Numerical and Laboratory Investigations for Maximization of Production from Tight/Shale Oil Reservoirs: From Fundamental Studies to Technology Development and Evaluation

ESD14089

George Moridis, Tim Kneafsey, Sharon Borglin, Jonathan Ajo-Franklin, Marco Voltolini, Matt Reagan, Glenn Waychunas

Lawrence Berkeley National Laboratory

U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology, Innovation and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

August 16-18, 2016

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Presentation Outline

- Objectives and Benefits
- Technical Presentation
  - Nano-
  - Micro-
  - Macro-Laboratory Studies
- Synergies

Benefit to the Program

- Goal: to **advance the fundamental understanding of hydrocarbon storage, release, and flow in shale/mudstone reservoirs under existing, and/or potential future, development scenarios with the goal of identifying strategies that lead to more prudent development strategies that appropriately balance resource conservation with environmental protection**.

- Benefit: This project was designed to identify and evaluate possible development improvement strategies and enhancements to producing light tight oil, using laboratory studies, molecular dynamics simulations, and reservoir simulations.

Project Overview: Goals and Objectives

- Project Goals: Using nano- to core-scale laboratory investigations and numerical simulations (from molecular to field-scale) we are working to:
  - (a) identify and quantify the mechanisms involved in hydrocarbon production from tight systems,
  - (b) describe the thermodynamic state and behavior of the fluids in the nanometer-scale,
  - (c) propose new methods for low-viscosity liquids production from tight/shale reservoirs,
  - (d) investigate production strategies, and identify the promising ones and quantitatively evaluate their expected performance.

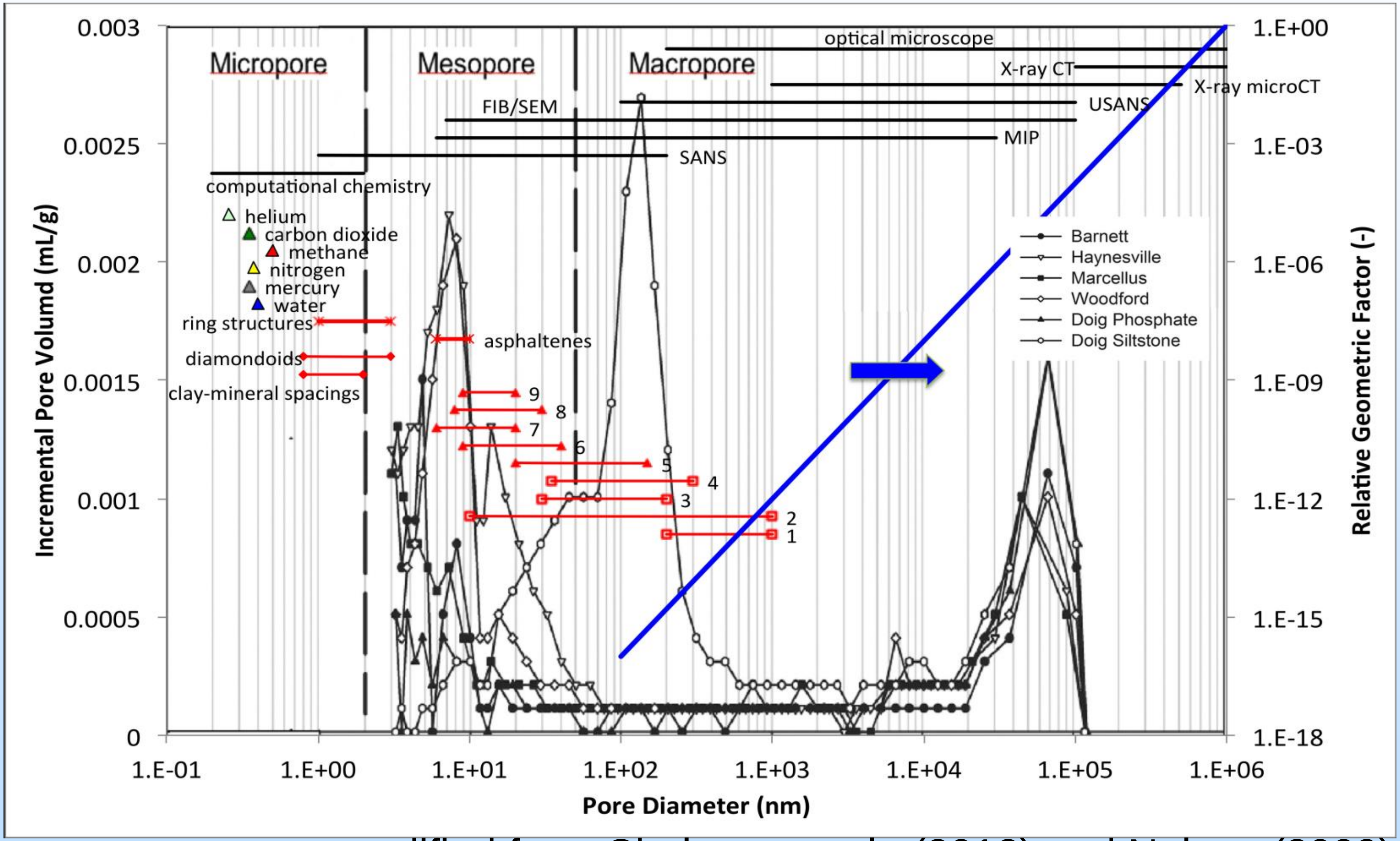
- Success criteria:
  - Develop methods to examine processes and compare production methods
  - Identify and compare a number of possible light tight oil production methods

