Refining upon the climatic background of the Early Pleistocene hominin settlement in western Europe: Barranco León and Fuente Nueva-3 (Guadix-Baza Basin, SE Spain)

Hugues-Alexandre Blain a, b, *, Iván Lozano-Fernández a, b, Jordi Agustí a, b, c, Salvador Bailon d, e, Leticia Menéndez Granda a, b, Maria Patrocinio Espigares Ortiz f, Sergios Ros-Montoya f, g, Juan Manuel Jiménez Arenas b, h, i, Isidro Toro-Moyano k, Bienvenido Martínez-Navarro a, b, c, Robert Sala a, b

a IPHES, Institut Català de Paleoecologia Humana i Evolució Social, c/ Marcel ll Domingo s/n (Edifici W3), Campus Sescelades, E-43007 Tarragona, Spain
b Area de Prehistòria, Universitat Rovira i Virgili (URV), Avinguda de Catalunya 35, E-43002 Tarragona, Spain
c ICREA, Institució Catalana de Recerca i Estudis Avançats (ICREA), Barcelona, Spain
d « Histoire naturelle de l’Homme préhistorique », UMR 7194, Sorbonne Universités, MNHN, CNRS, 1 rue René Panhard, F-75013 Paris, France
e « Arqueología, Arqueobotánica: societies, pratiques, environnements », UMR 7209, Sorbonne Universités, MNHN, CNRS 55 rue Buffon, CP 55, F-75005 Paris, France
f Departamento de Ecología y Geología (Áreas de Paleontología y Estratigrafía), Facultad de Ciencias, Campus Universitario de Teatinos, E-29071 Málaga, Spain
gh Departamento de Prehistoria y Arqueología, Facultad de Filosofía y Letras, Universidad de Granada, Carrera del Darro 41-43, E-18010 Granada, Spain
i Museo Arqueológico de Granada, Carrera del Darro 41-43, E-18010 Granada, Spain
j Museo de Prehistoria y Paleontología de Orce, Spain
k Museo Arqueológico de Granada, Carrera del Darro 41-43, E-18010 Granada, Spain

* Corresponding author. IPHES, Institut Català de Paleoecologia Humana i Evolució Social, c/ Marcel ll Domingo s/n (Edifici W3), Campus Sescelades, E-43007 Tarragona, Spain.
E-mail address: hablain@iphes.cat (H.-A. Blain).

http://dx.doi.org/10.1016/j.quascirev.2016.05.020
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A R T I C L E   I N F O
Article history:
Received 30 November 2015
Received in revised form 21 March 2016
Accepted 17 May 2016
Available online 3 June 2016

Keywords:
Palaeoclimate
Ombroclimate
Aridity indexes
Iberian Peninsula

A B S T R A C T
The Early Pleistocene sites of Barranco León and Fuente Nueva-3 (Guadix-Baza Basin, SE Spain) have yielded thousands of Mode 1 or Oldowan lithic artifacts (both sites) and one tooth (in layer D, formerly 5 of Barranco León), today considered to be some of the earliest evidence of humans in western Europe at ca. 1.2–1.5 Ma. Previous quantitative paleoclimatic reconstructions based on herpetile assemblages indicated that, during the formation of these two sites, the mean annual temperature and mean annual precipitation were higher than they are now in the southeastern Iberian Peninsula, with lower continentality. Here, we propose new climatic reconstructions where the mean monthly temperature and precipitation and the difference between the four driest months and the four rainiest months are estimated. Climatograms are built in order to specify the distribution and variation of temperature and precipitation during the year, and the Aridity Indices of Gaussen, Lautensach-Mayer, Dantin-Revenga and De Martonne are used to characterize ombroclimatic differences. According to these new climatic parameters, rainfall distribution through the year shows considerably higher precipitation in every season except summer and early autumn, which remain drier and thus consistent with a Mediterranean climate pattern. No change is observed in the duration of the aridity period, which remains four months long. However, the value of the Aridity Index of De Martonne is higher than 20 (subhumid climate) in Barranco León and Fuente Nueva-3, whereas today it is lower than 20 (semi-arid climate), suggesting major changes in the ombroclimatic type. These results yield a more precise scenario for the paleoclimatic conditions that prevailed during the late Early Pleistocene in the Guadix-Baza Basin and permit us to contrast the ages obtained from numerical dating and biochronology. The very warm and humid climate reconstructed for both Barranco León and Fuente Nueva-3 suggests that, in accordance with the numerical dating, these two sites are contemporaneous with the particularly warm interglacial peaks of
1. Introduction

Today, the Guadix-Baza Basin is a high, quasi-subdesert plateau located at an altitude of one thousand metres above sea level with an extremely arid continental climate, though with Mediterranean characteristics. It is an intramontane basin located in the Alpine Betic chain in the southern Iberian Peninsula (Fig. 1), in the contact area between the Mesozoic basement (Internal Zones, in the south of the basin) and the covering rocks (External Zones, in the north). This basin was filled by marine sediments during part of the Miocene. The basin uplift that had taken place by 8 Ma (see Hüsing et al., 2010, and references therein) created a disconnection from the sea, and the basin became a continental one. Continental infill was active until the Middle Pleistocene. Then, during the late Middle Pleistocene (at 400 ka: García-Tortosa et al., 2008a, 2008b; 280 ka: Díaz-Hernández and Julià, 2006) or Late Pleistocene (100–17 ka: Viseras and Fernández, 1992; Calvache and Viseras, 1997; 42 ka: Azañón et al., 2006), the Guadix-Baza Basin underwent intense erosion following the capture of its hydrographic network by the Guadiana Menor River, a tributary of the Guadalquivir River. This event is probably the main cause of the drying of the area and the subsequent predominance of badland landscapes in the region today, together with a mean annual precipitation as low as 200 mm in the inner parts of the depression.

