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Heinrich Event 4 characterized by terrestrial proxies in southwestern Europe

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Abstract

Heinrich Event 4 (H4) is well documented in the North Atlantic Ocean as a cooling event that occurred between 39 000 and 40 000 yr BP. Deep-sea cores around the Iberian Peninsula coastline have been analysed to characterize the H4 event, but there are no data on the terrestrial response to this event. Here we present for the first time an analysis of terrestrial proxies for characterizing the H4 event, using the small-vertebrate assemblage (comprising small mammals, squamates and amphibians) from Terrassa Riera dels Canyars, an archaeo-palaeontological deposit located on the seaboard of the northeastern Iberian Peninsula. This assemblage shows that the H4 event is characterized in northeastern Iberia by harsher and drier terrestrial conditions than today. Our results were compared with other proxies such as pollen, charcoal, phytolith, avifauna and large-mammal data available for this site, as well as with the general H4 event fluctuations and with other sites where H4 and the previous and subsequent Heinrich events (H5 and H3) have been detected in the Mediterranean and Atlantic regions of the Iberian Peninsula. We conclude that the terrestrial proxies follow the same patterns as the climatic and environmental conditions detected by the deep-sea cores at the Iberian margins.

1 Introduction

The Heinrich events have been generally defined, according to Cayre et al. (1999), by a decrease in δ^{18}O, peaks in magnetic susceptibility, an increase in the proportion of the foraminifer *Neogloboquadrina pachyderma*, as well as the appearance of IRD (Iceberg Rafted Detritus). Of these events, Heinrich Event 4 (H4), which occurred ca. 39–40 ka BP, is one of the most abrupt climate cooling episodes, well recorded in sediment cores throughout the North Atlantic Ocean and the adjacent continents (Roche et al., 2004; Sepulchre et al., 2007). Deep-sea cores around the Iberian Peninsula coastline have been analysed to characterize the Heinrich event fluctuations (Cacho et al., 1999; Sánchez-Goñi et al., 2002; Sierro et al., 2005; Naughton et al., 2009, among others). Taking into account the recent data provided by these deep-sea core analyses, the H4 event can be characterized at the Iberian margins, according to Naughton et al. (2009), by two main phases: (1) a first phase marked by a relatively wet and very cold atmospheric conditions; and (2) a second phase marked by an extreme continental dryness and cooler conditions. According to Sánchez-Goñi et al. (2002), moreover, there are differences between the data obtained by the deep-sea cores for the H4 event at the Mediterranean and the Atlantic margins of the Iberian Peninsula, the H4 event being more humid at the Atlantic than the Mediterranean margin. Furthermore, simulation models and pollen extrapolations from the deep-sea cores have been undertaken in order to observe the terrestrial response to the H4 event in the Iberian Peninsula (Sánchez-Goñi et al., 2002; Sepulchre et al., 2007, Naughton et al., 2009, among many others). Here we present a characterization of the environment and climate of the H4 event based on the small-vertebrate assemblage of the Terrasses de la Riera dels Canyars (henceforth, Canyars). Our results are compared with the pollen, charcoal, phytolith, avifauna and large-mammal data obtained for this site (Daura et al., 2012), as well as with the general H4 event fluctuations to see whether the phases detected by Naughton et al. (2009) can be observed for the Canyars data. They are also compared with data from other sites where H4 and the previous and subsequent Heinrich events (H5 and H3) have been detected in the Mediterranean and Atlantic regions of the Iberian Peninsula, to observe whether or not the terrestrial proxies follow the same patterns as the climatic and environmental conditions detected by the deep-sea cores at the Iberian margins.

2 Site description

Canyars is a fluvial deposit located in the town of Gavà, some 20 km to the west of Barcelona, in the Vall de la Sentiu valley, one of the creeks originating at the foot of the Garraf massif and flowing into the beaches of the Mediterranean seaboard.

The site was discovered in 2005 (Daura and Sanz, 2009; Daura et al., 2013) by an amateur archaeologist (C. Valls) and completely excavated by the Grup de Recerca del Quaternari from June to November 2007.

Nowadays, Canyars is located in an abandoned gravel-pit that remained active until the 1960 s. Pleistocene fossils from the same area were already known. The first discovery from Vall de la Sentiu was an Upper Pleistocene palaeontological collection from an emplacement that is not known precisely (Villalta, 1953); another corresponds to an isolated proboscidean remains (cf. *Mammuthus*) from a different gravel-pit 700 m from Canyars (Daura and Sanz, 2009). Other palaeontological remains from adjacent valleys have been recovered in the course of archaeological survey excavations; Riera de Sant Llorenç has provided large-mammal remains, mainly *Mammuthus, Coelodonta* and *Equus* (Daura et al., 2013).

Canyars is located at the confluence of two creeks, Riera dels Canyars and Riera de Can Llong. The former is the main stream, and its distal part probably consisted of a floodplain crossed by channels, nowadays modified by farming activity (Daura et al., 2013). A total of 9 lithological units have been described, consisting of a poorly sorted and coarse-grained complex of gradational and incised fluvial deposits. Palaeontological remains come from the only archaeological unit (MLU), consisting of mud-supported gravel filling a well-defined palaeochannel (LDU).

Several charcoal samples were collected for radiocarbon dating, with a ^{14}C dating result of ~ 34.6 ^{14}C (~ 39.6 cal.) ka BP (overall mean age estimate from four radiocarbon datings by Daura et al., 2013) (Fig. 2).

