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Experimental study on the difference between gas and water permeability of clay-rich fault rocks

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Gas permeability of clay rich rocks is generally higher than that measured with water as the pore fluid in laboratory. Besides the Klinkenberg gas slippage effect, the swelling and adsorption of clay minerals subjected to water may have strong influences (Faulkner and Rutter, 2000; Duan and Yang, 2014). To better understand the discrepancy between gas and water permeability of clay-rich fault rocks, we performed detail fluid transport property experiments on synthetic smectite-quartz, illite-quartz mixtures and natural fault gouge, as well as clay-deplete sandstones for the comparison purpose. Experiments were conducted on a fluid flow apparatus with effective pressures cycling between 5 and 105 MPa. Each sample was subject to nine pressure cycles (the first eight with nitrogen and the last one with de-ionized water as the pore fluid), along which permeability and porosity of either the dry or water-saturated samples were measured. In a few additional experiments, X-ray diffraction (XRD) analyses were used to examine the hydration state of the smectite before and after the introduction of water.

Results show that permeability of all the samples investigated decreases with increasing effective pressure, following a power law relation. Gas permeabilities exhibit strong pore pressure dependence, which can be attributed to the slippage effect. Water permeabilities of the samples are generally lower than the gas results after correction, with a few exceptions for the synthetic samples (clay content $\leq$10%). The permeability trends observed for samples after the introduction of water can be generally explained by the evolution of sample porosity, as can be obtained from the bulk and solid phase volume measurement results. Take the smectite-quartz synthetic samples for instance. Bulk volume of the samples generally expands after water saturation and XRD results show that almost three layers of water enter the smectite interlayers (001 basal spacing expands from about 14 to 19 Å). Simple calculations based on the combination of these two effects (bulk volume variation and clay swelling) reveal a possibility of diverse porosity evolution of water-saturated fault gouges, depending on the clay content.

Our preliminary results indicate that the water swelling and adhesion effects of clay minerals can reduce the effective pore space and prevent fluid transport efficiently. Additionally, due to their low frictional strength, the introduction of water can cause more efficient compaction than the dry samples at otherwise the same conditions, which may alter the pore fabric and even the supporting framework of the samples. Based on these considerations, a conceptual model for the evolution of pore network that incorporates grain rearrangement and clay expansion is proposed to describe the mechanism for water permeability in clay-rich fault rocks.