Paleoflood events recorded by speleothems in caves

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ABSTRACT

Speleothems are usually composed of thin layers of calcite (or aragonite). However, cemented detrital materials interlayered between laminae of speleothemic carbonate have been also observed in many caves. Flowstones comprising discontinuous carbonate layers form due to flowing water films, whilst flood events introduce fluviokarstic sediments in caves that, on occasion, are recorded as clayey layers inside flowstones and stalagmites. This record provides a potential means of understanding the frequency of palaeofloods using cave records. In this paper, we investigate the origin of this type of detrital deposits in El Soplao Cave (Northern Spain). The age of the lowest aragonite layer of a flowstone reveals that the earliest flood period occurred before 500 ka, though most of the flowstone formed between 422 +69/-43 ka and 400 +66/-42 ka. This suggests that the cave was periodically affected by palaeoflood events that introduced detrital sediments from the surface as a result of occasional extreme rainfall events, especially at around 400 ka. The mineralogical data enable an evolutionary model for this flowstone to be generated based on the alternation of flood events with laminar flows and carbonate layers precipitation that can be extrapolated to other caves in which detrital sediments inside speleothems have been found.

KEYWORDS: paleofloods, aragonite speleothems, flowstone, cave sediments, El Soplao Cave.

INTRODUCTION

Cave deposits (both clastic and chemical) provide evidence of geological processes and climatic trends that are not preserved at the surface in most karst regions (Ford and Williams, 2007). In particular, clastic sediments from caves have supplied valuable information about the evolution of karstic systems and geomorphological processes (e.g. Bull, 1981; Springer and Kite, 1997;

Klimchouk and Andrejchuk, 2002; Quinif et al., 2006; Lisker et al., 2010; Zupan Hajna, 2010; Martini, 2011) and palaeoclimatic events (e.g. Schmidt, 1982; Brook and Nickmann, 1996; Gospodarič, 1998; Šroubek et al., 2001; Sasowsky, 2007; White, 2007). In addition, clastic sediments have been used to reconstruct the history of archaeological and palaeontological sites (e.g. Murray, 1957; Karkanas, 2000; Farrand, 2001). Recent studies have demonstrated the importance of the role of sediment in transporting contaminants (Mahler et al., 1999; Vesper et al., 2003; Vesper and White, 2003) and microorganisms (Mahler et al., 2000) in karst systems.

Clastic cave sediments can be subdivided into two categories (White, 2007) with respect to their origin: autochthonous and allochthonous. Autochthonous clastic sediments are derived locally within the cave from weathering of the bedrock, or from breakdown, whereas allochthonous clastic sediments are transported into the cave from outside. Sediment influx into caves occurs through solutionally-widened fractures of the host rock or via shafts and sinkholes in the karst. The nature of the injected material depends on the rock types in the vicinity of the cave, and is usually a mixture from all these sources.

The cave entrances can act as a trap where sediments are unaffected by surface erosion. However, once inside the cave, sediments are transported as suspended load or bedload, depending on the particle size and the velocity of the stream flow (Ford and Williams, 2007). When sediments derive from flood events, the coarse fraction of the load frequently appears on the bed of streams inside the caves, whilst fine-grained materials (clays and silts) usually form the top part of the sedimentary sequence and are deposited when the energy of the flow decreases (Bosch and White, 2004; Van Gundy and White, 2009). In places, clayey sediments can coat the cave walls and ceiling, suggesting that cave passages were once totally filled with muddy sediments.

Magnetostratigraphy has been the most common method for dating clastic sediments from caves (Schmidt, 1982; Sasowsky et al., 1995; Šroubek et al., 2001; Chess et al., 2010; Zupan Hajna et al., 2010). As long as the sedimentary sequence has not been altered, the magnetic grains maintain the orientation according to the Earth's magnetic field at the moment of their deposition. Over the past decade, new techniques like OSL dating (optically stimulated luminescence) have been applied to cave sediments (Sanna et al., 2009), providing the absolute date when the sediments were trapped in the cave. On the other hand, the age of cave sediments have also been determined from radiocative decay of cosmogenic 26-Al and 10-Be (Granger et al., 2001; Stock et al., 2005). In addition to these three above-mentioned dating methods, cave sediments can also be chronologically constraint by means of dating of buried terrestrial shells (Molokov, 2001), charcoal, wood and bone collagen (Boaretto et al., 2009; De Waele et al., 2009).