3 Material and methods

3.1 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 dry and water-screening. All the sediment was dry-screened using superimposed 5 and 0.5 mm mesh screens during fieldworks, and ~ 500 kg of the sample was water-sieved (1.5–0.5 mm) in the La Guixera Laboratory (Castelldefels City Council, Barcelona). The fossils were processed, sorted and classified at the Institut de Paleoecologia Humana y Evolució Social of the University Rovira i Virgili (Tarragona, Spain). The assemblage includes a total of 362 fragments, 182 of which were identified to genus or species level and correspond to a minimum number of 26 small vertebrates, representing at least 15 taxa (Table 1; Figs. 3, 4). The fragments were identified following the general criteria given by Furió (2007) for insectivores, Van der Meulen (1973) and Cuenca-Bescós et al. (2010) for rodents, and Bailon (1999), and Sanchiz 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; jaws and vertebrae for lizards, and vertebrae for snakes; mandible, maxilla and isolated teeth for shrews; isolated teeth and humerus for Talpidae; first lower molars for 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 determined the sample (i.e. from each level) by counting the best diagnostic elements, taking into account, whenever possible, laterality and (for amphibians) sex.

3.2 Palaeoenvironmental reconstruction

In order to reconstruct the palaeoenvironment at Canyars, we use the method of habitat weightings (see Evans et al., 1981; and Andrews, 2006), distributing each small-vertebrate taxon in the habitat(s) where it can be found at present in the Iberian Peninsula. Habitats are divided into five types (in accordance with Cuenca-Bescós et al., 2005, 2009; Blain et al., 2008; Rodriguez et al., 2011; López-García et al., 2010a, 2011a): 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 (Table 1). 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" data were obtained from the percentage representation of the MNI by classifying our taxa according to chorotypes established previously by Sans Fuentes and Ventura (2000) and López-García et al. (2010b). These chorotypes are detailed as follows (Table 1): 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 those 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.

3.3 Palaeoclimatic reconstruction

Climatically, the Iberian Peninsula may be considered a minicontinent due to its large latitudinal range (between the parallels of 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 in Europe, and these mountains play a major role in the characterization of its climatic diversity. 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, taxonomic composition of the assemblage allow us to evaluate the climatic conditions. In order to assess palaeoclimatic data in Canyars, we evaluated the current distribution of all the taxa found there, permitting us to calculate the potential palaeoclimatic conditions at the site (mutual climatic range method = MCR, in accordance with 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 given stratigraphical level currently live. Because our sources for the distribution of the small-vertebrate taxa (Palomo and Gisbert, 2005; Pleguezuelos et al., 2004) are based on a 10 × 10 km UTM network, the climatic data are resolved to 10 × 10 km UTM squares. Careful attention is paid to ensure that the real current distribution of each species corresponds to its potential ecological/climatic distribution and has not been strongly affected by other limiting or perturbing parameters such as urban development, the human impact on the landscape, predation, or competition with other species, etc. Several climatic factors are estimated; the mean annual temperature (MAT), the mean temperature of the coldest month (MTC), the mean temperature of the warmest month (MTW), the mean annual precipitation (MAP), the mean precipitation for summer (June, July and August = JJA) and the mean precipitation for winter (December, January and February = DJF), using various climatic maps of Spain (Font-Tullot, 2000) and data provided by the network of Catalonian meteorological research stations over a period of 30 yr. From this variably sized region we can estimate the climatic parameters and compare them with the weather station at Barcelona Airport located about 15 km north of the site (current data from Font-Tullot, 2000). Barcelona Airport has a MAT of 15.6 °C (weather station at 6 m a.s.l.); the mean annual precipitation (MAP) is 659 mm; the mean temperature of the coldest month (MTC) is 8.8 °C; and the mean temperature of the warmest month (MTW) is 23 °C (Font-Tullot, 2000).

4 Results

4.1 Small-vertebrate taphonomic remarks

A total of 362 elements from Canyars have been studied in our taphonomic analysis; 57 % of the remains are from rodents or insectivores, and the remaining 43 % belong to amphibians and reptiles. The taphonomic study of the microvertebrates fossils is based on a descriptive-systematic method that analyses the modifications produced

by predation (Andrews, 1990). The surface alterations present on the microvertebrate remains are thus noted and described, making it possible to identify and recognize the effects of predators. To this end, the anatomical representation, the fragmentation and the digestion marks on the remains are analysed, and the results are compared with those obtained by studying modern pellets from well-known predators.

Alterations caused by digestion were found in most of the small mammals (Fig. 5) and in 32 % of the amphibians and reptiles (*P. punctatus*, *B. calamita* and *A. fragilis*). The high percentage of small-mammal incisors, molars and postcranial elements showing digestion marks (Fig. 5) and the degree of alteration point to the presence of a category 3 predator, which includes several avian predators (Andrews, 1990), as *Falco tinnunculus*. In this respect, we cannot rule out the activity of other carnivores (MNI = 39) and avian predator documented in the Canyars assemblage.

The general levels of representation and breakage lend weight to this hypothesis. This indicates that in both cases the accumulation is associated with predation, although in the case of the amphibians, in particular *P. punctatus* and above all *B. calamita*, in situ mortality cannot be ruled out given the NISP/MNI ratio, which is considerably higher than in the other anurans and the reptiles.

The common kestrel (*F. tinnunculus*) is a diurnal bird of prey with a moderately selective diet, which is generally based on small mammals (by choice mice, microtines and shrews), although it also consumes passeriform birds, insects, reptiles and amphibians (Andrews, 1990; Gil-Delgado et al., 1995). Predation on *A. fragilis*, certain lacertids and vipers by *F. tinnunculus* has been well documented (Elósegui, 1973; Braña, 1984; Salvador, 1997) Although there is no recorded predation of *C. austriaca* by *F. tinnunculus* it is well established that it may form the prey of certain diurnal birds (Salvador, 1997). As for anurans, the fact that they are largely nocturnal in habit (except during the reproductive season) makes them infrequent prey for diurnal raptors (García-París et al., 2004), although the predation of *Falco naumanni* on *P. punctatus* has been documented (Martín and López, 1990) As for its habitat, *F. tinnunculus* can be found on cliffs, steppe land, scrubland and open, sparse woodland. In general, it avoids densely forested areas and requires open spaces for hunting.