The Plio-Pleistocene basin infill was built up by the alluvial and fluvial Guadix Formation (see Viseras, 1991), while the lacustrine and palustrine formations are the Baza, Gorafe-Huelago and Solana (Vera, 1970). The archaeo-paleontological sites of Barranco León and Fuente Nueva-3 studied here are located in the Orce area, and belong to the Plio-Pleistocene Baza Formation. This geological unit contains abundant paleontological sites in its lower, middle and upper members (Vera et al., 1984; Oms et al., 2000). The lower member contains shallow lacustrine and palustrine calcareous deposits. The middle one is made up of fluvial mudstones and sandstones. The upper one is also of lacustrine and palustrine origin and results from the accumulation of silty calcareous deposits, though coarser rocks are also found. In the eastern part of this basin, two late Early Pleistocene archaeo-paleontological sites, Barranco León (layer D) and Fuente Nueva-3 (separated by a distance of 4.1 km, located to the east of Orce village at approximately 900 m asl), are famous for having brought to light some of the oldest hominid evidence in western Europe (Martínez-Navarro et al., 1997; Oms et al., 2000; Toro Moyano et al., 2010, 2013), dated by means of biostratigraphy (Agustí and Madurell, 2003; Agustí et al., 2010b; Lozano-Fernández et al., 2015), paleomagnetism (Oms et al., 2003; Scott et al., 2007), cosmogenic nuclides (Alvarez et al., 2015) and ESR (Duval, 2008; Duval et al., 2012; Toro Moyano et al., 2013) to ca. 1.2–1.5 Ma (Fig. 2). From an archaeo- logical point of view, these localities correspond to areas where early hominids exploited large carcasses (mainly hippopotamuses and elephants) on the shore of a large, shallow, slightly saline Pleistocene lake; and also to the earliest Oldowan (Mode 1) lithic industries from southern Europe (Martínez-Navarro et al., 1997; Toro Moyano et al., 2010; 2013).
The chronology and the factors driving the first human dispersal in Europe have recently been a subject of controversy. In particular, climate has been shown to be a factor affecting this dispersal and in particular the delay between the hominid presence in Dmanisi at ca 1.8 Ma and at 1.2-1.4 Ma in westernmost Europe (Agustí et al., 2009; Martinez-Navarro, 2010). Further, the timing of the hominid arrival in the Iberian Peninsula, where there are localities such as Sima del Elefante in the Sierra de Atapuerca (dated to 1.2 Ma) and Barranco León and Fuente Nueva-3 (dated to between 1.2 and 1.5 Ma) in the Guadix-Baza Basin, is unclear due to the imprecision of the numerical dating obtained from ESR and cosmogenic nuclide analyses (Duval et al., 2012; Álvarez et al., 2015), as well as controversies about the use of vole lineages such as Mimomys savini as a chronological tool (Lozano-Fernández et al., 2015). Given the importance of this early hominid presence, we here put forward new views about old fossils in order to specify with greater precision the chronology of such sites and reconstruct the climatic conditions and landscapes in which the first western European hominids once thrived.

2. Material and methods

2.1. Amphibians and reptiles fossil assemblages

The amphibian and squamate fossil remains used for this study consist of disarticulated elements collected by water screening (using superimposed 10, 5 and 0.8 mm mesh screens) the sediments obtained during the archaeological excavations at both sites during the field seasons from 1999 to 2006. At the time, layer “D” (from which the human tooth was recovered) of the 1999-2006 excavations at Barranco León was not separated into two different sub-layers, D1 and D2, as it is today (2010-2015 excavation campaigns; Agustí et al., 2015). The herpetofaunal material from these “new” excavations is still largely unstudied, and most of the residues from the washing are still in the process of being sorted. Fossils from the 1999-2006 excavations are provisionally housed at the Catalan Institute of Human Paleoecology and Social Evolution (Tarragona, Spain).

More than 5000 amphibian and squamate bone remains were
quantified and studied as part of a PhD thesis (Blain, 2005, 2009) and subsequently published by Blain et al. (2011); these included toads and frogs, lizards and several snakes. The turtle and tortoise fossil remains are from the excavation of Barranco León in 2001 and 2002 and consist of some 180 shell bones (Bailon, 2010). The chelonians from Fuente Nues-3 have still not been studied from a systematic point of view.

The systematic description of the amphibian and squamate fossil remains can be found in Blain (2003, 2005, 2009) and Blain and Bailon (2010), and descriptions of the chelonians in Bailon (2010). The most recent commented faunal list can be found in Blain et al. (2011).

