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

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Abstract

Rockglaciers often feature a prominent furrow-and-ridge topography. Previous studies suggest that this morphology develops due to longitudinal compressive flow during rockglacier creep; however, no mechanical/physical explanation for the observed characteristic wavelength has been provided. Our study promotes buckle folding as the main process forming the transverse furrow-and-ridge morphology on rockglaciers. As a case study we chose the Murtèl rockglacier (Switzerland), which exhibits a spectacular furrow-and-ridge morphology. We analyse a high-resolution photogrammetrically derived Digital Elevation Model using analytical buckle folding expressions, which provide a quantitative relationship between the observed wavelength, layer thickness, and the effective viscosity ratio between the folded active layer and the underlying ice. We feed this geometrical and rheological information into a numerical finite-element model to simulate gravity-driven 2D rockglacier flow. A buckling instability develops and amplifies, self-consistently reproducing several key features of the Murtèl rockglacier, such as wavelength, amplitude, and distribution of the furrow-and-ridge morphology, as well as the quasi-parabolic flow profile observed in boreholes. Comparing our model with published flow velocities allows estimating the time necessary to produce the furrow-and-ridge morphology to about 1000-1500 years.

Numerical Finite-Element Model

Based on the geometrical and rheological information, a FE-model is designed:
• Fitting measured surface velocities (5–6 cm/a), and including both corrections due to the mechanical layering of rockglaciers.
• Uzawa-type iteration to enforce incompressibility
• Mixed velocity-pressure-penalty formulation (Galerkin method)
• Isoparametric triangular T7/3 elements
• Automatic mesh generation

Dynamic Rockglacier Flow Model

FE-simulations do not capture the shear zone deformation (base of rockglacier); hence only 40% of the total deformation is modeled (Arenson et al., 2002).
• 3D flow field (Fig. 1 & 2) slows down rockglacier flow compared to modeled 2D flow by about 35% (open-channel flow assumption).
• Fitting measured surface velocities (5-6 cm/a), and including both corrections above, our simulation predicts 960–1460 years to develop the furrow-and-ridge morphology, Time 1=480–730 yrs; Time 2=960–1460 yrs after initial state (Fig. 5).

Timing of Furrow-and-Ridge formation
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Discussion and Conclusions

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