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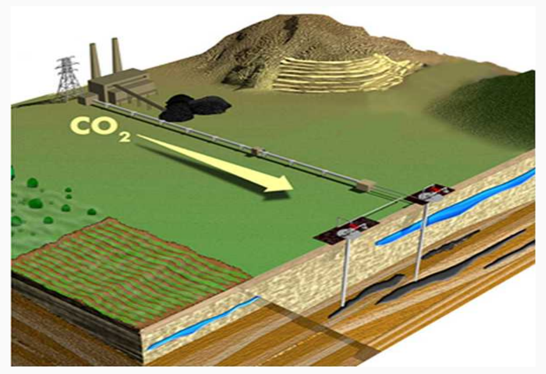
Impact of Roughness on CO_2 Migration

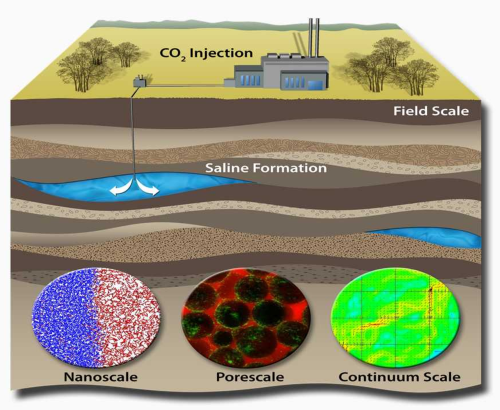
A. Kucala[1], Y. Wang[1], M.J. Martinez[1], B. Cardenas[2], and L. Wang[2]
Sandia National Laboratories[1]
University of Texas at Austin[2]

Introduction

Motivation



Global consumption of fossil fuels has significantly increased levels of atmospheric CO_2, a greenhouse gas. Carbon capture and storage (CCS) is a promising mitigation strategy.



Scientific Objective:
Understand and control *emergent behavior* arising from *coupled physics* in *heterogeneous geomaterials* associated with injection for GCS, especially at *intermediate length scales* (cm to m) where geologic variability plays a decisive role. Processes and strategies are based on mesoscale science from which non-equilibrium and emergent behaviors arise over a large range of time and length scales.

Theme 3: Buoyantly Driven Multiphase Flow of CO_2

Our Plan:

- Perform pore-scale and meso-scale simulations to elucidate and quantify the physics governing flow regimes from compact flow to capillary channel flow
- Develop new experimental-informed, physics-based flow models, focused on representing cm-scale heterogeneity.
- Apply hydrophobicity theory to assess the impact on permeability and CO_2 ganglion mobility.
- Develop methods to relate stress, facture closure stiffness and fracture permeability.

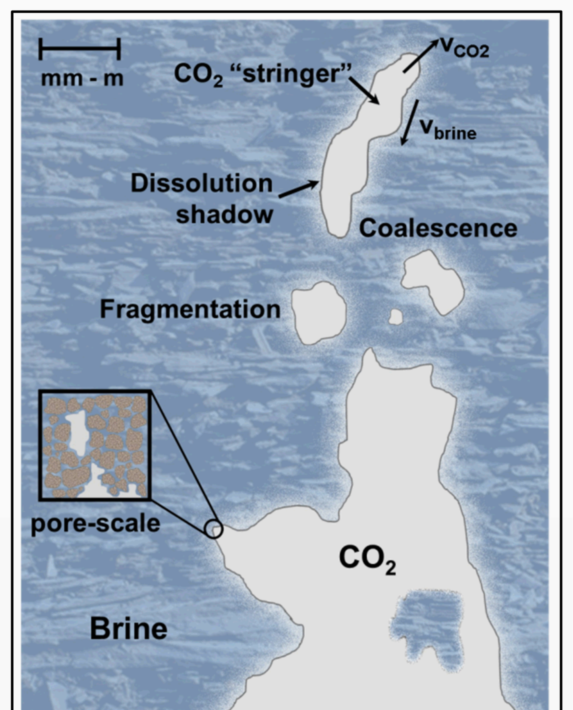
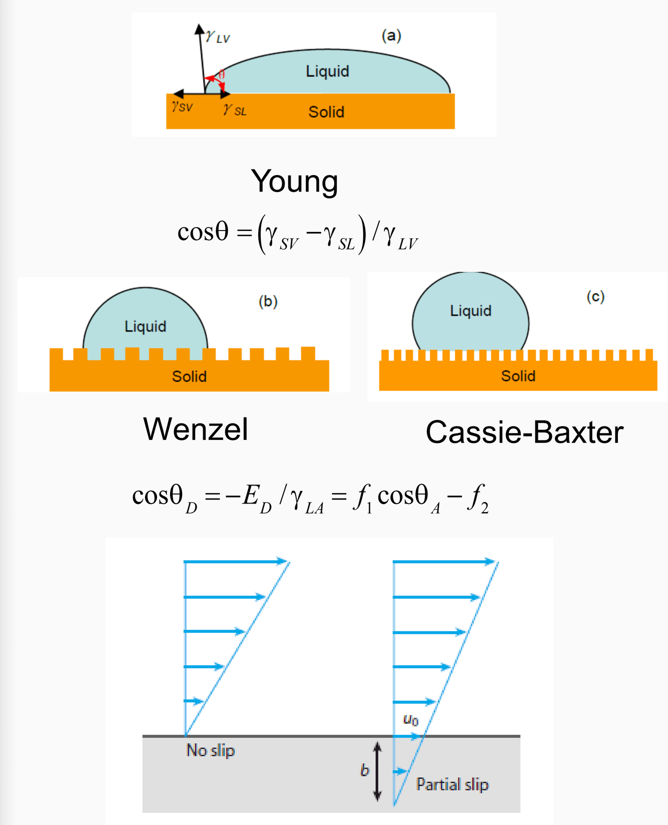


