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Raw data analysis and sensitivity to initial model velocities of 2.5D - seismic refraction tomographies of permafrost in steep bedrock

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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. To evaluate the degradation of permafrost in solid rock walls we used seismic refraction tomography (SRT). Refraction seismic in steep permafrost rock walls is a non-trivial task due to high topography, anisotropic seismic behaviour of rocks, an unknown range of subsurface velocities and a curved ray penetration that is difficult to judge. Here, we propose to create (i) a priori information on P-wave velocity behaviour from laboratory testing, (ii) to perform traveltime raw data analysis, (iii) to evaluate initial models with different initial velocities and gradients and (iv) to restrict initial models using the laboratory velocity.

The test data set derives from the Steintaelli, Matter Valley, Switzerland, at 3070-3150 m a.s.l. five parallel NE-SW transects were installed. P-wave velocities were measured repeatedly during the summer 2006 and 2007, first arrivals were picked manually and traveltimes were compared and analysed.

(i) Laboratory P-wave velocity measurements were measured using two cuboid water-saturated samples cooled from 20° to -5° C. These show that parallel to cleavage velocity increases 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, 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.

(ii) First arrival traveltimes derived from field measurements were plotted against the source-receiver offset. The traveltimes resolve no distinct layers but P-wave velocities above 5.3 km/s indicate the existence of definitely frozen rock (see i).

(iii) The reconstruction of the subsurface velocity pattern is based on the adaption of synthetic traveltimes calculated by the SIRT algorithm to the observed traveltimes in REFLEXW. The choice of the initial model velocity and gradient influences the ray path propagation of seismic waves. We first tested initial model velocities between 2.0 and 5.5 km/s for several transects. Models with initial velocities of 3.5 and 4.0 km/s respectively show the best results with RMS values between 1.48 and 1.90 ms and total absolute time differences between 1.06 and 1.24 ms. The incorporation of velocity gradients between 0.2 and 1.0 km/s increased the ray density in depth but degraded the quality of the tomography .

(iv) The results of laboratory P-wave measurements of the rock samples provided a priori information about subsurface velocity and suggest the use of the more realistic initial model velocities of 4.0 km/s. Moreover, the maximum P-wave velocities was restricted to 6.0 km/s.

We argue that (i) a priori information on P-wave velocity behaviour from laboratory testing, (ii) traveltime raw data analysis, (iii) initial model evaluation with different initial velocities and gradients are needed to create reliable SR tomographies in steep fractured bedrock. Here we show, that such calibrated SR tomographies provide a geometrically highly-resolved subsurface detection of active layer dynamics in steep permafrost rocks at the scale of instability.