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Morphological characteristics of overdeepenings in high-mountain glacier beds

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Overdeepenings, i.e. closed topographic depressions with adverse slopes in the flow direction, are characteristic for glacier beds and glacially sculpted landscapes. Besides their importance as geomorphological landforms, groundwater bodies and sedimentary archives, they are of increasing interest in relation to climate-induced lake formation in de-glaciating landscapes and to depth erosion under ice age conditions in connection with the long-term safety of radioactive waste repositories in some mid-latitude countries. Quantitative predictions of their shape, distribution and conditions of occurrence, however, remain difficult. One major problem thereby relates to the still unsatisfactory treatment in glacier erosion theory of sediment evacuation at glacier beds, especially by subglacial meltwater. An alternative way of searching for realistic/empirical quantitative estimates is, therefore, to analyse the geometry of well-documented overdeepenings. The present study attempts to do this by combining statistical analyses of (a) detailed bathymetries from recently exposed lakes in the Peruvian Andes, (b) numerous bed overdeepenigs below still existing glaciers of the Swiss Alps and the Himalaya-Karakoram region modelled with a robust shear stress approximation linking surface slope to ice thickness at high resolution, and (c, for comparison) reconstructed overdeepenings produced by ice age glaciers in the Swiss Plateau based on numerous drillings and geophysical soundings. The sample of (a) has the advantage that geometries are exactly measured and only subject to young/small sedimentation effects. Sample (b) allows for a comparison with a modern model calculation and with known glacier characteristics. Sample (c) may provide some insights into the question how safely results from high mountain topography can be transferred to sites with markedly different topographic, climatic and glaciological controls (cold-arid lowland).

Where possible, mean and maximum values of the parameters surface area, length, width, depth, volume, forward/adverse slope and their statistical interrelations are determined with their corresponding uncertainty ranges. For sample (b) basal shear stress (as used in the model), thermal ice types, glacier size/type, relation to flow characteristics (position along flow, confined-unconfined, confluence-diffluence-channel-forefield) are also included. As a principal problem thereby remains the unsolved question of when exactly the overdeepenings had formed (present-day conditions, Holocene maximum stages, ice ages?).

Some results nevertheless remain safe. The most striking phenomenon is the high variability of geometries observed with modelled as well as measured forms: small features can, for instance, be deep and large features shallow. Overdeepenings can form under conditions of low to high basal shear stresses at cirque, confluence, channel and terminus positions. Rather than the exact size, locations and general parameter values of overdeepenings from different model runs appear to be robust and comparable. Only weak correlations seem to exist between the investigated geometrical parameters; rather uncertain indications are found of an optimal elongation for maximum depths. Inclinations of adverse slopes do not differ significantly from those of forward slopes and are in most cases far higher than limiting values for floatation within the overdeepenings. Lakes, which fill exposed overdeepenings, can be dammed by huge (lateral/terminal) moraines or may form in polished rock beds but have comparable spreads of geometrical characteristics in both cases.