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Fracture Dynamics and Rock Slope Stability in Deglaciating Headwalls

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Deglaciation exposes rock surfaces to direct atmospheric forcing and alters rock-mechanical conditions. Deglaciating headwalls are therefore assumed to be particularly prone to rockfalls, rockslides, and rock avalanches. Fractures intersecting these rock masses represent potential planes of weakness. Their dynamics may thus reveal information about the magnitude and timing of stability-relevant processes. While numerous laboratory studies have been carried out on processes responsible for periglacial rock slope instability, field evidence is rare at present.

Here, we investigate a sediment-filled discontinuity on the recently deglaciated north face of the Kitzsteinhorn (3203 m a.s.l.), Hohe Tauern Range, Austria. Within the Open-Air-Lab Kitzsteinhorn (OpAL), two crackmeters are operated to measure horizontal (CDH) and vertical crack deformation (CDV) with a resolution of $\pm$0.003 mm as well as crack top temperatures (CTT). By calculating a deformation coefficient α=ΔCDH,V/ΔCTT, we can differentiate thermal from cryogenic forcing. Within a one-year (2016) time frame, this study aims (i) to identify seasonal patterns of crack deformation and (ii) to decipher and quantify associated stability-relevant processes.

(i) Crack deformation patterns generally show negative correlations between crack opening and CTT in summer and winter, with significant deviations around the freezing point in early summer and autumn. Maximum range of horizontal crack deformation is about 1.5 mm, maximum vertical shearing is around 1.4 mm. Within the monitoring period, a net horizontal crack opening of 0.6 mm was observed. During constant CTT between -1°C and 0°C in June, the horizontal crack deformation trajectory suddenly changes from a closing pattern to a fast crack opening of 0.4 mm within two weeks, before a sudden closing event of 0.9 mm within six hours occurs. In autumn, the crack opens up 1 mm, while CTT remains at about -0.5 °C.

(ii) Negative correlations between crack opening and CTT are associated with thermomechanical processes, whereas deviations relate to cryogenic processes. For most parts of the year, fracture dynamics are controlled by thermal contraction and expansion of the inter-cleft rock mass. Deviations mainly occur when CTT is in the freeze-thaw window between -1°C and 0°C in early summer and autumn. During these periods, available liquid water may exert a significant destabilizing effect by decreasing shear resistance and increasing cryostatic pressures due to refreezing.

Assuming that deformation patterns of adjacent fractures on the slope behave similarly, stresses may accumulate down-slope. The most recently deglaciated, lower part of the headwall, where potential shear planes dip out of the slope, may accordingly constitute the most unstable part of the slope. The emergent response of the slope to compound fracture deformation may therefore be expressed through failure at the foot of the rock slope.