Characterizing Shales as Seals for CO_2 Containment and Shales as Reservoirs for Geologic Storage of CO_2

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Presentation Outline

Shales as Seals and Unconventional Reservoirs: Product of this work is to quantify shales as sealing units for large scale CO_2 storage operations. Shales is investigated in the following terms:

(1) quantifying the chemical reactivity of shales with CO_2 in natural fractures and matrix pores

(2) quantifying flow properties of shale sealing units in both the matrix and natural fractures in terms of CO_2 containment

(3) explaining shale fracture behavior when stressed and exposed to scCO2 and fluids

Task 18.0 CO_2-Shale Interactions

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Task Technical Approach and Project Relevancy

- **Characterizing Shales as Seals for CO_2 Containment**

Objective:

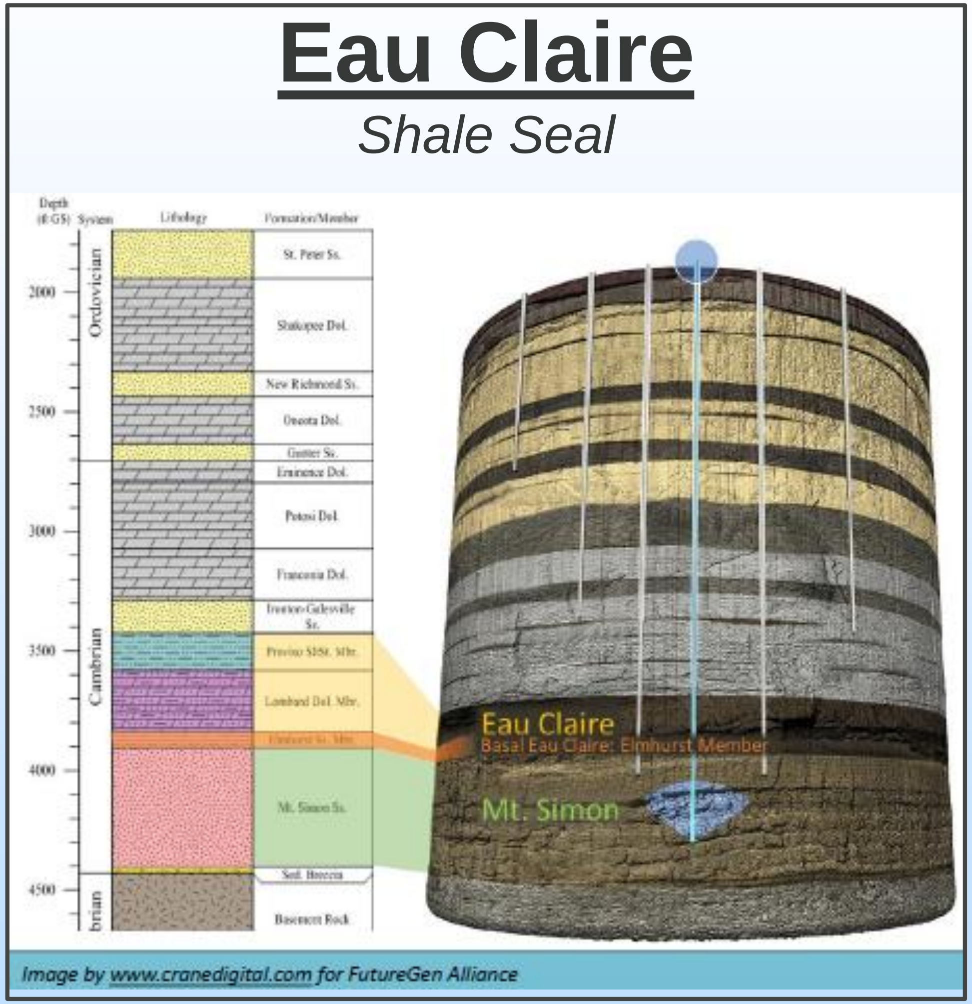
- – **Quantify shales as sealing units** for large scale CO_2 storage operations.

Challenges:

- Very few studies are considering the reactivity of CO_2 and fluids with shales.
- Reactions between CO_2, fluids, and shale may alter:
  - – Petrophysical **properties** such as porosity and permeability
  - – **Integrity** of the shale as a sealing unit
  - – Potential as a **storage reservoir**
  - – **Flow pathways** potentially impacting carbon storage seals, carbon storage reservoirs, and hydrocarbon extraction

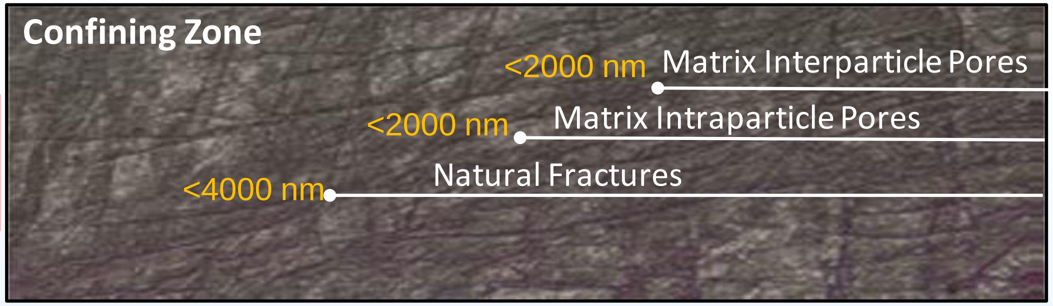
Approach:

- – Quantify the **Chemical Reactivity of Shales with CO_2** in Natural Fractures and Matrix Pores
- – Investigate How **Sub-Critical Stresses** Break Shale when Under Elevated Pressures Due to CO_2 Injection
- – **Quantify Flow Properties of Shale Sealing Units** in Both the Matrix and Natural Fractures in Terms of CO_2 Containment

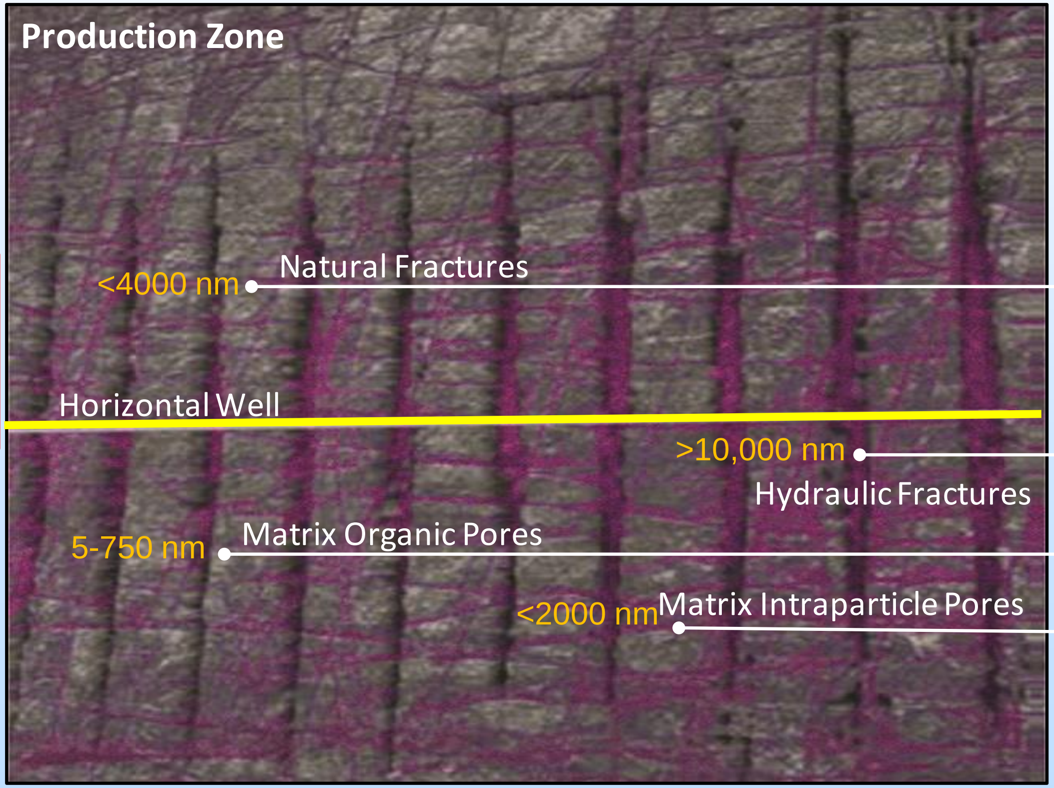


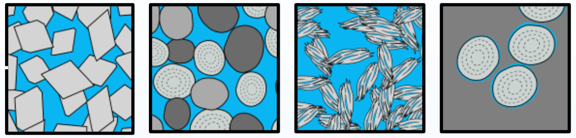
Shale Properties

Shale as Seals

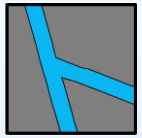


Shale for Production and Storage

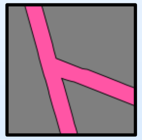




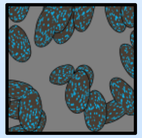
Matrix Interparticle Pores (<2000 nm) between mineral particles are more likely to be connected and hydrophilic. Examples include crystals, grains, clay platelets, and rigid grains



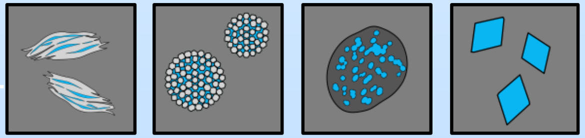
Natural Fractures (<4000 nm) can be sealed with calcite or bitumen and have a significant effect on hydrocarbon production.



