



Chronology for the Cueva Victoria fossil site (SE Spain): Evidence for Early Pleistocene Afro-Iberian dispersals



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ABSTRACT

Cueva Victoria has provided remains of more than 90 species of fossil vertebrates, including a hominin phalanx, and the only specimens of the African cercopithecoid *Theropithecus oswaldi* in Europe. To constrain the age of the vertebrate remains we used paleomagnetism, vertebrate biostratigraphy and ²³⁰Th/U dating. Normal polarity was identified in the non-fossiliferous lowest and highest stratigraphic units (red clay and capping flowstones) while reverse polarity was found in the intermediate stratigraphic unit (fossiliferous breccia). A lower polarity change occurred during the deposition of the decalcification clay, when the cave was closed and karstification was active. A second polarity change occurred during the capping flowstone formation, when the upper galleries were filled with breccia. The mammal association indicates a post-Jaramillo age, which allows us to correlate this upper reversal with the Brunhes–Matuyama boundary (0.78 Ma). Consequently, the lower reversal (N-R) is interpreted as the end of the Jaramillo magnetochron (0.99 Ma). These ages bracket the age of the fossiliferous breccia between 0.99 and 0.78 Ma, suggesting that the capping flowstone was formed during the wet Marine Isotopic Stage 19, which includes the Brunhes–Matuyama boundary. Fossil remains of *Theropithecus* have been only found *in situ* ~1 m below the B/M boundary, which allows us to place the arrival of *Theropithecus* to Cueva Victoria at ~0.9–0.85 Ma. The fauna of Cueva Victoria lived during a period of important climatic change, known as the Early-Middle Pleistocene Climatic Transition. The occurrence of the oldest European Acheulean tools at the contemporaneous nearby site of Cueva Negra suggest an African dispersal into SE Iberia through the Strait of Gibraltar during MIS 22, when sea-level was ~100 m below its present position, allowing the passage into Europe of, at least, *Theropithecus* and *Homo* bearing Acheulean technology.

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1. Introduction

Cueva Victoria is an Early Pleistocene cavern (>3 km of galleries) developed in the Triassic limestone of the Betic Cordillera (south-eastern Spain), in the San Ginés de la Jara hill, adjacent to the Cartagena Mining District (Fig. 1). It is located 3 km south of the Mar

Menor lagoon and 13 km east of Cartagena. Part of the cave was originally filled with breccia that was partially removed during manganese mining activities in the last century. In the Early Pleistocene, the cave had several natural connections to the outside and was filled with fossiliferous breccia, which have yielded >90 species of vertebrate remains including *Homo*, *Theropithecus*, and the first and last appearance data of several other vertebrate species (Ferràndez-Cañadell et al., 2014; Gibert and Ferràndez-Cañadell, 2015). The taphonomy of Cueva Victoria shows that the cave was not a human occupation site as previously suggested

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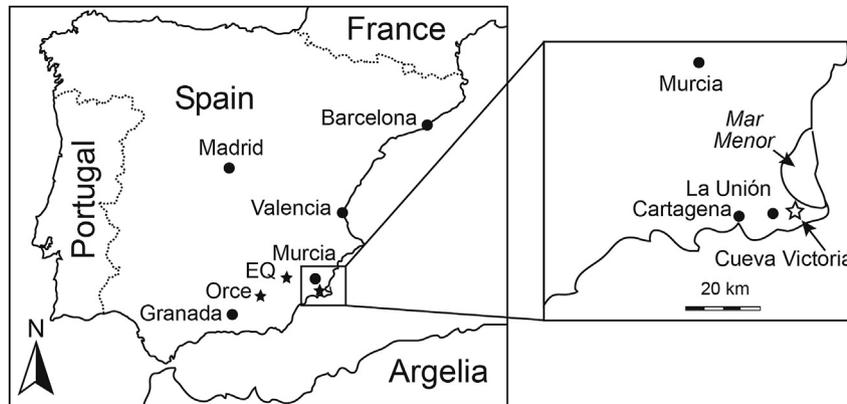


Figure 1. Geographical location of Cueva Victoria in SE Spain, and other SE Iberian sites mentioned in the text. EQ: Cueva Negra del Río Quípar.

(Carbonell et al., 1981). In contrast, it was a den of the hyena *Pachycrocuta brevirostris*, as indicated by the presence of accumulated layers of hyena coprolites, the abundance of deciduous teeth of hyena, the large number of bones with tooth marks and hyena type fractures, as well as digested bones, the remains of marine mammals, and the absence of lithic tools (Gibert et al., 1992, 1993a,b).

1.1. Cave infilling and stratigraphy of Cueva Victoria

Within Cueva Victoria, only those cavities connected with the outside during the Early Pleistocene were filled with breccia (i.e., Sala Unión and Victoria II, Fig. 2). The fossil collection from Cueva Victoria comes mainly from excavations in Sala Unión and adjacent secondary galleries. In this large room, several sub-vertical openings in the ceiling allowed breccia to completely fill the chamber (Fig. 2). The hill where the cave developed is still mantled with slope deposits of similar breccia, rich in angular pebbles of Triassic limestone but barren of fossils. At the foot of the hill, where the present entrances are located, these slope deposits are covered by recent stream-terrace gravels, rich in rounded pebbles of metamorphic rocks. Some lithic tools were collected from this younger unit and incorrectly interpreted as part of the cave infilling (Carbonell et al., 1981). We studied the sedimentary infilling in Cueva Victoria at different outcrops of Sala Unión and adjacent secondary galleries. In all of them, three lithostratigraphic units can be distinguished, which correspond to events occurring during and after the formation of the cave (Ferrández et al., 1989; Gibert et al., 2006): (i) A lower red clay unit, (ii) an intermediate fossiliferous breccia and (iii) a capping flowstone (Fig. 3).

1.1.1. The red clay unit This consists of 1–4 m of red clay, occasionally showing reworking features and Mn mineralization. The clay is made up of kaolinite and illite and is a residual product deposited after the dissolution of the Triassic limestone. It settled in the most depressed areas of the cave during the process of dissolution, when karst formation was active and the cave was closed. This unit always overlays the Triassic limestone and is usually covered by breccia in the studied galleries. To enable karst formation, environmental conditions would have been relatively wet, allowing underground water circulation and dissolution of the Triassic limestone.

1.1.2. The breccia unit This corresponds to allochthonous talus deposits, transported inside the cave through different entrances by slope-wash and gravity processes. The base of the breccia usually shows erosional features and consists of mud-supported angular clasts including vertebrate fossils, as well as authigenic and reworked Mn-oxides. The uppermost levels of

the breccia close to the main entrances show a clast-supported texture. The thickness of the breccia changes laterally, from ca. 18 m below one of the entrances to less than 1 m in the inner cavities, according to the topography of the cave. The grain size also changes laterally, becoming finer towards the internal parts of the cave. The breccia unit represents the time interval since the opening of the cave until it was filled with sediments. Lateral lithological changes in the breccia can occur in just a few meters, and the detailed internal stratigraphy is difficult to define. However, no major discontinuities have been identified within this deposit. Although brecciated sediments are difficult to interpret as paleoclimate archives, the heterometric clast-supported sediments that characterise the upper part of the breccia could have developed during a dry period, when porous soils allowed higher erosion during flooding events and slope deposits accumulated at the San Ginés mountain talus. Wet periods are probably represented by a larger proportion of fine-grained deposits occurring at the basal part of the breccia unit.

1.1.3. The flowstone unit This occurs on top of the breccia and consists of a 10–15 cm thick laminated calcite layer. This unit was deposited in the fossiliferous galleries once the cave was completely filled with allochthonous sediments and water seeped into the cave through fractures in the limestone and the porous breccia. Calcite precipitation from water supersaturated with respect to calcium carbonate first led to cementation of the upper breccia, and subsequently formed a speleothem on its surface. Deposition of speleothems relies on water supply and elevated soil pCO₂ (in comparison to the pCO₂ of the cave atmosphere) in order to enable dissolution of the limestone host rock and transport of reactants into underlying caves (Kaufmann, 2003). Arid conditions are, thus, not favorable for speleothem formation. Consequently, the period of flowstone deposition corresponds to a phase of relatively wet climate, although flowstone growth was not necessarily continuous. The period of flowstone deposition, thus, could correspond to several phases of relatively wet climate.

1.1.4. Post-flowstone sediments Locally, a fourth unit occurs. Post-flowstone sediments consist of about 5–10 cm of detrital sediment deposited on top of the flowstone at the eastern wall. At the north-western wall, about 4 cm of detrital sediment are interstratified between two flowstones. In addition, some cavities (>30 cm) filled with non-fossiliferous, non-cemented silt occur inside the breccia at the eastern wall section. All these sediments, with particular lithology, postdate the breccia and the flowstone, and correspond to the infilling of secondary cavities, during the middle or late Pleistocene.

