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Rockglacier furrow-and-ridge morphology explained by gravity-driven buckle folding: A case study of the Murtèl rockglacier (Switzerland)

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Rockglaciers often feature a prominent transverse furrow-and-ridge morphology. Previous studies have suggested that these structures develop due to a longitudinal compressive flow in the lower part of a rockglacier. However, these hypotheses are mostly based on descriptive observations and not on mechanical considerations and therefore remained speculative.

We propose that gravity-driven buckle folding is the dominating process leading to furrow-and-ridge morphology on rockglaciers. Buckle folding is the mechanical response to compression of a layered viscous material with significant mechanical contrast between the layers. The resulting buckle folds are common structures in rocks, which can be assumed viscous at elevated temperatures and pressures, and have extensively been studied in outcrops, experimentally, numerically, and analytically. In this cross-disciplinary study we use the buckle folding theory, which is well-established in the field of structural geology, and apply it to the field of rockglacier geomorphology. As a case study we use the Murtèl rockglacier in the Upper Engadin Valley (Switzerland), which features a very spectacular example of furrow-and-ridge morphology.

The internal structure of the Murtèl rockglacier is well-studied and can be approximated by two layers: an upper mixed rock-ice layer and a lower almost pure ice layer, both exhibiting a viscous rheology. Such a simple structure is a prerequisite for applying the analytical buckle folding expressions. We use the Fold Geometry Toolbox (FGT) to analyze a 1 m-resolution digital elevation model (DEM) based on low-altitude aerial photographs. This software incorporates the analytical buckle folding expressions and hence provides a quantitative relationship between the observed wavelength (from DEM), layer thickness (from boreholes), and the effective viscosity ratio between the folded layer and the underlying ice.

The geometrical parameters from the DEM and boreholes and the rheological parameters from the FGT analysis are fed into a custom-made numerical finite-element (FE) model to simulate the dynamics of realistic gravitational rockglacier flow. Due to the decreasing slope, the rockglacier experiences longitudinal compression towards its lower part, where a buckling instability of the upper layer develops due to the mechanical contrast to the underlying ice. The resulting wavelengths and amplitudes of the furrow-and-ridge morphology are comparable to the Murtèl rockglacier. In addition, the simulated rockglacier deformation highlights the basal shear zone and the quasi-parabolic deformation profile observed in boreholes.

Our study promotes gravity-driven buckle folding as the dominant process for the formation of transverse furrow-and-ridge morphology on rockglaciers. Key aspects are the mechanical layering of the rockglacier and the occurrence of longitudinal compression.