Hydraulic Fractures (>10,000 nm) are induced after hydraulic fracturing and have a significant effect on hydrocarbon production.



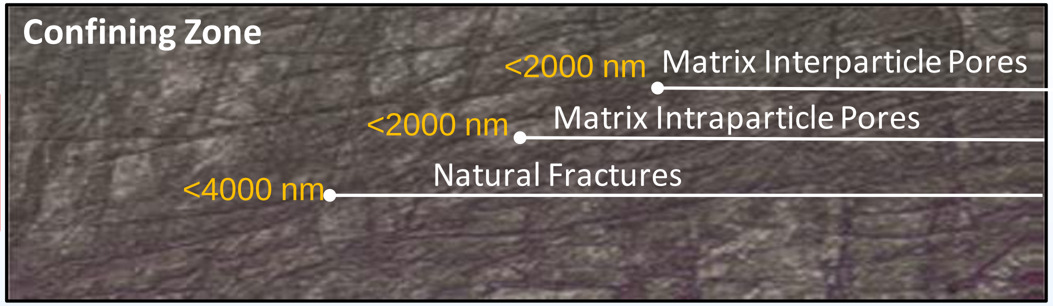
Matrix Organic–Matter Pores (~5-750 nm) intra-pores within the organic matter are more likely to be connected and hydrophobic.



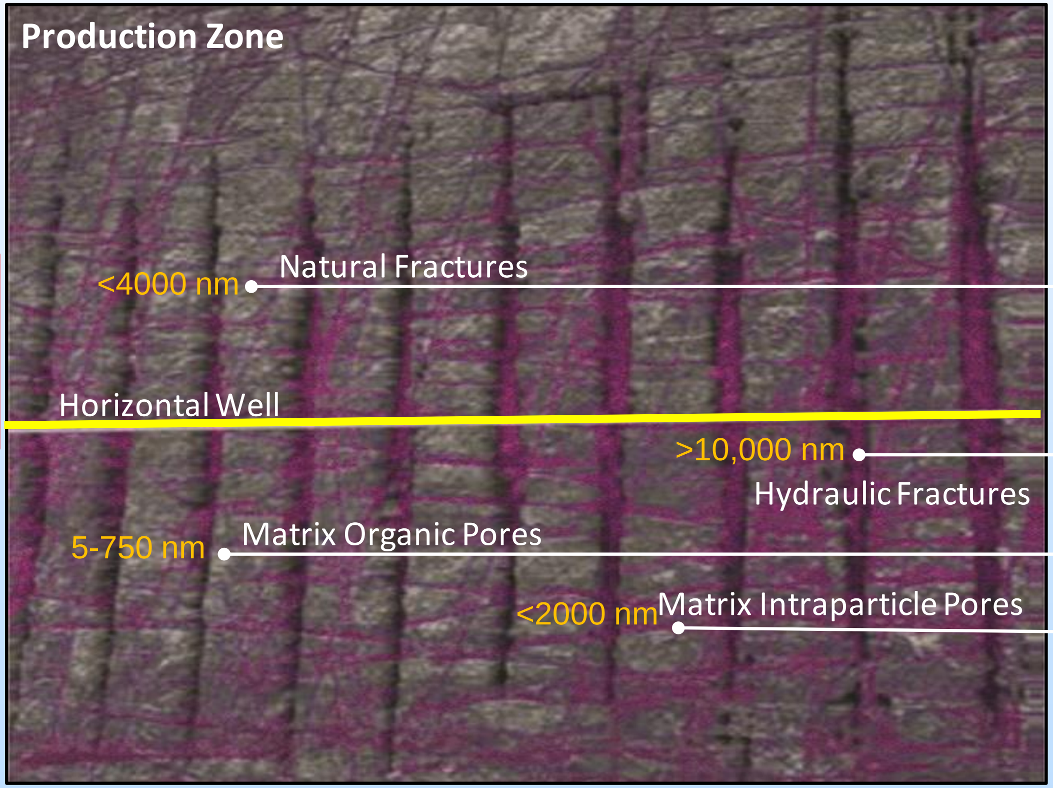
Matrix Intraparticle Pores (<2000 nm) within mineral particles are less likely to be connected and hydrophilic. Examples include clay aggregates, pyrite, pellets, and moldic pores.

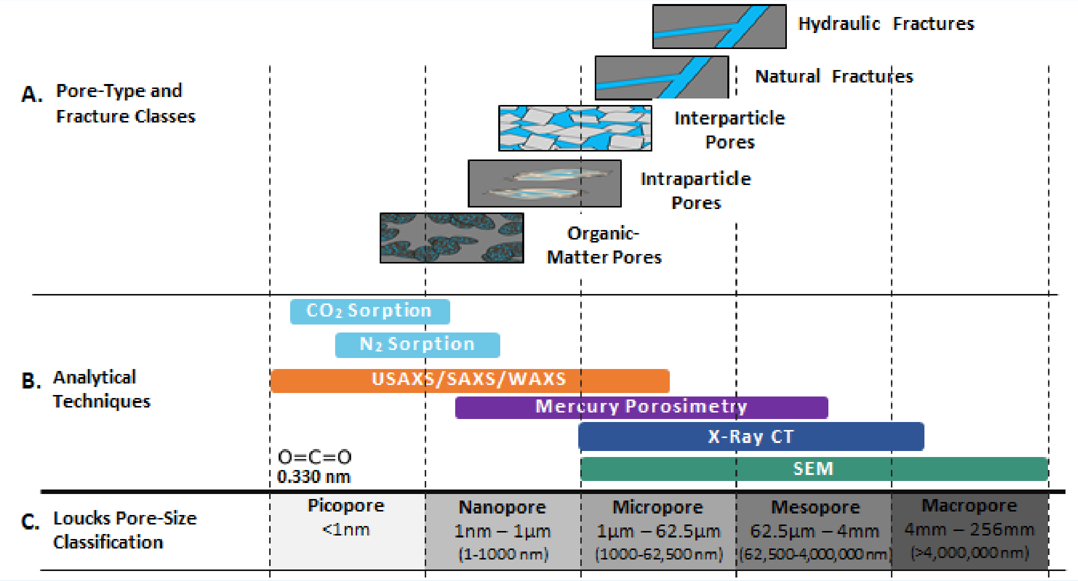
Shale Properties

Shale as Seals



Shale for Production and Storage



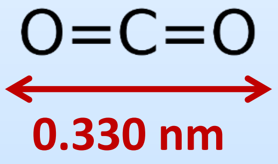


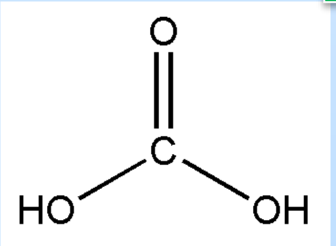
NETL has the capability to measure these pore types

