A Coupled Geomechanical, Acoustic, Transport and Sorption Study of Caprock Integrity in CO2 Sequestration

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Presentation Outline

- Benefit to the Program
- Goals and Objectives
- Technical Status
- Accomplishments to Date
- Synergy Opportunities
- Summary
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Benefit to the Program

- Area of Interest 2: Fractured Reservoir and Seal Behavior
- Measured changes in permeability, sorption, mass transfer, and mechanical and seismic properties of seal rocks due to supercritical CO_2 will allow us to:
  - Understand CO_2 migration in caprocks
  - Provide tools to identify and monitor damaged caprocks
  - Determine CO_2 escape pathway through shale
- Outcome: Our methods will allo a better assessment of storage security and develop certainty for Carbon Storage Program effort to monitor and ensure 99% CO_2 retention and storage permanence

Project Overview:
Goals and Objectives

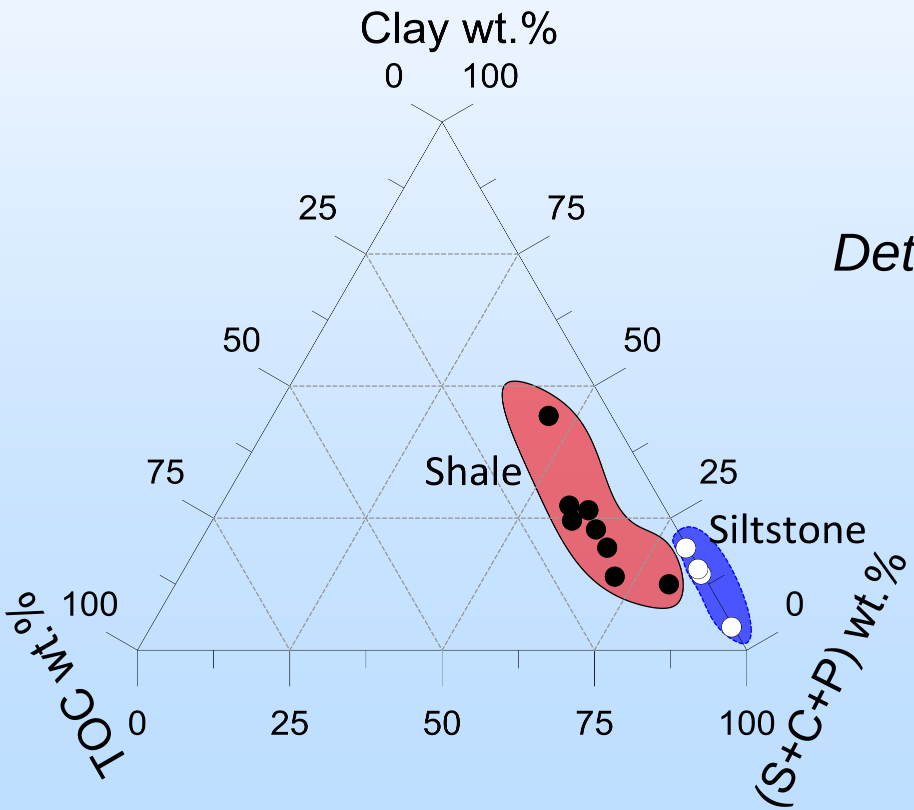
- **OBJECTIVE 1**: Determine the behavior of intact and fractured caprocks when exposed to supercritical CO_2 at elevated pressures.
  - ***GOAL 1***: Assess the risk of CO_2 leakage arising from geomechanically damaged shale.
- **OBJECTIVE 2**: Characterize the physical, chemical and geomechanical processes associated with fluid flow and storage in caprocks
  - ***GOAL 2***: Provide tools for monitoring and identifying damaged shale caprocks.

Technical Status

1. Direct-shear experiments on shale permeability
2. Sorption capacity of shale for hexane, CO_2, water vapor in dry and water-imbibed state
3. Changes in acoustic and NMR properties during CO_2 sorption

Methods and Materials

- Vapor adsorption isotherms: hexane, water, nitrogen
- BET apparent specific surface area (ASSA)
- Sample: Siltstone (no OM) and Organic-rich shales

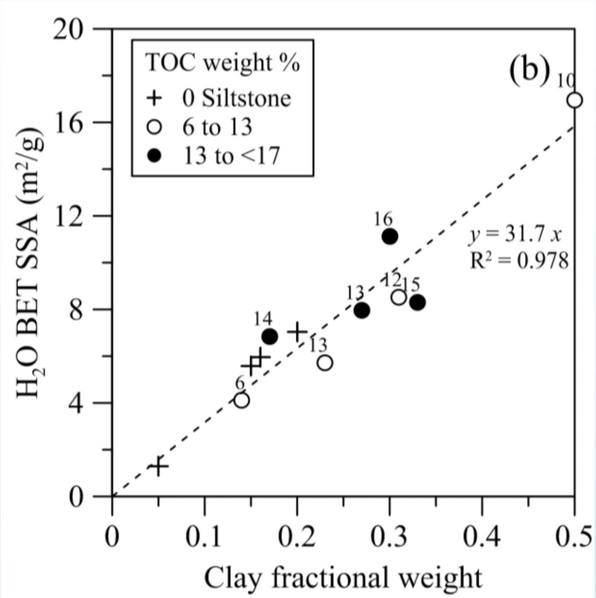


Details on Kumar-Zhang's poster

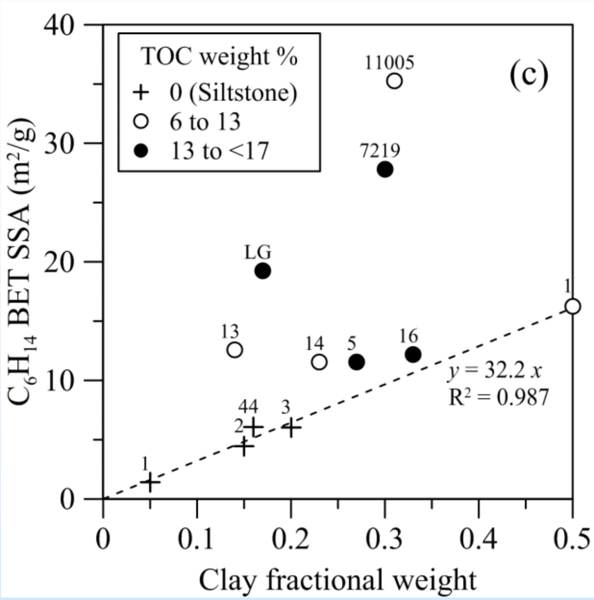
S: Siliceous Minerals
C: Carbonate Minerals
P: Pyrites

