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PRESENT-DAY ENVIRONMENTAL DYNAMICS IN ICE CAVE A294, CENTRAL PYRENEES, SPAIN

ABSTRACT: BELMONTE-RIBAS A., SANCHO C., MORENO A., LOPEZ-MARTINEZ J. & BARTOLOME M., *Present-day environmental dynamics in ice cave A294, Central Pyrenees, Spain.* (IT ISSN 0391-9838, 2014).

Several ice caves have been discovered in the Pyrenees. Among them, cave A294 hosts one of the most interesting ice deposits, which is mainly composed of firn ice. This paper investigates the present-day climate dynamics and the isotopic composition of precipitation, dripping water and ramp snow) to evaluate the palaeoclimatic potential of the ice cave deposit. The cave experiences a chimney effect during the winter but acts as a thermal trap during the summer. Four climate phases with mean annual temperatures ranging from –0.77 to 0.26ºC have been interpreted along the year. At present-day conditions, even though some congelation ice forms annually, the ice has a negative mass balance with an annual ice loss of ca. 12 m^3 that mainly affects the walls of the ice deposit. The seasonal variability of the stable isotopic ($\delta^{18}O$ and δD) composition of dripping water and ramp snow has a smaller amplitude compared to that of the precipitation (rain and snow). The data show a good correlation ($r^2=0.94$) and match the Global Meteoric Water Line. We hypothesise that the metamorphosis of snow into ice causes no significant postdepositional alteration, and thus the ice from cave A294 may be used as a reliable palaeoclimatic archive. Given the reduced volume of ice deposits in the region and their rapid melting, it is extremely urgent to study the ice record in cave A294.

KEY WORDS: Ice cave, Environmental conditions, Precipitation isotopes, Palaeoclimatic potential, Central Pyrenees.

RESUMEN: BELMONTE-RIBAS A., SANCHO C., MORENO A., LOPEZ-MARTINEZ J. & BARTOLOME M., *Dinámica ambiental actual en la cueva helada A294, Pirineo Central, España.* (IT ISSN 0391-9838, 2014).

Numerosas cuevas heladas han sido descubiertas en el Pirineo. Entre ellas, la cavidad A294 aloja uno de los depósitos de hielo más interesantes, formado principalmente por hielo de neviza. Este artículo investiga la dinámica climática actual en la cavidad y la composición isotópica de precipitaciones, agua de goteo y nieve de la rampa a fin de evaluar el potencial paleoclimático del depósito de hielo de la cueva.

La cavidad muestra un efecto chimenea durante el invierno pero actúa como una trampa térmica en verano. A lo largo del año se han detectado cuatro fases climáticas, con temperaturas medias anuales que van de los –0,77 a los 0,26ºC. En las condiciones actuales, y aunque se forma anualmente algo de hielo de congelación, el hielo muestra un balance de masa negativo con una pérdida anual de unos 12 m^3 que afecta sobre todo a la pared del depósito de hielo. La variabilidad estacional de la composición en isótopos estables ($\delta^{18}O$ y δD) del agua de goteo y nieve de la rampa tiene una amplitud menor que la de las precipitaciones (lluvia y nieve). El conjunto de los datos muestra una buena correlación ($r^2=0.94$) y concuerda con la Línea Meteórica Global. La hipótesis planteada es que la transformación de nieve en hielo no provoca una alteración postdeposicional significativa y, por tanto, el hielo de la cueva A294 puede usarse como un archivo paleoclimático fiable. Dado el reducido volumen de los depósitos de hielo en la zona, y su rápida fusión, es extremadamente urgente estudiar el registro de hielo de la cavidad A294.

PALABRAS CLAVE: Cueva helada, Condiciones ambientales, Isótopos de precipitaciones, Potencial paleoclimático, Pirineo central.

INTRODUCTION

The occurrence of ice caves in the Pyrenees, especially on the Spanish side of the mountains, has been recognised for several decades. However, geologists have paid little

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attention to the ice caves, and their current environmental conditions, the origin of the ice and palaeoclimatic information remain unknown.

One of the main Pyrenean morphostructural units, the Internal Range, contains limestones with ages ranging from Upper Cretaceous to Eocene. These units are up to ~2 km thick due to complex thrust sheet tectonics caused by the Alpine orogeny (Muñoz, 2002).

The Internal Range reaches elevations greater than 2000 m a.s.l., and parts of the range extend above 3000 m. An example is the Tres Sorores massif, also called the Monte Perdido massif, which at 3355 m a.s.l. is one of the highest calcareous massifs in Western Europe. The presence of karstified limestone massifs at high elevations favours the existence of ice deposits inside many high mountain caves in the Pyrenees (López-Martínez & Freixes, 1989).

Ice caves in the Tres Sorores massif have received the attention of cavers since the visit of Norbert Casteret at Espluca Negra (Casteret cave) in 1926 (Casteret, 1946). Inventories of ice caves in this massif (Bernand & van Thienen, 1987), as well as speleological descriptions (St. Pierre, 2007), are available. No work has been performed on other massifs such as Cotiella or Tendeñera, which also host subsurface ice deposits.

One of the main interests in these type of caves is their potential as palaeoclimatic archives (e.g. Holmlund & *alii*, 2005; Stoffel & *alii*, 2009; Feurdean & *alii*, 2011) because information can be extracted from the stable isotopes of the ice or the pollen trapped in the ice. Chronological control of the ice deposits is essential for placing the palaeoenvironmental information into a temporal framework.

Systematic research on the ice caves in the Central-Southern Pyrenees is now being performed, and preliminary results have been presented (Sancho & *alii*, 2012). This study contributes to the knowledge of the present-day dynamics by examining the environmental parameters, the ice formation and the evolution of ice volume in ice cave A294, one of the most outstanding ice caves in the Spanish Pyrenees.

CAVE SETTING

Cave A294 (UTM coord. 31T 0281171/4710349, 2238 m a.s.l.) is located within the Armeña cirque (Cotiella massif, Spanish Central Pyrenees, Huesca province) and is surrounded by summits greater than 2500 m a.s.l. (Cotiella peak, 2912 m) (fig. 1).

The area is situated in the Pyrenean climatic transition zone between the influences of the Atlantic Ocean and the Mediterranean Sea. Thus, the climate is perimediterranean. Snow usually falls from October to May, and the ground is covered by snow from November to May. Temperature and rainfall data from the area are shown in table 1.

