A Coupled Geomechanical, Acoustic, Transport and Sorption Study of Caprock Integrity in Carbon Dioxide (CO2) Sequestration

DE-FE-23223

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U.S. Department of Energy
National Energy Technology Laboratory
Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting
August 1-3, 2017

Presentation Outline

- Objectives and motivation
- Experimental Updates
  - NMR experiments
  - Adsorption measurements
  - Permeability and acoustics measurements; simulations
- Accomplishments to date
- Future work

Hypothesis and Objectives

Hypothesis:

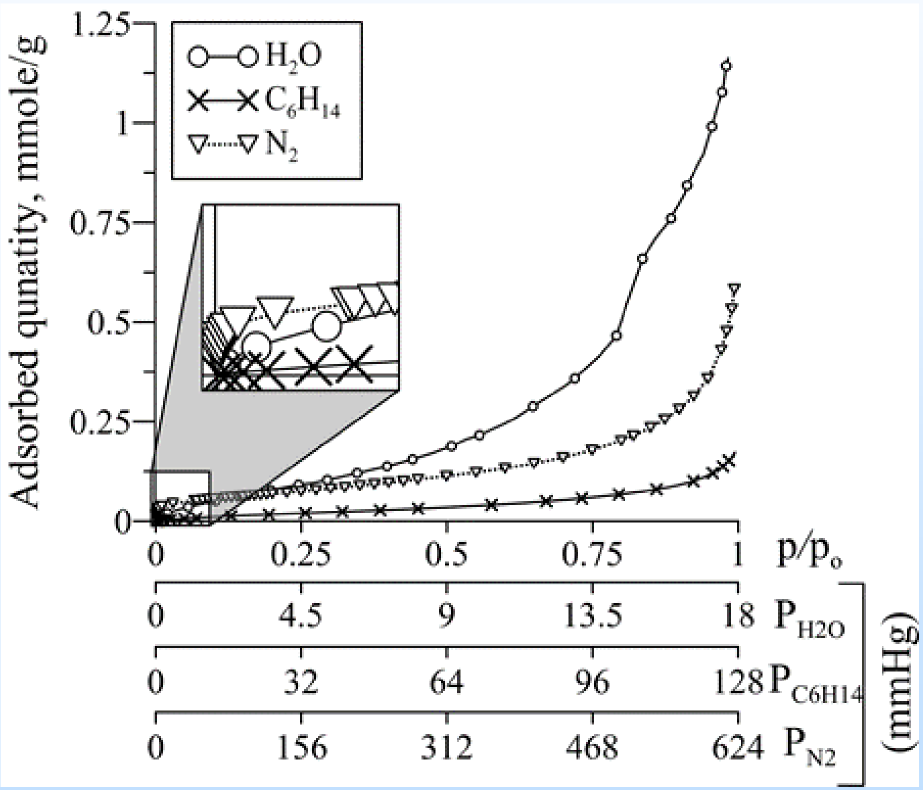
- Mechanical damage to shales does not necessarily lead to high permeability and substantial leak rates

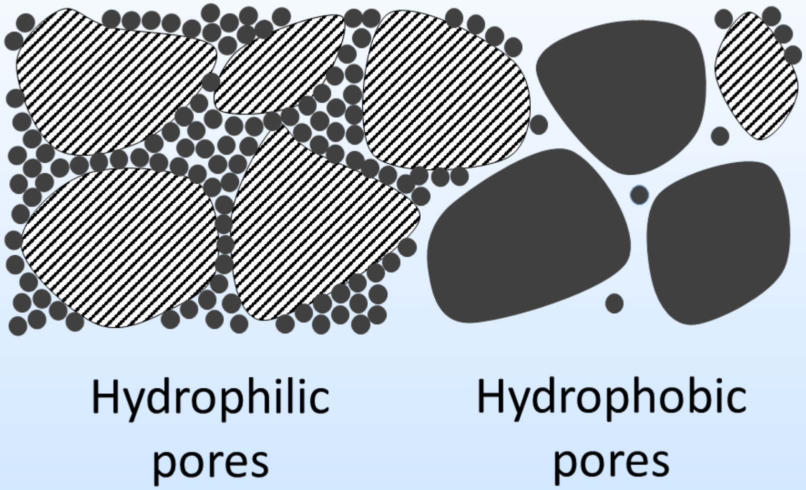
Objectives:

- Determine the behavior of intact and fractured caprocks when exposed to supercritical CO_2 at elevated pressures
- Quantify adsorption, strain and acoustic properties of shales with sorbed CO_2
- Provide framework for monitoring, verification and accounting (MVA) efforts of CO_2 sequestration and its effect on caprock

Motivation

Preferential sorption of fluids depends on polarity of surfaces





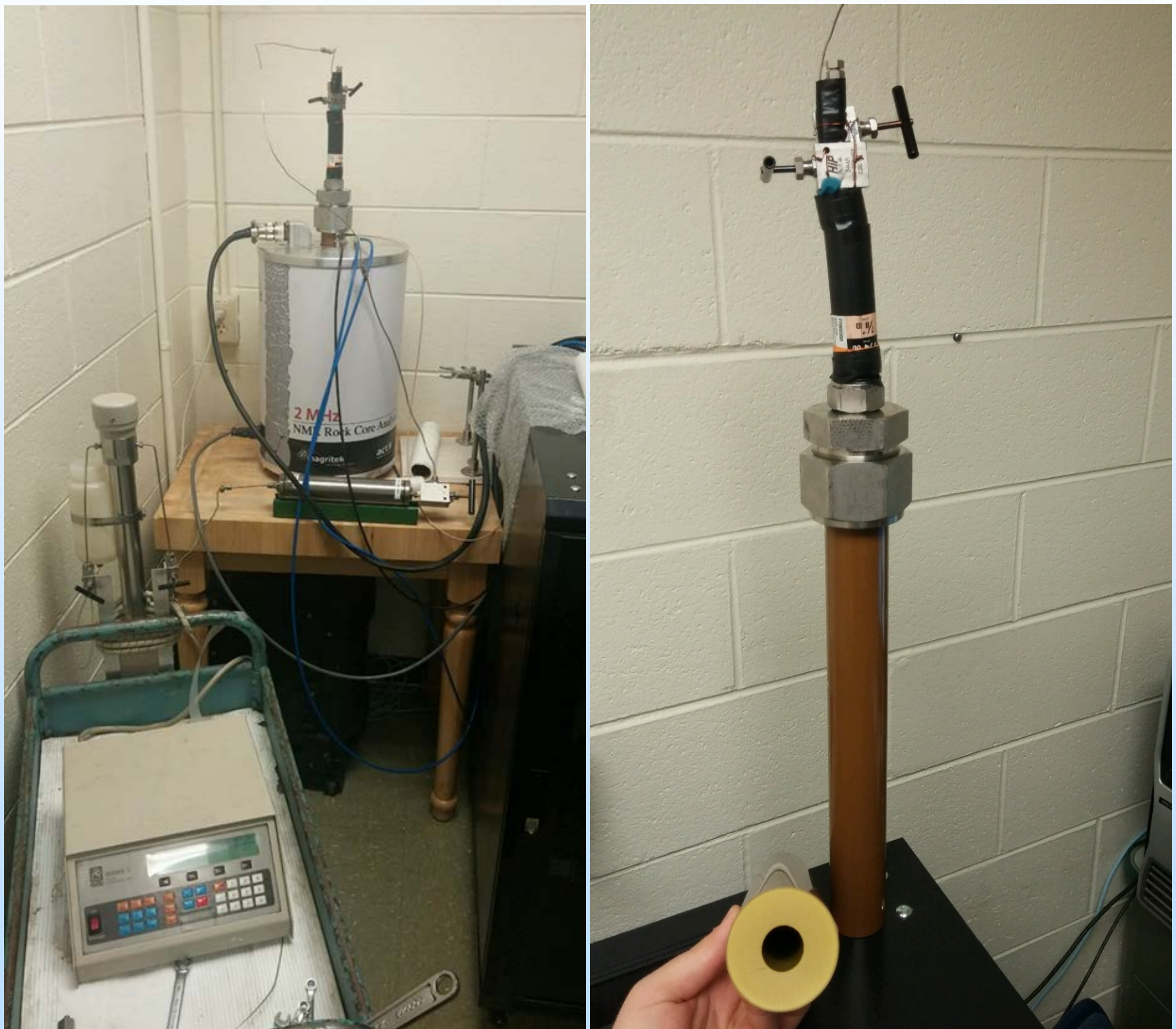
- Quantification of hydrophilic and hydrophobic pores of shales