Figure: Conceptual model and mechanistic processes in buoyancy-driven ganglia dynamics (note v_{CO2}, v_{brine} of "stringer") which collectively correspond to capillary channeling.

Challenges Addressed:

- Sustaining large storage rates
- Using pore scale with unprecedented efficiency
- Controlling undesired or unexpected emergent behavior

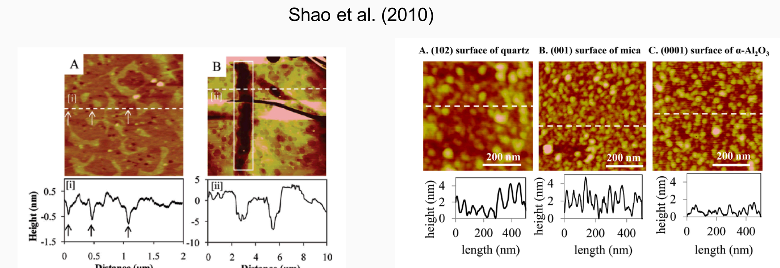
Impact of Roughness on Wettability



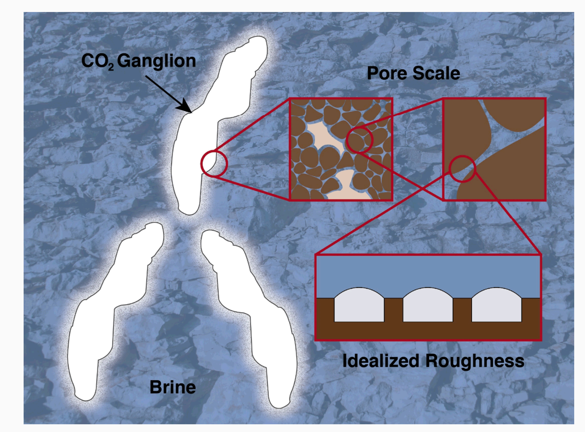
$\cos\theta = (\gamma_{SV} - \gamma_{SL})/\gamma_{LV}$

$\cos\theta_D = -E_D/\gamma_{LA} = f_1\cos\theta_A - f_2$

Shao et al. (2010)



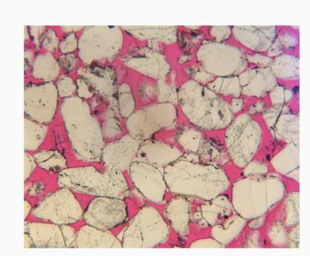
Examples of natural and/or reaction-induced roughness

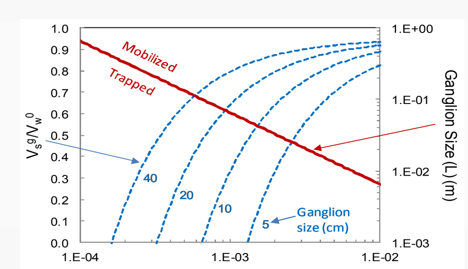


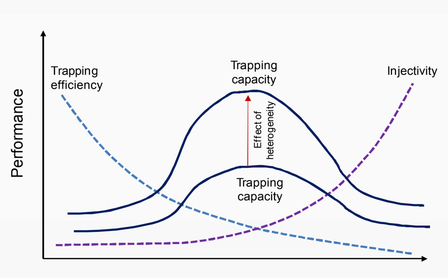
Conceptual surface roughness model

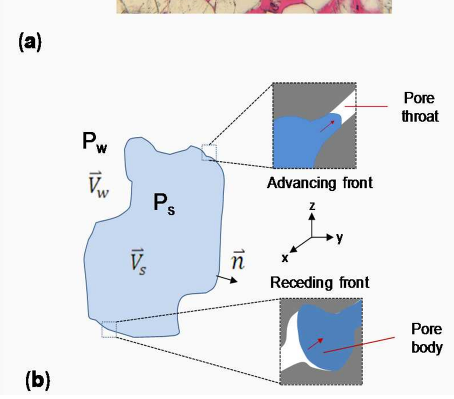
- Natural roughness in reservoir rocks can impact the apparent contact angle of CO_2 (wettability).
- Roughness can induce positive or negative flow slip which can increase or decrease permeability and CO_2 ganglion mobility.
- Hydrophobic effects impact both short term (injection) and long-term dynamics CO_2 ganglion migration.