The Cotiella massif is part of the Central South Pyrenean Unit (Seguret, 1972), which is mainly composed of Upper Cretaceous limestones that form a thrust sheet over Cretaceous to Eocene carbonate rocks and Eocene marls (fig. 2). Armeña is a former glacial cirque; however, karstic and periglacial processes are currently dominant in the

TABLE 1 - Climatic data in the area of Seira village (817 m a.s.l.), A294 cave (2238 m a.s.l.) and Cotiella peak (2912 m a.s.l.). MAT: mean annual temperature; Tjfm: mean winter temperature; Tjas: mean summer temperature

	SEIRA	A294	COTIELLA
MAT (°C)	9.9	1.5	-2.7
Tjfm (°C)	3.4	-5	-9.2
Tjas (°C)	17.92	9.5	5.3
Rainfall (mm/yr)	1086.2	1688	1950

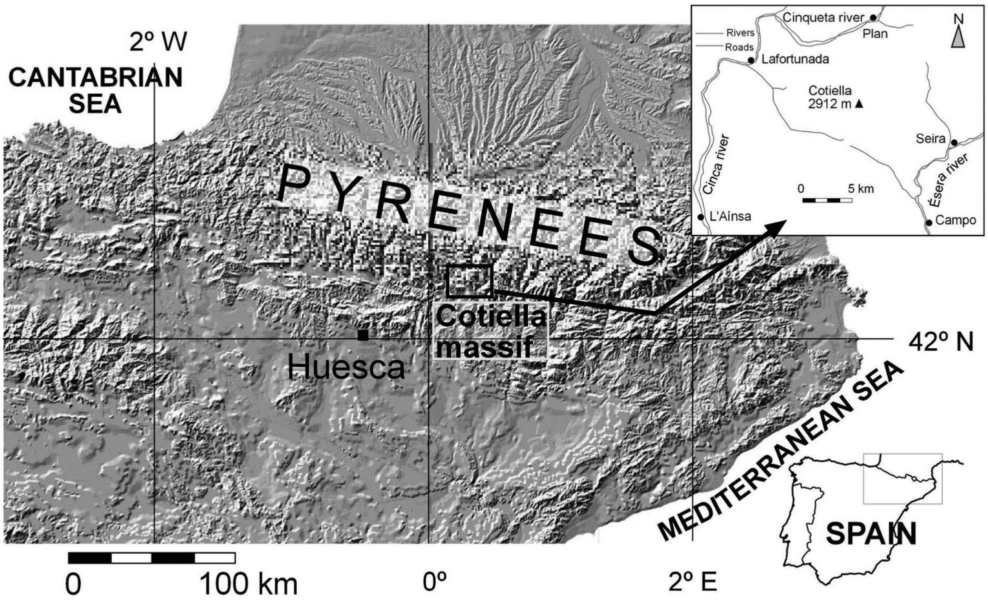


FIG. 1 - Location of Cotiella massif within the Spanish Pyrenees.

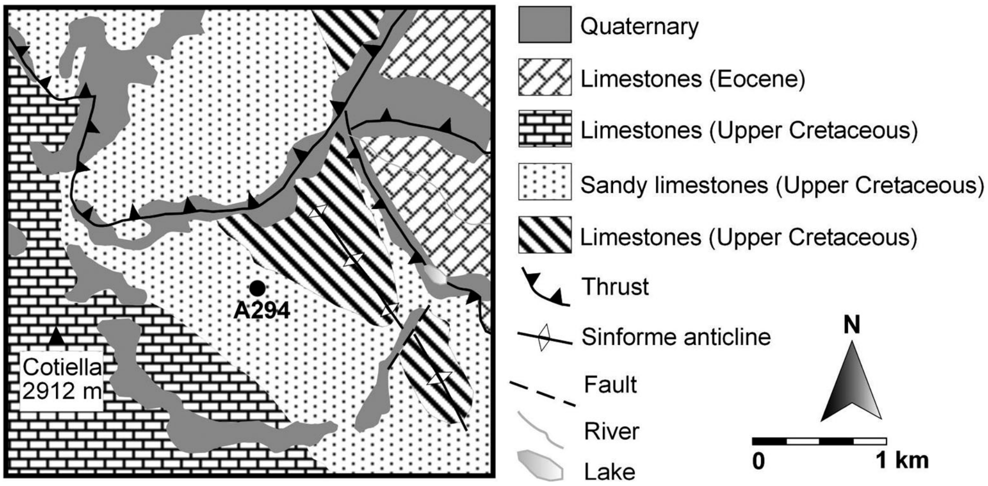


FIG. 2 - Geological map of the study area Armeña cirque and location of A294 ice cave.

area. An active rock glacier and a cave network more than 8 km long and 600 m deep are among the most significant geomorphological features in the region.

Cave A294 is not the only ice cave in the cirque but is the largest. It houses an ice deposit with a volume of nearly 250 m^3 in a complex glacio-karstic setting (fig. 3). Two types of ice are present inside cave A294. Most of the ice accumulation is firn ice. Snow is blown directly into the cave by the wind through the cave's wide entrance. The internal structure of the ice deposit contains aeolian bedforms (fig. 4), which reflect the effect of the wind. In addition, some congelation ice related to the input of dripping water is present. This ice does not play an important role in building the ice deposit because it is restricted to the areas below several drip points. A snow ramp connects the large entrance to the top of the ice deposit. An ice wall (ca. 10 m high) represents the northeastern limit of the ice deposit (fig. 3). Seasonal ice speleothems and a well-developed protalus rampart are also present in the cave.

METHODS

To determine the environmental conditions of ice cave A294, four Hobo Pro v2 U23-001 temperature/relative humidity (T/RH) data loggers were installed in July 2009 (CHC1 to 4), and two additional data loggers were installed in October 2010 (CHC5 and 6). Loggers 1, 2, 5 and 6 are located an average of 30 cm above the ground or the ice. In addition, an external meteorological station was installed outside the cave in June 2011. All of the equipment is operating currently. The locations of the data loggers are shown in figure 5.

Temperature is measured at an accuracy of ±0.21°C and a resolution of 0.02°C at 0°C. The drift is less than 0.1°C per year. Relative humidity is measured at an accuracy of ±2.5% from 10% to 90% and a resolution of 0.03%. The drift is less than 1% per year. The outside temperature is recorded by an EL-USB-1 data logger at an accuracy of ±1°C and a resolution of 0.5°C. Data are recorded hourly inside and outside the cave.