The presence of detrital materials interbedded between chemically precipitated speleothems has been reported in some caves (Dorale et al., 1992; Sasowsky et al., 2007; Stöll et al., 2008; Dasgupta et al., 2010; Pickering et al., 2010; Ballesteros et al., 2012). However, few cases describe clastic materials intercalated with subhorizontal aragonite layers whereby a flowstone is formed due to the degassing (and evaporation) of a water lamina flowing over a surface. Dating the carbonate layers of the speleothem that are sandwiched between clastic materials is an alternative to direct dating of detrital sediments (Pickering et al., 2007; Sanna et al., 2010; Ballesteros et al., 2012).

The current article deals with evidence of paleofloods events in caves, as recorded by speleothems, in particular through the study of flowstones recently discovered in El Soplao Cave (Northern Spain), which are composed of aragonite laminae interlayered between successive thin strata of cemented silt and clay. The geochronology of four carbonate layers was determined using the U-Th dating method. These data, together with the mineralogical observations enabled the evolution of this flowstone to be reconstructed and allowed us to identify the flood periods when detrital materials were injected into the cave. Our work shows how dating carbonate layers of speleothems is an accurate method for determining periods in which caves were affected by paleofloods events, what represents an alternative to direct dating of detrital sediments.

DESCRIPTION OF THE STUDY AREA

Geological setting

El Soplao Cave (43º17´45, 42"N - 4º25´45, 76"W) is located in the Sierra de Arnero, in the Escudo de Cabuérniga mountain range (Cantabria, Northern Spain). The Sierra de Arnero mountain chain runs parallel to the Cantabrian Coast, between the Bustriguado and Nansa valleys (municipal districts of Valdáliga, Rionansa and Herrerías) (Fig. 1A). This natural cavity was accidentally discovered in the early-nineteenth century as a result of mining activity in La Florida mine (Carcavilla and Durán, 2011).

The cave is developed in the Reocín Formation, shallow platform carbonate rocks of Early Cretaceous (Aptian) age that is inclined 40º N. There is considerable metallogenic interest in the region due to the large patches of dolomitization associated with sulphide deposits that are the result of rising hydrothermal fluids in the carbonates (Quesada et al., 2005; López-Cilla et al., 2009; López-Horgue et al., 2009). In fact, important deposits of lead and zinc sulphides occur in the Florida Mine and in the El Soplao Cave itself, appearing as pre-existing patches of mineralization that were intersected by the cave (Tornos and Velasco, 2011). Tectonic efforts in this area are shown by a fault system that runs parallel to the Sierra de Arnedo mountains and is inclined 50º SE (Jiménez-Sánchez et al., 2011).

From a hydrogeological point of view, the Reocín Formation comprises a carbonate sequence 300 m thick on average that is significantly karstified and fractured due to tectonic efforts, which in the El Soplao area gave rise to La Florida aquifer (Meléndez-Ansesio and Rodríguez-González, 2011). The mining activities carried out in the Florida mine since 1900 produced considerable modifications in the hydrogeological regime of the aquifer. In fact, several springs placed few meters below the cave level dried as a result of the drainage of the carbonate formation, in contrast to several artificial artesian pits arisen upon the mining exploration.

Recent hydrogeological studies reveal that 21 natural spring plus 6 artificial upwellings supply water to the Nansa River and the Bustriagudo Spring, with flow rates ranging 10 to 120 l/s depending on the time of year (Meléndez-Ansesio and Rodríguez-González, 2011). The present-day water table level in the El Soplao setting is inferred to be at around 150-200 m a.s.l, coinciding with the altitude of these main springs, whilst the base level is given by the bed of the Nansa River, 100 m a.s.l.