The above considerations lead us to infer on the one hand that the taxa identified in this study might reflect the existent past community of microvertebrates, though this should be taken with caution given the diurnal and moderately selective habits of *F. tinnunculus*. On the other hand, the probable accumulation of small mammal by *F. tinnunculus* suggests that open or semi-open palaeoecological conditions prevailed in the area around Canyars.

As for post-depositional alterations, Canyars exhibits a predominance of light manganese oxide precipitations and alterations caused by roots (Table 4), thus would indicate a predominantly humid fossilization microenvironment. Further, marks caused by trampling on small mammal bone surface have been recorded, suggesting a post-deposicional sediment abrasion. Alterations caused by weathering, as well as other forms of alteration associated with changes in humidity and desiccation (fissures and concretions) are present in low percentages.

4.2 Small-vertebrate assemblage from Canyars

The small vertebrates of Canyars comprise at least 15 species (Table [illegible]; Figs. 3 and 4): 3 amphibians (*Pelodytes punctatus*, *Bufo* cf. *bufo* and *Bufo calamita*); 4 squamates (Lacertidae indet., *Anguis fragilis*, *Coronella* cf. *austriaca* and *Vipera* sp.); 2 insectivores (*Talpa europaea* and *Crocidura* sp.); and 6 rodents (*Microtus arvalis*, *M. agrestis*, *M.* (*Terricola*) *duodecimcostatus*, *M.* (*Iberomys*) *cabrerae*, *Apodemus sylvaticus* and *Eliomys quercinus*).

The small-mammal assemblage at Canyars is characterized by the abundance of *Apodemus sylvaticus* and *Microtus arvalis*. Mediterranean taxa, such as *Microtus* (*Iberomys*) *cabrerae* and *Microtus* (*Terricola*) *duodecimcostatus*, and mid-European taxa, such as *Microtus arvalis*, *Microtus agrestis* and *Talpa europaea*, are equally well represented. From a quantitative point of view, the wood mouse (*Apodemus sylvaticus*) and the common vole (*Microtus arvalis*) are ~~very well~~ represented at Canyars, often

accounting for more than 40 % of the total sample. Among the fossil material analysed here, *A. sylvaticus* corresponds to 27.3 % and *M. arvalis* corresponds to 18.2 % of the total sample. The presence of *A. sylvaticus* at Late Pleistocene sites is common, but such 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, 2012a, b), because during these generally cold periods the dominant species, such as *M. arvalis* or *M. agrestis,* are normally associated with open environments, replacing *A. sylvaticus*. Today, however, *A. sylvaticus* is 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 (Palomo and Gisbert, 2005). On the other hand, the abundance of *M. arvalis* is relatively common in Late Pleistocene cave localities (Pokines, 1998; Sesé, 1994, 2005; Cuenca-Bescós et al., 2008, 2009; López-García, 2008; López-García et al., 2010a, 2011a), and today it is a very abundant species in central and northern Spain. *M. arvalis* is currently reported to be more frequent in open lands, and common in relatively dry regions of Spain (Palomo and Gisbert, 2005).

However, apart from *Crocidura* sp., *M.* (*Terricola*) *duodecimcostatus*, *Apodemus sylvaticus* and *Eliomys quercinus*, none of the taxa represented at Canyars is currently found in the vicinity of the site. Nowadays, 13 small-mammal species live on this part of the Catalonian coast, among them insectivores and rodents (Vigo, 2002). Including the species introduced in historical times (such as *Atelerix*, *Suncus*, *Rattus* and *Mus*), the Canyars small-mammal assemblage represents 61.5 % of the current small-mammal fauna of the Catalan coast in terms of species number.

As far as amphibians and squamates are concerned, the fossils from Canyars only document 30.4 % of the current diversity of the Garraf area: 37.5 % of the anurans and 26.7 % of the squamates (modern data from Montori, 1996; Llorente et al., 1995; Rivera et al., 2011). As said above, ~~such a~~ low representation of the current herpetofauna may be because the accumulation could be produced by a diurnal bird of category 3 (*F. tinnunculus*), ~~even~~ natural death is not excluded in some cases for *P. punctatus* and

B. calamita. All the taxa represented as fossils in the locality, except *C. austriaca* and *Vipera*, are well represented today in the Garraf area (Montori, 1996). The scarcity of *Vipera* today may be linked with the increasing urbanization of the landscape, whereas *C. austriaca* is currently absent from the Catalan seashore following a postglacial regression (Llorente et al., 1995; Rivera et al., 2011). It is interesting to note here that *C. austriaca* is found today in Catalan mountain regions (Eurosiberian habitats or humid mountain areas; Rivera et al., 2011), where MAT is lower than 11 °C and MAP higher than 700–800 mm (Llorente et al., 1995). Although mention of the genus *Coronella* is not rare in the Catalonian Pleistocene fossil record, *C. austriaca* has only been cited in the southern part of its current distribution in the Late Pleistocene (ca. 90–30 ka) of Teixoneres cave (Moià, Barcelona; López-García et al., 2012b).

4.3 Palaeoenvironmental and Palaeoclimatic reconstruction

The resulting intersection for Canyars suggests a mean annual temperature (MAT) lower than at present (−5.2 °C) and a mean annual precipitation (MAP) slightly higher than at present (+99 mm). The mean temperature of the coldest month (MTC) is lower than the current mean (−6.1 °C), and for the warmest month (MTW) it is lower too (−4.5 °C). The mean winter precipitation (DJF) is higher (+55 mm) and the mean summer precipitation (JJA) is lower (−29 mm) than at present (Table 3). These data suggest ~~harsher climatic conditions~~ and slightly ~~more humid conditions~~ than at present for the H4 event in northeastern Iberia. Such data are well supported by the presence of taxa such as *C. austriaca* at Canyars, which, as pointed out above, currently lives in mountain areas where MAT is lower than 11 °C and MAP higher than 700–800 mm (Llorente et al., 1995).

