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Integrated Multiscale Imaging and Numerical Simulations of Capillary/Buoyancy Driven CO_2 Flow

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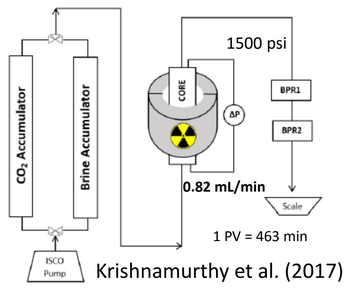
Objectives

- Characterization of capillary/buoyancy driven CO_2 flow flow in sandstone at small to large core scales
- Mechanistic understanding of controlling CO_2 flow with nano-particles
- Workflow for digital rock physics to upscale petrophysical and elastic properties for multiphase flow

Methods

- Multiscale CT scanning of CO_2 flow in sandstone cores
- Characterization of pore structures and surface properties using multiscale imaging techniques (microCT, medical CT, optical microscopy, QEMSCAN, SEM, BSEM)
- Microfluidic application for controlling CO_2 flow with silica-based nanoparticles

High pressure CO_2 core flood experiment

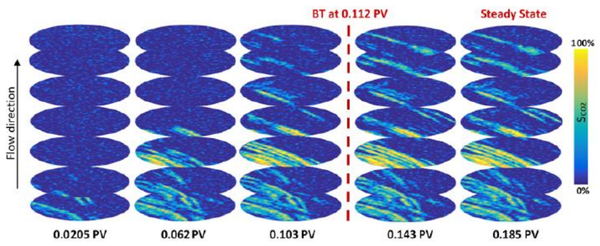


Krishnamurthy et al. (2017)

Boise sandstone
(30cm long,
7.2 cm diameter)
k =3.75 x 10^{-12} m^2
Porosity = 0.308
Brine = 1010 kg/m^3
CO2 = 818 kg/m^3

- 1cm scanning thickness (also 0.2 cm thickness)
- CT images at 0.257 mm x 0.257 mm pixel resolution
- Images are taken at an interval of ~0.02 to 0.05 PV

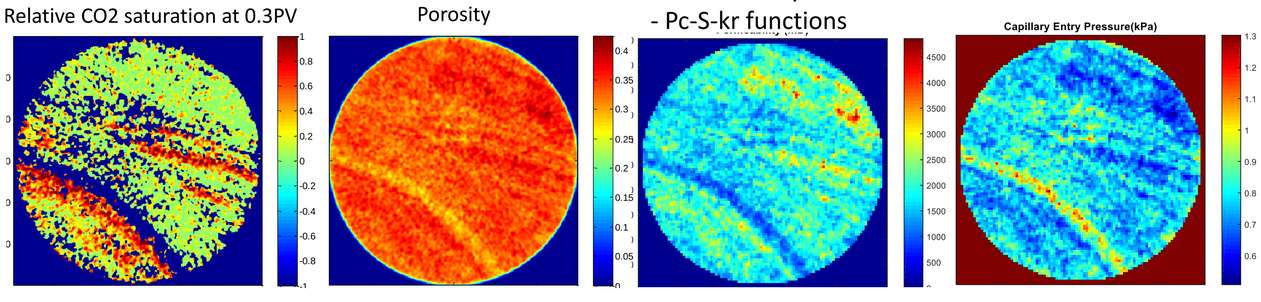
CO_2 Saturation Profiles from CT data



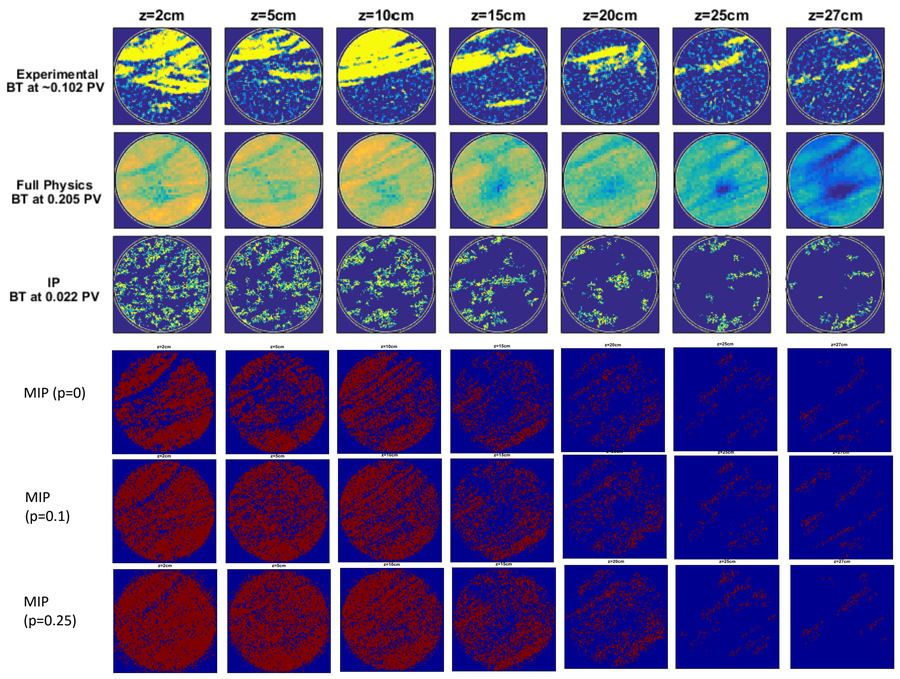
Multiphase flow simulation (STOMP)
- Permeability
- Pc-S-kr functions

