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Identification of paraglacial and periglacial processes and resulting rockfall activity

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Rockfall is characteristic of deglaciated alpine rockwalls. Small (<5 km²) to very small (<0.5 km²) alpine glaciers are located at altitudes where periglacial and paraglacial processes jointly influence rockfall processes. In this study, we (i) reconstruct glacier retreat history, (ii) quantify rock fracture damage, (iii) model permafrost distribution, (iv) model patterns of frost weathering, and (v) assess how these may combine to influence rockfall processes around a small alpine glacier in the Hungerli Valley (Swiss Alps). To achieve this, we use geomorphic, geophysical, geotechnical and remote sensing techniques on three rockwalls (RW1-3) with different glacial retreat history and elevation.

(i) Glacier retreat is reconstructed based on existing LGM ice extent models, mapping of moraines and analysis of historic photos. The resulting retreat history is used as an upper age limit for the calculation of paraglacial rockwall retreat rates.

(ii) Rockwall fracture damage is quantified in the field using laboratory-calibrated seismic refraction tomography and our results demonstrate that rockwall fracture density increases with proximity to the glacier. This relationship suggests that rockwalls in proximity to the glacier are still experiencing paraglacial stress-release jointing and that rockfall is yet to remove these fractured blocks.

(iii) Local permafrost modelling based on temperature logger data indicates that areas with likely permafrost occurrence (<-3°C) are limited to the peaks and upper cirque walls (>3000 m). Areas of 'possible' permafrost (<0°C) extend to elevations as low as 2700 m.

(iv) We determined rock strength properties in the lab (Draebing and Krautblatter, 2019) and monitored rock temperature in the field for three years. These data were applied to the physical-based frost cracking model by Rempel et al. (2016). Model simulations show that frost cracking is highly sensitive to lithology and increases with altitude due to decreasing rock temperatures.

(v) We applied terrestrial laserscanning of the rockwalls to quantify rockfall activity. Rockfall volumes demonstrate a typical frequency-magnitude distribution. Applying a space-for-time substitution using glacier retreat history reveals that rockwall retreat rates are increased in

proximity to the glacier where rockwalls experience permafrost and a high frost cracking intensity.

In conclusion, our data suggest a synergy of paraglacial processes, frost cracking and permafrost thaw in preparing and triggering rockfalls. This synergy follows an altitudinal gradient that moves upwards with glacier retreat, permafrost thaw and frost cracking trajectories.

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Rempel, A. W., Marshall, J. A., & Roering, J. J.: Modeling relative frost weathering rates at geomorphic scales. Earth and Planetary Science Letters, 453, 87-95, 2016.