TECHNICAL STATUS

Kurt Livo, Ph.D. cand

I: NMR EXPERIMENTS

NMR CO_2 Injection



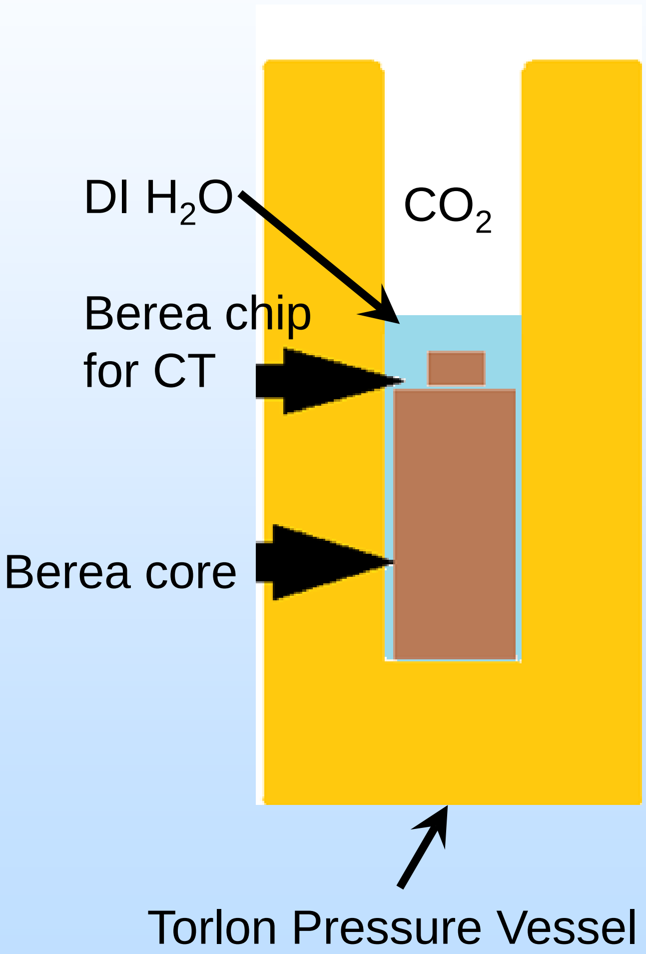
- NMR Measurements
  - 2 MHz
  - 0.05 Tesla
  - Laplace non-negative least square (NNLS) fitting inversion
- Pressure Vessel Design
  - 9 Electrical inlet lines
  - 2 Fluid flow lines
  - 5000 psi tested pressure
  - 10000 psi rated pressure
  - 1 in. core capability

(Machining courtesy of the Colorado School of Trades)

CO_2 Berea Core Injection

- CO2 injection at 900 psi
- Measurements occurred for 3.5 days
- Depressurization measurements for 16 hours

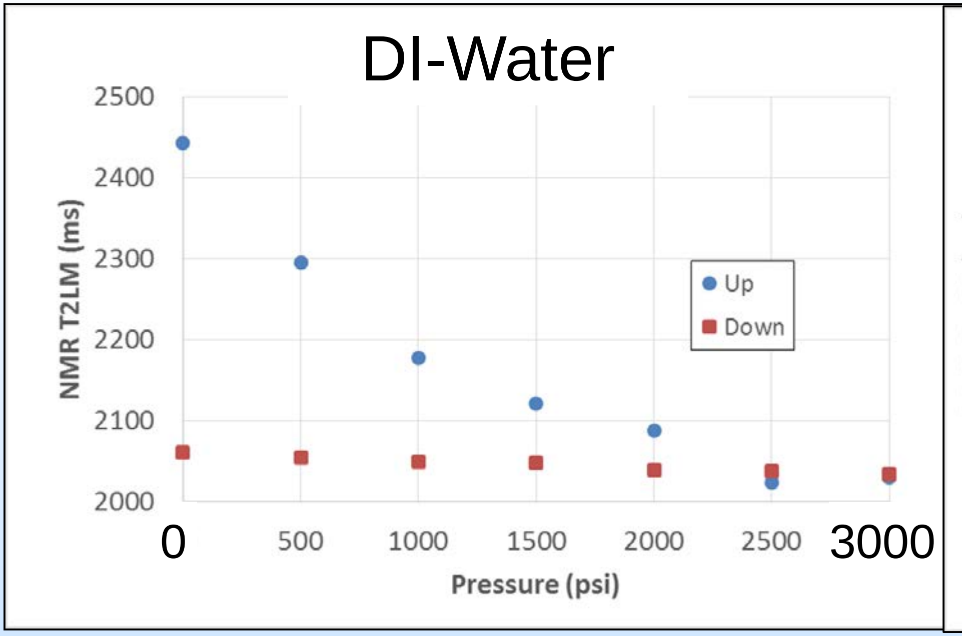
- Mineralization verified with micro-CT images

