Late Quaternary paleoenvironmental record from a sedimentary fill in Cucú cave, Almería, SE Spain

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ABSTRACT

Cucú cave is a small cavity, 1600 m above sea level on the southern slope of Sierra de María (Almería Province, SE Spain), where current mean annual precipitation is <450 mm. Fossils and palynomorphs contained within a sedimentary sequence, up to 9 m in depth, allow us to consider the prevailing climatic conditions, and the timing of cavern development. The lithological sequence is dominated by clast-supported detrital material with no evidence of alluvial transport. These sediments were formed by freeze-cracking during periglacial conditions, causing further cave enlargement after initial solutional development. The clastic sequence formed during cold climates is covered by a flowstone that was deposited during a period of warmer, wetter conditions. This provides a minimum U–Th isochron age of 40.2 ± 4.5 ka for the timing of periglacial action. Micro-mammal fossil species indicate a chronology between 140 and 80 ka. Paleoecological data based on the structure of the mammal community indicates that cold conditions prevailed at the time of deposit. In the studied sequence the presence of anthropogenic components has not been documented. The pollen assemblages identified are a common feature of Pleistocene cold stages that are in semi-arid regions.

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Introduction

The western Mediterranean is a particularly interesting region for Quaternary climate reconstruction because it currently occupies a boundary position between polar and subtropical air masses, and its climate is influenced by both the Mediterranean Sea and the Atlantic Ocean. A better understanding of past climate variations is needed for establishing and verifying climate models in the region. At present, relatively little is known about the Quaternary climate in the region due to the paucity and ephemeral nature of available records, compared to northwest Europe, for example.

Some of the most significant paleoenvironmental records from southern Spain are based on speleothems, mammal fossils, pollen sequences and archeological proxy records found in cave settings (Carrión and Munuera, 1997; Carrión et al., 1998, 2008; Montoya et al., 2001; Cortés-Sánchez et al., 2008; Ramos et al., 2008). Carbonate deposits, particularly speleothems, have been the object of many studies of climatic and hydrological variations, because they are less affected by post-depositional processes than are surficial sediments (Poulson and White, 1969; Fairchild et al., 2006; Matthews, 2009). Speleothems can be dated precisely by means of the U–Th decay series and, consequently, they can contribute to our knowledge of paleoclimatic and paleohydrologic events in continental areas (Atkinson et al., 1978; Schwarcz, 1986; Gascoyne, 1992; Richards and Dorale, 2003). Moreover, geochemical studies can be performed on the same material with a very high temporal resolution using stable isotopes such as $\delta^{18}O$ and $\delta^{13}C$ (Durán et al., 2004; Hodge et al., 2008), which may reflect past temperature and vegetation changes, and trace elements such as Mg and Sr, which are potential indicators of past hydrological balance (Roberts et al., 1998; Fairchild et al., 2001, 2006; Huang and Fairchild, 2001). Also, paleontological mammal remains found in cave sediments can provide valuable information about past environmental conditions (Ruiz Bustos, 2002).

A range of complimentary approaches (geological, paleontological, pollen and geochronological) were adopted in this study of the sediments and precipitates found in Cucú cave (province of Almería, southern Spain, Fig. 1) to contribute to a better understanding of the environmental changes of the last 200 ka in the southeast of the

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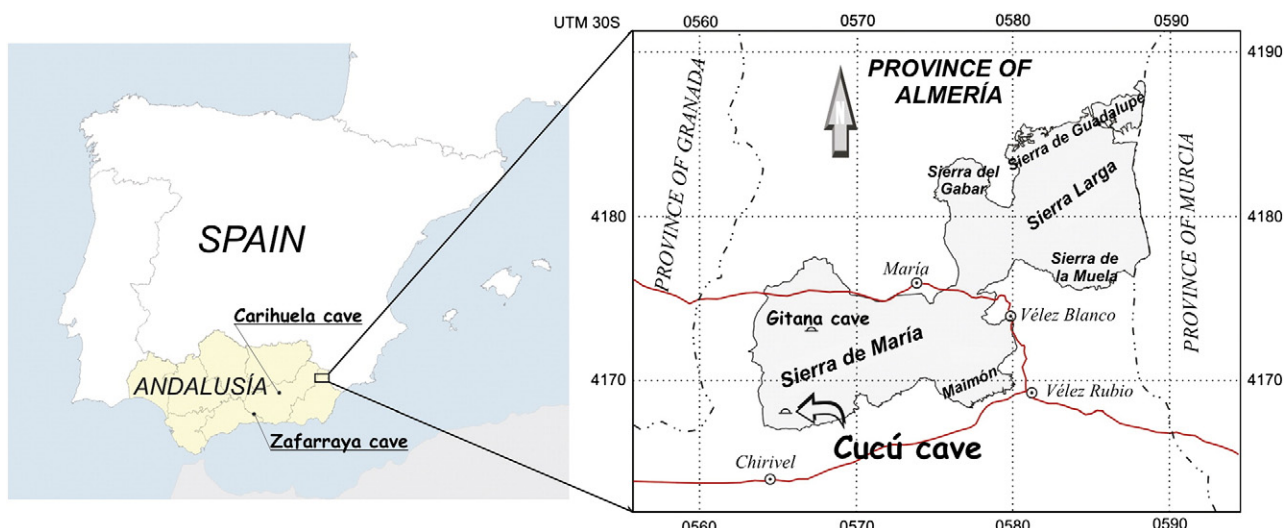
Figure 1. Location of Cucú cave, Almería, SE Spain. Extent of the Sierra María-Los Vélez Natural Park is shown in gray.

Iberian peninsula and these are compared to other proxies from records obtained from nearby marine and continental settings.

Setting and cave description

Cucú cave is located at an altitude of 1600 m above sea level on the southern slopes of El Cabezo mountain, which rises to 1948 m a.s.l. This belongs to Sierra de María massif, part of the Betic Cordillera, southern Spain (Fig. 1).