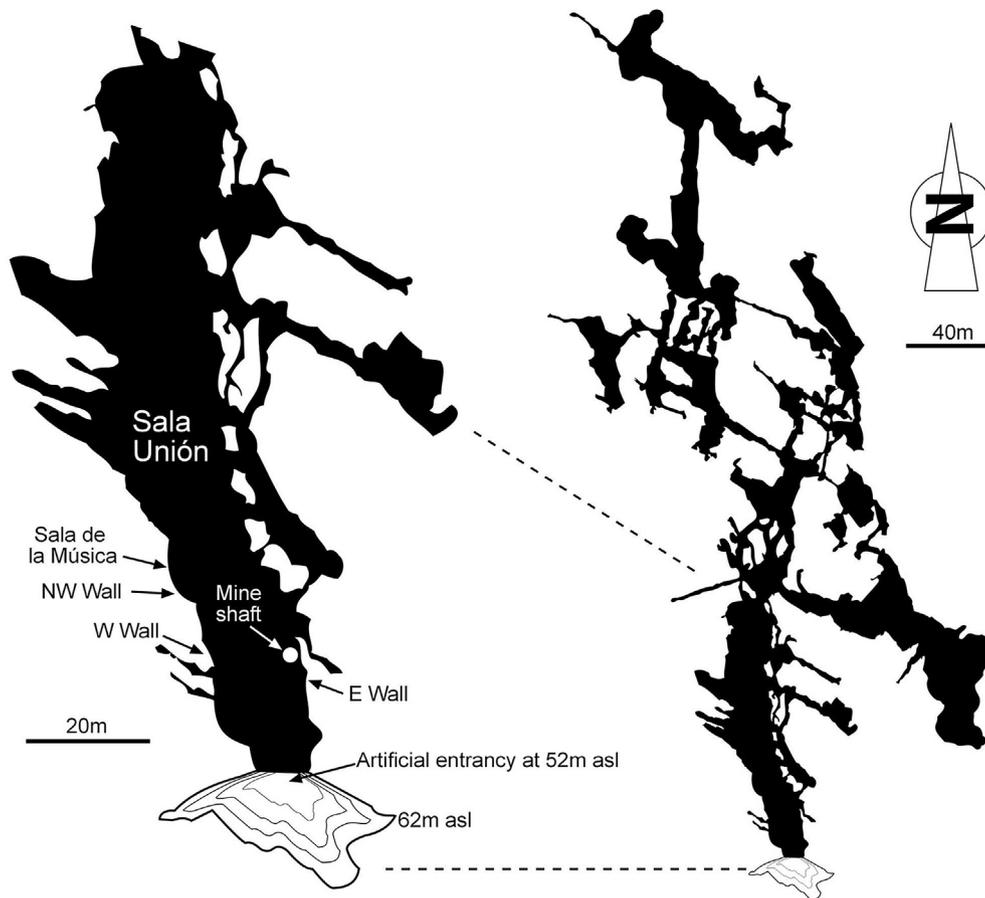


Figure 2. Cave map of Cueva Victoria (right) showing the main room (Sala Unión, left) filled with fossiliferous breccia. Modified from Ros and Llamusi (2015).

1.2. Paleontology and biostratigraphy

Cueva Victoria shows a remarkable faunal biodiversity with at least 90 species of vertebrates (including birds) (Gibert et al., 2006; Gibert and Ferrández-Cañadell, 2015). The faunal assemblage of Cueva Victoria suggests a late Early Pleistocene age (Table 1). Different macromammal species identified at Cueva Victoria also occur at the Early Pleistocene sites of Venta Micena, Barranco León and Fuentenueva 3 in the Baza Basin (100 km west), dated at >1.3–1.2 Ma (Scott et al., 2007), although some of these common taxa occur also in sites dated between 0.9 and 0.75 Ma (Table 1).

There are four well determined species of micromammals in Cueva Victoria: *Victoriamys chalinei*, *Apodemus* aff. *mystacinus*, *Eliomys quercinus* ssp., and *Castillomys crusafonti*. The last three genera occur at the reverse deposits of Atapuerca TE site but not at TD site (Cuenca-Bescos et al., 2015). Among the rodents, arvicolid tend to have the greatest value for biostratigraphy on the Iberian Peninsula (Cuenca-Bescós et al., 2010; Martin, 2012). The only arvicolid present at Cueva Victoria is *V. chalinei*, which has been reported from the sites of Cueva Negra, Atapuerca (Trincherá Dolina, levels 3–8), Almenara-Casablanca 3, Cal Guardiola in the Vallparadís section, and El Chaparral (Agustí and Galobart, 1986; Minwer-Barakat et al., 2011; López-García et al., 2012; Martin, 2012). *V. chalinei* (= *Allophaiomys chalinei*), was initially reported from the late Early Pleistocene deposits of Trincherá Elefante (TE-14) at Atapuerca (Laplana and Cuenca-Bescos, 2000; Van der Made et al., 2003) but later cited only from the younger Trincherá Dolina (Cuenca-Bescos et al., 2015). Martin (2012) noted that *V. chalinei*

had been recovered only from localities between the Jaramillo subchron and the base of the Brunhes (0.98–0.78 Ma), and referred Cueva Victoria to that time period. In addition, some new taxa have been described from Cueva Victoria: a new species of canid, *Cuon rosi* (Pons-Moyà and Moyà-Solà, 1978), the arvicolid, *A. chalinei* (Alcalde et al., 1981), later assigned to *V. chalinei* (Martin, 2012), a new species of a lagomorph, *Oryctolagus giberti* (De Marfà, 2008), and a new species of deer, *Megaloceros novocarthaginiensis* (Van der Made, 2015). The First Appearance Datum (FAD) in Iberia is recorded at Cueva Victoria for four taxa: *Bufo viridis* (Blain et al., 2010), *Testudo hermanni* (García-Porta, 2001; Pérez-García et al., 2015), *Himantopus himantopus* (Sánchez Marco, 2015), and *Ovis antiqua* (Crégut-Bonnoure, 1999). These first appearance data also suggest a latest Early Pleistocene age for the site because these species have only been recovered before in Middle Pleistocene sites. In fact, the association of *Hemitragus bonali* and *O. antiqua* was used to place Cueva Victoria in the Middle Pleistocene (Crégut-Bonnoure, 1999, 2005). A phalanx (CV-0) from Cueva Victoria was classified as human using morphometric techniques (Pons-Moyà, 1985; Gibert and Pons-Moyà, 1985; Gibert et al., 1985; Gibert and Pérez-Pérez, 1989). A subsequent interpretation of CV-0 as a pedal phalanx of *Theropithecus* (Martínez-Navarro et al., 2005) was refuted with further anatomic and metric arguments showing that the phalanx falls out the of the range of *Theropithecus* variability and falls within human variability (Gibert et al., 2008; Ribot et al., 2015).

The geographical location of Cueva Victoria, 200 km from Africa, and the presence among its faunal assemblage of African primates and human remains (Gibert et al., 1985, 1998, 2006; Pérez-Peréz,

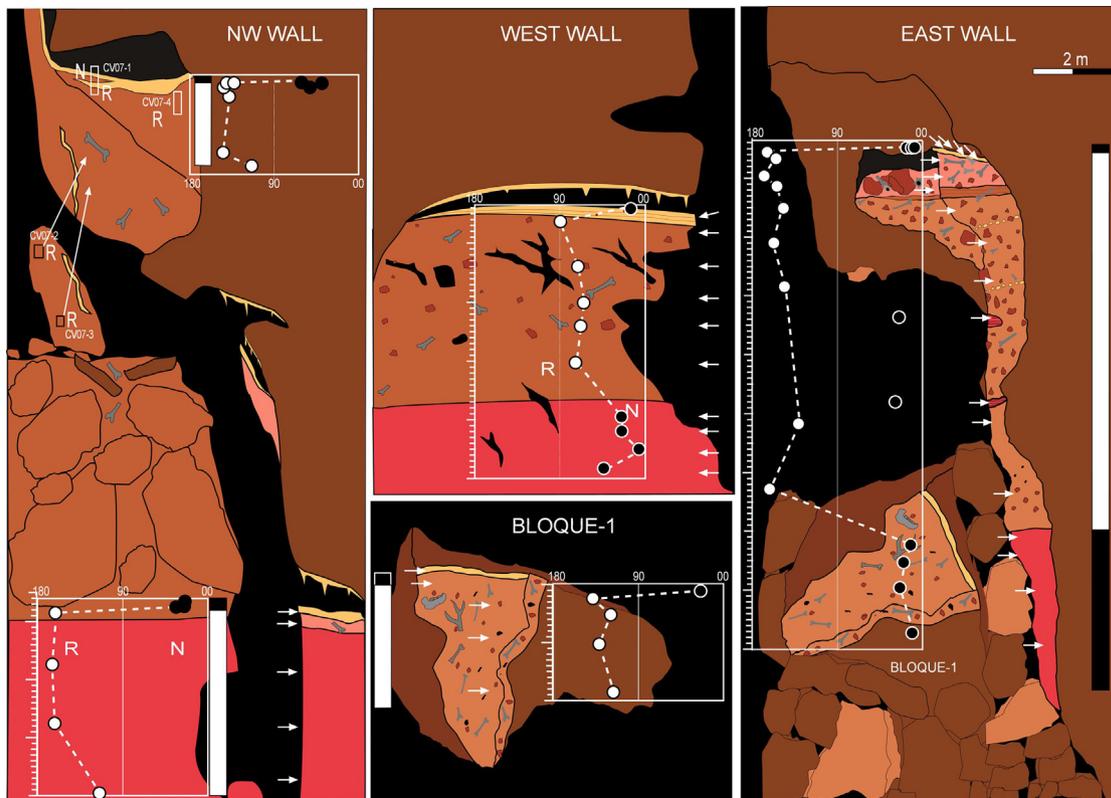


Figure 3. Sections sampled for paleomagnetism at Sala Unión. The eastern wall shows normal directions in the basal red clay, followed by reverse directions throughout the breccia up to the flowstone, and a final change to normal directions within the flowstone. Two samples collected from post-breccia infilling deposits show normal polarity interpreted as the Brunhes chron. Four samples from Bloque-1 show similar results with reverse directions in the breccia and normal directions in the flowstone. The samples collected from the western wall show normal polarity during clay deposition and a mixture of reverse and normal during the deposition of the breccia. This normal overprint could be related to cementation with new minerals of the breccia during Brunhes times. The north-western wall shows reverse directions throughout the breccia and normal directions in the capping flowstone. In this area, the claystone unit outcrops only in an isolated adjacent topographically lower gallery (Sala de la Música), where it is covered by a few centimetres of breccia and flowstone. This clay shows reverse polarity and was probably deposited during post-Jaramillo times when the main Sala Unión was filled with breccia. The polarity of the paleomagnetic samples are expressed as delta (i.e., the angle to the present field direction 000° , 57°). Arrows show the samples' position, N and back dots indicates normal polarity, R and empty dots shows reverse polarity.