Results (from 2015)

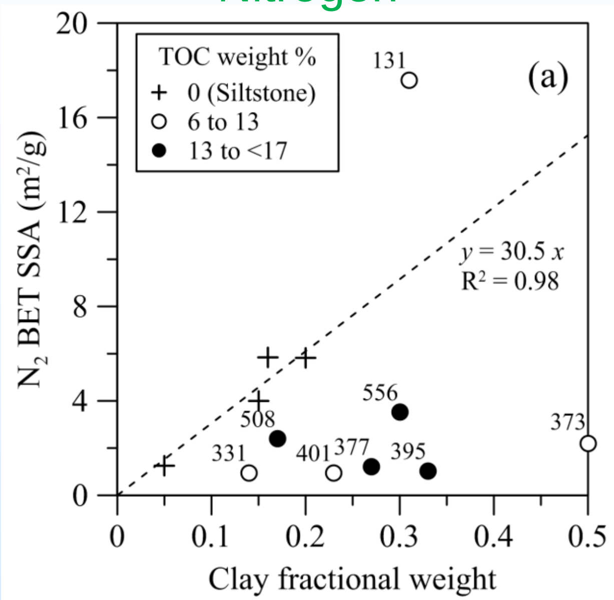
Water



Hexane



Nitrogen



- Cryogenic N_2 selectively blocked by nano-sized pores in OM*
- OM* pores are hydrophobic
- OM* pore development starts at the onset of oil window
- Presence of **bitumen free OM* pores**

*OM = organic matter

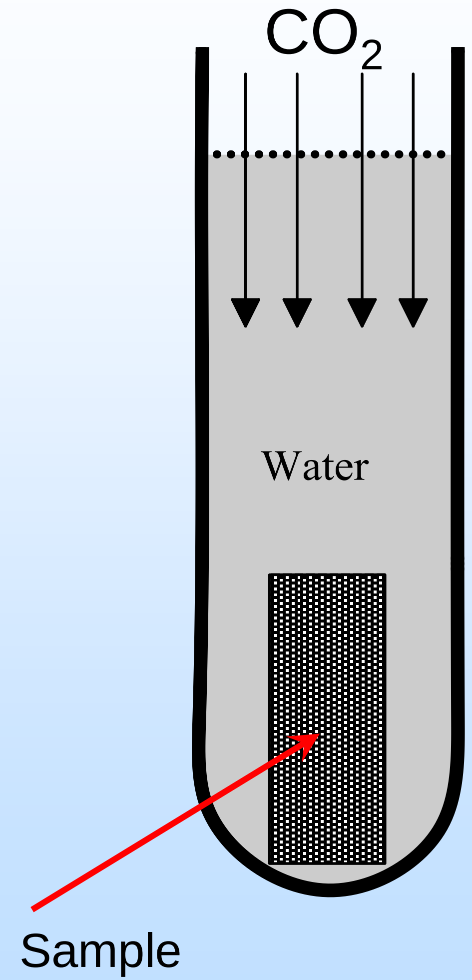
Details on Kumar-Zhang's poster

Preferential Sorption

- CO_2 sorption capacity in dry state
- CO_2 sorption capacity in water-imbibed state (imbibition at 4000 psi)

Samples used:

- Illite clay samples
- Organic-rich shales



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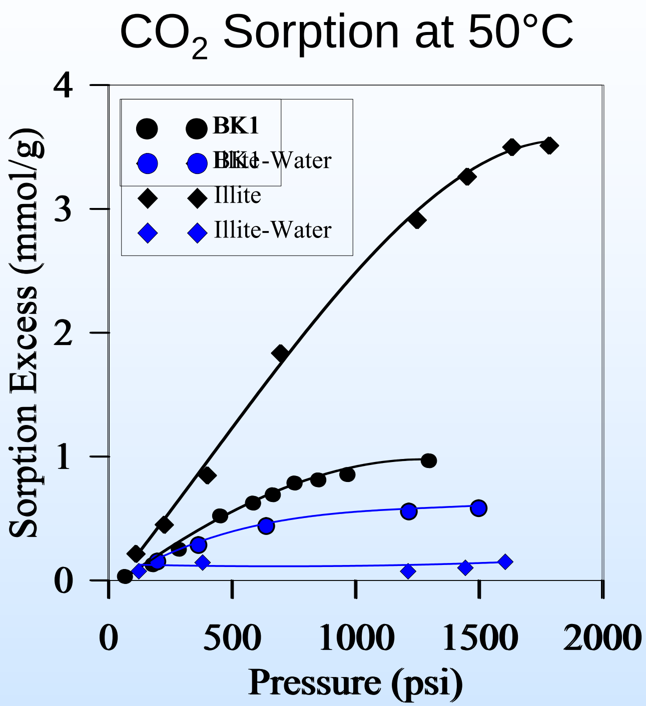
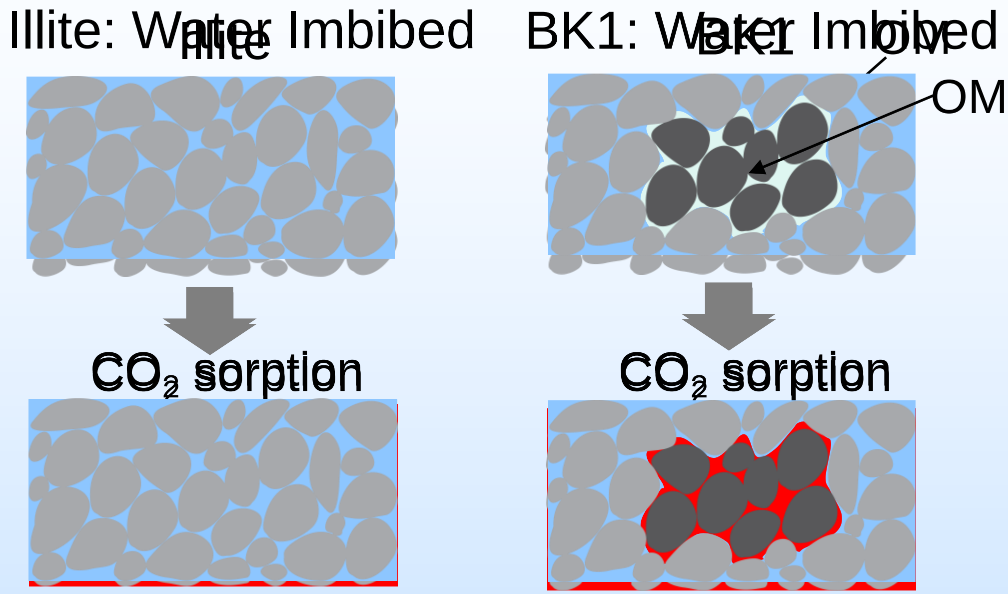
Sorption in shales with water



