Furrow-and-ridge morphology on rockglaciers explained by gravity-driven buckle folding: A case study from the Murtèl rockglacier (Switzerland)

Marcel Frehner, Geological Institute, ETH Zurich, Switzerland
Isabelle Gärtner-Roer, Department of Geography, University of Zurich, Switzerland
Anna Hui Mee Ling, ETH Zurich and University of Zurich, Switzerland

Rockglaciers often feature a prominent furrow-and-ridge topography. The Murtèl rockglacier in the Upper Engadin valley (Switzerland) is a very spectacular example for such morphology, with amplitudes and wavelengths in the order of 5 m and 20 m, respectively. Previous studies have suggested that these structures develop under the influence of a longitudinal compressive flow regime in the lower part of a rockglacier. However, these hypotheses have mostly been based on descriptive observations and therefore remained speculative.

Buckle folding is the mechanical response of a layered viscous material to compression if the mechanical contrast between the layers is significant. The resulting buckle folds are common structures in rocks and have been studied extensively in field outcrops, experimentally, numerically, and mathematically. We believe that buckle folding is also the main responsible process for the formation of the transverse furrow-and-ridge morphology on rockglaciers. 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.

The Murtèl rockglacier is an ideal case study due to its well-studied internal structure, which 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 the mathematical buckle folding expressions, which assume a single layer embedded in a weaker material. A 1 m-resolution digital elevation model (DEM) based on low-altitude aerial photographs of the Swiss Permafrost Monitoring Network, is analyzed using the Fold Geometry Toolbox (FGT). This software uses the mathematical buckle folding expressions and hence provides a quantitative relationship between the observed wavelength, layer thickness, and the effective viscosity ratio between the folded layer and the underlying ice.

We developed a numerical finite element (FE) algorithm to simulate dynamical 2D buckle folding of a layered viscous medium and apply it to the gravitational flow of a two-layer rockglacier. For the lower almost pure ice layer we use standard density and viscosity values for ice; for the upper mixed rock-ice layer we use material parameters obtained from the previous FGT-analysis of the Murtèl rockglacier DEM. The model setup is inspired by the Murtèl rockglacier geometry. The simulated gravitational flow leads to a buckling instability of the upper layer due to the mechanical contrast to the underlying ice layer. The resulting wavelengths and amplitudes are similar to the Murtèl rockglacier. In addition, the modeled deformation field highlights the basal shear zone and the quasi-parabolic deformation profile, both of which are also observed in boreholes.

Our study promotes buckle folding as the dominant process for the formation of transverse furrow-and-ridge morphology on rockglaciers.