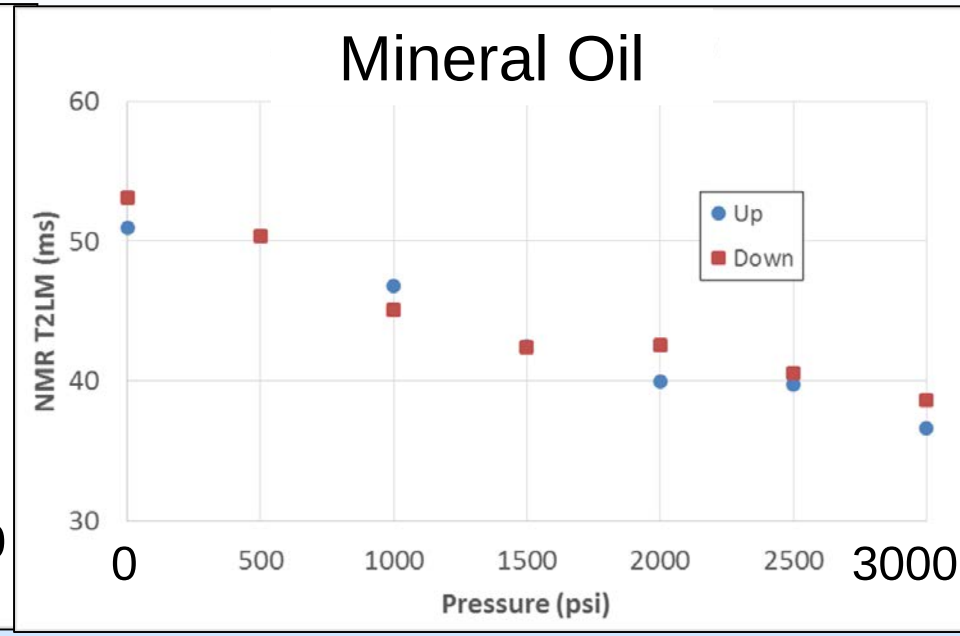


I: NMR EXPERIMENTS

FLUID-PRESSURE RESPONSE

T2 Pressure Variations in Bulk Fluids





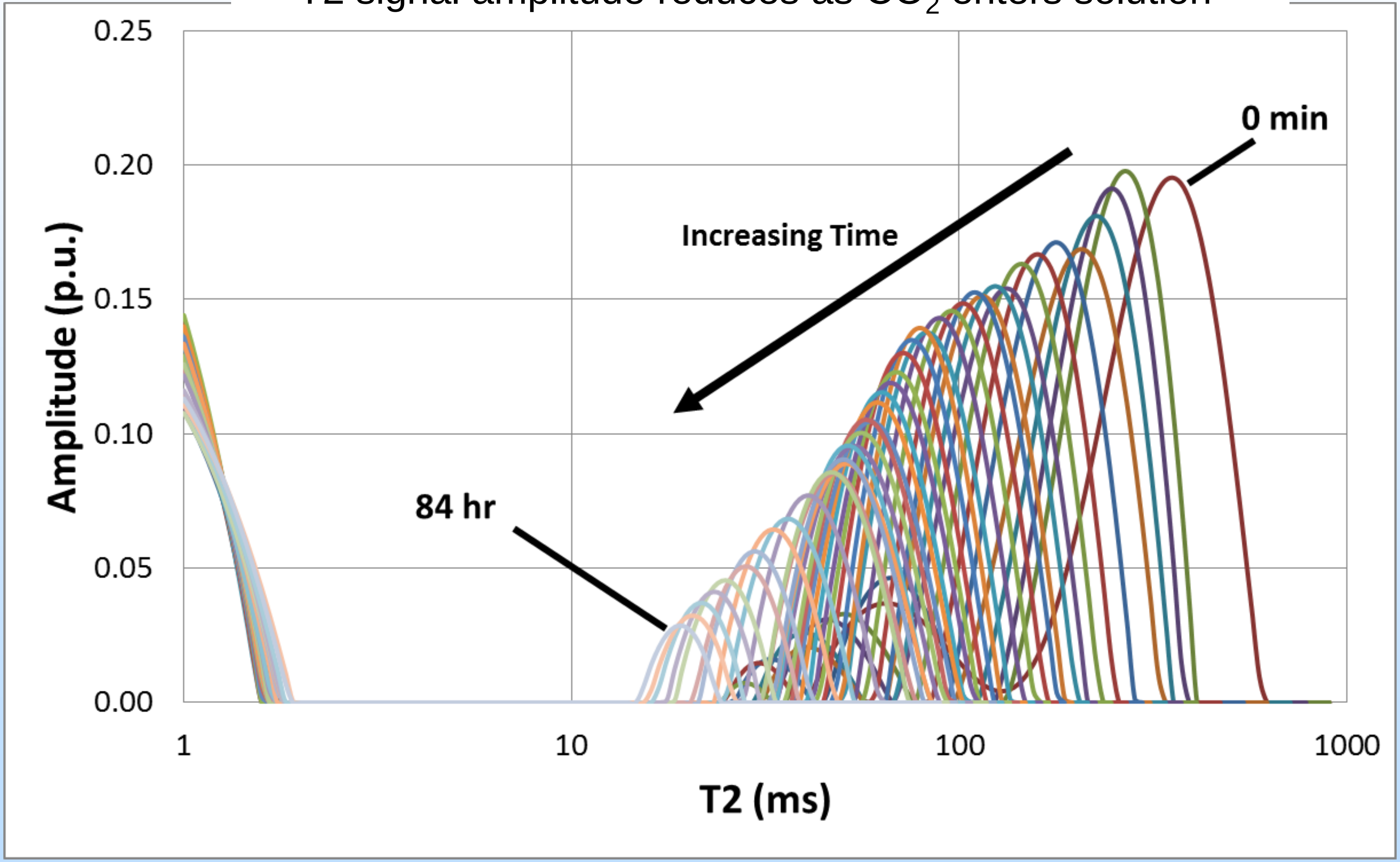
Large changes in T2-relaxation with pressure in both fluids
T2 relaxation changes are irreversible in DI water and reversible in mineral oil

I: NMR EXPERIMENTS

CO2 INJECTION RESPONSE

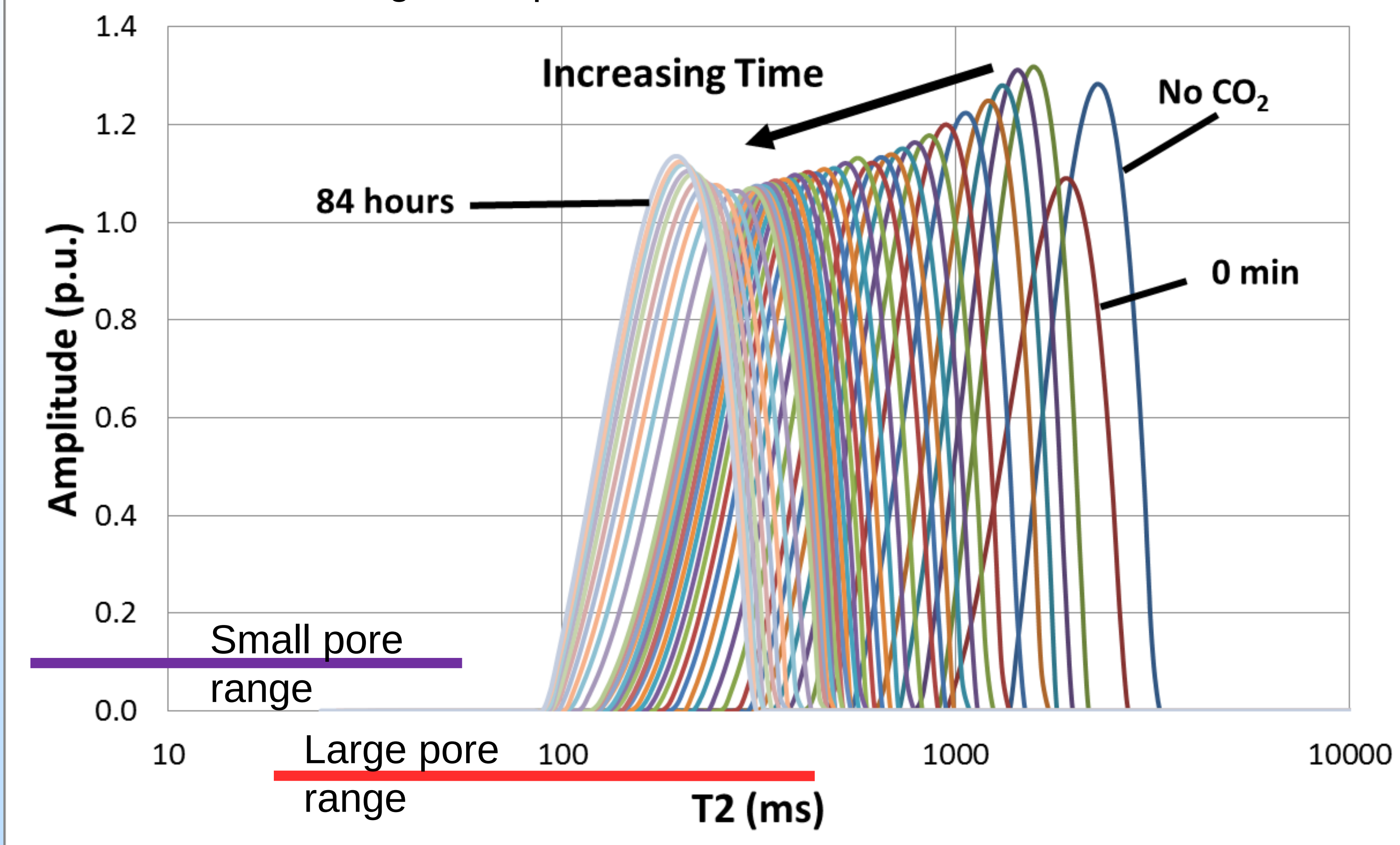
Berea Sst Saturated with CO_2

- T2 relaxation time changes from 360 ms to 18 ms
- T2 signal amplitude reduces as CO_2 enters solution



Bulk Water with CO_2 Injection

- T2 relaxation time changes from 1.8 sec to 0.2 sec
- T2 signal amplitude does not reduces much



