Pore-Scale Migration and Trapping Using Micromodel Experiments

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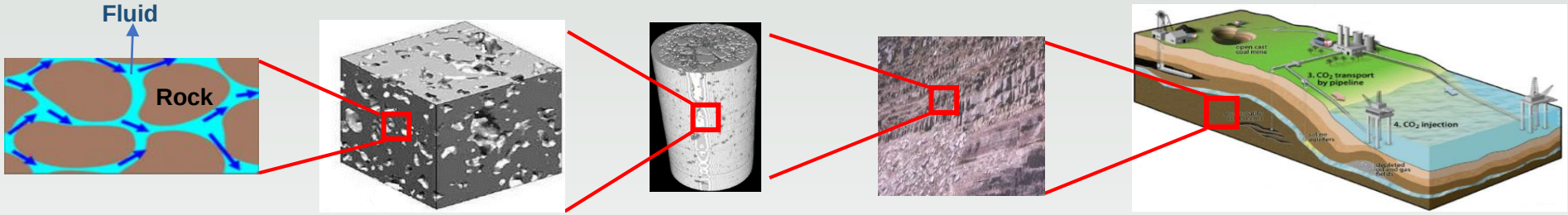
Subsurface reservoirs: A multiscale system

- Geological structures in reservoirs occur at a range of length scales.
- Multiscale characteristic have a profound impact on fluid flow.

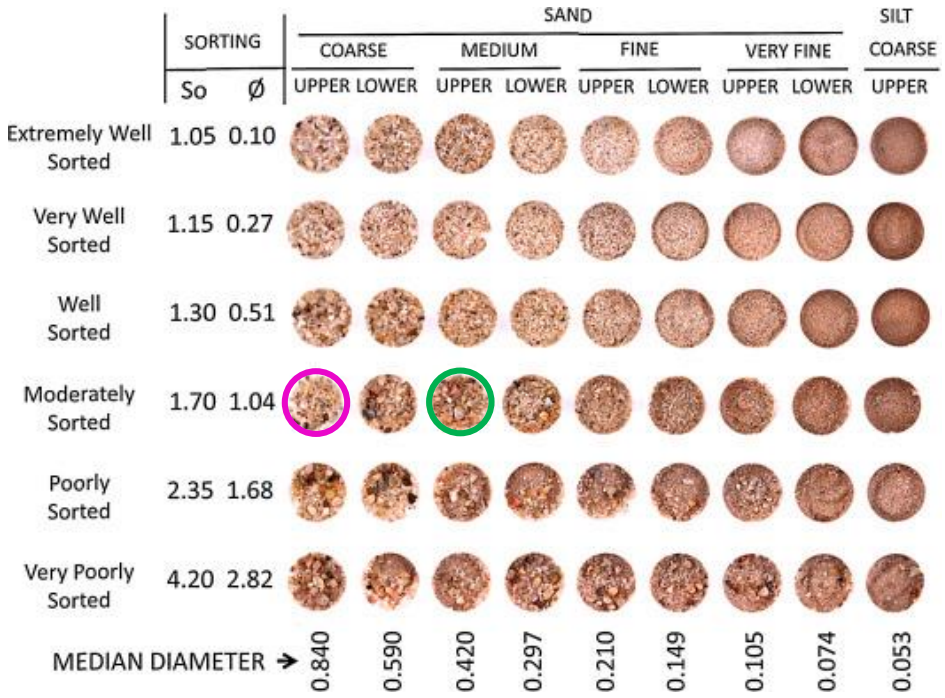


A multi-scale phenomenon

Multiphase Flow at the Pore Scale

- Pore Scale: Controlled experiments and simulations that can isolate variables and visualize supercritical drainage and imbibition focusing on capillary dominated flow regime
  - ❑ Capillary Pressure
  - ❑ Capillary Trapping
  - ❑ Residual Saturations
  - ❑ Flow Patterns and Relative Permeability

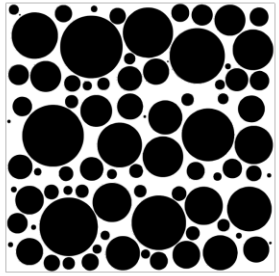
Grain Size Distribution and Pattern Generation

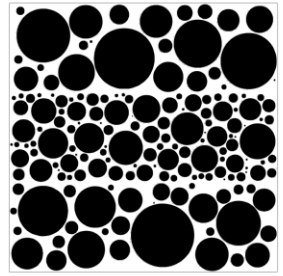


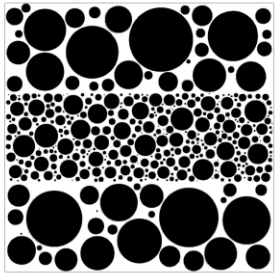
(Meckel et al. 2015)

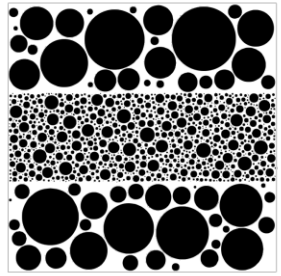
Outer Layers: MUMSa 0.420 mm median diameter

Inner Layer:


MUMSa

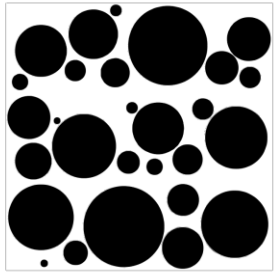

MUFSa

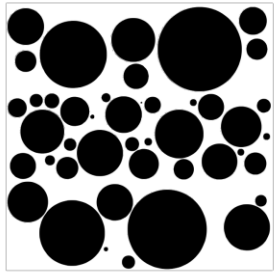

MUVFSa

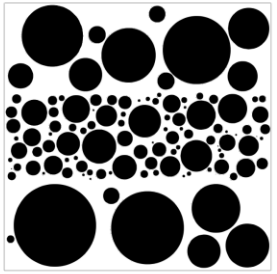

MUCSi

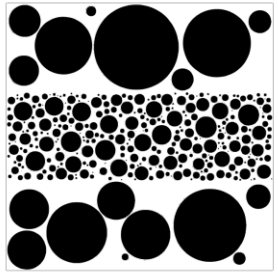
Outer Layers: MUCSa 0.840 mm median diameter

Inner Layer:


MUCSa


MUMSa


MUFSa


MUVFSa

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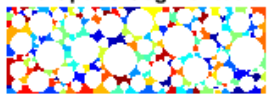
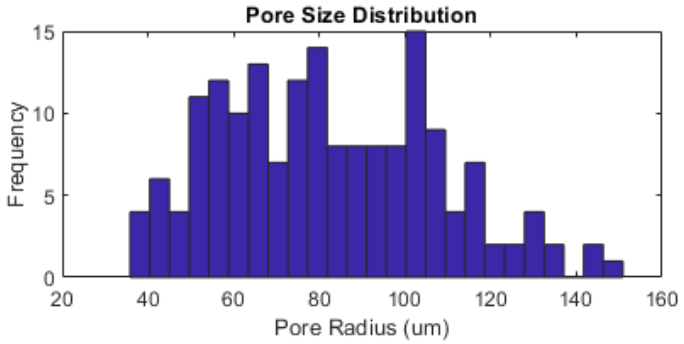
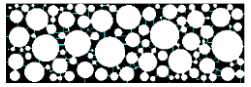
Pore sizes and Pore throats

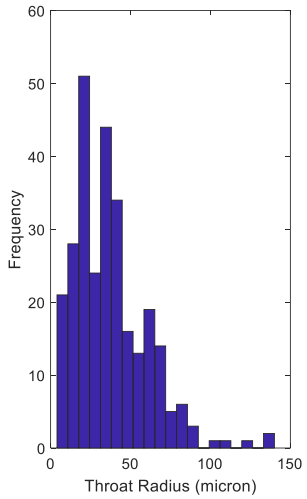
Pore Space Segmentation





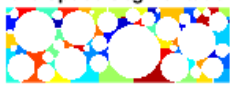
Average Pore Radius = ~82 µm

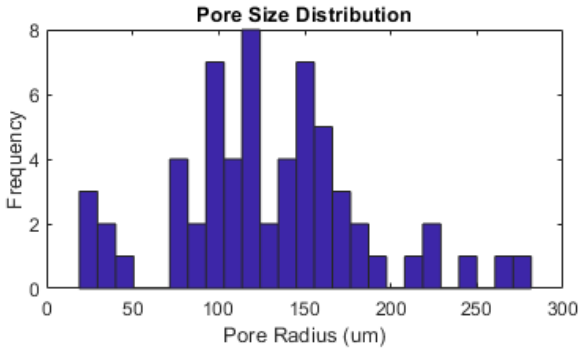




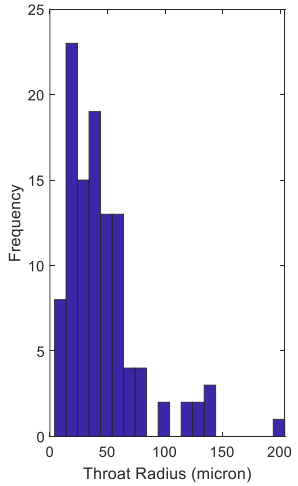
Average Pore Throat = 37 µm

Pore Space Segmentation



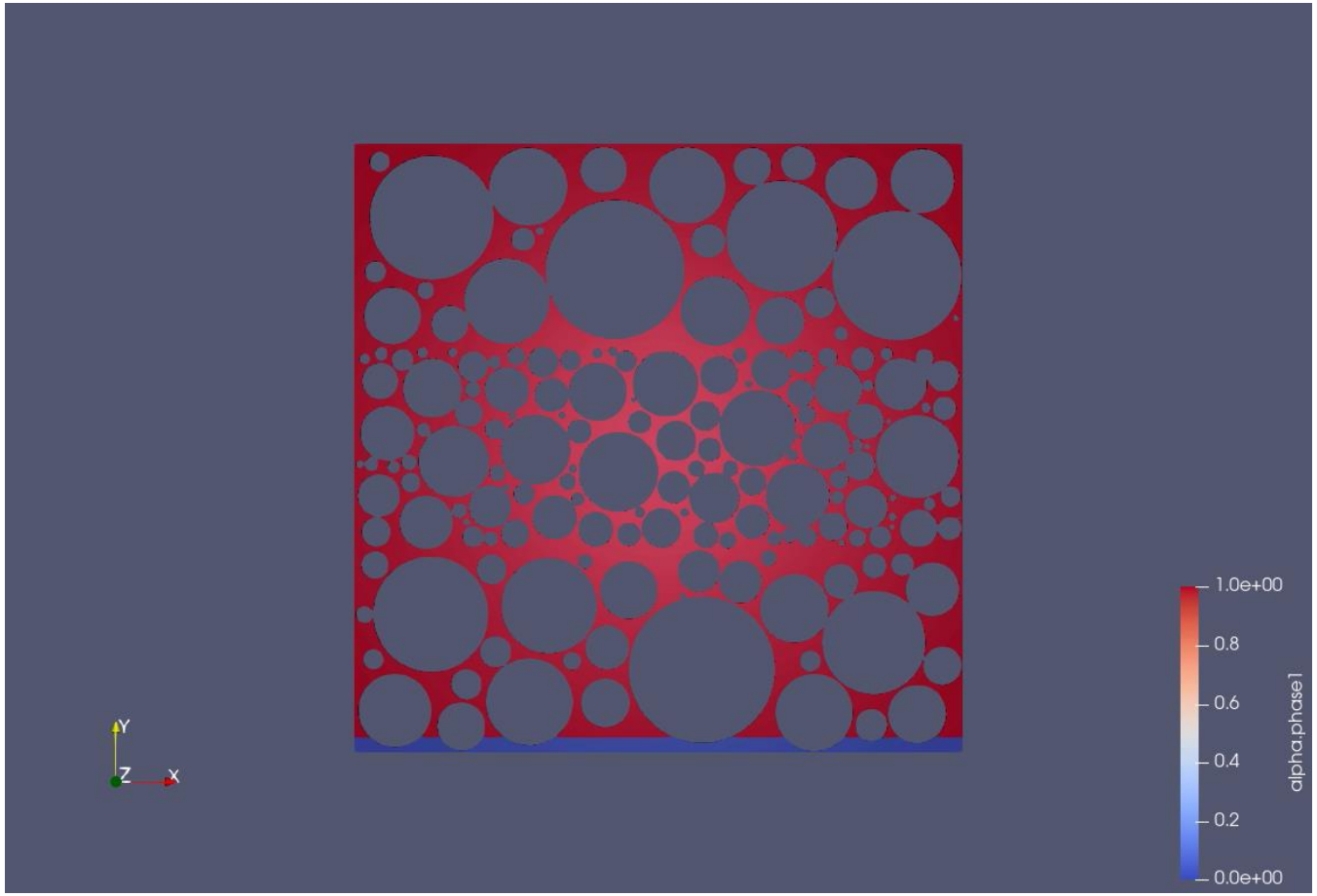