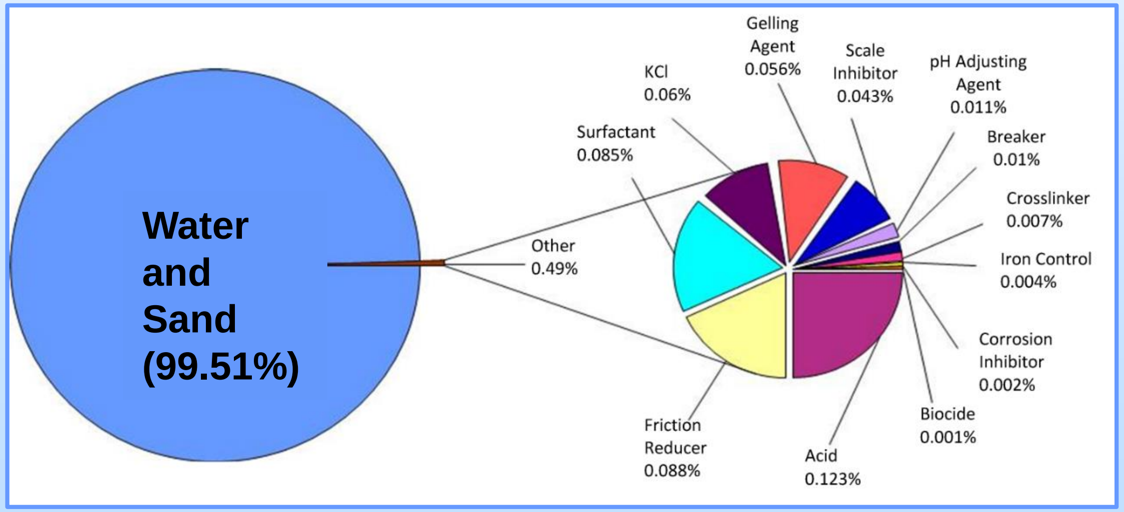
Research Questions

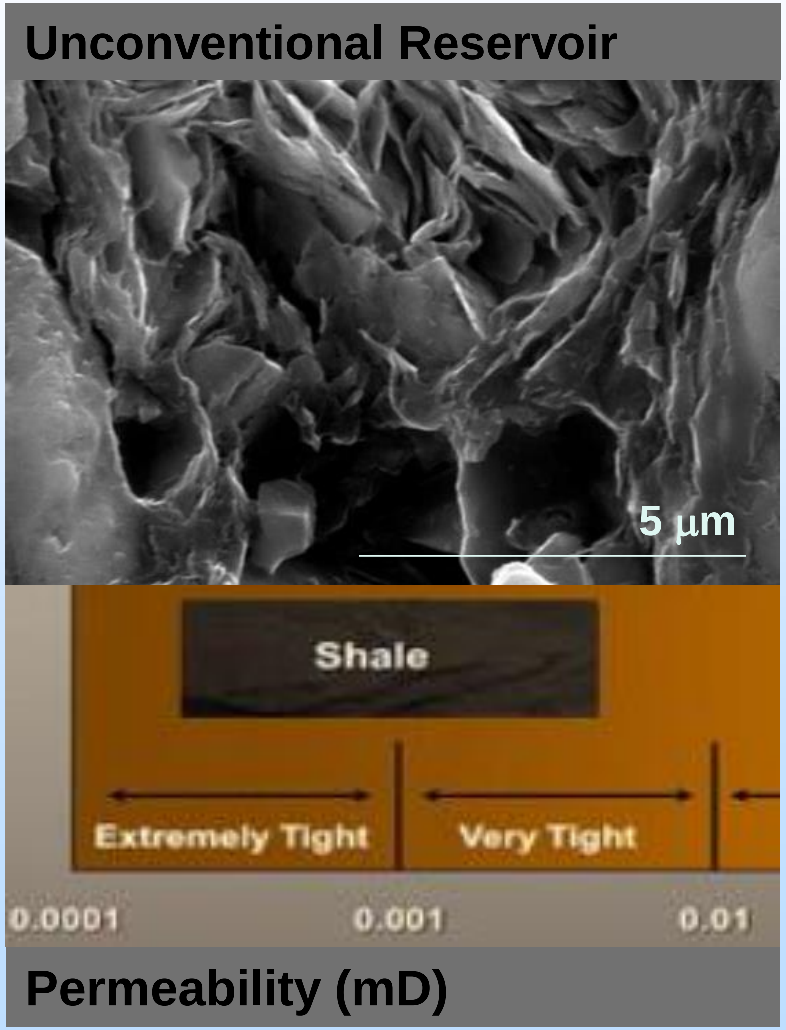
How does CO_2 interact with shale and fluids?

- How is CO_2 stored in shales?
- How does CO_2 alter seals?
- How do we classify shales?
- Can CO_2 enhance hydrocarbon recovery?
- Can CO_2 be used as a fracturing agent?









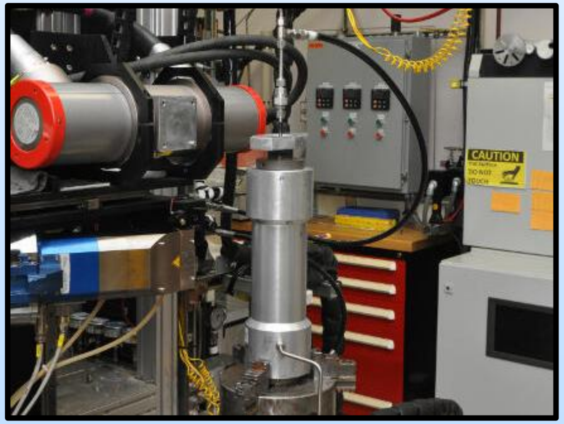
Research Capabilities

Feature Relocation SEM/EDS

Static batch reactors for long-term experimentation

BET Pore Size Analysis

X-Ray Diffraction



High-Resolution Industrial Computed Tomography

In-situ Fourier Transform Infrared Spectroscopy

Autolab 1500

Rapid Medical Computed Tomography with Controlled Flow

Key Findings

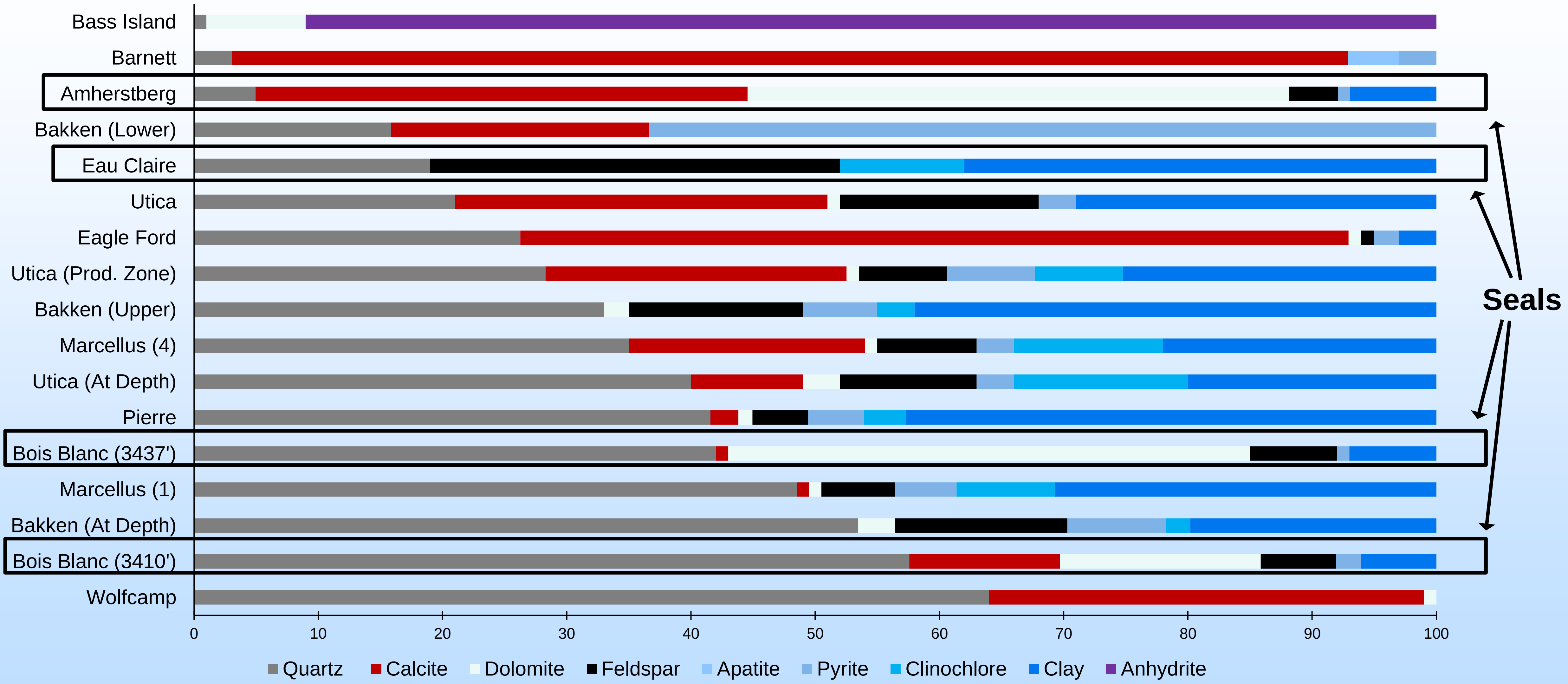
Chemical composition of shale has a major effect on CO_2-shale reactivity

- *Carbonate-rich* shale samples
  - CO_2 and water cause significant alterations in pore sizes by increasing porosity at the micro-scale while decreasing porosity at the nano-scale.