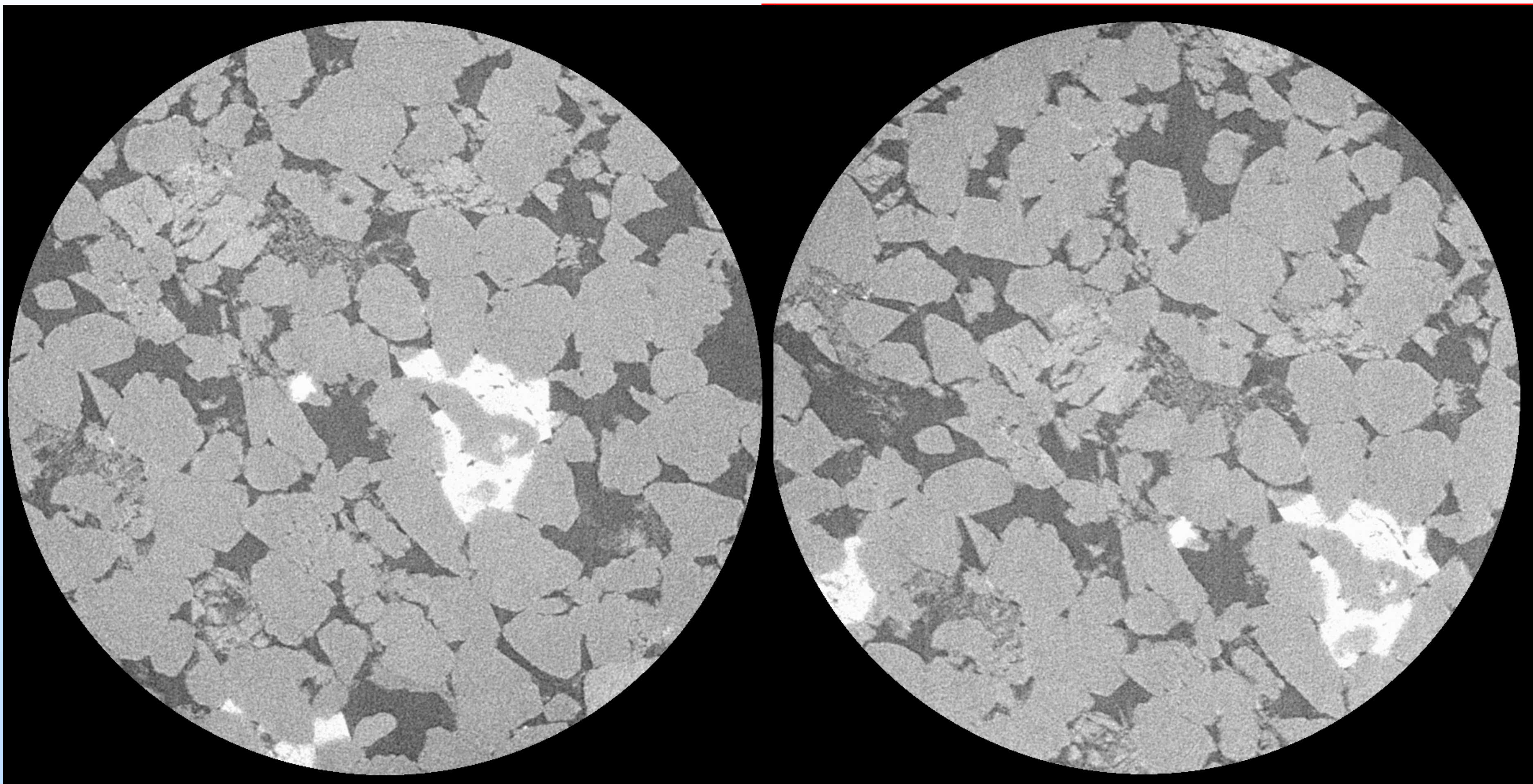
I: NMR EXPERIMENTS

POSSIBLE EXPLANATIONS

Mineralization Effects?

CT Image before CO_2 exposure

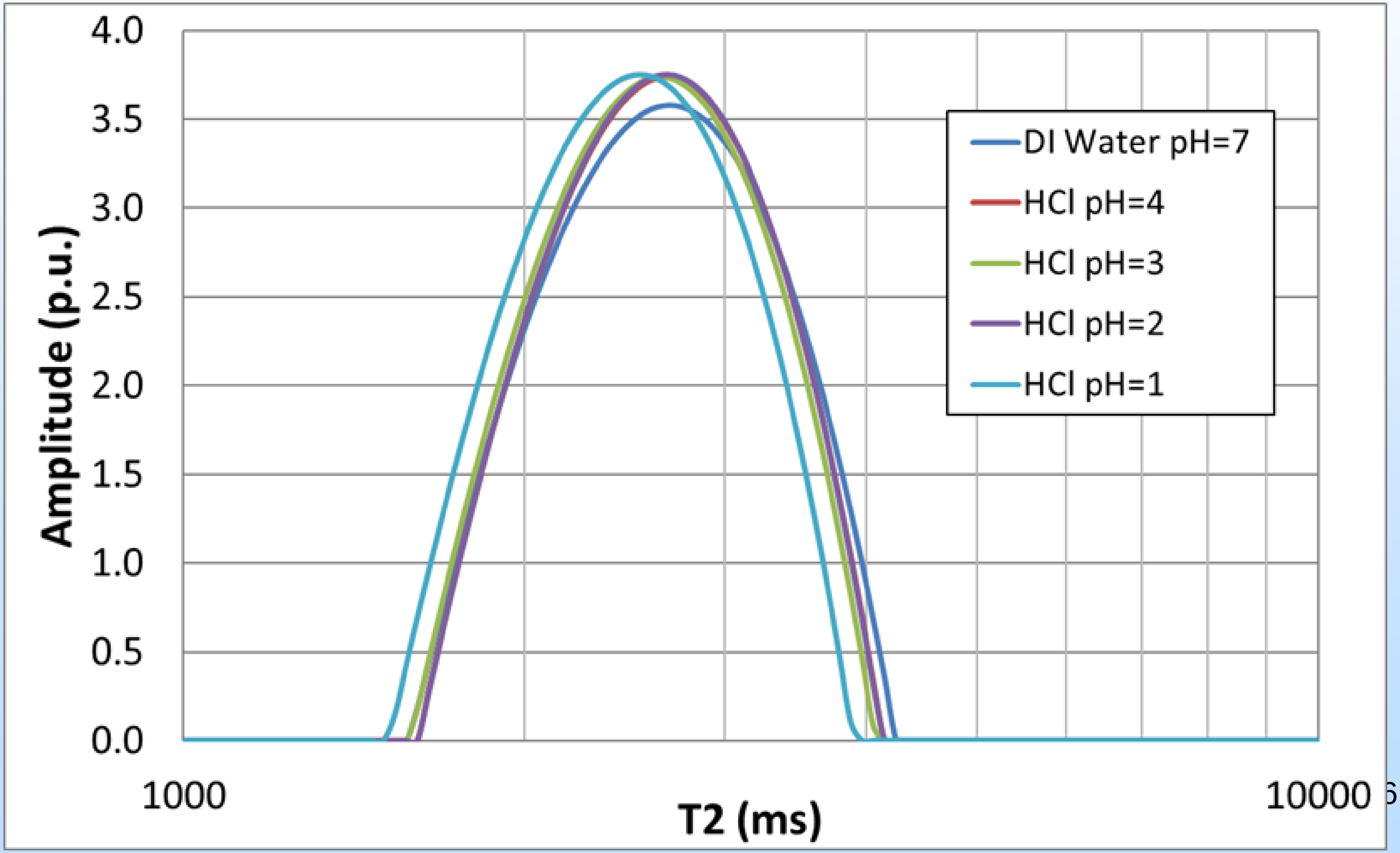
CT Images after CO_2 exposure



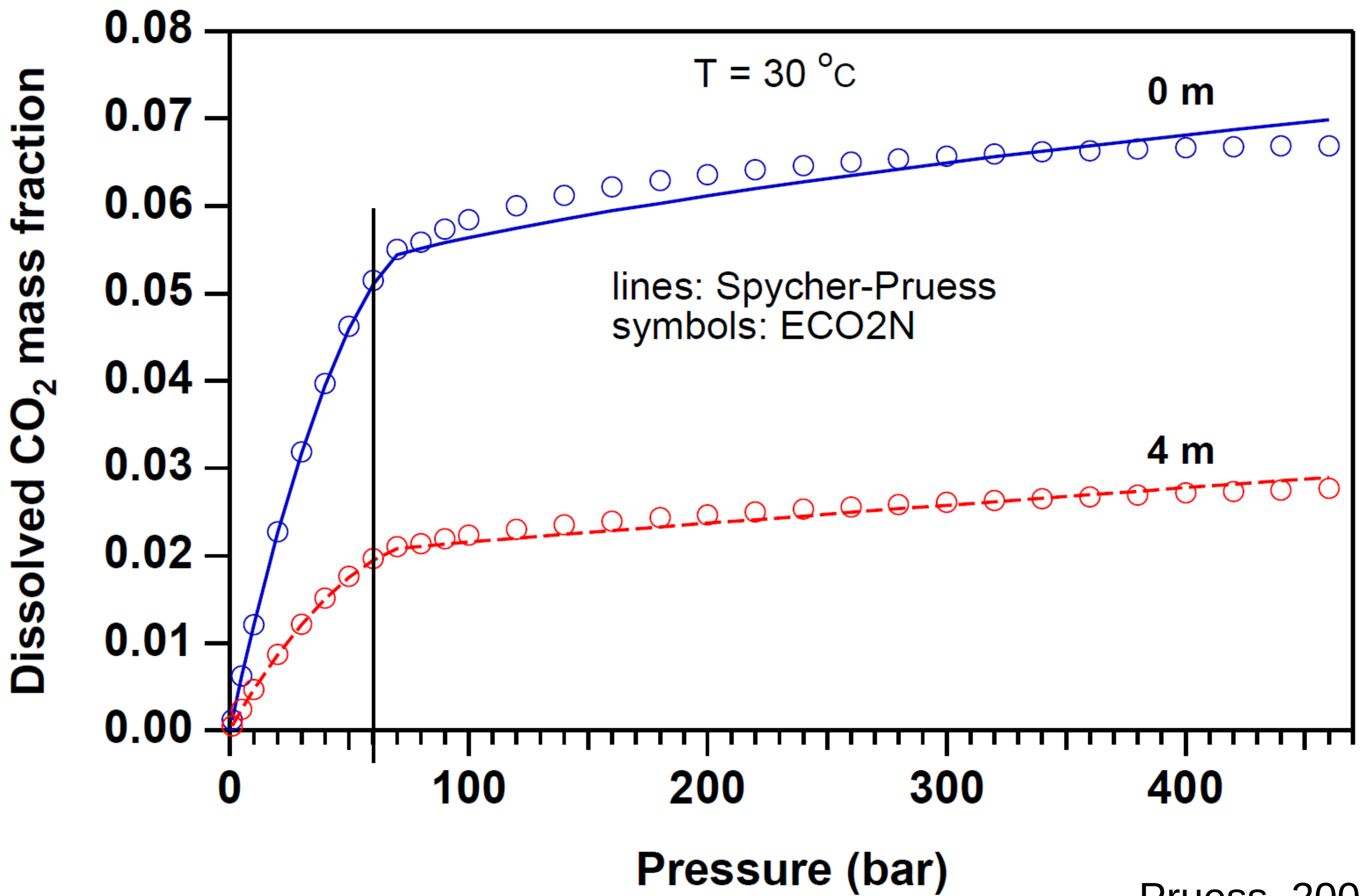
(Courtesy of Mandy Schindler)

