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Combining surface characteristics and rock-mechanical properties to identify unstable glacier headwalls on a regional scale

Andreas Ewald, Jan-Christoph Otto, Christoph von Hagke, and Andreas Lang
Geography and Geology, University of Salzburg, Salzburg, Austria (andreas.ewald@sbg.ac.at)

Global warming triggered retreat of alpine glaciers exposes large surface areas in the proglacial zone but also a significant headwall area above. The thermal and mechanical changes in the headwalls foster destabilisation and trigger rockfalls. Patterns of headwall destabilisation are complex due to variable rock strength and external atmospheric forcing and results are usually site-specific and do not allow regional scale stability assessments.

In order to understand sensitivity of alpine rock walls to instability following glacier retreat on a regional scale, we classify glacier headwalls based on a combination of surface and rock-mechanical characteristics. This includes (i) a semi-automatic detection of glacier headwalls using object-based image analysis, (ii) a morphometric analysis of headwalls, (iii) a regionalisation of rock-mechanical properties of the bedrock, and (iv) an analysis of other site conditions like potential permafrost occurrence and glacier retreat. We apply this workflow in the Hohe Tauern Range, Austria, to identify headwalls in recently deglaciated cirques and valleys with the highest potential for increased slope instability and rock fall processes.

For the central Hohe Tauern Range high-resolution digital datasets of topography, geology, glacier extent, and permafrost distribution are available. eCognition was used for semi-automatic headwall detection. Segmentation is derived from DEM derivatives like slope, aspect and a TPI-based landform classification. Headwall segments are classified based on slope and elevation thresholds that have been identified and validated using manual headwall mapping. Foliation information extracted from regional geological maps was compared to local geological surveys in order to specify type of foliation. Bedrock structure was interpolated based on a non-continuous azimuth distribution approach (NADIA). By combining topographic and geological data we derived a geotechnical classification scheme from cataclinal to anaclinal slopes with various dip-slope relations.

Preliminary results indicate that semi-automated headwall detection largely reproduces local observations. However, we observed an overestimation of 61% of total headwall area compared to the manually mapped headwalls. The rate of undetected areas is considered to be negligible. Overestimation mainly arises from inclusion of high-altitude profile straight slopes, matching the classification requirements without obvious glacial imprints such as schrundlines. Landform classification revealed a dominance of cataclinal slopes in the entire landscape. At steeper terrain, including glacier headwalls, anaclinal slopes prevail. Unstable situations such as overdip slopes are

rare and predominantly found in the lower sections of glacier headwalls marked by schrundlines. Steep permafrost rock walls were found to be almost exclusively anaclinal, which might be considered as site-specific.

Our approach offers a new methodology to detect deglaciating headwalls and characterise their sensitivity to instability at a regional scale. Our classification can be used for up-scaling local headwall dynamics for a better anticipation of the destabilisation pattern of steep alpine slopes following glacier retreat.