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Temporal and spatial variations in movement of a small rock glacier near the lower limit of permafrost in the Swiss Alps

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This study focuses on rock-glacier creep, which is downslope deformation of perennially frozen talus. Few have addressed internal movement of rock glaciers, although recent studies have revealed in detail the distribution, structure, surface movement and thermal conditions. In this study, field observations including direct monitoring of permafrost deformation were performed on a small rock glacier lying close to the boundary between permafrost and non-permafrost terrains in the eastern Swiss Alps.

The study site, BN rock glacier, is located on the northeastern slope of Piz dal Buez. The rock glacier consists of an upper lobe, 70 m long and 120 m wide, and lower lobe, 90 m long and 100 m wide. The upper lobe has a steep front 10 m high, dipping 35 degrees, while the lower lobe lacks a distinct front. The observations include excavation with portable drills, triangulation survey, inclinometer measurement, seismic and two-dimensional DC resistivity soundings and ground temperature monitoring. The surface temperature and movement have been observed from 1998, and the internal temperature and movement in the upper lobe from 2000.

The rock glacier has mean annual surface temperatures close to 0 degree C. A borehole 5.4 m deep dug on the upper BN showed ice-saturated pebbles and cobbles below a 2 m thick active layer. The permafrost temperatures were almost the melting point throughout five years. A DC resistivity tomogram also indicated that permafrost in the rock glacier is extremely warm and probably thinner than 20 m. The frontal parts of BN have an active layer thicker than 5 m, resulting from degradation of permafrost. The triangulation survey indicated that BN is active. The upper BN showed rapid movements (50-150 cm/a at the surface) with a large inter-annual variation, although the lower BN moved downslope very slowly. Two inclinometers installed at 4 m and 5 m depth also showed rapid deformation with large seasonal and inter-annual variations in permafrost.

The rapid movement of the upper BN is primary attributed to creep of the frozen debris close to 0 degree C, which contains a significant amount of unfrozen water. Whereas interlocked debris tends to strengthen permafrost, such unfrozen water may weaken the shear resistance of permafrost by reducing effective stress. In addition, the movement is sensitive to seasonal and inter-annual changes in ground thermal conditions, which are mainly controlled by the thickness and duration of snow cover. The rapid increase in deformation during the snowmelt period in each year implies that snow meltwater infiltrated into the permafrost, because of the quick response of movement in 4-5 m deep to change in surface temperature. In particular, the maximum seasonal acceleration in the spring 2001 appears to have resulted from a large amount of meltwater derived from the unusually thick snow cover. In contrast, the minimum seasonal acceleration in the next spring corresponded to the unusually thin snow cover in 2002.

The differences in movement and structure between the upper BN and lower BN suggest a sequence of inactivation of rock glaciers. Warming of a thin permafrost layer to the melting point makes a rock glacier much unstable and sensitive to seasonal and inter-annual variations in ground temperature (e.g. upper BN). Such an unstable condition is temporary and eventually followed by inactivation of the rock glacier because of insignificant debris input and progressive permafrost melting (e.g. lower BN).