El Cabezo mountain is formed by dolomite and limestone of Early Jurassic age, and by oolitic limestone of Middle Jurassic age. The structure of Sierra del Cabezo is an anticline with N60°E direction, which has been affected by faults in the E–W and NE–SW directions giving rise to several scarps on the southern slope (Andreo, 1990; Baena and Guzmán del Pino, 1979). The Cucú cave is developed along a fault in the highly deformed Jurassic limestones and at the base of one of the scarps in El Cabezo mountain. The fractures also involved Cretaceous marls, which form a discontinuity in the permeability of the Jurassic limestones. Consequently one small spring appeared at the bottom of the cave, which only drains water in wet periods. The existence of perched drainage at the rear of the cave, part of this flowing toward the small spring, during periods of cold climate, could contribute to cryoclastic action and, as a result, the fracture trough widened. This widening could cause instabilities of roof and walls enlarging the cavity and forming the studied fill. At a later stage stalagmitic flowstone covered the sediments.

The cavity is ~30 m long (González-Ramón, 2002) with a very large opening and one main chamber. There is a second, smaller chamber at the end, where a group of rimstone pools have evolved, precipitated from the small spring. At the cave entrance there is a 9-m-thick sediment fill, the stratigraphic column of which is shown in Figures 2 and 3. This sediment is capped by a flowstone thickness from 0.2 to 0.6 m. The sediment fill is composed of angular gravels and blocks with scarce silty matrix (clast-supported deposits). Sampling was done on the slope of the mountain which is coinciding with the fill at the cave entrance, where the deposits are well exposed (Figs. 2–4). No excavation has been done for sampling at the moment.

In the studied sequence, no evidence of anthropogenic components has been documented. The location of the cavity at high altitude (1600 m a.s.l.) in comparison with the Vélez Rubio-Chirivel valley (Fig. 1; located around 900 m a.s.l.), where living conditions would be more favorable, probably conditioned the human activity mainly at lower altitudes.

The actual climate is continental Mediterranean (semi-arid conditions), with a mean annual temperature of over 10°C and precipitation of about 450 mm/yr, although this value displays important seasonal and inter-annual variations.

Methodology

Sedimentology

The thickness and characteristics of the sediments were noted in detail (Figs. 3 and 4), including lithology, sedimentary structures, texture, grain size and roundness, ordered granulometries, presence of matrix and cement, and fossil remains.

Paleontological mammal remains

Faunal remains, bones and predominantly rodent teeth, were extracted from wet-sieved sediment samples of ~5 kg from 8 locations in the clastic sequence (Figs. 2–5, Table 1). Manual sieved with sacks, shovels and sieves was done. The screen has a square size, from 1 cm to 0.5 mm. Inside of the screen with a 1-cm size, all the rest of macro-mammals remained.

Fossil remains from the cave sediment filling were dated using the biochronological scale proposed by Ruiz Bustos (2011) into the Event E0.27 inside of biozonemarks SI0.27.3 (140–70 ka). The criterion for establishing Intrazone subdivisions (SI) is the progressive growth of the lower first molar (m1) of the *Arvicola* genus.

The paleoecology of the remaining mammal fossils in the Cucú cave deposit was determined using the biocenogram method (Ruiz Bustos, 2002, 2007, 2011). This method consists of a double-entry table in which the x-axis describes the possible habitats within a region, and the y-axis, the mammal species identified in each deposit, and the period of time or stratigraphic unit for the same region. The table then quantifies the ecological preferences of each mammal species for each habitat and, on this basis, the corresponding paleological conclusions are drawn.

Speleothem analysis

Four coeval calcite sub-samples from the densest and cleanest parts of the flowstone that caps the sedimentary sequence (M-9 in Fig. 3) were targeted for U–Th dating (Table 2, Fig. 6). Total sample dissolution isochron methods (Luo and Ku, 1991) were used because even the cleanest material had very high levels of clastic Th
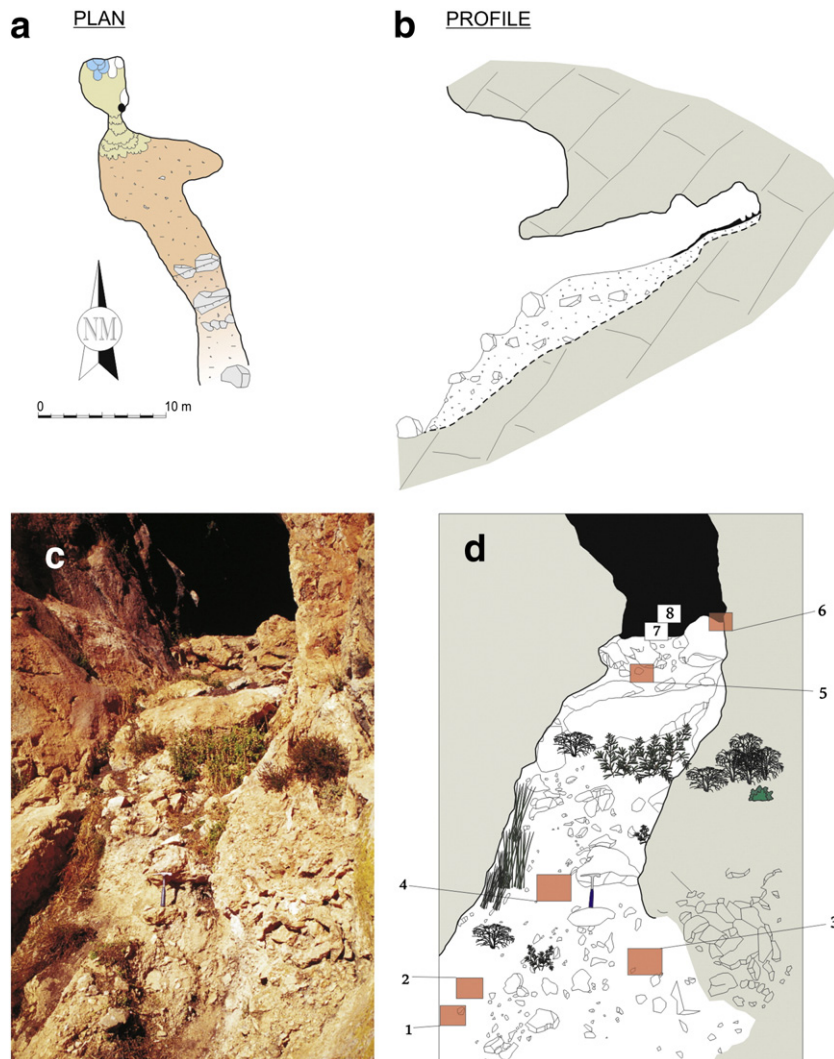
Figure 2. (a) and (b) Map view and sketch profiles of Cucú cave. (c) and (d) photograph of the studied sequence (entrance of the cave) and explanatory sketch showing the location of the samples. In (d), the rectangles indicate the number of samples referenced in Figs. 3 and 7.