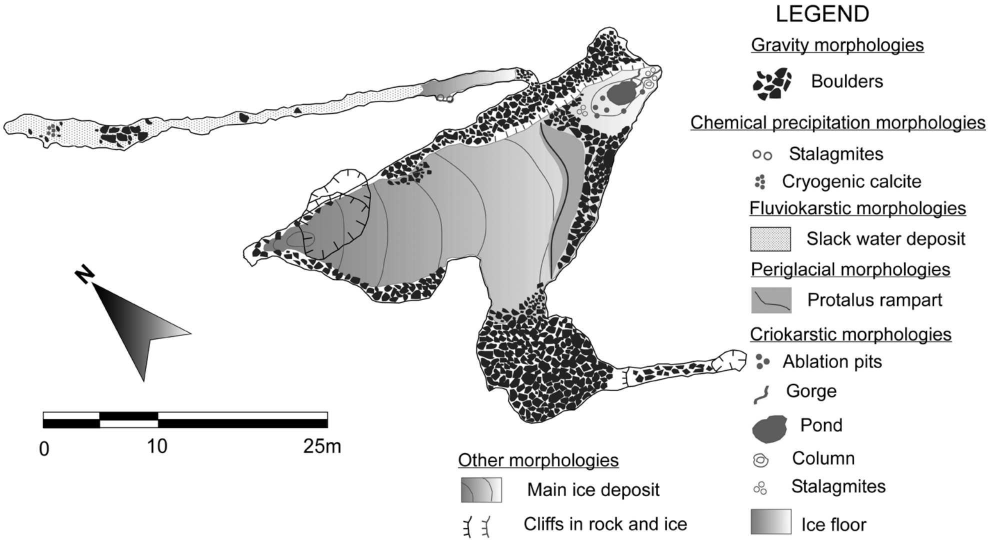


FIG. 3 - Geomorphological map of A294 ice cave.

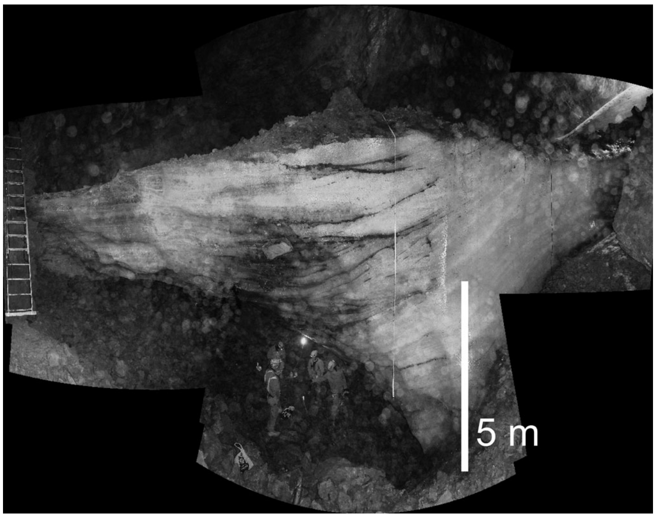


FIG. 4 - Photomontage of ice deposit in A294 ice cave.

Water and snow have been sampled for isotopic analysis since October 2011. Precipitation from every rainfall event was sampled in the village of Plan (1100 m a.s.l.), while snow was sampled in the area between Plan and cave A294 after several snow events during the winter. The snow from the cave ramp and drip water was also sampled in the summer of 2011. All the samples were stored at cold temperatures and analysed for their stable isotope composition in the laboratories of the Universidad Autónoma de Madrid. The $\delta^{18}O$ was analysed in a GasBench Thermo coupled in continuous flow to a Thermo Delta V Advantage IRMS (Isotope Ratio Mass Spectrometer). The δD was analysed by pyrolysis in an EA Thermo 1112 HT (Elemental Analyser) coupled in continuous flow to a Thermo Delta V Advantage IRMS. The data are expressed as ‰ relative to V-SMOW for δD and $\delta^{18}O$. The standard deviations of the analysis are 0.6‰ for δD and 0.07‰ for $\delta^{18}O$.

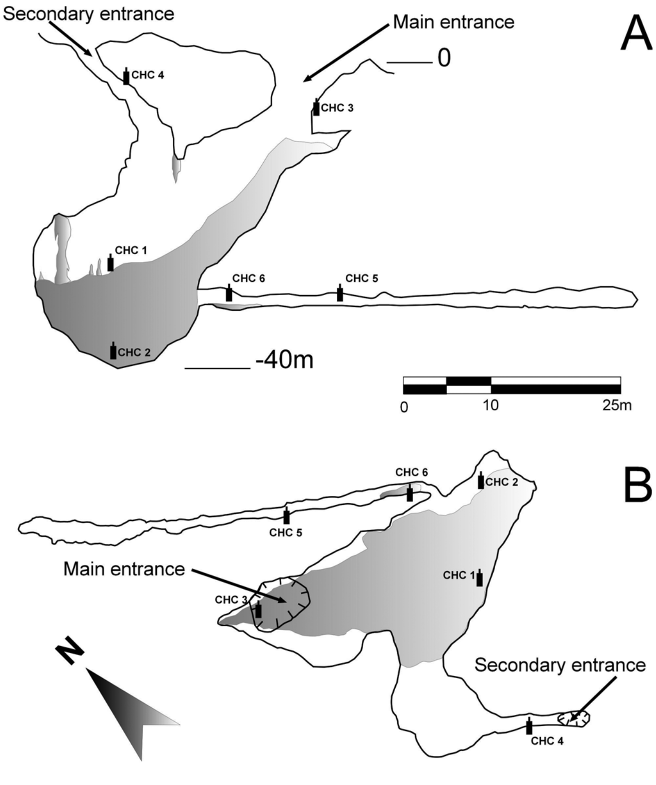


FIG. 5 - Idealized cross section (A) and plan view (B) of A294 ice cave. Position of data loggers is indicated (CHC1 to 6).

In addition, the ice cave volume was periodically monitored by older pictures, visual references between the ice and the cave walls and by screw markers.

RESULTS AND DISCUSSION

ENVIRONMENTAL PARAMETERS

– *External and internal climate relationships*

A comparison between the external and internal temperatures (fig. 6) reveals different behaviour of the cave's climate during distinct periods along the year.

