CO_2 from Benchtop to Outcrop

Multiphase Reactive Transport and a Natural Analogue for Leakage

CFSES

Center for Frontiers of Subsurface Energy Security

Hongkyu Yoon[1], Matt Balhoff[2], Steve Bryant[2], Peter Eichhubl[2], Tom Dewers[1], Yashar Mehmani[2], and Tie Sun[2]

[1] Sandia National Laboratories, Albuquerque, NM

[2] University of Texas, Austin, TX

TEXAS

Sandia National Laboratories

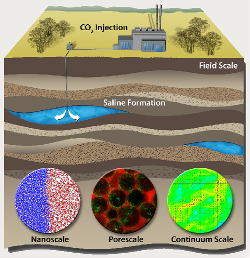
U.S. Department of Energy, Office of Science

SAND2011-3636C

Geologic Storage of CO_2

Greenhouse gas carbon dioxide (CO_2) produced by power plants and other industrial processes can be captured and safely stored for thousands of years underground in deep saline reservoirs . If CO_2 is injected into these reservoirs, CO_2 will behave more like a liquid than a gas as supercritical CO_2 ($scCO_2$), dissolve in saline water and become widely dispersed in the reservoir over hundreds to thousands of years. Dissolved CO_2 can also react with minerals within reservoirs, precipitate, and remain underground for a long time.

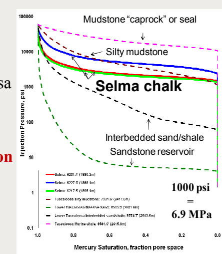
Once it is stored, slow releases of CO_2 from geological reservoirs are likely to occur over time. Development and mitigation of leakage pathways from subsurface CO_2 storage reservoirs may well depend on coupled thermal, mechanical, hydrological, and chemical interactions.



Rock Samples and Multiphase Flow

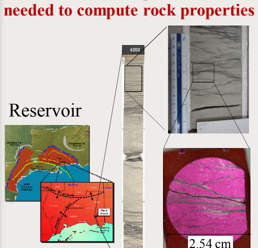
Selma chalk:

- Secondary "seal" for NETL's SEACARB Phase II Plant Daniel site for CO_2 injection into Lower Tuscaloosa
- Of interest as "leaky caprock" to mitigate injection pressure hazard



Reservoir rock samples at the resolution needed to compute rock properties

Reservoir



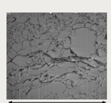
Thin section

Core (3′ long) at depth 6202′

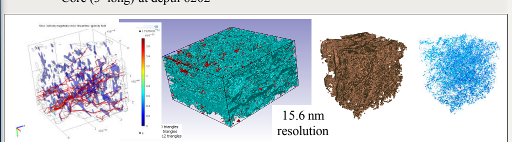
3D Solid material (calcite + clay) in "horsetail" structures

1821 microns (1.77 μm resolution)

Focused Ion Beam image slice



4 microns (15.6 nm resolution)



CFD pore scale modeling with streamlines

Reconstructed 3D pore network showing connected and unconnected porosity

Multiphase modeling: CO_2 saturation (left) and residual water saturation (right)

We link laboratory micro-scale and rock core-scale experimental and modeling efforts to examine:

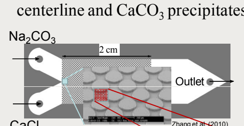
- How does $scCO_2$ interact with water, brines, and mineral surfaces? [multiphase flow]
- What are the relevant physics of CO_2 fate and transport? [reactive transport and rock-fluid interactions]
- How can pore scale processes be synthesized and upscaled into more powerful continuum models?
- How can observed leaks such as natural analogs be incorporated into improving the predictive models?

