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A rock-/ice mechanical model for the destabilisation of permafrost rocks

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The destabilisation of permafrost rocks is commonly attributed to changes in ice-mechanical properties (Davies et al. 2001). The effect of low temperatures on intact rock strength and its mechanical relevance for shear strength and brittle fracture propagation has not been considered yet. But this effect is significant since compressive and tensile strength are reduced by up to 50% and more when rock thaws (Mellor, 1973). Here we show, that the reduction of the shear resistance of rock-rock contacts in joints plays a key role for the onset of larger instabilities in thawing permafrost rocks.

Based on a Mohr-Coulomb assumption, we defined a failure criterion of an ice-filled rock cleft, with cohesive rock bridges, contact of rough fracture surfaces, ductile creep of ice and with a representation of rock-ice "failure" mechanisms along the surface and inside the ice body. The synoptic models are based on the principle of superposition, i.e. that shear stress "absorbed" by one component reduces the amount of shear stress applied to the other components.

Failure along existing sliding planes can be explained by the impact of temperature on shear stress uptake by creep deformation of ice, the propensity of failure along rock-ice fractures and reduced total friction along rough rock-rock contacts. This model may account for the rapid response of rockslides to warming (reaction time). In the long term, brittle fracture propagation is initialised. Warming reduces the shear stress uptake by total friction and decreases the critical fracture toughness along rock bridges. The latter model accounts for slow subcritical destabilisation of whole rock slopes over decades to millennia, subsequent to the warming impulse (relaxation time).

To test the importance of reduced friction, we conducted shearing tests on homogeneous fine-grained limestone specimen taken from a permafrost site (Zugspitze, Germany). In a temperature-controlled shearing box, we repeatedly tested mechanical properties of identical sand-blasted surfaces between +5° and –7°C. Normal stress was set to a level that equals 4 m rock overburden and promotes the shearing of the asperities on the fracture surface. First results show that the friction decreases by a mean value of approximately 30 % subsequent to thawing (even after enhanced fracture smoothing due to repeated shearing experiments).

Here we show, that thawing-related changes in rock-mechanical properties may dominate early stages of the destabilisation of larger thawing permafrost rocks irrespective of the presence of ice in the system. The models imply that only after the deformation accelerates to a certain velocity level (where significant strain is applied to ice-filled discontinuities) ice-mechanical properties outbalance the importance of rock-mechanical components. We present two quantitative models that relate the destabilisation of thawing permafrost rocks to temperature-related effects on rock- and ice-mechanics.