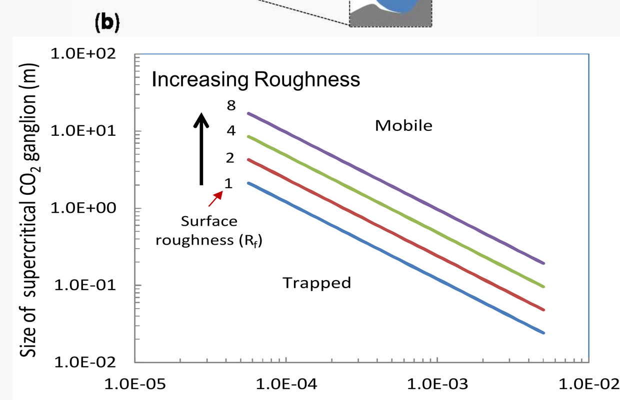
Ganglion Dynamics







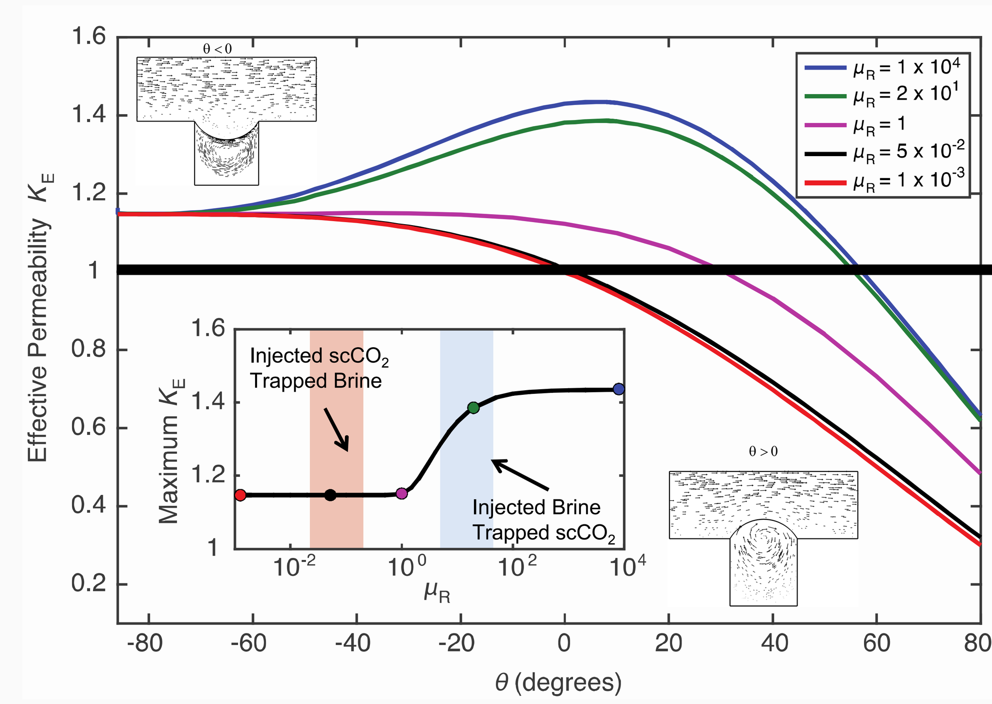




Develop engineering approaches to maximizing storage efficiency

- **Mobility of a ganglion is inversely dependent on its size.**
- **Breaking the injected $scCO_2$ into small disconnected ganglia enhances the efficiency of capillary trapping.**
- **Supercritical CO_2 ganglia can be engineered by promoting CO_2-water interface instability during immiscible displacement.**
- **Ganglion size distribution can be controlled by injection mode (e.g., water-alternating-gas) and rate.**
- **Vertical structural heterogeneity within a reservoir can inhibit the buoyant rise of $scCO_2$ ganglia.**

