



## Deglaciation, permafrost, and rock glacier activity in the Central-Eastern Pyrenees: Insights from the Clot de la Menera cirque (Andorra)

Anna Echeverria<sup>1\*</sup>, Marc Oliva<sup>2</sup>, Josep Ventura<sup>2</sup>, Oriol Monserrat<sup>3</sup>, Pedro Espín-López<sup>3</sup>, Valentí Turu<sup>4</sup>, Xavier Ros<sup>4</sup>, Attila Çiner<sup>5</sup>, M. Akif Sarıkaya<sup>5</sup>, Claudia Pérez-Ramos<sup>2</sup>, Julia García-Oteyza<sup>2</sup>

<sup>1</sup> *Andorra Recerca+Innovació, Sant Julià de Lòria, Andorra*

<sup>2</sup> *Department of Geography, Universitat de Barcelona, Catalonia, Spain*

<sup>3</sup> *Centre Tecnològic de Telecomunicacions de Catalunya, Castelldefels, Catalonia, Spain*

<sup>4</sup> *Marcel Chevalier Earth Science Foundation, Andorra la Vella, Andorra*

<sup>5</sup> *Eurasia Institute of Earth Sciences, Istanbul Technical University, Istanbul, Türkiye*

\*Corresponding author. E-mail: [aecheverria@ari.ad](mailto:aecheverria@ari.ad) (A. Echeverria)

**Abstract.** Understanding postglacial environmental evolution in mid-latitude mountain ranges is crucial for assessing how past climate changes shaped present-day landscapes and for predicting future dynamics under ongoing warming. In the Clot de la Menera cirque (Grau Roig, Andorra), located in the Central-Eastern Pyrenees, we carried out a multidisciplinary investigation to reconstruct the environmental evolution from the Late Pleistocene to the present. Our study combines cosmogenic exposure dating, remote sensing (DInSAR), geomorphological mapping, geophysical surveys and ground thermal monitoring to trace the evolution and dynamics of rock glaciers and frozen ground features.

The research addresses critical questions regarding the timing of deglaciation, the formation and activity of rock glaciers, and the possible presence of buried ice or permafrost in this high mountain cirque. In particular, the study focuses on rock glaciers that formed shortly after cirque deglaciation and are currently undergoing slow downslope movement. Preliminary results suggest that these rock glaciers originated in the Early Holocene and continue to be active, offering a rare opportunity to examine the long-term persistence of permafrost below the regional 0 °C isotherm. These features serve as key indicators of cryospheric dynamics, and their analysis sheds light on how internal frozen masses can sustain movement despite rising air temperatures.

Part of this research was carried out as part of the European project PERMAPYRENEES (Interreg POCTEFA EFA063/01), which aims to improve knowledge of the distribution and evolution of permafrost in the Pyrenees. Future borehole investigations at the Clot de la Menera cirque may clarify the nature and depth of the frozen cores, offering key insights into their climate resilience and reinforcing the site's value as a reference for mid-latitude alpine permafrost under climate change.

**Keywords:** rock glaciers; deglaciation; Pyrenees; Andorra.