Barranco León D has so far yielded some 19 amphibian and reptile taxa; seven anurans (Discoglossus cf. jeanneae, Pelobates cultripes, Bufo bufo s.l., Epidalea calamita, Bufotes sp. (viridis group), Hyla sp., Pelophylax cf. perezi), two turtles (Emys cf. orbicularis and Mauremys cf. leprosa), one tortoise (Testudo sp.), four lizards (cf. Chalcides, Timon cf. lepidus, indeterminate small lacertids and Dopsia sp.) and five snakes (Coronella gurionica, Natrix maura, Natrix natrix, Rhinechis scalaris and Malpolon monspessulanus).

The faunal list of Fuente Nuesa is somewhat poorer (13 taxa in total) with four anurans (Discoglossus cf. jeanneae, Pelobates cultripes, Bufo bufo s.l., and Pelophylax cf. perezi), four lizards (Chalcides cf. bedriagai, Timon cf. lepidus, indeterminate small lacertids and cf. Dopsia) and five snakes (Coronella gurionica, Natrix maura, Natrix natrix, Rhinechis scalaris and Malpolon monspessulanus).

2.2. Quantitative climate reconstruction

Paleoclimatic interpretations are based on the presence of the amphibian and reptile species from each site using a simple quantitative climate reconstruction method previously used at a regional level by Blain (2005, 2009) and at a larger peninsular scale by Martinez-Solano and Sanchiz (2005) and since then by Blain et al. (2009) and derived publications. Such a method has not been named in Martinez-Solano and Sanchiz (2005), but was called “Intersection des aires de distribution actuelles” in Blain (2005, 2009) and since Blain et al. (2009) was compared to be a sort of mutual climatic range (MCR) method. Recent remarks by many colleagues (Krister Smith and David Horne among others during review processes or round-table discussions) suggesting that such methodology should probably be more accurately be termed a modern analogue technique (MATEch) than a MCR method have to be developed here.

Using the review of existing quantitative climate reconstructions by Birks et al. (2010), it is said that MCR is part of indicator-species approaches (based on the “presence/absence of one or few taxa”) whereas MATEch is part of assemblage approaches (based on the “presence/absence of many taxa”). It is true that because we do not generate a bioclimate envelope approach for each taxon our methodology seems to be closer to a MATEch reconstruction than a MCR. Moreover in contrast to the indicator/species approaches, the assemblage approach considers the fossil assemblage as a whole (as we do, even if we are aware that generally a very few ecologically strong indicator species have more weight in such reconstruction than other more ubiquitous ones) and the relative abundances of all the different fossil taxa (which we are not able to do due to the lack of significant modern data). Also we assume here (as in MCR approaches) that a taxon has an equal probability of occurrence anywhere within its climate range (Hupper and Solow 2004; Horne and Mezquita, 2008) even if this has been shown not to be true in many empirical studies. In conclusion, it seems that the quantitative climate reconstruction method used in Blain (2005, 2009), Martínez-Solano and Sanchiz (2005) and Blain et al. (2009), and the derived subsequent publications using this methodology) is a particular method that does not fit in a well defined category as established by Birks et al. (2010). In order to avoid further confusion we propose to name it Mutual Ecogeographic Range (MER) method as we use geographic co-occurrence.

Assuming methodological uniformitarianism and niche conservatism, we find the modern sample(s) that is (are) most similar to the fossil assemblage and the past climate for the fossil sample is inferred to be equivalent to the state of the climate variable(s) for the analogous modern sample(s). Such a method is based on the fact that most of the Spanish fossil Quaternary amphibians and reptiles belong to extant species (e.g. Blain, 2005, 2009). The climate reconstruction is then based on the mean of the whole analogous modern samples (expressed here as 10 x 10 km UTM squares) without any weighting as usually the distribution of the obtained values is normal (see for example Martinez-Solano and Sanchiz, 2005). Such a method, based only on absence/presence (and not abundance), is consequently free from taphonomical bias and over-representation of some species in the fossil assemblages that may be more linked with the diet preference of the agent of accumulation or to the close proximity of a peculiar environment (rocky areas for karst sites or water biotopes for lake sites) than with climate.

Martínez-Solano and Sanchiz (2005) stressed that in the estimation of a mean climatic value for each 10 x 10 km square (i.e. 100 km² area) in some parts of the Iberian Peninsula (especially in mountainous areas), strong spatial heterogeneity may be a factor of imprecision in the method. However we can also argue that the accumulation processes in archaeological sites can sometimes also be a mixture of various but nearby environments, as in the case of an accumulation by an avian raptor where the fossil assemblage would be characteristic of the range of a particular bird of prey. In addition also the use of statistical means to describe the climatic values obtained from the whole analogous assemblages tends to reduce outliers.

Lobo et al. (2016) verified the validity and accuracy that current ecological niches for amphibians represent a reliable inference tool to infer past environmental conditions. Such assumption can also certainly be extended to reptiles. They also demonstrate that for direct raw inferences of the so-called Mutual Climatic Range method, the combined taxa sets do not increase in accuracy with the number of species included. Another concern is the use of a modern distributional dataset “restricted” to the Iberian Peninsula that can be supported by the fact that most of the species represented today in the Iberian Peninsula correspond to Iberian endemic species (for example Discoglossus jeanneae, Pelophylax perezi, Chalcides bedriagai), French-Iberian species (Pelobates cultripes, Bufo spinosus, Timon lepidus or Rhinechis scalaris) or Ibero-Maghrebian species (Mauremys leprosa) and consequently that non-analogous modern assemblage can be found outside of the Iberian Peninsula.