Permeability and Pore Geometry

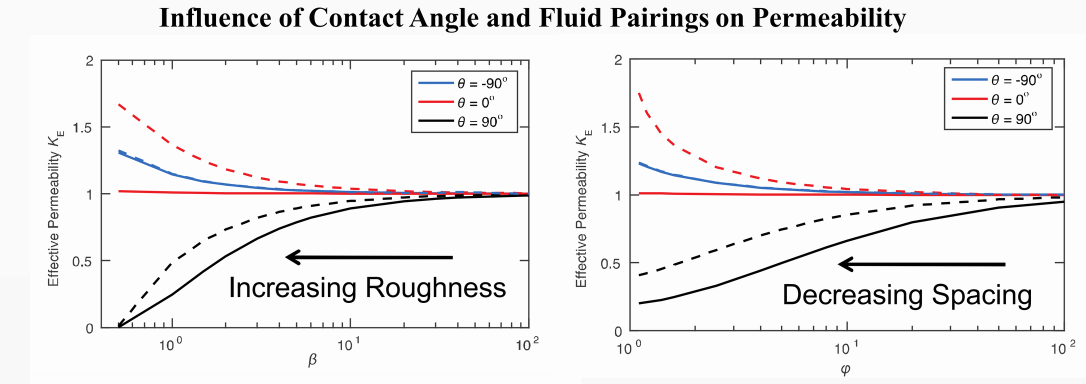


More Permeable
$K_E > 1$

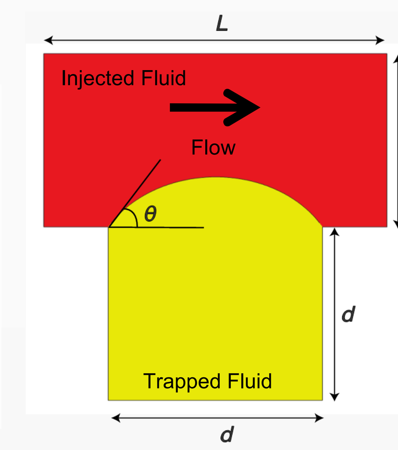
Less Permeable
$K_E < 1$

$$K_E = 1 + \frac{3b}{b+h}$$

Influence of Contact Angle and Fluid Pairings on Permeability



Influence of Reservoir Rock Geometry on Permeability



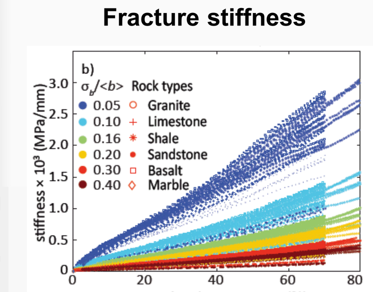
Flow Geometry

Fracture Permeability

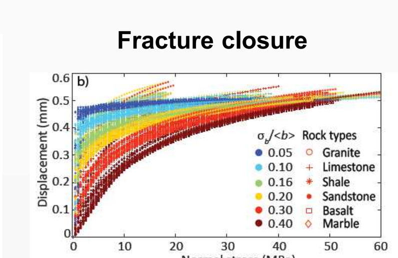
Motivation and Goal:
Develop a coupled mechanics and hydrological model relating stress, fracture closure stiffness and fracture permeability.

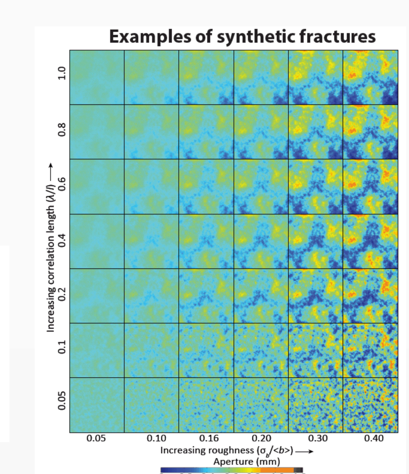
Methods: Utilize synthetic fractures in Hopkins fracture deformation model combined with modified Local Cubic Law

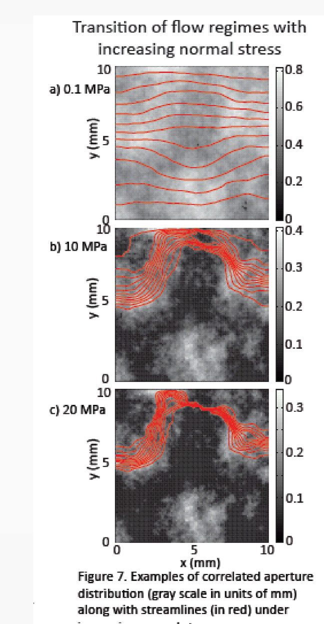
Fracture stiffness



Fracture closure







Concluding Remarks

- Pore-scale surface roughness can impact long-term CO_2 migration, impacting permeability and CO_2 ganglion mobility.
- Fracture-scale roughness can impact flow morphology.

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