contamination. U-series analyses were carried out using multi-collector inductively coupled plasma mass spectrometry (MC-ICPMS). The chemical procedures used, involving ^{229}Th–^{236}U tracer addition, separation of U and Th by dissolution, and ion exchange columns, differ only slightly from those described by Chen and Wasserburg (1981) and Luo et al. (1997). U–Th isotopic measurements were performed on a ThermoFinnigan Neptune MC-ICPMS, located at the facilities of the Bristol Isotope Group, University of Bristol, UK. Details of the methods, including standards used for mass fractionation and SEM yield correction, can be found in Hoffmann et al. (2007).

Palynology

Pollen analysis was conducted on 4 samples of ~20 g (nos. 2, 4, 5 and 6) (Fig. 3). All samples were treated according to the method of Girard and Renault-Miskovsky (1969). Small aliquots of the residues were mounted in glycerine, sealed with Histolaque and all recognizable pollen and spores were counted under a light microscope using 400× magnification, until a pollen amount of at least 200 units was reached. Non-pollen palynomorphs (NPPs) were identified using the nomenclature proposed by Van Geel (2001). Palynological identification and counting were aided by the reference collection available at the Laboratory of Archaeobiology at the CSIC, Madrid. The pollen percentage diagram

(Fig. 7) was constructed using Tilia 1.12 and TiliaGraph 1.18 software (Grimm, 1991). Hygrophyte pollen (*Cyperaceae*), fern (*Filicales monoletes*) and fungal spores (*Sordaria* sp.) were excluded from the pollen sum. Asteraceae (*Cardueae*, *Cichorioideae*) and other ubiquitous herbs with possible zoophily were also excluded.

Results and discussion

Stratigraphical data

The cave sediment fill is composed predominantly of angular, unrounded clasts of limestone, with dimensions ranging from sand-grain size to large blocks, several meters across. The sediments are mainly clast-supported, the matrix is scarce and of a silty nature. Although no clear stratification can be observed, it is possible to distinguish levels with coarsely ordered granulometries, and even coarsening upward sequences (Fig. 4c). There is a capping calcite flowstone above the most recent sediments (Figs. 3 and 4b).

Three main levels of blocks can be distinguished (Fig. 3). These indicate rockfall events from the top of the cavity. The existence of water flow during periods of cold climate must have favored cryoclastic action, which gradually caused the fissure to widen. This widening led to instabilities that promoted rockfalls from the roof and enlarged the cave.
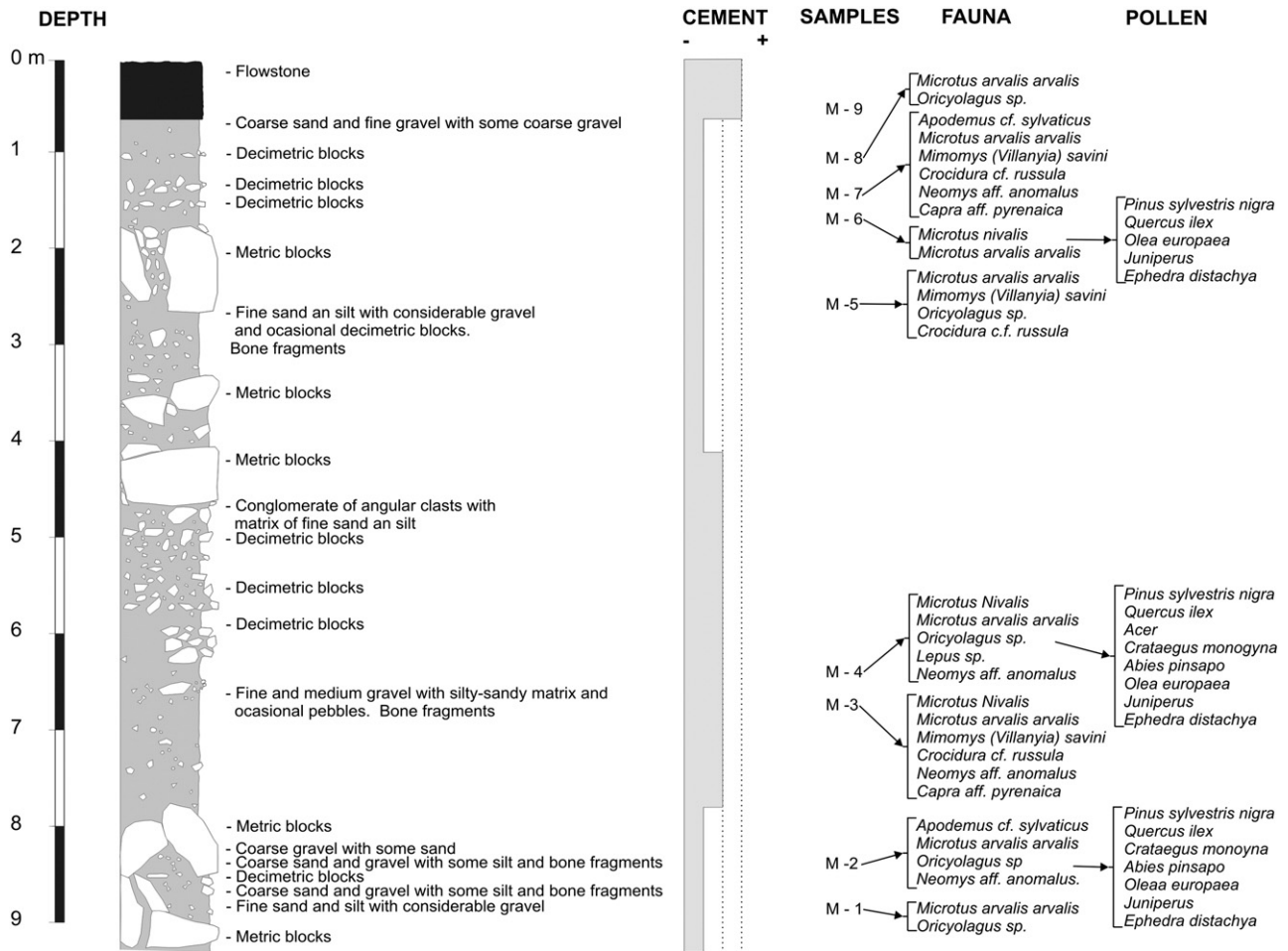
Figure 3. Stratigraphic column of the Cucú cave fill and faunal and pollen content of the samples obtained.