Description of El Soplao Cave

The cave entrance lies 540 m a.s.l. and its passages extend over 17 km, with around 200 metres variation in altitude. The total length of the cave, including the mining galleries, is approximately 20 km (Fig. 1B and C). An artificial cave mouth excavated parallel to the Isidra gallery serves as entrance for tourist visits. In addition, there are two natural cave entrances: Torca Ancha and Torca Juñosa, by which access is difficult (González-Hierro, 2011). Preliminary studies inside and outside the cave suggest other entrances may exist, influencing the microclimate dynamics and cave environment.

The main passage of the cave is a low-gradient canyon, ~2 km long, developed along the strike of the beds (Fig. 1C). It represents a relict “ideal water table” cave segment (Ford and Williams, 2007), formed when the water table was ~400 m higher than is today. The cave morphology is controlled by a fault running E-W, inclined 50 º SE (Jiménez-Sánchez et al., 2011) and its passages are oriented following this fault, with a secondary axis running NE-SW. The fault’s displacement controlled the evolution of the cave morphology, and very probably the direction of the vadose water flows in the past. In fact, the external geomorphology of the mountains range in which the cave is developed could differ considerably from its current aspect. Today, the main cave passages describe a horizontal plane that is inclined 1.5 º to the east (González-Hierrao, 2011) and the most elevated cave passages lie at 545 m a.s.l, coinciding with the Galería Gorda Chamber, practically at the same level as the natural cave entrances (Fig. 1C). However, the altitude of the entrance sinkholes was probably higher in the past, and was gradually reduced due to erosion and denudation mechanisms, as well as tectonic efforts. Consequently, a part of the detrital sediments produced in this area were introduced by water flows into the cave, in which were stored. Recent speleological surveys revealed that the deepest part of the cave lies just beneath these natural entrances, at a depth of 150 m below the surface (450 m a.s.l). At present, there are no permanent streams flowing in the cave and water flows are limited to dripping water from speleothems.

The cave presents much evidence of subaqueous speleogenesis, such as corrosion cupolas and phreatic tubes, whose floors were subsequently eroded by a stream under vadose conditions, as revealed by the presence of several stalagmite pavements at different elevations (Fig. 2B). Up to three “banquettes” or floor levels have been observed in some passages (Jiménez-Sánchez et al., 2011) and there is also evidence of palaeoflood events that introduced fine-grained sediments into the cave. Flood level marks evidenced by silt lines on earlier carbonate speleothems (Fig. 2.E, G and H), mud deposits on the cave floor (Fig. 2A) and layered detrital deposits in several cave passages (Fig. 2A) suggest that flood events have occurred quite recently in El Soplao Cave.

El Soplao Cave was opened as a show cave in 2005. Spectacular helictites, anthodites and huge speleothems are the most relevant aesthetic features of this mine show-cave. Other unusual speleothems have also been described in this cave, including the dark amberine speleothems whose colour is related to lixiviates from a carbonaceous stratum located above this speleothem formation (Gázquez et al., 2012), black ferromanganese crusts (Gázquez et al., 2011) and ferromanganese stromatolites (Rossi et al., 2010).

The current cave temperature ranges between 9 and 13 ºC, depending on the mean annual temperature outside the cave, while its relative humidity is usually around 80-100%. The CO_2 concentration in air is around 440-600 ppm, depending on the number of visitors per day (Calaforra et al., 2011).

METHODS

Sample description and sampling methods

The sample analysed consisted of a fragment of carbonate flowstone, weighing about 3 kg, collected from the Pasillo de los Cubos (also called “Contessa Passage”) of El Soplao Cave (Fig. 1B, C). The speleothem is a horizontal stalagmite pavement up to 20 cm thick that hangs 30 cm above the cave floor (Fig. 2A).

The sample was cut using a rock-cutting machine along its main growth axis. Subsequently, the cut surface was manually polished and a high-resolution image of its cross section was scanned. Mineralogical analyses were performed by XRD, using the methodology described by Gázquez et al. (2011). Four powdered samples from the whiter carbonate layers were collected for U-Th dating using a Dremel drill with a 0.8 mm diameter bit. Sampling was done at the lower part of the flowstone (SPL-00), and at 30 mm (SPL-30), 60 mm (SPL-60) and 67 mm (SPL-67) from the speleothem base, following the horizontal aragonite layers.

