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Impact of Roughness on CO_2 Migration

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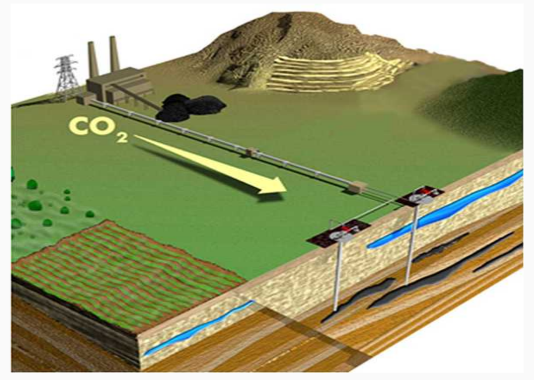
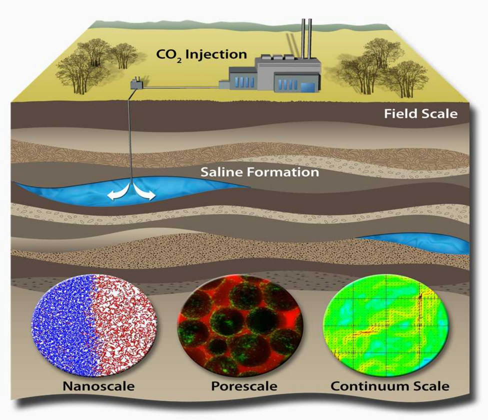
Introduction

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.
- Model the migration of CO_2 through reservoir rocks using moving contact line models
- Work closely with UT to experimentally validate computational models

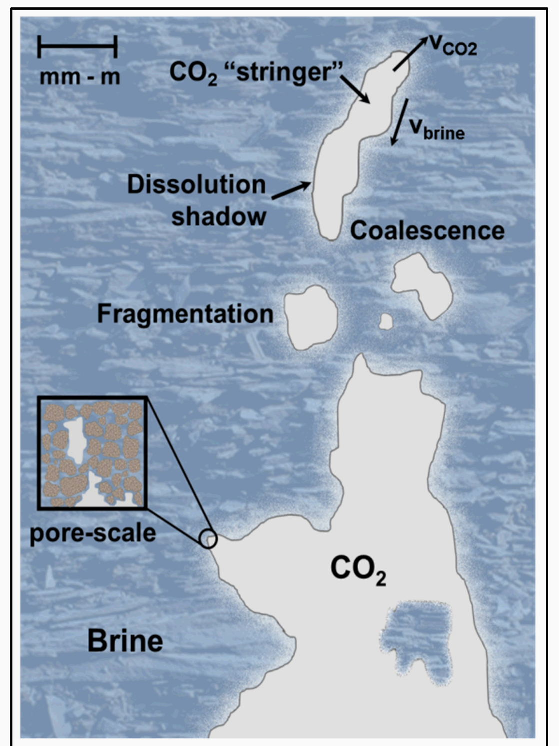


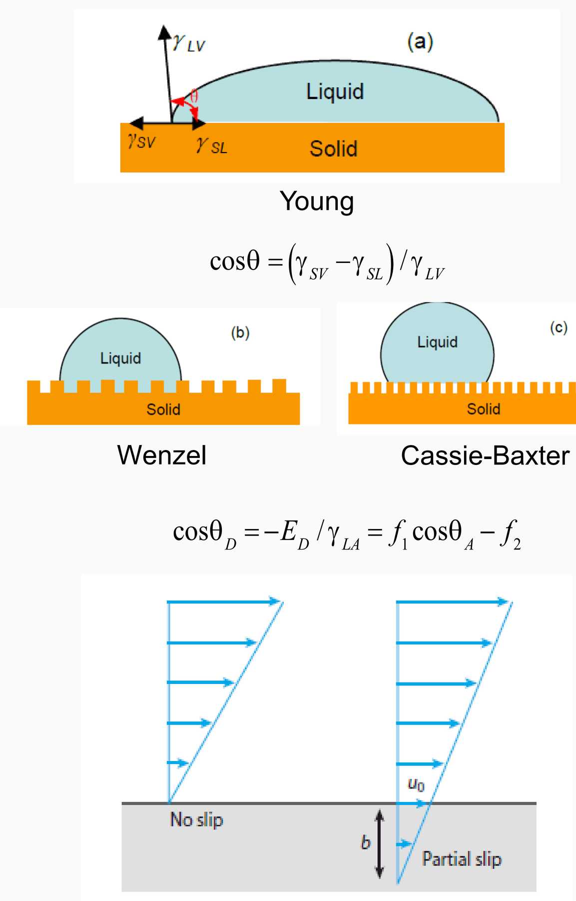
Figure: Conceptual model and mechanistic processes in buoyancy-driven ganglia dynamics (note v_{CO2}, v_{brine} of "stringer") which collectively correspond to capillary channeling.

