Combining exposure dating, finite-element modelling, and feature tracking to decipher rockglacier evolution: A case study from the *Bleis Marscha* rockglacier (Val d'Err, Grisons)

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We attempt to reconstruct the formation of the *Bleis Marscha* rockglacier in the Val d'Err, Grisons (Switzerland). It is a one kilometer long, multi-unit talus rockglacier (Barsch 1996) with an active upper part that overrides a lower part. Lichen-covered boulders, vegetated, stabilized slopes, and signs of settling suggest that the parts below ~2500 m a.s.l. are relict. Internal front scarps separate the rockglacier into different units, each with its own activity phase. Morphological evidence suggests that the rockglacier started forming in the earliest Holocene.

Surface exposure dating with cosmogenic ^{10}Be and ^{36}Cl places a temporal framework (ka scale) on rockglacier movement periods (Ivy-Ochs et al. 2009). Furthermore, the present-day dynamics are numerically modelled using a two-dimensional finite-element approach to gain insights into the mechanical and material properties. Deformation above the shear zone is well captured by a linear viscous flow law (Frehner et al. 2015). The model is constrained with

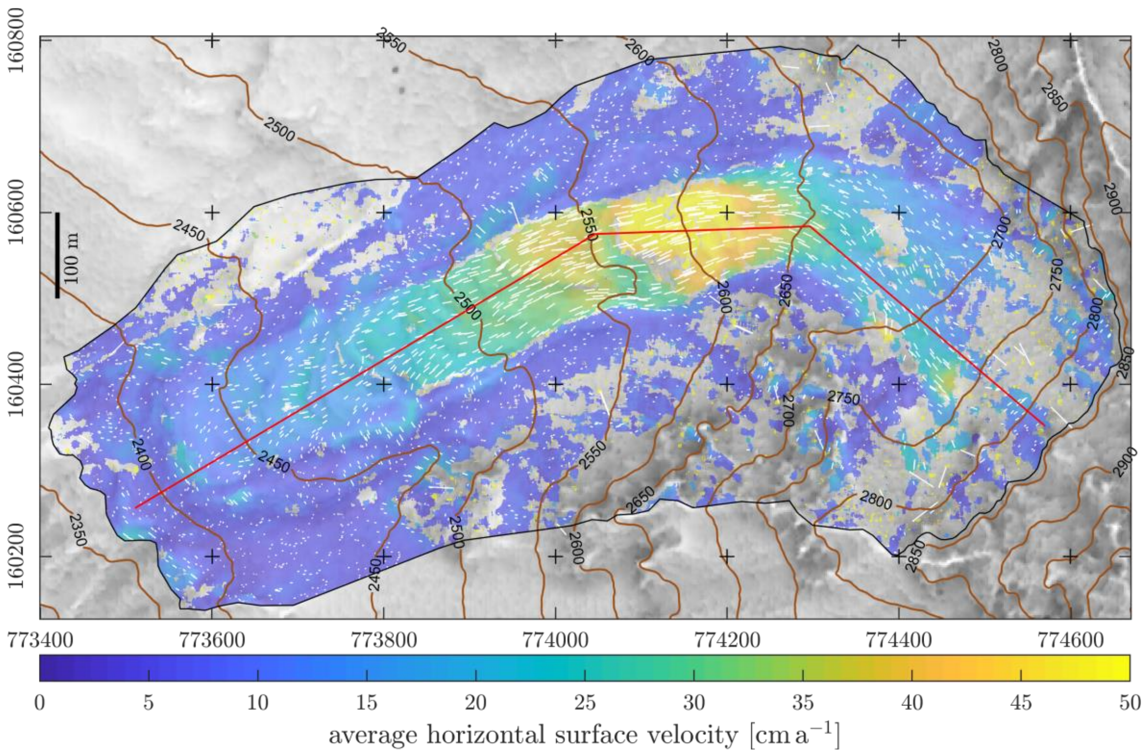

Figure 1. Noise-filtered horizontal surface velocity field 2003-2012 as obtained from feature-tracking analysis of orthorectified aerial images, draped over a sky-view map. Magnitude shown by colours, direction by white arrows. Significance level is 5 cm/a.

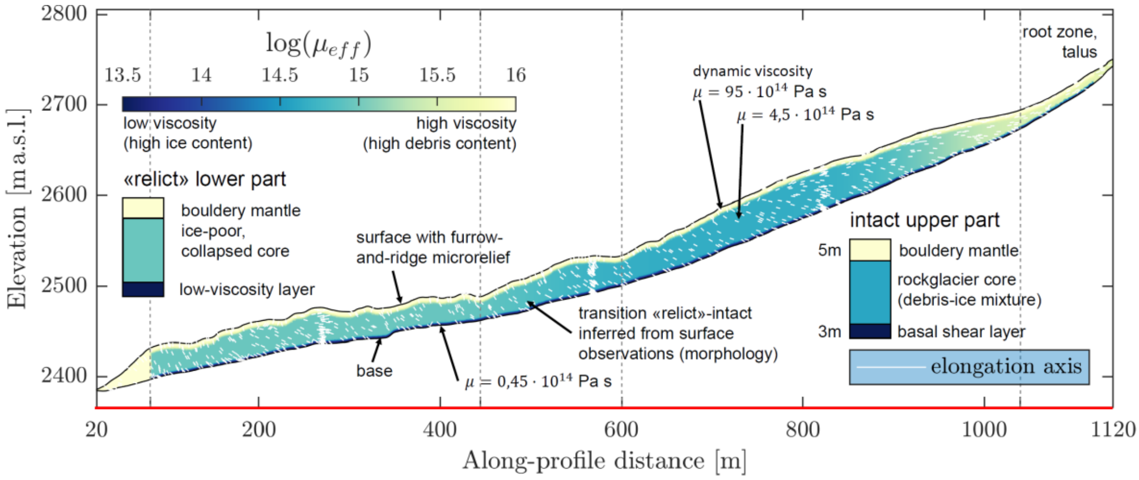

Figure 2. Inferred viscosity structure along a longitudinal section (trace in Fig. 1). Viscosity is interpreted as a proxy for ice and liquid water content.

horizontal surface velocities obtained from feature-tracking analysis of multitemporal orthorectified aerial images (Messerli & Grinsted 2015).

An illumination-invariant method for correlating the orthophotos (Fitch 2002) yielded reliable displacements on the rugged rockglacier surface. The image correlation results (Fig. 1) support the subdivision of the *Bleis Marscha* rockglacer in an active upper part, characterised by moderate to high surface velocities controlled by the topography on a 100-m scale, and a relict, collapsing lower part, characterised by an irregular surface velocity field strongly coupled to the small-scale topography (“effet camembert”). However, surface velocities of up to 30 cm/a on the apparently relict part could only be numerically reproduced assuming a considerable fraction of ice and/or water that weakens the material (Fig. 2). The subsurface ice either has been preserved throughout the Holocene or has reformed more recently.

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