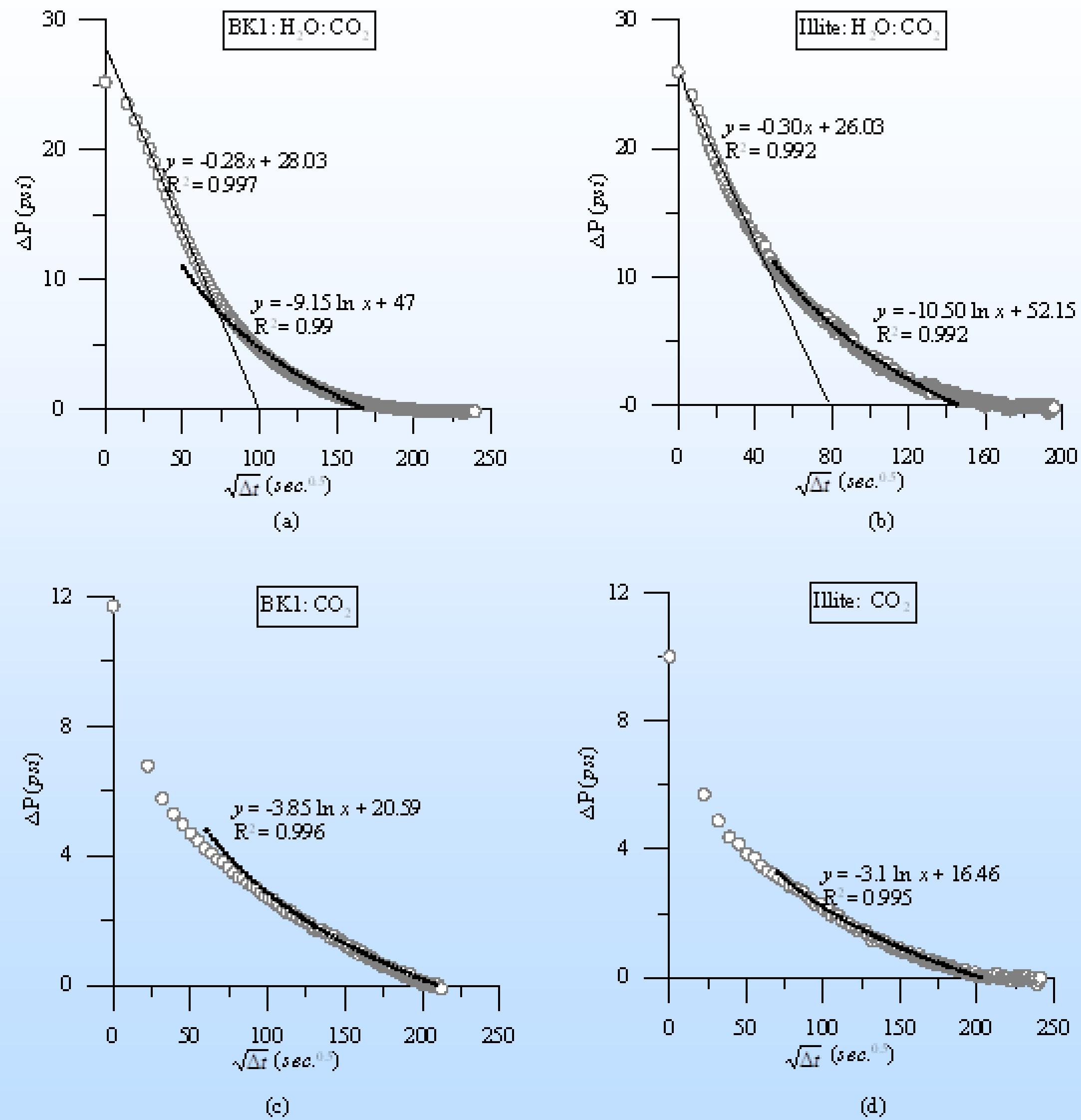


- CO_2 sorption in dry rock: OM pores and Illite pores fill with CO_2
- CO_2 sorption after forced imbibition with water: Illite pores fill with water; OM pores fill with CO_2

Details on Kumar-Zhang's poster

Kinetics of CO_2 sorption: presence of water

Rate of sorption is reduced substantially in the presence of water due to the much lower diffusion coefficient of CO_2 in liquid water than that of its gas state.



