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Effect of carbonate content on the mechanical behaviour of clay fault-gouges

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Carbon dioxide capture and storage (CCS) in depleted oil and gas reservoirs is considered to be the most promising technology to achieve large-scale reduction in anthropogenic emissions. In order to retain the stored CO_2 from the atmosphere for the very long-term, i.e. on timescales of the order of 103-104 years, it is essential to maintain the integrity of the caprock, and more specifically of any faults penetrating the seal. When selecting suitable CO_2-storage reservoirs, pre-exisiting faults within the caprock require close attention, as changes in the stress state resulting from CO_2-injection may induce fault slip motion which might cause leakage. Little is known about the effect of fluid-rock interactions on the mineral composition, mechanical properties and the integrity and sealing capacity of the caprock.

Previous studies on the effect of mineral composition on the frictional properties of fault gouges have shown that friction is controlled by the dominant phase unless there is a frictionally weak, through-going fabric. However, the effect on stability is less clear. Since long-term CO_2-exposure might cause chemical reactions, potentially resulting in the dissolution or precipitation of carbonate minerals, a change in mineralogy could affect the mechanical stability of a caprock significantly. Calcite, for example, is known to be prone to micro-seismicity and shows a transition from velocity-strengthening to velocity-weakening behaviour around 100-150°C. Therefore, we investigated the effect of varying clay:carbonate ratios on fault friction behaviour, fault reactivation potential and slip stability, i.e. seismic vs. aseismic behaviour. Three types of simulated fault gouges were used: i) carbonate-free, natural clay-rich caprock samples, consisting of predominantly phyllosilicates ($\sim$80%) and quartz $\sim$20%), ii) pure calcite, and iii) mixtures of carbonate-free clay-rich caprock and pure calcite, with predetermined clay:carbonate ratios. For the natural clay-rich caprock material we used Opalinus Claystone (Mont Terri, Switserland), which is considered to be an analogue for many shaly caprocks in Europe. We performed rotary shear experiments at in-situ reservoir conditions (T = 20-150˚C, σneff = 50 MPa, Pp = 25 MPa) at shear velocities of 0.22 -100 μm/s.

Preliminary results show that the frictional strength of the carbonate-free, natural clay-rich caprock samples is 40-50% lower than for the pure calcite samples. Typical steady-state friction coefficient values obtained for the carbonate-free clay samples are $\sim$0.3-0.4. These values are significantly smaller than the values of $\sim$0.6-0.7 obtained for pure calcite. The friction coefficient values obtained for the mixture plot between the carbonate-free and pure calcite values. The samples show predominantly velocity-strengthening behaviour. However, the 90% pure calcite (and 10% clay-rich caprock) and 100% pure calcite samples show velocity-weakening behaviour at 100-150°C. This suggests that large amounts of carbonates, and thus significant carbonate precipitation as a result of CO_2-exposure, are required to cause a transition from aseismic to seismic behaviour, at least under the experimental conditions investigated here.