Rockglacier flow law determined from deformation data and geomorphological indicators: An example from the Murtèl rockglacier (Engadin, SE Switzerland)

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Rockglaciers are tongue-shaped permafrost landforms creeping downslope due to gravity. They consist of unconsolidated rock fragments (silt/sand–rock boulders) with interstitial ice. Therefore, their creep behavior (i.e., rheology) may deviate from the simple and well-known flow-laws for pure ice.

During creep, rockglaciers develop typical flow structures (e.g., furrow-and-ridge morphology; Figure 1A) on time scales of decades to centuries. For the Murtèl rockglacier (upper Engadin valley, SE Switzerland), Frehner et al. (2015) reproduced these surface structures using a linear viscous (Newtonian) flow model. However, here we demonstrate why and how these flow structures provide much more detailed information about the flow law that governed rockglacier creep in the past centuries. In addition, we use the readily availabe deformation data (both borehole (Arenson et al., 2002; Figure 1B) and surface data) of the Murtèl rockglacier to further determine the flow law that governed rockglacier creep in the past decades and today.

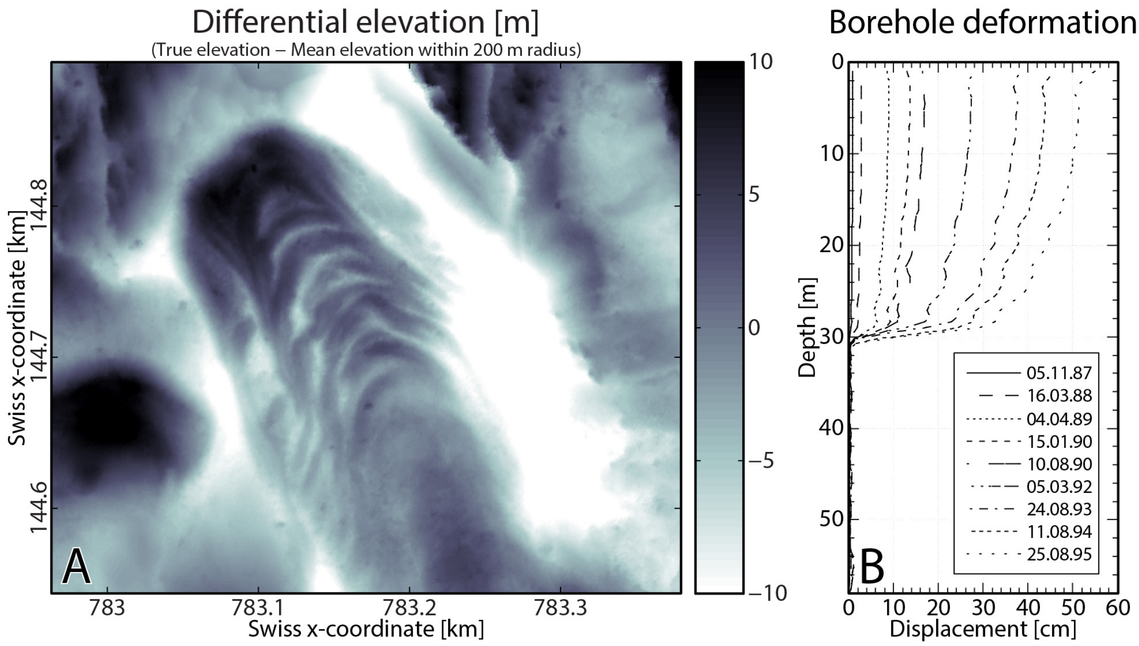
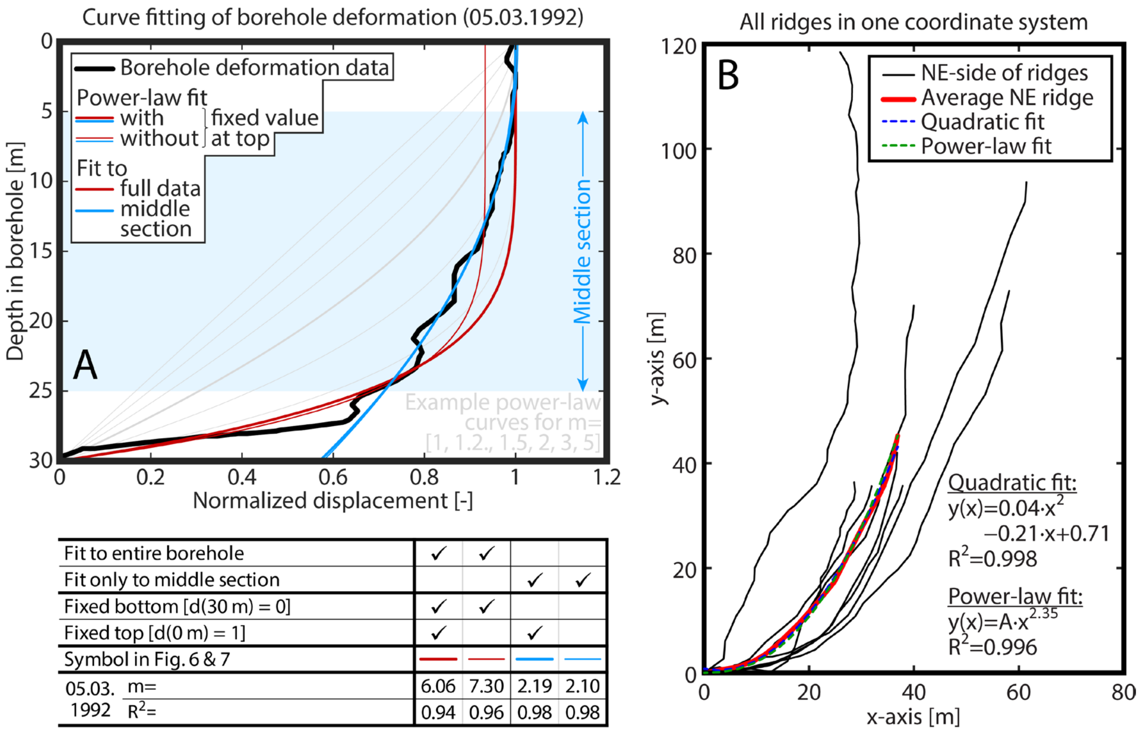