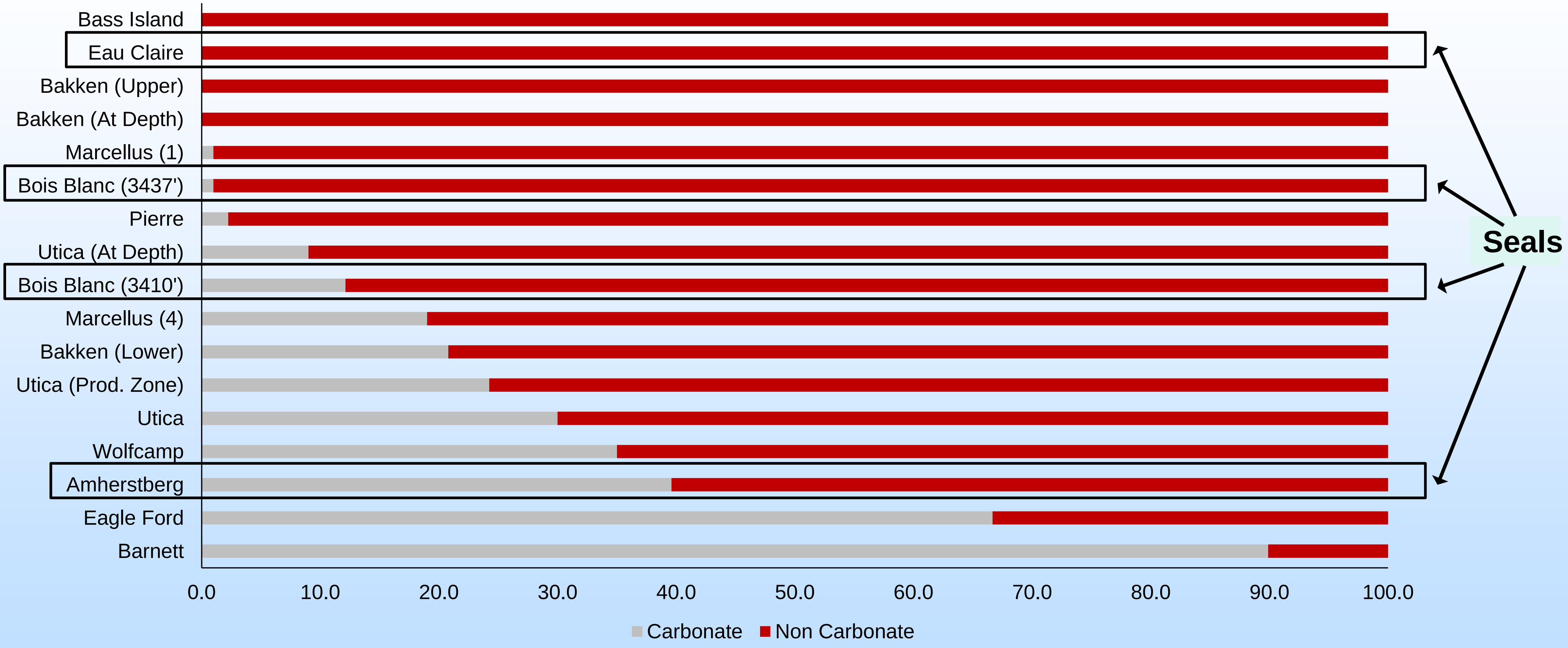
- *Carbonate-poor* shale samples
  - CO_2 and water DO NOT alter pore sizes
  - Moderate increases in fracture sizes were observed.

- Shale fluid saturation and structure influence geomechanical properties
  - Dry shales exhibit more localized breakage under stress than water saturated shale
  - Shear fracturing along bedding planes common in low stress experiments.