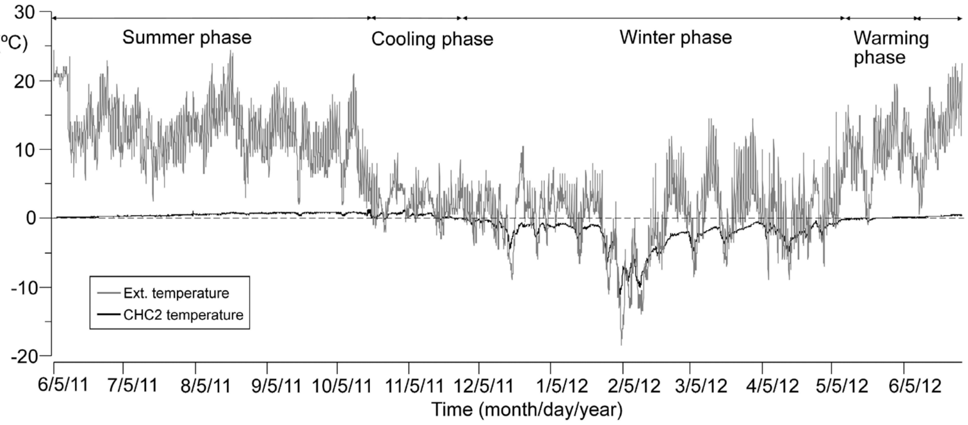
Summer phase. This stage extends from June to October, though these dates can vary from year to year. During this phase, there is no connection between the outside atmosphere and the cave atmosphere, so we describe this as a closed period. While the external temperature increase as high as to 25ºC, the temperatures in the cave remain constant at slightly above 0ºC. Oscillations in the outside air temperature are not correlated to the temperature in the cave. With no air flow from outside, the factors that control the increase of temperature during this phase are water, both dripping and flowing directly through the entrance (Badino, 2010; Perşoiu & *alii*, 2011a), geothermal heat and the melting of ice.

Winter phase. The temperatures from November to May are consistently below 0ºC. Only small variations were observed from the yearly conditions. This period shows a close relationship between the external and cave conditions. All the temperature changes inside and outside the cave occur in phase, so this period may be considered an open circulation regime. It begins with a strong density-driven influx of cold air that sinks into the cave, reduces the cave temperature to below 0ºC and prevents the temperature from recovering. At the end of this phase, water input from dripping snowmelt and rainfall, as well as the end of the inflow of cold air, progressively warm the cave. The temperatures recorded at the limit of the entrance shaft (logger 3) and in the cave (logger 2) are highly correlated (r^2=0.87) during this phase.

Two additional short phases may also be defined.

Cooling phase. The transition between the summer and winter phases corresponds to the period when the decreasing outside temperature begins to be reflected in the inside temperatures. First, cold air begins to enter the cave, but subsequent temperature changes influence the cave as well. The first negative temperatures outside and inside

FIG. 6 - One year's temperature record outside A294 ice cave and inside (CHC2 data logger). Different phases defined are indicated.



the cave are registered during this phase but are not permanent; thus, periglacial conditions are established in this phase. The cooling phase usually lasts from October to November.

Warming phase. This phase represents the beginning of the disconnected behaviour between the inside and outside conditions. Although a clear increase in the external temperature is observed, the temperature inside the cave remains at approximately 0ºC. This period extends from May to June.

Ice cave A294 has two entrances. The main entrance is a large shaft, and the secondary entrance is a smaller trench. They are located at the same elevation (fig. 5A). However, even though the external conditions are the same at both entrances, several differences are found in the air temperature data (fig. 7). CHC4, which is located in the trench, records less extreme temperatures with lower amplitudes, and the air is warmer for most of the year. These characteristics suggest an air circulation pattern in which the larger entrance is the main access for cold air into the cave, while the secondary trench acts as the exit for warmer air pushed out by the incoming cold air (fig. 8A). When closed conditions prevail in the cave, these differences are reduced considerably or disappear, and both loggers display similar behaviour. Thus, the cave experiences a chimney effect during the winter season, in which the cave is connected to the external atmosphere. In the summer, however, the chimney effect reverses, and the cave acts like a thermal trap. A similar pattern has been described in other ice caves, such as Monlési in Switzerland (Luetscher & Jeannin, 2004a; Luetscher & *alii*, 2008) and Focul Viu in Romania (Perşoiu & *alii*, 2007). This behaviour classifies cave A294 as a statodynamic ice cave (Luetscher & Jeannin, 2004b).

– *Internal climate variability*

While data loggers CHC3 and 4 are strongly influenced by external conditions due to their locations, the other data loggers properly reflect the climate conditions inside the cave. Table 2 and figure 8B show temperature data from 2011-12 and the different phases for the four inner loggers.

The most distant area from the entrance (location of CHC5) has a lower amplitude of temperatures compared with the loggers in the chamber (CHC1 and 2). This area, which is far from the main ice body and from outside influences, reaches the highest temperatures and has the shortest winter phase, maintaining frozen conditions for only one to one and a half month per year. The onset of

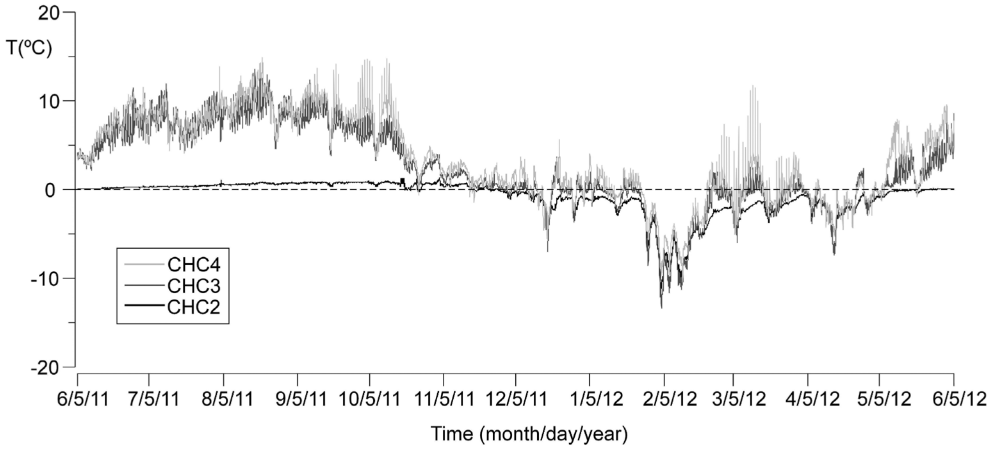


FIG. 7 - Comparison between annual temperature in CHC3 and CHC4 data loggers. CHC2 record has been included to compare with the internal temperature conditions. See fig. 5 for location of data loggers.