1989; Ribot et al., 2015) makes Cueva Victoria a key site in discussions of dispersal routes out of Africa during the Early Pleistocene.

2. Materials and methods

2.1. Paleomagnetism

The complex sedimentary dynamics within karst systems may result in local sedimentary interruptions in some areas of the talus cones that infill the cave. To maximize chrono-stratigraphic coverage, we collected sequences at five localities in Sala Unión close to the original entrances, where most of the fossil remains are located. Four of the five sampled sections show the complete stratigraphic sequence with the three units (red clay, breccia and flowstone).

Samples were collected in three sections near the walls of Sala Unión and in a large block (18×5 m), named Bloque-1, rich in fossils, which dropped from its original position during mining operations. Bloque-1 has supplied a large fossil collection and shows a continuous stratigraphic series through the upper breccia up to the flowstone. Its internal bedding (tilted at 70°) was used to perform a paleomagnetic 'tilt test'. An additional section was sampled in Sala de la Música, an adjacent, topographically lower gallery, located farther from the original entrance and therefore lacking fossils. Of these localities (Fig. 2), the longest series (9 m) comes from the eastern wall ($n = 18$), where the current

paleontological excavation was performed. The other sections are: western wall (5 m, $n = 10$), north-western wall (4 m, $n = 6$), Bloque-1 (2 m, $n = 5$), and Sala de la Música (3 m, $n = 5$). Oriented samples were collected directly from the walls in the lower red clay unit, the breccia, and the capping flowstone (Fig. 3). At least three specimen cubes ($9\text{--}13\text{ cm}^3$) were cut from each sample ($n = 39$), then sanded and cleaned with compressed air. Alternating field (AF) demagnetization to at least 12 mT (to remove recent viscous remanence) was followed by thermal demagnetization in 8–17 steps (from 80°C up to $440\text{--}610^\circ\text{C}$ depending on mineralogy and magnetic stability). The flowstone that caps the eastern wall section is finely laminated, thus we cut sub-specimens (~ 3 mm thick) from two of the thicker samples ($n = 17$). These laminated sub-specimens are important for the determination of the specific position of the polarity change inside the flowstone. We also measured subsamples from the non-laminated flowstone from Sala de la Música ($n = 15$). All analytical procedures and continuous sample storage were conducted in a magnetically shielded laboratory (<400 nT) at the Berkeley Geochronology Center. Laboratory experiments used a cryogenic magnetometer (noise level 5×10^{-12} Am²), a 2-axis static AF demagnetizer (residual field ~ 15 nT), and a non-inductive furnace (residual field <2 nT).

All specimens showed a two-component magnetization (Fig. 4), made up of a low coercivity/low temperature component (in a modern field direction) and a higher temperature component (in the expected normal or reverse direction). For most specimens, the

Table 1

SE Iberia Early Pleistocene key mammal sites with associated paleomagnetic data. The table shows vertebrate species with biostratigraphic meaning from Cueva Victoria (CV) compared with the fauna from other paleomagnetically dated sites from south-east Iberia: Cueva Negra del Río Quípar (CNRQ), Fuentenueva-3 (FN3), Barranco León-5 (BL5), Venta Micena, (VM), Huéscar-1 (HU-1), Cúllar Baza (CB-1). The fauna of CV can be placed between the pre-Jaramillo sites (VM, BL, FN3) and CB-1 site that occurs just above the B/M boundary. Data from Scott et al. (2007), Gibert et al. (2007), Scott and Gibert (2009), Martin (2012, 2015), and Gibert and Ferrández-Cañadell (2015).

PALEOMAGNETIC CHRONOLOGY		PRE-JARAMILLO			POST-JARAMILLO		BRUN.
SEQUENCED SITES		VM	BL	FN-3	CV	HU-1	CB-1
KARSTIC SITES (BAZA BASIN)						CNRQ	
SMALL MAMMAL	<i>Castillomys crusafonti</i>	●	●	●	●	●	
	<i>Allophaiomys cf. pliocaenicus</i>	●	●	●			
	<i>Mimomys savini</i>			●		●	
	<i>Victoriomys chalinei</i>				●		
	<i>Pliomys episcopalis</i>					●	
	<i>Iberomys aff. Huescarensis</i>					●	
	<i>Iberomys brecciansis</i>					●	●
	<i>Arvicola cantianus</i>						●
	<i>Praeovibos</i> sp.	●	●	●	●		
	<i>Pachycrocuta brevisrostris</i>	●	●	●	●		
LARGE MAMMAL	<i>Megantereon</i> sp.	●	●	●	●		
	<i>Xenocyon (Lycaon) lycanoides</i>	●	●	●	●	●	
	<i>Mammuthus meridionalis</i>	●	●	●	●		
	<i>Hippopotamus antiquus</i>	●	●	●			
	<i>Eucladoceros giulii</i>	●	●	●			
	<i>Equus cf. sussembornensis</i>		●	●	●	●	●
	<i>Canis arnensis / mosbachensis</i>		●	●	●	●	●
	<i>Homotherium latidens</i> / sp.	●	●	●	●	sp.	
	<i>Stephanorhinus hundsheimensis/ etruscus</i>	●	●	●	●	●	●
	<i>Equus altidens</i>	●	●	●	●	●	●
	<i>Pannonictis cf. nestii</i>		●	●		●	
	<i>Panthera gombaszoegensis</i>				●	●	
	<i>Bison</i> sp.				●	●	●
	<i>Megaloceros</i> sp.				●	●	●
	<i>Sus</i> sp.					●	●
	<i>Macaca</i> sp.					●	●
	<i>Dama 'nestii' vallonnetensis</i>				●	●	
	<i>Elephas antiquus</i>					●	
	<i>Hippopotamus major</i>					●	
	<i>Crocota crocuta</i>					●	●
	<i>Mammuthus trogontherii</i>					●	●
	<i>Homo</i>	●	●		●	●	
Lithic artifacts		●	●		●	●	

modern field component was eliminated or greatly reduced by AF treatment and heating to 200 °C. The mean direction from this modern overprint is: Decl. = 353°; Incl. = 56°; $n = 41$ samples; $\alpha_{95} = 2.1^\circ$ (Fig. 5). Likewise for the tilt test, 'Bloque-1', which fell during mining operations (more than 50 years ago), showed a 'pre-tilting secondary overprint, rotated to: Decl. = 306°; Incl. = 41°; $n = 5$; $\alpha_{95} = 3.4^\circ$. This successful tilt test (Fig. 6) is reflected in 1) the distinct, but well-clustered secondary remanence, 2) a similar 'normal polarity' (from the flowstone), and 3) an antipodal 'reverse polarity' group (from the breccia). This test gives us confidence in the antiquity of remanence measured from the higher temperature demagnetization in all the samples. To identify the magnetic minerals carrying the magnetization of these sedimentary rocks, isothermal remanent magnetization (IRM) acquisition experiments were done. Two samples, one from the red clay and the other from the breccia were exposed to progressively stronger DC magnetic fields, with the remanence being measured after each exposure until the rock was magnetically saturated. The different coercivity components in the sample were identified and quantified. Low coercivities (<100 mT) are usually interpreted to indicate magnetite, whereas higher coercivities indicate either hematite (hundreds of mT to 1 T) or goethite (>1–2 T).

Sample CV15, collected from the red clay, has multi-domain magnetite and some hematite. Sample CV19, collected from the breccia, is noisy and difficult to interpret, but apparently contains

hematite (Fig. 7). In both cases magnetite and hematite are considered primarily deposited magnetic minerals.

2.2. $^{230}\text{Th}/\text{U}$ -dating

The age of the Cueva Victoria fauna is constrained by paleomagnetic data to be older than the beginning of the Brunhes magnetochron (0.78 Ma). We used the $^{230}\text{Th}/\text{U}$ -method to date a section of the capping flowstone that includes the polarity change at the eastern wall and another flowstone section at Sala de la Música that shows only normal polarity. The dating range of the $^{230}\text{Th}/\text{U}$ -method is approximately 500–600 ka, depending on the U content and the initial ($^{234}\text{U}/^{238}\text{U}$) activity ratio of the samples, as well as on analytical precision (Scholz and Hoffmann, 2008). Thus, dating this old (~0.78 Ma at the reversal) flowstone with the $^{230}\text{Th}/\text{U}$ -method is challenging.