Mineralogy Characterization

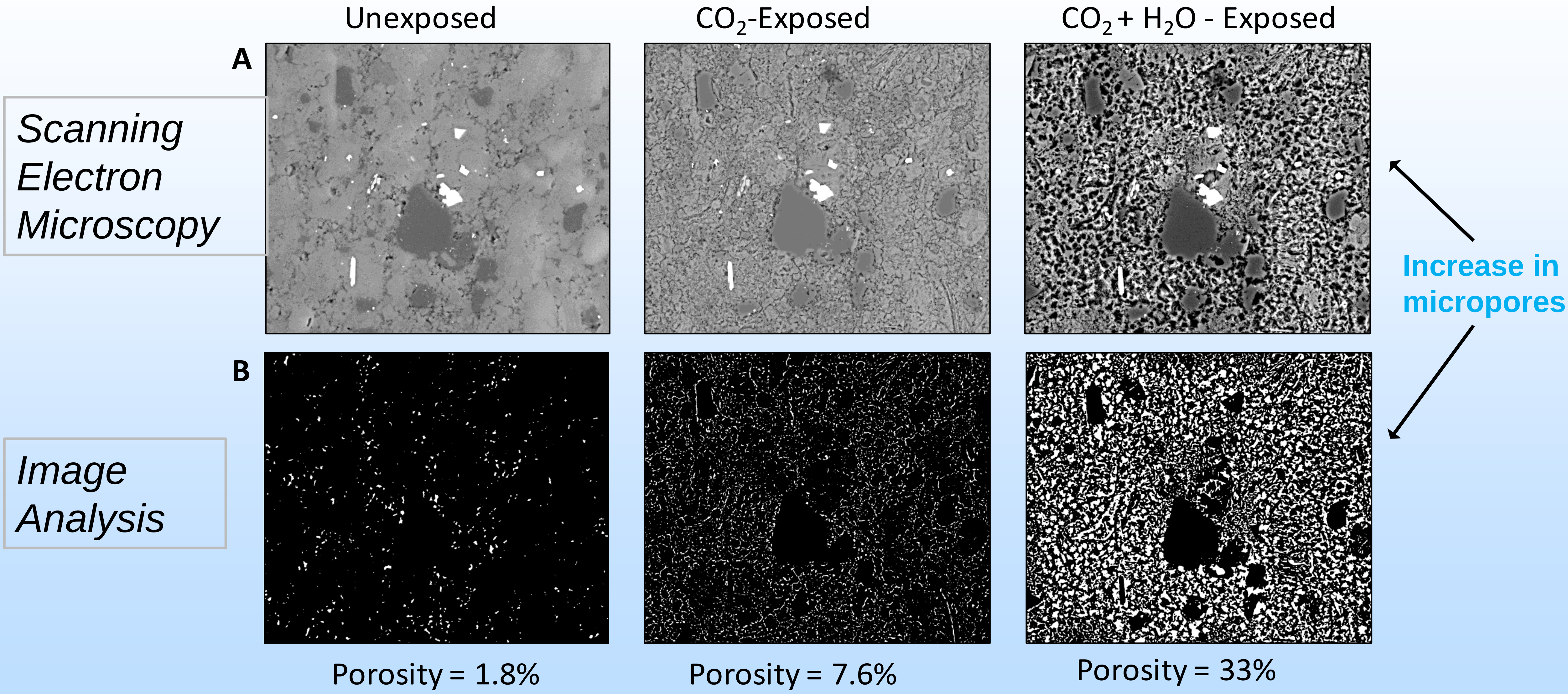


Mineralogy Characterization



Results: CO_2 Reactivity with Shale

Carbonate-Rich Shale



Results: CO_2 Reactivity with Shale

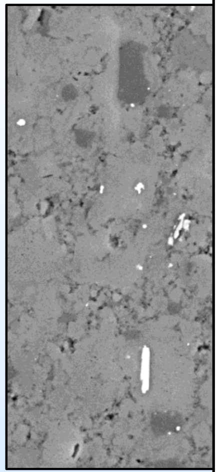
Carbonate-Rich Shale

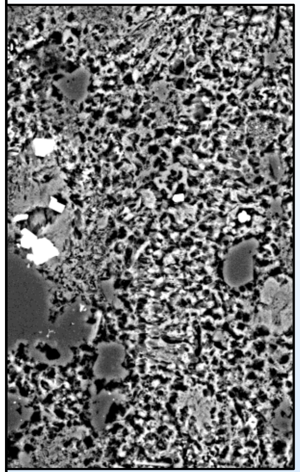
Une

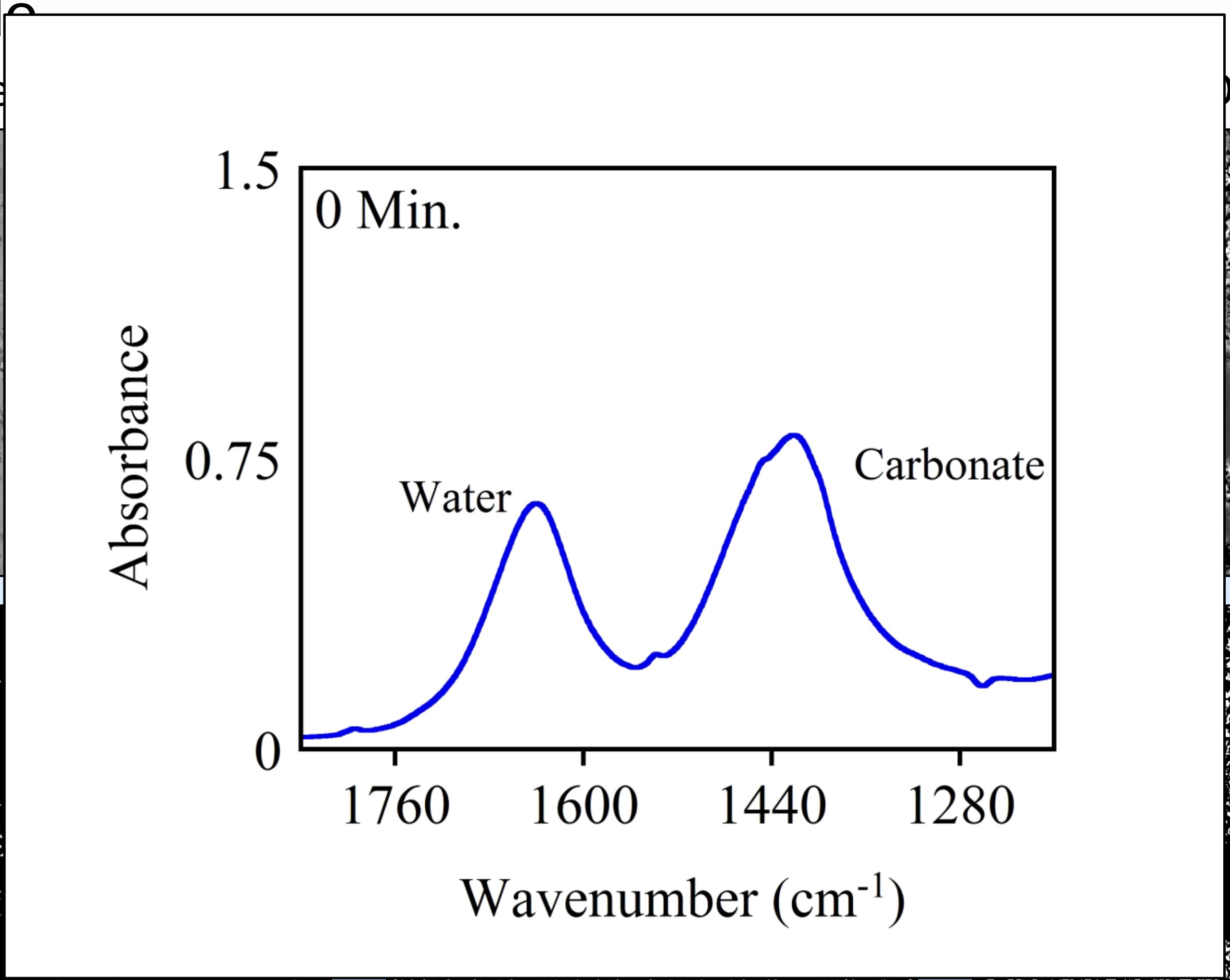
- Exposed

A

Scanning Electron Microscopy







B

Image Analysis

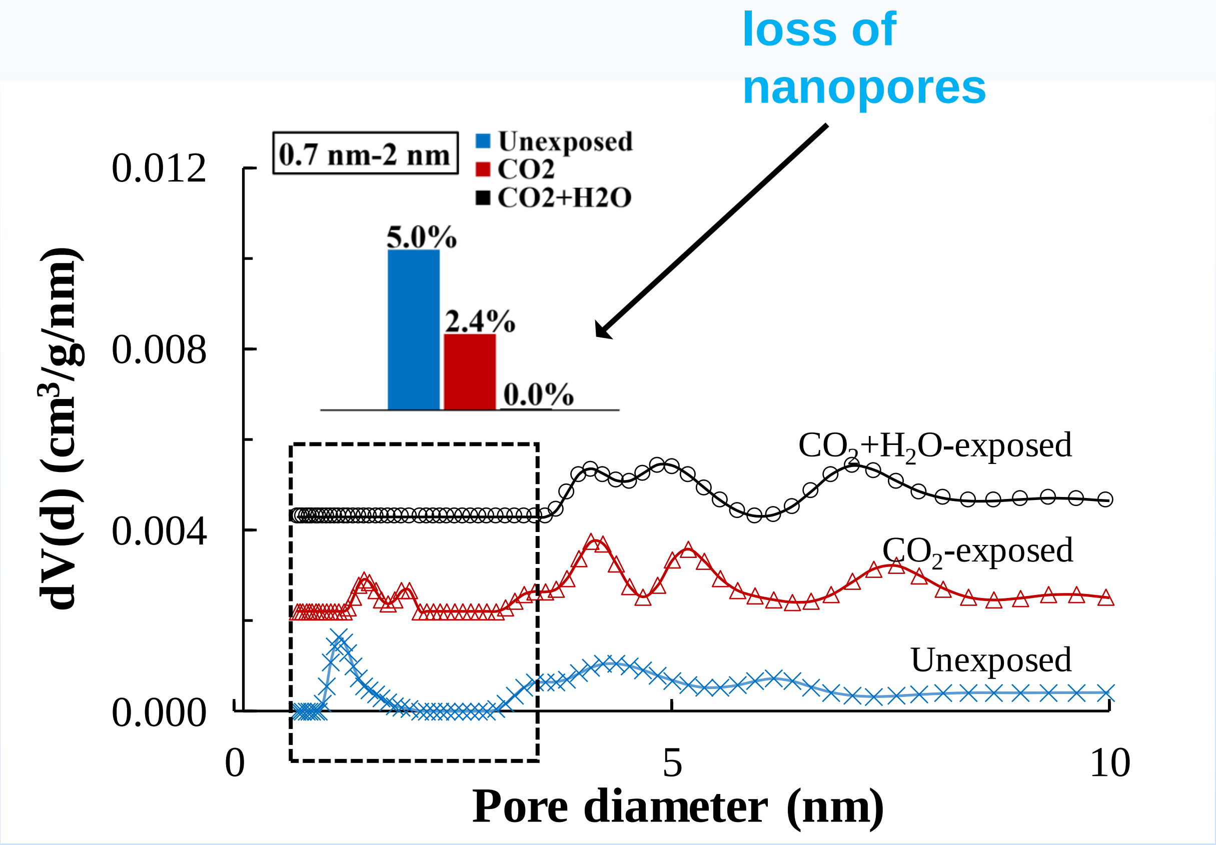
Porosity = 1.8%

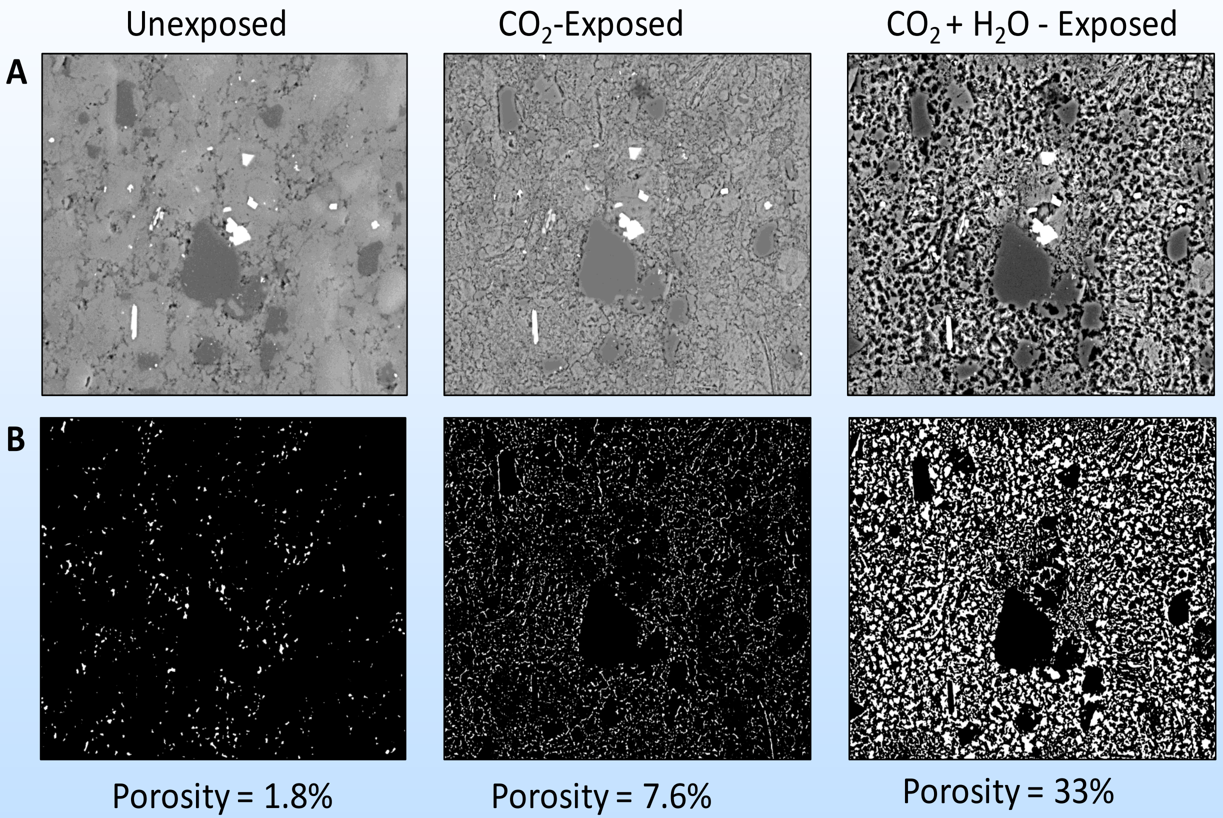
Porosity = 7.6%

Porosity = 33%

Results: CO_2 Reactivity with Shale

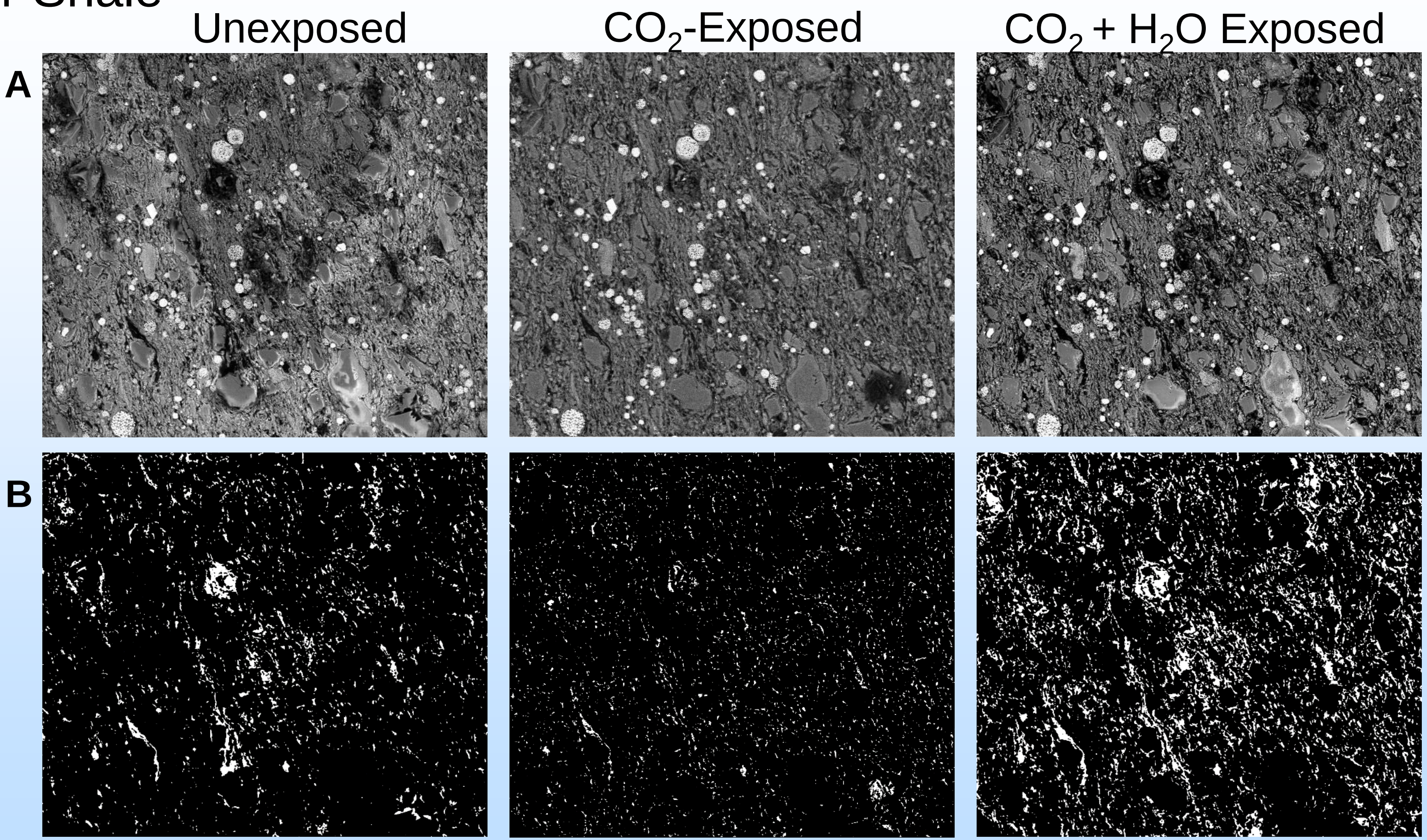
Carbonate-Rich Shale





Results: CO_2 Reactivity with Shale

Carbonate-Poor Shale



Scanning Electron Microscopy

Image Analysis

Potential Increase in fracture size – needs further investigation

Porosity = 5.6%

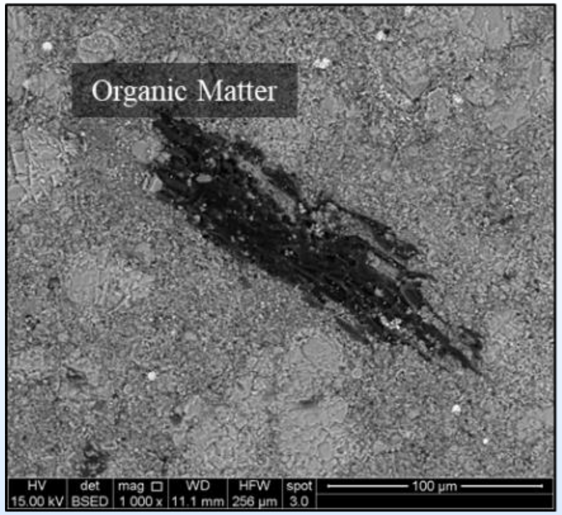
Porosity = 3.6%

Porosity = 13.5%

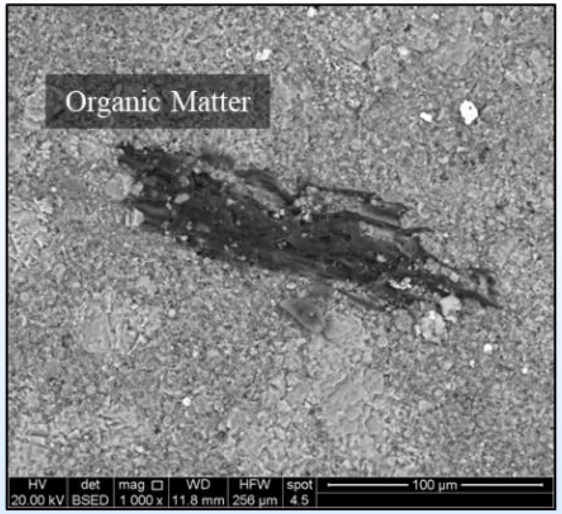
