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Large landslides lie low: Vertical domains of denudation processes in the arid Himalaya-Karakoram orogen

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Large bedrock landslides (defined here as affecting >0.1 km^2 in planform area) are thought to substantially contribute to denuding active mountain belts, and limiting the growth of topographic relief produced by concurrent tectonic uplift and fluvial or glacial incision. While most research on large landslides has focused on tectonically active, humid mountain belts with varying degrees of rainstorm and earthquake activity, lesser attention has been devoted to arid mountain belts. Especially in the Himalaya, where high denudation rates are commonly associated with high landslide activity, previous work has largely ignored landslide processes in the arid compartments of the orogen.

This was motivation for us to compile a landslide inventory covering the arid Himalaya-Karakoram of NW India and N Pakistan within the Indus catchment. Our data set contains 493 rock-slope failures that we compiled from published studies and mapping from remote sensing imagery. Using an empirical volume-area scaling approach we estimate the total landslide volume at >250 km^3. This is more than thousand times the contemporary annual sediment load in the Indus River. We analyse the distribution of these volumetrically significant landslides with respect to the regional hypsometry, contemporary glacier cover, and the distribution of rock glaciers.

We find that large bedrock landslides in the arid Himalaya-Karakoram region preferentially detach near or from below the study area's median elevation, while glaciers and rock glaciers occupy higher elevations almost exclusively. This trend holds true for both the study area and parts thereof. The largest and highest-lying landslides occur in the Karakoram mountains, where local relief exceeds 6 km, and $>90\%$ of the landslide areas lie below the region's median elevation.

Our analysis reveals a hitherto unrecognized vertical layering of denudation processes, with landslides chiefly operating below the median elevation, whereas mass transport by glaciers and rock glaciers dominates higher elevation bands. Given a SE-ward decreasing topographic amplitude and increasing median elevation, bedrock landslides tend to affect higher portions of the landscape, while their vertical drop heights decrease accordingly.

We conclude that these vertical domains of denudation processes conflict with the view that large bedrock landslides contribute to limiting relief in active mountain belts, unless (a) more frequent and smaller rock falls take on this role, and/or (b) evidence of large bedrock landslides above the permanent snow line is being censored rapidly. In either case, our data favour a model where large rock-slope failures undermine the lower portions of arid high-relief landscapes near the limits of Pleistocene glaciations, potentially signalling a regional postglacial hillslope adjustment. We thus call for a more detailed and refined view on how large rock-slope failures contribute to shaping arid mountain belts.