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Fault slip in clay-rich rocks due to water-clay interactions

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Clay-rich rocks occur in a wide range of tectonic settings. They are of great interest, for example, for the mechanical properties of shallow subduction zone interfaces, but also for natural barriers in nuclear waste deposits or as subsurface caprocks for CO_2 storage. In contact with a polar fluid (e.g., water), the interaction between clay minerals and fluid can lead to swelling or, under confined conditions, build-up of swelling stress. Many studies have focused on the closure of cracks in clay-rich sedimentary rocks by swelling (also referred to as 'self-sealing'). However, less is known about how water-clay interactions affect the stress state of clay-rich rocks and whether they may induce slip along pre-existing faults. We try to address this knowledge gap in the present study by conducting triaxial shear experiments.

The experiments are performed using oblique saw-cut cylindrical samples, where the top half consists of a clay-rich rock (Opalinus claystone) and the bottom half of a permeable sandstone (Berea sandstone). To estimate the frictional properties of the sandstone-claystone interface, dry experiments are performed at 4 to 25 MPa confining pressure and constant axial displacement of 0.1 mm/min. Fluid injection experiments, where fluids are injected through the permeable footwall sandstone, are performed at 10 and 25 MPa confining pressure, constant piston position (no axial displacement), and an initial differential stress of about 70 % of the expected yield stress. The effect of water-clay interactions on the stress state is estimated by comparing the fluid pressures required to initiate slip when a non-polar fluid is injected (no water-clay interactions are expected) and when a polar fluid is injected (water-clay interactions will occur). In some experiments, the sample assemblage is equipped with fiber optics strain sensors glued to the surface of the sample to distinguish between (poro)elastic deformation of the matrix, deformation due to water-clay interaction, and elastic relaxation due to slip along the saw-cut.

For fluid injection experiments with a non-polar fluid (decane), the mechanical data indicate that slip along the saw-cut occurs at fluid pressures close to what is expected based on the friction slip envelope determined for the dry state. For fluid injection experiments with a polar fluid (deionized water), a differential stress drop already occurs when the water initially reaches the sandstone-claystone interface at ambient fluid pressure (0.1 MPa), which is not expected based on the dry friction slip envelope. The fiber optics strain sensor data indicate that swelling of the claystone is

followed by a microstructural collapse before slip along the saw-cut likely occurs. In summary, our data suggest that water-clay interactions may initiate slip due to (1) the alteration of the friction slip envelope, (2) build-up of swelling stress, and (3) collapse of the claystone microstructure. However, to what extent these three mechanisms contribute to the according differential stress drop requires further research.