Results: CO_2 Reactivity with Shale

Organic-Rich Shale

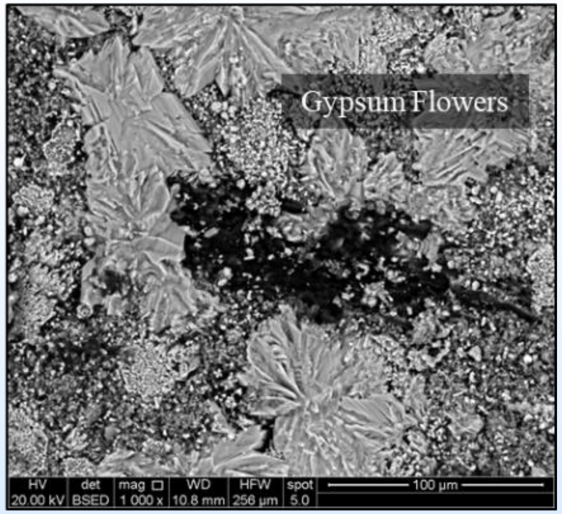
Unexposed



CO_2 Exposed

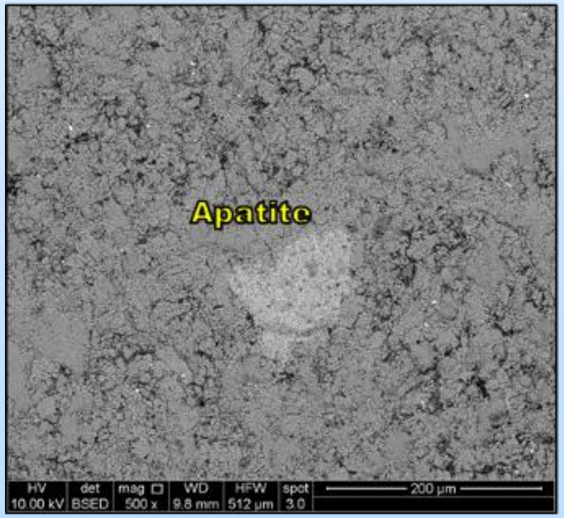


$CO_2 + H_2O$ Exposed

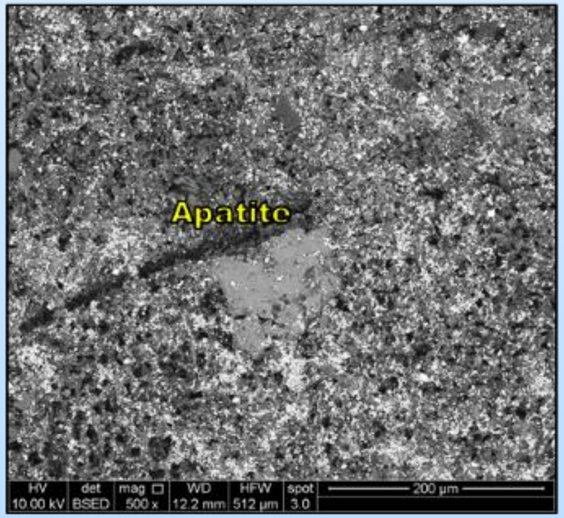


Sample ID	TOC	TIC	TC	S
ES-1	10.33	1.29	11.62	0.62
BS-1	10.51	1.08	11.59	BDL

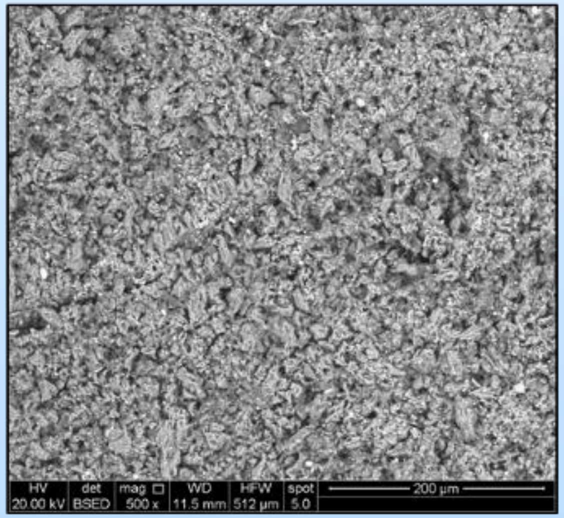
Unexposed



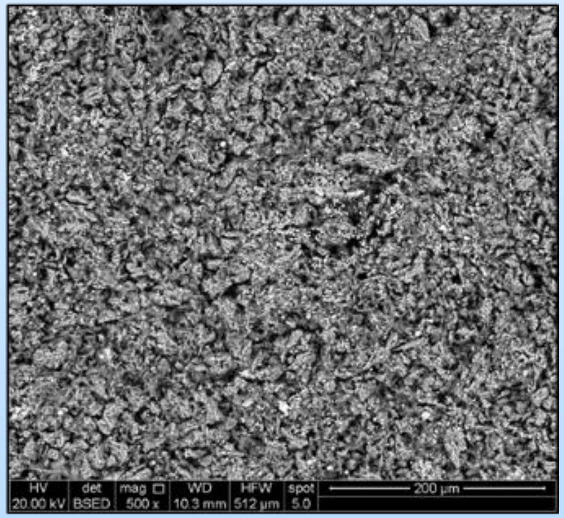
FF Aged



CO_2 Exposed



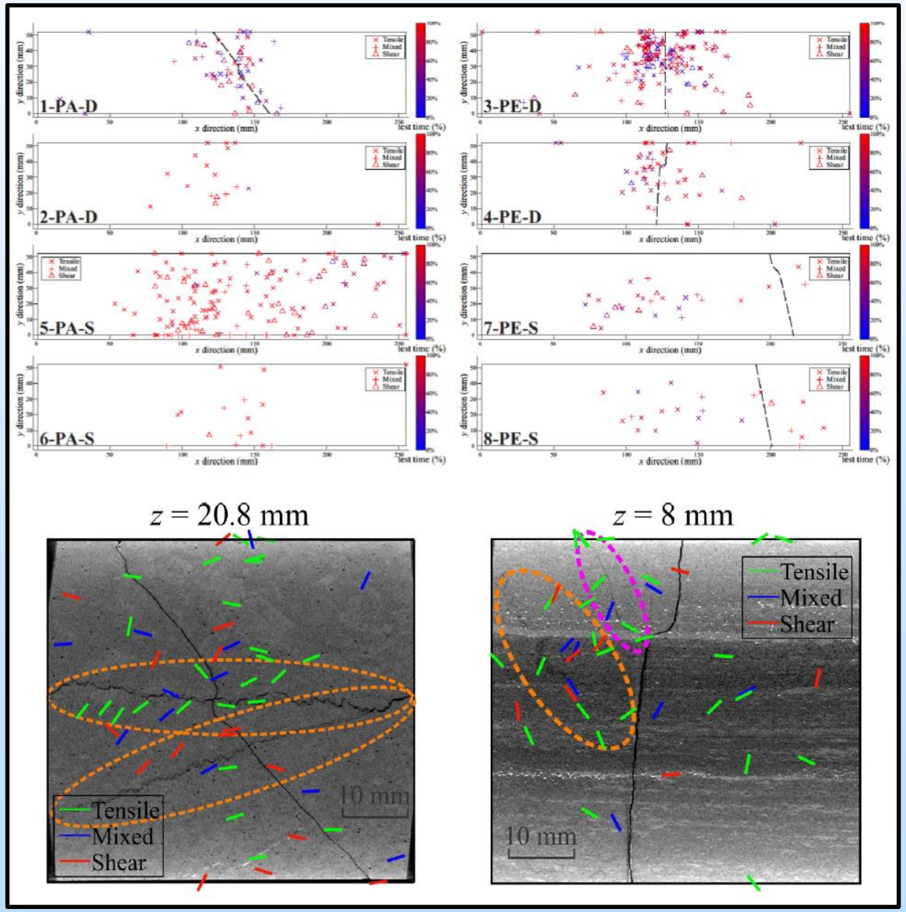
$CO_2 + H_2O$ Exposed



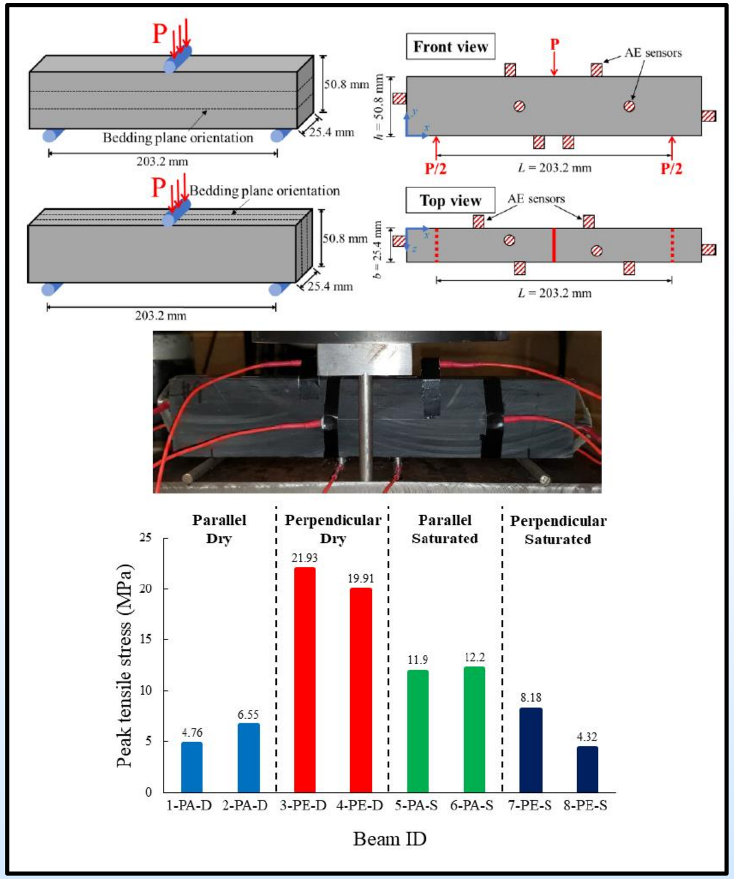
CO_2-Shale Interactions- Geomechanics

Low pressure cracking of shales

- The goals of the proposed research was to observe and quantify breakage in shales due to low stresses using acoustic emissions (AE) and CT.



- Time dependent failure of shale due to stresses that are insufficient to instantaneously break the rock may still create flow pathways.
- Successfully used AE to identify low stress crack formation and type