Average Pore Radius = ~130 µm



Average Pore Throat = 47 µm

Computational Fluid Dynamics Simulations in OpenFOAM



Water

CO_2

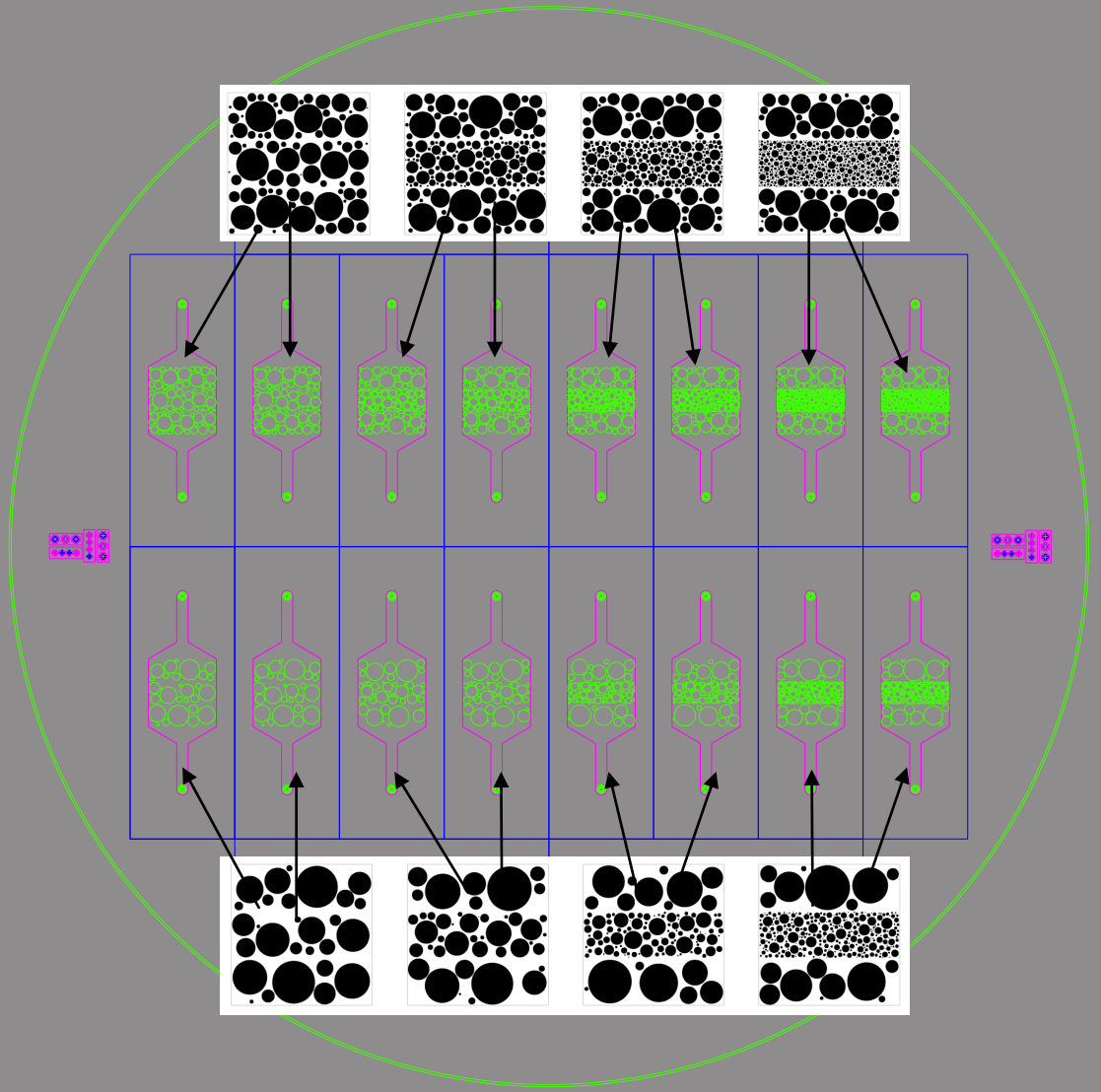
Experimental Solution: Microfluidics

- Experimental approach to understanding pore scale behavior of carbon dioxide injection for carbon sequestration
- Utilize microfluidics and microscale experiments to visualize pore scale flow

Photomask Pattern

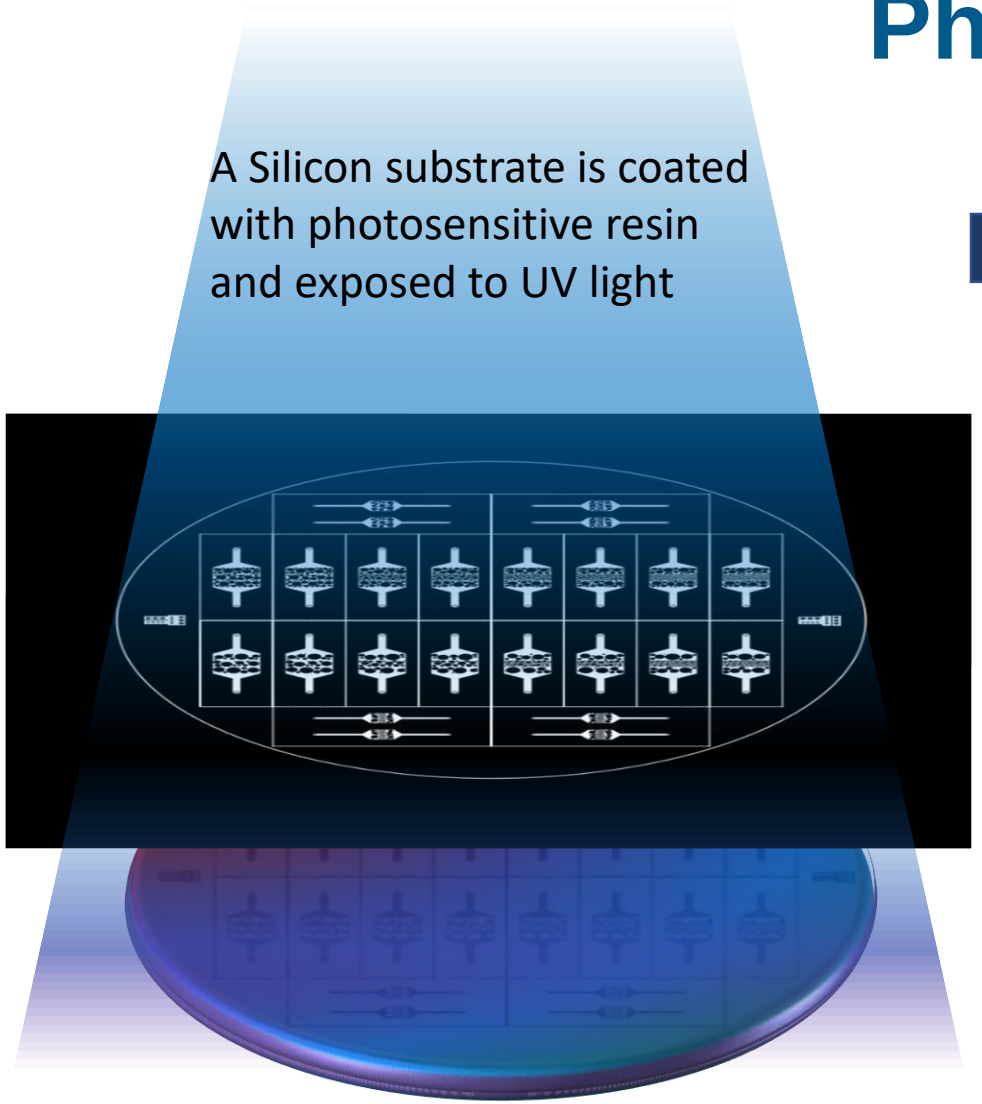
Take generated pattern geometry and input them into devices structures