U-Th dating

U/Th dating was carried out at the GEOTOP research centre of the University du Quebec in Montreal. Subsamples of 0.5 g of carbonate (n=4) were weighed and transferred to 250 mL Teflon beakers, into which weighed amounts of a mixed ^{233}U-^{236}U-^{229}Th spike had been placed and evaporated. Actinides (Th and U fractions) were selectively retained and subsequently eluted using 0.2 mL U-Teva (Eichrom) resin volume, following the method described in Hillaire-Marcel et al. (1996). The U and Th fractions were deposited on a Re filament between two layers of graphite and measured using a Triton Plus mass spectrometer (TIMS) equipped with an RPQ (retardation potential quadrupole). Mass fractionation for U was corrected by the double spike of ^{236}U/^{233}U (1.1322), while mass fractionation for Th was considered negligible with respect to analytical error. The overall analytical reproducibility, as estimated from replicate measurements of standards, was generally better than 0.5% for U concentration and ^{234}U/^{238}U ratios, and ranged from 0.5% to 1% for ^{230}Th/^{234}U ratios (2σ error range).

The presence of the non-authigenic ^{230}Th in the carbonate samples was negligible as indicated by the high ^{230}Th/^{232}Th (up to 5200), thus no correction for detrital contamination was required. U-Th ages were calculated from the isotopic ratios ^{235}U/^{236}U, ^{235}U/^{234}U, ^{236}U/^{234}U, ^{232}Th/^{229}Th and ^{229}Th/^{230}Th using ISOPLOT/Ex version 2.0 software (Ludwig, 1999).

RESULTS

The carbonate flowstone is 20 cm thick, including white aragonite layers. In addition, up to eleven cemented detrital layers, varying from several microns to centimetres in thickness, were identified (Fig. 3). There were two further dark layers at the upper part of the speleothem, interlayered with clayey and carbonate layers. An incipient stalagmite was presented in the middle of the stratigraphic sequence. The flowstone occurs on a 30 cm thick stratum of non-consolidated sediments that was partially eroded by a stream in more recent times (Fig. 2A). Observations on a polished thin section of the speleothem did not reveal dissolutional or corrosion of carbonate layers to have occurred after precipitation (Gázquez, 2012).

U-Th dating of the flowstone revealed that this speleothem grew during a period beginning more than 500 ka. Sample SPL-00 is in secular equilibrium for the U-Th system as suggested by the ratio $^{230}Th/^{234}U \approx 1$, thus exceeding the dating limit of the U-Th method (≈ 500 ka).

Before 500 ka, a 30 cm-thick layer of sediments beneath the earliest carbonate layer was deposited. In places, these detrital sediments were removed by more recent stream flows, leaving the flowstone hanging above the cave floor (Fig. 2A). Subsequent deposition of layers of aragonite “fossilized” these first detrital sediments. Further floods occurred before 500 ka, as suggested by a 2.5 cm-thick layer of cemented detrital materials. The ages of the further aragonite layers analysed, SPL-30 and SPL-60, were 422 +69/-43 ka and 400 +66/-42 ka, respectively. Hiatuses represented by thin detrital layers can be observed intercalated with the aragonite layers, in addition to a 1 cm high stalagmite which was “fossilized” by further aragonite laminae (Fig. 3).

In the top part of the flowstone, several thin dark layers of polymetallic oxyhydroxides were observed, previously characterized by Gázquez et al.

(2011). Above the Fe-Mn-Zn deposits a further aragonite layer was found, which dates to 32.7 ± 0.4 ka (Table 1) constraining the age of the latter.

