



## Chronology of a Pyrenean subsurface ice deposit (A294 cave, Cotiella massif, Spain)

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A294 cave (2238 m.a.s.l.) is located in the Cotiella massif (highest peak Cotiella, 2912 m.a.s.l.) in the Spanish central Pyrenees, a very interesting region under Atlantic and Mediterranean climatic influences. The climate in the cave area is peri-mediterranean with high mountain characteristics (eg. snow covers the surroundings of the cave about six months a year).

The cave is situated within the Armeña ice-free polylobulated glacial cirque. Nowadays, the main morphogenetic processes in the area are karst and periglaciariism. An active rock glacier is relatively close to the studied cave. The landscape is rich in glaciokarstic features, like large dolines overdeepened by glaciers and decapitated pits. Many of these pits represent entrances to the complex cave network of Armeña. The main cavity is A8 cave, with a development up to nine kilometres. Five caves in the cirque have perennial ice deposits, most of them not relevant from a quantitative point of view.

The studied cave, A294, has a relatively simple shape. The main entrance is a shaft that leads to a ramp of ice, usually covered by snow. Then there is a room with the ice deposit at the bottom. The room is about 22 m high from the ice surface to the roof and 40 m wide. There is a secondary entrance, trench-shaped, of small dimensions. Overlying the ice, there is a huge scree deposit that ends in an active protalus rampart morphology. In spite of the low temperatures inside the cave, no other periglacial morphologies have been observed.

Inside the cave there are some ice speleothems, usually only seasonal, like a four meter high column non active every year. Along the ice wall, big scallops and karren can be observed.

Since 2009, four temperature/relative humidity loggers are installed at different points of the cave. Based on the collected environmental data and on the morphology, the cave can be classified as a statodynamic ice cave. The cave acts as a thermal trap with cold air entering through the big shaft in winter season and with no circulation in summer. The average temperature outside the cave is above 0°C, so the thermal trap is the factor that makes possible the ice formation and preservation within A294 cave. The average summer temperature around the ice block is 0.736°C pointing out general ablation conditions during this season and the winter one is -4.325°C.

The deposit is nearly 13 meters thick, measured in an overhanging wall and the total estimated volume is about 242 m<sup>3</sup>. Its structure shows a stratified ice with many debris layers. Due to this fact, several units can be distinguished. Most of the ice is congelation ice, even though there is some firn in the deposit as a huge quantity of snow enters through the cave entrance. Within the deposit, many vegetal remains can be seen, normally associated with the debris layers. The lower section of the deposit (about three meters thick) includes seven debris layers and eight radiocarbon calibrated ages were obtained, ranging from  $5516 \pm 70$  to  $3808 \pm 104$  y BP, indicating that it is one of the oldest subsurface ice deposits known so far in Europe. In addition, occurrence of this ice deposit during Middle Holocene matches well with other speleothemic, tufa and lacustrine regional palaeoenvironmental records.