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Exploiting induced carbonate precipitation to improve reservoir storage integrity and geothermal system efficiency

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Biomineralization, through microbially, thermally, or enzyme induced carbonate precipitation (MICP/TICP/EICP), is a cost-effective cementation process for changing porosity and permeability in the subsurface. This study aims to optimize compositional and injection parameters for biomineralization fluids, and to develop understanding of the interactions between geochemical reactions and fluid transport properties at the pore (micron) scale. Utilizing real-time in situ X-ray computed tomography (XCT), we compare traditional Microbially Induced Calcium Carbonate Precipitation (MICP) with novel thermally delayed (TICP) and Enzyme Induced Calcium Carbonate Precipitation (EICP) in a range of lithologies. This allows us to investigate the impact of mineralogy, grain size distribution, and temperature as well as the injection composition and strategy. We present quantitative analysis of crystal locations, the volume of carbonate and of individual crystals, and the effect of crystals on permeability and flow localisation over time. Coupled to measured changes in microstructural and macroscopic properties over repeated precipitation and dissolution cycles we present refined models of reactive transport for different injection strategies, and identify the optimal treatment strategy for different subsurface applications. This includes validation of the durability of precipitated calcite during dissolution phase simulating the behaviour of CO2-enriched brines.

This work provides the underpinning understanding principles of crystal formation, growth and hydrodynamic feedback mechanisms necessary for accurate modelling of reservoir scale dynamic processes. However we also show how TICP and EICP strategies can improve performance of real-world Carbon Capture and Storage systems, driving more homogeneous, widely distributed and larger volumes of precipitated CaCO3 by maintaining permeability during treatment at higher degrees of cementation when compared to MICP. We also show how variable injection strategies allow improvement of other physical properties (e.g. mechanical strength) and enables the addition of highly conductive additives or phase change materials without reducing precipitation and flow. Using CaCO3 precipitation we observed a 470% increase in the thermal conductivity of unsaturated quartz sand after 9 cycles of MICP, and an 800% increase following addition of 5 wt% expanded natural graphite (ENG). Our findings also demonstrate the compatibility of integrating paraffin as a phase-change material within the porous structure of ENG prior to MICP/EICP treatment significantly increasing specific heat capacity. These new geomaterials have widespread implications for thermal energy storage, specialized geothermal grouts/backfill, shallower wells and reduced geothermal energy costs.

The project's outcomes impact the commercialization of engineered biomineralization and its role in the subsurface energy transition.

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