

Knowns and unknowns in assessing the impacts of climate change on rock slope failures in the Norwegian Arctic and sub-Arctic and implications for hazard assessment

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Abstract:

Over the past 50 years, seven known large rock slope failures (>100,000 m³ — large enough to generate rock avalanches) have occurred in Norway. Six occurred in Arctic Norway and one in a southern glacial setting. Five originated on slopes with relief contrasts exceeding 200 m, and three events failed as rock avalanches and two as rock creep flows. The remaining two, lower-relief slopes failed as rapid to very rapid rotational rockslides. Comparison with modelled permafrost maps (Magnin et al., 2019) and local temperature data shows that all failures occurred within or near areas (<100 m) of sporadic to continuous permafrost. Currently, unstable rock slopes threatening settlements or water bodies with adjacent communities are hazard-classified following a standardized workflow (Hermanns et al., 2012; Oppikofer et al., 2017). This approach assesses morphology, structure, and activity but assumes all slopes fail as rock avalanches. Runout distances are estimated using global H/L–volume relationships, and displacement wave run-up is evaluated with the empirical SPLASH model (Oppikofer et al., 2018). This last tends to overestimate the impacted area and is used today for susceptibility mapping. Recent observations challenge these assumptions by revealing (1) additional failure types such as rock creep flows, and rotational slides, and (2) the influence of degrading permafrost, neither of which are considered in the existing workflow. Non-rock avalanche failures typically have shorter runouts and lower velocities, reducing their capacity to generate displacement waves and thus leading to overestimated hazard zones. In addition, neglecting permafrost conditions may result in underestimated failure likelihoods under a changing climate. To address these challenges, the Geological Survey of Norway and the Norwegian Water and Energy Directorate, together with an expert board, are developing a revised classification system that incorporates both failure type and likelihood, with potential integration of climate-sensitive parameters. Discussion continues on whether to integrate climate-related parameters, as the links between climate change and rock slope stability are not entirely understood and permafrost data are scarce in Norway. Preliminary tests— using failures with known pre-failure conditions at Piz Cengalo, Switzerland (2017), Elliot Creek, Canada (2020), Forkastningsfjellet, Norway (2022), and Kleines Nesthorn, Switzerland (2025)—suggests the revised system may be an effective tool for assessing slopes approaching critical stability.

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