This is then patterned into a physical binary transparency mask



Photolithography

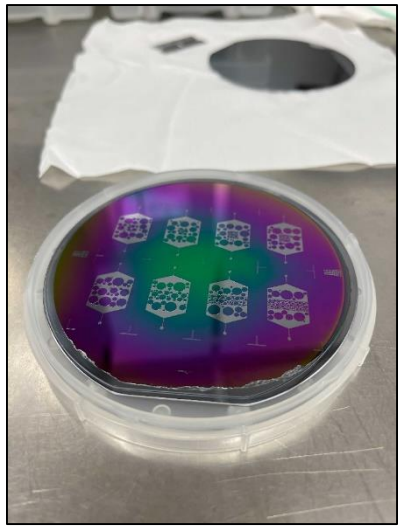
A Silicon substrate is coated with photosensitive resin and exposed to UV light

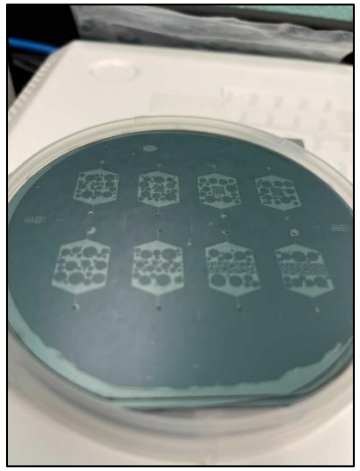


The unmasked area is then etched using gas plasma

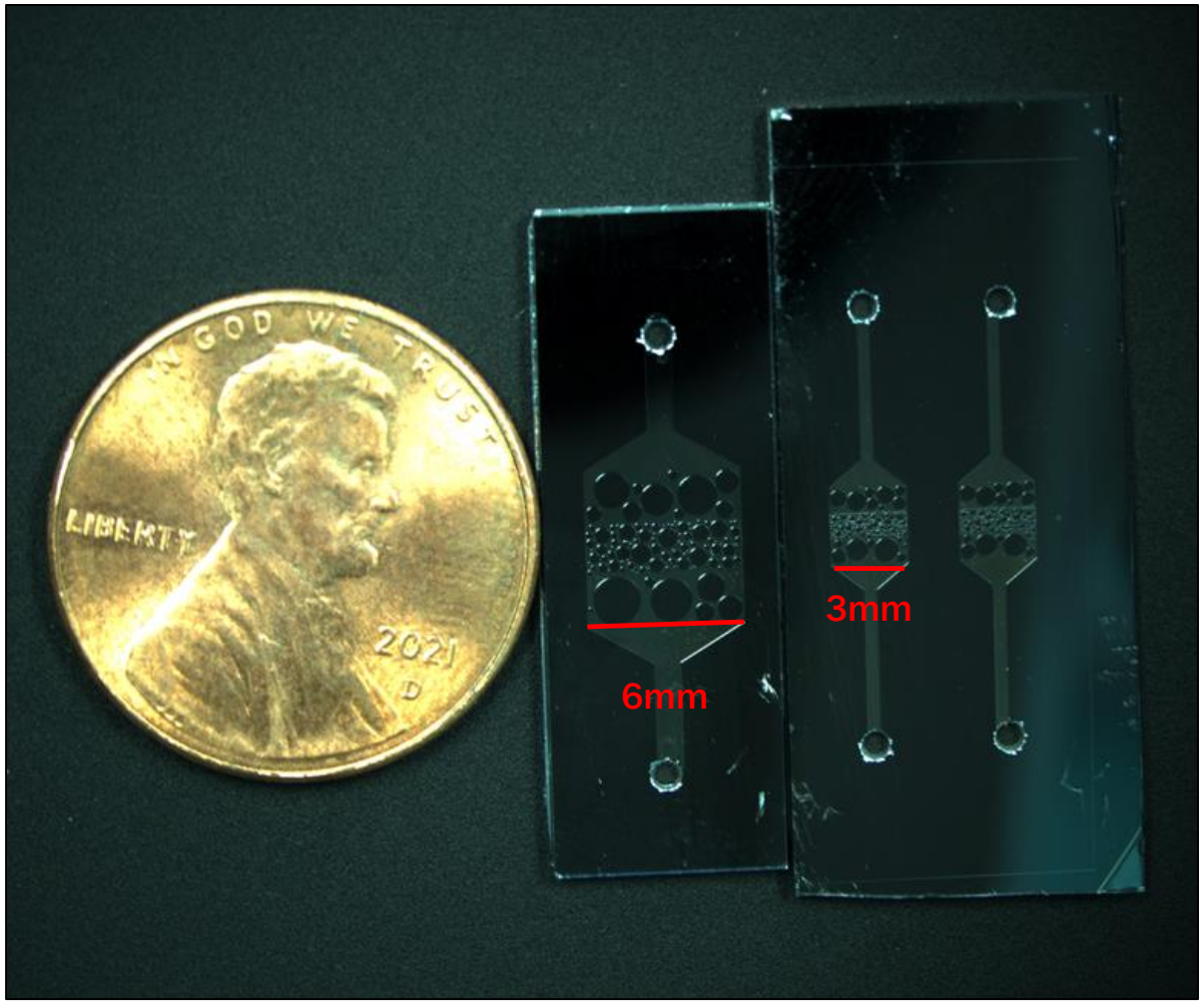
The etched silicon is then bonded to glass using anodic bonding

