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Dynamic change of flow rate in impermeable fault rock

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Hydrological and hydro-geochemical changes are often observed soon after big earthquakes at active faults and hot springs, and a part of them were caused by a rapid change of permeability structure of a fault zone. Change of fluid transport properties in fault zones plays an important role in dynamic processes during large earthquakes as well as earthquake cycle processes. However, the physical and chemical processes responsible for the evolution of hydrological properties in fault zones during earthquake are not well known.

Therefore a rotary shear testing apparatus at Kochi Core Center was used to understand the physical process for the changes of fluid transport properties in a fault zone by real-time measurement of gas flow rates during and after frictional sliding.

We prepared a pair of hollow cylinder (inner diameter=9 mm, outer diameter= 25 mm, length=20 mm), and to demonstrated the frictional sliding, one cylindrical specimen was fixed and the other rotated under a fixed axial stress. To measure the permeability, radial flow from the inner wall to the outer wall of the specimen was induced by applying a differential pore pressure between the inner and outer walls. Real-time change in permeability is evaluated by monitoring the flow rate during the frictional test. Nitorgen gas was used as a pore fluid. We conducted friction tests at various slip rates (0.076 mm/s to 190 mm/s) and 2 MPa of normal stress with 1.5m of displacement. We used Aji granite in friction tests, and gas permeability of intact host rock that shows 10^{-19} m^2 was lower than that of the simulated fault specimen before sliding (10^{-16} m^2 at 2 MPa of normal stress, and 10^{-18} m^2 at 50 MPa).

Permeability is changed during the sliding in all tests, and when initial permeability is smaller than 10^{-17} m^2, average flow rate during sliding increases, on the contrary, flow rate decreases during sliding when initial permeability is larger than 10^{-17} m^2. Flow rate decreased by 10 % of the flow rate at the end of sliding, reaching a steady state within ten minutes, but for slip velocities greater than 50 mm/s, the flow rate increased after the end of sliding. The reduction in flow rate after sliding is probably caused by the thermal expansion of sliding surface due to frictional heating, and the cooling after sliding decreased the aperture and results in the decrease in permeability of slip surface. Increase in flow rate at high velocity condition is induced by the increase in viscosity of nitrogen gas by frictional heating.

At the same slip velocity, average flow rate during sliding is proportional to coefficient of friction. Slip surfaces of hollow specimen is partly covered with sheet silicate fine-grained gouge layers, and the gouge layers imply low friction and low permeability. Therefore the increase in the ratio of gouge materials among the contact area will induce a reduction in flow rate that associates with lower friction and permeability. A connectivity of sheet-silicate gouge layers will influence on the permeability as well. In the future, we can estimate the friction coefficient from the flow rate or permeability of sliding surface of active fault zone by applying our study.

Keywords: permeability, frictional heating, wear, earthquake, fault, flow rate