Regarding age uncertainties, relatively high uranium concentrations in the aragonite layer (18 - 47 ppm), meant that the dating error was less than 1.2% for the youngest sample (SPL-67). However, dating errors up to +16/-10% were obtained for the oldest aragonite layers (SPL-30 and SPL-60), which ages are close to the upper dating limit of the U-Th dating method. Additionally, relatively low contamination due to detrital thorium is suggested by $^{230}Th/^{232}Th$ ratios that exceeded 500 in the oldest samples and up to 5200 in the youngest aragonite layers. Since $^{230}Th/^{232}Th$ ratios were higher than 100, no correction for non-authigenic thorium was needed (Kaufman et al., 1998), because of the low concentration of detrital thorium.

DISCUSSION

The flowstones found in El Soplao Cave are an example of complex speleothems consisting of alternating layers of carbonate and cemented detrital materials, similar to others described in a variety of caves (Dorale et al., 1992; Sasowsky et al., 2007; Stöll et al., 2008; Dasgupta et al., 2010; Pickering et al., 2010; Ballesteros et al., 2012). In the upper part of the El Soplao’s flowstone, up to 11 layers of clay and silt cemented in a calcite matrix are sandwiched between aragonite layers in just a 7 cm section, followed by several polymetallic oxyhydroxide layers in the upper part of the speleothem.

The U-Th dating of four aragonite layers allows confirmation that the flowstone started growing more than 500 ka ago as the basal aragonite lamina is in secular equilibrium in terms of the U-Th system. This fact is consistent with data reported in previous studies by Rossi et al. (2010) in which stalagmites around 1 Ma old (983 ka, 896 ka, 1016 ka, 1024 ka and 1075 ka with errors of ± 245 ka obtained by U-Pb dating) were found in other parts of the cave, so suggesting that speleothem precipitation in El Soplao cave has occurred at least since the Middle Pleistocene. On the other hand, recent work has identified stalagmites of Holocene age in El Bosque Gallery, near the Pasillo de los Cubos, whose growth extends to the present day (Carcavilla et al., 2011). Consequently, it can be postulated that speleothems, both dripstones and flowstones, have precipitated intermittently in El Soplao cave over the past million years at least. In addition to vadose stages when dripstones and flowstones were generated, there is ample evidence that the cave was partially flooded in repeated occasions.

In fact, before the vadose stage when aragonite laminae began to precipitate in the Pasillo de los Cubos, the cave floor was already covered by a thick layer of fluviokarstic sediments, which underlie the flowstone (Fig. 4A). The granulometry of these sediments corresponds to silts and clays (20 – 200 µm), whilst granulometric gradation has not been observed along the stratigraphic sequence. According to the classification of cave sediments facies proposed by Bosch and White (2004), these materials correspond to the "slackwater facies", characterized by fine- and medium-grained sediments. Slackwater facies are thin layers of fine-grained silt and clay, usually deposited from muddy water, as also described in other caves (Chess et al., 2010; van Hengstum et al., 2011). They are often found in blind side passages, pockets, and other niches in caves that are unlikely to be reached by flowing water. Rising floodwaters fill all available voids, which are then ponded during some periods. While the passage is filled with water, suspended sediments have time to settle down and form a stratified deposit (Bosch and White, 2004).

These kinds of sediments are usually injected into the cave by a water flow coming from outside. In the case of El Soplao cave, sediments entered through the natural cave entrances (Fig. 1C), which in the past were probably at higher altitude and more elevated than the current cave passages, favouring the water and sediments flows into the cave. In fact, the cave's evolution has been controlled by an active fault that surely modified the relative altitude of the cave passage with respect to the main cave entrances in the past.

In the Pasillo de los Cubos, the layers of detrital sediments were covered by aragonite layers (Fig. 4A). Aragonite precipitation occurred mainly around 400 ka. During this period, the cave was under vadose conditions and water films began to flow over the detrital sediments deposited in earlier periods. CO_2 degassing (and probably evaporation) of the solution resulted in precipitation of calcium carbonate as aragonite, a common mineral in dolomite caves like El Soplao. The precipitation of aragonite as flowstone speleothems, however, is not a frequent occurrence (Hill and Forti, 1997), although other cases have recently been described elsewhere (Caddeo et al., 2011). Precipitation of $CaCO_3$ as aragonite is frequently favoured by a high Mg/Ca ratio in the water, a situation in which calcite precipitation is inhibited (Frisia et al., 2002).

