

Mass and energy transport in subduction system as supercritical geothermal resources

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In Japan, we are living on subduction zone and our Earth scientists always recognize mass and energy transport processes are one of essential phenomena for Earth scientific events such as earthquake and volcanic eruption. Establishing stable supplies of energy and metal resources and realizing carbon neutrality are urgent issues that need to be addressed to maintain an Earth that can support a sustainable human society. Effective harnessing of fluids circulating in subduction zones could be a game changer for Japan, both in terms of energy and resources as **"Sustainable Terrestrial Energy & Resources (SusTER)"** in achieving an SDG-oriented society. NEDO (New Energy Developing Organization) is planning engineering project of supercritical geothermal resources, and currently four candidates are nominated for pilot drilling.

A granite–porphyry system, associated with hydrothermal activity and mineralization, provides a adequate natural analog for studying a deep-seated geothermal reservoir for energy and metals where stock-work fracture systems are created in the presence of supercritical geothermal fluids. In this condition, fracture networks and their formation mechanisms were realized on the basis of petrology and fluid inclusion studies in order to understand this “beyond brittle” supercritical geothermal reservoir (Tsuchiya et al., 2016).

The hypothesis that the brittle–ductile transition (BDT) drastically reduces permeability implies that potentially exploitable geothermal resources (permeability $> 10^{-16}$ m²) consisting of supercritical fluid could occur only in rocks. Our research group performed experimental results suggesting that the BDT is not the first-order control on rock permeability, and that potentially exploitable resources may occur in rocks with much lower BDT temperatures, such as the granitic rocks that comprise the bulk of the continental crust even in subduction zone. We obtained empirical equations for this permeability behavior suggest that potentially exploitable resources exceeding 450°C may form at depths of 2–6 km even in the nominally ductile crust (Watanabe et al., 2017).

Thermodynamic behaviors of supercritical fluids and mineral equilibrium are unstable due to the non-applicability of the Helgeson–Kirkham–Flowers (HKF) electrostatic model for aqueous species in low-density regions. Our research group experimentally investigated the dissolution equilibria of albite–K-feldspar–quartz in hydrothermal solutions at 400, 420°C and 20–35 MPa, and compared the experimental results with thermodynamic calculations. The thermodynamics data based on the HKF model available through SUPCRT92 were extrapolated into the low-density regions with water density. Our results suggest that the extrapolated data are useful as a first approximation for evaluating feldspars–fluid equilibria even under supercritical and low-density hydrothermal conditions (Okamoto et al., 2021).

These fundamental works provide the academic impetus and motivation for this research from the Earth science perspective. However, the energy problem is not simply an Earth science issues. The release of energy in the island arc-subduction zone system is also of key societal importance, for instance when it appears in the form of hot springs and is used as geothermal energy. To realize the holistic understanding of the energy cycle, we will combine the Earth science studies with analyses from the social scientific perspective.

I would like to describe current research status of development of supercritical geothermal resources in

terms of mass and energy transport of fluid in subduction zone coupled with experimental works, particularly as an example of Northeast Japan.

Selected references :

Okamoto et al. (2021), *Geothermics*, 94(2021)102109

Tsuchiya et al. (2016), *Geothermics*, 63, 182-194

Watanabe et al. (2017) *Nature Geosciences*, DOI:10.1038/NGEO2879

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