Faunal data

It is most likely that the remains of micromammal species found in some of the levels were carried there by raptors nesting within the cave. The entrance of the cave is a natural mound where raptors currently nest. The actual distribution of bones in the superficial layer of sediments is like the rest of the sedimentary record, so that during the late Pleistocene there must have been a similar activity.

The following inventory has been made of the fauna contained in samples obtained from the sedimentary infilling (Table 2 and Fig. 3):

Apodemus cf. *sylvaticus*; *Microtus nivalis*; *Microtus arvalis arvalis*; *Mimomys* (*Villanyia*) *savini*; *Neomys* aff. *anomalus*; *Crocidura* cf. *russula*; *Oricyolagus* sp.; *Lepus* sp.; *Capra* aff. *pyrenaica*; *Passeriformes* indet.; *Lacerta* sp.; *Bufo* sp.; *Salmo* cf. *trutta*.

The most abundant of these species is *M. arvalis arvalis*, and the morphology of its molar (m1) (Fig. 5a) has been cataloged by Ruiz Bustos (1988). In the filling, associated with *M. arvalis arvalis* are the arvicolids *M. nivalis* and *M.* (*Villanyia*) *savini*. The characteristics of the molars of this latter species (Figs. 5b and c) were defined by Ruiz Bustos (1987).

Data from the same region, collected prior to the study of the fauna in Cucú cave, indicate that the first appearance of *M. arvalis arvalis* in this region was in the SI0.27-2 Biozonemark after Ruiz Bustos (2011), which means 200 to 140 ka, associated with *Allocricetus bursae* and *M.* (*Villanyia*) *savini*. This assemblage was last recorded in the basal levels of the filling within the Carihuela deposit, in the neighboring province of Granada, which like Cucú, is situated in the area of influence of the Sierra Nevada (Ruiz Bustos, 2000).

The lower levels of the Carihuela deposit were dated using thermoluminescence techniques by Göksu et al. (1974), results that were slightly modified in Göksu's subsequent Ph.D. thesis as having an age to 82.5 ± 4.5 ka (Carrión et al., 1998).

The upper levels of the Carihuela deposit, and their equivalents in nearby Zafarraya (Barroso et al., 1983), show that *M. arvalis arvalis* is present, but that the species *A. bursae* and *M.* (*Villanyia*) *savini* have disappeared. This disappearance is unlikely to be a matter of chance, as the birds that consumed *M. arvalis arvalis* would also have hunted *A. bursae* and *M.* (*Villanyia*) *savini* if these had lived in the biocenosis of the Betic region. In the Zafarraya deposit, these levels have been dated using U–Th methods to 40 ka, and correspond to the SI0.27-4 intrazone sector of Ruiz Bustos (2011).

In Cucú cave, the mere presence of *M.* (*Villanyia*) *savini*, irrespective of whether the absence of *A. bursae* is circumstantial or otherwise, indicates that the deposit in the Cucú cave is older than that of Zafarraya.

According to available data, the upper limit of the Cucú cave filling exceeds 40 ka, which is close to the upper limit of SI0.27-3 (140–70 ka). The lower limit is determined by the upper limit of SI0.27-2 (200–140 ka), coinciding with a cold environment (Ruiz Bustos, 2011).

Paleoecological mammal data

The ecological preferences of the mammal species identified in the Cucú cave filling, for each of the basic habitats of the region, were determined in accordance with the ecomorphology implied by the fossil remains and by the ecological preferences of the most direct living descendants of the fossil species found in the deposit.
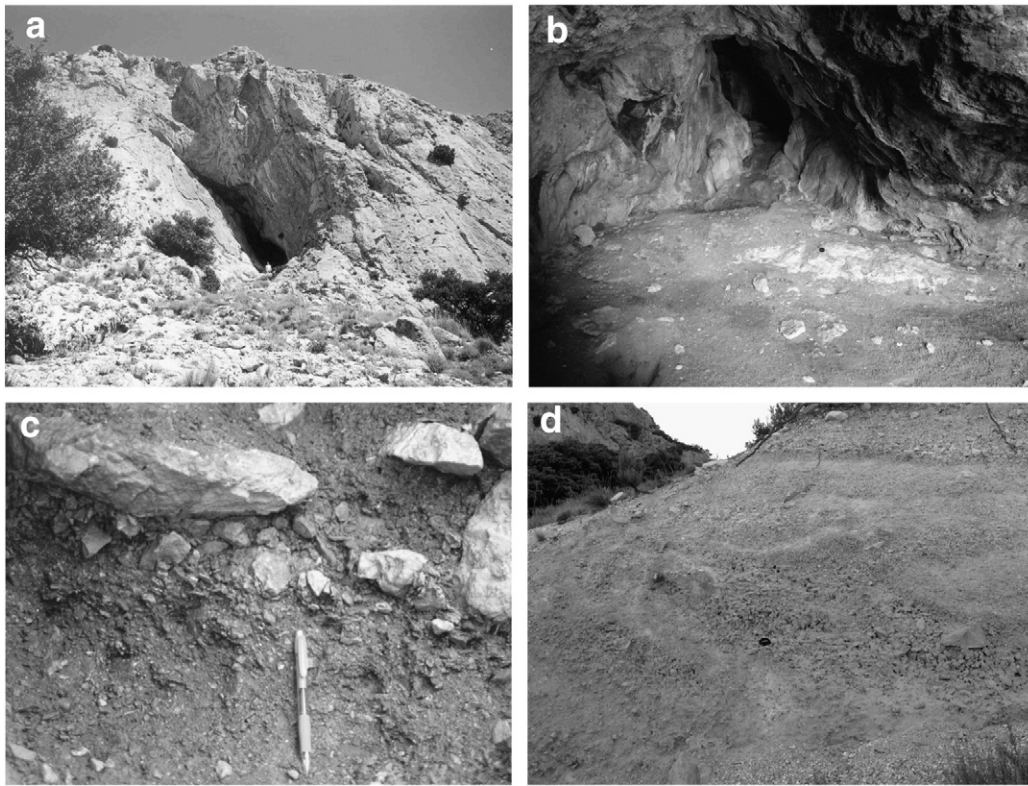
Figure 4. (a) Cucú cave entrance in a scarp of El Cabezo mountain developed along a fault plane; (b) flowstone covering the clastic sequence; (c) coarsening upward sequence of clastic deposits; (d) stratified breccias in El Cabezo mountain.