T2 Relaxation with varying pH

pH variation of the fluid phase does not effect NMR response and cannot account for the large spectra shift due to CO_2 in solution



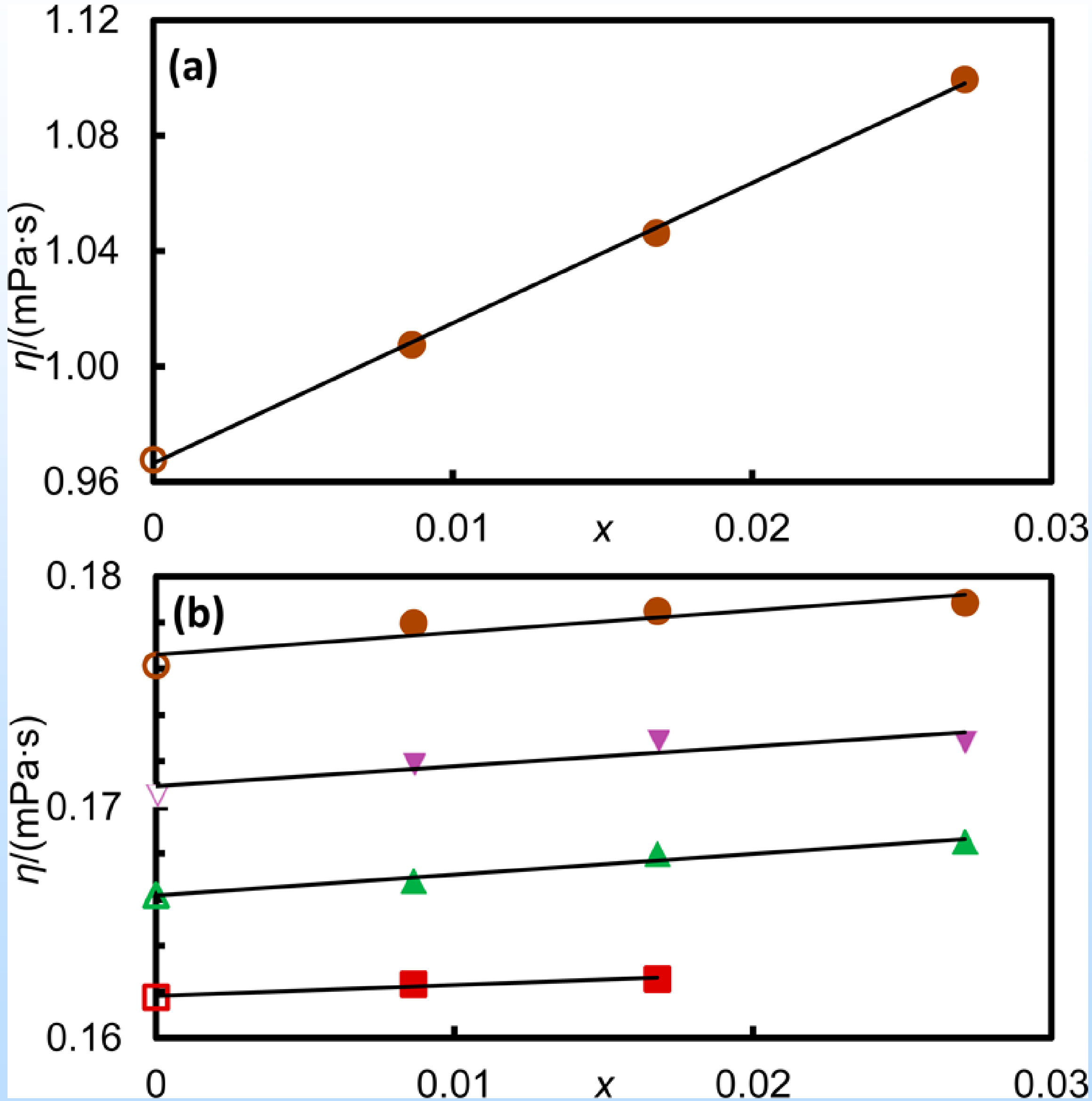
Solubility of CO2 in water



Pruess, 2005

Viscosity Change

Viscosities change:
[(1 - x) H_2O + x CO_2]



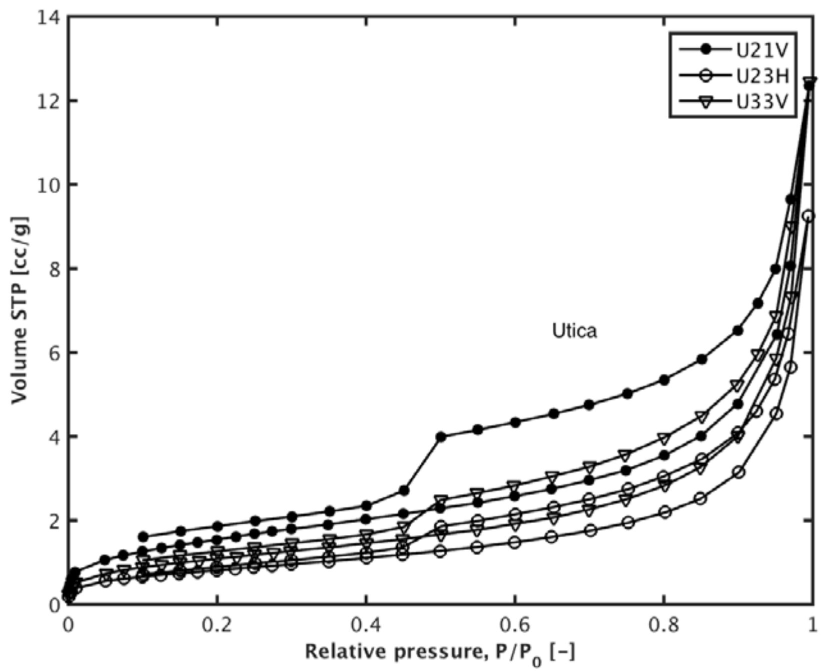
McBride-Wright et a., 2014

Nerine Joewondo, M.S. cand

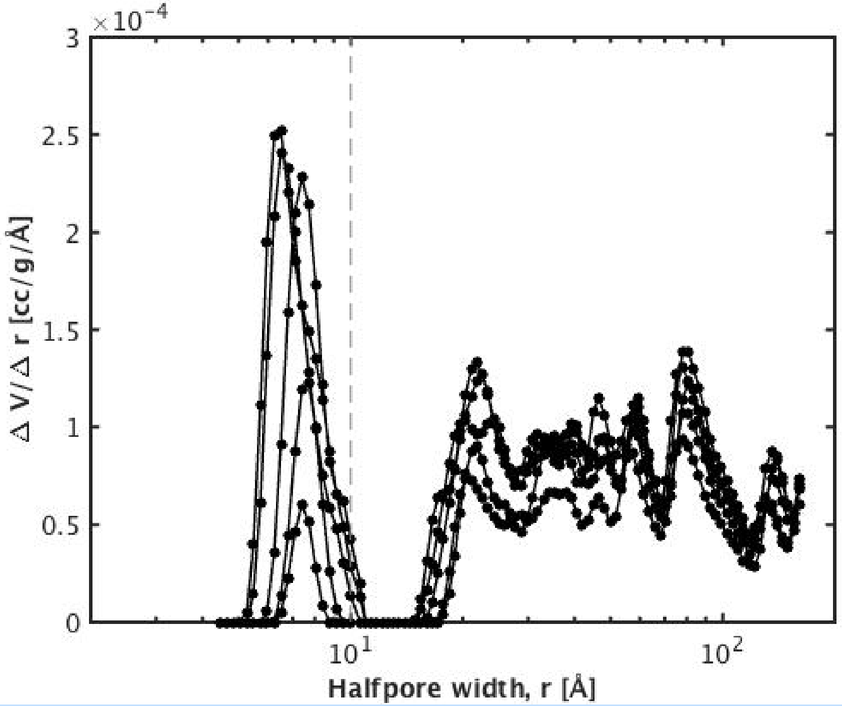
II: LOW PRESSURE SORPTION

Utica Shales: N_2 adsorption

TOC: 2-3.2 wt. %
Pore Size Distribution (PSD) from Density Functional Method (DFT) (radius > 0.7 nm)



