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How low-permeability rocks freeze: A laboratory study on resistivity pathways of thawed, supercooled and frozen permafrost rocks

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Resistivity – temperature paths are among the most important proxies in permafrost research. Testing 8 sedimentary, metamorphic and igneous rocks from European permafrost summits, we found evidence that the theoretical background developed in the 70s does not describe the physics of low-permability rocks correctly, which dominate these environments.

Saturated rocks with permeabilities below 10 μD have an equilibrium freezing point depression of -0.5°C to -1.55°C and indicate metastable supercooling effects between -0.5 and -1.4 °C. Instantaneous freezing from metastable stages occurs with sudden warming of the rock sample with up to 0.9°C temperature difference. This is due to the spontaneous dissipation of freezing energy subsequent to supercooling. Warming occurs over tens of seconds to a few minutes and coincides with a jump in resistivity.

Unfrozen and frozen temperature-resistivity paths match bilinear functions with an R^2 of 0.88 to 1.00. The frozen temperature-resistivity gradient is 12-34 times steeper that the unfrozen resistivity gradient. Low permeability may decide the ratio of frozen and unfrozen gradients while porosity influences the 0°C resistivity value and the unfrozen gradient. Here we show that separate linear approximation of unfrozen, supercooled and frozen temperature–resistivity behaviour provides a better explanation of involved physics than exponential fits.