Title

Paraglacial drivers of Late Quaternary rockfall in the high mountains of the Pyrenees

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Abstract

While rockfalls and bedrock landslides may contribute significantly to mountain denudation, the geophysical processes which control their timing and their relative and overall importance in the evolution of mountainous topography are poorly understood. However, robust chronologies can provide valuable information on their magnitude, age and recurrence: information which can inform our understanding of the mechanisms and drivers of bedrock failure. In this study, we estimated the timing of Late Quaternary rockfall events from granitic bedrock cliffs in the Ésera catchment, southern Pyrenees, based on Schmidt hammer exposure dating. This calibrated-relative age technique is based on a robust calibration dataset comprising 54 ^{10}Be dated surfaces and enables exposure ages to be estimated based on rock surface weathering. As this approach is cost- and time-effective, it can be applied widely to undated rockfall deposits and can complement targeted cosmogenic nuclide sampling in poorly dated regions. Samples were obtained from a range of sub-catchments in the Maladeta (3,312 m) and Posets (3,371 m) massifs, and from sites with varying deglacial ages, ranging from the Last Glacial Maximum to the early Holocene. Based on a large dataset of sampled rockfall boulders (n = 945; ~28,350 Schmidt hammer R-values), we utilised a Monte Carlo style approach to isolate component normal distributions (Gaussians) to investigate the frequency and drivers of rockfall over the last ~25 ka. These data indicate that while most bedrock cliffs are still geomorphologically active, as evidenced by the distribution of “fresh” failure scars and the deposition of unweathered rockfall boulders on weathered rockfall deposits, many deposits appear primarily paraglacial in origin. However, paraglacial intensification of rockfall activity was focused in the first few thousand years following deglaciation, with subsequent and current activity likely driven by permafrost degradation, seismicity and thermal stressing.