MIP & IP simulation
Entry pressure field

Relative CO2 saturation at 0.3PV | Porosity | Capillary Entry Pressure(kPa)



Comparison of Experimental and Simulation results

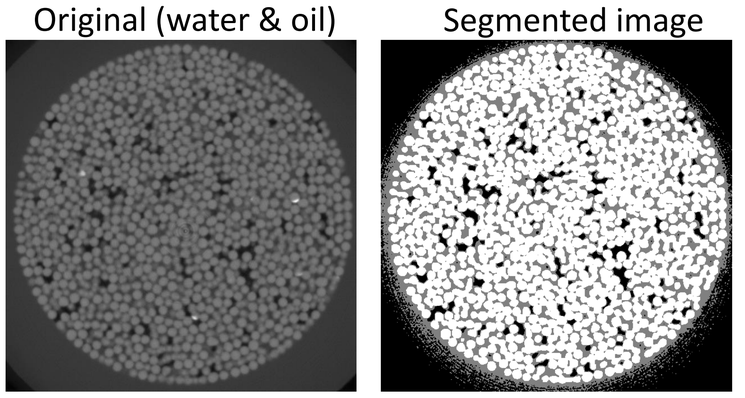


- Experimental data based on medical CT images every 1cm interval
- Full physics results with Darcy-based model
- IP (invasion percolation) results with Permedia (commercial software)
- MIP (Modified IP) results with OpenMIP where p stands for stochastic selection probability with zero for no stochastic and one for completely stochastic

Krishnamurthy, Senthilnathan, Yoon, Thomassen, Meckel, DiCarlo, Comparison of Darcy's law and invasion percolation simulations with buoyancy-driven CO2-brine multiphase flow in a heterogeneous sandstone core, J.Petrol. Sci. Eng. (2017, In Press)

Micro-CT Image Analysis

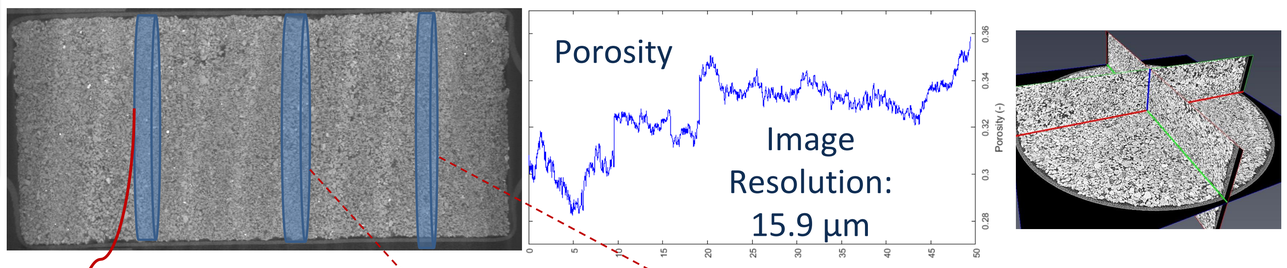
Original (water & oil) | Segmented image



