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# Permeability evolution of sandstones during inelastic deformation

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The interplay of hydraulic and mechanical processes in porous rocks is a common concern of many scientific and engineering fields. This is particularly true for CO2 aquifer sequestrations where a huge volume of CO2 is to be injected and stored for a long time in deep brine aquifers or oil/gas reservoirs that are confined by overlying low-permeability cop rocks. How long the gas may stay there depends mainly on the permeability of the aquifers overlying storage aquifers. Situated in the circum-Pacific seismic belt, Japanese islands experience significant crustal deformation and frequent stress variations. Therefore, the long-term safety assessment of a sequestration site requires a deep understanding of the permeability evolution during inelastic deformation of Japanese sedimentary rocks.

In this study, we have measured the permeability change in the entire process from elastic, plastic, post-failure to axial stress unloading for Shirahama sandstone subjected to triaxial compressions under various confining pressures. The measurements showed the confining pressure, i.e. burial depth, plays an important role in controlling inelastic deformation behavior and the tendency of the permeability evolution. In the brittle regime under a low confining pressure, significant increase in permeability accompanied by dilatancy can be observed. In brittle-ductile transition regime and ductile regime, faulting or inelastic deformation dose not necessarily significantly enhance the permeability, and the permeability during deformation is lower than their corresponding initial values. Microscopic observations revealed that two mechanisms: 1) Shear-enhanced cracking, and 2) grain crushing are responsible for these inelastic deformation and permeability evolution behavior.

The above observations have valuable implications for selecting the sites of CO2 aquifer sequestrations. Japan has tens of sedimentary basins on land and offshore for potential storage sites. In terms of long-term safety, such sites are preferable as with few faults, and therefore, low risks of permeability enhancement due to the propagation of these faults. As our experiments revealed, the confining pressure controls the deformation, failure and permeability evolution behavior. In brittle-ductile transition regime and ductile regime, the permeability during entire deformation process is lower than their corresponding initial values. It is well known that the minimum stress (confining pressure) in the crust increases with depth. Thus, our results suggest that sequestrating CO2 in aquifers below some depth is safer, below which the ductile deformation prevails.

Thus, we propose a limit over the burial depth of a sequestration system based on the transition behavior, which is called as mechanical depth limit, beside the economic depth limit of around 800m at which CO2 is in supercritical state (density: about 0.5g/cm3). One may prefer a site with the mechanical depth limit less than the economic depth limit to decrease the injection cost. Therefore, we make a brief discussion on the mechanical depth limit. The mechanical depth limit depends on whether the crustal minimum stress is enough high to promote the brittle-ductile transition. At a depth of 800m, the effective minimum stress in the crust is less than 10MPa, as summarized by Sugawara (1997), not enough for the transition for Shirahama sandstone and for the 31 Tertiary arenaceous rocks tested by Hoshino et al (1972). However, at this depth in Japanese basins, generally encountered are Quaternary rocks. In general, the Quaternary sedimentary rocks, less consolidated and with a higher porosity, may require lower minimum stress for the transition than Tertiary sedimentary rocks. Therefore, we may possibly find such sites in some Quaternary strata. This idea need be confirmed by further systematic experiments, computer simulations and field investigations.