M. arvalis arvalis were prolific consumers of small grasses in cold, open areas, with large expanses of humid grassland. The trend toward colder climatic conditions forced the individuals living in the more southerly areas of the species distribution to behave like mountain-dwelling animals. In the Iberian peninsula today, *M. arvalis* is located above 40°N, which means it does not inhabit the Betic Cordillera.

In the present day, *M. arvalis arvalis* and *Microtus brecciensis cabrerae* are competitors; although they do not coexist in the same area of grassland, they are found in neighboring areas (Ruiz Bustos,

2000). The species *M. arvalis arvalis* prefers all or some of the climatic conditions corresponding to high latitudes, in contrast to the preference for warmer temperatures of the southern areas evidenced by *M. brecciensis cabrerae* (Ruiz Bustos, 2000) and coinciding with *P. duodecimcostatus duodecimcostatus*. The absence of the species *M. brecciensis cabrerae* and *Pitymys duodecimcostatus duodecimcostatus* is of very significant value for inferring the climatic conditions of the Cucú cave deposit.

M. nivalis live in cold, rocky, high-mountain areas. At present, this species inhabits the Betic Cordillera, on the mountains of the Sierra
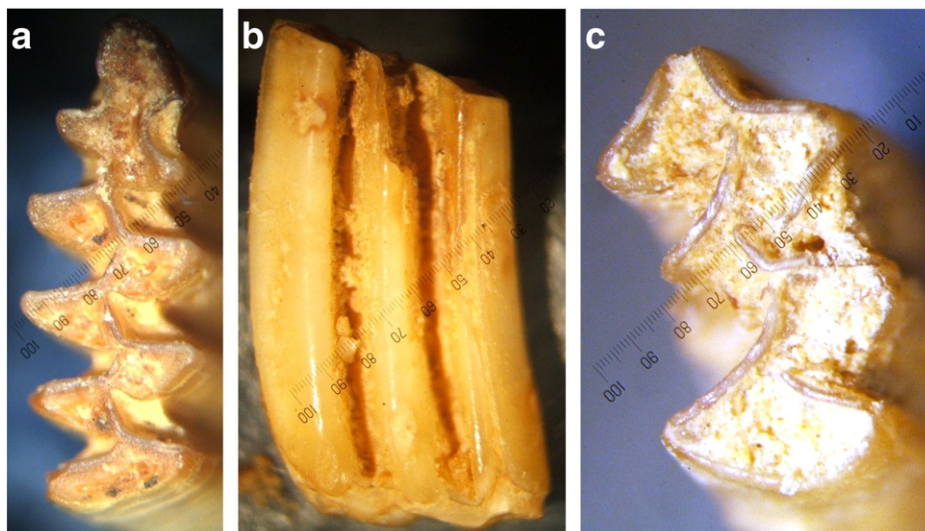

Figure 5. (a) *Microtus arvalis arvalis*: Cu3, first right lower molar (m1 right). (b) *Mimomys* (*Villanyia*) *savini* (occlusal view): Cu15, second left lower molar (m2 left). (c) *Mimomys* (*Villanyia*) *savini* (external lateral view): Cu15, second left lower molar (m2 left).

Table 1
Fauna and pollen data in the Cucú Cave sampling site. These are the fundaments to infer the Sierra Nevada regional biotopes. The sample situation is in Figs. 2 and 3. The terrestrial betic ecosystem, as consequence of its altitude (3000 m in Sierra Nevada mountains) and latitude 36°N), reproduces in its altitudinal biotopes the fauna, flora and climate of the Eurasian ecosystem. Biotopes caption: A; tundra and cold deserts. B; cold steppes with trees. C; conifer forests. D; deciduous forests. E; sclerophyllous forest of Holm oak and thermophilous pine. F; temperate steppe (meadow/savannah type). G; dry steppe (shrubland type). K; deserts and arid zones. H; cold continental waters, gallery vegetation. I; warm continental waters, riverbank vegetation.

SAMPLES	FAUNA	POLEN	A	B	C	D	E	F	G	K	H	I
M-1	*Microtus arvalis arvalis* *Oricyolagus sp.*											
M-2	*Apodemus* cf. *sylvaticus* *Microtus arvalis arvalis* *Oricyolagus sp* *Neomys* aff. *anomalus*	*Pinus sylvestris!nigra* *Quercus ilex* *Crataegus monoyna* *Abies pinsapo* *Oleaa europaea* *Juniperus* *Ephedra distachya*										
M-3	*Microtus Nivalis* *Microtus arvalis arvalis* *Mimomys (Villanyia) savini* *Crocidura* cf. *russula* *Neomys* aff. *anomalus* *Capra* aff. *pyrenaica*											
M-4	*Microtus Nivalis* *Microtus arvalis arvalis* *Oricyolagus sp.* *Lepus sp.* *Neomys* aff. *anomalus*	*Pinus sylvestris nigra* *Quercus ilex* *Acer* *Crataegus monogyna* *Abies pinsapo* *Olea europaea* *Juniperus* *Ephedra distachya*										
M-5	*Microtus arvalis arvalis* *Mimomys (Villanyia) savini* *Oricyolagus sp.* *Crocidura c.f. russula*											
M-6	*Microtus nivalis* *Microtus arvalis arvalis*	*Pinus sylvestris nigra* *Quercus ilex* *Olea europaea* *Juniperus* *Ephedra distachya*										
M-7	*Apodemus* cf. *sylvaticus* *Microtus arvalis arvalis* *Mimomys (Villanyia) savini* *Crocidura* cf. *russula* *Neomys* aff. *anomalus* *Capra* aff. *pyrenaica*											
M-8	*Microtus arvalis arvalis* *Oricyolagus sp.*											