Up to eleven flood events alternating with "quiet" periods of carbonate precipitation were repeated between 422 +69/-43 ka and 400 +66/-42 ka in El Soplao Cave. The cave was flooded by muddy water that introduced sediments into the cave (Fig. 4B). When the inflow of water declined, water remained temporally trapped in depressions in the cave as subterranean lakes where suspended clay and silt settled down. CO_2 degassing of pounded water resulted in supersaturation in calcium carbonate, thus a matrix of calcite was precipitated that cemented the silty and clayey materials (Fig. 4C).

It is likely that the Mg/Ca of this underground water pool was lower, compared to that of the water film flowing on the flowstone in previous stages, as a result of paleoflood events. This was conditioned by the limited contact time between the water flow and dolomitic host rock during paleofloods. In such situation of low Mg/Ca ration in the water, the precipitation of calcite nucleation was favoured on aragonite (Frisia et al., 2002). There are no evidences of dissolution or corrosion of the carbonate layers on microscopic scale (Gázquez, 2012). This indicates that the water floods -subsaturated in calcite- were in contact during a short time with aragonite layers precipitated in previous stages. Otherwise, the earlier aragonite laminae would have been corroded by the subsaturated pounded water. In addition, energy flow was low enough for the sediments load deposition.

When the stagnant water disappeared due to evaporation or more probably infiltration to deeper levels in the karst, a further water film flowed over the cemented detrital sediments, so renewing the conditions for aragonite precipitation. During some phases of aragonite precipitation, contributions of water to the flowstone were not exclusively from sheet flows but also came from dripwater from the cave ceiling impacting the speleothem surface. In this situation, aragonite stalagmites formed on the calcareous pavement (Fig. 4D). When the dripping slowed, a water film traversing the flowstone was again dominant over dripwater from the ceiling. Thus, emergent stalagmites that had begun to grow on the flowstone were fossilized inside new deposits of aragonite (Fig. 4E). Subaerial periods, in which aragonite was precipitated were repeatedly interrupted by flood events, when detrital sediments were introduced into the cave, as revealed by the presence of thin brownish layers interbedded in the aragonite lamina up to the 6.6 cm level of the flowstone (Fig. 3). Regarding the uncertainties of the U/Th age of this relatively old speleothems, we can only assert that sediments were introduced into the cave due to extreme rainfall events that took place between MIS 11 and MIS 9. This period comprised major paleoclimatic changes, including two interglacials and one glacial stage. Therefore, it is not possible to attribute the occurrence of paleofloods in El Soplao Cave to specific climatic conditions but to extreme rainfall events, which occurred repeatedly in an unknown climatic framework.

Bluish-black layers appear in the upper strata of the flowstone which EDX analysis (Gázquez et al., 2011; Gázquez, 2012) revealed to be oxides of Fe-Mn-Zn, similar to those found in ferromanganese crusts near the Campamento Gallery (Gázquez et al., 2011). The precipitation of these metal oxides in the El Soplao Cave is related to the mobilization of metals (Fe, Mn and Zn) from the host rock probably under phreatic anaerobic conditions (Fig. 4F) and their subsequent precipitation on the walls and floors of the cave as oxides when the water table fell and conditions were again oxygenic (Fig. 4G). In particular, the ferromanganese layers appear on clayey sediment covering the ceiling of the Campamento Gallery (Fig. 2C).

The existence of this black crust indicates that the water table was present at that cave level in the past. Oxidation of Mn and Fe could be mediated by microorganisms (as suggested by the presence of fossil bacteria inside ferromanganese stromatolites recently discovered in this cave by Rossi et al., 2010). Although the dark layers observed in the upper strata of the flowstone are younger than 358 ka, precipitation of ferromanganese oxyhydroxides occurred in El Soplao Cave also before 1 Ma BP (the age of the stromatolite studied by Rossi et al., 2010) and these are crowned by carbonate stalagmites with ages around 900 - 1000 ka. This suggests that El Soplao Cave has remained hydrodynamically active, with alternating vadose and phreatic/epiphreatic periods for at least the past 1 Ma.