Otherwise, the small-vertebrate assemblage for Canyars indicates an open dry environment (33 %) (Fig. 6), given the presence of the species *Pelodytes punctatus*, *Bufo calamita*, *Vipera* sp., *Crocidura* sp. and *Microtus arvalis*. It further suggests a landscape alternating between dry meadowland and Mediterranean-type woodland. The species associated with "woodland" habitats represent 44 % of the total association

(Fig. 6), mainly composed of *B*.cf. *bufo*, *Anguis fragilis*, *Apodemus sylvaticus* and *Eliomys quercinus*. There is also a low percentage representation of species associated with open humid meadows (13 %) and water streams (4 %) (Fig. 6), suggesting the existence of stable watercourses in the vicinity of the site, with riverbanks with loose soils favourable for digging species such as *A. fragilis, Bufo* cf. *bufo, C.* cf. *austriaca* and *Talpa europaea*.

Finally, the small-vertebrate assemblage of the Canyars site is dominated by taxa related with mid-European requirements (chorotype 1 and 2, 60 %), but with a high percentage representation of taxa related with Mediterranean requirements (chorotype 3, 40 %) (Fig. 6). According to Sommer and Nadachowski (2006), the co-occurrence of temperate and cold-adapted species is the normal dynamic detected in south European peninsulas such as the Iberian Peninsula, which functioned as refuges for species in cold periods, in this case during the H4 event. However, in Cova del Gegant (López-García et al., 2008, 2012c), another Late Pleistocene locality of the Garraf Massif, chronologically placed between 49–60 ka (i.e., before HE4), Mediterranean taxa are dominant (chorotype 3, 89 %) showing a different climatic signal in small vertebrates assemblage. Moreover the proximity of the Canyars to the coastline meant that in cold periods, when the sea level decrease, there was a coastal plain with probably drier conditions in front of the site and behind a forested areas with more humid conditions offering rocky and woodland habitats.

5 Comparison and discussion

5.1 Comparison with other terrestrial proxies

Other terrestrial proxies such as charcoal, pollen, phytoliths, avifauna and large mammals from the Canyars site have also been analysed (Daura et al., 2013). The pollen, avifauna and large-mammal results indicate the presence of a steppe-dominant landscape ~~(cf. *Mammuthus* sp., *Coelodonta antiquitatis*, *Equus ferus*, *Pyrrhocorax graculus*~~, Artemisia) surrounding the Canyars site. Together with woodland environment taxa such as *Pinus sylvestris*, temperate forest taxa such as *Sus scrofa*, *Lynx pardinus* and *Ursus arctos* also coexist. The charcoal results indicate a dominance of forest (*Pinus sylvestris*) formations, while the phytoliths indicate a dominance of grasslands, representing arid conditions (Daura et al., 2013).

What is indicated by all these studies is the same as with the small-vertebrate analysis: “woodland taxa” such as *Anguis fragilis*, *Apodemus sylvaticus* and *Eliomys quercinus* are dominant, but they alternate with abundant “open dry taxa”, such as *Microtus arvalis* and *Bufo bufo*. Accordingly, the small-vertebrate assemblage from the Canyars site contains species that currently live at high latitudes in Catalonia (chorotype 1 and 2), such as *Anguis fragilis*, *Coronella austriaca*, *Talpa europaea*, *Microtus arvalis* and *Microtus agrestis*, which represent 60 % of the association and indicate colder conditions than nowadays in the area. These species coexist at Canyars with Mediterranean taxa, such as *Crocidura* sp., *Microtus* (*Terricola*) *duodecimcostatus* and *Microtus* (*Iberomys*) *cabrerae*, which represent 40 % of the association.

As pointed out above, this sort of association is typical of cold periods in southern European peninsulas such as the Iberian Peninsula, which functioned as refuges for species during unfavourable climatic periods (Sommer and Nadachowski, 2006). In this respect, Cova del Gegant (above mentioned) is absolutely dominated by temperate taxa in 89 % of the association showing a reduction of chorotype 3 and woodland conditions from layer V to III while Canyars is formed mainly by Ch1&2.

On the other hand, the presence of a “patchy landscape” signal at Canyars is normal, given the location of the site near the sea and the relief of Garraf Massif behind, nevertheless the environment is dominate by arid conditions. In cold periods the sea level was lower than today (López-García et al., 2008), and the area around the site would have consisted of a large plain in front of it, with probably drier conditions, together with a temperate forest in riparian woodland and behind it, with probably more humid conditions with pines (*Pinus sylvestris*) woodland, as is the case with other nearby sites, such as Cova del Gegant (López-García et al., 2008, 2012c).