Because of these premises, when searching for analogous assemblage, careful attention is paid to ensure that the real current distribution corresponds to the potential ecological/climatic distribution and has not been strongly affected by other limiting or perturbing parameters, such as urbanism, landscape anthropization, predation, competition with another species, etc. This is the case in particular for tortoises (Testudo sp.) that are excluded from the analysis. We have also excluded from our analysis Dopsia and Bufotes sp. (viridis group) not only because they are currently absent from the Iberian Peninsula but also because they may represent extinct taxa and the imprecision of their systematic attribution hampered comparison with extant taxa. However, the climatic requirements of existing populations (mostly at genus or family level) can be compared with the quantitative results.
Analysis of the MER in each level is based on the distribution atlases of the Iberian herpetofauna (Pleguezuelos et al., 2004), divided into 10 × 10 km UTM squares. Climatic parameters have been estimated for each 10 × 10 km UTM square, using various climatic maps of the Iberian Peninsula (Ninyerola et al., 2005). The mean annual temperature (MAT), mean monthly temperatures for each month, mean annual precipitation (MAP) and mean monthly precipitation for each month have been calculated for this study; in addition, the difference between the four driest months (June, July, August, September) and the rainiest months (January, February, November, December) (DDR) has been calculated for each site (Table 1).

Because Barranco León and Fuente Nueva-3 are located in a similar climatic environment, we used the data from a point (X,Y: Orce (1970–2001)). The de definitions of the terminology, parameters and indexes used for the climatic interpretation of the climato-


correspondences between the means of two samples (Welch's t-test, a variant of the independent sample test, a variant of the independent sample test, is calculated as:

\[
K = \frac{(\bar{x}_1 - \bar{x}_2)^2}{2S_{x_1}^2 + 2S_{x_2}^2}
\]

where \(\bar{x}_1\) and \(\bar{x}_2\) are the respective means and \(S_{x_1}^2\) and \(S_{x_2}^2\) is the pooled variance in both samples. Given that the percentage of mis-
classifications with a variable (X) is approximately the probability that a normal deviate exceeds \(\sqrt{X}/2\), the greater K is, the better X serves as a discriminator.

Although the LT has been used significantly less than the other two statistical techniques, it has been used successfully in paleon-
tology (Palmqvist et al., 2007), forensic anthropology (Jiménez-Arenas and Esquivel, 2013) and archaeology (Esquivel et al., 2015).

3. Results

For Barranco León D, the co-occurrence overlap gives 29 UTM


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squares (Fig. 3, Table 1). These squares mainly occur in the warmest area (MAT > 18 °C) of the Iberian Peninsula in the Guadalquivir valley and in a few cases in south-central Spain. The statistical analysis of the values from these 29 UTM squares correspond to a mean value of 16.8 ± 1.5 °C for MAT (MIN = 15.0 °C/MAX = 18.5 °C) and 700 ± 191 mm for MAP (MIN = 500 mm/MAX = 1100 mm) (Table 1). The climate can be characterized as warm, with a high atmospheric temperature range. The summer is warm and the winter is mild. Rainfall is low and it is irregular, with the highest amount during winter and to a lesser extent spring, with four months during summer and early autumn (from June to September) with low rainfall (Fig. 3). The Lautensach-Mayer and Dantin-Revenga Aridity Indices suggest a semi-arid continental Mediterranean climate with four dry months in summer (Fig. 3, Table 3). By contrast, the De Martonne Index classifies the climate as semi-humid (Table 3).

For Fuente Nueva-3, the overlap gives a total 58 UTM squares (Fig. 3, Table 1). As for Barranco León, these squares mainly occur in the Guadalquivir valley, although the overlap is more extended and a few squares reach northern Spain, near to the boundary between Mediterranean and Atlantic climates (Fig. 3). MAT is 16.4 ± 2.1 °C (MIN = 12.0/MAX = 18.5 °C) and MAP is 738 ± 232 mm (MIN = 500 mm/MAX = 1200 mm) (Table 1). The climate is warm too, with a lower atmospheric temperature range. The summer is warm and the winter is mild. Rainfall is low and it is irregular, as in the case of Barranco León D, with four dry months during summer and early autumn. The Aridity Indices also yield the same results as for Barranco León D (Fig. 3, Table 3).

In comparison with the current climatic data from the vicinity of Orce village, both the MCR-estimated MATs are much higher (+3 °C and +2.6 °C) than at present. For both localities, the warmer climatic conditions are mainly linked with a greater increase in temperature in winter (+3.2 °C and +3.4 °C) than in summer (+2.5 °C and +0.8 °C). The total amounts of rainfall are higher (+394 mm and +432 mm) than at present in the Guadix-Baza Basin. This is corroborated by the value of the Aridity Index of De Martonne, which is greater than 20 (subhumid climate) in Barranco León D and Fuente Nueva-3, whereas today the value is less than 20 (semi-arid climate), suggesting that during the late Early Pleistocene conditions were much more humid than today. An overall comparison suggests that the climate was warmer with mild winters and that the level of precipitation was higher than today, particularly during winter and spring. It is noteworthy here that such a direct comparison, especially for temperature, between our results and the modern data should be contextualised by the fact that during the Early Pleistocene the region may well have been some 200 m below its present elevation, given the uplift of the Betic Cordillera (Gilbert et al., 2015; García-Aguilar et al., 2014, 2015).

