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Evolution of porosity structures in a fracture during quartz vein formation

YAMADA, Ryo[1*] ; OKAMOTO, Atsushi[1] ; SAISHU, Hanae[1] ; NAKAMURA, Michihiko[2] ; OKUMURA, Satoshi[2] ; SASAKI, Osamu[3] ; TSUCHIYA, Noriyoshi[1]

[1]Tohoku university, [2]Tohoku university, [3]The Tohoku university museum

Ubiquitous occurrences of quartz veins suggest that dissolution/precipitation of silica provides significant effects on the hydrological and mechanical properties within the crust. For example, a model has been proposed that fracture sealing processes control the change of pore fluid pressure and thus earthquake cycle. Previous studies on natural quartz veins have focused on estimates of P-T conditions, stress and strain fields and fluid compositions; however, details of dynamics of fluid flow and how fractures are sealed during vein formation are still unclear. In this study, we synthesized quartz veins by the hydrothermal experiments, and observed the aperture structures by using X-ray CT to clarify how aperture structures evolve during vein formation.

We conducted the hydrothermal flow-through experiments for quartz precipitation from Si-supersaturated solutions under controlled high temperature and high pressure condition. The experimental apparatus consists of two vessels for preparation of the Si-supersaturated solution and for precipitation, respectively. The precipitation vessel has double-structure : the main flow path was the inner alumina tube (diameter=4mm), and the outer SUS tube was filled with static solutions. The advantage of this system is that we can take out the non-destructive sample for the X-ray CT analyses. We conducted two types experiments: first one is precipitation in porous media with alumina balls, the second one is rock slice as analog of a fracture.

In the alumina-ball experiments, we carried out the precipitation experiment at supercritical (430C, 30MPa) and vapor condition (370C, 20MPa). In both experiments, the significant silica precipitation within few days, but showed contrasting porosity structures. Under supercritical condition, amorphous silica was predominantly formed with covering the surfaces of the alumina balls and alumina tube, and discrete quartz crystal (50 um) within the amorphous silica layers. The porosity (ϕ) gradually decreases with minimal porosity (ϕ = 0.4) at $\sim$ 38mm from the inlet. In contrast, under vapor condition, fine-grained quartz grains (0.1-1 um) were directly nucleated in solutions using surface of vapor, and immediately settled on the bottom. The porosity rapidly decreases from 18 mm (ϕ = 0.8) to 25 mm (ϕ <0.1) from the inlet. These results suggest that a depressurization of crustal fluids related to fault dilation by earthquakes would cause a formation of fine-grained silica particles, and their mineralogy and transport/deposition properties strongly depend on properties water.

In the experiment with rock slits, we evaluated the effect of rock substrate (amount and distribution quartz in the fracture wall). The P-T conditions and solution chemistry are similar to the previous experiments, but we used granite core with a slit ($\sim$ 300 um). The mineralogy and aperture structures changes systematically along the fluid flow path. From the inlet to 35 mm of fracture, nucleation of quartz and other silica polymorphs predominantly occurred, regardless of vein wall minerals. From >35mm low Si concentration, silica precipitates occurred as epitaxial overgrowth from quartz crystal. The wavelength of aperture structures is controlled by distribution and grain size of quartz of the host granite. Accordingly, fractures are not sealed homogeneously, but complex flow pathways are evolved during vein formation. Such a variation in the precipitation mechanism and porosity structures during quartz vein formation may affect the evolutions of permeability and strength of rock fractures in the Earth's crust.

Keywords: Hydrothermal experiments, Quartz, Vein, Fracture, Porosity