TABLE 2 - Extreme and mean temperatures (in ºC) of interior data loggers in A294 ice cave during a year (2011-2012) and split in the four different phases

		CHC1	CHC2	CHC5	CHC6
2011-2012	Min.	-8.43	-11.146	-4.408	-7.477
	Max.	1.588	1.453	1.588	0.77
	Range	10.018	12.599	5.996	8.247
	Mean	-0.42	-0.776	0.268	-0.606
Summer	Min.	0.004	0.004	0.004	0.024
	Max.	1.558	1.344	1.588	0.77
	Range	1.554	1.34	1.584	0.746
	Mean	0.779	0.584	0.944	0.353
Cooling	Min.	-0.535	-0.283	-0.732	-0.507
	Max.	0.079	1.453	0.715	0.605
	Range	0.614	1.736	1.447	1.112
	Mean	-0.098	0.399	-0.012	0.221
Winter	Min.	-8.43	-11.146	-4.408	-7.477
	Max.	-0.004	-0.024	0	-0.004
	Range	-8.39	-11.122	4.408	-7.473
	Mean	-1.68	-2.221	-1.314	-1.428
Warming	Min.	–	-0.563	-1.842	-0.004
	Max.	–	0.051	0.163	0.051
	Range	–	0.614	2.005	0.055
	Mean	–	-0.129	-0.469	0.007

winter conditions can be delayed by as much as two months compared to CHC2. Early ablation in the area may be related to the distance from the ice body, the external air flow and heat transmitted by conduction from the rock (Luetscher & *alii*, 2008).

The winter phase in logger CHC6 is synchronised with CHC2. The conditions are uniform and similar in these two locations, but CHC6 has a longer winter phase, less extreme temperatures and smaller oscillations during the year.

The data from loggers CHC1 and 2 are very similar. CHC2 records slightly colder conditions because it is located at the bottom of the cave and near the large ice body, which decreases the temperatures and maintains the cold conditions.

EVOLUTION OF THE ICE VOLUME

Currently, snow is not being transformed into firn ice, so we can consider the ice in the cave as a fossil deposit. The snow that falls during the winter does not extend deep into the cave, and snow only reaches the ridge of the protalus rampart at the end of the humid winters (fig. 9). Snow deposited during the winter melts and exposes the ice from the ramp, which suggests a zero or negative mass balance.

However, the conditions in the cave during part of the year are suitable for the formation of congelation ice. Ice stalagmites 1 m long and ice lens 20 cm thick develop during winter. This process requires the input of water and temperatures below zero (Perşoiu, 2004; Mavlyudov, 2008; Luetscher, 2013). The air T and RH data (fig. 10) indicate that winter is not the ideal season for ice formation because the cold sinking air dries the cave atmosphere. Only some events at the beginning or, mainly, at the end of the winter phase are favourable for ice formation. In this case, the water input is related to snow melting in the early spring.

Conditions that are more suitable for the formation of congelation ice are present at the end of the winter phase and during the warming phase. Logger CHC1 shows a short period of less than one month in which all the ice speleothems form over the ice deposit. The ideal conditions last longer in the area of CHC6, but water availability is reduced because of the greater rock thickness above the gallery (a phreatic conduit) where CHC6 is located and because drip points are scarce. This results in the formation of two sets of ice stalagmites over the ice deposit

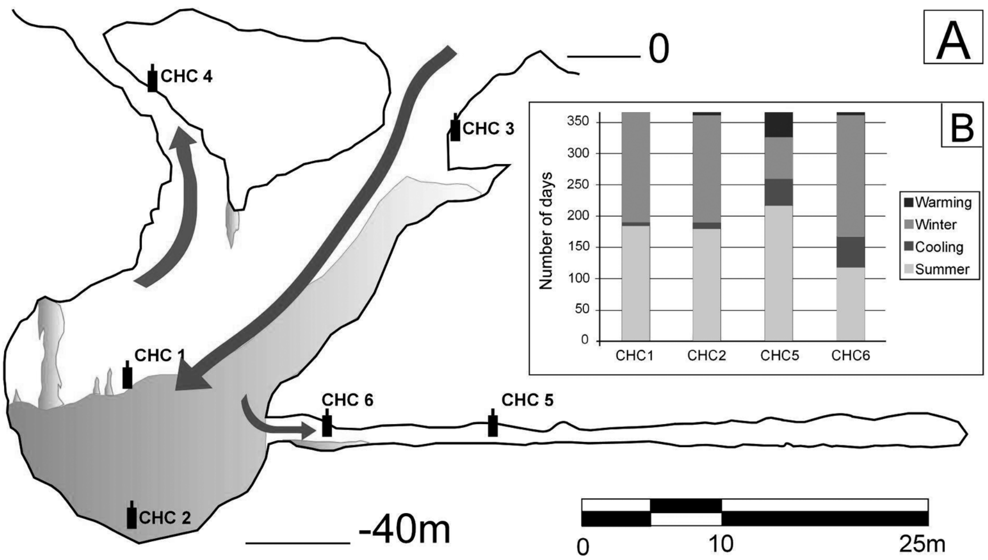


FIG. 8 - Air circulation pattern during winter phase (A) and length of the different phases defined in A294 ice cave during a year record as Recorded by different temperature sensors (2011-2012) (B).