The statistical results are shown in Table 4. MAP is slightly higher in Fuente Nueva-3 than in Barranco León D because the p value (<0.05) permits us to determine a statistical difference between the two means (p = 0.042). However, this value must be
taken with caution because it is very close to the critical value ($p = 0.05$). Nevertheless, DFA and LT shed some light on this because the % of correct reclassifications is very low (DFA = 58.60) and the % of overlap is very high (LT = 82.65). The results obtained
for the DDR are even more conclusive because no difference between the respective means was found (t-test, p > 0.05). In addition, the % of correct reclassifications (56.30) and the % of overlap (86.09) are indicative of very similar values for both archaeopalaeontological sites. The statistical scenario for MAT is very similar to that for DDR because no significant difference is found between the respective means (t-test, p > 0.05). Accordingly, DFA gives a very low % of correct reclassifications (44.80) and LT produces a very high % of overlap (81.99).

4. Discussion

4.1. Comparison with other proxies

Comparisons with other proxies recovered from the earlier excavation campaigns at the two sites have already been drawn in Blain et al. (2011). Briefly, pollen analyses by Jiménez Moreno (2003) “possibly” (because this author confesses some doubts about his results) show the predominance of arboreal taxa such as Pinus, Olea, Phillyrea, Cupressaceae and Quercus sp. for Barranco León. The occurrence, even in low percentages of taxa with strong affinities for humidity such as Betula, Corylus, Ilex, Ligustrum and Fraxinus, indicates some wooded areas with higher hydric requirements. Along the rivers or lake shore, Alnus and Salix would have grown. Pollen analyses also reveal the presence, in small percentages, of trees typical of mountain areas (Cedrus and Picea), today absent from the studied region. Herbs include Artemisia, Plantago, Amaranthaceae-Chenopodiaceae, Asteraceae type tubuliflores, Cruciferae, Ephedra and Centarea, whereas Gramineae are present in low percentages. Consequently, palynology shows the existence of well-developed woodlands (50% arboreal pollen) with predominantly Mediterranean taxa (Cupressaceae, Quercus sp., Olea, Phillyrea), although some taxa (such as Betula, Corylus, Quercus, Cedrus and Picea) indicate more humid conditions than at present, thus concordant with the results of the herpetofaunal assemblage from Barranco León D in characterizing warm and humid conditions.

The degree of diversity among the small mammals is relatively high (Agustí et al., 2010a, b). One of the more noteworthy components is the insectivore assemblage, which includes Erinaceus cf. praeglacialis, Galemys sp., Asoriculus gibberodon, Sorex minutus, Sorex sp. and Crocidura sp. (Purió Bruno, 2003; 2007). This corresponds to the richest assemblage of insectivores recorded in the Guadix-Baza Basin and reinforces the idea of warmer, wetter conditions.

As far as large mammals are concerned, the faunal lists from the two sites are almost the same, only differing in the occurrence of Ammotragus europaeus and Megantoreon cf. whitei in Fuente Nueva-3, which have not been recovered from Barranco León D (Martínez-Navarro et al., 2010). The large-mammal record (Abbazzi, 2010; Alberdi, 2010; Lacombat, 2010; Madurell-Malapeira et al., 2011; Martínez-Navarro et al., 2003, 2004, 2010; Medin et al., in press: Moullé et al., 2004) is characterized by the occurrence of inhabitants of open habitats (Mammuthus meridionalis, Bison sp., Hemimyces cf. albus, Equus altidens, Equus sussenbornensis and Stephanorhinus cf. hundshheimensis), aquatic environments (Hipopotamus antiquus) and wet woodland areas (Praemegaceros cf. verticornis and Metacervus rhenanus). Carnivores are represented by cf. Homotherium sp., Pachydracuta brevirostris, Ursus etruscus, Meles meles, Vulpes sp. and Canis mosbachensis. Among these, the good representation of the extinct giant Hipopotamus antiquus, which accounts for 27.1% of the large mammals at Barranco León D (Espigares Ortiz et al., 2010), provides evidence supporting the presence of large bodies of water under warm climatic conditions (Martínez-Navarro et al., 2003).

In addition, the presence in Barranco León D of the thermophilous gastropod Melanoides tuberculata (Anadón et al., 2015), a taxon today restricted to lower latitudes in tropical and subtropical areas of Africa and Asia, with a water temperature survival range of between 18 °C and 32 °C (Duggan, 2002), suggests that the lake water temperature was always higher than 18 °C, possibly related to warmer climatic conditions or more probably to hydrothermal activity in that part of the Basin, as suggested by paleohydrochemical analyses (García-Aguilar et al., 2014, 2015). However, other freshwater mollusks and ostracods are also present (Bithynia, Valvata, Sphaeridiidae, Cyprididae torosa nodded, Ilyocypris), none of which show evidence of growth in thermal waters, thus suggesting that Melanoides tuberculata must have been transported by a stream into a throughflow open fluvo-lacustrine environment fed by surface and groundwaters (Anadón et al., 2015).

