Silica dissolution and precipitation in granite fracture and its implications to porosity evolution in deep geothermal reservoirs

*Atsushi Okamoto[1], Hiroto Tanaka[1], Noriaki Watanabe[1]

1. Graduate School of Environmental Studies

The solubility of silica in water changes significantly as function of pressure and temperature, and thus dissolution and precipitation of silica minerals could affect the spatial and temporal of porosity and permeability of the Earth’ s crust. A profile of silica solubility along the deep drilling well of the Kakkonda geothermal field (Saishu et al., 2014) revealed that the solubility reaches maximum at around 350 degreeC, and that it decreases to the local minimum at around 400 degreeC. The depths of maximum and minimum silica solubility correspond to those at prominent seismic reflectors and at permeable-impermeable boundary, respectively. To understand the long-term behaviors of the deep reservoirs, we conducted hydrothermal flow through experiments for dissolution and precipitation experiments with using granite fracture. We developed a new apparatus, which realizes experiments under supercritical conditions with confining pressure. The core of Aji granite (10 mm in diameter and 20 or 40 mm in length) with tensile fracture was covered by thin SUS jacket, which enables us to capture X-ray images repeatedly.

In the dissolution experiments at T = 350 degreeC and P_{fluid} = 20 MPa, the output solution of dissolution of granite plates contains 90 ppm of Si, 4-10 ppm of Al, Na and K, indicating that the dissolved quartz volume was at least 2 times greater than feldspars. This is consistent with the formation of pockets on quartz surfaces. Then we conducted the dissolution experiments with a sample with a tensile fracture with effective confining pressure of 20 MPa. The permeability decreased at initial 1 hour, and then increased about one-order within 10 hours. The average aperture increased from 0.02 to 0.06 mm. The 2D aperture maps before and after the experiments by X-ray CT indicate that quartz grains on the fracture surface was dissolved preferentially, but more interestingly a large connected pore was produced along the wall of the reaction tube, which acts as preferential flow path. Such large pores were produce by dissolution of gauges (fine powders of granites), which generated in the time of tensile fracturing. The gauges in natural fractures and faults posses huge surface areas, and the dissolution of such particles could change the porosity of the rocks fractures. Our experiments revealed that preferential dissolution of quartz and gauges within granite fracture produce heterogeneous apertures with fluid pockets. Such a pockets would be sustained by less-reactive feldspars grains, which correspond to fluid pockets as observed as seismic reflectors.

In the precipitation experiments T = 400 degreeC, P_{fluid} = 25 MPa, we used a high supersaturated solution (saturation ration $C_{Si}/C_{Si,Qtz,eq}$ = 5.2). To reveal the effects of mineral precipitation clearly on porosity and permeability evolutions, the applied effective confining pressure was samll (< 1MPa). Within 10 hour, permeability decreased in one order, and experiment was stopped when fluid pressure difference reached at 10 MPa. Most of the parts of the fracture shows a homogeneous decrease in aperture from 0.05 to 0.02 mm, but it is not enough to explain the signify permeability drop. Instead, at the inlet of the fracture (< 2mm from the inlet), preferential precipitation of silica was observed. Silica precipitation occurs not only as overgrowth of pre-existing quartz surface, but also precipitation as fine grained quartz crystals and amorphous silica covering fracture surfaces uniformly; accordingly, fracture was clogged effectively. The influx of high Si solution in our experiments may correspond to downward-flow along the geotherm with a significant solubility drop, or fluid pressure drop by breakage of impermeable layer. Our results suggest that, in such situations, self-sealing by silica plays a primary control to formation and maintenance of impermeable layers, but that such impermeable layer could be thin.

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