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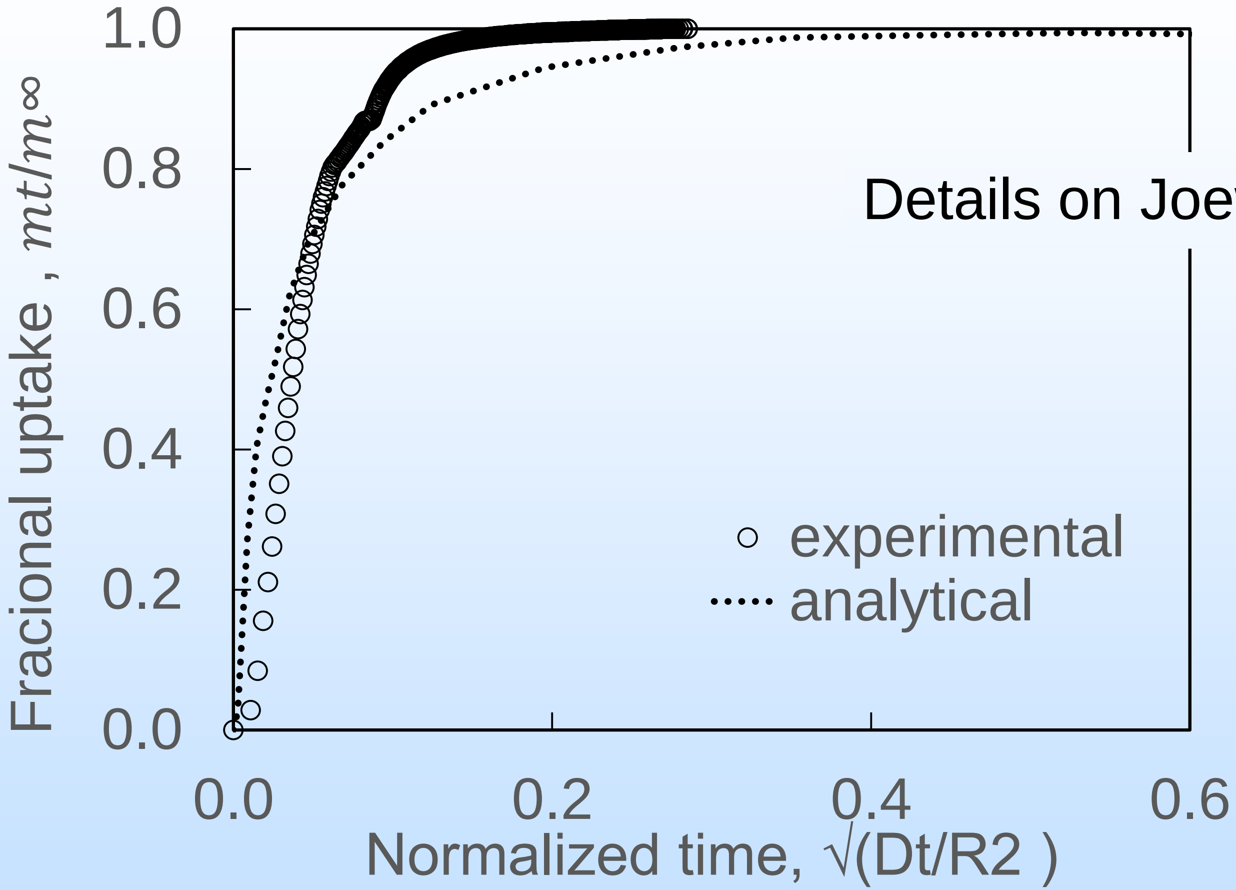
Fractional Uptake and Analytical Solution



Details on Joewondo poster

	illite	4A zeolite
pressure (psi)	2.77	1.64 -1.45*
D/R^2 [s^{-1}]	$1x10^{-4}$	$0.067 - 2.9x10^{-3}$*
***Cejka et al.**		

Method

- Ultrasonic p-wave measurements on water and hexane vapor sorbing clay aggregates
- Distinct flow and deformational properties of liquid and gas fluids in pores affect P-wave modulus differently
- Resonance frequency (FFT) used as proxy for attenuation

Sample	**Porosity, ϕ (%)**	**Bulk Density, ρ_d (g/cc)**	**Grain Density, ρ_d (g/cc)**
Illite	17.66	2.21	2.68
Smectite	17.46	2.27	2.75
I-S Mixed Layer	20.95	2.11	2.67

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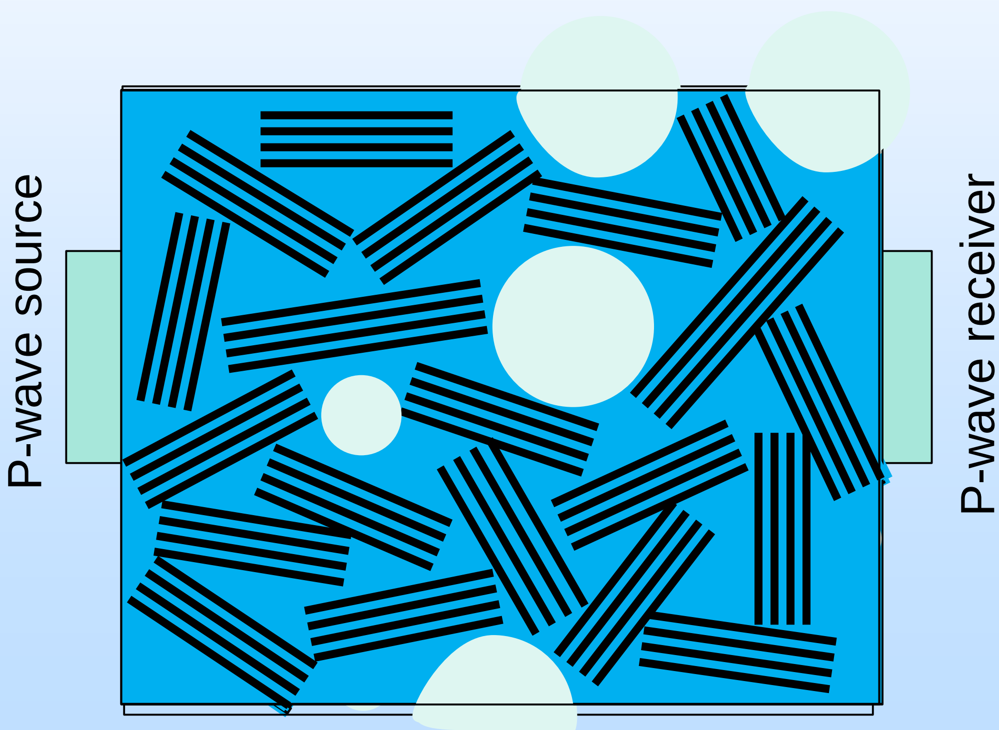
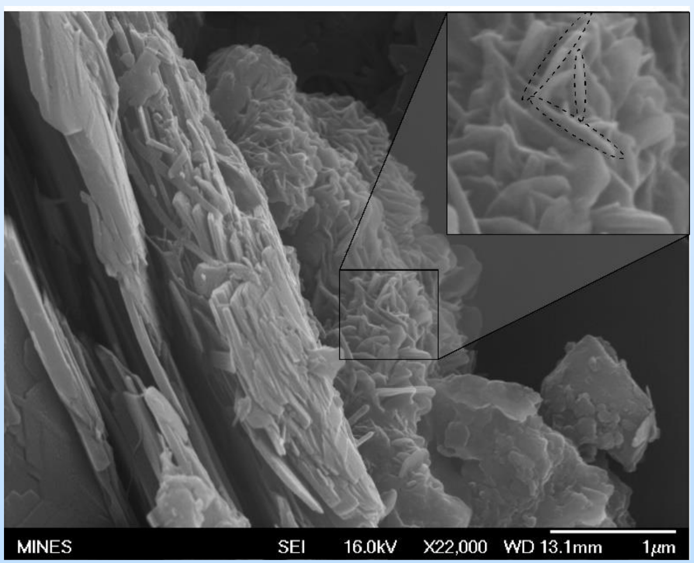
Vapor Adsorption in Clays