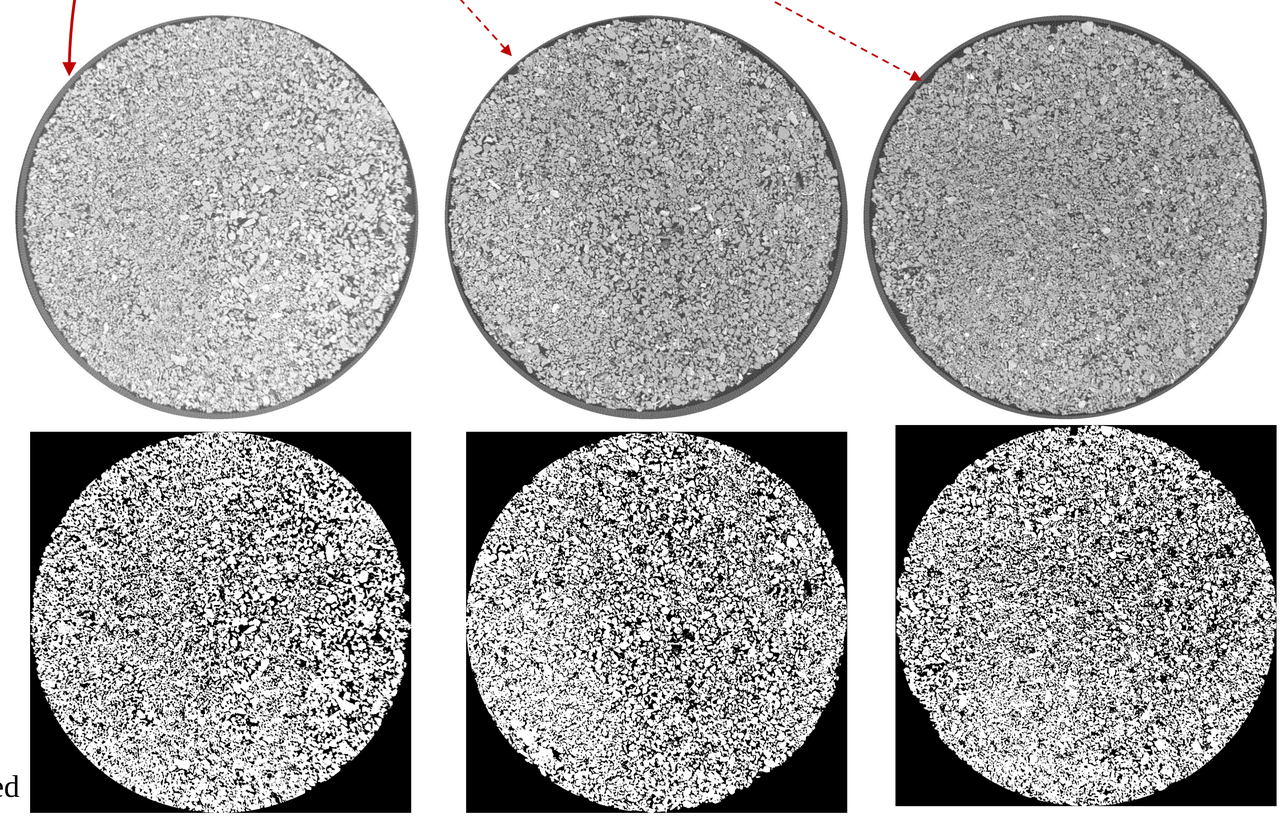
Segmentation Algorithm

- Segmentation of solid phase
- Segmentation of oil phase
- Normalized image (range from 0 to 1)
- Contrast-limited adaptive histogram equalization (CLAHE) or histogram equalization
- Histogram equalization
- Identify binary gradient mask between solid and liquid
- Imerode and Imreconstruct to increase the contrast of oil phase
- Segmentation using the threshold value based on the average value corresponding to the binary gradient mask
- Segmentation using the threshold value of 0.25
- Dilate the segmented image to match the quality of CT image
- Combine two segmented images to construct 3-phase distribution

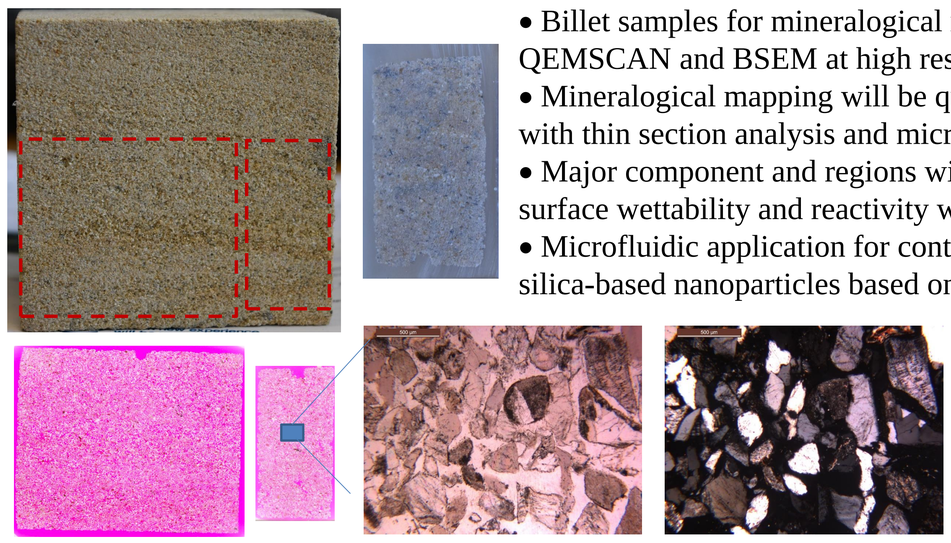
MicroCT images of Boise Sandstone (1” core x 2” height)



Cross section al view of 1600x1600x3200 images (above) and microCT images (below)



Thin Sections of Boise Sandstone (3” x 3” x 1” block)



- Billet samples for mineralogical mapping with QEMSCAN and BSEM at high resolution
- Mineralogical mapping will be quantitatively correlated with thin section analysis and microCT images
- Major component and regions will be identified and surface wettability and reactivity will be determined
- Microfluidic application for controlling CO_2 flow with silica-based nanoparticles based on thin section analysis

Multiple thin sections (left) and petrographic images (transmitted & polarized)

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