

## **Spatial distribution and morphometry of permafrost-related landforms in the Central Pyrenees**

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Present and past permafrost distribution in the Pyrenees is still under discussion. As in other mid-latitude mountain regions, rock glaciers and protalus lobes are the main indicators of permafrost conditions. In this study, we examine the distribution of these landforms in the Boí valley, a formerly glaciated U-shaped valley ranging from 850 to 3000 m a.s.l. The valley encompasses a surface of 247 km<sup>2</sup>, mainly composed of granite and shales. The spatial distribution of rock glaciers and protalus lobes and their chronostratigraphic position within the valley allow a better understanding of the climatic and environmental conditions necessary for their development.

Geomorphological mapping of these landforms was built using high resolution imagery provided by the Institut Cartogràfic i Geològic de Catalunya, complemented with Basemap ESRI images and Google Earth Pro, and subsequently improved with field observations. The map was generated in a GIS environment following the RCP 77 mapping system of the Centre National de la Recherche Scientifique (CNRS) (Joly, 1997). Several parameters of each landform have been measured (Table 1): area (ha), altitude (maximum, minimum, mean), length (L), width (W), aspect and slope. This information provides accurate characterization of the morphometric properties of these landforms as well as a detailed identification of their spatial distribution.

Up to 121 permafrost-related landforms were identified in the Boí valley, including 84 rock glaciers and 37 protalus lobes. Most of the landforms (93% for rock glaciers and 95% for protalus lobes) are located inside the glacial cirques, while the rest is distributed in the valley bottom or slopes of the formerly glaciated valleys. The lowest elevation of both forms is situated at 2100 m a.s.l. Therefore, this altitude may be indicative of the lowest level recording permafrost conditions during the period in which these landforms formed. The maximum elevation of the landforms usually corresponds to the highest parts of the cirques, oscillating between 2700 m a.s.l. for protalus lobes and 2900 m a.s.l. for rock glaciers. Nevertheless, 77% of the rock glaciers and 78% of the protalus lobes are located in the elevation belt ranging from 2200 to 2600 m a.s.l., which is assumed to be the optimal elevation range for their development in the study area. Aspect does not show any prevailing orientation in the case of rock glaciers, though protalus lobe formed preferably on SW aspects (27%), being almost absent in the S, SE and E aspects (only 5%).

Regarding morphometry, the average area occupied by the rock glaciers decreases with altitude (6.4 ha to 1.2 ha). This trend is not observed in the case of protalus lobes, which show the largest surfaces between 2200 and 2600 m a.s.l. The W/L ratio reveals that the rock glaciers distributed at lower altitudes are more elongated (W/L ratio > 2), while those at higher elevations are shorter. No clear patterns are observed when comparing the morphology of protalus lobes and the altitude. The average slope of both landforms lies between 21-22°, with a maximum of 29° for rock glaciers and 31° for protalus lobes. The minimum slope necessary for the development of these two landforms is 11°.

The geomorphological mapping of the glacial landforms that is being now conducted will allow identifying the chronology of the development of these landforms based on its chronostratigraphic position within the valley and with respect to the four moraine complexes (glacial stages) identified in the area.