SAND2015-9329C

Characterizing 3-D flow velocity in evolving pore networks driven by $CaCO_3$ precipitation and dissolution

Kirsten Chojnicki, Hongkyu Yoon, Mario Martinez
Sandia National Laboratories, Albuquerque, NM

1. Carbon Dioxide Sequestration

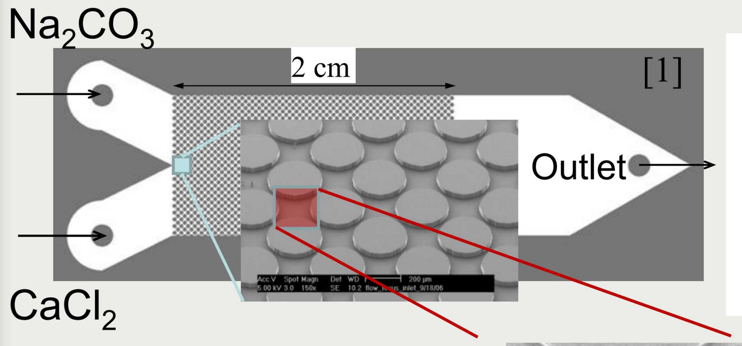
- Carbon dioxide will be sequestered by inducing precipitation in the subsurface.
- But, there is uncertainty in how much precipitation will occur, where it will occur and how long the reactions will take.
- In storage reservoirs with highly reactive materials precipitation may be quick (years to decades)
- Precipitation must be timed just right in such reservoirs: too fast, and precipitation will clog reservoir and limit storage to a fraction of the estimated capacity
- Key is to maintain permeability during precipitation reaction, a difficult scenario to ensure in practice as the flow may evolve over time leading to undesired or unexpected behavior
- Thus, to 1) SUSTAIN LARGE STORAGE RATES, 2) USE PORE SPACE EFFICIENTLY, and 3) CONTROL EMERGENT BEHVIOR on the time scale of YEARS TO DECADES, we need more information about the coupling between reactive transport and flow in pores (1-100 μms)

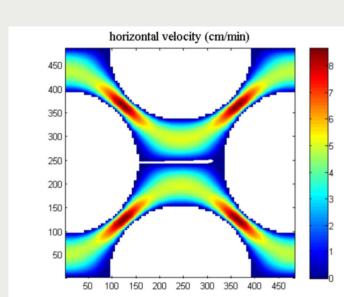
2. Pore Scale Modeling of Reactive Transport

- Transverse mixing-induced calcium carbonate ($CaCO_3$) precipitation

Laboratory Experiments

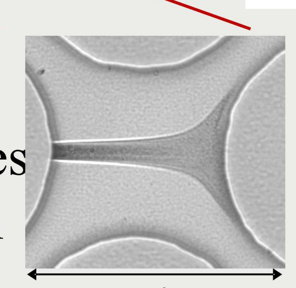
Simulations

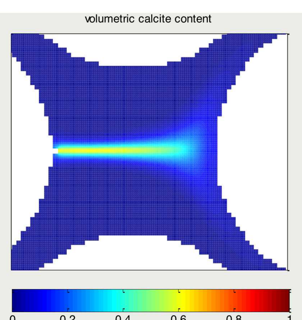




Lattice Boltzmann method for water flow velocity at 1μm resolution

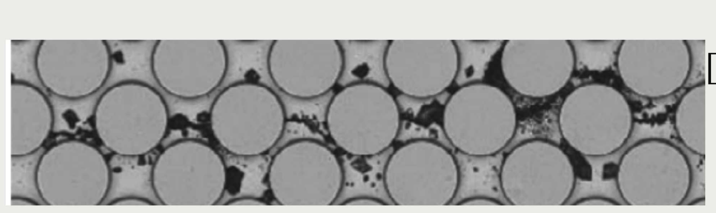
Microscopic image of $CaCO_3$ precipitates at 0.6μm resolution