- Partial saturation for vapor phase adsorbed (*CUC) phase
- Saturation of adsorbed phase: $S_{\text{ads}} = \dfrac{(Q_l v_l)}{(\phi/\rho_g)}$

Adsorbed phase volume

Pore volume





*CUC: Confined undersaturated condensate

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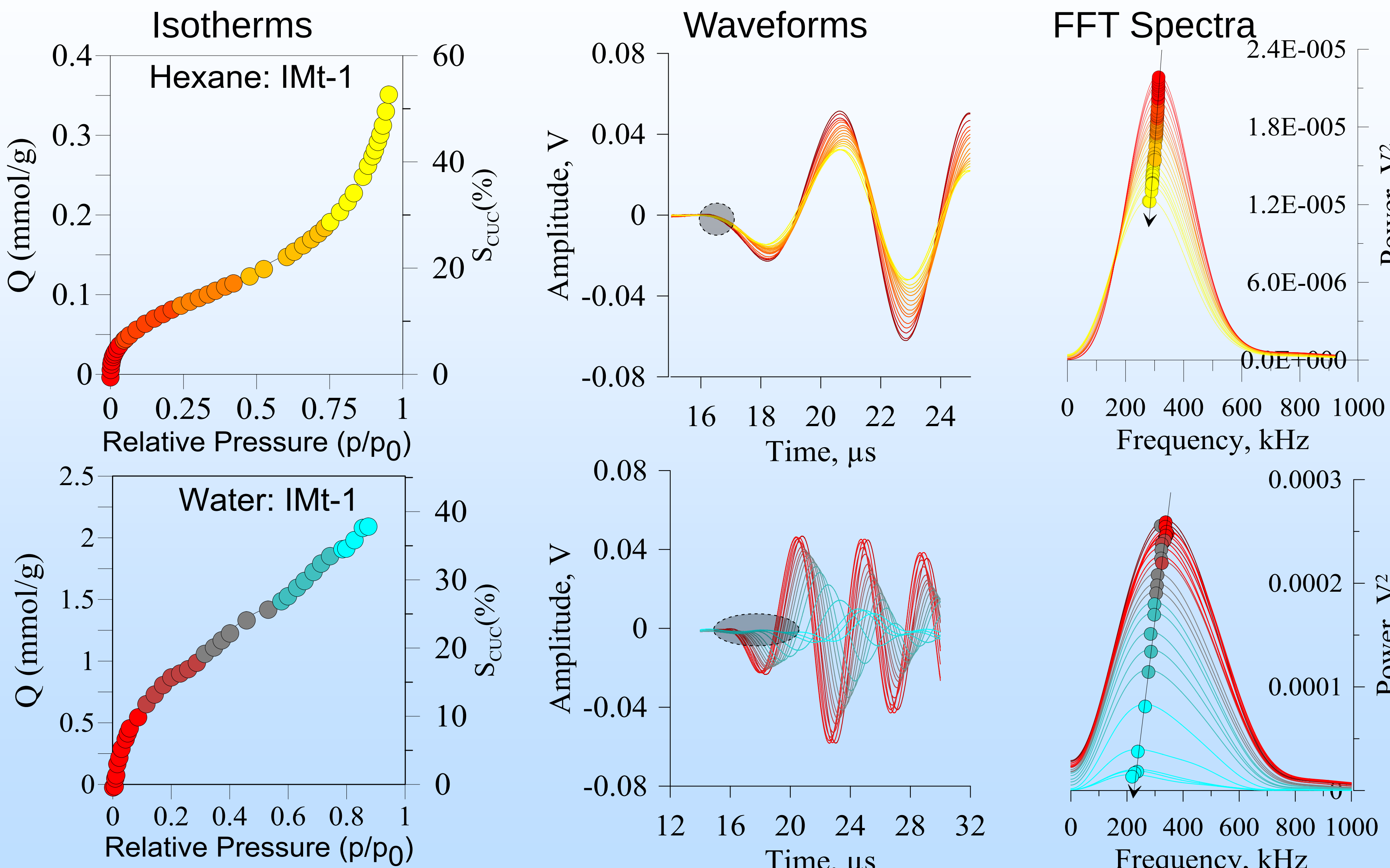
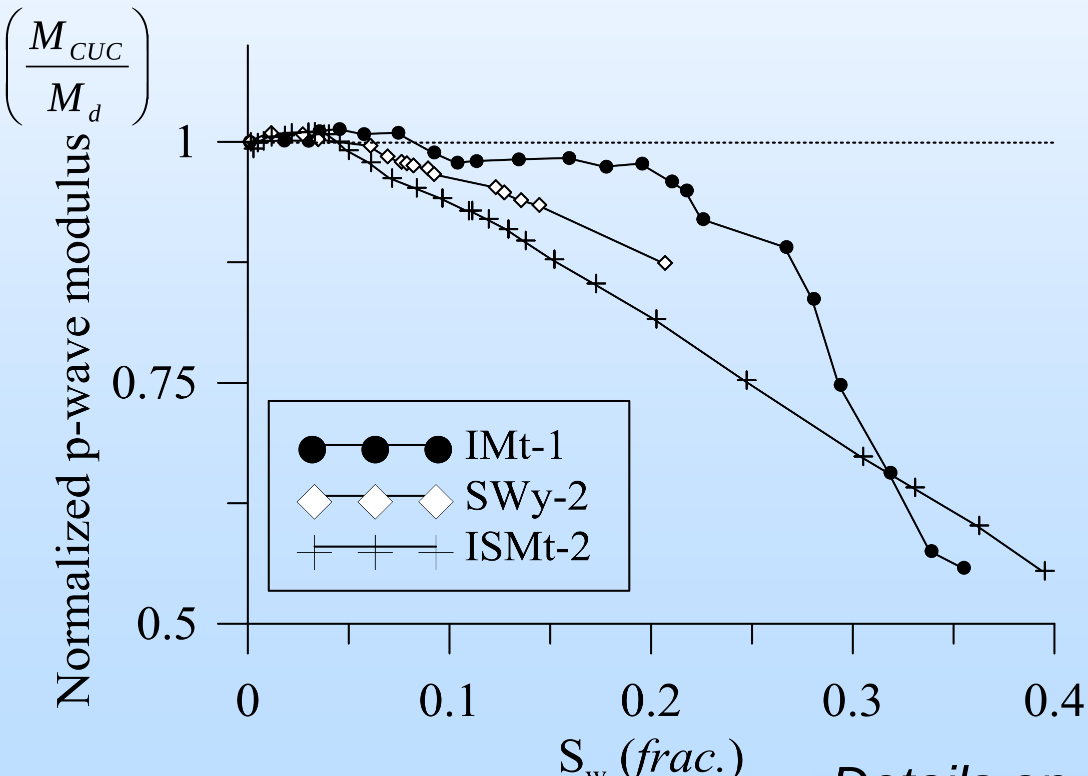
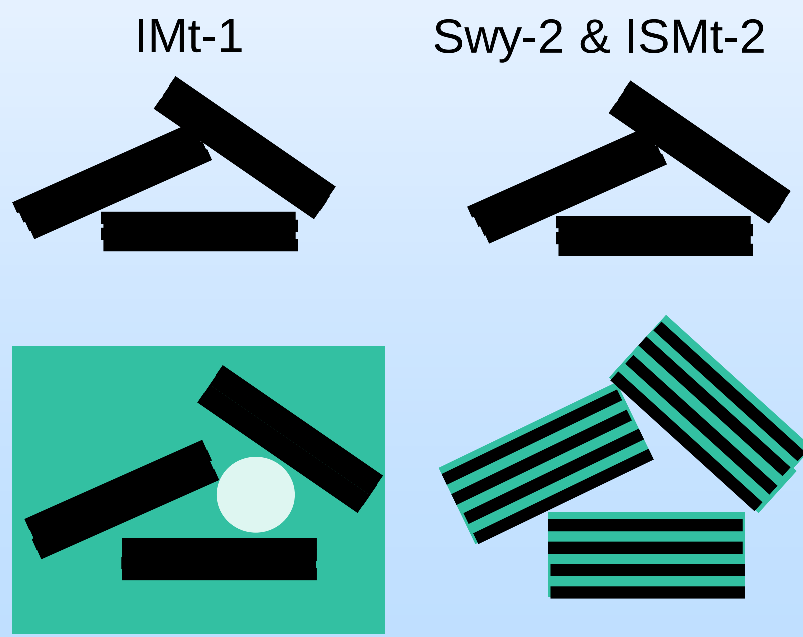
Isotherms, Waveforms, Spectra



