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Bedrock stresses and extensional fracture development within an evolving Alpine landscape

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This study focuses on clarifying the effects of repeated glacial/interglacial cycles on the geomorphic evolution of a major Alpine valley within the southern Swiss Alps (in the region of Zermatt). We find that high erosion rates associated with the development of the Alpine landscape are likely to have induced an elastic response in exhuming bedrock that led to the generation of near-surface stresses in excess of both regional tectonic and topographic stress. Analysis using 1-D and 2-D elasto-plastic numerical models allows us to assess the development and distribution of stresses within a range of tectonic and topographic conditions, and yields results consistent with both Alpine in situ stress measurements and a global comparison of near-surface stresses with local bedrock strengths. Our 2-D model differs markedly from previous studies of topographic stress, which generally ignore the effects of endogenic and exogenic processes, and limitations resulting from long-term brittle rock behaviour. The model allows us to assess particular fracture mechanisms that lead to the development of micro- and macroscopic fractures in association with Alpine glaciation (including, but not limited to, sheeting joints in cratonic shield regions and exfoliation fractures in formerly glaciated areas). Predicted macroscopic fracture distributions within our assumed pre-glacial landscape correspond to the location of the present-day inner U-shaped valley trough in our study region. When combined with supporting sedimentary evidence from the periphery of the Alps, we propose a mechanism in which sub-glacial fracturing of intact bedrock during early glacial cycles significantly enhanced glacial erosion within this critically-stressed region, leading to the rapid erosion of the spectacular U-shaped Alpine valley.