After the period of metal oxide deposition in the Pasillo de los Cubos, conditions for aragonite precipitation were renewed and new carbonate laminae were precipitated, in this case fossilizing the dark layers. Conditions could be phreatic/epiphreatic until at least 33 ka, when a further layer of aragonite was precipitated, as recorded in the flowstone (Fig. 4H). In the period between 358 and 33 ka the evolution of the speleothem is uncertain. Most probably, precipitation of carbonate layers alternated with flood events that deposited additional clastic sediments. However, these materials could have been eroded and remobilized by turbulent flows, thus removing some of the paleoclimatic information recorded in the speleothem. This hypothesis is strongly supported by evidence of stream erosion in the cave notches in the lower parts of the cave walls and hanging flowstones (Jiménez-Sánchez et al., 2011), similar to the flowstone studied in the current work. Suspended flowstones appear in several locations in the cave, like in the Organ Chamber (Sala del Órgano) (Fig. 2B). In the False Floor Chamber (Fig. 2F) a stalagmite pavement hangs 3 metres above the cave floor as a result of the erosion of a thick deposit of detrital sediments below it.

Finally, muddy coatings frequently cover older speleothems and the cave walls. For instance, in the Campamento Gallery the height of the mud lamina is easily identified on older speleothems (Fig, 2E, G and H), though the absence of mud coatings on younger speleothems (Fig. 2E and H) suggests that flood events did not occur in recent periods.

CONCLUSIONS AND PALEOENVIRONMENTAL IMPLICATIONS

Detrital sediments are introduced into caves due to extreme rainfall events, and then are mobilized or stored depending on the particle size, the velocity of the stream flow and the characteristics of the cave passages. If after paleofloods “quite” vadose conditions take place during a long period, fluviokarstic sediments can be covered by chemically precipitated sediments in the form of flowstones or stalagmites. In cases, speleothemic carbonate layers prevent older detrital sediments from being eroded by further energetic water flows.

In the present paper, we have demonstrated that dating carbonate layers deposited over detrital sediments represents an alternative to direct dating of clayey materials. In particular, a flowstone comprising aragonite and cemented detrital layers from El Soplao Cave (Cantabria, northern Spain) was dated using the U/Th method, revealing that this speleothem was intermittently formed during the Quaternary, and sediments introduced into the cave mainly around 491-358 ka. Remarkably, this flowstone represents one of the few sedimentary records of the period comprised between MIS 11 and MIS 9 discovered in the

Cantabrian Mountains to date (Villa et al., 2013), in particular by studying cave sediments, and if so it might yield valuable paleoclimate information.

Further geochemical analyses, including stable isotopes and trace element analysis together with a more precise geochronology of detrital sediments in caves, could provide more details about the climatic framework in which subterraneous paleofloods took place, not only in El Soplao Cave but also in other cavities where detrital materials interlayered between laminae of speleothemic carbonate have been found.

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Sample ID	**Distance from base (mm)**	**^{238}U (ppb)**	**^{234}U/^{238}U**	**^{230}Th/^{232}Th**	**^{230}Th/^{234}U**	**Age (yrs)**	**σ + (yrs)**	**σ – (yrs)**
SPL-00	1	47,490 ± 161	1.129 ± 0005	459 ± 6	1.058 ± 0.010	> 500.000*	-	-
SPL-30	30	34,578 ± 206	1.136 ± 0.004	1155 ± 13	0.261 ± 0.002	421.847	69.835	42.886
SPL-60	60	41,315 ± 285	1.111 ± 0.012	4593 ± 47	1.011 ± 0.011	400.315	66.331	41.975
SPL-67	67	18,211 ± 60	1.148 ± 0.010	5188 ± 57	1.027 ± 0.010	32.671	369	367

Table 1. Uranium concentration, measured U and Th activity ratios and ages of subsamples from the flowstone of Pasillo de los Cubos. *The age of sample SPL-00 was beyond the threshold of the U-Th method.