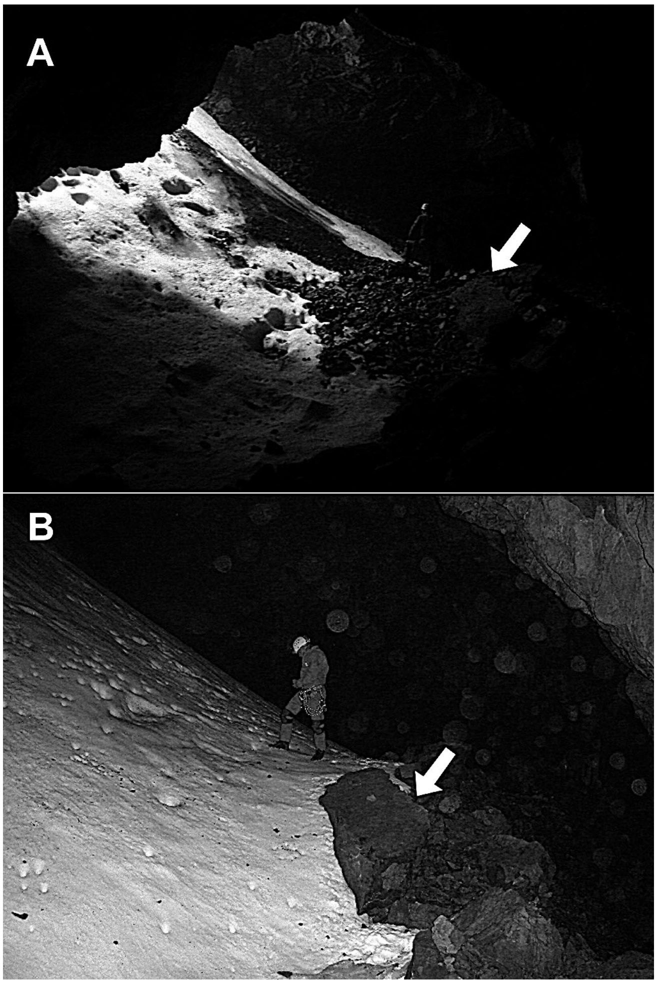


FIG. 9 - Changes in snow cover in the ramp connecting the entrance shaft and the top of the ice deposit. A: Summer of 2008, B: Summer of 2009. White arrow points the same rock block for reference.

(and, sporadically, a large ice column), while only a thin ice pavement forms in the conduit (fig. 3). No congelation ice forms near the base of the main ice deposit.

No significant ice forms near data logger CHC5. The mean annual temperature is greater than 0°C (table 2). The summer phase is much too long (fig. 8B), and the period where water is available while the temperatures are below zero is rather short. It is worth noting that a small number of cryogenic cave pearls is present below a water outlet in the ceiling of the phreatic tube, indicating that seasonal freezing occurs even in this part of the cave.

Ablation conditions prevail during most of the year. Despite the cold temperatures, dry air may cause some sublimation over the ice wall during the winter. The scallops observed on the wall (fig. 4) evidence this process. The long summer phase, during which the temperatures reach 1.58°C, causes melting not only of the speleothems but also of some areas of the ice wall, contributing to the dramatic retreat of this wall (7.35 m over the last 34 years; R. Queraltó, personal communication). No ice loss was observed along the contact between the rock wall and the ice deposit.

Measurements taken over the last three years by using ice screws and laser distanciometers, indicate a mean retreat along the ice wall of 25 cm/yr, which is equivalent to a yearly ice loss of ca. 12.5 m^3. The rate of retreat is similar to that over the last 34 years. There is also considerable variation in the snow content (fig. 9). The evolution of the ice in the cave is similar to that described for most ice caves around the world (Kern & *alii*, 2008; Kern & Perşoiu, 2013).

The thick debris cover on top of the deposit preserves it from ablation. Ice formation and ablation are balanced in the area of the congelation ice except for the inner part of the cave, where a pond forms every year from the dripping and melting water. The gorge-shaped drainage of this pond is other factor that influences the melting of the distal part of the ice deposit.

ISOTOPIC DATA

Establishing the way that external climate signals are transferred into the cave is the first step towards using the ice cave as a palaeoclimatic indicator (Perşoiu & *alii*, 2011b). In this sense, it is important to determine the relationship between the isotopic composition of the water inputs and that of the ice deposit (Kern & *alii*, 2009). Thus, rain, snow, dripping water and snow from the ramp that connects the entrance to the top of the ice deposit were sampled for isotopic analysis.

The basic isotopic characteristics of the Studied elements are shown in table 3. The ranges of variation are quite different and represent rain fall and snow fall at one extreme and drip and ramp snow on the other. The difference between the maximum and minimum are higher for the former. This may reflect different sources of precipitation in this part of the Pyrenees, where fronts from both the Atlantic and the Mediterranean are common, as well as the influence of air temperature and the amount of precipitation.

However, the ramp snow and dripping water show less variability than the precipitation and thus have a smaller

Table 3. Average values of $\delta^{18}O$ and δD of rain, snow, drip and ramp snow for the studied period. σ: standard deviation

	$\delta^{18}O$ (‰ VSMOW)				
	Minimum	**Maximum**	**Range**	**Mean**	**σ**
Rain	–13.15	–6.34	6.81	–10.18	2.71
Snow	–16.06	–7.57	8.49	–13.08	4.78
Ramp snow	–9.66	–5.33	4.33	–7.5	2.17
Drip	–9.1	–8.56	0.54	–8.87	0.28
	δD (‰ VSMOW)				
	Minimum	**Maximum**	**Range**	**Mean**	**σ**
Rain	–116.83	–41.64	75.19	–78.8	31.13
Snow	–120.99	–66.5	54.49	–102.9	24.99
Ramp snow	–70.34	–36.4	33.94	–53.44	16.7
Drip	–61.68	–56.35	5.33	–59.31	2.71

