



EGUsphere, referee comment RC2  
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## **Comment on egusphere-2022-349**

Anonymous Referee #2

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Referee comment on "Mountain permafrost in the Central Pyrenees: insights from the Devaux ice cave " by Miguel Bartolomé et al., EGUsphere,  
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### **Overall evaluation**

The present study documents the presence of mountain permafrost in a cave of the Pyrenees, in a region where it is generally absent. The authors set out to characterise the permafrost conditions in Devaux ice cave and make a well-structured argument for the occurrence of past and present permafrost in a high elevation cave of the Pyrenees, and this assertion is well supported by adequate monitoring and observations of cryogenic cave sediment or morphologies.

The authors present a clear inventory of cryogenic and ice-related geomorphological features in a glaciated cave and attempt to link their spatial distribution to the various microclimatic or hydrological dynamics of the respective chambers/galleries. Substantial conclusions are reached on the causative mechanisms controlling the different ice morphologies reported in specific regions of the cave. To achieve this the authors use a combination of air, rock and water temperature monitoring to demonstrate the influence seasonal ventilation and hydrological activity in cave sector on the resulting cave ice morphologies. The monitoring set up adequately addresses the complex geometry of the cave, identifying both ventilated and poorly ventilated sections, and the attendant air and rock temperature patterns.

Additionally, the authors successfully demonstrate the cryogenic origin of several types of cave minerals using appropriate major ion geochemical analyses and stable isotope geochemistry. With special emphasis on cave gypsum, the authors explore the spatial relationships of the gypsum crystals with surrounding ice and cryogenic carbonate at both macro- and micro-scale, and provide a convincing first report of cryogenic gypsum in a limestone-bedrock cave.

Overall, the authors present a consistent and well-rounded studyhighlighting the localised

nature of mountain permafrost, and those interpretations are well supported by figures of consistently high quality. This study is timely, it fits within the scope of the cryosphere and should be published with minor corrections, as outlined below.

### **Minor comments**

A) I90-91: I think this statement could be clarified or rephrased. Because one could argue that ice is also still being preserved at lower elevation sites due to the ventilation-driven thermal anomalies. In the frame of the present study, the main contrast between the mid and high elevation/latitude sites appears to be the contribution of heat conduction to the thermal balance of the cave (positive for the former, negative for the latter).

B) I98-99: The authors mention a little earlier that often ice caves do not inform about the wider thermal characteristics of the bedrock. When citing the example of ice cave A-294 (Sancho et al., 2018), which is located at an elevation of 2238 m asl with positive MAAT at the entrance, the authors could perhaps point out that this is another observation of sporadic permafrost, driven by the cave geometry, rather than by mountain permafrost as in the sense of this study. I would also suggest rephrasing this sentence (see technical comments).

C) I83 - here there could be some additional quantitative description of the cave geometries for the reader unfamiliar with cave exploration (include perhaps cross-section dimensions when mentioning narrow passages?). Figure 2B is good, but the blue-grey bedrock colouring is not included in the legend. For the reader, it could be helpful to add items in the legend, and perhaps colour coding the parts of the cave influenced by different thermal regimes, the outer sector and the inner one.

D) I506-513, high thermal inertia - how long does it take to erase a climate signal from about 150 years ago, is the bedrock temperature consistent with the approx 1.5°C temperature rise since 1881 at Bigorre station?

E) I315 - figure 5d, the air temperature variations at T11 and T5 (and T2) could be discussed in additional detail (at line 481 for instance). I think that, in summer, the lower correlation between the (T) loggers and the outside air (T) can also be explained by the influence of the outward air flow, whereby air temperature variations are more muted than during the winter inward air flow regime. Could the authors comment on this?

F) I315 - rock temperature sensor R2 is included in the results and discussion with 'well ventilated' parts of the cave, yet it lies in the vicinity of a massive ice body, near the Terminus Devaux, suggesting that there is perhaps little air flow there. Indeed, at line 331, the authors mention that the chamber morphology shields them from the air flow. Perhaps the discussion of its record could be moved to the 'poorly ventilated' section?.

Could the authors comment on the lag between the seasonal rock temperature maxima and minima compared to the external and cave air temperature? Given the thermal conductivity of limestone and a sensor depth of 60 cm, does the record support a simple heat conduction model?

G) I518 - the only place where perennial hoarfrost is indicated on figure 2B is a small recess appears to be surrounded by ventilated galleries containing seasonal hoarfrost, and as mentioned adjacent to a small ice body of room SPD. This certainly speaks to the frozen nature of the bedrock in this part of the cave, and demonstrates the clear effect of the negative thermal anomaly brought about by the ventilation pattern in the surrounding galleries. But if this is the case, could the authors comment on why there is no perennial hoarfrost in the galleries leading to room D, where such hoarfrost could also have developed?

H) Could the authors elaborate on why CCC or CCG related ice, rich in air inclusions could be related to the formation in a subaqueous environment?

I) I689: the authors mention that 'exceptional insights' into the origin of mountain permafrost are gained by the study of the Devaux ice cave deposit. In this study, three potential mechanisms are put forward, which all go some way to explain the permafrost conditions at the site. 1) negative thermal anomalies due to cold air advection in winter, 2) negative radiative anomaly due to the mountain topography/orientation and 3) inherited past cold climate signals, not entirely erased by current warming due to thermal inertia. In the discussion, the authors could comment on a ways to quantify the potential contributions of each to the current thermal state of the cave?

**Technical comments (T: suggested typographic correction, R: suggested rephrasing)**

I55-57: (R) snow cover distribution and thickness, topography, water availability, surface and rock temperature all influence the spatial distribution of mountain permafrost

I57-61: (R) In light of these processes, [ ... ] are needed to gain a comprehensive understanding of mountain permafrost.

I98-99: (T) the presence of a few ice caves has only recently been documented

I315: I think this could be reformulated, as the authors list water, and rock T sensors together with the air T sensors.

I357: I think R1 could be dropped from the list in parentheses, as it is not an air temperature sensor.

I396: (T) transparent and massive ice (~15.5 m above the Brulle spring) currently fills a cupula or chimney

I452: (T, American English spelling) milliliter

I453: (T) in room SPD, CCC and CCG

I456: for the sake of consistency, I would drop the s at the end of CCC here.

I501: (T) with more continuous permafrost starting at 2900 m asl

I535-536: massive ice is formed by slow freezing - there should perhaps be a reference here.

I568: (T) The cave ice bodies [...] therefore represent

I596: (T) which contrasts with

I615: for the sake of consistency, drop s at the end of CCG here.

I636: (T) related to hydrocarbons

I666-667: (T) is the size and well-developed shape of the crystals

I718: (T) rich in air inclusions

I724: (T) in Devaux cave

Figure 2A: could it be helpful to indicate on the cross-section the assumed extent of mountain permafrost (200 m thick, over 350 m in an E-W direction)?