Crystal Clear: A Petrophysical Databank of Crystalline Rocks for Assessing Deep Geothermal Reservoirs in Fault Zones

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Keywords: Crystalline reservoirs, geothermal energy, petrophysics, hydrothermal alteration

Large petrophysical datasets are essential for assessing the performance of geothermal targets. As part of the Deep-HEAT-Flows project, we collected petrophysical data from crystalline rocks intersected by faults, including samples from outcrops and boreholes extending up to 2 km deep across Finland. We analyzed the density, electrical resistivity, magnetic susceptibility, elastic wave velocity, porosity, permeability, and thermal properties of over 300 rock samples, generating a comprehensive dataset that captures the petrophysical variations across fault zones. To understand the key controls on reservoir formation and determine their age, we conducted detailed mineral and pore space characterization on targeted rocks using petrography, micro-XRF, SEM-EDS, X-ray CT scans, and isotope dating. Our findings reveal a clear relationship between brittle deformation, hydrothermal alteration, and enhancement of reservoir properties. Most petrophysical parameters decrease as porosity increases, a pattern also observed in sedimentary and volcanic rocks. Porosity and permeability are typically directly proportional and controlled by the degree of brittle deformation and alteration processes. Altered and brecciated rocks from fault cores exhibit the highest porosity (up to 30%) and permeability (up to 1.5×10^{-11} m² = 15 Darcy). Fractured rocks from fault cores and damage zones show low porosity (2–5%) and high permeability (up to 8×10^{-13} m²) at unconfined pressure. Massive rocks, with the lowest porosity (<2%) and permeability ($<1.23 \times 10^{-17}$ m²), primarily occurs at host blocks. At increasing confining pressure, altered rocks demonstrate minimal reduction in porosity and permeability, underscoring their reservoir potential for heat and fluid flow at greater depths. Hydrothermal alteration and leaching of mafic minerals, feldspar, quartz, and garnet are often linked to the formation of secondary porosity and minerals like chlorite, epidote, zeolite, prehnite, and titanite. These alterations result in moldic, intracrystal, and sieve pores, achieving up to 60% and, in some cases, 96% pore connectivity at 11 µm CT scan resolution. We performed U-Pb isotope dating of secondary titanite to serve as a proxy for the age of porosity formation, indicating Paleoproterozoic ages and challenging the conventional perception that Precambrian shield rocks are typically sealed by mineralization. To provide a first-order estimation of heat production in a typical Finnish geothermal setting, we conducted a sensitivity analysis of hypothetical reservoirs based on our new petrophysical dataset. Results indicate that a 3 km-deep doublet EGS constructed within fault-related crystalline reservoirs could deliver an average power capacity of nearly 3 MW_{th} over a 50-year production scenario. Our databank will be made publicly available for future research, providing valuable information for modeling and assessing geothermal targets beyond traditional volcanic and rifting areas.