4.2. Comparison with other Mediterranean records

Throughout the Mediterranean area, climate proxies indicate particularly warm forested conditions for the late Early Pleistocene interspersed with short cooler events of more open vegetation. The pollen analyses of the long Pleistocene sedimentary succession from Leffe (Southern Alps, Italy) revealed climatic cycles from warm-temperate to cool, with warmer-wet floristic associations especially during the time period between Jaramillo and Olduvai (i.e. between 1.07 and 1.78 Ma = subunits 4 to 7; Muttoni et al., 2007; Ravazzi et al., 2009). In the Leffe sequence, these climatic cycles (18 cycles in total) are characterized by the succession of an initially dry and warm-temperate, then warmer and very moist, subsequently cool-temperate and wet and, finally, dry and continental climate over short intervals with increasing open vegetation (Muttoni et al., 2007). On the basis of their faunal content, subunits 6 and 7 have been correlated with the Colle Curti Faunal Unit (between 1.1 and 1.4 Ma), and subunit 5 with the end of the Tasso and beginning of the Farneta Faunal Unit (around 1.6–1.7 Ma) (Ravazzi et al., 2009), Ravazzi and Rossignol Strick (1995) described, within such cycles in subunit 5, the occurrence of some “Carya peaks” (together with Fagus, Juglans cinerea-type and Aesculus), which they associated with a climate that was warm-temperate (14–16 °C mean annual temperature, i.e. around 2 to 4 °C higher than the present temperature in the area, roughly similar to what has been observed in Barranco León and Fuente Nueva-3) and humid, with a long growth season and abundant available moisture. These authors also reviewed other sites in southern Europe, such as Stirono (northern Italy), Pietrafratta (central Italy), Camerota (southern Italy), Bernasso and Nogaret (southern France), and Bobila Ordis (northeastern Spain), where phases of Caraya abundance appear in the middle of interglacial periods, under a humid climate. In a more recent study in the Crotona area (southern Italy), Joannin et al. (2007) identified three interglacial-related forest phases: deciduous forest, subtropical–humid forest, and altitudinal coniferous forest. This last step constitutes a transition toward a fourth step, which is glacial-related open vegetation. Combourieu-
Nebout (1993) also identified a subtropical humid phase in her idealized glacial-interglacial cycle for the Early Pleistocene of southern Italy and proposed a succession of four phases: open vegetation (dry), deciduous/evergreen woodland (warm but still dry), subtropical humid forest (warm and humid) and altitudinal coniferous forest (cooler but still humid).

Such a background may suggest that Barranco León D and Fuente Nueva-3, given the particularly warm and humid herpetofauna-based reconstruction (indicating the warmest temperature for the Early Pleistocene archaeo-paleontological sites studied in Agustí et al., 2009), are contemporaneous with subtropical climatic conditions, with mild winter temperatures (i.e. longer growth seasons) and higher winter precipitation. Although no subtropical-humid pollen has been found at these sites, it is interesting to note here the relict presence of subtropical reptiles such as the anguid Dopasia (not used in our climatic reconstruction because currently absent from the whole European continent), which may also suggest the occurrence of subtropical environmental conditions during the formation of Barranco León D and Fuente Nueva-3. It is also noteworthy that according to a review of the Pliocene to Pleistocene vegetation of Italy by Bertini (2010), subtropical ecosystems disappeared at ca. 1.2 Ma, thus suggesting an age for these two sites certainly older than 1.2 Ma and contemporaneous with one another, in accordance with other dating estimations.

In as much as last interglacial models can be used for an interpretation of pre-Middle Pleistocene Transition cycle patterns before 1.2 Ma, careful comparisons with models of the last interglacial vegetation suggest that the occurrence of well-developed woodlands in Barranco León (Jiménez Moreno, 2003), with the presence of deciduous Quercus, Mediterranean sclerophylls (Olea, Cedrus, Corylus, Cupressaceae and Phillyrea) and Picea, is characteristic of the “temperate phase” of the idealized vegetation phases in south European sites (van der Hammen et al., 1971; Tzedakis, 2007), although the presence of Betula would be a relict of the pre-temperate phase of open woodland. As demonstrated by Tzedakis et al. (2002, 2003) and Tzedakis (2005) for the last interglacial at Ioannina (Greece), interglacial forest expansion is closely associated with the timing of the summer insolation peak, with Mediterranean sclerophylls and other summer-drought-resistant taxa expanding during the period of maximum summer insolation. Long pollen records from the Mediterranean region have revealed the influence of precession on the Mediterranean vegetation on orbital timescales (Magri and Tzedakis, 2000). Precession-related patterns probably reflect an enhancement of the essential summer-dry/winter-wet character of the Mediterranean climate at times of precession minima (Fletcher and Sánchez-Goni, 2008). It is relevant to note that Barranco León D and Fuente Nueva-3 show very similar estimated values for the DDR, indicating the same precession-related pattern. Enhanced summer dryness and warmth during precession minima in the western Mediterranean is linked with enhanced west African monsoons (Balé et al., 2004), while net precipitation over the Mediterranean basin should increase during precession minima and winter precipitation should be favored by stronger land/sea temperature contrasts over the Mediterranean Sea in autumn (Tuenter et al., 2003; Meijer and Tuenter, 2007). Together with the well-calibrated environmental reconstructions of Joannin et al. (2007) for the late Early Pleistocene of Santa Lucia (southern Italy), such data should make it possible to identify the particular periods with warm and humid conditions and better constrain the chronology of Barranco León D and Fuente Nueva-3 within the range given by the biostratigraphy and numerical dating.