Microfluidic fabrication



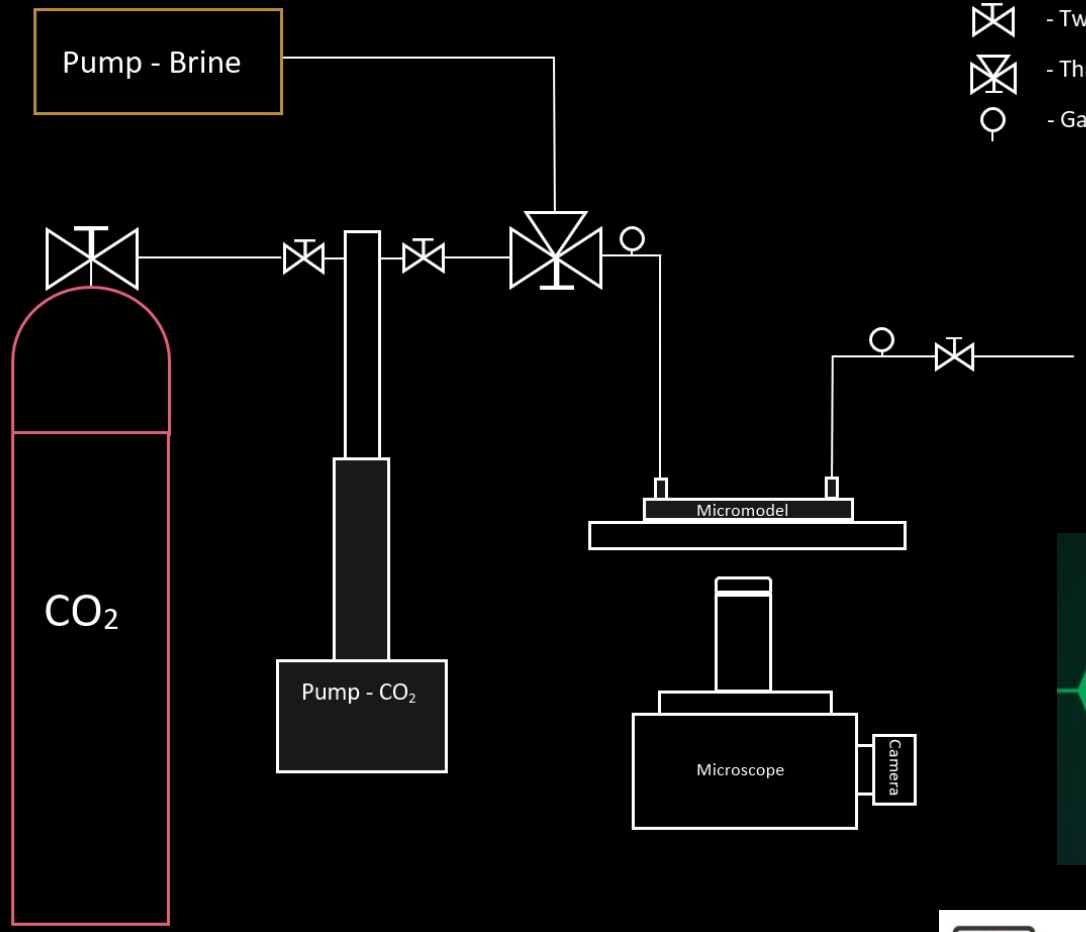


Various stages of the microfabrication



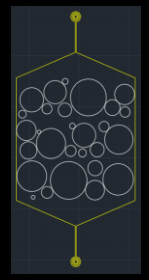
Completed Microfluidic devices with penny for scale