Figure 1. Base data for our study. A) Differential elevation model of the Murtèl rockglacier (Frehner et al. 2015). B) Time-lapse borehole deformation data (Arenson et al. 2002).

Both the surface flow structures (Figure 1A) and the borehole deformation data (Figure 1B) exhibit curved deformation in map view and in vertical direction, respectively. We use this curved flow geometry to constrain the viscous flow law governing the creep of the rockglacier. Linear viscous creep results in perfectly parabolic flow geometries; non-linear creep leads to non-parabolic flow geometries. Hence, by fitting theoretical functions to the curved flow geometry (Figure 2), we determine the non-linear viscous flow law that describes the rockglacier creep most adequately.



Fit to entire borehole	✓	✓		
Fit only to middle section			✓	✓
Fixed bottom [d(30 m) = 0]	✓	✓		
Fixed top [d(0 m) = 1]	✓		✓	
Symbol in Fig. 6 & 7				
05.03.1992 m=	6.06	7.30	2.19	2.10
R^2=	0.94	0.96	0.98	0.98

Figure 2. A) Borehole deformation curve and power-law fitting functions using different boundary conditions (curve fitting details in table). Best fits are obtained fitting only the middle section of the borehole. B) Digitized ridges on the NE side of the rockglacier (black) and calculated average ridge geometry (red). The latter is fitted with quadratic (blue) and power-law curves (green). Both fits work equally well.

Both the surface morphology (Figure 2B) and the middle section of the borehole (Figure 2A) are governed by a linear viscous rheology (i.e., close to quadratic flow geometry). However, considering the entire borehole (i.e., including the shear zone at about 30 m depth), a power-law flow law has to be used. Therefore, We interpret that the surface morphology is not controlled or influenced by the shear zone, but solely by the bulk rockglacier flow.

REFERENCES

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Frehner, M., Ling, A.H.M. & Gärtner-Roer, I. 2015: Furrow-and-ridge morphology on rockglaciers explained by gravity-driven buckle folding: A case study from the Murtèl rockglacier (Switzerland), Permafrost and Periglacial Processes, 26, 57–66.