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The hydro-mechanical properties of sealing horizons consisting of mechanical multilayers

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Sealing horizons are often sedimentary sequences characterized by alternating strong and weak clay-rich lithologies. When involved in fracturing and faulting processes mechanical multilayers, characterized by competence contrasts, develop complex fault geometries that strongly influence their sealing maintenance. Here we investigate fault initiation and evolution integrating field observations, on outcropping faults affecting a mechanical multilayer, and rock deformation experiments, on the lithologies collected in the field.

Faults initiate with a staircase trajectory that partially reflects the mechanical properties of the involved lithologies, as suggested by triaxial and biaxial deformation experiments. However, the small angles of fault initiation in calcite-rich (i.e. θ_i = 5°-20°) and the high angles in clay-rich layers (i.e. θ_i = 45°-86°) indicate an important role played by structural inheritance, i.e. joints and foliation, at the onset of fault development. With increasing displacement (5 cm - 20 m), faults evolve towards more straight trajectories and wider fault zones. At early stages fault rock consists of a calcite-rich cataclasite. Then it evolves toward a well-organized marly foliated fault rock that embeds sigmoidal fragments of limestones and localizes slip along surfaces where ultra-cataclasite forms. The angles of fault reactivation concentrated between 30° and 60°, consistently with the low friction coefficient (μ_s = 0.3) measured in our laboratory experiments, indicates that clay minerals exert a main control on fault friction. Moreover, the presence of calcite mineralization in all the investigated faults, i.e. within cataclastic fault rocks, dilational jogs and in form of slikenfibers, suggests that faulting is the main mechanism allowing fluid flow within the sealing horizon. This is supported by our triaxial deformation experiments showing fluid flow across the sealing lithology only during the development of a thoroughgoing fault.

Our integrated analysis indicates that incipient faults with a staircase trajectory promote fluid flow through the opening of dilational jogs. With accumulating displacement, the development of an impermeable foliated fault rock allows for fluid flow only during fluid-assisted fault reactivation. This suggests that the overall fluid flow within the mechanical multilayer is localized along small displacement faults and the sealing integrity can be compromised only by larger faults cutting across the entire sealing horizon.