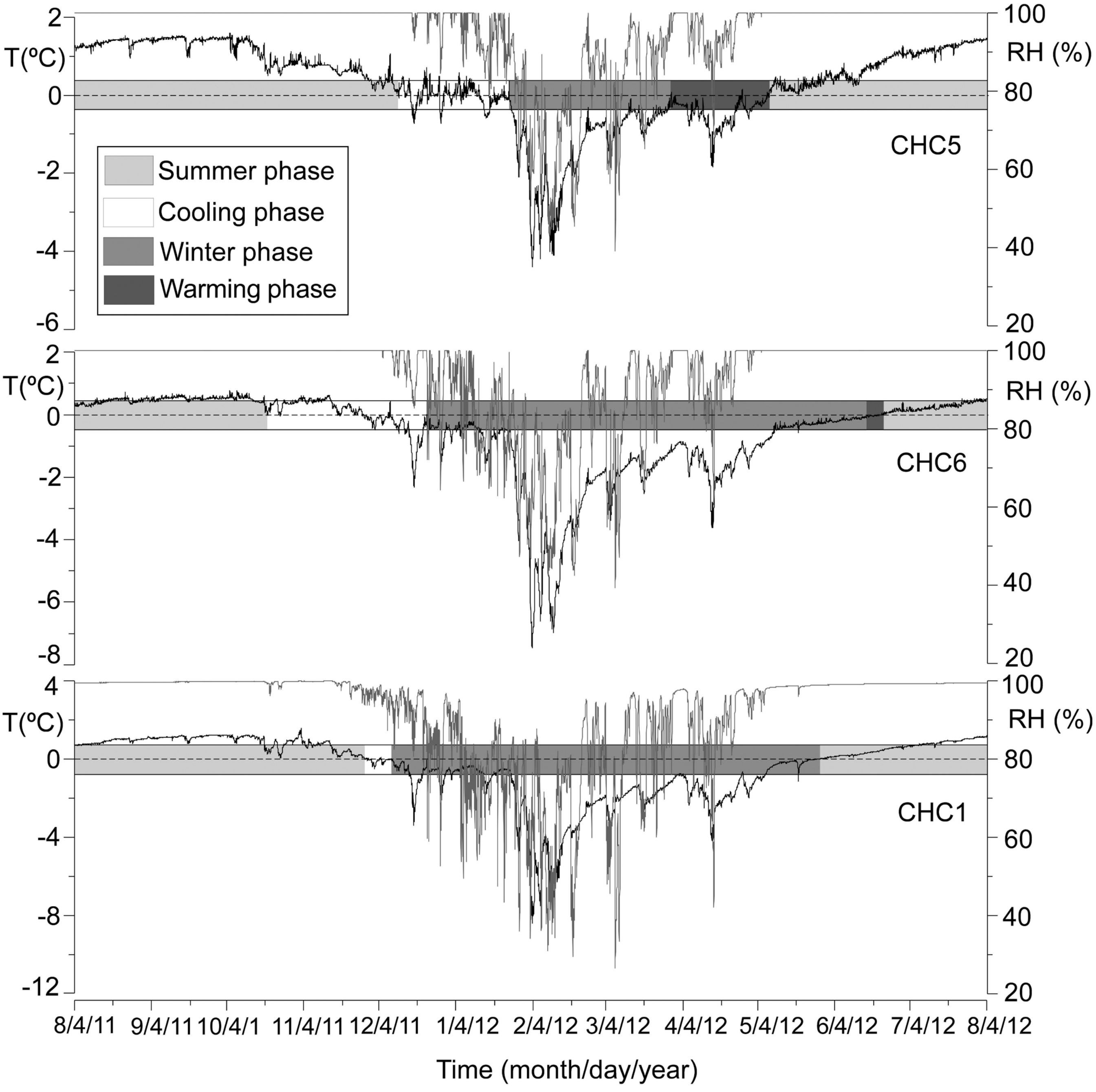


FIG. 10 - Temperature and relative humidity record during a year (2011-2012) in A294 ice cave. The different climatic phases have been marked.

standard deviation. The main recharge of water in the epikarst occurs in the spring, when melting snow and large rainfalls occur in the area. Therefore, the isotopic signal of the drip water most likely indicates the mixture of these waters, leading to a subsequent homogenisation of their isotopic compositions. This has also been observed in monitoring studies conducted in other caves (Mattey & *alii*, 2008).

The local meteoric water line (LMWL) from rainfall and snowfall in the study area is very similar to the Global Meteoric Water Line (GMWL) proposed by Craig (1961). The values of drip and ramp snow also agree well with the LMWL, which suggests negligible changes between the external and internal signals (fig. 11). This is important because the ramp snow had been inside the cave for at least four months since the last noticeable snowfall occurred. The ramp snow shows firn features that represent an early stage of the transformation to ice. The water necessary to activate this change most likely comes from dripping (Bini & Pellegrini, 1998). Due to the fact that the isotopic signal

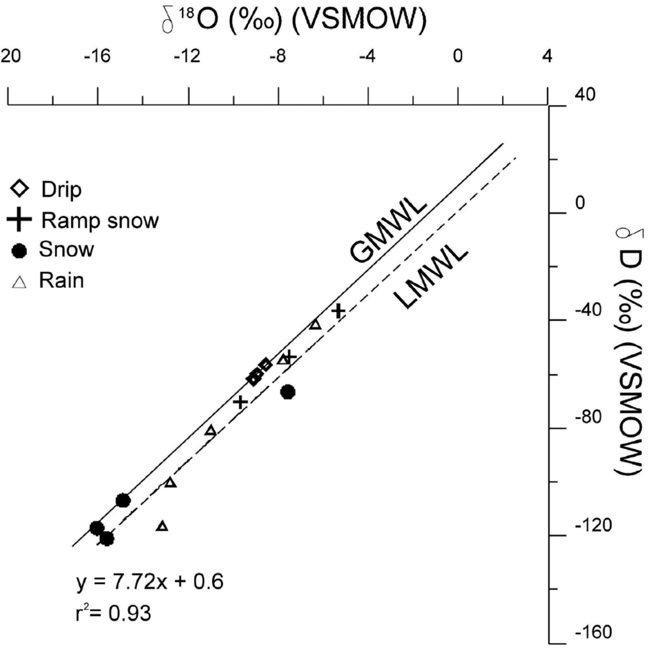


FIG. 11 - Stable isotope data of rain and snow in the study area and resulting Local Meoteoric Water Line (LMWL) (dashed line). Isotopic data of drip and ramp snow in A294 ice cave are superimposed. Global Meteoric Water Line (GMWL) is also drawn.

of precipitation, dripping water and ramp snow-firn ice is constant we hypothesise that the behaviour of the ramp snow isotopes indicates that no fractionation occurs during the formation of firn ice. Thus, the isotopic composition of the A294 ice deposits could be used as a palaeoclimatic indicator in future studies.

CONCLUSIONS

Ice cave A294 (Cotiella massif, Spanish Pyrenees) contains an ice deposit with a volume of ca. 250 m^3 that is composed mainly of firn ice. Some congelation ice is present in the most distal part of the cave.

Temperature and relative humidity data collected throughout a complete annual cycle define four phases of the year with distinct relationships between the climatic conditions inside and outside the cave. Open conditions occur in the winter phase, and the cave experiences a chimney effect, but the connection is closed in the summer phase, and the cave acts as a thermal trap. Therefore, A294 is a statodynamic ice cave.

Firn ice does not form at present-day conditions, but congelation ice forms in the area of the cave where water drips from the ceiling. Melting prevails for several months along the ice wall. The debris cover prevents the top of the deposit from melting, and no appreciable fusion occurs at the contact between the rock wall and the ice. The average melting rate is approximately 12 m^3/yr. Given the reduced size of the ice block and its rapid melting, it will disappear in ca. 20 years. This makes a study of the ice block extremely urgent.