P-wave Modulus

- P-wave modulus (M_{CUC}) is unaffected by Hexane CUC in pores
- Two regimes with water CUC in pores
  - Initial slight rise in P-wave modulus up to 3-5% saturation
  - Drastic drop in P-wave modulus with further increase in saturation





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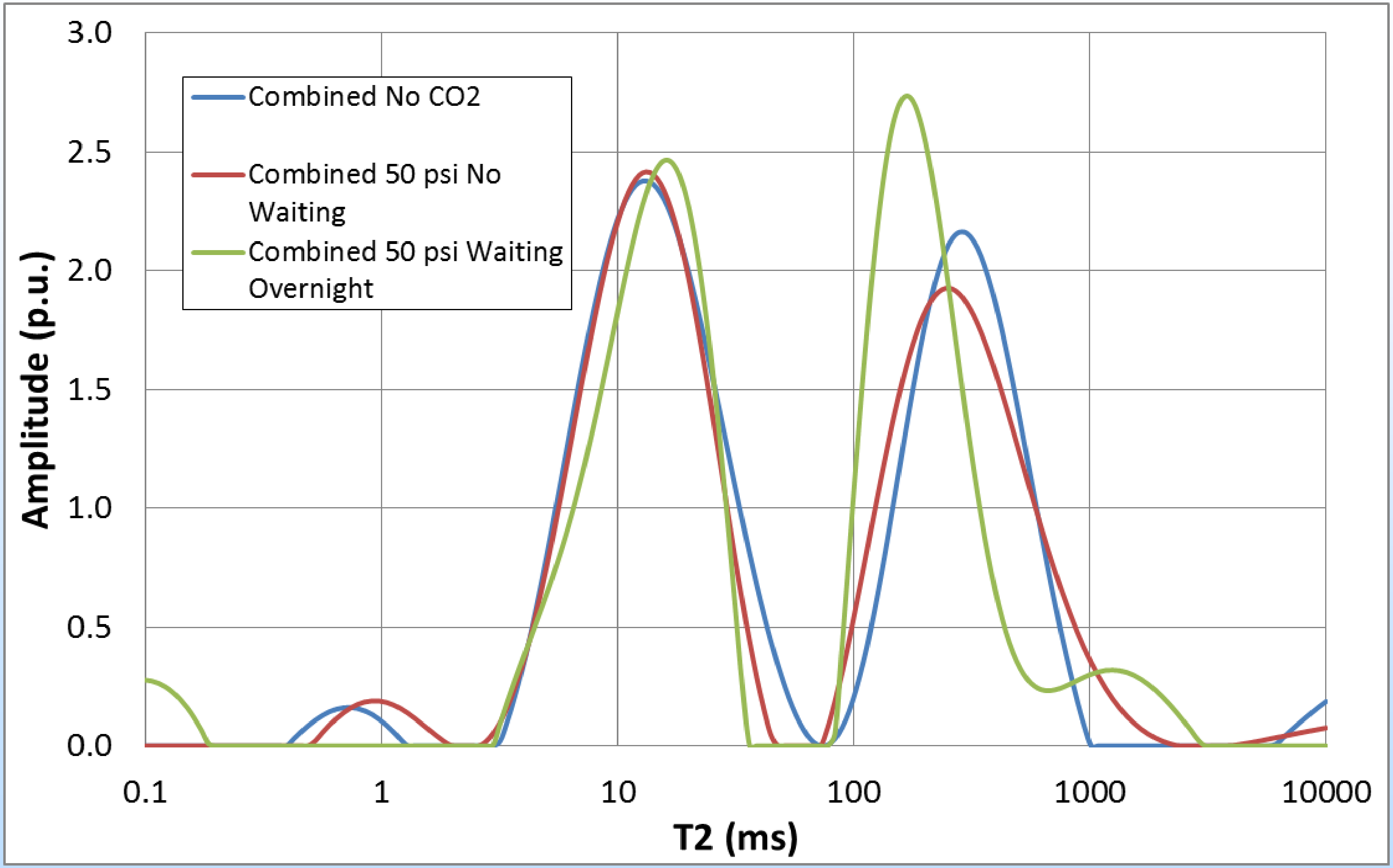
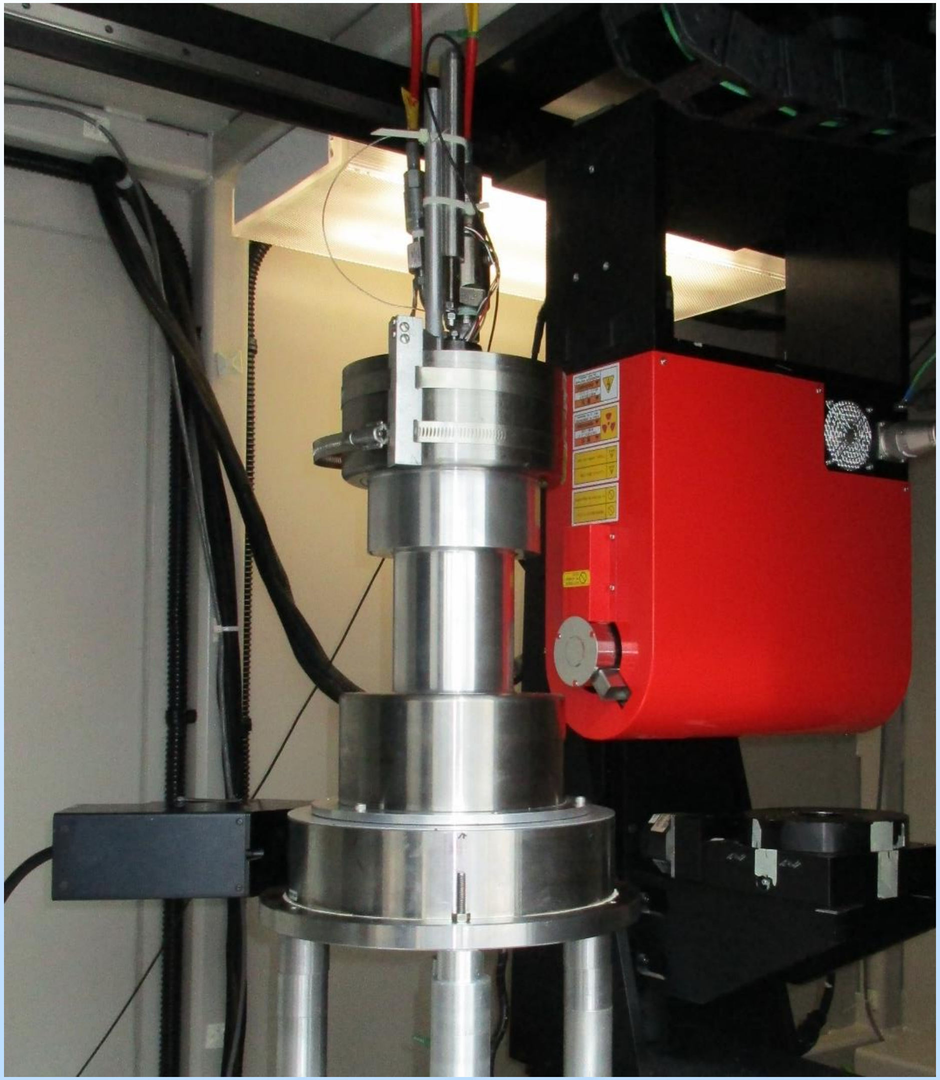
NMR T2 Relaxation Times