Nitrogen adsorption isotherms

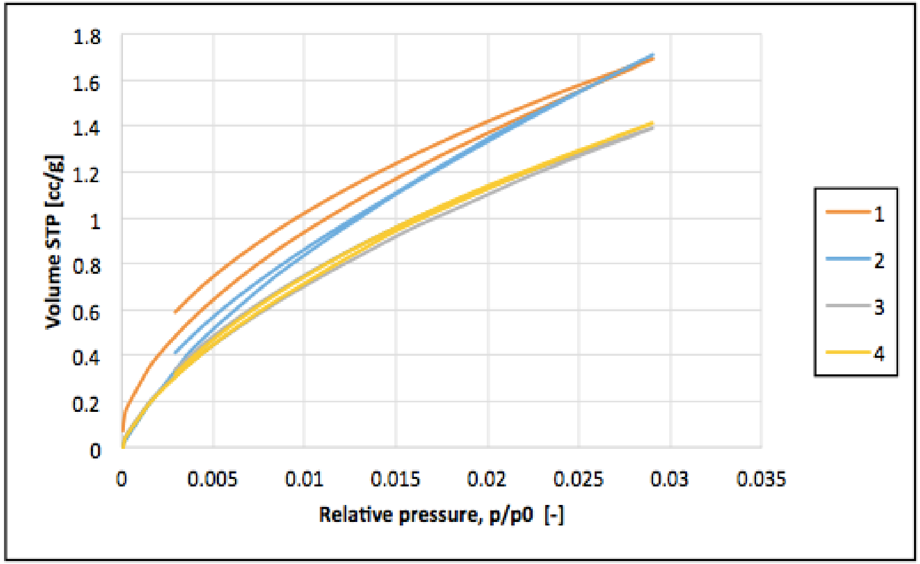


PSD of Utica samples

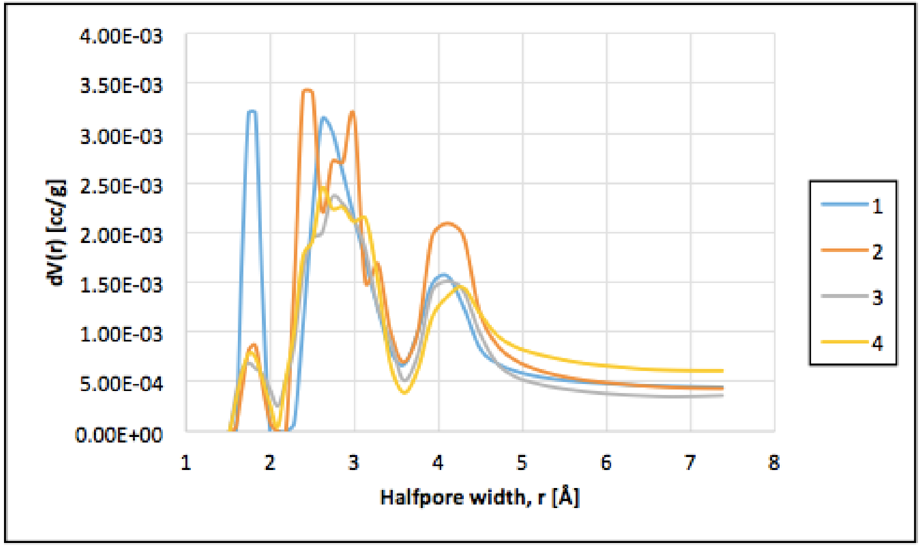
Utica Shales: CO_2 adsorption

CO_2 adsorption – PSD (radius > 0.7 nm) (*in progress)*

- Repeatability tests on standard clay



Repeated CO_2 adsorption on standard clay

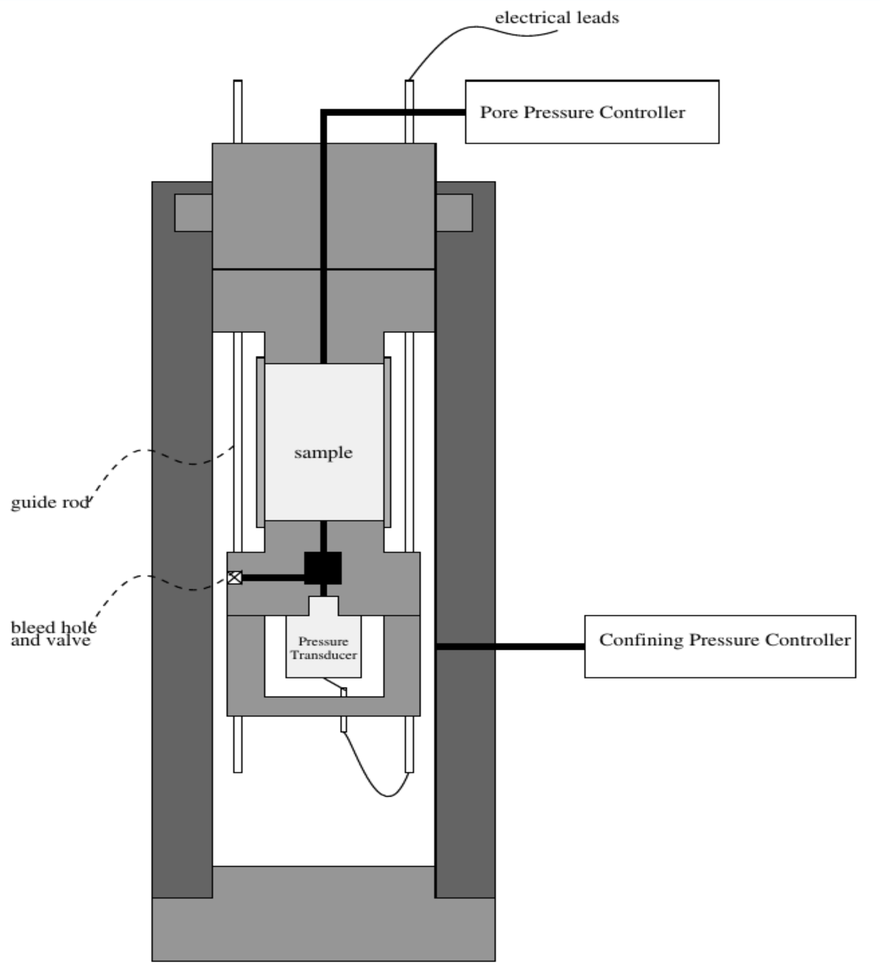


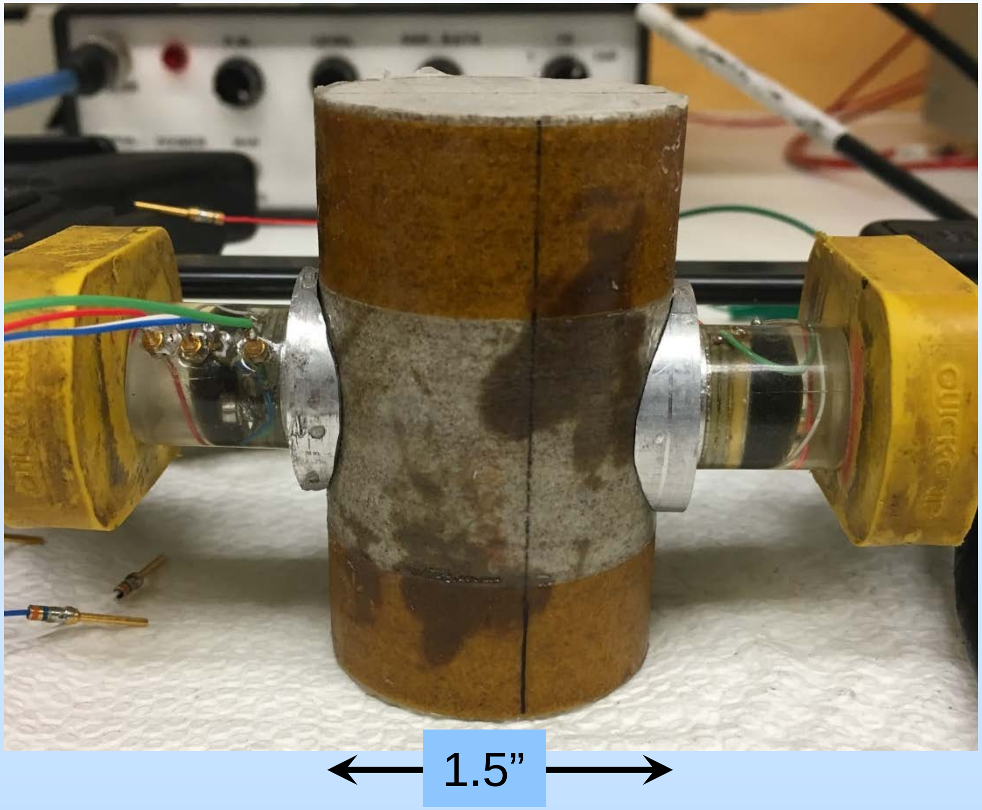
PSD of standard clay from repeated CO_2 measurements

III: PERMEABILITY AND ACOUSTICS

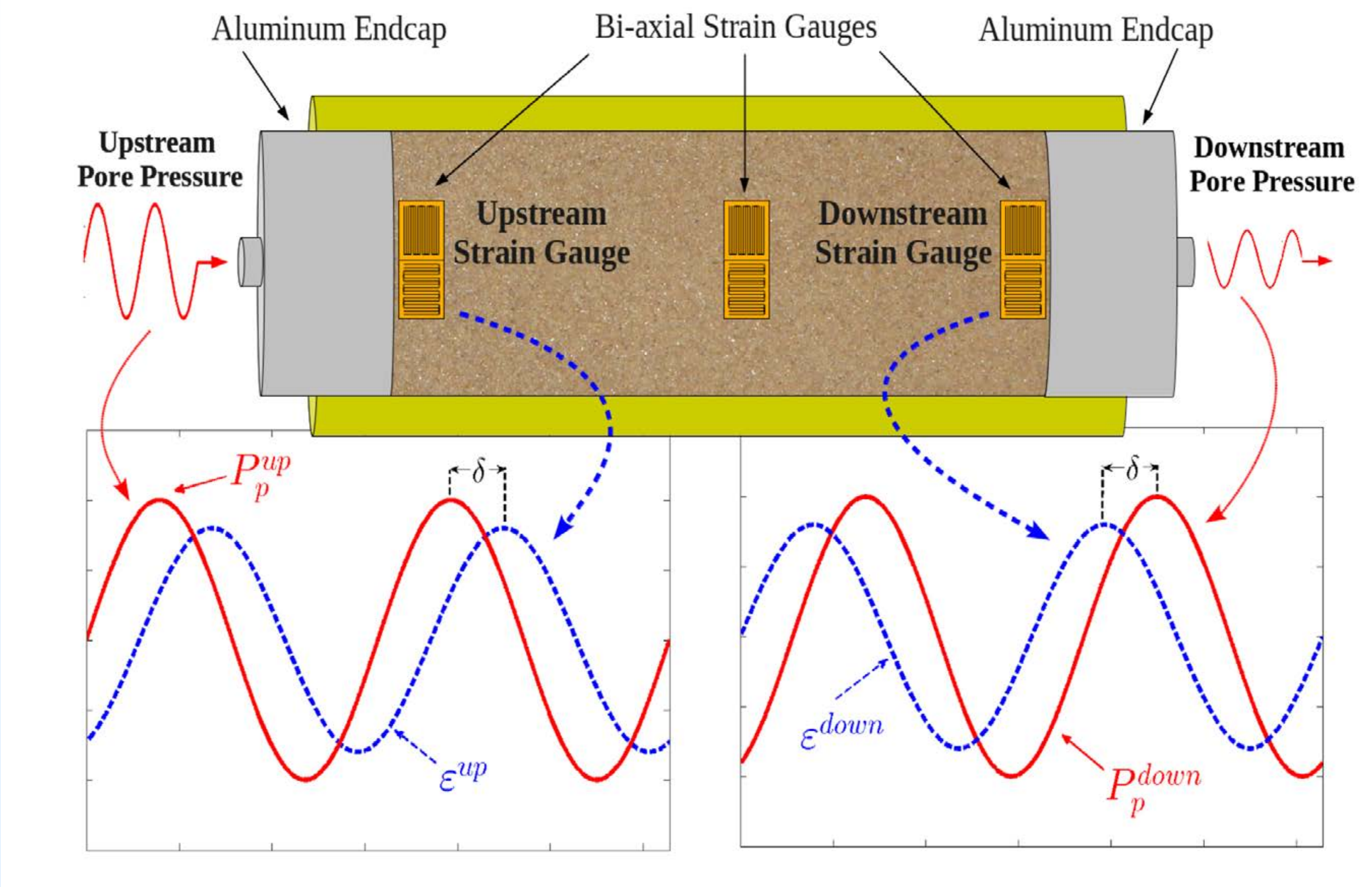
Experimental Apparatus

