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Multiscale forward modeling of the interplay between carbonate precipitation and porous media transport properties during geological carbon sequestration

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Geologic storage of CO2 is a critical decarbonization pathway. CO2 and other fluids are primarily stored through four trapping mechanisms (physical/structural, capillary, dissolution, and mineralization trapping) all of which exhibit spatial-temporal changes throughout a porous material. Controls on the distribution of mineral dissolution and carbonate precipitation and the evolution of porosity and permeability as a function of in-situ and operational parameters is highly multivariate. This research seeks to quantify the effects of early carbonate precipitation on formation CO2 storage capacity, hydrodynamic patterns, and mineralization rate with multiscale forward modeling in several key storage rock lithologies. Here early time refers to a time period on the order of the lifetime of an injection project (~50 years).

We posit that a strategic forward modeling approach using several pore-scale modeling tools and multiple realizations of accessible reactive surface area afforded by high performance computing (HPC) combined with complementary experimental data (feedback-loop) will: (a) elucidate the impact of mineralization for a given range of routine petrophysical properties and (b) provide a framework for upscaling the impact of concurrently investigated reactive transport functional relationships. A combination of pore network models (PNM) and pore-scale computational fluid dynamics (CFD) models are used for digital evaluation of key porous media transport properties that inform a reservoir-scale storage model: cell porosity, permeability, and brine-CO2 capillary pressure-saturation (Pc-Sw) and relative permeability (Kr-Sw). The studied rock types represent a spectrum of porosity, permeability, and reactive mineral surfaces: porous sandstones, volcanic-rich sandstones, igneous and metamorphic rocks (e.g., basalts and serpentinites), and synthetics/composites. This work concentrates on two main injection scenarios, supercritical CO2 injection in deep saline aquifers and dissolved CO2 injection in a mafic/ultramafic formation. The morphological distributions of mineral dissolution and carbonate precipitation (nucleation) are incorporated by way of experimentally-based and theoretical models at the pore scale, determined or benchmarked by reactive transport experiments and pre-/post-reaction characterization and imaging, generated from concurrent in-house and collaborator studies. Pore-scale reactive transport modeling is also used to establish local relationships, where applicable.

In consideration of the heterogeneous nature of geological formations and lithologies, the numerical modeling with the precipitation rules will be applied to multiple 3D representations (informed by routine and special core analysis data and petrographic images) of the selected rock types, and a probability density distribution of the alteration and flow relationships will be established. To demonstrate the impact of the pore-scale findings, the dynamic Pc-Sw and Kr-Sw relationship ranges acquired from the pore-scale modeling processes are upscaled with a reservoir-scale model to show the effect of pore-scale precipitation on storage capacity, hydrodynamic patterns, and the total mineralization ratio of injected CO2 for a selected reservoir geometry and injection scenario. The authors note that the multiscale workflow can be used to determine precipitation pathways for various environmental porous media including surface rocks, mine tailings, and the build environment. Ongoing and future work will include incorporation of controlled fluidic experiments to inform the functional relationships on carbonate precipitation, particularly in complex pore systems such as nanoscale confinements.

Participation

In-Person

References

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