5.2 Comparison with other sites associated with the H4 event

Few are the sites with small-vertebrate studies in Iberia where the H4 event has been detected, and Canyars is the only known site located on the Mediterranean and below 41° N latitude. Apart from Canyars, two sites are documented with small-vertebrate assemblages from the H4 event: El Portalón level P16 (Sierra de Atapuerca, Burgos), with a chronology of ca. 38 ka BP for this event; and the Cueva del Conde level N20b (Santo Adriano, Asturias), with a chronology ca. 39 ka BP for this event (Fig. 1) (López-García et al., 2010a, 2011b). All the sites associated with the H4 event are characterized by a landscape dominated by open forest formations, lower mean annual temperatures (MAT) and mean temperatures of the coldest month (MTC), and relatively high levels of mean annual precipitation (MAP) (Fig. 7). However, direct comparison of these three sites shows differences between them in terms of open dry and open humid meadowland and MAP. While in El Portalón (P16) and Cueva del Conde (N20b) the environment is dominated by open humid meadowland reaching values higher than 25 %, in Canyars the landscape is dominated by open dry meadowland with values above 30 % (Fig. 7). Similarly, the MAP, although higher than at present in all three cases, is proportionally higher at El Portalón (P16) and Cueva del Conde (N20b), where it reaches values higher than 1000 mm, while in Canyars the values are lower than 800 mm (Fig. 7). The differences in the H4 event at these three sites can be explained by their geographical position within the Iberian Peninsula: while El Portalón and Cueva del Conde are located in the Atlantic climatic influence, Canyars is located in the Mediterranean climatic influence. According to Sánchez-Goñi et al. (2002) and Sepulchre et al. (2007), the Atlantic sea core (MD95-2042) shows a MAP about 300 mm higher than the Mediterranean sea core (MD95-2043) during the H4 event, providing the Iberian Atlantic region with more humid environmental conditions than in the Mediterranean region today, as is also shown by the results obtained from the small-vertebrate studies.

5.3 Discussion

In general, the studies of the sea cores (MD95-2042, MD95-2043 and MD99-2343) from the Iberian margins show the Heinrich Events, including the H4 event, to have been characterized by low sea surface temperatures (SST), with values of −7 °C to −10 °C, and a climate on land drier than today, with lower levels of Mediterranean forest and higher levels of steppe vegetation (Cacho at al., 1999; Sánchez-Goñi et al., 2002; Sánchez-Goñi and d'Errico, 2005; Sierro et al., 2005; Sepulchre et al., 2007). Despite these general data, there are differences between the Heinrich Events and within them. The H4 event and the previous (H5) and subsequent events (H3) are characterized by a fluctuation in woodland taxa and in the extrapolated mean temperatures of the coldest month (MTC) and mean annual precipitation (MAP) (Sánchez-Goñi et al., 2002; Naughton et al., 2009) (Fig. 8). According to these data, the H4 event is considered the most abrupt event compared with the H3 and H5 events, with the MTC between −6 and −10 °C compared to nowadays and the MAT 400 mm lower than at present in the Iberian Mediterranean region and 200 mm lower than currently in the Iberian Atlantic region (Sánchez-Goñi et al., 2002; Naughton et al., 2009). According to Cacho et al. (1999) and Sierro et al. (2005), the H3 event is the least cold in comparison to the H4 and H5 events. The data obtained with small-vertebrate studies for the H4 event and the H3 and H5 events (López-García et al., 2010a, 2011b, 2012a, c; López-García and Cuenca-Bescós, 2010) seem to follow the same patterns previously established by the sea-core studies at the Iberian margins (Fig. 8). The small-vertebrate studies show that fluctuations in the percentage values for woodland taxa follow the same pattern as the woody taxa established for the sea core MD95-2043, reaching minimum values (25 %) in H5 event layer E from the Abric Romaní (López-García and Cuenca-Bescós, 2010; Burjachs et al., 2012) (Table [illegible]). As with the woodland percentage representations, the MTC and the MAP established by means of small-vertebrate studies for the H5 to H3 events follow the same pattern as the curves extrapolated from the sea core MD95-2043 (Sánchez-Goñi et al., 2002) (Fig. 8), reaching minimum values in H5

event layer E from the Abric Romani (MTC = −6.41 °C; MAP = +90 mm, in relation to the present) (López-García and Cuenca-Bescós, 2010) and in the H4 event from Canyars (MTC = −6.08 °C; MAP = +99 mm, in relation to the present) (Table [illegible]). Moreover, direct comparison between level III of Cova del Gegant and the Canyars site reveals less rigorous conditions for the H5 event at the former, where there is no representation of the mid-European species *M. agrestis*, *T. europaea*, *A. fragilis* and *C. austriaca*, which do appear at Canyars (López-García et al., 2012c). As has previously been pointed out by Cacho et al. (1999) and Sierro et al. (2005), however, small-vertebrate studies show the H3 event to be the least harsh of these Heinrich Events, with values for MAP = +378 mm and MTC = −0.1 °C with respect to the present for layer P11 of El Portalón (López-García et al., 2010a) (Table [illegible]).

6 Conclusions

The data derived from the studied small vertebrates recovered from Canyars add further to our knowledge of the H4 event in the Iberian Peninsula. The small-vertebrate assemblage reveals that the H4 event was characterized in northeastern Iberia by cold climatic conditions, with a landscape alternating between dry meadowland and Mediterranean-type woodland. This assemblage is dominated by mid-European taxa together with a high percentage representation of Mediterranean taxa, a co-occurrence that is the normal dynamic detected in south European peninsulas, which functioned as refuges for species in cold periods. The location of Canyars may have also provided a coastal plain in front of the site with drier conditions and a Mediterranean forest behind with more humid conditions than today.

Secondly, a direct comparison of the data obtained from the small-vertebrate association from Canyars with other terrestrial proxies that have been studied, such as charcoal, pollen, phytoliths, birds and large mammals, corroborates our data, showing that the climate during the H4 event was harsher and drier than today in the northeastern Iberian Peninsula.

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Furthermore, a comparison with the other small-vertebrate studies in the Iberian Peninsula where the H4 event has been detected, such as El Portalon layer P16 or Cueva del Conde layer N20b, shows this event to be characterized by a landscape dominated by open forest formations, with lower mean annual temperatures (MAT) and mean temperatures of the coldest month (MTC), and relatively high levels of mean annual precipitation (MAP). However, the H4 event provides the Iberian Atlantic region (El Portalón and Cueva del Conde) with more humid environmental conditions than the Mediterranean region (Canyars), as is also shown by the previous results obtained by sea core samples from the Iberian margins.

