EGU24-4423
EGU General Assembly 2024
© Author(s) 2024. This work is distributed under
the Creative Commons Attribution 4.0 License.

A comprehensive petrophysical databank of crystalline reservoirs for assessing deep geothermal exploration targets in Finland and abroad

Michael Heap[1], Alan Bischoff[2], Toni Luoto[2], Thierry Reuschlé[1], Satu Vuoriainen[2], Marion Spitz[1], and Marianne Leon-Stackow[1]
[1]University of Strasbourg, Strasbourg Institute of Earth & Environment, Strasbourg, France (heap@unistra.fr)
[2]Geological Survey of Finland (GTK), Vuorimiehentie 5, PO Box 96, 02151, Espoo, Finland

Context

As part of the Deep-HEAT-Flows project (https://deep-heat-flows.voog.com), we have collected a comprehensive geological and petrophysical dataset of crystalline reservoirs formed within fault zones and at the contact of igneous intrusions across Finland, evaluating their potential as deep geothermal reservoirs. Our investigations involve a range of laboratory-based experiments encompassing measurements of rock density, elastic wave velocity, electric resistivity, porosity, and permeability under various confining pressures, and the thermal properties of 120+ samples collected from diverse crystalline rocks. Additionally, we apply mineral and pore space caracterization techniques including petrography, micro-XRF spectrometry, SEM-EDS, hyperspectral imaging, and CT scans to understand the processes that control crystalline reservoir formation.

Findings

Our findings highlight a common trend among various petrophysiscal parameters: rock density, resistivity, elastic wave velocity, thermal conductivity, and heat capacity typically reduce as the porosity increases, a characteristic observed across many sedimentary and volcanic rocks. Reservoir quality is primarily determined by the morphology of the pore network, encompassing fractures and interconnected moldic, sieve, and interparticle pores. The most promising reservoir properties were observed in rocks intersected by regional shear zones and therefore affected by intense brecciation, cataclasis, and hydrothermal alteration, leading to a notable porosity of ~20% and permeability in the order of 10^{-12} m^2 (1 darcy). Moreover, the contact margin of rapakivi intrusions also include fractured and hydrothermally altered rocks that have significantly high porosity and permeability. In detail, rocks dominated by fractures typically have little porosity (<4%) and exhibit extremely high permeability (~10^{-12} m^2) only at low confining pressures, which sharply decreases to ~10^{-19} m^2 as the confining pressure surpasses 20–30 MPa (corresponding to depths around 700–1000 m). From our dataset, only fractures linked to mineral dissolution have the potential to sustain permeability above 10^{-16} m^2 at 50 MPa confining pressure (simulating depths of ~2 km). Conversely, rocks that underwent cataclasis and hydrothermal alteration exhibit comparatively milder permeability reductions, maintaining high values even when subjected to high confining pressures of 50 MPa. Throughout the entire dataset, a consistent observation emerges: mafic minerals are commonly substituted by chlorite and epidote, suggesting hydrothermal alteration processes occurring at relatively high temperatures (200–300 °C).

Implications for geothermal exploration

Exploring deep geothermal resources in crystalline settings offers a promising solution for direct space heating, industrial applications, and electricity generation. However, the typically low porosity and low permeability of crystalline rocks remain a key obstacle in deep geothermal exploration. The identification of hydrothermally altered rocks as potential deep geothermal reservoirs could mark a substantial shift in geothermal exploration within crystalline regions, broadening target prospects beyond the conventional focus on volcanic and rifting areas. Brecciation, cataclasis, fracturing, and mineral dissolution collectively contribute to the creation of exceptional reservoir properties, which have been widely overlooked in deep and ancient (over a billion years) crystalline settings. Our results hold paramount importance for identifying highly productive permeable zones within crystalline settings and also to the advancement of Enhanced Geothermal Systems that could prioritize the creation of more intricate fracture networks through thermal and chemical stimulation.