- Successfully used CT to confirm the location of these cracks and structural influence of the shale on fracture modes
- Unsuccessful at merging these two measurements simultaneously and missed a Go/No-Go milestone associated with this work.
- Work halted and manuscript submitted covering observations completed.



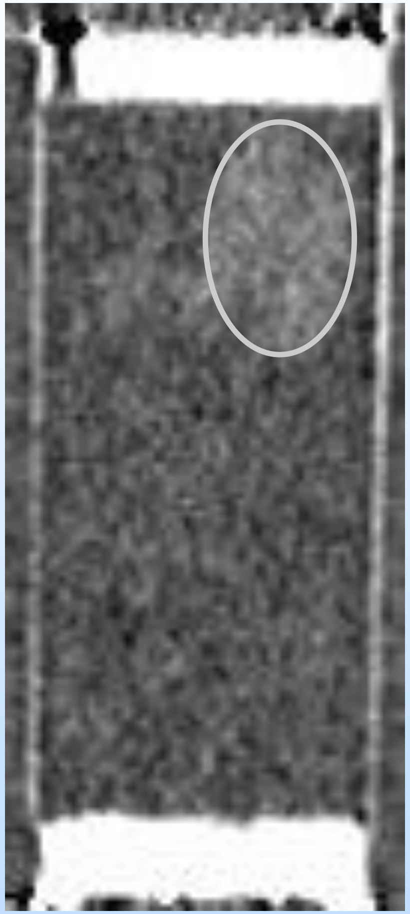
Lu, G., Crandall, D., and Bunger, A. (*submitted*) **Observations of breakage for transversely isotropic shale using Acoustic Emission and X-Ray Computed Tomography: Effect of bedding orientation, preexisting weaknesses, and pore water**, *International Journal of Rock Mechanics and Mining Sciences*

Next Steps: Flow Pathways

- Quantify if pore alterations **impact flow pathways**
  - Core flow tests in progress to evaluate whether pore changes impact flow pathways in the shale matrix

- Investigate other shale properties:
  - Thermal maturity
  - Ductility
  - Mineralogy other than carbonate
  - Clay Content
  - Organic Content (kerogen)