Challenges Addressed:

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

Impact of Roughness on Wettability

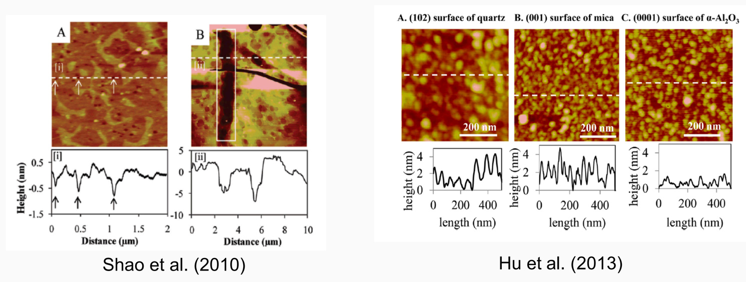
Hydrophobicity Theory



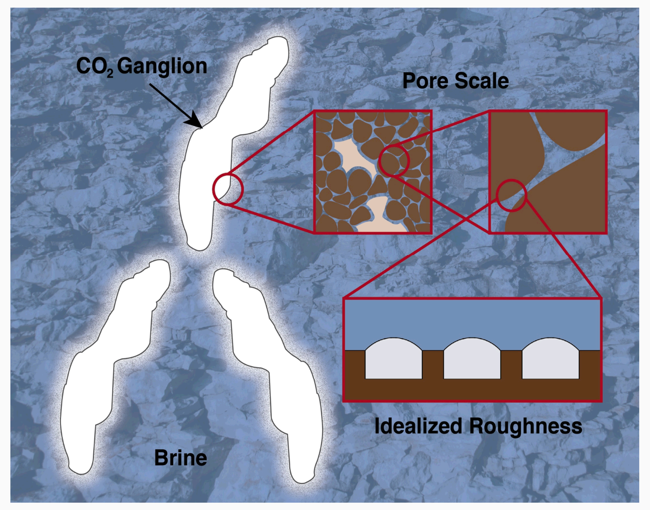
$\cos\theta = (\gamma_{SV} - \gamma_{SL})/\gamma_{LV}$