Micromodel lab and Microfluidic Setup



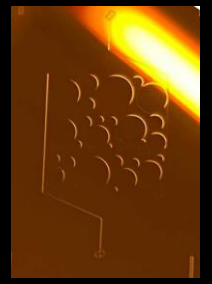
Experimental Setup

Device with designed pore geometries



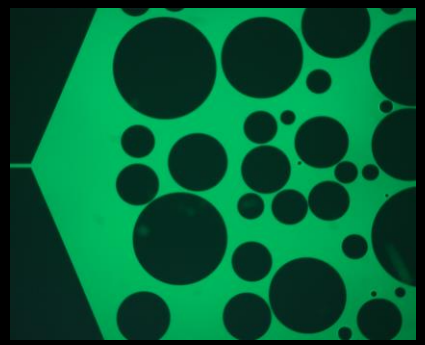
AutoCAD drawing

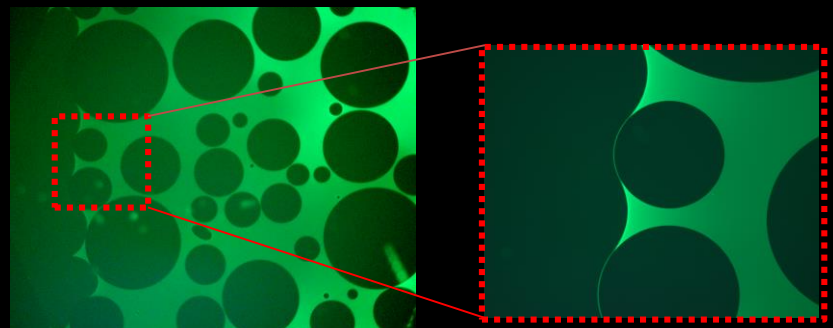
Patterned Silicon



Etched silicon

Silicon-glass flow cell





Fluorescent imaging during flow fest

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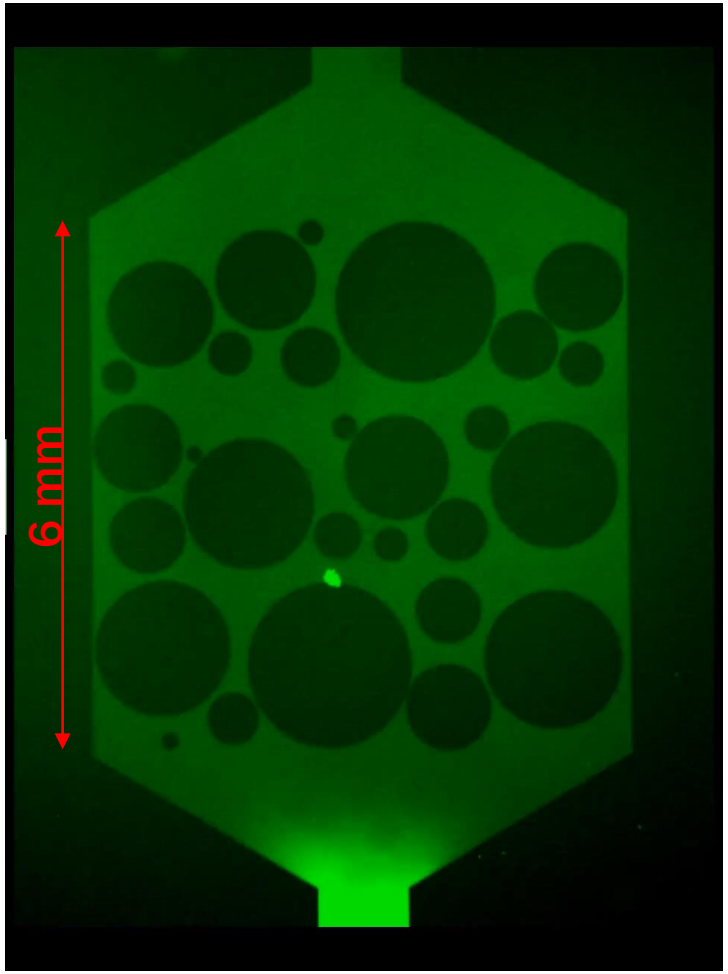
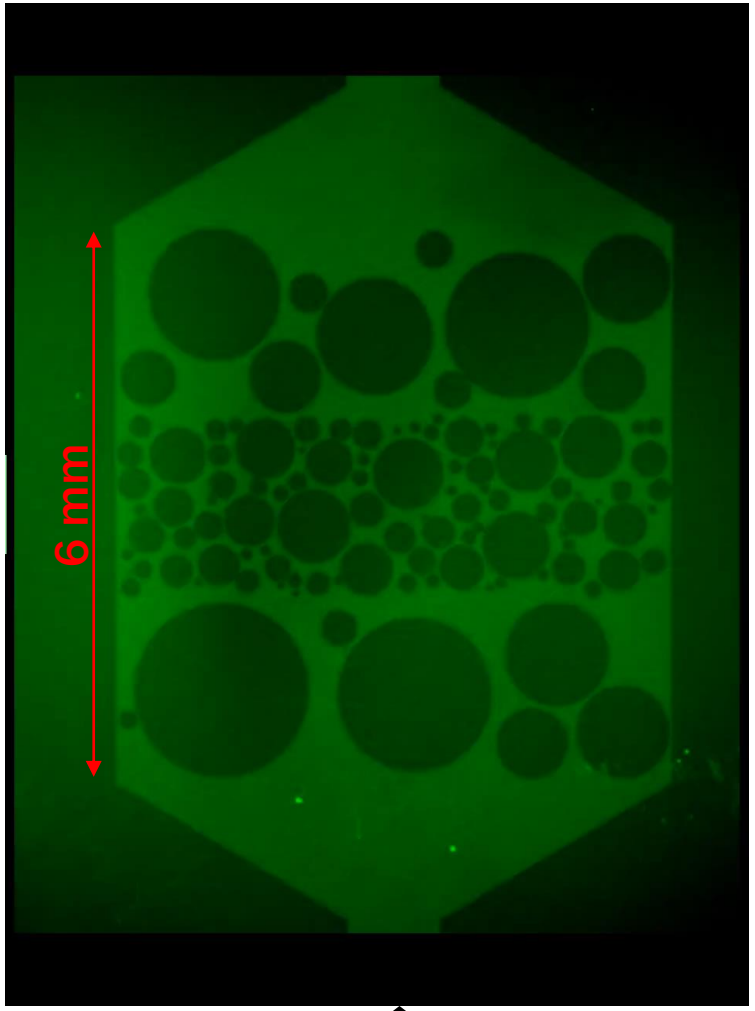
CO2 Drainage in Different Contrasts at 0.005 mL/min



