berlin, 588.
- Lisiecki L.E., Raymo M.E. (2005) - A Pliocene-Pleistocene track of 57 globally distributed benthic $\delta^{18}\text{O}$ records. *Paleo* 20, PA1003, 1-17.
- López-García J.M., Blain H.A., Allué E., Bañuls S., Bargalló A., Martín P., Morales J.I., Pedro M., Rodríguez A., Solé A., Oms F.X. (2010a) - First fossil evidence of an "interglacial refugium" in the Pyrenean region. *Naturwissenschaften*, 97, 753-761.
- López-García J.M., Dorado-Valiño M., Blain H.-A., Cuenca-Bescós G., Ruiz-Zapata M.B., Valdeolmillos A., Gil-García M.J., Arsuaga J.L., Carretero J.M., de Castro J.M.B., Carbonell E., Ortega A.I. (2010b) - Palaeoenvironmental and palaeoclimatic reconstruction of the latest Pleistocene of El Portillon site, Sierra de Atapuerca, northwestern Spain. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 292, 453-464.
- López-García J.M., Blain H.A., Cuenca-Bescós G., Alonso S., Vaquero M., Alonso, C. (2011) - Small vertebrates (Amphibia, Squamata, Mammalia) from the late Pleistocene-Holocene of the Valdavara-1 cave (Galicia, northwestern Spain). *Geobios*, 44, 253-269.
- López-García J.M., Blain H.A., Bennàsar M., Alcover J.A., Bañuls-Cardona S., Fernández-García M., Fontanals M., Martín P., Morales J.I., Muñoz L., Pedro M., Vergés J.M. (2014) - Climate and landscape during the Heinrich Event 3 in southwestern Europe: the small-vertebrate association from Galls Carboners cave (Mont-Ral, Tarragona, north-eastern Iberia). *J. Quat. Sci.*, 29, 130-140.
- López-García J.M., Soler N., Maroto J., Soler J., Alcalde G., Galobart À., Bennàsar M., Burjachs F. (2015) - Palaeoenvironmental and palaeoclimatic reconstruction of the Latest Pleistocene of L'Arbreda Cave (Serinyà, Girona, northeastern Iberia) inferred from the small-mammal (insectivore and rodent) assemblages. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 435, 244-253.
- Moreno-García M. (2002) - The Faunal Element in the Burial, in: Zilhão J., Trinkaus E. (Eds.), *Portrait of the artist as a child. The Gravettian human skeleton from the Abrigo do Lagar velho and its archaeological context*. IPA (Trabalhos de Arqueologia, 22), Lisbon, 139-151.
- Moreno-García M., Pimenta C.M. (2002) - The Paleofaunal Context, in: Zilhão J., Trinkaus E. (Eds.), *Portrait of the artist as a child. The Gravettian human skeleton from the Abrigo do Lagar velho and its archaeological context*. IPA (Trabalhos de Arqueologia, 22), Lisbon, 112-131.
- Palomo J.L., Gisbert J., Rey J.C. (2007) - *Atlas de los Mamíferos Terrestres de España*. Dirección General para la Biodiversidad-SECEM-SECEMU, Madrid, 586.
- Paupério J., Vale-Gonçalves H. M., Cabral J. A., Mira A., Bencatel J. (2017) - *Roedores (Rodentia)*, in: Bencatel, J., Álvares, F., Moura, A. E., Barbosa, A. M. (Eds.), *Atlas de Mamíferos de Portugal*. Universidade de Évora, Portugal, 39-59.
- Peel M.C., Finlayson B.L., McMahon T.A. (2007) - Updated world map of the Köppen-Geiger climate classification. *Hydrol. Earth Syst. Sci.*, 11, 1633-1644.
- Pettitt P.B., Van Der Plicht H., Bronk Ramsey C., Monge Soares A.M., Zilhão J. (2002) - The Radiocarbon Chronology, in Zilhão J., Trinkaus E. (Eds.), *Portrait of the artist as a child. The Gravettian human skeleton from the Abrigo do Lagar velho and its archaeological context*. IPA (Trabalhos de Arqueologia, 22), Lisbon, 132-138.
- Peyron O., Guiot J., Cheddadi R., Tarasov P., Reille M., de Beaulieu J.-L., Bottema S., Andrieu V. (1998) - Climatic Reconstruction in Europe for 18,000 YR B.P. from Pollen Data. *Quat. Res.*, 49, 183-196.
- Queiroz P.F. (2002) - The Anthracology of Burial, in: Zilhão J., Trinkaus E. (Eds.), *Portrait of the artist as a child. The Gravettian human skeleton from the Abrigo do Lagar velho and its archaeological context*. IPA (Trabalhos de Arqueologia, 22), Lisbon, 152-153.
- Queiroz P.F., Mateus J.E., van Leeuwen W. (2002) - The Paleovegetational context, in: Zilhão J., Trinkaus E. (Eds.), *Portrait of the artist as a child. The Gravettian human skeleton from the Abrigo do Lagar velho and its archaeological context*. IPA (Trabalhos de Arqueologia, 22), Lisbon, 92-111.
- Reimer P.J., Bard E., Bayliss A., Beck J.W., Blackwell P.G., Bronk Ramsey C., Buck C.E., Cheng H., Edwards R.L., Friedrich M., Grootes P.M., Guilderson T.P., Hafflidason H., Hajdas I., Hatté C., Heaton T.J., Hoffmann D.L., Hogg A.G., Hughen K.A., Kaiser K.F., Kromer B., Manning S.W., Niu M., Reimer R.W., Richards D.A., Scott E.M., Southon J.R., Staff R.A., Turney C.S.M., van der Plicht J. (2013) - IntCal13 and Marine13 radiocarbon age calibration curves 0-50,000 years cal BP. *Radiocarbon*, 55, 1869-1887.
- Sans-Fuentes M.A., Ventura J. (2000) - Distribution patterns of the small mammals (Insectivora and Rodentia) in a transitional zone between the Eurosiberian and the Mediterranean regions. *J. Biogeogr.*, 27, 755-764.
- Sommer R.S., Nadachowski A. (2006) - Glacial refugia of mammals in Europe: evidence from fossil record. *Mammal Rev.* 36, 251-265.
- Zilhão J., Almeida F. (2002) - The archaeological framework. In: Zilhão, as a child. *The Gravettian hu-*

man skeleton from the Abrigo do Lagar velho and its archeological context. IPA (Trabalhos de Arqueologia, 22), Lisbon, 29-57.

Zilhão J., Trinkaus E. (Eds.) (2002) - Portrait of the artist as a child. The Gravettian human skeleton from the Abrigo do Lagar velho and its archeological context. IPA (Trabalhos de Arqueologia, 22), Lisbon, pp. 609.

Zilhão J. (2005) - Burial evidence for social differentiation of age classes in the Early Upper Paleolithic, in: Vialou, J., Renault-Miskowsky, J., Patou Matthis, M. (Dir.), Comportements des hommes du Paléolithique moyen et supérieur en Europe: territoires et milieux. ERAUL, Liège, 231-241.

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