4.3. Constraining the chronology on the basis of climate

The first indications of the age of the Barranco León and Fuente Nueva-3 sections were provided by Martínez-Navarro et al. (1997) and Oms et al. (2000), who showed that the whole sections had a reverse geomagnetic polarity. Since then a combination of magnetostratigraphy and biostratigraphy has been used to date the archaeo-paleontological sites of Barranco León and Fuente Nueva-3. This has suggested that these two sites fit within the upper Matuyama chron, between the Olduvai and Jaramillo subchrons, on the basis of the presence of the archaic vole Allocanthomys aff. lavocati (Agustí and Madurell, 2003; Agustí et al., 2010a, 2015) together with the reversed polarization of the sediments (Oms et al., 2003; Agustí et al., 1997). A range of between 1.2 and 1.4 Ma was then proposed (Agustí and Madurell, 2003). Based on magnetostratigraphy Scott et al. (2007) proposed a minimum age of 1.25 Ma for Barranco León and 1.2 Ma for Fuente Nueva-3. ESR dating obtained prior to 2008 assigned these sites an age of 1.46 Ma for Barranco León D and between 1.34 and 1.67 Ma for Fuente Nueva-3 (Duval, 2008). Subsequently, new ESR results were published for Fuente Nueva-3, according to which the age of the site would be 1.19 ± 0.21 Ma (Duval et al., 2012) and 1.4 ± 0.38 Ma for Barranco León D (Toro Moyano et al., 2013). More recently, a new cosmogenic nuclide burial age of 1.5 ± 0.31 Ma has been estimated for Fuente Nueva-3 (Alvarez et al., 2015) (Fig. 2). In addition, the use of evolutionary tendencies for the purpose of numerical dating estimates, in this case the increase in size over the evolutionary history of Mimusops savini, has provided slightly younger ages for Fuente Nueva-3 (1.2 ± 0.12 Ma) and Barranco León D (1.26 ± 0.13 Ma) (Lozano-Fernández et al., 2015). Discussing the validity of this method is far from the aim of this paper. However, because such estimates are based primarily on ESR dating (with important uncertainties) from other Iberian sites such as the lower layers of Gran Dolina in the Sierra de Atapuerca (Lozano-Fernández et al., 2013), this may induce certain problems in the chronological calibration of such linear evolutionary tendencies.

Also of interest is the combined uranium series–electron spin resonance (US-ESR) dating obtained for the nearby site of Venta Micena (Guadix-Baza Basin, southeastern Spain) by Duval et al. (2011). This yielded an age of 1.37 ± 0.24 Ma, thus somewhat younger than some of the estimates for Barranco León and Fuente Nueva-3 (Fig. 2). The presence in Venta Micena of a more archaic form of vole, Allocanthomys ruffoi (probably the ancestor of Allocanthomys lavocati; Agustí et al., 1987a, 1987b, 2010a, 2015), and of the ovibovine Soergelia minor, as well as the dental features of Mammutthus meridionalis (Ros-Montoya et al., 2012) suggest that Venta Micena is clearly older than Barranco León and Fuente Nueva-3, either leading to the conclusion that the dating estimation for Venta Micena should be revised or constituting an argument constraining the chronology of Barranco León and Fuente Nueva-3 to be younger than 1.4 Ma.

According to the detailed late Early Pleistocene environmental reconstruction by Joannin et al. (2007), the vegetation dynamics is separated into three main steps: 1) development of mesothermic elements, mainly Olea (warm and humid conditions correlated with MIS 43 and 42); 2) expansion of mid- and high-altitude elements (temperate but still humid conditions correlated with MIS 42–41); and 3) strengthening of steppe and herb elements (cooler, dry conditions correlated with MIS 40). The existence of such cold periods during the earliest Pleistocene in southern Europe is well attested by the temperature reconstructions for the period comprised between 2.11 and 2.46 Ma (Klotz et al., 2006), with estimated MAT up to 6.4 °C lower when compared to the present-day climate. Taking this into account, we can interpret the time period between 1.25 and 1.55 Ma using the oxygen isotope
composition (ODP 967; Kroon et al., 1998) as a proxy for temperature; sapropel events (ODP 967; Kroon et al., 1998) as an indication of enhanced runoff; and Saharan dust deposition (Larrasoaña et al., 2003) as a proxy for humidity on the North-African Mediterranean shore, thus identifying warm and humid environmental periods (Fig. 4).

