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Mineralization in Variably Saturated Porous Media and its Impact on Effective Diffusivity: Experiments and Pore-Scale Modeling

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Mineral precipitation in porous media with variable saturation plays a critical role in various geoscientific systems, e.g., CO_2 sequestration, H_2 storage, oil recovery and during other processes like soil salinization in agriculture or degradation of monuments. In geological disposal systems for radioactive waste, partially saturated conditions are expected to persist after closure while coupled thermal-hydrological-chemical-biological processes, including corrosion and microbially mediated reactions, may further modify gas and porewater distributions, thereby generating spatial and temporal variability in saturation across engineered barrier interfaces and host rock. The presence of gas may enhance mineralization in the system, changing pore geometry and connectivity, possibly leading to porosity clogging which could impact the efficiency of storage or extraction of the mentioned systems. At present, solute and contaminant transport in low-permeability rocks under partially saturated conditions is commonly described using the Quirk-Millington framework, an empirical formulation that has not been systematically validated for systems undergoing mineral precipitation.

In this study we provide a porosity-diffusivity relationship of partially saturated porous media undergoing mineral precipitation. We developed a diffusion-column experiment monitored by dynamic micro-computed tomography (micro-CT). Three experiments with varying initial levels of water saturation were conducted to evaluate the evolution of mineral precipitation patterns over time. Micro-CT imaging enabled visualization of precipitation patterns with special focus on the water-gas interface. Results of micro-CT imaging were analyzed to determine the representative elementary volume (REV) using two-point statistics; several REVs were randomly selected. Lattice Boltzmann pore-scale simulations are performed on these 3D REVs to evaluate the effective diffusivity in the system. The current approach provides a robust constitutive equation that describes the evolution of transport properties in partially saturated porous media undergoing mineral precipitation.