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How thawing ground ice can affect the mobility of landslides: the case study of Móafellshyrna Mountain in northern Iceland

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The risks associated with permafrost degradation in Arctic and alpine environments have received growing attention, but few studies address the effects of thawing ground ice on the landscape of Iceland. Permafrost degradation can affect slope stability [1], but its role in conditioning mass movements in Iceland is poorly understood. Our study focusses on the effects of ground-ice on the behaviour and mobility of landslides, using a case study in northern Iceland to assess the morphology and mobility of the unstable mass. Characterizing this kind of landslide is crucial in order to mitigate the risks of similar landslides that might occur in the future.

The landslide occurred in 2012 on the northwest-facing flank of Móafellshyrna Mountain (Tröllaskagi peninsula, Iceland), mobilising about 500,000 m3 of debris. Immediately after the failure, we observed large blocks of ice-cemented sediments both in the main body of the landslide and perched on a topographic bench - the source of the failure. The landslide originated at 870 m a.s.l., an altitude that corresponds to the modelled elevation limits of the discontinuous permafrost in northern Iceland [2]. The failure happened after an unusually warm and dry summer, followed by weeks of heavy precipitation (440 mm during the month before the event, when the mean annual precipitation here is $\sim$ 670 mm) and earthquake activity (three events, all above 4 M on the Richter scale).

We present the results of our analysis of the Móafellshyrna landslide. Our study includes differential GPS, Ground Penetrating Radar and Digital Elevation Model (DEM) creation using Structure from Motion (SfM) to provide morphological and volumetric characterisation of the slide's features. We also used air photography and 1 m resolution airborne LiDAR data, collected in 2015. We used these data to identify and analyse the landforms and processes involved during the failure. We quantify the volumes eroded, transported and deposited along the flow, characterising the mobility of the landslide.

The joint use of field observations, remote sensing, photogrammetry and geophysical survey revealed that the landslide's motion was complex. It began as a rock-debris fall - with failures of blocks of ice-rich sediments, boulders and frozen deposits - and evolved into a mobile large-scale debris flow/slide. During the "rock-debris fall" phase, ground-ice was still cementing the debris, allowing the cemented sediment to behave like blocks, rather than being transported like loose material. During the "debris flow" phase, rainwater, along with ground-ice meltwater, over-saturated the landslide material, causing it to evolve into a debris flow. Therefore, ground-ice had a major role in the development of the landslide by affecting the mechanical behaviour of the debris, promoting the failure and contributing to the transport with the thaw process that provided an additional volume of fluid. Our study shows that analysing the morphology and mobility of permafrost thaw-induced slope failures is essential for mitigating the hazard in the case of similar events in inhabited regions.

References:

[1]Haeberli, W. et al., 1997. Eclog. Geol. Helve, 90.3: 407-414.
[2]Etzelmüller, B. et al., 2007. Perm. Per. Proc., 18(2): 185-199.