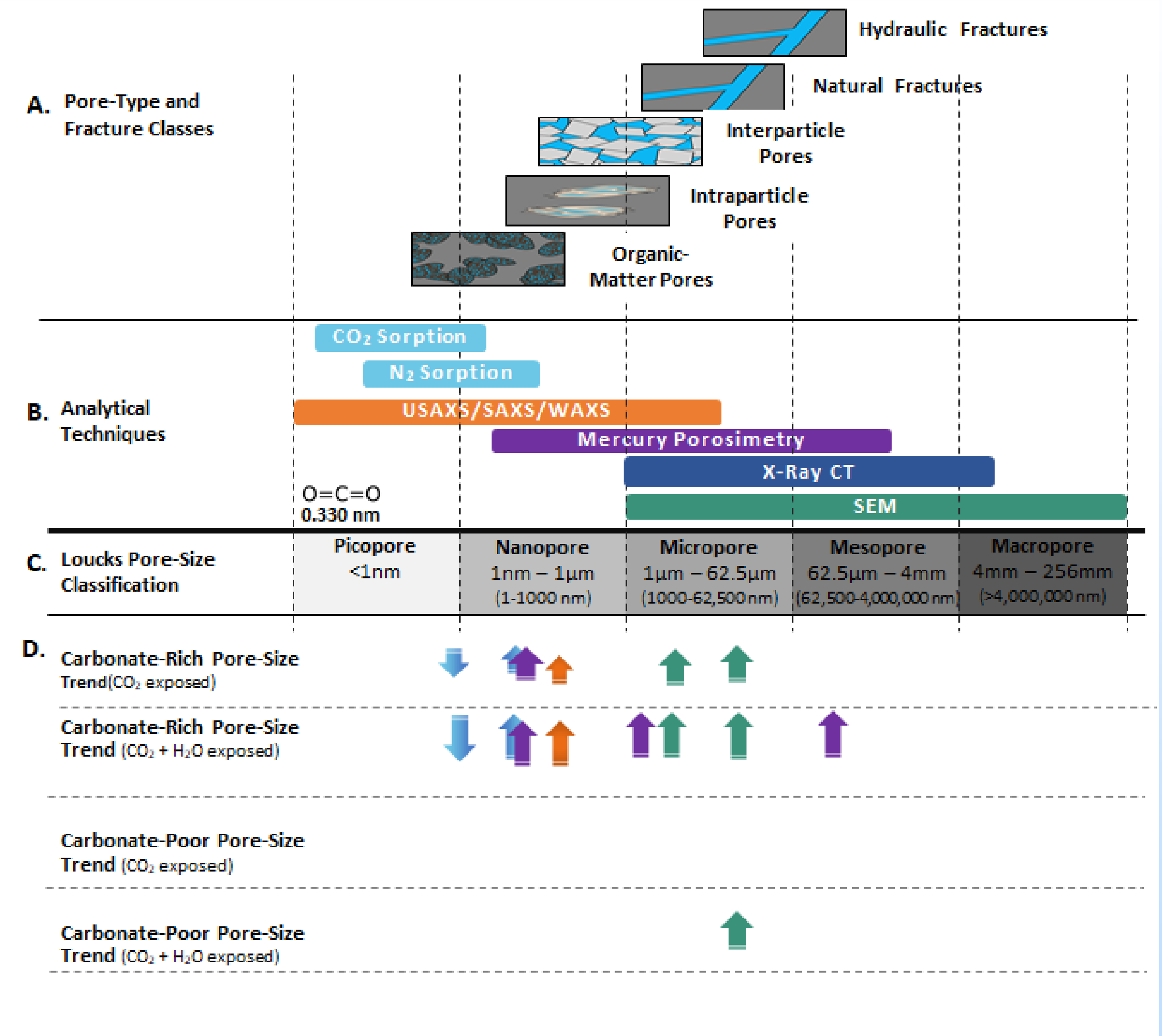
Carbonate-Rich Shale



Summary

- Chemical composition of shale has a major effect on CO_2-shale interactions
  - **Carbonate-Rich vs Carbonate-Poor** shales affect CO_2-fluid interactions
- Carbonate-rich: changes in pore sizes, etching/pitting
  - **Micro-scale porosity increases** with CO_2 and CO_2/H_2O
  - **Nano-scale porosity decreases** with CO_2 and CO_2/H_2O
- Carbonate-poor: Increase in micro fracture abundance and size

- Shale fluid saturation and structure influence geomechanical properties
  - Dry shales exhibit more localized breakage under stress than water saturated shale
  - Shear fracturing along bedding planes common in low stress experiments.



Appendix

– These slides will not be discussed during the presentation, but are mandatory.

Benefit to the Program

Problem Statement

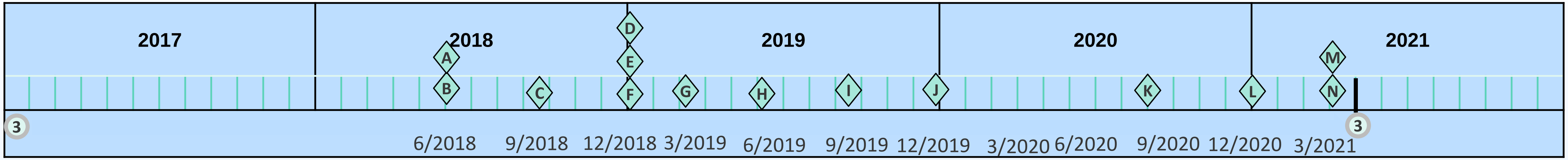
- Shale formations are expected to be impermeable sealing layers for CO_2 storage reservoirs due to their low permeability. Although a large body of work has been conducted on shales, fundamental research is needed to understand shale properties in terms of sealing layers for CO_2 storage reservoirs. The injected CO_2 will interact with reservoir fluids and shale components such as clays and organic matter. The injection process will affect shale properties through chemical alteration, matrix swelling/shrinkage, and geomechanical stress effects from either chemical reactivity or changes in reservoir pressure. These changes in shale properties could alter the flow pathways of the shale sealing unit. As potential changes in shale sealing properties will impact anthropogenic CO_2 storage, it is imperative to quantify CO_2-shale and stress related interactions with shale sealing units. This work directly addresses the administration goals relevant to the Program: ***Reduce risk and ensure certainty in safe, permanent storage and cost-effective integrated storage facilities***.

Justification and Benefits

- Shale formations are widespread throughout the United States. Quantifying fundamental shale properties in terms of a sealing layer for CO_2 storage reservoirs is needed to develop a national strategy for CS. Fundamental research examining the geochemical and stress-induced interactions of CO_2 and fluids with shale is limited from the perspective of understanding shale as an effective natural seal. Reaction of CO_2 with native fluids and reactive shale interfaces may generate new reactive surfaces or intermediates that may alter the properties of the formation. It is known that geochemical reactions influence storage mechanisms and that reaction kinetic rates vary significantly from occurring immediately after injection to hundreds of years later. When shale interacts with CO_2 and fluids the geomechanical properties of the shale may change. Geochemical and stress-induced alterations have a direct impact on flow pathways, porosity and permeability changes, and integrity of the formation seal. A fundamental understanding of the reactivity of CO_2 with shale and how shale fracture properties alter under stresses will help in identifying and reducing risk associated with shale sealing units in CCS activities.

Task 18: Project Timeline Overview

- CO_2-Shale Interactions (PI: Angela Goodman/Dustin Crandall)



Milestones

18.A Present the results of the CO_2/shale interactions literature review. **Completed**
18.B Continue testing the Bakken shale/CO_2 interactions with core flow apparatus and EERC. **Completed**
18.C Submit a peer reviewed publication on the assembled literature review. **3 TRS - Completed**
18.D Perform MD simulations of hydrated and dry shale with mixtures of CH_4/CO_2 to determine preferential sorption potential under varying realistic conditions. **Completed**
18.E Assemble a bench scale full immersion pulse decay device and shakedown apparatus. Compare/contrast measurements to traditional pulse decay. **NO-GO**
18.F Quantify the geochemical impact of CO_2 and fluid interactions on Utica and Marcellus Shale at the nano- and micro-scale. **Completed**
18.G Quantify the potential changes in flow properties of Utica Shale that has been modified with CO_2 and fluid. **Completed**
18.I Observe microstructural changes during stress corrosion cracking and complete core-scale experiments. **Completed**
18.J Quantify the geochemical impact of CO_2 and fluid interactions on shale as a seal. **Completed**
18.K Quantify the potential changes in flow properties of shale as a seal that has been modified with CO_2 and fluid. **On-going**
18.L Complete experiments of two shale fractures showing alteration of fracture geometry and flow when exposed to (1) water and (2) water and CO_2.
18.M Quantify the geochemical impact of CO_2 and fluid interactions on shale as a seal and potentially relate shales as seals and shales as storage reservoirs.
18.N Submission of manuscript describing observed changes in fracture closure, with recommendations about what constituents in the shale matrix can have the largest impact on the fracture closure behavior.

Impact

Key Accomplishments/Deliverables	Value Delivered
Quantified interactions of CO_2 with Utica, Marcellus Shale, Eagle Ford, Barnett, Eau Claire Published comprehensive literature review of CO_2/H_2O/shale interactions Observed CO_2 can reduce fractured shale permeability under in situ conditions	• How geochemical CO_2 alterations and subcritical stress of shale may affect flow pathways and sealing properties • Database of shale sealing properties when influenced by CO_2 reactivity and subcritical stress

Go / No-Go

Chart Key

\# TRL Score | Go / No-Go Timeframe | Project Completion | Milestone

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