U and Th isotopes were analysed by multi-collector inductively coupled plasma mass spectrometry (MC-ICPMS) at the Max Planck Institute for Chemistry in Mainz. Sample preparation and mass spectrometric analysis was similar to that described elsewhere (Hoffmann et al., 2007; Zak et al., 2012; Bosle et al., 2014; Scholz et al., 2014). Due to the relatively old age of the samples investigated in this study, the calibration of the mixed ^{233}U – ^{236}U – ^{229}Th spike is particularly important. A detailed description of the calibration is given by Scholz et al. (2014). Here we only briefly

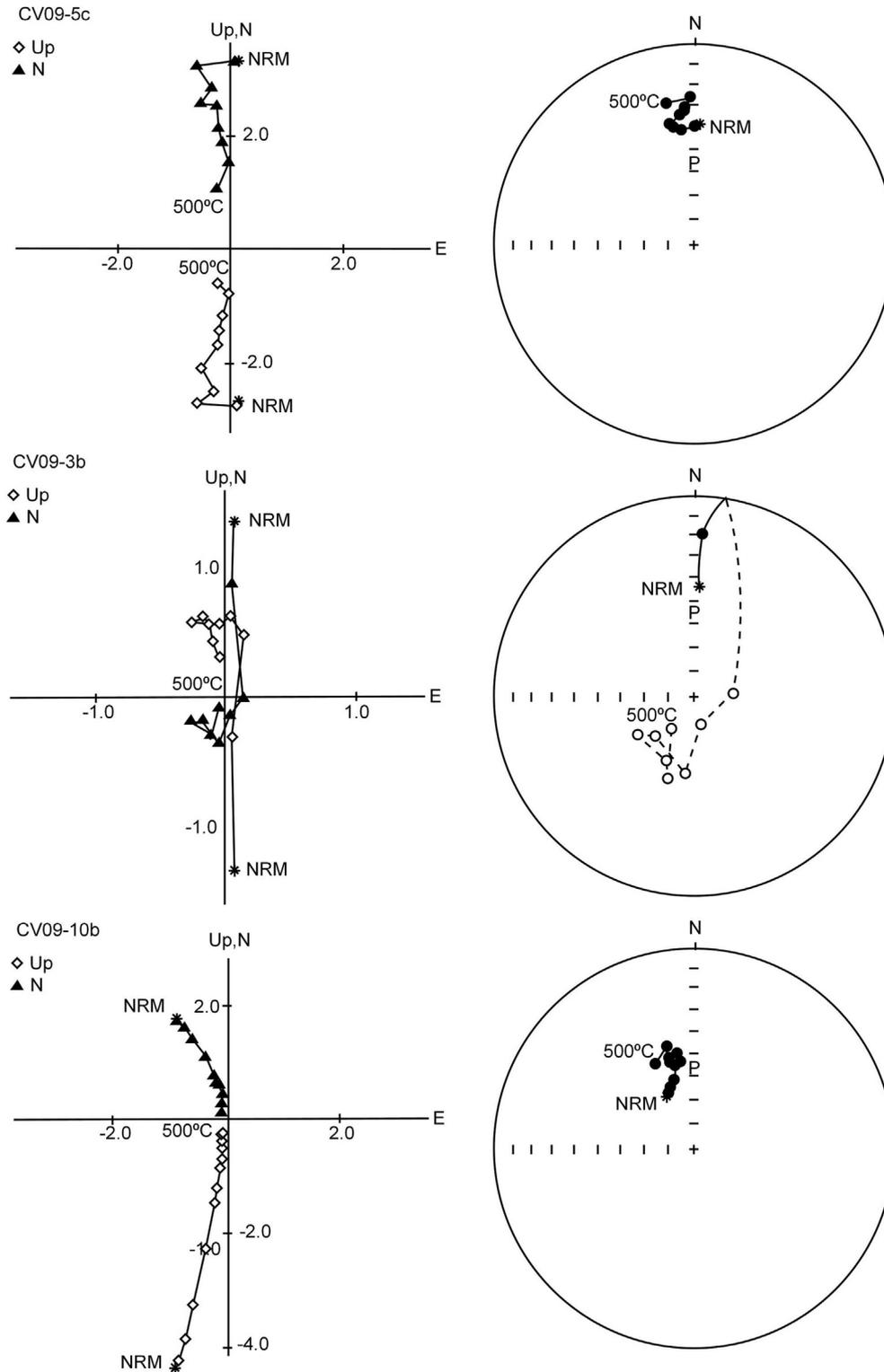


Figure 4. Orthogonal vector endpoint projections and stereo-net plot of directions from progressive AF followed by thermal demagnetization: (top) Normal specimen from the capping flowstone; a reverse specimen from the fossiliferous breccia; and a normal specimen from the red clay (bottom) from the east wall section. NRM is the (undemagnetized) natural remanent magnetization, P the position of the present axial dipole field direction.

summarise the procedure. The U concentration of the spike was calibrated against a gravimetric U standard solution, which was prepared from an NBL-112a metal bar. The same gravimetric U standard solution was also used to calibrate the U–Th spike used at the Heidelberg Academy of Sciences (Hoffmann et al., 2007). Then,

the ^{229}Th concentration of the spike was calibrated against a secular equilibrium standard solution prepared from a 2 Ma-old speleothem sample (WM-1) from Wilder Mann Cave, Austria (Meyer et al., 2009, 2011), which was previously shown to be in secular equilibrium (Hoffmann et al., 2007; Cheng et al., 2013). The

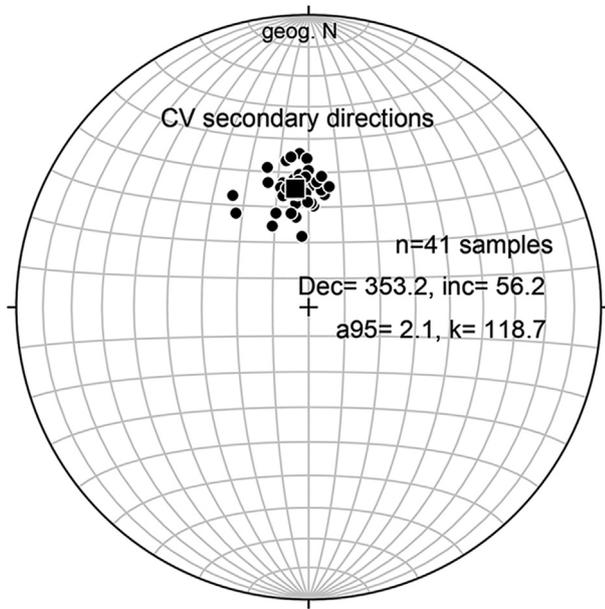


Figure 5. Paleomagnetic results showing the modern overprint directions for Cueva Victoria samples. The mean direction from this modern overprint is: Decl. = 353°; Incl. = 56°; $n = 41$ samples; $\alpha_{95} = 2.1^\circ$.

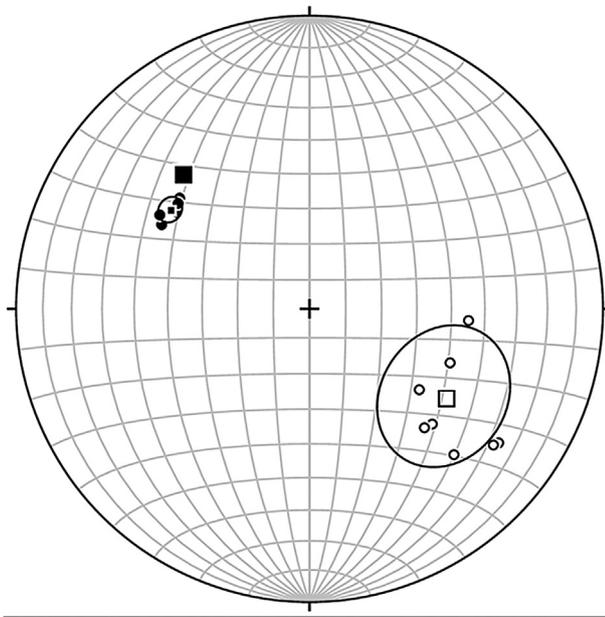


Figure 6. Paleomagnetic results, Tilt test on Bloque-1 showed a 'pre-tilting secondary overprint, rotated to: Decl. = 306°; Incl. = 41°; $n = 5$; $\alpha_{95} = 3.4^\circ$. This successful tilt test is reflected in 1) the distinct, but well-clustered secondary remanence, 2) a similar 'normal polarity' (from the flowstone), and 3) an antipodal 'reverse polarity' group (from the breccia). This test gives confidence in the antiquity of remanence measured from the higher temperature demagnetization in all the samples.

calibration was tested by comparison with another secular equilibrium solution (Harwell Uraninite, HU) that was used to calibrate the U–Th spike used at the Heidelberg Academy of Sciences (Hoffmann et al., 2007).

In total, 26 analyses of the WM-1 speleothem have been performed for calibration. The relative uncertainty of the spike calibration is 0.15% (2σ -standard error) and is propagated to all reported age errors.