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

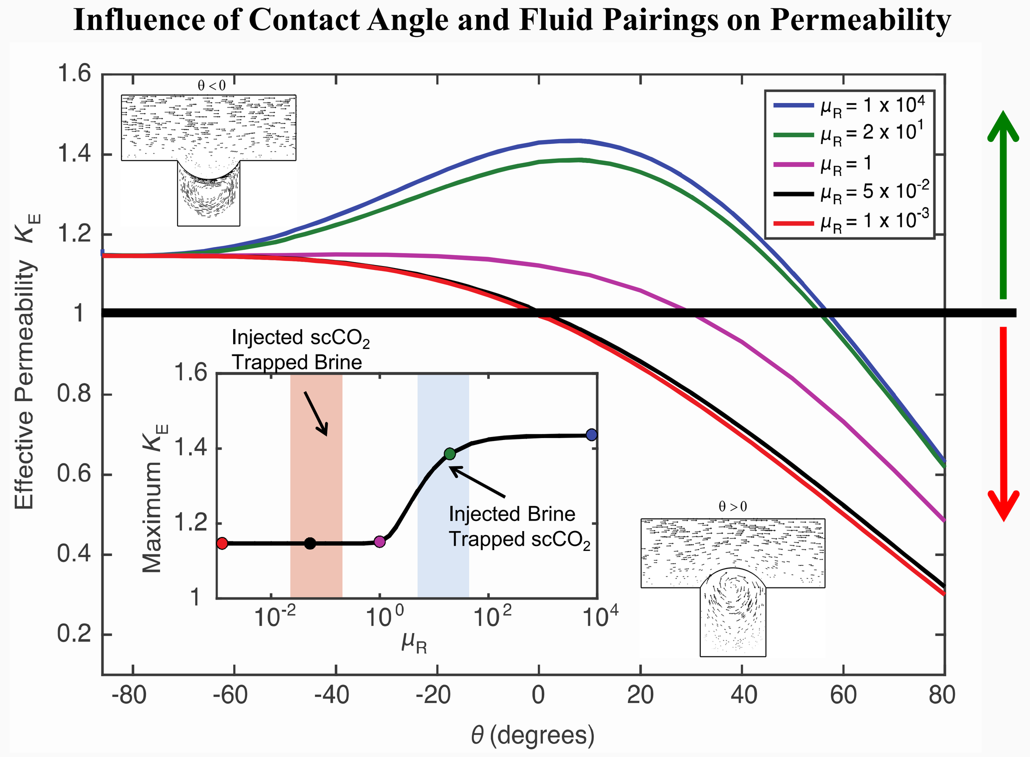
Examples of Natural and Reaction-Induced Roughness



Conceptual Surface Roughness Model



Influence of Contact Angle and Fluid Pairings on Permeability

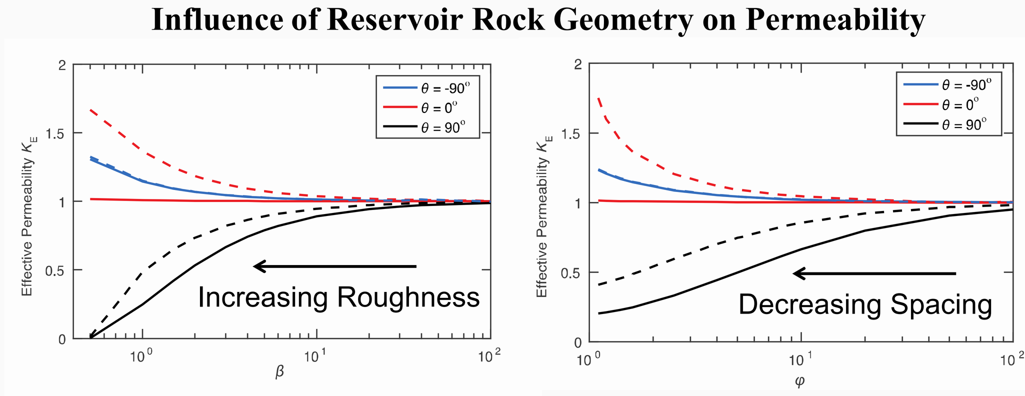


More Permeable $K_E > 1$

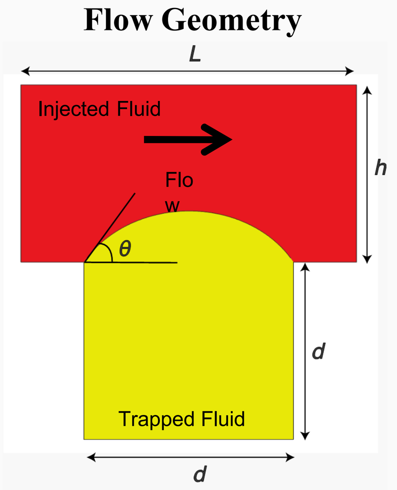
Less Permeable $K_E < 1$

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

Influence of Reservoir Rock Geometry on Permeability



Flow Geometry

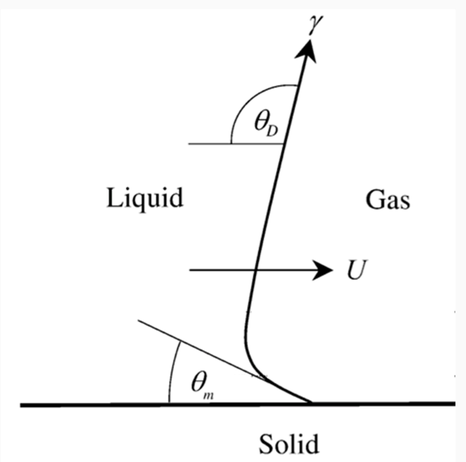


- …reservoir rocks can impact the apparent …ettability).
- … positive or negative flow slip which can …rmeability and CO_2 ganglion mobility.
- …pact both short term (injection) and long-term dynamics CO_2 ganglion migration.