Finally, a comparison of our data obtained from the small-vertebrate assemblage with the general dynamic of the Heinrich events reveals that the small-vertebrate studies for the H3 to H5 events in the Iberian Peninsula follow the same pattern as the previous studies undertaken for the Iberian margin sea cores, showing that the H4 event is the most abrupt event compared with the H3 and H5 events and that H3 is the least cold of the three.

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Table 1. Representation of the Number of Identified Specimens (NISP), the Minimum Number of Individuals (MNI) and the percentage of the MNI (%) for the small vertebrates from Canyars, and the 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.

	NISP	MNI	%	OD	OH	Wo	Ro	Wa	Ch1	Ch2	Ch3
Pelodytes punctatus	24	4	15.38	0.5		0.2	0.1	0.2			x(g)
Bufo cf. *bufo*	3	1	3.85	0.1	0.3	0.4		0.2			x(g)
Bufo calamita	97	5	19.23	0.75		0.25					x(g)
Lacertidae indet.	6	2	7.69								
Anguis fragilis	5	1	3.85		0.25	0.75				x	
Coronella cf. *austriaca*	6	1	3.85	0.25	0.25	0.25	0.25			x	
Vipera sp.	8	1	3.85	0.25	0.25	0.25	0.25				x(m)
Ophidia indet.	12	–									
Talpa europaea	1	1	3.85		0.5	0.5				x	
Crocidura sp.	1	1	3.85	0.5		0.5					x(m)
Microtus arvalis	3	2	7.69	0.5		0.5			x		
Microtus agrestis	2	1	3.85		0.5	0.5				x	
M. (*Terricola*) *duodecimcostatus*	2	1	3.85		0.5	0.5					x(m)
M. (*Iberomys*) *cabrerae*	1	1	3.85		0.5	0.5					x(m)
Apodemus sylvaticus	9	3	11.54			1					x(g)
Eliomys quercinus	2	1	3.85			0.5	0.5				x(g)
Total	182	26	100								

Table [illegible] Percentage representations of alterations caused by post-depositional agents in Canyars microvertebrates.

Alterations caused by post-depositional agents	
Manganese oxide	54
Root grooves	10.3
Abrasion	5.3
Chemical corrosion	4
Fissures	2.5
Concretions	0.7
Calcium carbonate	0.7
Weathering	0.3

Table [illegible] Relation of temperature and precipitation for Canyars. MAT = mean annual temperatures; MTC = mean temperature of coldest month; MTW = mean temperature of warmest month; MAP = mean annual precipitation; DJF = mean winter 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	mean	Max	Min	SD
MAT	46	10.11	13.00	6.00	1.75
MTC	46	2.72	9.00	0.00	1.59
MTW	46	18.50	22.00	16.00	1.35
MAP	46	757.6	1200	450	177
DJF	46	175.2	256	95	40
JJA	46	96.96	197	71	37

Table [illegible]elation between woodland percentage, mean annual precipitation (MAP) and mean temperature of coldest month (MTC) for the different sites where the H3 to H5 events have been detected.

HE	Ka BP	Sites	Woodland (%)	MAP (mm)	MTC (°C)
3	ca. 30	Portalón (P11)	34	378	−0.1
4	ca. 38	Portalón (P16)	32	841	−0.6
	ca. 38–39	Canyars	44	98.6	−6.08
	ca. 39–40	Conde (N20b)	40	127	−5
5	ca. 46	A. Romaní (E)	25	90	−6.41
	ca. 45–48	Xaragalls (C4)	66	266	−6.05
	ca. 49	Gegant (III)	48	191	−6.2

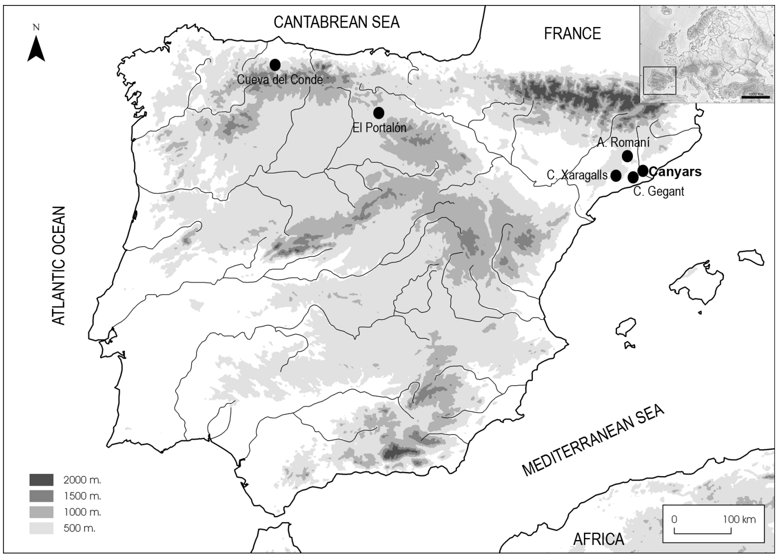

Fig. 1. Location of the sites mentioned in text in the Iberian Peninsula, including Canyars (Terrasses de la Riera dels Canyars).