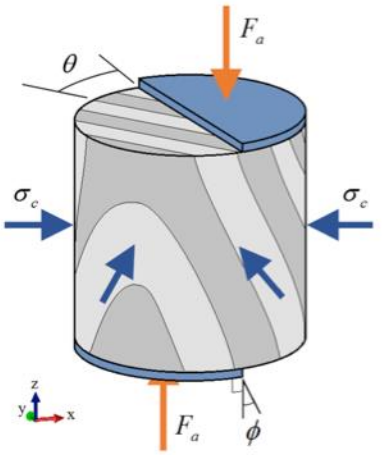
NMR spectra in a combined Berea sandstone and a Niobrara mudstone sample

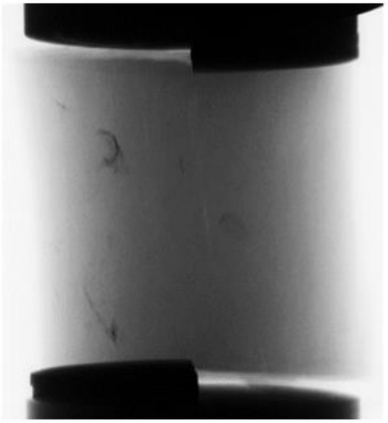
Direct-Shear Experiments on Shale Perm

Carey, LANL



Direct-Shear



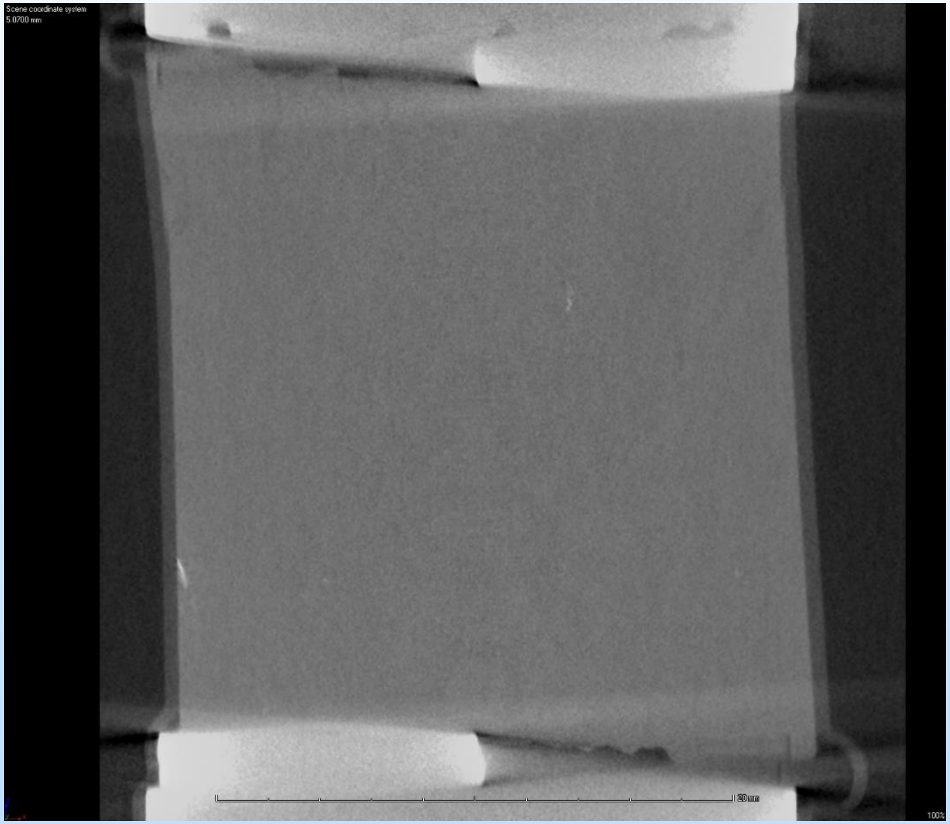


Effect of Confining Pressure (Depth)

Carey, LANL

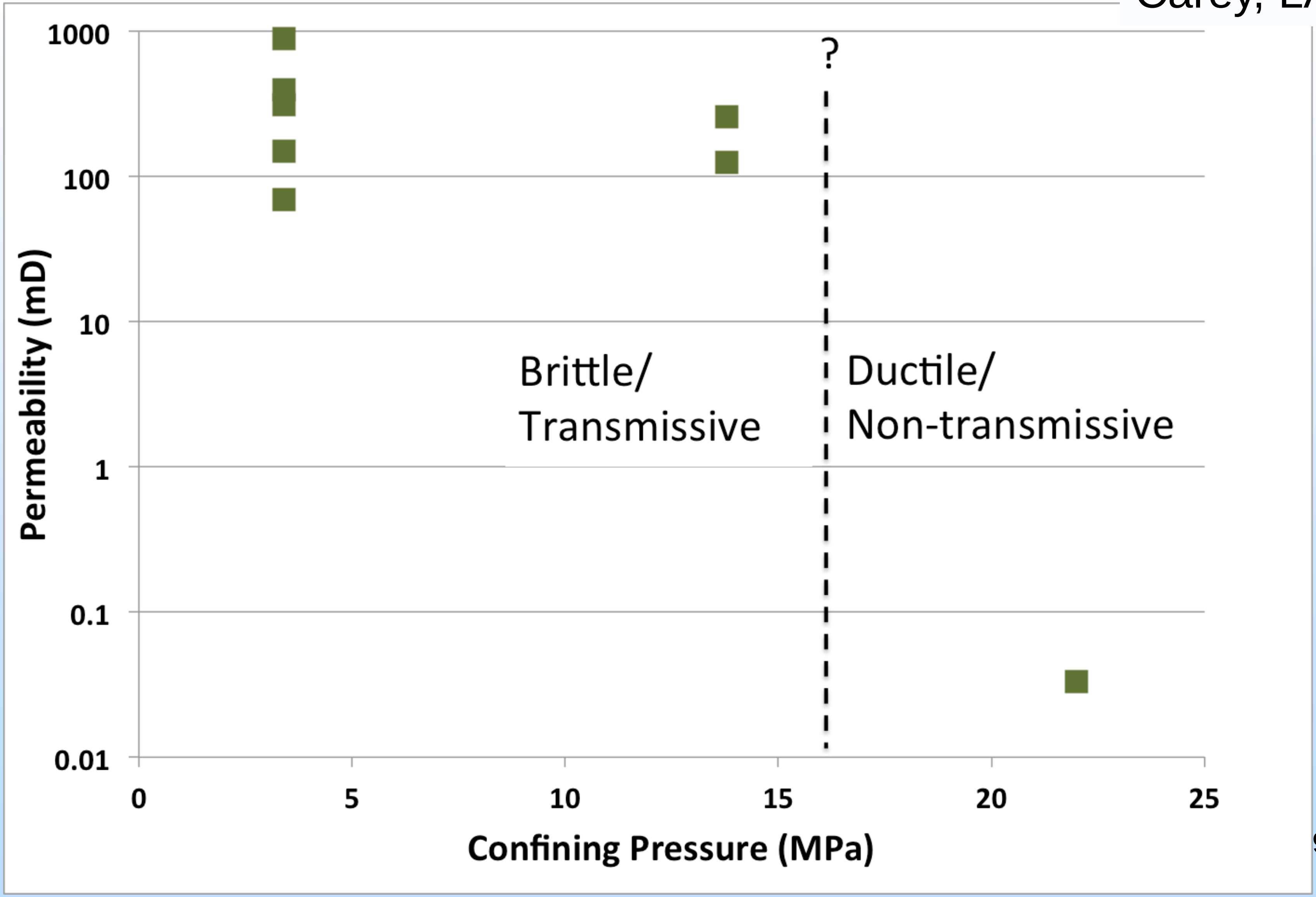
Utica shale at 3.5 MPa

Utica shale at 22 MPa



Permeability Behavior and Depth

Carey, LANL



Accomplishments to Date

Completed:

- Experimental Setup
- Subcritical Adsorption on various fluids
- CO_2 sorption in shales / clay
- Acoustic tests during sorption
- Permeability of shear fractures in Utica shale
- Leakage through damaged caprock is critically dependent on the interaction shale properties and depth

Ongoing:

- Acoustic Tests
- Equation of state calculations
- High pressure and temperature tests
- NMR experiment during CO_2 injection
- Triaxial tests for strength and fracture permeability

Synergy Opportunities

Our work on changes in acoustic and NMR properties of caprocks with CO_2 has synergies with research on:

- Quantification of CO_2 storage from remote seismic surveys used to monitor, measure, and verify CO_2
- Evaluation of storage capacity of CO_2 storage sites using well log analyses of NMR and acoustic logs
- Assess changes in geomechanical strength of caprocks after CO_2 injection
- Kinetics of supercritical CO_2 adsorption

Summary

– Key Findings:
  - Transition from transmissive to non-transmissive fracture systems (for Utica shale > 15 MPa)
  - Sorption dependent on sorptive and mineralogy
  - No CO_2 sorption in clays in the presence of water

– Lessons Learned:
  - Sorption experiments should be conducted in presence of water

– Future Plans:
  - Acoustic tests with simultaneous measurements of storage capacity and acoustic properties
  - Acoustics, NMR, and permeability tests with more cap rocks