Close analysis of Fig. 4 shows that the periods of enhanced runoff (sapropel events) are contemporaneous with the second part of the warm periods (with some differences for MIS 47), thus suggesting that the end of such periods must be much more humid than the first part, following in this respect the vegetation succession of Combouvier-Lebrun (1993) and Ravazzi and Rossignol Strick (1995) etc., where an initially dry and warm-temperate period precedes a warmer and very moist phase. Because
Barranco León D and Fuente Nueva-3 show very similar values for MAP we infer that both sites should be located in the second part of the period. For the time between 1.25 and 1.55 Ma, such warm and humid periods are roughly contemporaneous with the precessional amplitude maxima (eccentricity), as suggested by Joannin et al. (2007) for the time period from MIS 40 to 43. Whereas oxygen isotope composition mainly follows obliquity, these latter warm moister periods can be correlated with precession minima and insolation maxima. In the case of MIS 43 and 45, the precession minima are contemporaneous with the obliquity maxima, whereas for MIS 47 and 49 they are not, thus creating two oxygen isotope peaks (as well as two sapropel events in the case of MIS 47). In conclusion, and because the evolution of Mimomys savini suggested that the chronological difference between the two sites is rather small (60,000 years) with Barranco León D being slightly older than Fuente Nueva-3 (Lozano-Fernández et al., 2015), our climatic reconstructions can be interpreted as that Barranco León D and Fuente Nueva-3 correspond to a same warm and humid phase within a climatic cycle but from two consecutive periods synchronous with summer insolation maxima, i.e. at around 1.36, 1.40, 1.43, 1.45 or 1.47 Ma (Fig. 4). Further analyses, probably based on material from the new excavation campaigns (2010–2015) still in the process of being coarse-grained and stratigraphic approach made possible by such excavations, will allow us to make these clima-chronological proposals more precise. At the same time, additional terrestrial reconstructions for the period under study will permit us to better understand the differences between the interglacial periods from MIS 43 to 49.

5. Conclusions

New paleoclimatic reconstructions based on the use of the newly-coined Mutual Ecogeographic Range (MER) method on herpetile assemblages have been carried out in order to obtain the mean monthly temperature and precipitation and the difference between the driest and the rainiest season for the late Early Pleistocene sites of Barranco León D and Fuente Nueva-3 (Guadix-Baza Basin, SE Spain). As in previous analyses, the climate is shown to have been much warmer and moister than it is now in the south-eastern Iberian Peninsula, with lowericontinentality. According to the new climatic parameters: 1) rainfall distribution through the year shows considerably higher precipitation in every season except summer and early autumn, which remain drier and so consistent with a Mediterranean climate pattern; 2) no change is observed in the duration of the aridity period, which remains four months long; 3) the Aridity Index of De Martonne suggests that there has been a major change in ombroclimatic type between the late Early Pleistocene (subhumid) and today (semi-arid); 4) the absence of clear differences between MAT, MAP and DDR at the two sites is an additional argument in support of a very similar climatic context for the two sites. The contextualization of such climatic results within the evolution of global proxies and orbital parameters and comparison with other climate records (such as pollen reconstruction) permit us to contrast the ages obtained from numerical dating and biochronology for Barranco León D and Fuente Nueva-3. The very warm and humid climate reconstructed from the amphibian and reptile assemblages suggests, within the range given by the biostratigraphy and the numerical dating, that these sites may be contemporary with two successive particularly warm interglacial peaks of MIS 43 (i.e. around 1.36 Ma), MIS 45 (i.e. around 1.40 Ma), MIS 47 (where two peaks are observed around 1.43 and 1.45 Ma) or MIS 49 (i.e. around 1.47 Ma). Using climatic considerations to constrain the chronology is thus shown to be an interesting way of reducing the imprecision of the numerical dating obtained from ESR or cosmogenic nuclide analyses in the case of Early Pleistocene sites.

Acknowledgments

We thank the journal editor Prof. Danielle Schreve (Royal Holloway University of London) and the two reviewers Prof. David J. Horne (Queen Mary University of London) and Dr. Angela A. Bruch (Senckenberg Forschungsinstitut, Frankfurt) for their comments on an earlier version of the manuscript. Some of the ideas of the present manuscript have been presented during the International ROCEH Conference on Human Expansions (“Expansions 2015”, July 13–17, 2015) at Senckenberg Biodiversity and Climate Research Center (Frankfurt am Main, Germany). We are grateful to the audience for their questions and constructive comments and especially to the organizers Angela A. Bruch, Christine Hertler and Miriam Haidle for their invitation. We are particularly grateful to Jesús Rodríguez (CENIEH, Spain) for the constructive discussion during that meeting in Frankfurt and for the suggestion of the “new name” for our quantitative climatic reconstruction method. This paper is part of projects B120489SV18BC “Presencia humana y contexto paleoecológico en la Cuenca continental de Guadix-Baza. Estudio e interpretación a partir de los depósitos plio-pleistocenos de Orce (Granada, España)” (Junta de Andalucía), CGL2012-38358, CGL2011-28681 and CGL2010-15326 (Ministerio de Economía y Competitividad), and SGR2014-416, SGR2014-901 (Generalitat de Catalunya) and HUM-607 (Junta de Andalucía). I. Lozano-Fernández was the beneficiary of a pre-doctoral subsidy from the Fundación Atapuerca assigned to the IPHES. H.-A. Blain is grateful to Sébastien Joannin (CNRS, Montpellier) for supplementary information about Early Pleistocene orbital parameters.

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