Ph.D. Dissertation Defense

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MICROBIALLY INDUCED CALCIUM CARBONATE PRECIPITATION: MESO-SCALE OPTIMIZATION AND MICRO-SCALE CHARACTERIZATION

Major geomicrobiological events, while macro-scale in nature, are driven by complex micro-scale interactions between micro-organisms and their surrounding environments. Microbially Induced Calcium carbonate Precipitation (MICP) is an ideal example of micro-scale interactions involving microbes and minerals (microbe-mineral interactions). Metabolic processes of ureolytic bacteria can lead to a rise in alkalinity, favoring the precipitation of calcium carbonate. These calcium carbonate precipitates can be used as 'biocement' for caprock sealing to prevent leakage of subsurface stored carbon dioxide, soil strengthening, or even stone heritage protection. MICP-based co-precipitation offers an attractive method for removal of heavy metals and radionuclides present in groundwater at various DOE waste sites due to its ability to remove even trace concentrations of contaminants without the use of harmful chemicals.

The kinetics of MICP and co-precipitation are well understood in static (no-flow) laboratory systems but for effective field deployment of these technologies, it is important to control these processes under flow conditions that can exist in application environments. Meso-scale experiments were performed under porous media flow conditions to investigate MICP and strontium co-precipitation. MICP was studied under radial flow conditions, which are often encountered near wells used to inject MICP-promoting fluids. Controllable parameters such as injection flow rate and media concentrations were tested to determine their utility for controlling MICP distribution and extent. A spatio-temporal investigation of strontium co-precipitation alongside MICP in porous media flow cells revealed a spatial decoupling between ureolysis and calcium carbonate precipitation.

In addition to the meso-scale, micro-scale experiments were performed using drop-based microfluidics to observe the fundamental process itself. Starting from single cells, ureolysis-facilitated MICP was visualized in 25 µm diameter drops and individual micro-precipitates were characterized using a multitude of microscopy and microanalysis techniques. This experimental platform can be utilized to study a wide range of microbe-mineral interactions to gain a deeper understanding of such interactions at the single cell scale.