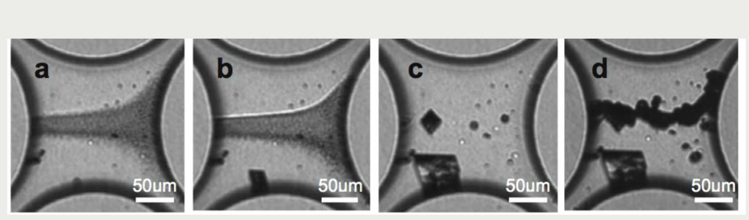


Numerical simulation result of $CaCO_3$ precipitation

- Mixing induced chemical reactions can alter pore structure in space



- And over time

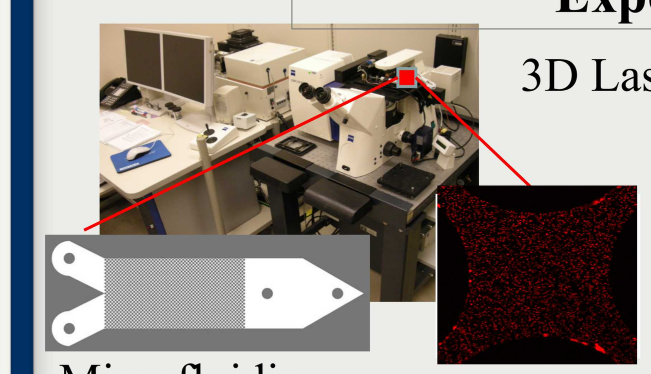


3. Characterization of 3-D flow field using micro-PIV

Laboratory Experiments

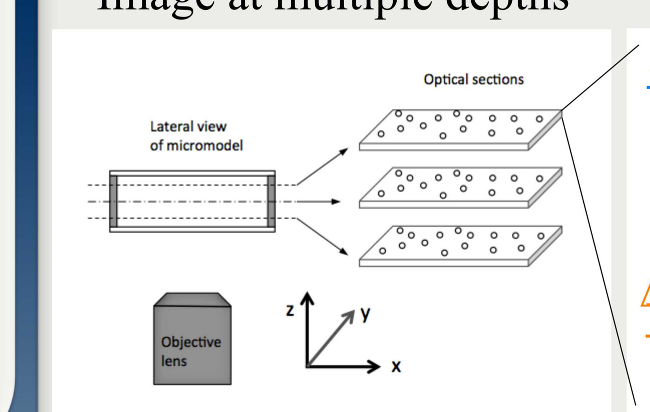
Experimental setup

3D Laser scanning confocal microscope

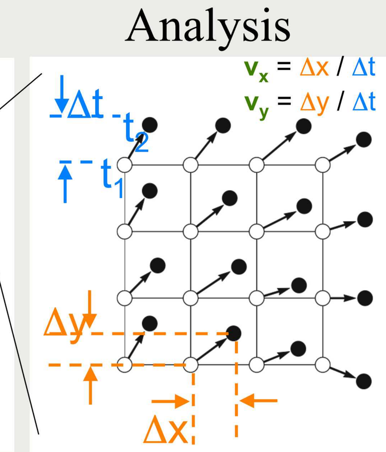


- Steady flow with a constant pore geometry
- 1-μm fluorescent particles added to the flow for imaging and analysis

