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Reactive Alteration of Rough-Walled Fractures in Gradient and Kinetic Regimes with Applications

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Flow and transport processes in fractured rock are strongly influenced by fracture aperture and diffusive interactions between the fractures and rock matrix. The transmissivity of fractures is highly sensitive to fracture aperture (a cubic dependence). Complex thermo-hydrologic-mechanical-chemical (T-H-M-C) coupled processes that alter fracture apertures thus drive feedbacks and pattern formation. For example, dissolution of fracture surfaces increases their aperture and transmissivity, whereas precipitation has the opposite effect. We adopt aperture-integrated approaches for modeling fracture alteration and the resulting evolution of flow, concentration, temperature and aperture fields. I will present examples from previous and ongoing research on fundamental aspects of fluid flow, reactive transport and coupled processes in fractured rock, including comparisons to controlled high-resolution experiments. Behavior in both kinetic regimes (where disequilibrium drives water-rock interaction) and gradient reaction regimes (where solubility gradients drive dissolution-precipitation) are considered. Dissolution of fracture walls by reactive solutions produces highly preferential aperture growth, either by unstable finger propagation in the kinetic regime, or by selective growth in the gradient reaction regime. These phenomena are relevant in the context of acid injection for permeability enhancement in energy recovery systems, water-rock interactions during geological CO2 sequestration, and natural phenomena such as karst and cave formation. Precipitation reactions lead to unusual growth of elongate precipitate bodies perpendicular to the mean flow direction. We also present results from geological scale mountain-hydrologic systems with thermo-hydro-chemical coupling relevant to the formation of hypogene or thermal karst systems. In these systems, both the temperature-dependent (retrograde) solubility of calcite, onset of buoyant convection after a threshold Rayleigh number is reached due to the growth of fracture transmissivity by dissolution, influence the growth patterns that result. Recent applications of our modeling approach to thermo-hydro-chemical coupling in geothermal energy doublet-flow systems reveals useful strategies for sustaining energy production. In silica-dominated geothermal energy reservoirs, we show that injection of undersaturated water leads to long-term sustainable operation of the system. We also show that after an initial period of 1-2 years, sustained energy extraction can be sustained even with recirculation, because silica concentrations do not build up in recirculated water. The large difference in solute versus thermal diffusivity of the rock matrix, however, ensures that thermal energy recovery is sustained. With oversaturated injection, a band of precipitation forms at some distance from the injection well, encapsulating the flow system and limiting heat recovery.

References

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