Pore-Scale Modeling for Reactive Transport

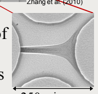
- Pore scale modeling of mixing-induced calcium carbonate ($CaCO_3$) precipitation and dissolution in a microfluidic pore-network

Experimental setup | **Pore scale modeling**

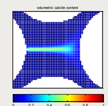
- Two solutions are mixing along the centerline and $CaCO_3$ precipitates

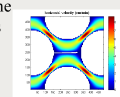


Microscopic image of calcium carbonate ($CaCO_3$) precipitates at 0.6μm resolution



Lattice Boltzmann Method for water flow velocity in pore space at 1μm resolution

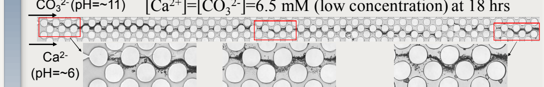




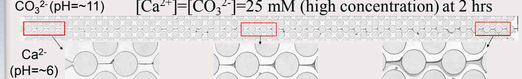
Direct Numerical Simulation result of $CaCO_3$ precipitation and dissolution

Precipitate Morphology (Microscopic image)

CO_3^{2-} (pH=~11) $[Ca^{2+}]=[CO_3^{2-}]$=6.5 mM (low concentration) at 18 hrs

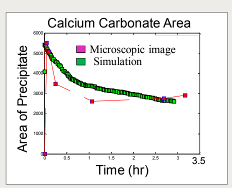


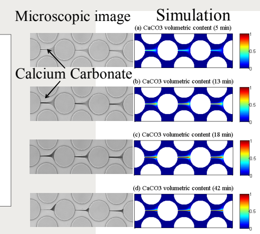
CO_3^{2-} (pH=~11) $[Ca^{2+}]=[CO_3^{2-}]$=25 mM (high concentration) at 2 hrs



- Precipitate is more uniform and narrow transverse to flow at higher conc.

Pore-scale modeling results

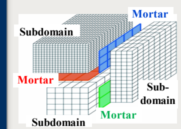




- Pore scale simulation with a newly developed crystal growth model captures governing physics of crystal growth and dissolution patterns
- Results will be applied for core-scale (~ 10 cm) data and more realistic environmental conditions

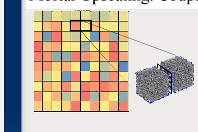
Multi-Scale Modeling of Reactive Transport through Porous Media

Mortar Coupling Pore Network models



- Mortar is a finite element based interface of pressure/flux/fluid saturation fields
- Mortar is used to couple two networks by matching the flux from both sides
- Subdomains are decomposed and solved separately using pressures at interface

Mortar Upscaling: Couple one million pore networks

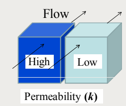


- The entire domain is solved by coupling individual networks using mortars; the overall permeability (K_{mortar}) is estimated by ensuring continuity at all interfaces.
- The boundary condition on each network is much more realistic

Example Problem

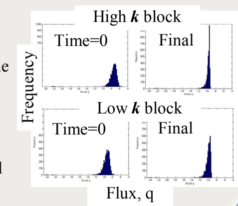
To understand the impact of mineral precipitation on CO_2 saturated brine flow

- A governing equation controlling the rate of mineral precipitation in pore-throats was used
- Two pore-scale blocks were assembled parallel to flow direction



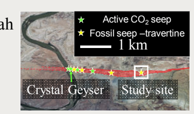
Results

- Faster decrease in permeability of the high ***k*** blocks results in a narrower pore-throat-flux (q) distribution and similar q in both blocks at later time
- These results imply that uniform cementation occurs, leading to equal fluxes through the entire medium



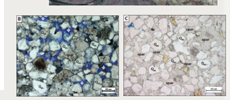
Natural analogue for carbonate sealing of CO_2 leakage pathways

CO_2 Leakage Analogue, Crystal Geyser, Utah



Key results

- Increase in calcite pore cementation near CO_2 conduit (C) ~ decrease in porosity and permeability (sealing)
- Cementation confined to immediate vicinity (~100 m) of structurally controlled flow conduit



Inside fault zone: 152 m (left) and 33 m (right) from conduit

For more information on natural analogue, visit the poster P2-F5 CFSES

Selected Research Highlights

- Characterized reservoir rock properties (e.g, pore size distribution, mechanical properties) at core- to nano-meter scales
- Developed a mechanistic crystal growth model at pore scale and applied to reactive transport experiments in a microfluidic pore network
- Invented upscaling approach that includes more detailed pore-scale properties (e.g., K_{mortar}) and demonstrated carbonate cementation reduces ***k*** at the pore scale relevant to long-term security of CO_2

Acknowledgments

This material is based upon work supported as part of the Center for Frontiers of Subsurface Energy Security, an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences under Award Number DE-SC0001114. Sandia National Laboratories is a multi-program laboratory operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin company, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.