Nevada, which rise to >3000 m a.s.l. *M. nivalis* shares this habitat with the species *Capra* aff. *pyrenaica* (Ruiz Bustos, 2000).

The morphology of *M.* (*Villanyia*) *savini* is identical to that of the genus *Arvicola*, although *Mimomys* has molars with roots; moreover, these molars do not grow continuously. Its habitat is the grassy banks of rivers and streams.

The insectivore *Neomys* aff. *anomalus* lives in the proximity of mountain streams, although it can also be found in wet grassland surrounded by woods. The species *Crocidura* cf. *russula* lives in diverse habitats, being found both in areas of dry shrubland and in mixed woodland. It avoids low temperatures.

A comparison between the climatic conditions deduced from the biocenogram for Cucú cave and those prevailing at present in the Betic Cordillera indicates the existence of a cold, dry period, comparable with that indicated by the lower levels of the Carihuela deposit.

Speleothem dating

It is clear from the low ^{230}Th/^{232}Th activity ratios (Table 2 and Fig. 6) that clastic contamination is very high, thus necessitating a 3-dimensional isochron approach (Ludwig and Titterington, 1994). Only by using multiple coeval samples with a range of Th concentrations could we draw age information from this flowstone. Using 4 sub-samples of the flowstone capping the sedimentary sequence, we obtained a reasonable linear relationship, but with high MSWD. The derived age is 40.2 ± 4.5 ka (95% confidence limits for age are expanded here to account for the large MSWD of 30) (Fig. 6). Initial ^{230}Th/^{232}Th is 0.13 ± 0.06 (atomic ratio), which is less than the typical Bulk Earth value of 0.8, indicates that model age determination using a priori estimates can lead to erroneous ages.

Table 2
Measured U and Th activity ratios and concentrations (2σ errors).

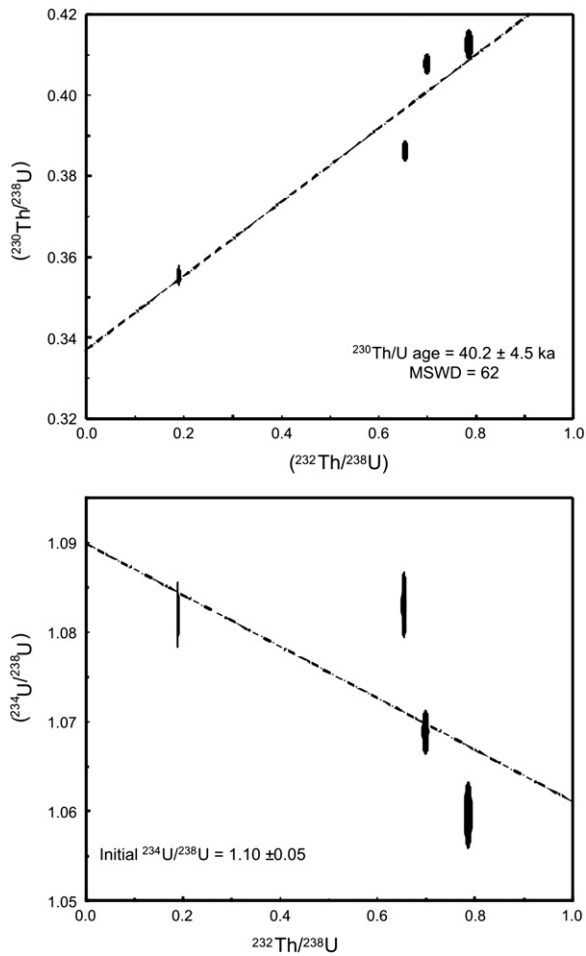|	^{238}U (ng g^{-1})	^{232}Th (ng g^{-1})	(^{230}Th/^{232}Th)	± error	(^{230}Th/^{238}U)	± error	(^{234}U/^{238}U)	± error
CUCU-02B-1	249	597	0.527	0.003	0.413	0.003	1.060	0.003
CUCU-02B-2	136	290	0.585	0.002	0.408	0.002	1.069	0.002
CUCU-02B-3	238	–	–	–	–	–	–	–
CUCU-02B-4	247	491	0.592	0.002	0.386	0.002	1.083	0.003
CUCU-02B-5	425	243	0.621	0.002	0.356	0.002	1.082	0.003

Figure 6. Two projections of the 3-dimensionsal U–Th isochron plot for the 4 coeval sub-samples from Cucú flowstone deposit.

Paleopalynological data

Pinus nigra type percentages are relatively high (19–46%), indicating a pine forest in the vicinity of the cave (Fig. 6 and Table 1). *P. nigra* subsp. *salzmannii* is the most likely pine-pollen producing species in Cucú cave, because it currently dominates high-altitude karstic relief in the oromediterranean belt of Sierra de María to 1600 m a.s.l. (Mota et al., 1993). Assemblages of pollen types that match the present-day composition of high-altitude communities (>1600 m a.s.l.) are represented by the morphotypes *Genista* (*Erinacea* sp., *Genista* sp.), *Juniperus* (*J. communis*, *J. sabina*), *Acer*, *Crataegus monogyna* and Brassicaceae (*Vella spinosa*). A notable semi-arid pollen signal of *Ephedra nebrodensis*, *Artemisia*, *Reseda lutea*, Lamiaceae and Chenopodiaceae is recorded (Carrión et al., 1998). *Pinus*-dominated spectra displayed relatively important values of evergreen *Quercus* (12–20%) and Cichorioideae (32% in sample 5). With lesser occurrences there are *Abies* (1–3%), *Juniperus* (2–6%), *Salix*, *Erica arborea* and Poaceae. Cichorioideae pollen are well preserved in sample 5 (36%), suggesting that their relative abundance could be partially or wholly the consequence of differential preservation, although other possibilities such as animal introduction—together with Boraginaceae, Cardueae, *Convolvulus arvensis*, *Malva sylvestris*, *Plantago lanceolata*, *Polygonum aviculare* and *Sordaria* sp.—cannot be dismissed (Navarro et al., 2000, 2001).

