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Towards relative permeability-mineralization paradigms in vesicular basalt pore systems

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This talk discusses pore-scale controls on multiphase flow in vesicular basalts for carbon storage and mineralization processes. Multiphase flow adds an additional mass transfer step across brine-CO2 phase boundaries and spatially impacts reactant mixing paths, mineral (e.g., carbonate) growth patterns, and relative permeability during supercritical CO2 injection. Ergo, consistent quantification of CO2-accessible pore systems and reactive mineral surface area in basalts (and other mafic/ultramafic rocks) as a function of partial water saturation state (Sw) and flow regime is critical for effective carbon storage and mineralization. However, unlike conventional rocks, there are no established paradigms for basalt capillary-pressure (Pc-Sw) and relative permeability (Kr-Sw) relationships. These relationships are challenged in basalts due to their unconventional nanoporous and/or dual-porosity pore systems and complex primary and secondary (altered) mineral assemblages. First, this work identifies basalt pore and mineral (primary and secondary) microstructures as a function of alteration with combined optical microscopy, SEM/EDS, microCT, NMR, BET, and gas pycnometry techniques and relates these to Pc-Sw paradigms. The study highlights microstructures from subsurface vesicular basalt samples of varied alteration states from carbon mineralization and geothermal exploration projects (e.g., Columbia River Basalts, Newberry Volcano, American Samoa). Quantified microstructure includes grain fabric assemblages (e.g., phenocrysts, glass, and alteration clays), pore morphology (e.g., surface roughness, tortuosity), and pore-facing mineral surfaces. Next, brine-CO2 or brine-non-wetting phase distributions within subsets of the aforementioned pore systems are probed through a combination of computational fluid dynamics (CFD, lattice Boltzmann method), dual-porosity microfluidic proxy work, and imbibition data. Previous CFD work by the authors in collaboration with Pacific Northwest National Lab have revealed that partial saturation states are a control on engineered carbonate growth at PNNL's Wallula Basalt Injection Pilot. This work further probes phase distributions in dual-porosity microstructures (nanopores and micro-to-macropores) through flow rate and Sw states, whereby low Sw values are thin film regimes, Sw = 1 is single phase flow, and immediate values are capillary flow and bubble regimes. While the representative elementary volume (REV) for basalts remains uncertain, insights from these combined static and dynamic analyses reveal the major impacts of alteration state, pore to throat aspect ratio, pore size distribution, and connectivity on brine-CO2 phase distributions in vesicular basalt pore systems. Finally, we discuss implications and next steps towards relative permeability curves in vesicular basalt for optimized carbon mineralization.

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