An initial analysis of the stable isotopes (δ^{18}O and δD) in the precipitation (rain and snow), drip water and ramp snow-firn ice showed a very good correlation with the GMWL. The data suggest that the transformation process from snow precipitation to ramp snow-firn ice in the cave does not cause any detectable alteration in the isotopic character. Therefore, the ice deposit could be used as a palaeoenvironmental indicator.

The next step of study should be directed to complete the isotopic analysis of the rain, snow and drip and extend the analysis to the ice deposit to confirm this hypothesis. Additional chronological control is required to validate this deposit as an archive of past Pyrenean climate conditions.

REFERENCES

Badino G. (2010) - *Underground meteorology - «What's the weather underground?»*. Acta Carsologica, 39(3), 427-448.

Bernand P. & Van Thienen M. (1987) - *Les Grottes Glacées du Marboré*. Authors edition, 134 pp.

Bini A. & Pellegrini A. (1998) - *Depositi di ghiaccio e neve*. Geologia Insubrica, 3, 89-100.

Casteret N. (1946) - *Diez años bajo tierra*. Editorial Nacional, Madrid, 222 pp.

Craig H. (1961) - *Isotopic variations in meteoric waters*. Science, 133(3465), 1702-1703.

Feurdean A., Perşoiu A., Pazdur A. & Onac B.P. (2011) - *Evaluating the palaeoecological potential of pollen recovered from ice in caves: A case study from Scarisoara Ice Cave, Romania*. Review of Palaeobotany and Palynology, 165, 1-10.

Holmlund P., Onac B.P., Hansson M., Holmgren K., Mörth M., Nyman M. & Perşoiu A. (2005) - *Assesing the palaeoclimate potential of cave glaciers: the example of the Scarisoara ice cave (Romania)*. Geografiska Annaler, 87A(1), 193-201.

Kern Z., Bocic N., Horvatincic N., Fórizs I., Nagy B. & László P. (2008) - *Palaeoenvironmental records from ice caves of Velebit Mountains - Ledena Pit and Vukusic Ice Cave, Croatia*. In: Kadebskaya O., Mavlyudov B.R. & Pyatunin M. (Eds.), 3rd International Workshop on Ice Caves Proceedings, Kungur, 108-113.

Kern Z., Fórizs I., Perşoiu A. & Nagy B. (2009) - *Stable isotope study of water sources and of ice core from the Bortig Ice Cave, Romania*. Data of Glaciological Studies (Material y Glyatsiologicheskikh Issledovanly), 107, 175-182.

Kern Z. & Perşoiu A. (2013) - *Cave ice - the inminent loss of untapped mid-latitude cryospheric palaeoenvironmental archives*. Quaternary Science Reviews, 67, 1-7. doi:10.1016/j.quascirev.2013.01.008

López-Martínez J. & Freixes A. (1989) - *El karst en los Pirineos españoles*. In: Durán, J.J. & López-Martínez, Eds., *El Karst en España*. Monografía 4, Sociedad Española de Geomorfología, 131-144.

Luetscher M. & Jeannin P.Y. (2004a). *The role of winter air circulations for the presence of subsurface ice accumulations: an example from Monlési ice cave (Switzerland)*. Theoretical and Applied Karstology, 17, 19-25.

Luetscher M. & Jeannin P.Y. (2004b) - *A process based classification of ice caves*. Theoretical and Applied Karstology, 17, 5-19.

LUETSCHER M., LISMODE B. & JEANNIN P.Y. (2008) - *Heat exchanges in the heterothermic zone of a karst system: Monlesi cave, Swiss Jura Mountains*. Journal of Geophysical Research, 113, F02025, doi:10.1029/2007JF000892.

LUETSCHER M. (2013) - *Glacial processes in caves*. In: Schroder, J. (Editor in Chief), Frumkin A. (Ed.), *Treatise of Geomorphology*. Academic Press, San Diego, CA, vol. 6, Karst Geomorphology, pp. 258-266.

MATTEY D., LOWRY D., DUFFET J., FISHER R., HODGE E. & FRISIA S., (2008) - *A 53 year seasonally resolved oxygen and carbon isotope record from a modern Gibraltar speleothem: Reconstructed drip water and relationship to local precipitation*. Earth and Planetary Science Letters 269, 80-95.

MAVLYUDOV B.R. (2008) - *Caves glaciation*. Russian Academy of Sciences, Moscow, 290 pp.

MUÑOZ J.A. (2002) - *The Pyrenees*. In: The geology of Spain (Gibbons, W. & Moreno, T., Eds.), Geological Society, London, 370-385.

PERŞOIU A. (2004) - *Ice speleothems in Scarisoara Ice Cave: dynamics and controllers*. Theoretical and Applied Karstology, 17, 71-76.

PERŞOIU A., FEIER I., CITTERIO M., TURRI S. & MAGGI V. (2007) - *Preliminary data on air temperature in Focul Viu Ice Cave (Bihor Mts., Romania)*. In: Zelinka J. (Ed.), *Proceedings of the 2nd International Workshop on Ice Caves*. Liptovsky Mikulás, 62-64.

PERŞOIU A., ONAC B.P. & PERŞOIU I. (2011a) - *The interplay between air temperature and ice mass balance in Scariosara Ice Cave, Romania*. Acta Carsologica, 40(3), 445-456.

PERŞOIU A., ONAC B.P., WYNN J., BOJAR V. & HOLMGREN K. (2011b) - *Stable isotope behavior during cave ice formation by water freezing in Scarisoara Ice Cave, Romania*. Journal of Geophysical Research, 116, D02111, doi:10.1029/2010JD014477.

SANCHO C., BELMONTE A., LÓPEZ-MARTÍNEZ J., MORENO A., BARTOLOMÉ M., CALLE M. & SANTOLARIA P. (2012) - *Potencial paleoclimático de la cueva helada A294 (Macizo de Cotiella, Pirineos, Huesca)*. Geogaceta, 52, 101-104.

SEGURET M. (1972) - *Etude tectonique des nappes et series décollées de la partie centrale du versant sud des Pyrénees*. Publications de USTELA, Série Géologie Structural, 2, 155 p.

ST. PIERRE D. (2007) - *Grotte Casteret*. BCRA Cave Studies Series, 17, 48 pp.

STOFFEL M, LUETSCHER M., BOLLSCHEWEILER M. & SCHLATTER F. (2009) - *Evidence of NAO control on subsurface ice accumulation in a 1200 yr old cave-ice sequence, St. Livres ice cave, Switzerland*. Quaternary Research, 72, 16-26.

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