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Permeability structure and permeability evolution of the fault systems in a shallow depth of Nankai subduction zone

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Fault slips during earthquakes can cause the dynamic change in hydraulic properties around fault slip surface, and this change will influence on the fault slip behavior. However, it is not well understood that how much hydraulic property will change due to fault slip including slip velocity dependence on the change of hydraulic property. Here, we measured fluid transport properties at effective pressure of 40 MPa in core samples from the megasplay fault system and the frontal thrust in IODP NanTroSEIZE drilling project Expedition 316. In addition, we estimated the change of hydraulic property in fault rocks by slip deformation using the same core samples.

Permeability and specific storage of the fault zone at the megasplay fault system (Site C0004) and the frontal thrust (Site C0007) shows $7.6*10^{-18}$ m^2 and $8.6*10^{-9}$ Pa-1, and $8.7*10^{-18}$ m^2 and $5.8*10^{-9}$ Pa-1, respectively. Hydraulic diffusivities of both fault zones at shallow depth were about $1*10^{-6}$ m^2/s, which is small enough to cause the dynamic fault weakening by the pore pressure generation. Stratigraphic variation of transport property indicates that the megasplay fault zone can act as a seal to fluid flow, though fault zone at frontal thrust may not.

We used the core samples from the fault zones to estimate the permeability change by sliding deformation. To simulate fault gouge material, the fault breccia and fractured siltstone samples were roughly crushed with an agate mortar and pestle and sieved to retain only grains of less than 0.2 mm diameter. A 1g sample of gouge, which has about 1 mm thickness, was placed between a pair of quartz rich sandstone cylinders from India (12 ~ 14 % of porosity, 10^{-15} ~ 10^{-16} m^2 of permeability) of about 25 mm diameter and 20 mm length. A gouge layer was shared by rotating the one of the cylinders to produce the fault slip. To evaluate the shear-induced permeability change, permeability was measured in the ascending order; 1) A pair of sandstone cylinders, 2) Simulated fault rocks before friction test (sandstone cylinders and a gouge layer), 3) Simulated fault rocks after friction test. Friction tests were performed on the gouge samples by using the high-speed rotary-shear testing apparatus in Kochi Core Center. Friction tests were performed at 1.5 MPa of normal stress and 150 rotation (about 8m slip displacement). We performed friction test at 3 different conditions; a) high-velocity sliding at 1m/s with fully water saturated, b) low-velocity sliding at 0.013 m/s with water saturated, and c) high velocity sliding at 1m/s with dry (unwetted) condition. Simulated gouge layer showed $2*10^{-18}$ m^2 ~ $4*10^{-19}$ m^2 in permeability, and the gouge permeability was one order of magnitude smaller than bulk permeability. Permeabilities in both fault gouges were decreased after sliding in wetted condition, and permeability reduced much larger in low velocity friction test than that in high velocity friction. On the other hand, permeability after sliding deformation in dry condition was increased.

We assume that shear compaction and fining of grain size by shear deformation around the slip surface reduced permeability of gouge layer. However, in high velocity friction, permeability reduction was prevented by the expansion of gouge layer due to thermal pressurization mechanism. It is supposed that permeability enhancement by dry friction experiment was a result of thermal cracking and thermal expansion of gouge layer.

Keywords: Nankai Trough, NantroSEIZE, permeability, permeability evolution, fault zone, thermal pressurization