

Effects of stress relaxation and clay mineral contents on permeability changes of mudstones during fracturing processes

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An understanding of fluid transport within aquifers plays an important role for geological CO₂ storage (GCS). During CO₂ injection into the reservoirs, a change in stress induced by increasing pore pressure might lead to deformation of surrounding reservoir rocks including caprocks, and this might also result in occurrence of seismic or aseismic slip along fractures/faults because of decreasing rock matrix and fault strengths. Thus, the presence of fractures and faults into caprocks such as mudstones and shales should provide an impact on the relationship between hydraulic properties (i.e., permeability and capillary pressure) and rock deformation. A few studies on measurement of permeability during shear fracturing in mudstones have been reported so far, but evolution of permeability throughout fracturing, slipping, stress-relaxing and variations of effective pressure levels processes has rarely been investigated. The objective of this study is to measure experimentally a change in permeability in a series of complex processes from fracturing to effective pressure dependency for mudstones. Particularly, we investigate impacts of stress relaxation and clay mineral contents on permeability evolution in response to variations of effective pressure levels which assume change in stress within targeted reservoirs resulting from the occurrence of overpressure. In this study, permeability tests were performed by employing the four steps: (i) fracturing, (ii) slipping, (iii) stress-relaxing, and (iv) effective pressure dependency at temperature of 40°C and effective pressure ranging from 2 to 15 MPa (confining pressures: 12-25 MPa and pore pressure: 10 MPa at constant) for two mudstones. The two samples tested were taken from GCS demonstration site of Tomakomai in Hokkaido (DS) and lower formation of Tentokuji in Akita associated with screening of all GCS sites in Japan (SS). Based on mode analysis of mineral compositions, it was shown that majority of mineral compositions for the SS sample was about 70 vol.% smectite-rich matrix. On the other hand, for the DS sample, little clay minerals was observed. Our results demonstrated that the rock samples tested exhibited brittle failure behaviours in stress-strain curves. As for the process (iii), it was apparent that permeability values measured after the long relaxation time (almost 7 days) were a significantly more susceptible to change in effective stress than that after the short time within 1 day. A comparison result showed that for the DS sample, magnitude of change in permeability values with decreasing effective pressure for the DS was almost two times larger than that for the SS sample relative to permeability values in the stress-relaxation state. This result showed that in the case of lower contents of clay minerals such as smectite and kaolinite, if the pre-existing fractures/faults into such mudstones had several events of tectonic movement over a long period, it might possibly lead to slipping behaviour easily due to the decrease of effective pressure induced by CO₂ injection. Also, it is further shown that its degree of slipping and magnitude of change in permeability could be depending strongly on the types of mudstones such as clay mineral contents. The present results should be pointed out that time of stress relaxation and clay mineral contents could provide a significant impact on change in permeability against effective pressure levels depending on the types of caprocks.

Keywords: Stress relaxation, clay mineral contents, change in permeability, mudstones