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Frictional healing and sealing in anhydrite-filled faults: from short duration experiments to long-term CO_2 storage

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The efficacy of long-term subsurface CO_2 storage requires that the stored gas remains isolated from the atmosphere for thousands of years. Faults crosscutting the reservoir and topseal system of storage sites are considered one of the most likely leakage pathways, especially if reactivation leads to fault dilation. For a proper risk assessment it is important to know if CO_2 affects the self-sealing potential of fault gouges, as well as how it affects strength recovery after fault slip ceases (frictional healing). A thorough understanding of the physical processes operating in the fault gouge will help to extrapolate the data from short-term experimental time scales to long-term storage time scales. Anhydrite is a common caprock mineral in many hydrocarbon fields worldwide, and particularly in the Netherlands. In cases where faults crosscut the caprock, it is likely that these contain fine-grained, anhydrite-rich, damage material, or "fault gouge". Therefore, we have performed two sets of experiments: 1) fault shearing experiments on simulated anhydrite fault gouge, to investigate the frictional behavior of anhydrite faults, and 2) compaction creep experiments, to investigate the potential for self-sealing. All experiments were performed under pressure and temperature conditions representative for CO_2 storage conditions (set 1: T = 80-150°C; normal stress = 25MPa; Pf = 15MPa; set 2: T = 80°C; stress = 5-12MPa and P¬f = 15MPa). The use of different pore fluid phases (air, vacuum, water, CO_2 saturated solution, moist CO¬2 and dry CO_2), as well as the range in pressures and temperatures, allows us to study the effect of the in-situ conditions on the frictional behavior, and also to identify the mechanisms responsible for the compaction behavior. Our results indicate that in both types of experiments water plays an essential role, by enhancing both fault-healing (type 1) and fault-sealing potential (type 2). The compaction experiments indicate fault sealing in fine-grained gouges ($<40\mu$m) is controlled by diffusion-controlled pressure solution, which implies fault healing could also be influenced by a pressure solution-type mechanism. The latter appears to be confirmed by the preliminary results of the fault healing experiments conducted at elevated temperature (T=120°C), which show that dry anhydrite fault gouges show negligible frictional healing compared to experiments with (even small amounts of) water, which show significant frictional healing. In both experimental sets there is no significant effect found of the presence of CO_2 for wet and dry anhydrite gouges, implying the presence of CO_2 does not have an effect on fault sealing or healing in anhydrite. However, high CO_2 pressures and/or fluxes have been hypothesized to have the potential to desiccate an initially water-wet fault gouge, thereby inhibiting water-driven mechanisms leading to healing and sealing. This is still under investigation. Combined with microstructural analyses and microphysical models, these results will increase our understanding of how fault porosity (and hence permeability) and fault strength evolve upon cessation of fault slip.