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Permeability evolution of oceanic basalt at Nankai subduction zone: implication from on shore basalt at Shimanto belt

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A large slip displacement was observed at shallow portion of the plate boundary fault during 2011 Tohoku earthquake, and this slip has contributed to cause a huge tsunami disaster. One of possible mechanisms that caused the large slip is a formation of excess pore pressure zone, which can reduce the fault strength for a long period of time, at middle to deeper portion of subduction zone. The excess pore pressure can be generated by chemical dehydration, fluid influx from deeper crust and pore volume reduction which associates with permeability reduction at a large subduction plate boundary. The same process would be caused at the Nankai Subduction zone as well. Fluid transport properties (i.e. permeability, porosity) and their changes during subduction can strongly influence on the pore pressure generation. In the present study, the evolution of fluid transport properties for oceanic basalt at Nankai Subduction zone are investigated by measuring the transport properties for basaltic rocks from the on shore Shimanto belt, South-western Japan.

We collected basalt brocks in the Cretaceous Shimanto accretionary complex of Japan from Okitsu-Kozurutsu, Kure, Mugi (Upper and Lower), and Makimine sites in the southeast Japan. Vitrinite reflectance value, Ro, that is the indicator of the maximum experienced temperature, ranges from 1 to 4.5 in our samples. The basalt from Lower Mugi site shows the lowest value, and the largest value is observed in Makimine site. We measured porosity, elastic wave velocity, and rock electric resistivity of each basalt at atmospheric pressure and room temperature. Permeability was measured at room temperature and under confining pressure from 1 to 160 MPa. The steady state gas flow method was applied to evaluate the permeability by using N_2 gas as a pore fluid. Pore pressure at the upper end of the specimen was kept at constant pressure from 0.05 to 2 MPa to apply constant differential pressure, and mass flow rate at atmospheric pressure that flows out from the lower end of the specimen was measured.

The permeability testing results show gas permeability was proportional to the inverse of the pore pressure at the same confining pressure. This trend agrees with the Klinkenberg effect, therefore most of the gas permeability data were transformed to 'water' permeability using the relationship between gas permeability and pore pressure. Permeability of all samples decreased with an increase of confining pressure, and permeability decreased three orders of magnitude by increasing confining pressure from 5 to 120 MPa. Permeability was lower for more maturated basalt, and permeability of the Lower Mugi basalt was $7*10^{-18}$~$9*10^{-19}$ m^2 and that of Makimine basalt showed the lowest value of $2*10^{-22}$ m^2. Variation of permeability in the same unit varied from 1 to 2 orders of magnitude. Pore diameters for all samples showed less than 0.01μm, which is the lower limit of the machine.

Permeability reduction by the diagenesis is consistent with the reduction of porosity, and this indicates that a reduction of pore diameter and pore volume induced by a mechanical and chemical compaction during subduction caused gradual permeability reduction. Internal structure of basalt observed from the μX-ray CT image suggests the variation of the permeability in the same unit is influenced by the variation of fracture density for the basalts.

Our results suggest that both pore volume and permeability reductions can significantly contribute to pore pressure generation. Therefore, timing and area of high pore pressure generation can be controlled by the evolution of permeability and porosity with subduction.

Keywords: permeability, diagenesis, pore pressure, Nankai earthquake, Shimanto belt, basalt