Hydrothermally altered shear zones: a new reservoir play for the expansion of deep geothermal exploration in crystalline settings

Alan Bischoff[a], Michael J. Heap[b], Perttu Mikkola[a], Jukka Kuva[a], Thierry Reuschlé[b], Ester M. Jolis[a], Jon Engström[a], Heini Reijonen[a], Tuomas Leskelä[a]

[a] Geological Survey of Finland (GTK), Vuorimiehentie 5, PO Box 96, 02151, Espoo, Finland, [b] Institut Terre et Environnement de Strasbourg, UMR 7063, Université de Strasbourg, CNRS, 5 rue René Descartes, F-67084 Strasbourg Cedex, France

Context

This abstract introduces an innovative approach to deep geothermal exploration in crystalline settings. Traditionally, geothermal energy production has relied on the exploitation of permeable reservoirs, which are rarely found in crystalline settings. However, recent research has unveiled a promising reservoir play—brittle shear zones that have undergone hydrothermal alteration—that could leverage the expansion of deep geothermal exploration in crystalline settings.

Scientific challenges

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. Faults and fractures are understood to play a substantial role in defining permeable zones that facilitate efficient heat extraction from crystalline reservoirs. Nevertheless, fractures constitute just a part of the potential void space in crystalline rocks. Besides fracturing, the effects of other equally important processes such as brecciation, cataclasis, and mineral dissolution have received limited attention as potential contributors to creating prolific crystalline reservoirs.

Methodology

Our study involves a comprehensive geological and petrophysical investigation of granitic reservoirs formed within a brittle shear zone in central Finland, evaluating their feasibility as deep geothermal targets. This investigation combines petrography, hyperspectral imaging, CT scans, micro-XRF spectrometry, and a suit of laboratory-based experiments (i.e. porosity, permeability, density, elastic wave velocity, and thermal conductivity) to characterize the reservoir performance of these granites.

Discoveries

Optimum reservoir properties were observed in granites affected by cataclasis and mineral dissolution, leading to a notable porosity of ~20%. Reservoir quality is largely controlled by the pore network morphology. Alongside fractures, interconnected moldic, sieve, and interparticle pores contribute to substantial permeability of $\sim 5 \times 10^{-14}$ m^2 (50 mD), even under high confining pressures of 50 MPa (~2 km deep). These processes are typical of brittle shear zones that have undergone high-temperature (200–300°C) propylitic alteration, which have the potential to create extensive (>100 m) interconnected crystalline reservoirs. Additionally, we find that granites dominated by fractures only have high permeability ($\sim 10^{-12}$ m^2) at relatively shallow depths, which sharply decreases to $\sim 10^{-21}$ m^2 as the confining pressure increases. Conversely, granites that have undergone alteration and brittle shearing exhibit comparatively milder permeability reductions as confining pressure increases.

Implications for geothermal exploration

The discovery of hydrothermally altered shear zones as viable geothermal reservoirs may represent a paradigm shift in deep geothermal exploration in crystalline settings. Highlighted is the pivotal role of pore-network morphology in altered and brecciated granites, bearing great significance for identifying prolific permeable zones in crystalline settings. This observation is of paramount importance not only for finding prolific permeable zones within crystalline settings but also for advancing Enhanced Geothermal Systems (EGS), which could mimic natural reservoirs by prioritizing the development of intricate fracture networks through thermal and chemical enhancements.