Moving Contact Lines

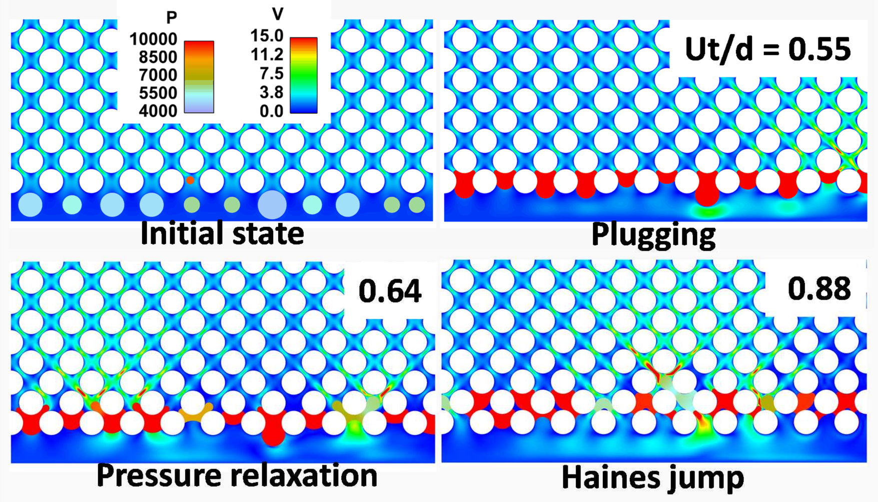
- Moving Contact Line (MCL) problems are important to model the migration of wetting/non-wetting fluids through reservoir rocks
- Accurate modeling can improve IP and other methods
- Finite Element Method (FEM) used to model MCL
  - CDFEM using the level-set method to model two-phase interface
  - Blake's model used to model MCL velocity
- Good agreement with canonical problems
  - Capillary rise
  - Dynamic angle dependence on flow velocity

