Geophysical Research Abstracts
Vol. 17, EGU2015-15389, 2015
EGU General Assembly 2015
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Topographic position of large slope failures revealed by excess topography in the Himalaya-Karakoram Ranges

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Large slope failures (defined here as affecting >0.1 km^2 in planform area) substantially contribute to denuding hillslopes, thereby limiting the growth of topographic relief in active mountain belts produced by tectonic uplift and fluvial or glacial incision. The region around Nanga Parbat, situated in the Himalaya-Karakoram ranges (HKR), has been shown to exhibit one of the largest clusters of large scale slope failure known. However, a thorough analysis of the pattern of landslides in the wider region, let alone an inventory of large slope failure is lacking.

We take this as a motivation to create a landslide inventory covering the upper Indus catchment located in the HKR of NW India and N Pakistan. Our data set contains 492 large landslides 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 landslides with respect to the regional hypsometry, contemporary glacier cover, and the distribution of rock glaciers. We further introduce excess topography ZE, which quantifies the vertical column of rock material above a hypothetical failure plane, as a first-order metric of potentially unstable rock slopes.

We find that large bedrock landslides in the HKR preferentially detach near or from below the study area's median elevation, while glaciers and rock glaciers occupy higher elevations almost exclusively. This picture is supported by the distribution of excess topography ZE that peaks along major fluvial and glacial inner gorges, which is where the majority of large rock-slope failures occur.

Our analysis suggests a hitherto unrecognised vertical layering of denudation processes, with landslides chiefly operating below the median elevation, whereas mass transport in higher elevations seems to be dominated by glaciers and rock glaciers, or high-frequency low-magnitude failure («0.1 km2). Whatever causes this pattern, the distinct position of excess topography ZE and large bedrock landsliding challenge the notion of widespread threshold hillslopes in the HKR. We therefore conclude that hillslope adjustment to fluvial and glacial incision along inner gorges through large-scale rock-slope failures is protracted and far from exhausted.