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Long-term geoelectrical monitoring of laboratory freeze-thaw experiments on bedrock samples

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Much attention has recently focussed on the continuous and near-real-time geophysical monitoring of permafrost-affected bedrock with permanently installed sensor arrays. It is hoped that such efforts will enhance process understanding in such environments (permafrost degradation, weathering mechanisms) and augment our capability to predict future instabilities of rock walls and slopes. With regard to electrical methods for example, recent work has demonstrated that temperature-calibrated electrical resistivity tomography (ERT) is capable of imaging recession and re-advance of rock permafrost in response to the ambient temperature regime. However, field experience also shows that several fundamental improvements to ERT methodology are still required to achieve the desired sensitivity, spatial-temporal resolution and long-term robustness that must underpin continuous geophysical measurements.

We have applied 4D geoelectrical tomography to monitoring laboratory experiments simulating permafrost growth, persistence and thaw in bedrock over a period of 26 months. Six water-saturated samples of limestone and chalk of varying porosity represented lithologies commonly affected by permafrost-related instability. Time-lapse imaging of the samples was undertaken during multiple successive freeze-thaw cycles, emulating annual seasonal change over several decades. Further experimental control was provided by simultaneous measurements of vertical profiles of temperature and moisture content within the bedrock samples. These experiments have helped develop an alternative methodology for the volumetric imaging of permafrost bedrock and tracking active layer dynamics.

Capacitive resistivity imaging (CRI), a technique based upon low-frequency, capacitively-coupled measurements emulates ERT methodology, but without the need for galvanic contact on frozen rock. The latter is perceived as a key potential weakness, which could lead to significant limitations as a result of the variable quality of contact between sensors and the host material as it freezes and thaws. Our experiments have directly compared the CRI and ERT approaches. Numerical simulation of dense capacitive multi-sensor geometries shows that the basic assumptions of CRI remain valid for our experimental setup; as a consequence, conventional ERT methodology (including time-lapse inversion) becomes applicable to the capacitive measurements.

Permafrost processes tend to be multi-scale in space and time; any imaging technique must therefore be capable of resolving subtle changes in rock properties over a range of spatial scales and long periods of time. Frequent data acquisition (three times per 24-hour period) allowed us to obtain 3D resistivity models of all samples as the freeze-thaw experiment progressed. Data from different stages of the simulated seasonal cycles show that CRI is capable of imaging temperature-dominated changes in resistivity, associated with an approximate temperature range between 20°C and -5°C. Volumetric temperature models of the samples were obtained using calibration curves determined by separate freeze-thaw experiments using identical material. Below the freezing point temperature dominates the resistivity response and the resistivity-based temperature models show very good agreement with point estimates from temperature probes.

The CRI and ERT methodologies both hold promise for the systematic and strategic assessment of the thermal state of bedrock permafrost in the field using geoelectrical monitoring.