Experimental Apparatus





Experimental Procedure



Transport and Poroelastic Properties

- Permeability (k) - ability of fluids to flow through rocks; defined through Darcy law:

$$\vec{q} = -\frac{kA}{\mu}(\nabla \vec{P} + \rho_f g \nabla \vec{D})$$

- Storage capacity (β_{st}) - responsible for fluid storage.
  Volume of fluid one can squeeze into a rock by an increase of pore pressure:

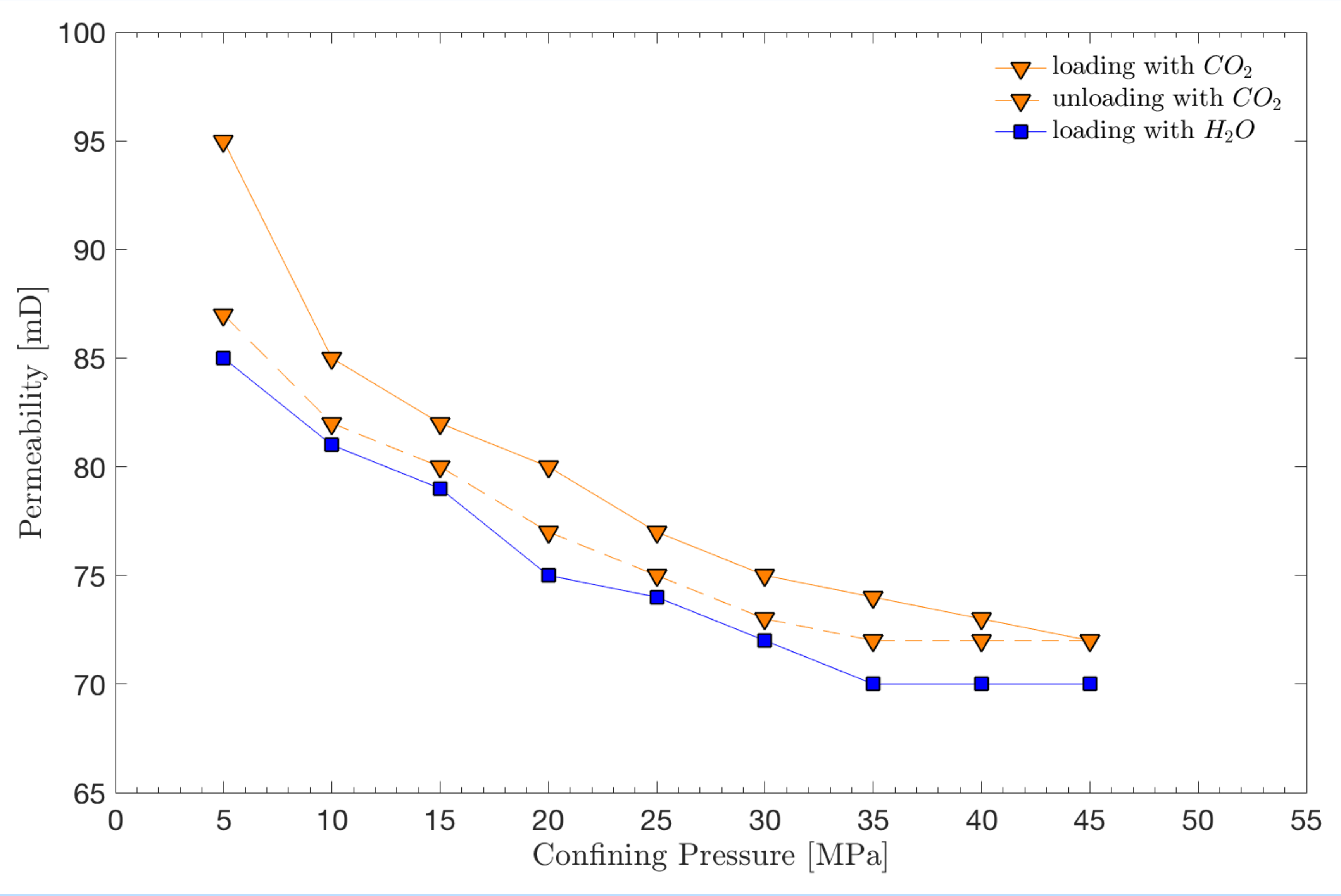
$$\beta_{st} = -\frac{1}{V_{bulk}} \left(\frac{\partial V_{fluid}}{\partial P_p} \right)_{\delta P_c = 0}$$