Blake's Moving Contact Line Model

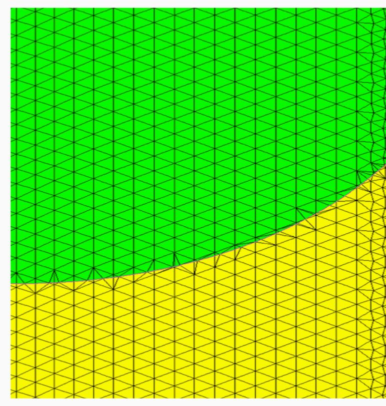


$$V_W = V_0 \sinh(g[\cos(\theta_s) - \cos(\theta_d)])$$

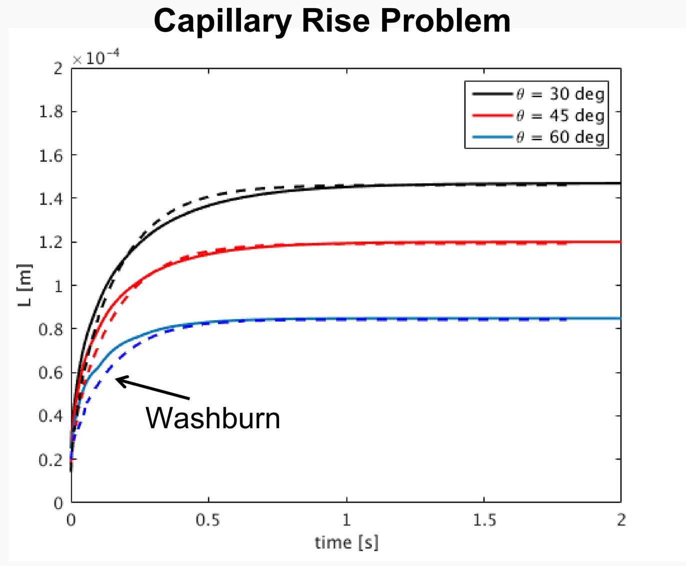
Microscale Pore Flow Through Bead Pack



Finite Element Model

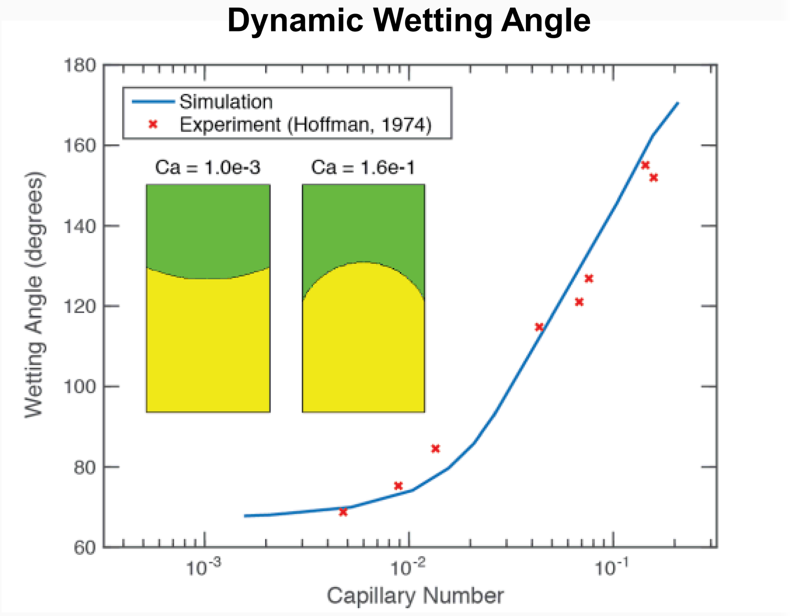


Capillary Rise Problem

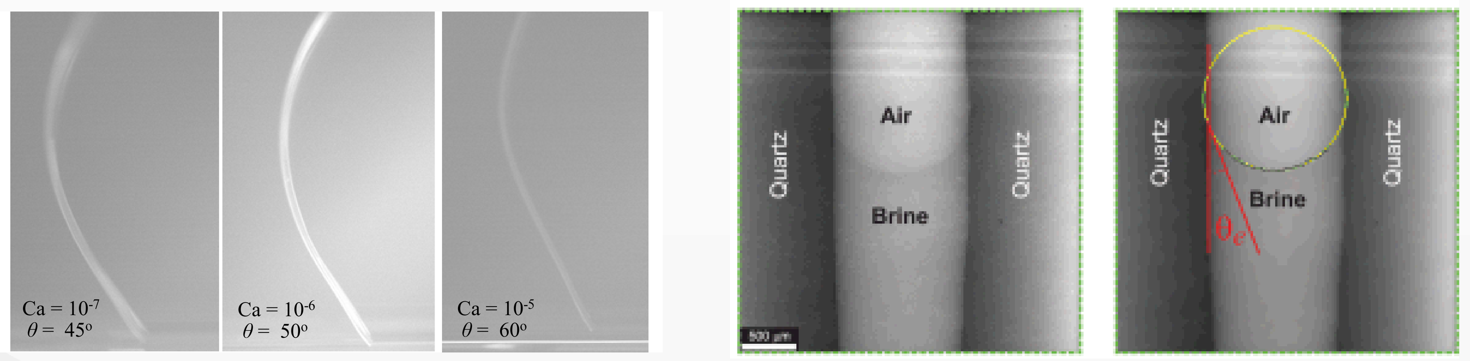


$$\frac{dh}{dt} = \frac{r^2[\rho(L-h) + \gamma\cos(\theta)/r]}{12\mu h}$$

Dynamic Wetting Angle



Experimental Measurements



Concluding Remarks

- Pore-scale surface roughness can impact long-term CO_2 migration, impacting permeability and CO_2 ganglion mobility.
- Improvement in MCL models can be used to accurately predict CO_2 migration in reservoir rocks

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