Paleoenvironmental interpretation

The paleontological and palynological record found in the Cucú cave filling is relatively uniform throughout the series. The fauna studied, and their comparison with those found in other cavities in southern Spain, reveal that the clastic filling of Cucú cave corresponds to SI20-3 of Ruiz Bustos (2011), which means 140 to 70 ka, and a colder, drier environment than the present day, with low levels of precipitation, but with snow, and streams containing cold snowmelt runoff.

At this time, pine forests and high-mountain shrublands were the dominant vegetation, with *Juniperus* probably occupying the shallowest
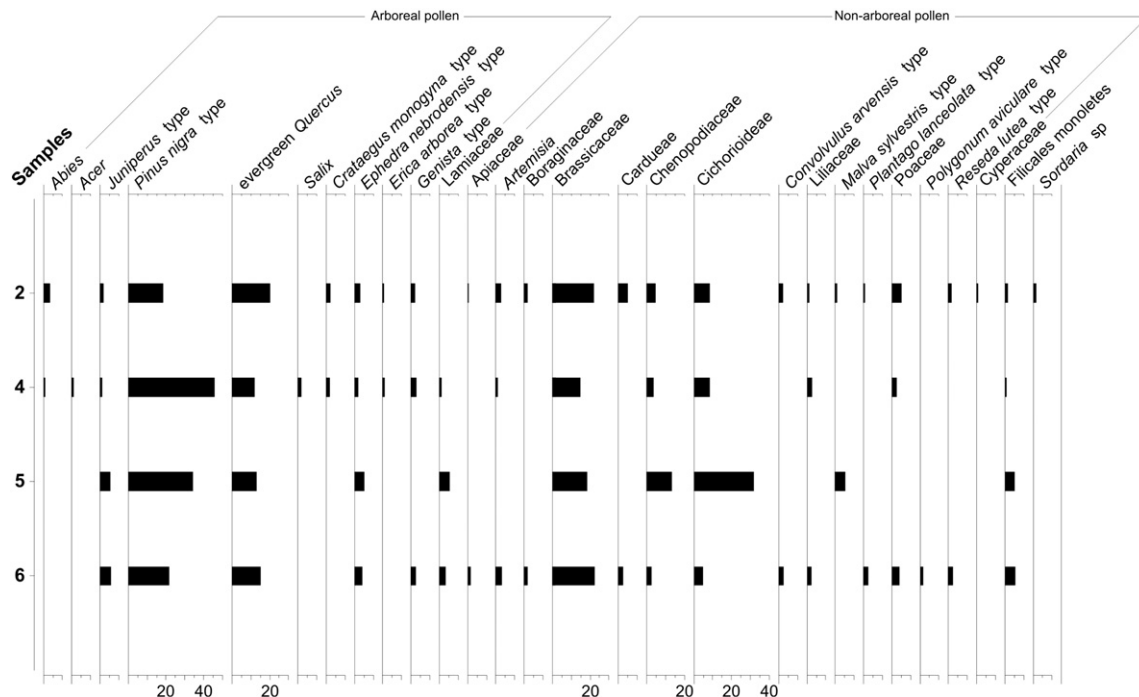

Figure 7. Palynological record of the Cucú cave. The position of sample points can be seen in Figs. 2 and 3.

soils and most continental biotopes. High percentages of xerophyte pollen indicate the proximity of semi-arid vegetation. A prevailing dry climate could explain the abundance of evergreen oaks at lower altitudes. These pollen assemblages are a common feature of Pleistocene cold stages, often in the context of freeze-cracking and periglacial lithology, and may be regarded as a remnant of glacial vegetation at this site (Carrión et al., 2001).

The sedimentary fill is poorly stratified, although there is a grain size sorting (*grèze litées*) that is characteristic of periglacial climates. This type of deposit can also be observed on the slopes of Sierra de Cabezo, near the Cucú cave (Fig. 4d). Breccia of similar characteristics deposited on the slopes of the Subbetic Sierras of the province of Córdoba have been dated at around 80 ka, using a U–Th dating of secondary carbonate crystals (Torres-Girón and Recio-Espejo, 1997).

The deposit examined in this study displays gross coarsening upward cycles, ending in rockfalls of blocks from the cavity ceiling. Each of these cycles can be interpreted as the consequence of a gradual cooling of the climate, which provoked periglacial breccias, with stones and rocks that increased in size as the destabilization of the cave ceiling progressed.

Figure 8 shows the stratigraphic column for the cave filling, together with the seawater temperature curves obtained using marine cores from the Alborán Sea (Maltrat et al., 2004) and the Atlantic Ocean (Pailler and Bard, 2002; De Abreu et al., 2003). Also shown are the δ13C variation curves in speleothems obtained in the nearby Gitana cave (see location in Fig. 1; Hodge et al., 2008), in the Villars cave, in SW France (Genty et al., 2003, 2005; Genty, 2008) and in the Soreq cave, Israel (Matthews et al., 2000), which are interpreted as changes in the humidity of the Mediterranean environment. The sequence studied could well correspond to the colder periods that occurred between 60 and 140 ka; the level of the blocks appearing at depths of 8–9 m might be related to the end of MIS 6, a period in which marine proxies present a significant temperature decrease, as reflected in the Gitana cave speleothems by the reduction in humidity. Between 6 and 7 m displays an increase in the size of the sediment, with the appearance of decimeter-sized blocks which can relate to MIS 5d. This stage also shows in the speleothems of the nearly Gitana

Cave with a change in the 13δC content indicating greater aridity in the environment (Hodge et al., 2008).

