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The influence of ice-pressure on p-wave velocity in alpine low-porosity rocks: a modified time-average model

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Most polar and many mountainous regions are affected by permafrost. Seismic field and laboratory measurements represent a standard approach to investigate permafrost since the early 1970s. Laboratory research has focussed on arctic high-porosity sandstones, shales and carbonate rocks and results have been implemented in various seismic models (Carcione and Seriani, 1998).

However, alpine rock walls consist of low-porosity bedrock and some authors deny the applicability of seismic approaches to these (McGinnis et al., 1973). Models developed in high-porosity rocks explain bulk p-wave velocity of bedrock due to changing velocities in the pore infill (ice/water/air) while the matrix velocity of bedrock remains constant. Here we show, that in low-porosity rocks matrix velocities change considerably while changes in pore velocities are insignificant. Hence, p-wave refraction seismics is applicable in low-porosity alpine rock walls.

For this, we (1) present data of p-wave measurements of 23 different alpine rocks, (2) evaluate the influence of ice pressure on seismic velocities, (3) determine anisotropic decrease due to ice pressure and (4) extend Timur's (1968) 2-phase model for alpine rocks.

The tested rocks derive from alpine locations in Switzerland, Germany, Austria, France and Svalbard, and German sub alpine locations. All samples possess effective porosities lower than 6 %. P-wave velocities were measured parallel and perpendicular to cleavage or bedding in a temperature range from +20° C to -15° C in a WEISS WK 180/40 high-accuracy climate chamber. Rock temperature was monitored continuously with two or three calibrated thermometers; p-waves were generated with a Geotron ultrasonic transducer and measured with a Fluke Scopemeter.

(1) All rock samples show p-wave velocity increase dependent on lithology due to freezing. P-wave velocity increase is in the range of 7.33 (±3.73) % for Gneiss and 78.45 (±7.00) % for carbonate rocks parallel to cleavage/bedding; perpendicular measurements show an increase between 11.10 (±2.38) % for Gneiss and 166.01 (±56.93) % for carbonate rocks. The increase of p-wave velocity of carbonate rocks is independent of effective porosity.

(2) Velocity increase due to freezing is not only derived through higher velocity of ice in relation to water; ice pressure induces an increase of the velocity of the rock matrix. Matrix velocity increases parallel to cleavage/bedding between 5.08 (±4.08) % for Gneiss and 59.44 (±9.33) % for carbonate rocks; perpendicular measurements indicate matrix velocity increase reaching from 8.95 (±4.51) % for mafic metamorphic rocks and 168.53 (±62.00) % for carbonate rocks.

(3) Anisotropy decreases as a result of crack closure due to ice pressure in 15 of 23 rock samples. This effect is specially pronounced for schists.

(4) We extend Timur's (1968) 2 phase equation with a lithology dependent variable to increase the matrix velocity responding to developing ice pressure while freezing.

This study shows the general applicability of refraction seismics in low-porosity permafrost rocks. The expansion of rigid bedrock upon freezing is restricted and, thus, ice pressure will increase matrix velocity. Here, we present a modified "Timur (1968) 2 phase equation" implementing a 4-21 % change in matrix velocity dependent on lithology.

References:

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