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Pseudo 3D - P-wave refraction seismic monitoring of permafrost in steep bedrock: laboratory calibration, error assessment and field techniques

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Degrading permafrost in rock walls can cause instabilities due to changes in rock- and ice-mechanical as well as hydraulic properties. For the first time, we used seismic refraction tomography (SRT) to evaluate the degradation of permafrost in solid rock walls. Five parallel NE-SW transects were installed across a crestline on the Steintälli, Matter Valley, Switzerland, at 3070-3150 m a.s.l.. P-wave velocities were measured repeatedly during the summer 2006 and 2007, first arrivals were picked manually and traveltimes were compared and analysed.

P-wave velocity was calibrated in the *laboratory*. Two cuboid water-saturated samples were cooled from 20° to -5° C. P-wave velocity was measured parallel and perpendicular to the direction of cleavage. Parallel to the cleavage, P-wave velocities respond to freezing with a sudden increase from 5228±25 m/s (sample S1) and 5239±19 m/s (S4) to values of 5774±21 m/s (S1) and 5895±27 m/s (S4). Perpendicular to the cleavage direction, p-wave velocity increases from 1953±15 m/s (S1) and 1667±14 m/s (S4) to values of 4331±12 m/s (S1) and 4404±36 m/s (S4) respectively. Supercooled conditions were possibly observed between 0° C an 0.25±0.15° C (S4).

Traveltime analysis provides P-wave velocities in the range of the laboratory results and indicates permafrost existence. Initial P-Wave velocities of 3500 - 4000 m/s yielded best model fits, in terms of total absolute time difference. For all five transects and recorded time steps the total absolute time difference was 1.1-1.5 ms. Raytracing and ray density provide insight into the distribution of P-wave ray paths in the subsurface. Large ray densities up to 100 and more rays delimit the upper boundary between unfrozen and frozen bedrock and thus facilitate an accurate positioning of the upper limits of frozen rock (i.e. permafrost).

SRT was used to monitor monthly alterations of the thawing front in August and September 2006, as well as annual changes in August 2007. SR tomographies display permafrost close to the north face and below ice-filled fractures at the crestline mostly in depths of 4-8 m. Due to remaining snow cover or glacier ice contact, perennially frozen bedrock persisted close to the surface especially in 2007. In contrast to ERT, SRT provides a geometrically more accurate detection of the upper bedrock permafrost boundary and a novel independent tool for the validation of permafrost fluctuations in steep bedrock throughout time.