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Laboratory methods for quantitative geophysics in permafrost bedrock

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Thawing and warming destabilise permafrost rocks in Alpine and Arctic Environments and cause rock creep and rock slope failure which pose high risks for infrastructure and individuals exposed to the hazard. The anticipation of rock slope hazards requires a detailed spatial assessment and monitoring of ice content, degree of fracturing and the thermal state of the system which is only possible with geophysical methods.

However, important geophysical targets such as P-wave velocity and resistivity of hard low-porosity rocks are often inadequately described in previous papers. This is important as low-porosity rocks constitute most hazardous steep rock walls and as the temperature range relevant for instability between –5°C and 0°C is significantly misrepresented in prior models.

We have tested P-wave velocity and resistivity paths of a double digit number of sedimentary, metamorphic and igneous rocks from Arctic and Alpine permafrost environments in a freezing chamber with a high thermal resolution (ca. 0.2°C) around the freezing point.

While previous papers state that low porosity rocks show no detectable change in P-wave velocity (McGinnis 1973), we can show they respond to freezing with a considerable velocity increase often from 8% to 10% (e.g. metamorphic rocks in the direction of cleavage and sedimentary rocks) up to 100% (e.g. metamorphic rocks perpendicular to the cleavage). Thus, seismics are capable of revealing the state of freezing between 0°C and –3°C in hard permafrost rocks walls.

The exponential increase in resistivity with declining temperature, evident for unconsolidated sediments, has often been transferred to hard low-porosity rocks. We can show that the exponential behaviour is still apparent in high-porosity rocks but is substituted by a bilinear temperature-resistivity behaviour in hard rocks. The steep linear resistivity increase below the freezing point is typically ten times steeper than the unfrozen T- path and, ideally, provides good information on the thermal state of hard frozen frock walls.

The accurate description of geophysical key parameters from –5°C to 0°C is a prerequisite for the spatial and temporal monitoring of instability propagation in steep permafrost bedrock. Here we show, that both, P-wave velocity and resistivity can reveal reliable quantitative information on the thermal state of hard permafrost rocks if their physics are accurately described.