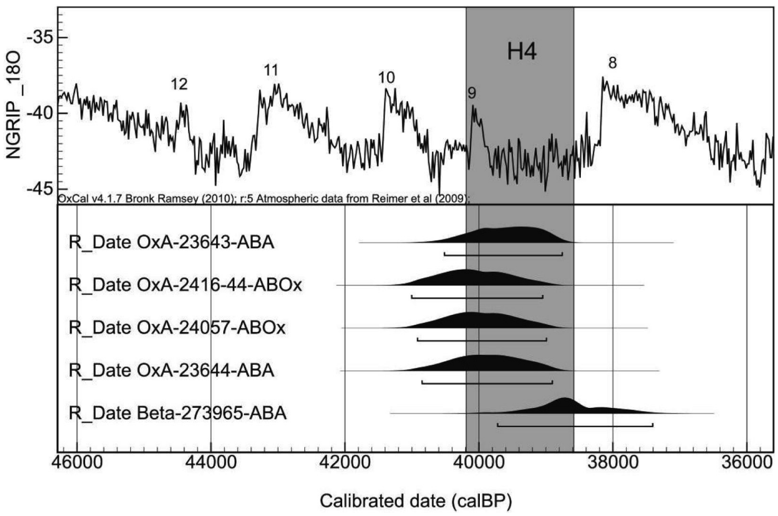

Fig. 2. Plot of the Canyars ^{14}C dates, calibrated with the Intcal09 curve (Reimer et al., 2009) and compared with the North Greenland Ice Core Project NGRIP δ^{18}O ice-core record of Svensson et al. (2006) and Andersen et al. (2005), showing GI interestadials and Heinrich Event 4 according to Svensson et al. (2008) (Prepared using OxCal v. 4.1.7; Bronk Ramsey, 2009).

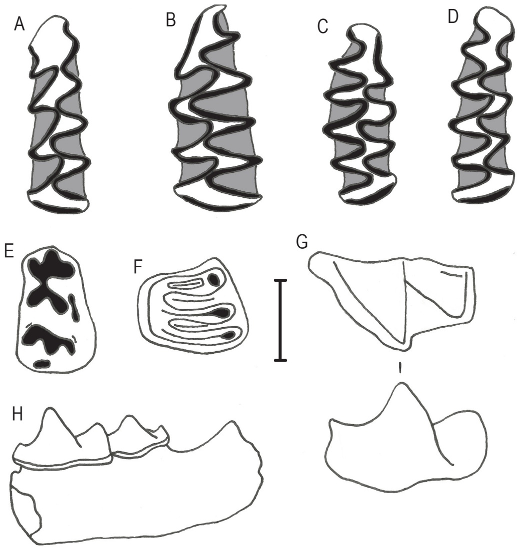

Fig. 3. Some small mammals from Canyars. A: first left lower molar (m1) *Microtus* (*Terricola*) *duodecimcostatus* (occlusal view); B: m1 left *Microtus* (*Iberomys*) *cabrerae* (occlusal view); C: m1 right *Microtus agrestis* (occlusal view); D: m1 right *Microtus arvalis* (occlusal view); E: m1 right *Apodemus sylvaticus* (occlusal view); F: m1 right *Eliomys quercinus* (occlusal view); G: third left lower molar (m3) *Talpa europaea* (occlusal and labial views); H: left mandible (m2–m3) *Crocidura* sp. Scale 1 mm.

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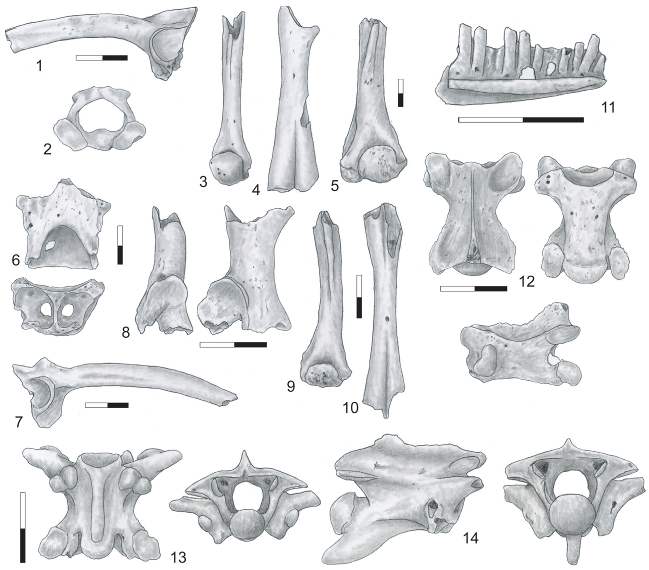

Fig. 4. Some amphibians and squamates from Canyars. 1–4, *Pelodytes punctatus*. 1: left ilium, lateral view; 2: atlas, anterior view; 3: right humerus of female, ventral view; 4: radioulna, lateral view; 5, *Bubo* cf. *bufo*, left humerus of female, ventral view; 6–10, *Bufo calamita*. 6: spheneth-moid, dorsal and anterior views; 7: right ilium, lateral view; 8: right scapula, posterior and dorsal views; 9: right humerus of female, ventral view; 10: tibiofibula, dorsal view; 11, Lacertidae in-det., left dentary, medial view; 12, *Anguis fragilis*, trunk vertebra, dorsal, ventral and left lateral views; 13, *Coronella* cf. *austriaca*, trunk vertebra, ventral and posterior views; 14, *Vipera* sp., trunk vertebra, right lateral and posterior views. All scales equal 2 mm.