Injected CO2



Injected CO2

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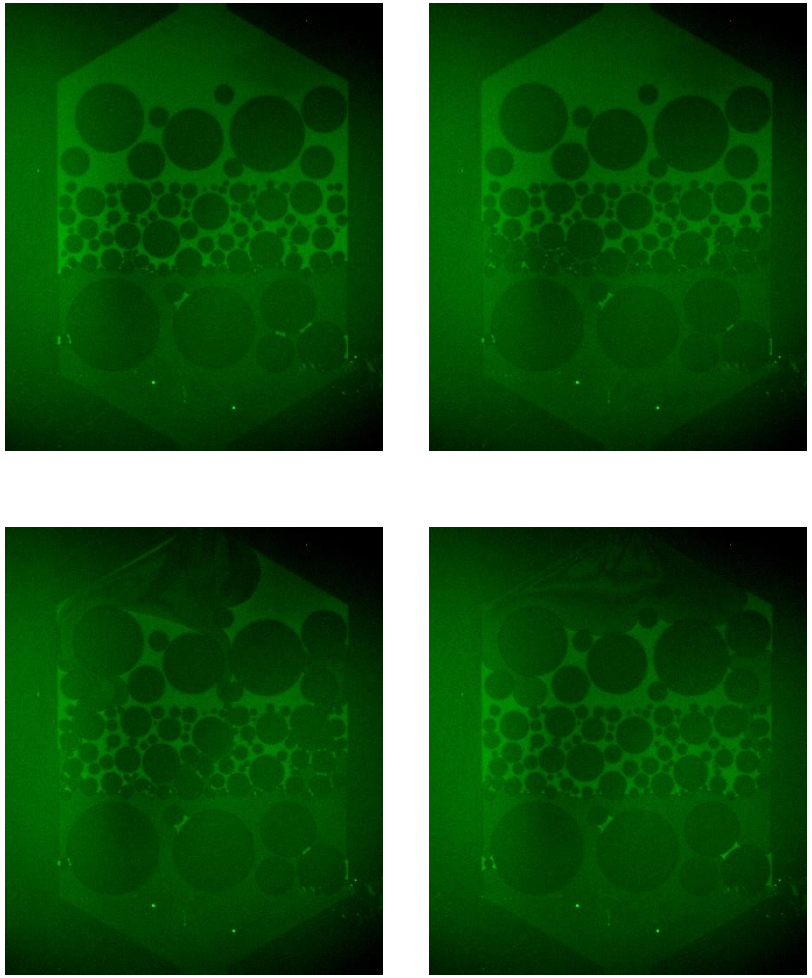
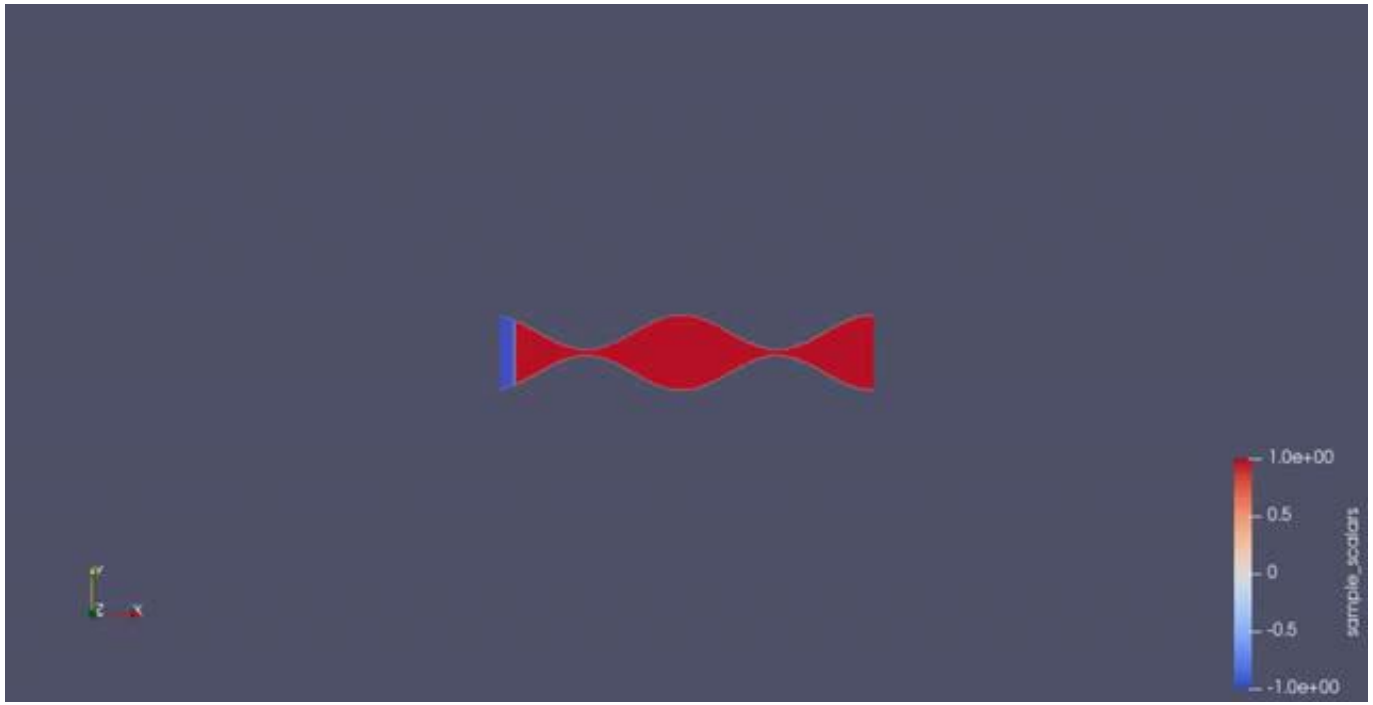
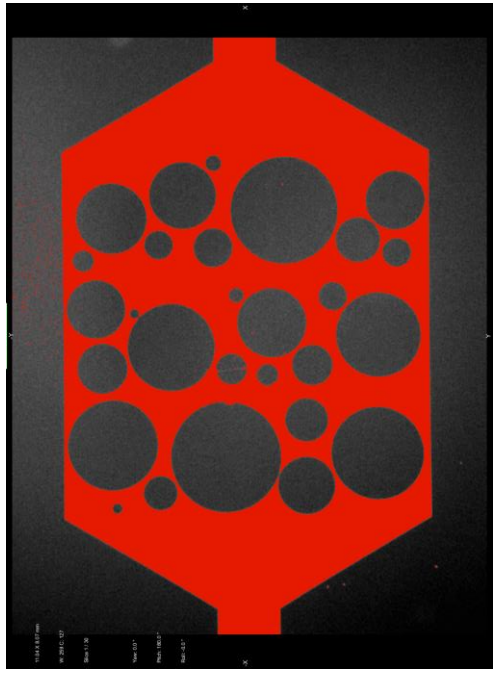
Experimental Results: Observed Snap-Off