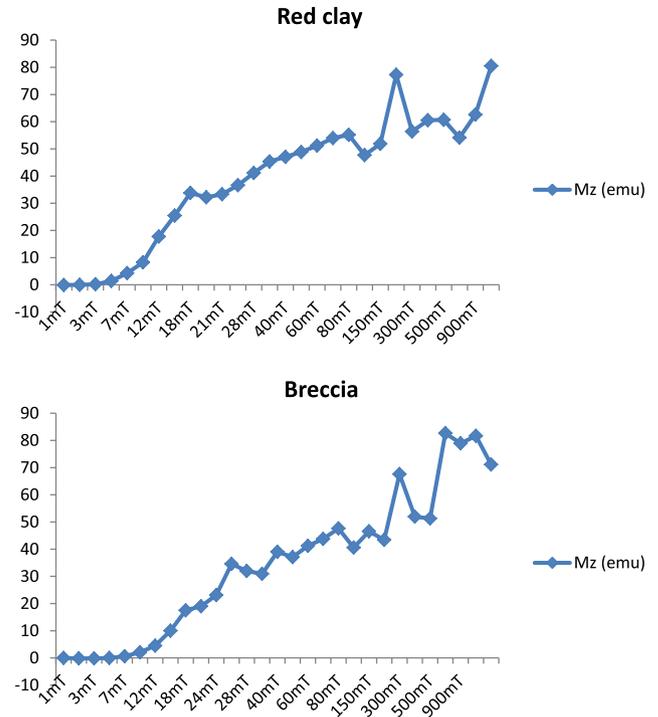


Figure 7. Isothermal remanence acquisition experiments (IRM). X axis: applied magnetic field (mT); Y axis: remanence magnetization (emu) that is parallel to that applied field. The sample of red clay (cv15, from eastern wall) shows a mixture of magnetite and hematite (data at ~250, and 1,200 mT appear to be artifacts). The breccia sample (cv19, also from eastern wall) is noisy, but also appears to have both magnetite and hematite as remanence carriers.

Analytical MC-ICPMS techniques involve a standard-sample bracketing procedure to derive correction factors for mass fractionation and Faraday cup to ion counter gain. All activity ratios were calculated using the decay constants from Cheng et al. (2000) and corrected for detrital Th assuming a bulk Earth $^{232}\text{Th}/^{238}\text{U}$ weight ratio of 3.8 for the detritus and ^{230}Th , ^{234}U , and ^{238}U in secular equilibrium.

We collected 11 samples in total from the eastern wall, eight from the upper part of the flowstone, above the paleomagnetic reversal, and three from the lower part, below the paleomagnetic reversal in order to determine the age of the youngest infilling material. Figure 8A shows a picture of the flowstone sample after sampling for $^{230}\text{Th}/\text{U}$ -dating. Furthermore, we dated six samples from the section at Sala de la Música. Figure 8B shows a picture of this flowstone after sampling. The sample size ranged from 0.04 to 0.3 g.

3. Results

3.1. Age of the Cueva Victoria fossils

3.1.1. Paleomagnetic results The basal red clay shows normal polarity at both the eastern and western walls. These normal polarity strata are overlain by reverse polarity strata, indicating a polarity change in the upper part of the red clay unit. The breccia deposits show reverse polarities, although some samples from the western wall show a persistent normal overprint (Figs. 3 and 4). Two samples were taken from non-fossiliferous, laminated silts that fill fissures and small cavities within the breccia at the eastern wall. These two samples have normal polarity and correspond to younger sediments, infilling cavities in the breccia formed after

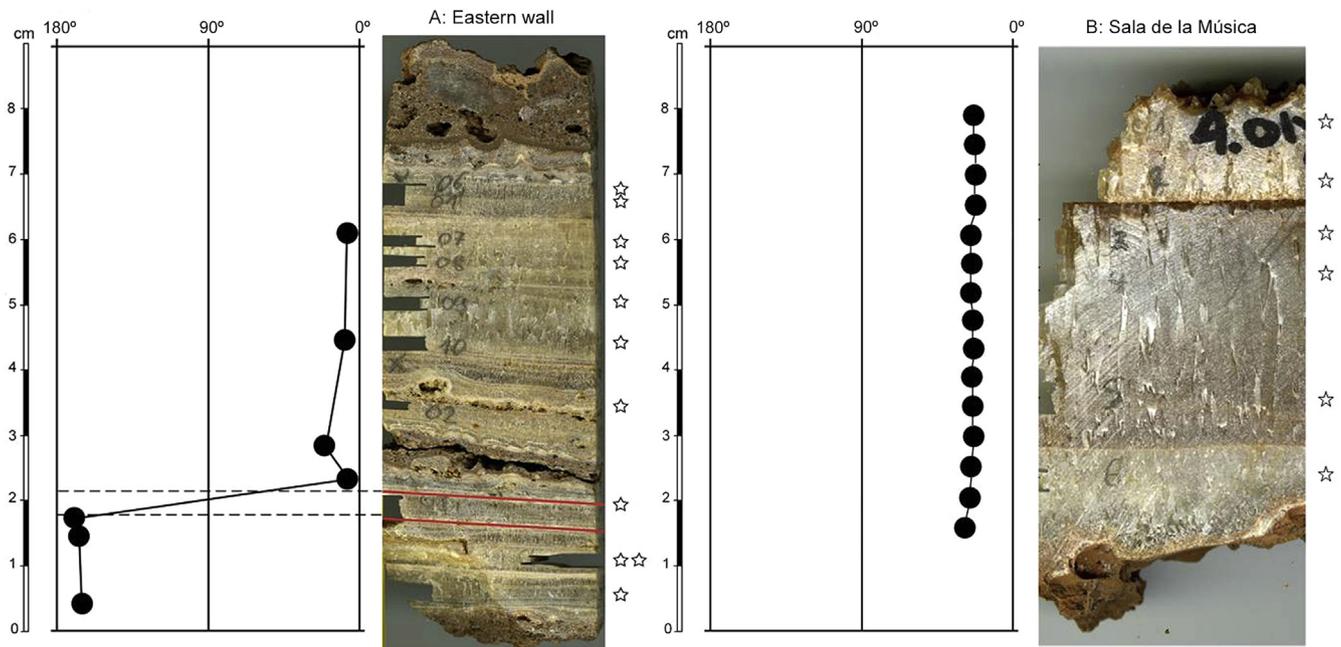


Figure 8. Flowstone sequences used for $^{230}\text{Th}/\text{U}$ -dating and paleomagnetic measurements at the eastern wall and Sala de la Música. The sampling locations for $^{230}\text{Th}/\text{U}$ -dating are visible and for reasons of clarity also indicated by the stars. The figures also shows paleomagnetic directions for samples collected from the other half of these samples. Remanent paleomagnetic directions are expressed as the angular distance to the present dipole field (δ). A: Flowstone that caps the wall section showing the location of the reversal, that is interpreted as the Brunhes/Matuyama boundary with great accuracy, (between lines). B: Flowstone from Sala de la Música that exhibits only normal polarity.

the flowstone deposition. The capping flowstone shows normal polarity ($n = 6$). Exceptions are restricted to the lower part of the topographically higher flowstone at the eastern wall where the higher temperature component shows reverse polarity ($n = 9$), whereas the upper part shows normal polarity ($n = 8$; Fig. 3).

General biostratigraphic constraints date the fauna assemblage of Cueva Victoria into the later part of the Early Pleistocene. The presence of the arvicolid *V. chalinei* (Martin, 2012) and the identification of the FAD for four vertebrate species commonly identified in Middle Pleistocene deposits refine this age and place the fauna between Jaramillo and Brunhes. This biostratigraphic age allows a correlation with the Geomagnetic Polarity Time Scale (GPTS) assigning the upper polarity change (flowstone) to the Brunhes–Matuyama (B/M) boundary, and the lower change (red clay) to the Jaramillo boundary. This results in a paleomagnetic age of 0.99–0.78 Ma for the Cueva Victoria fauna. An alternative interpretation would be to correlate the upper polarity change to the B/M boundary and the lower normal zone to the Olduvai subchron. This would imply that Jaramillo is not recorded at Cueva Victoria, which is, however, not supported by stratigraphy and results at different sections.

3.1.2. $^{230}\text{Th}/\text{U}$ -dating The $^{230}\text{Th}/\text{U}$ -dating results are presented in Table 2. All samples of the flowstone from the eastern wall are close to the limit of the $^{230}\text{Th}/\text{U}$ -method, and for some samples, the age equation cannot be solved, resulting in an infinite age (Table 2). As discussed by Ludwig (2003), infinite ages violate the two basic assumptions of $^{230}\text{Th}/\text{U}$ -dating, i.e., a closed system and no presence of initial ^{230}Th . Thus, activity ratios resulting in infinite ages can be reasonably ignored in a Monte-Carlo simulation with the additional constraint that the age must be finite (Ludwig, 2003). We performed Monte-Carlo simulations with this additional constraint for our flowstone samples, and the corresponding percentage of iterations yielding a finite age is provided in Table 2. For most samples, the percentage is between 10 and 90% (Table 2). Two samples yielded very low and high percentages, respectively. For sample CV09-4, the percentage is

99.3%, suggesting a high probability that the age is finite. In contrast, for sample CV09-10, the percentage is 0.01, suggesting the opposite. In general, our simulations show that –considering the uncertainties of the ($^{230}\text{Th}/^{238}\text{U}$) and ($^{234}\text{U}/^{238}\text{U}$) activity ratios– both finite and infinite ages can be calculated for all samples (Table 2). If we adopt the suggestion of Ludwig (2003) and ignore the infinite ages, we can calculate 95%-confidence intervals for the finite ages. These are shown in Table 2 and Figure 9. It is obvious that, except for one sample (CV09-8), all ages are significantly younger (i.e., within the corresponding 95%-confidence limit) than the Jaramillo boundary and in agreement with the B/M boundary (Fig. 9). One age (CV09-4) is even younger than the B/M boundary. This is particularly surprising because this sample is below the paleomagnetic reversal. We note, however, that the strategy suggested by Ludwig (2003) is a subject of debate and that $^{230}\text{Th}/\text{U}$ -dating of samples close to the age range of the method is challenging. Even minor post-depositional alteration of the U-series system, such as U gain and/or loss, may have a large effect on the determined ages (Scholz et al., 2014).

