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# Bedrock gorges incising glacial hanging valleys: insights from morphometric analysis and numerical modelling

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Bedrock gorges are frequent features in glacial or post-glacial landscapes and show the potential of fluvial or subglacial erosion in relief evolution. Even though it is clear that these gorges are mainly shaped by fluvial processes, their dynamics has been rarely quantified and timing of their formation is poorly constrained. Here we focus on gorges incising glacial hanging valleys in the French Western Alps (Pelvoux-Ecrins massif), aiming to quantify the processes associated with gorge deepening. Using digital elevation models, aerial photographs, topographic maps and field reconnaissance in three major watersheds of the massif, we have identified 30 tributary hanging valleys incised by gorges toward their confluence with the trunk streams. Longitudinal profiles for all these tributary streams are convex and present abrupt knickpoints when entering the gorges. "Initial" profiles were reconstructed from glacially polished bedrock knobs surrounding the gorges, in order to reconstruct the initial glacial knickpoint and the amount of fluvial incision and knickpoint retreat. Incision and knickpoint retreat rates, assuming gorge incision during post-glacial times (i.e. since 20 ka) are high at 0.3-15 mm.yr$^{-1}$ and 1-220 mm.yr$^{-1}$ respectively, but remain concordant with other studies of postglacial fluvial incision. From a morphometric analysis, we find that mean channel gradients and widths, as well as knickpoint evolution, are dictated by fluvial processes and are strongly influenced by bedrock lithology and upstream drainage area. We use numerical modelling to test the ability of different fluvial incision models to predict the inferred evolution of the gorges. The well-known Stream

Power erosion law was used and first results show that Transport-Limited models reproduce observed river profiles much better than Detachment-Limited models. Coupling with hillslope processes can explain these results, as gorge sidewalls provide large amounts of meter-scale blocks to the gorges. As a consequence, the bedrock is partly protected from erosion and fluvial incision only operates during large floods, which leads to a Transport-Limited evolution at large time scales. Our numerical results do not shed light on the timing of formation of the gorges (i.e. post-glacial vs. glacial origin) as the erosion laws used in this study are temporally linear. Absolute dating of incision by cosmogenic isotopes is in progress and will allow discriminating between the two hypotheses.