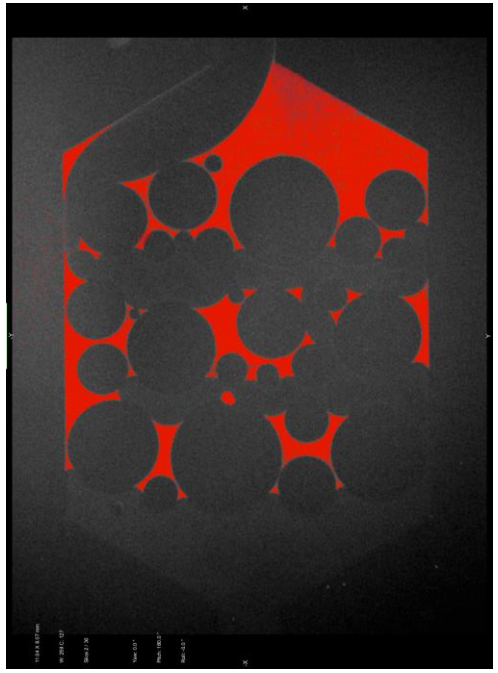


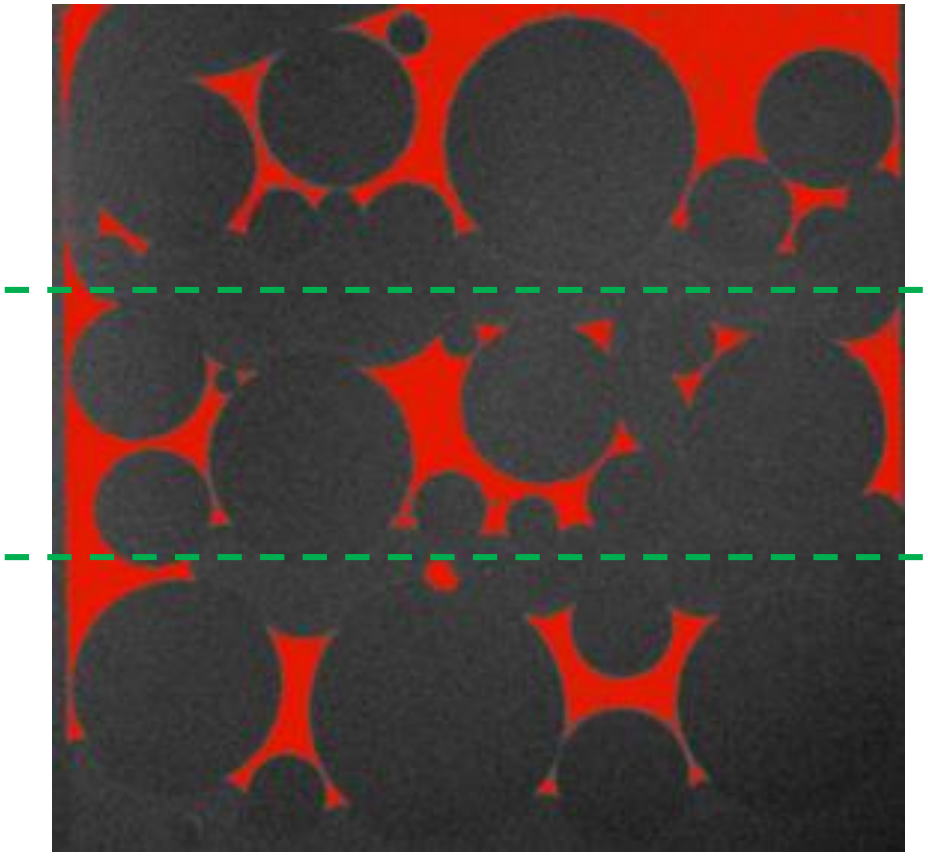


Snap off During Drainage in a Constricted Capillary Tube, Sahar Bakhshian

Experimental Results - Saturations







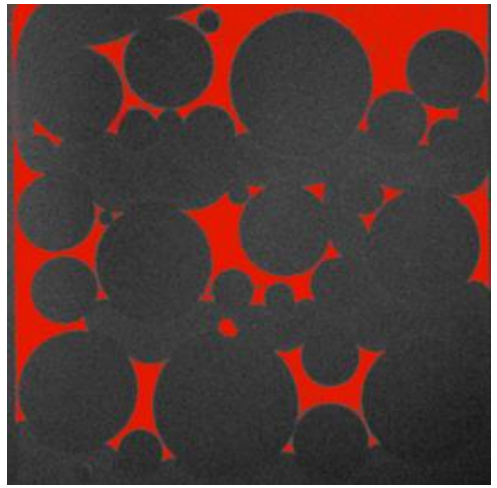
S_w=46%

S_w=32%

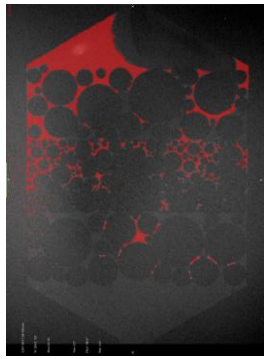
S_w=19%

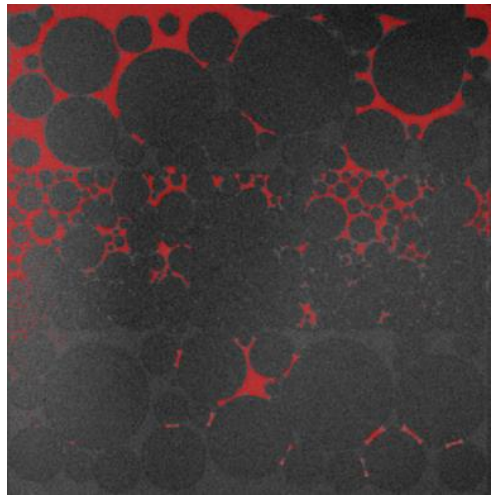
Experimental Results - Saturations

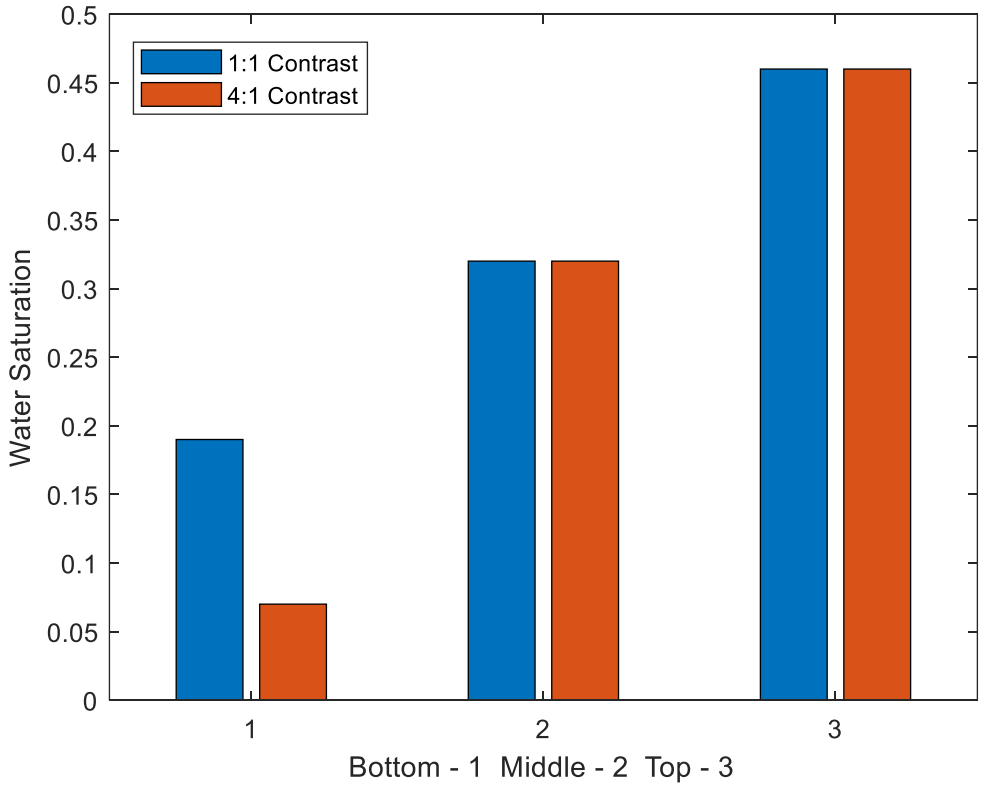
1:1 Contrast (Control)



4:1 Contrast







Summary and Next Steps

- Experimental Results: show observed phenomenon and quantitative outputs
- Recreate reservoir P&T conditions
- Varying fluid parameters
- Devices with varied surface properties and roughness (wettability)
- Support and resolve aspects of numerical simulations (CFD)
- Apply pore scale variations to carbon sequestration fluid flow models

Thank you!
Questions?