Our Monte-Carlo simulations are based on two basic assumptions, i.e., a closed system and no presence of initial ^{230}Th . The first assumption has been shown to be fulfilled for most speleothems due to their protected occurrence in caves. Thus, post-depositional diagenetic processes can be excluded for most speleothems (Scholz et al., 2014), and even extremely old samples of Permian age have been shown to be very well preserved (Woodhead et al., 2010). However, diagenetic alteration cannot be completely excluded for speleothems. The majority of studies reporting diagenetic alteration of speleothems refers to aragonitic samples, which may gradually recrystallize to calcite (e.g., Frisia et al., 2002; Ortega et al., 2005; Hoffmann et al., 2009; Lachniet et al., 2012), but a recent study also documented diagenetic alteration in a calcite speleothem (Scholz et al., 2014). Thus, even if we cannot exclude diagenetic alteration for the Cueva Victoria flowstone, it is relatively unlikely, which is supported by the study of thin sections of this

Table 2
Results of $^{230}\text{Th}/\text{U}$ dating.

Sample	Distance from top [mm]	^{238}U [$\mu\text{g/g}$]	\pm	$(^{230}\text{Th}/^{232}\text{Th})$	\pm	$(^{234}\text{U}/^{238}\text{U})$	\pm	$(^{230}\text{Th}/^{238}\text{U})$	\pm	Age uncorrected [ka] ^a	Age corrected [ka] ^b	Lower 95%-confidence limit of finite ages [ka] ^b	Upper 95%-confidence limit of finite ages [ka] ^b	Percentage of iterations yielding a finite age [%] ^c
CV09-06	8	0.6413	0.0048	544.3	5.2	1.0076	0.0043	1.0126	0.0061	infinite	infinite	526.4	1020.2	35.4
CV09-01	10	0.3170	0.0021	196.4	2.0	1.0111	0.0027	1.0137	0.0060	673.1	672.6	512.0	948.7	74.3
CV09-07	15.5	0.2853	0.0019	342.2	3.4	1.0097	0.0032	1.0132	0.0062	785.1	784.9	519.1	987.6	58.3
CV09-08	19	0.3485	0.0024	634.6	6.0	1.0096	0.0036	1.0189	0.0060	infinite	infinite	565.7	1099.1	10.3
CV09-09	25	0.2928	0.0021	277.0	4.5	0.9999	0.0038	1.0023	0.0088	infinite	infinite	504.5	989.7	31.8
CV09-10	31	0.3119	0.0022	103.75	0.93	0.9999	0.0039	1.0158	0.0060	infinite	infinite	665.1	1028.1	0.01
CV09-02	40	0.5229	0.0035	35.37	0.37	1.0307	0.0023	1.0424	0.0064	707.9	705.8	523.9	993.1	71.8
CV09-03	55.5	0.6436	0.0044	260.3	4.9	1.0125	0.0032	1.0169	0.0097	752.2	752.2	483.3	951.8	58.9
CV09-04	62	0.5908	0.0042	308.5	2.8	1.0144	0.0038	1.0112	0.0055	517.1	517.0	452.6	673.1	99.3
CV09-04r	62	0.576	0.0022	547.0	4.6	1.0102	0.0042	1.0170	0.0057	infinite	infinite	538.1	1048.0	29.5
CV09-05	67	0.518	0.0020	99.17	0.91	1.0144	0.0042	1.0188	0.0065	697.0	696.6	498.1	954.7	66.9
CV04.01-01	5	0.12916	0.00088	23.90	0.26	0.9831	0.0027	0.3045	0.0022	40.5	39.4	38.7	40.1	—
CV04.01-02	13	0.12701	0.00079	42.36	0.48	0.9649	0.0020	0.4531	0.0037	69.6	68.6	67.6	69.6	—
CV04.01-03	22	0.08696	0.00057	33.83	0.35	1.0184	0.0021	0.6387	0.0040	107.3	105.6	104.2	107.1	—
CV04.01-04	27.5	0.12035	0.00078	133.4	1.8	0.9964	0.0019	0.6475	0.0063	114.7	114.3	112.3	116.3	—
CV04.01-05	47	0.1982	0.0013	16.20	0.15	1.0301	0.0018	0.7789	0.0036	152.2	148.1	145.6	150.7	—
CV04.01-06	59	0.4399	0.0032	1138	11	1.0615	0.0042	0.7617	0.0047	135.4	135.3	133.3	137.3	—

^a "Infinite" denotes that the $^{230}\text{Th}/\text{U}$ -age equation cannot be solved using the determined activity ratios.

^b Confidence limits were calculated using a Monte-Carlo simulation discarding iterations yielding an infinite age (see text for details).

^c Percentage of the Monte-Carlo simulations used to calculate the confidence limits yielding a finite age. This value can only be provided for the samples close to the limit of the method.

flowstone using a petrographic microscope. The second assumption (i.e., no initial ^{230}Th) can be tested by the amount of detrital ^{232}Th . The Cueva Victoria flowstone contains only low amounts of ^{232}Th . Nine samples have less than 10 ng/g ^{232}Th . Two samples have elevated ^{232}Th (CV09-2: 47.1 ng/g and CV09-5: 16.3 ng/g). This is also reflected in the lower ($^{230}\text{Th}/^{232}\text{Th}$) activity ratios of these samples (35.4 and 99.2, respectively, Table 2). However, these values are still much higher than the values necessitating a correction for detrital contamination ($(^{230}\text{Th}/^{232}\text{Th}) < 20$, Schwarcz, 1989), which is also reflected in the insignificant difference between the corrected and uncorrected ages of these two samples (Table 2). Furthermore, due to the relatively old age of the flowstone (~780 ka), potential initial ^{230}Th would have almost entirely decayed (only 4% of the initial ^{230}Th would still be present after 780 ka) and can thus be ignored. Finally, the occurrence of initial ^{230}Th always results in older ages. Thus, if the flowstone sample was significantly affected by detrital contamination, the effect would rather result in a bias towards the Jaramillo boundary than towards the B/M boundary. In summary, the $^{230}\text{Th}/\text{U}$ -dating results suggest that the identified reversal located at the top of the sedimentary sequence corresponds to the Brunhes–Matuyama boundary, but we cannot exclude that it corresponds to Jaramillo.

The flowstone in the topographically lower Sala de la Música, where paleomagnetic data show reverse polarity for the red clay and breccia and normal polarity for the flowstone (Fig. 3), does not show a magnetic reversal. Thus, we expected younger ages for this flowstone. The ages range from ca. 40 to ca. 135 ka (Table 2) showing that this section grew during MIS 5 and probably during two short episodes of MIS 3. One sample shows a relatively low ($^{230}\text{Th}/^{232}\text{Th}$) activity ratio suggesting substantial detrital contamination. This age is not in stratigraphic order with the sample below, which has a very high ($^{230}\text{Th}/^{232}\text{Th}$) activity ratio, confirming that the age of the low ($^{230}\text{Th}/^{232}\text{Th}$) sample may not be reliable. All other ages appear accurate. The much younger ages of this flowstone compared to those at the eastern wall indicate a sedimentary hiatus between the flowstone and the breccias. Since flowstone growth strongly depends on the availability of water inside the cave, it is not surprising that the Cueva Victoria flowstone contains several hiatuses, probably related to climate change above the cave.

This has also been confirmed by a recent study, which dated several younger flowstone sequences at Cueva Victoria (Budsky et al., 2015). These preliminary data suggest that speleothem growth at Cueva Victoria mainly occurred during wet and warm interglacial periods (i.e., Marine Isotope Stages (MIS) 5, 7, 9, and 11) (Budsky et al., 2015). If the reversal recorded in the flowstone from the eastern wall corresponds to the B/M boundary, our results would place the breccia capping flowstone at MIS 19 (790–761 ka, Lisiecki and Raymo, 2005), when wet conditions favored flowstone growth.

This means that the infilling of the cave (i.e., the deposition of the red clay, the breccia and the flowstone) probably occurred between 1.07 and 0.78 Ma, in a period of 290 ka. The breccia of reverse polarity would have been deposited in the reverse period between 0.99 and 0.78 Ma.

We consider an interval of time between the sedimentation of the uppermost layers of breccia inside the cave and the beginning of the flowstone formation. This interval is indicated by the thickness of the breccia accumulated in the entrance areas, showing that sedimentation continued in the hill slope after the breccia had filled the cave. The main fossil collection comes from Bloque-1 and the eastern wall, where fossils were mainly collected 1–2 m below the reversal. This indicates that this fauna is temporally in a position between the two reversals (Jaramillo and B/M), probably closer to the B/M boundary, suggesting an age of 0.9–0.85 Ma for the Cueva Victoria fauna.