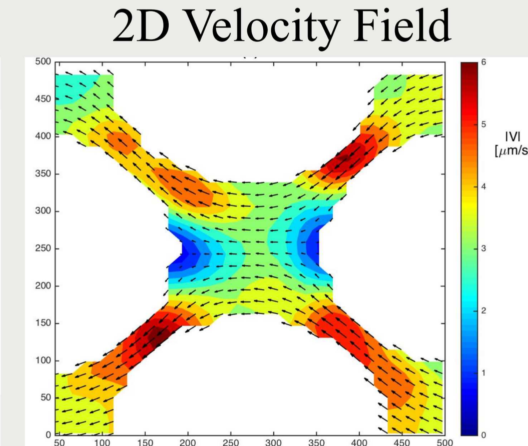
Image at multiple depths



Analysis



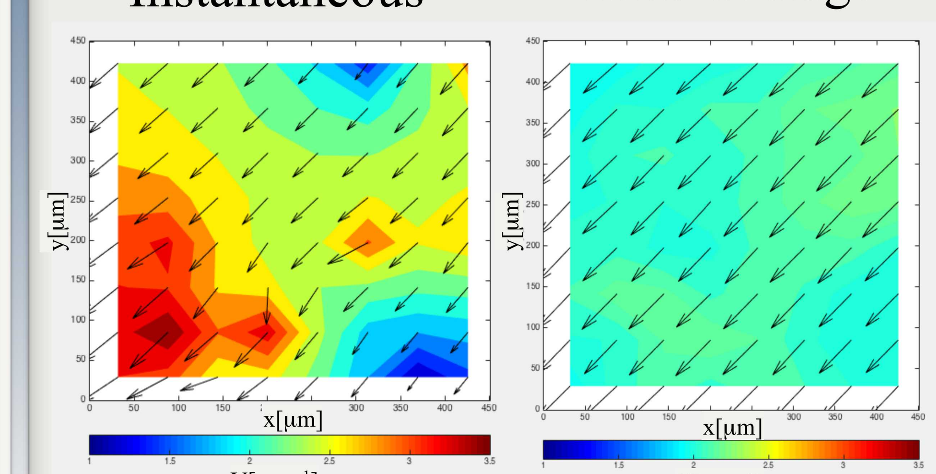
2D Velocity Field



Results for a constant geometry

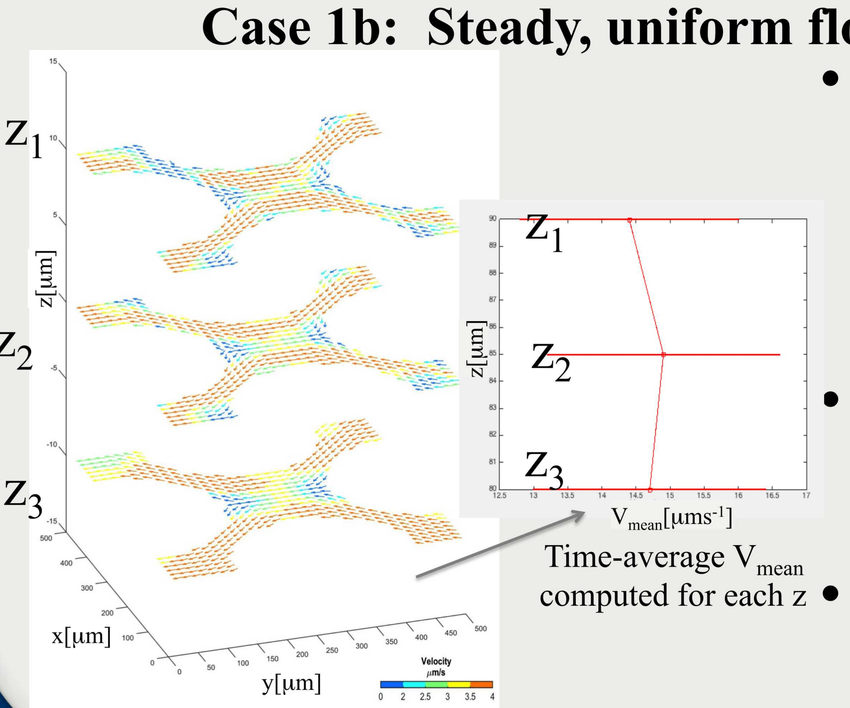
Case 1a: Steady, uniform flow in a channel

Instantaneous — Time-average



- Each field is time-averaged over 200 instants
- Observed : 35 μm/s
  Calculated: 54 μm/s

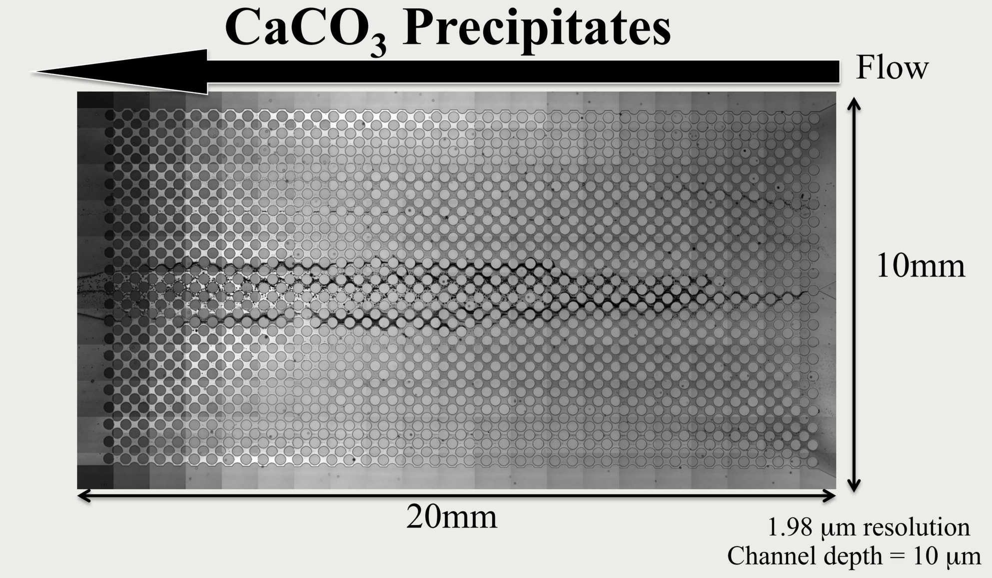
Case 1b: Steady, uniform flow in a clean pore body



