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Reactive transport under stress: Permeability evolution in deformable porous media

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We study reactive transport in a stressed porous media, where dissolution of the solid matrix causes two simultaneous, competing effects: pore enlargement due to chemical deformation, and pore compaction due to mechanical weakening. We use a novel, mechanistic pore-scale model to simulate flooding of a sample under fixed confining stress. Our simulations show that increasing the stress inhibits the permeability enhancement, increasing the injected volume required to reach a certain permeability, in agreement with recent experiments. We explain this behavior by stress concentration downstream, in the less dissolved (hence stiffer) outlet region. As this region is also less conductive, even its small compaction has a strong bottleneck effect that curbs the permeability.

Our results also elucidate that the impact of stress depends on the dissolution regime. Under wormholing conditions (slow injection, i.e. high Damkohler number, Da), the development of a sharp dissolution front and high porosity contrast accentuates the bottleneck effect. This reduces transport heterogeneity, promoting wormhole competition. Once the outlet starts eroding, the extreme focusing of transport and hence dissolution—characteristic of wormholing—becomes dominant, diminishing the bottleneck effect and hence the impact of stress at breakthrough. In contrast, at high flow rates (low Da), incomplete reaction upstream allows some of the reagent to traverse the sample, causing a more uniform dissolution. The continuous dissolution and its partial counteraction by compaction at the outlet provides a steady, gradual increase in the effect of stress. Consequently, the impact of stress is more pronounced at high Da during early stages (low permeability), and at low Da close to breakthrough. Our work promotes understanding of the interplay between dissolution and compaction and its effect on the hydromechanical property evolution, with important implications for processes ranging from diagenesis and weathering of rocks, to well stimulation and carbon geosequetration.