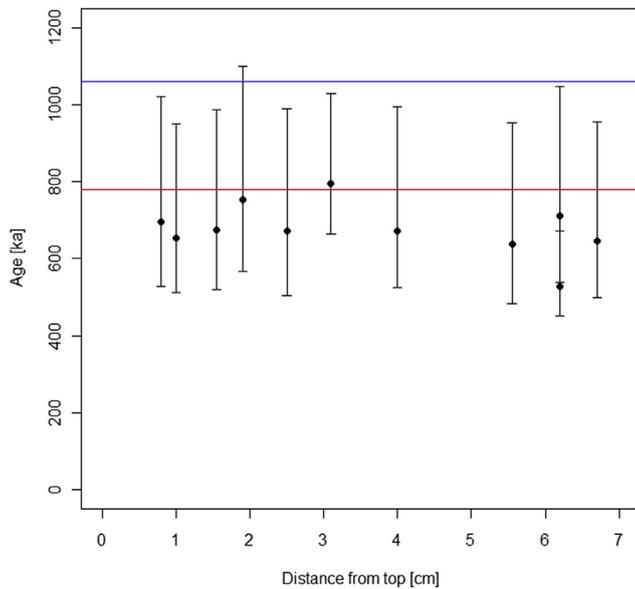


Figure 9. Mean values of the ages simulated with the additional constraint that the age must be finite. The error bars represent the corresponding 95%-confidence limits. The red and blue horizontal lines show the age of the Brunhes/Matuyama and Jaramillo paleomagnetic boundaries, respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

4. Discussion

4.1. Early Pleistocene Afro-Iberian dispersal events

During the Early-Middle Pleistocene climatic transition (EMPT), between 1.2 and 0.7 Ma (Mudelsee and Schulz, 1997; Raymo et al., 1997; Clark et al., 2006), the global climatic system underwent major changes, with the establishment of large ice sheets in the northern hemisphere (Prell, 1982; Ruddiman et al., 1989). During this period, a transition occurred from a dominant 40 ka climatic cyclicity to the 100 ka glacial–interglacial cyclicity (Head and Gibbard, 2005; Head et al., 2008), accentuating global eustatic sea-level changes. Its onset was accompanied by a decrease in sea surface temperatures in the North Atlantic and tropical-ocean upwelling regions and an increase in African and Asian aridity and monsoon intensity (Clark et al., 2009). These global changes in climate dynamics affected the hydrosphere and biosphere, and in particular the continental vertebrate fauna. The ecological systems in North Africa were strongly influenced by the fluctuating climate that generated Green Sahara Periods (GSP) with wetland-spotted savanna landscapes spread through the Sahara that allowed the dispersal of fauna into North Africa (Larrasoana et al., 2013). Aridification in North Africa during MIS 22 might have triggered migration pulses of large mammals and humans towards northern latitudes (Almogi-Labin, 2011; Muttoni et al., 2013). Cueva Victoria is located in a region with a Mediterranean climate, similar to that at the North African coast (ca. 200 km south). Thus, African fauna could have established themselves during glacial times at Cueva Victoria. The presence of *Theropithecus oswaldi leakeyi* in Cueva Victoria (Gibert et al., 1995; Ferrández-Cañadell et al., 2014) and its absence in contemporaneous sites around the Mediterranean Basin suggest a dispersal from Africa into Europe during Marine Isotopic Stage 22, when the first dramatic Quaternary sea-level fall, of ~100 m, occurred (Miller et al., 2005; Berger, 2008; Fig. 10).

The only other *Theropithecus* remains that have been reported in Europe are three cervical vertebrae from Pirro Nord, another Early Pleistocene site in northern Italy (Rook et al., 2004). Their

assignment to *Theropithecus* was questioned (Frost and Alemseged, 2007; Patel et al., 2007; Ferrández-Cañadell et al., 2014) and they were finally reassigned to the porcupine *Hystrix refossa* (Alba et al., 2014). Therefore, Cueva Victoria is currently the only locality in Europe with remains of *Theropithecus*. The site of Cueva Negra del Río Quípar, located 100 km west-north-west from Cueva Victoria, also dated using paleomagnetism and rodent biostratigraphy at ~0.9 Ma (MIS 22), has yielded human remains and the oldest evidence of hand-axes in Europe (Scott and Gibert, 2009; Walker et al., 2013). The coincidence of the occurrence of *Theropithecus* and the first Acheulean technology, usually associated with *Homo erectus*, in south-east Iberia at ~0.9 Ma suggests a primate dispersal (*Homo* and *Theropithecus*) from Africa into Europe. The presence of primitive Acheulean in Thomas Quarry in Casablanca (Morocco) at 1–1.2 Ma (Geraads et al., 2010) and *T. oswaldi* in Ternifine (Algeria) at 0.7 Ma (Delson and Hoffstetter, 1993) or 0.99–1.07 Ma (Sahnouni and Van der Made, 2009) suggests a dispersal across the Strait of Gibraltar, which would have acted as a filter bridge (sensu Simpson, 1940) allowing only a limited number of species to cross. Older evidence of human dispersal across marine barriers during this time have already been proven in Flores Island (Java), where humans were able to cross the Lombok Strait and the Wallace Line (Morwood et al., 1998; Brumm et al., 2010), when the strait was reduced to 19 km.

This MIS 22 human dispersal associated with Acheulean tools and *Theropithecus* was not the first human dispersal into south-west Europe. A previous arrival of humans has been recorded at the sites of Orce associated with Oldowan industry and older vertebrate fauna, linked to the FAD in Europe of the African species *Hippopotamus antiquus* and *Equus altidens* (Gibert et al., 1998, 2002, 2006; Toro-Moyano et al., 2013; Ribot et al., 2015; Fig. 11). In contrast to other sites in Iberia claimed to be older than 1 Ma but with limited karstic stratigraphies (Carbonell et al., 2008), the Orce sites occur in a long (>60 m) fluvio-lacustrine sequence that shows a Reverse-Normal-Reverse polarity sequence. The ages of the sites of Venta Micena, Barranco León and Fuenteneuva-3 (1.3–1.25 and 1.2 Ma) have been estimated using their stratigraphic distance to the Olduvai magnetozone and assuming a minimum sedimentation rate (Scott et al., 2007; Scott and Gibert, 2009). Failure to identify the Jaramillo subchron (1.07–0.99 Ma) above the archaeological sites has been used by some authors to propose a younger age for the Orce sites (e.g., Muttoni et al., 2013). However Jaramillo is not recorded at the sections from archaeological sites at Orce because it was either eroded, not deposited or not sampled; in contrast, the presence of the Olduvai magnetochron (1.75–1.98 Ma) below the sites, supported by the MN17 associated fauna, is a secure and unique occurrence in Spain that can be used to anchor the polarity sequence to the geomagnetic polarity timescale (GPTS). The presence of Oldowan industry in Ain Hanech and El Kherba (Algeria) at 1.77–1.95 Ma (Sahnouni et al., 2004; Sahnouni and Van der Made, 2009) suggests that this first dispersal also took place across the Strait of Gibraltar (Gibert et al., 1986, 1989, 2003; Iglesias et al., 1998; Santonja and Pérez-González, 2010). These Afro-Iberian dispersal events postdate the first hominin dispersal out of Africa at ~1.8 Ma, which occurred via the Levant corridor towards Dmanisi and Java (Fig. 10).

4.2. Wider implications

The presence of Early Pleistocene hominin sites with Oldowan and Acheulean tools in North Africa, and the fact that up to now the first evidence of Oldowan and Acheulean tools in Europe is in SE Spain, do not prove per se that there was a migration across the Strait of Gibraltar. Neither does the presence of *Theropithecus* in Cueva Victoria deposits, 200 km from Africa, at an equivalent time

as remains in North Africa prove that this species crossed the Strait of Gibraltar. Even taking into account that hominins crossed longer marine barriers before 1 Ma (e.g., reaching Flores Island), and the correlation of the age of Spanish sites to a period of low sea-level that reduced the distance between the two continents considerably is not enough evidence to prove that these primates crossed the Strait of Gibraltar. This is because Iberia is not an island and these migrations could also occur by land, traveling from North Africa around the Mediterranean (>9000 km) or from the Nile Delta (>5000 km). This different scenario, where hominins and *Theropithecus* came to SE Iberia across the Anatolian Peninsula and the Po Valley is supported by some authors. Some of them suggest that a migration following this route would not be possible before 0.9 Ma because the Po Valley was below sea-level prior to the sea-level fall that occurred during MIS 22 and because of the existence of climatic barriers north of the Alps (Muttoni et al., 2010, 2011, 2014). But again, this alternative hypothesis cannot be proven due to the lack of evidence along this route for the presence of hominins or *Theropithecus* remains older than those in SE Iberia. This lack of evidence along this long circum-Mediterranean route can be attributed to a discontinuous or incomplete record, or uncertainties in the chronologies (see Muttoni et al., 2013 among others). However, as Hughes et al. (2008) show in a dispersal model, it would be easier for *Theropithecus* to reach Cueva Victoria

across the Strait of Gibraltar than around the Mediterranean Basin. It is also much easier to explain the oldest Oldowan and Acheulean cultures in SE Iberia with punctuated entries through Gibraltar than traveling around the Mediterranean without leaving evidence of their passage. The evolution of the Strait of Gibraltar is not well known since its origin during the Zanclean flood at the Mio-Pliocene boundary. We can reasonably assume that the glacioeustatic lowstand during MIS 22 would have reduced the strait substantially, decreasing the communication between the Atlantic and the Mediterranean Sea and making it easier to cross. However, other processes, such as tectonic and isostatic uplift, are important (Rodríguez-Vidal et al., 2004; Anzidei et al., 2014), and should be considered in the development of a detailed paleogeographic model for the Gibraltar Strait during the Early Pleistocene.