- Zimmerman's pseudo-bulk modulus (Zimmerman, 1986).
  Bulk strain caused by pore pressure change:

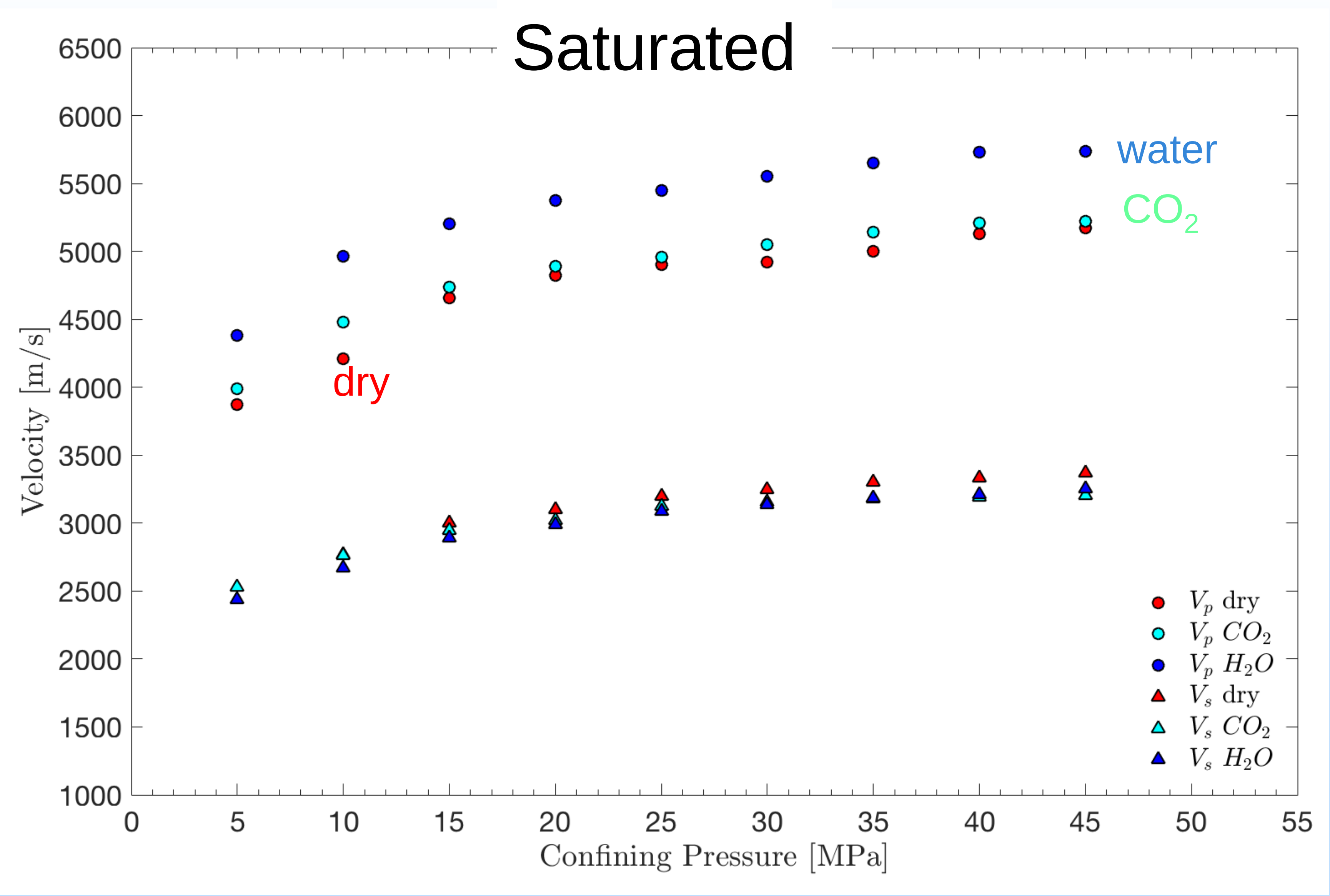
$$\beta_{bp} = \frac{1}{K_{bp}} = -\frac{1}{V_{bulk}} \left(\frac{\partial V_{bulk}}{\partial P_p} \right)_{\delta P_c = 0}$$

$$\beta_{bp} = \frac{1}{K_{bp}} = \frac{\varepsilon_V^{upstr}}{P_p^{upstr}}$$

Permeability vs. Confining Pressure



Velocity vs. Confining Pressure



Accomplishments to Date

INSTRUMENT CONSTRUCTION:

- Constructed pressure and flooding setup for NMR and CT imaging with capability for simultaneous acoustic or conductivity measurements
- Constructed pressure setup for supercritical sorption experiments with capability for simultaneous acoustic or conductivity measurements

EXPERIMENTS:

- NMR relaxations with pressure in fluids & rocks + fluids
- Permeability and acoustic measurements with pressure
- CO_2 sorption with various fluids (N_2, CO_2, H_2O+ CO_2) - with acoustics – in progress

Synergy Opportunities

- Calibrate NMR signals with changes in the fluid versus changes in the rock due to rock – fluid interactions. Relevance: CO_2 operations BUT oil & gas operations too
- Calibrate seismic models with partial saturation due to mineralogy – dependent preferential sorption of CO_2 and water. Relevance: Indirect fluid monitoring operations
- Joint acoustic – permeability changes with CO_2 before and after shearing. Relevance: caprock changes with stress changes

APPENDIX

Future Work

- Simultaneous high PT **sorption with acoustic & resistivity;** Calibrate seismic models with partial saturation with mineralogy – dependent preferential sorption of CO2 and water.
- Theoretical models of physical process in shales; **multilayer adsorption**; Compare permeability of CO_2, N_2, and H_2O in fractured shale
- Compile and compare permeability, acoustics, resistivity, and sorption data
- Distinguish between adsorption effects on relaxivity and fluid pressure effects; Quantifying adsorbed volume, diffusion coefficients, and acoustic measurements during pressurization; make T1-T2 maps
- Calibrate NMR signals with changes in the fluid versus changes in the rock due to rock – fluid interactions.
- Joint acoustic – permeability changes with CO2 before and after shearing.

Background

- Carbon capture and storage in deep geological settings
- Caprock seals and prevents buoyant migration of CO_2
  - Permeability of caprock ~ Nanodarcy
  - Permeability of tight-gas shales ~ Nano to Microdarcy
- CO_2 injection changes the state of stress in reservoir rocks and in caprocks
- **Could faults or fractures develop in caprocks that allow CO_2 transport and escape?**

Accomplished to Date

Completed:

- Experimental Setup
- Subcritical Adsorption on various fluids
- High pressure adsorption with CO2 on a shale and a clay sample
- Acoustic tests during sorption
- NMR experiment during CO2 injection

Ongoing:

- Acoustic Tests
- Equation of state calculations
- High pressure and temperature tests
- Triaxial tests for strength and fracture permeability