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Collapse of chemically altered porous surface decreases fracture permeability, frictional strength and stability

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In many subsurface energy activities, such as hydraulic fracturing, geologic carbon storage, deep well disposal, and geothermal energy, the injection or extraction of fluids results in significant mechanical and chemical perturbations. These perturbations pose risks in promoting unwanted fluid leakage pathways, such as faults and fractures, through chemical reactions and mechanical failure. The flow of reactive fluids through fractures has been shown to dissolve reactive minerals and thereby increase permeability. However, it remains unclear how this dissolution influences the frictional properties of fractures and how the altered fractures behave during shear rupture. To properly assess the risks associated with subsurface energy activities, this study experimentally investigates how mineral dissolution on fracture surfaces affect fracture flow and frictional properties under stress.

Experiments were performed using 1.5-inch long saw-cut rock fractures from the Eagle Ford formation, a calcite-rich laminated shale. Experiments were performed in two stages: reactive fluid flow experiments and tri-axial shearing experiments. During the first stage, samples were organized into two sets, where one set was exposed to an acidic brine and the other exposed to a near-neutral brine. After flow, X-ray computed tomographic imaging showed the formation of a highly porous altered layer for samples exposed to the acidic brine, and no significant alteration for samples exposed to the near-neutral brine. This altered layer is created primarily from the dissolution of calcite grains, leaving a porous intact matrix of non-reactive minerals at the fracture surface. During the second stage, samples were sheared in a tri-axial testing apparatus that independently supplied confining pressure and differential pore pressure along the fracture length at prescribed sliding velocities, independently measuring friction and permeability. Samples were confined to 3 MPa effective stress with shear velocity down- and up-steps of 1 $\mu\text{m/s}$ and 10 $\mu\text{m/s}$.

X-ray computed tomographic imaging following the shearing experiments revealed that the porous altered fracture surface layers had collapsed into a layer of fine particles that filled the fracture aperture, effectively sealing the fracture. This is confirmed by permeability measurements during the initial compaction in the shearing apparatus, where the permeability of samples with an altered surface layer decreased one order of magnitude lower than the samples without an altered layer. This difference in permeability between the sample sets persisted through the entire shearing experiments. Results from the shearing experiments show that the altered sample set exhibited both lower frictional strength and stability. This is because for the samples exposed to non-reactive brine, the micro-roughness at the fracture interface results in interlocking micro-asperities that both increase the fracture strength and stability. For the altered samples, however, the layer of fine grained particles filling the aperture separate the two fracture walls, preventing the formation of interlocking micro-asperities. As a result, we describe the fracture surfaces as “surfing” on the layer of fine-grained particles.

References

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