- Each 2D velocity field shows fast flow in narrow throats and slow flow in wide pore bodies
- Flow is uniform with depth, shown by similar patterns at all heights
- 3D effects minimal in the steady flow and uniform configuration

2D flow field in the presence of precipitates

$CaCO_3$ Precipitates

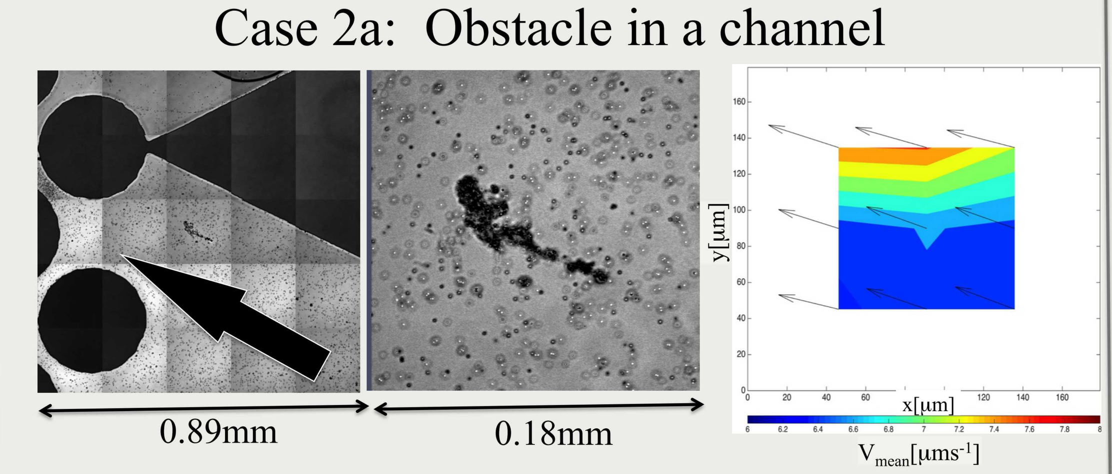


3D Flow Profiles Induced by Precipitation

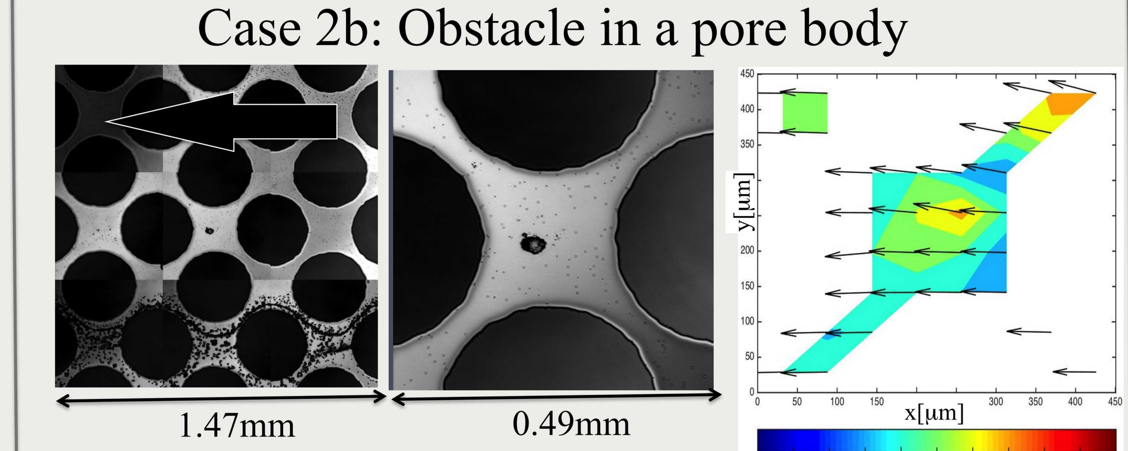
- imaged with steady and uniform flow of particles in water

Area surrounding structure — Structure — Time-average V_{mean} computed for each z

