



Cryogenic cave carbonate formation during the Industrial Era in the Central Pyrenees (Iberian Peninsula)

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Cryogenic cave carbonates (CCC) are rare speleothems that form when water freezes inside cave ice bodies. CCC have been used as an proxy for permafrost degradation, permafrost thickness, or subsurface ice formation. The presence of these minerals is usually attributed to warm periods of permafrost degradation. We found coarse crystalline CCC types within transparent, massive congelation ice in two Pyrenean ice caves in the Monte Perido Massif: Devaux, located on the north face at 2828 m a.s.l., and Sarrios 6, located in the south face at 2780 m a.s.l. The external mean annual air temperature (MAAT) at Devaux is ~ 0°C, while at Sarrios 6 is ~ 2.5°C. In the Monte Perdido massif discontinuous permafrost is currently present between 2750 and 2900 m a.s.l. and is more frequent above 2900 m a.s.l. in northern faces. In Devaux, air and rock temperatures, as well as the presence of hoarfrost and the absence of drip sites indicate a frozen host rock. Moreover, a river flows along the main gallery, and during winters the water freezes at the spring causing backflooding in the cave. In contrast, Sarrios 6 has several drip sites, although the gallery where CCC were collected is hydrologically inactive. This gallery opened in recent years due to ice retreat. During spring, water is present in the gallery due to the overflow of ponds forming beneath drips. CCC commonly formed as sub-millimeter-size spherulites, rhombohedrons and rafts. ²³⁰Th ages of the same CCC morphotype indicate that their formation took place at 1953±7, 1959±14, 1957±14, 1958±15, 1974±16 CE in Devaux, while in Sarrios 6 they formed at 1964±5, 1992±2, 1996±1 CE. The cumulative probability density function indicates that the most probable formation occurred 1957-1965 and 1992-1997. The instrumental temperature record at 2860 m a.s.l. indicates positive MAAT in 1964 (0.2°C) and 1997 (0.8°C). CCC formation could thus correspond with those two anomalously warm years. The massive and transparent ice would

indicate a sudden ingress of water and subsequent slow freezing inside both caves during those years. Probably, CCC formation took place at a seasonal scale during the annual cycle.