Finally, we cannot rule out the possibility suggested by Rolland (2013) that the initial colonization of Europe involved some immigrants from Western Asia into east and southeast Europe, as well as other founder populations of immigrants from the Maghreb into Iberia and Western Europe. Our new data show that the First Appearance Datum in Europe of two African species near Africa (SE Iberia) occurred during a period when the communication between the Atlantic Ocean and Mediterranean Sea was restricted. This was not the first time that the Gibraltar region had acted as a filter bridge (sensu Simpson, 1940), allowing the passage from one

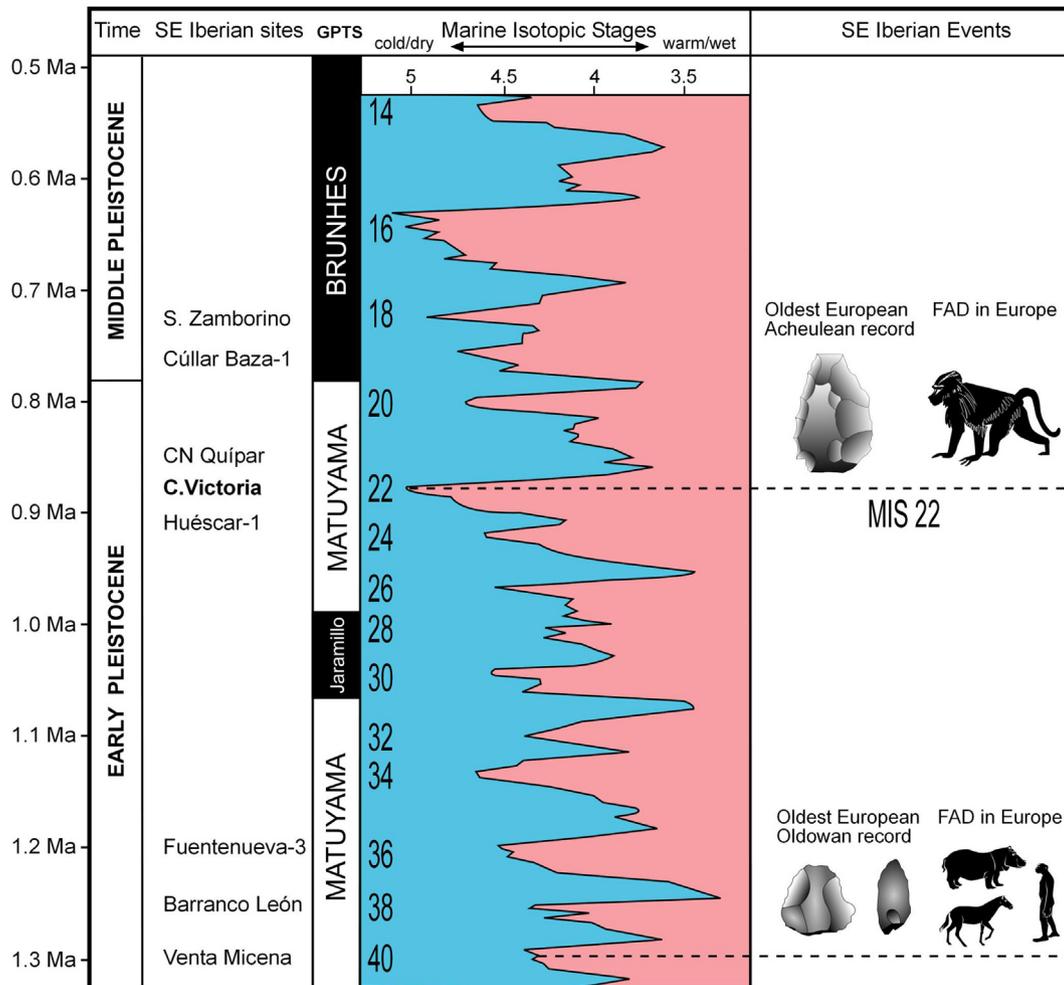


Figure 10. Chronological and paleoclimatic context for Early Pleistocene sites with human occupation in south-eastern Spain. According to published data, the Orce sites have an age of 1.3–1.2 Ma and show the oldest Oldowan technology in Europe (Scott et al., 2007; Gibert et al., 2007). During and after the time of MIS 22, another group of sites shows evidence of human presence associated with Acheulean technology (Scott and Gibert, 2009). Isotopic stages from Gibbard and Cohen (2008).



Figure 11. A: General scenario for Afro-European dispersals during the Early Pleistocene with potential routes of dispersal. Some of the most relevant sites are represented in the map with the type of lithic technology (Oldowan or Acheulean) associated with the site. B: The three postulated out-of-Africa dispersal events during the Early Pleistocene. The oldest dispersal reached Dmanisi, in the southern Caucasus, at ~ 1.8 Ma (B1), probably coinciding with the dispersal to China and Java (Larick et al., 2001; Zhu et al., 2004; Zaim et al., 2011; Lordkipanidze et al., 2013). A second African dispersal (B2) has been identified in south-eastern Spain at 1.3–1.2 Ma, associated with Oldowan tools, *Hippopotamus antiquus*, *Equus altidens*, and *Homo* remains (Gibert et al., 2006; Scott et al., 2007). A third dispersal (B3) took place between Jaramillo and Brunhes, most probably during MIS 22 when sea-level fell >100 m. This dispersal has also been identified in south-eastern Spain, and associated with *Theropithecus* and the first evidences of Acheulean technology in Europe (Scott and Gibert, 2009, this work). The first occurrence of different African emigrant species and African lithic technology in SE Spain at two different times suggests that the Strait of Gibraltar was a permeable barrier at least twice during the Early Pleistocene. A trans-Caucasian dispersal above 42° latitude seems difficult because climatic conditions were hostile. The alternative would be a route through the Anatolia Peninsula, but several mountain barriers, such as the Antitaurus, Taurus, Carpathes, Alps and Pyrenees would have to be crossed. A route through the Po Valley would allow Iberia to be reached without crossing the Alps, but the Po Valley was below sea-level until the regression associated with MIS 22 at 0.87 Ma (Muttoni et al., 2011; Santangelo et al., 2012). C: Paleogeography of Gibraltar with the present topography and a sea-level drop of -120 m. 1: Orce, 2: Cueva Victoria, 3: Cueva Negra, 4: Atapuerca, 5: Monte Poggiolo, 6: Pirro Nord, 7: Dmanisi, 8: Gester Benot, 9: 'Ubeidiya, 10: Thomas Quarry, 11: El Kherba, 12: Ternifine, 13: Ain Hanech, 14: Gona, 15: Konso Kandula, 16: Omo, 17: Turkana, 18: Peninj, 19: Olduvai, 20: Wonderwerk Cave, 21: Sterkfontein.

continent to another of particular mammals. Afro-Iberian dispersals had already been documented between the two continents during the previous period of restricted communication between the two oceans just before the Messinian Salinity Crisis (MSC, Gibert et al., 2013). Thus, we consider the arrival of selected species of vertebrate fauna associated to hominins bearing different lithic cultures directly from Africa into a warm region of Europe across the Gibraltar Strait in at least two moments of the Early Pleistocene as the most plausible model based on the available data.

5. Conclusions

The fossil mammal fauna collected from the fossiliferous breccia at Cueva Victoria has an Early Pleistocene age, that postdates the

fauna from the Orce sites dated at 1.3–1.2 Ma. The new paleomagnetic, biostratigraphic and $^{230}\text{Th}/\text{U}$ -data indicate that the deposition of the red clay in the Sala Unión recorded the Jaramillo-Matuyama reversal (0.99 Ma), and the breccia capping flowstone includes the Matuyama–Brunhes shift (0.78 Ma). Consequently, the age of the intermediate breccia is constrained between 0.99 and 0.78 Ma. The age of the *Theropithecus* fossil assemblage of Cueva Victoria can be further constrained to 0.9–0.85 Ma based on sedimentological assumptions. A similar age has been found for the nearby site of Cueva Negra del Estrecho del Río Quípar, which has also yielded early humans associated to the oldest Acheulean tools in Europe (Scott and Gibert, 2009).

This study dates the presence of African primates, *Theropithecus* and *Homo*, during the Early Pleistocene at the Mediterranean coast

of south-east Iberia at 0.9–0.85 Ma. This period overlaps with MIS 22, when the first dramatic sea-level fall in the Quaternary occurred, between 0.9 and 0.86 Ma. The presence of *Theropithecus* and *Homo* in North Africa at similar times and the absence of *Theropithecus* at other localities in Europe suggest that a dispersal of at least two taxa of primates took place through the Strait of Gibraltar during MIS 22. Probably, other hominins and fauna also dispersed during this period through similar marine barriers, such as that in Flores Island (Morwood et al., 1999).

The presence of the oldest evidence of Oldowan and Acheulean tools in Europe in south-east Iberia, associated with the FAD of African species and separated by a temporary hiatus of more than 300 kyr, suggests two different Pleistocene Afro-Iberian dispersal events of *Homo*. The first was associated with Oldowan technology and linked to the FAD in Europe of the African species *H. antequus* and *E. altidens* at the beginning of the EMPT at ~1.3 Ma, while the second was associated with Acheulean technology and *Theropithecus* during MIS 22 at ~0.9 Ma. The presence of similar technologies and fauna at slightly older sites in Morocco and Algeria suggests that Gibraltar was a permeable marine barrier for early humans and some other vertebrates at specific times during the Early Pleistocene. Previous Afro-Iberian dispersals across the sea have been only described just before the MSC, when connections between the Atlantic and the Mediterranean also decreased.

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