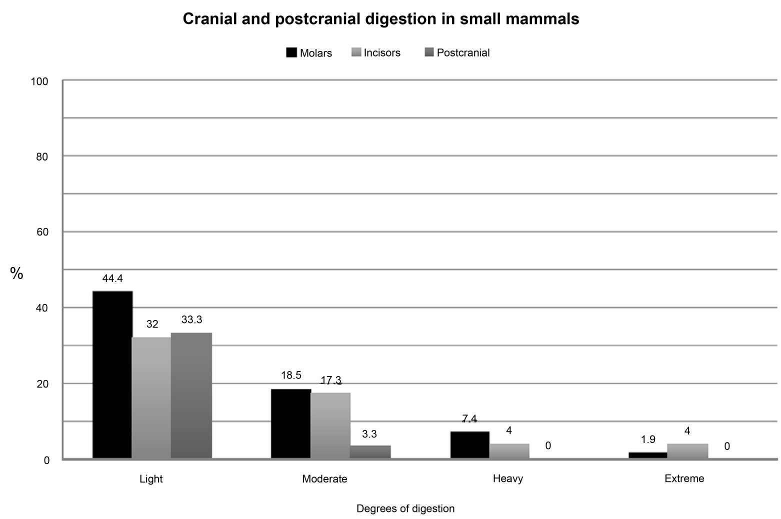

Fig. 5. Percentages of small-mammal elements from Canyars showing different degrees of digestion. We identify 4 degrees of digestion, from light to extreme, following the method of Andrews (1990) for incisors and molars, and the method of Fernández-Jalvo (1992) for postcranial elements. Thefractures in 2 incisors and 12 postcranial elements have prevented us from classifying these remains according to a specific degree of digestion.

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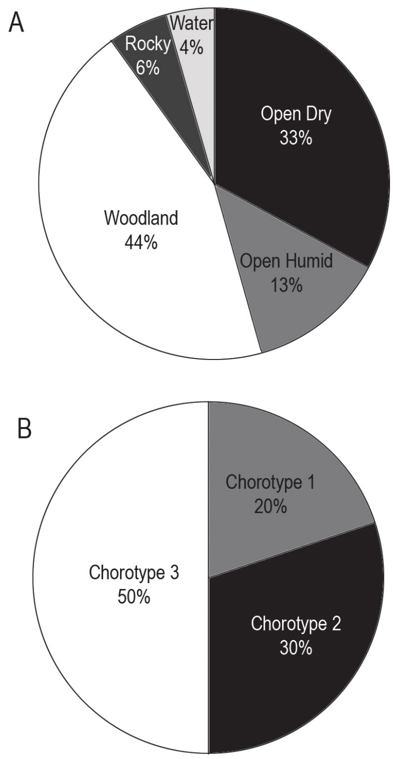

Fig. 6. (A) Small-vertebrate association by habitat. **(B)** Small-vertebrate association by chorotype. Data have been taken from the percentage of the Minimum Number of Individuals.

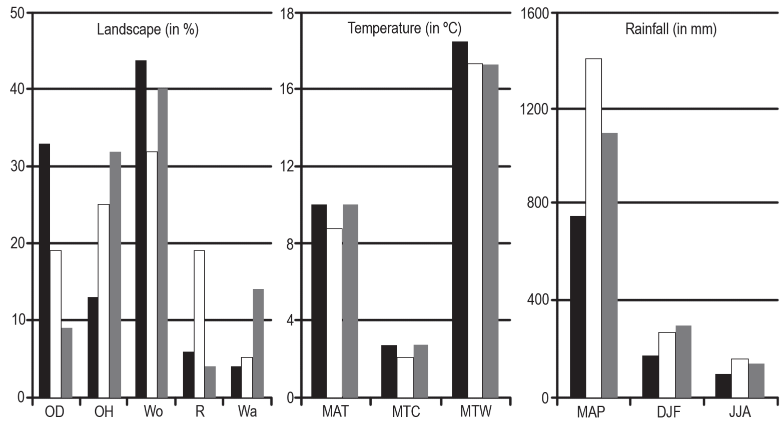

Fig. 7. Environmental and climatic comparisons between Canyars (black bar), El Portalón (white bar) and Cueva del Conde (grey bar). Data for El Portalón are from López-García et al. (2010a) and for Cueva del Conde are from López-García et al. (2011b). Abbreviations: OD, open-dry; OH, open-humid; Wo, woodland; R, rocky; Wa, water edge; MAT, mean annual temperature; MTC, mean temperature of the coldest month (January); MTW, mean temperature of the warmest month (July); MAP, mean annual precipitation; DJF, mean winter precipitation; and JJA, mean summer precipitation.

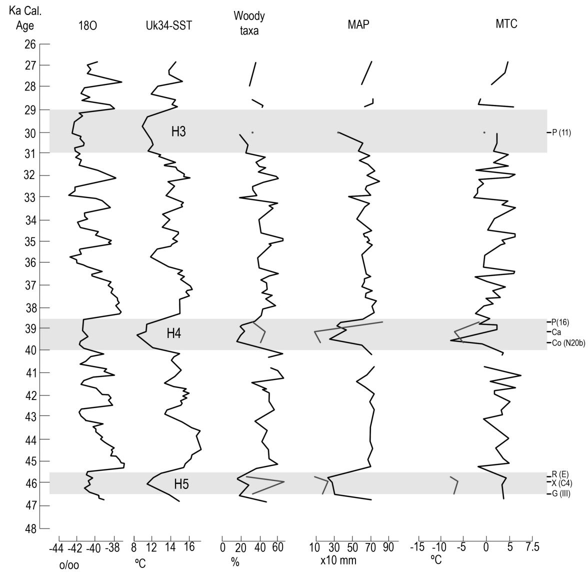

Fig. 8. Proposed correlation of the NorthGRIP2 Isotope (^{18}O) curve, the quantitative variation in the annual sea surface temperature (Uk37-SST), the synthetic pollen diagram from the last glacial section (47 000–27 000 cal yr BP) of core MD95-2043, and the values estimated for annual precipitation (MAP) and mean temperature of the coldest month (MTC) in southeastern Iberia (modified from Sánchez-Goñi et al., 2002) with the various layers with smallvertebrate studies where H3 to H5 events have been detected. P (11 and 16): El Portalón layer P11 and P16; Ca: Terrassa Riera dels Canyars (Canyars); Co (N20b): Cueva del Conde layer N20b; R (E): Abric Romaní layer E and G (III): Cova del Gegant layer III (grey lines indicate the data obtained with these studies).