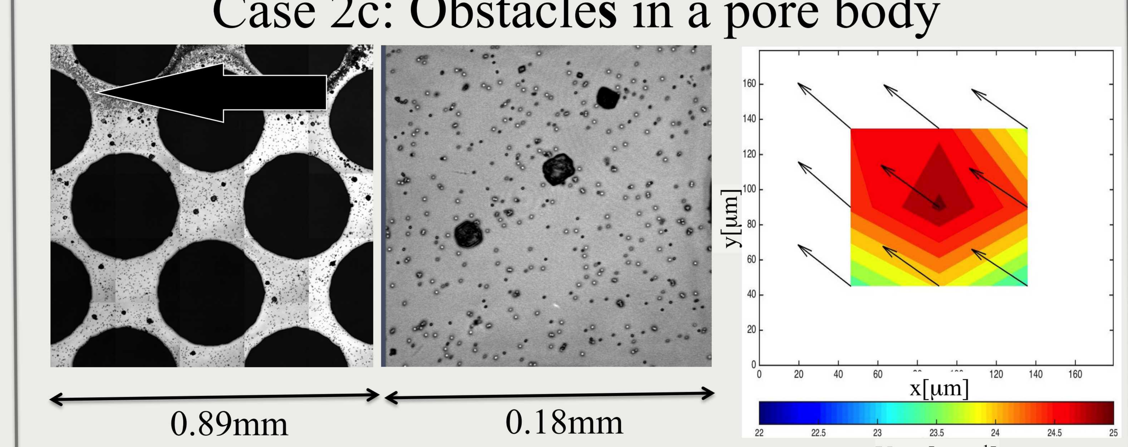
Case 2a: Obstacle in a channel



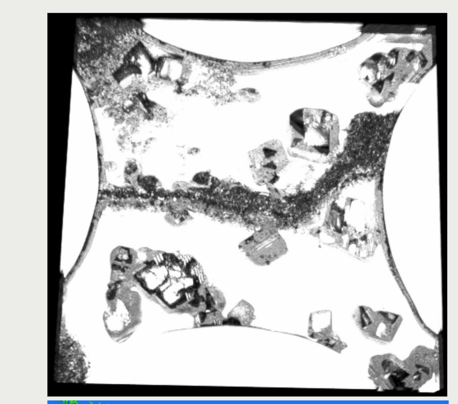
Case 2b: Obstacle in a pore body



Case 2c: Obstacles in a pore body

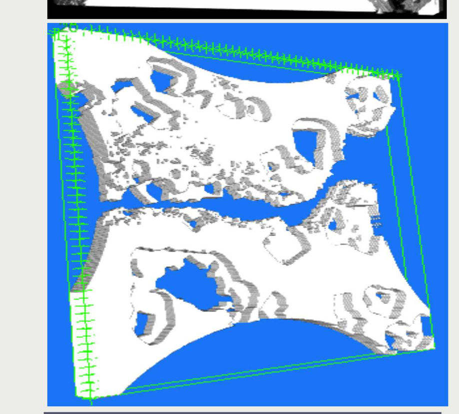


Simulations



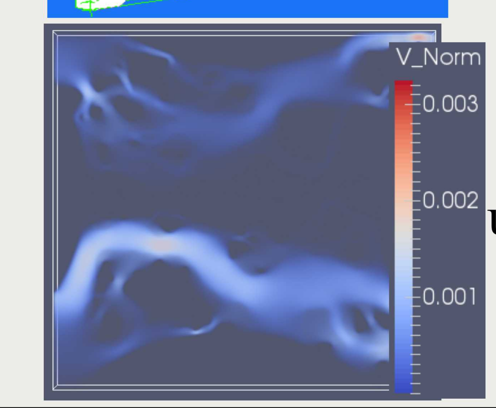
3D pore structure from confocal microscope

↓



Mesh generated from structure image

↓



Simulated flow in pore using Lattice-Boltzmann method

Preliminary Conclusions

- Confocal microscopy can be used to characterize 3D heterogeneous structures and flow field
- Heterogeneous pore structures induced by precipitations may have a significant impact on estimating reaction rate

Future Work

- Experimental and numerical validation of 3D velocity fields in representative precipitation patterns
- Estimation of reactive surface area from 3D profiles of precipitates and reaction rates across scales
- Extend the current workflow to multiphase flow in heterogeneous pore structure and mineral distributions

References: [1] Yoon, H., A.J.Valocchi, C.J.Werth, and T.Dewers (2012), Pore-scale simulation of mixing-induced calcium carbonate precipitation and dissolution in a microfluidic pore network, Water Resour. Res., 48, W02524, doi:10.1029/2011WR011192.
[2] Boyd, V., H. Yoon, C. Zhang, M. Oostrom, N. Hess, B. Fouke, A.J.Valocchi, C.J. Werth (2014), Influence of Mg^{2+} on $CaCO_3$ precipitation during subsurface reactive transport in a homogeneous silicon-etched pore network, Geoch. et Cosmo. Acta, 135, 321-335, doi:10.1016/j.gca.2014.03.018

Acknowledgements This work was 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, Basic Energy Sciences under Award Number DE-SC0001114.
Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.