Permeability and porosity evolution during progressive deformation on the Miura Group siltstone

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Many applications in geology, environmental science, engineering and seismology require good estimates of permeability and porosity evolution in response to pore collapse, dilatancy, and grain-redistribution due to deformation. There are various studies about permeability and porosity evolution during progressive deformation on low-porosity rocks. In contrast, the current understanding of the effect of stress on permeability in porous rocks (10-30 %) is less comprehensive because in some cases permeability increases with an increase of axial strain and in other cases decreases. Therefore, in this study, first of all, permeability and porosity of Miocene Miura Group, which has higher porosity (40-50 %), were measured under triaxial deformation condition to understand the behavior of permeability and porosity changes during deformation. Hydrostatic condition tests were also conducted to examine basic hydrological properties of the Miura Group, and these properties were compared with those of Nankai mudstone, site 1174 ODP core.

The Misaki formation, which is the lower part of the Miura Group, was assumed to be accretionary prism. Permeability and porosity of samples taken from all formations of the Miura Group were measured at confining pressure from 3 to 100 MPa and constant pore pressures of 0.2-1 MPa. As a result, permeability and porosity of the Miura Group decreased with an increase of effective pressure. Permeability of the Miura Group sandstones showed at the value of range from 10^-13 to 10^-15 m^2 and permeability of siltstones showed at the values of range from 10^-13 to 10^-17 m^2. Permeability of all formations crucially depended on sedimentary age. Porosity of the Miura Group sandstones showed at the values from 63 to 52 % and that of siltstones showed at the values from 50 to 43 %. Porosity of the Misaki formation showed higher value than that of the Nankai accretionary prism at the same age and depth. In the cyclic compaction experiments for Misaki siltstone and Nankai sandstone, porosity of the Misaki siltstone elastically decreased with an increase of effective pressure until 50 MPa and then its porosity change showed non-elastic behavior beyond the yielding point of 50 MPa confining pressure. In the case of the Nankai mudstone, porosity change showed non-elastic behavior in all effective pressure conditions. Porosity reduction rate of the Miura Group siltstone showed lower than that of the Nankai trough mudstone under low confining pressure condition.

In the deformation experiments, permeability and porosity showed linear decrease with an increase of axial strain before dynamic stress drop, and approximately increased nonlinearly after dynamic stress drop under low confining pressure. Under high confining pressure, permeability and porosity also showed linear decrease with an increase of axial strain before yielding points, but decreased nonlinearly after yielding points. Then measured axial strains were divided into two components of elastic strain and plastic strain. Only non-elastic changes on porosity were extracted and then non-elastic changes on porosity as a function of plastic strain were plotted. As a result, at the beginning of plastic strain evolution, plastic porosity change showed positive and then showed negative beyond a certain strain. Theoretical yielding points was estimated from experimental results using the Cam clay model, which is based on the soil mechanics, and this experimentally evaluated yielding point showed slightly higher than model predicted one. This discrepancy might be caused by no consideration of bond force between grains observed in Misaki siltstone.

Our results imply higher porosity of the Miura Group than that of Nankai trough is caused by the differences in compressibility and structure material, and the deformation under low confining pressure.