The levels of the blocks situated at a depth of about 4 m could be related to the cold climatic variations of MIS 5b, while the level of blocks at a depth of 2 m is correlative with the first cold oscillation of MIS 4. These latter cold pulses seem to be marked, in the Villars cave, by gaps in the speleothem deposits and by mild reductions in humidity in the Gitana cave speleothem.

At 40.2 ± 4.5 ka ago, the flowstone that covers the clastic filling of the cave was formed, under conditions in which the climate must have been warmer, and possibly more humid, too. This warmer episode is also deduced from the pollen record in the Carihuela cave at ~45 ka (Carrión et al., 1998), which would also have been accompanied by the generation of stalagmitic flowstones. In the records for the stalagmites in the Villars cave there is evidence of a major warm event between 43 and 46.6 ka (Genty et al., 2003, 2005; Genty, 2008).

Conclusions

Paleontological records show that the Cucú cave sediment fill was deposited in the period 140 to 70 ka (SI0.27-3), because the fauna assemblage detected is undoubtedly older than that of the Zafarraya deposit (40 ka, according to Barroso et al., 1983) and includes fossils that are correlated with the basal levels of the Carihuela deposit (82.5 ± 4.5 ka, according to Carrión et al., 1998). The palynological record reveals the proximity of semi-arid vegetation, and displays features that are common to the assemblages of the cold stages of the Pleistocene, often in the context of freeze-cracking and a periglacial environment. The paleontological and palynological information obtained enables us to reconstruct the climate prevailing during the deposit—in general, cooler and drier than at present.

Our study of the stratigraphy of the fill revealed three sequences of breccias, larger toward the cave ceiling, ending in blocks. These sequences are interpreted as being the consequence of temperature reductions, which could be related to the main cold pulses observed, for the period in question, in the marine records obtained close to the
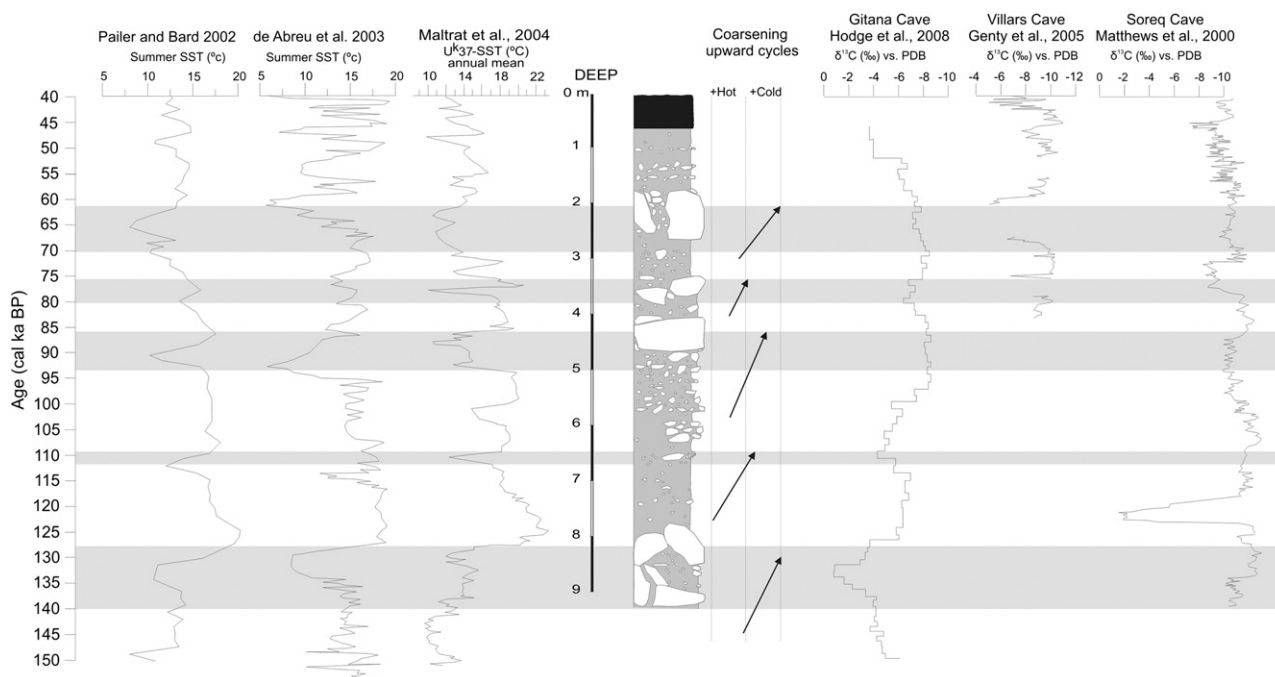

Figure 8. Paleoclimatic interpretation of the Cucú fill. On the left, the reconstructed sea surface temperature (SST) curves for the West Atlantic Iberian margin (Pailler and Bard, 2002; De Abreu et al., 2003) and for the Alborán sea (Maltrat et al., 2004). On the right, the δ13C records obtained from speleothems in the Gitana cave (Hodge et al., 2008), Villars cave (Genty et al., 2005) and Soreq cave (Matthews et al., 2000). The horizontal gray bars represent cold periods according to Maltrat et al. (2004).

Iberian peninsula and in speleothems in diverse caves in the Mediterranean region. The levels of blocks are interpreted as being the culmination of the coldest pulses, which provoked the destabilization of the cave ceiling, and the subsequent falls of blocks. The oldest of these sequences could be correlated with the end of MIS 6, around 130 ka, while the second could be the consequence of pulse 5b, around 90 ka, and the final one might be associated with the first cold pulse recorded in MIS 4, between 60 and 70 ka. The cold pulse MIS 5d, around 110 ka, which could be related to gradual appearance of decameter-sized blocks in the sedimentary record, can also be deduced.

Finally, the flowstone covering the deposit has been dated at around 40 ka, which would identify this age as marking the onset of environmental conditions suitable for the precipitation of calcite, the end of periglacial action within the cave and in its surroundings, and an increase in air temperature.

Acknowledgments

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