Technical Status

Objectives

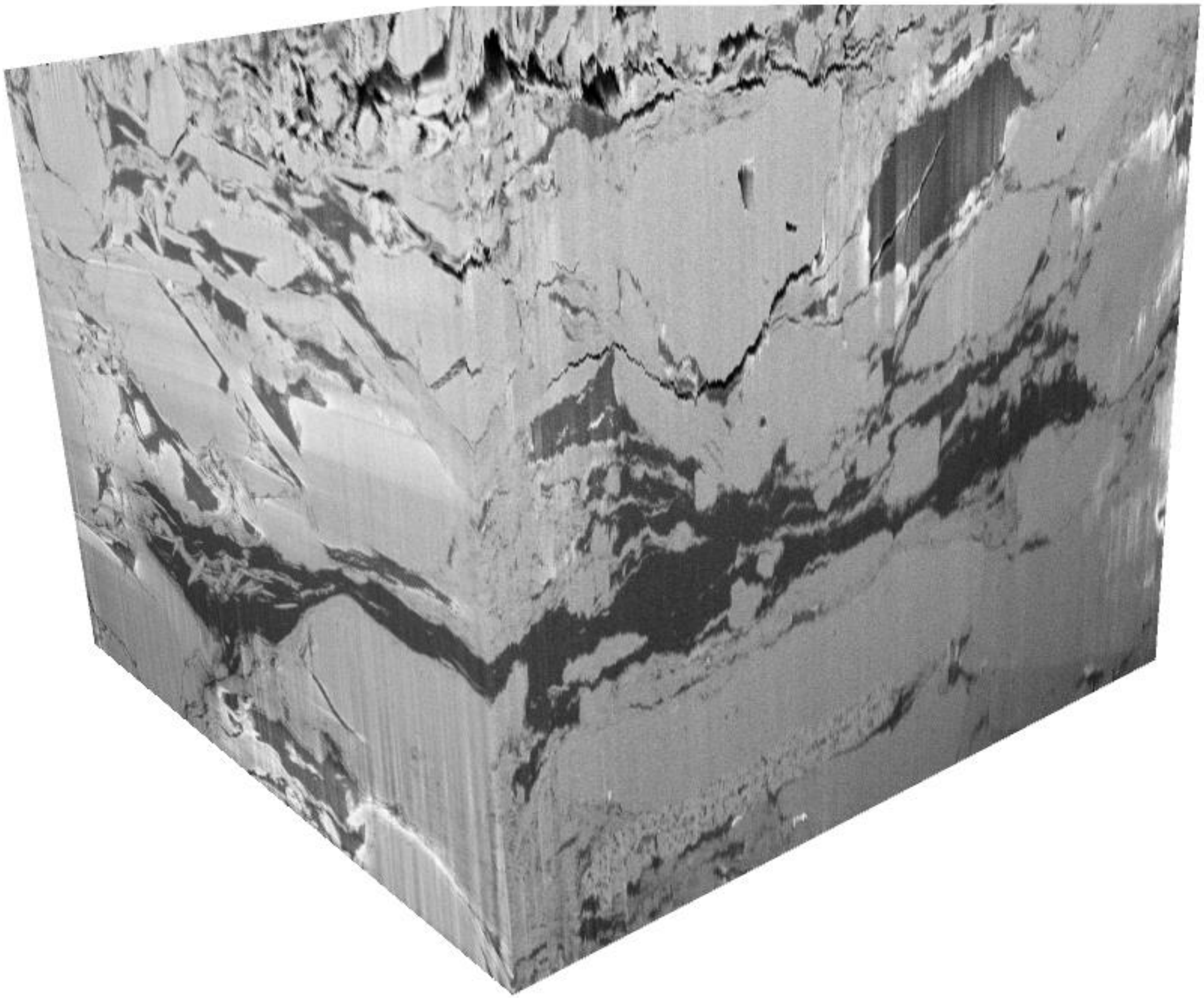
- Nano scale investigations
  - Begin to understand the nature of the porespace, its connectivity, pore structure, mineralogy, mechanical structure

Pores and Scales



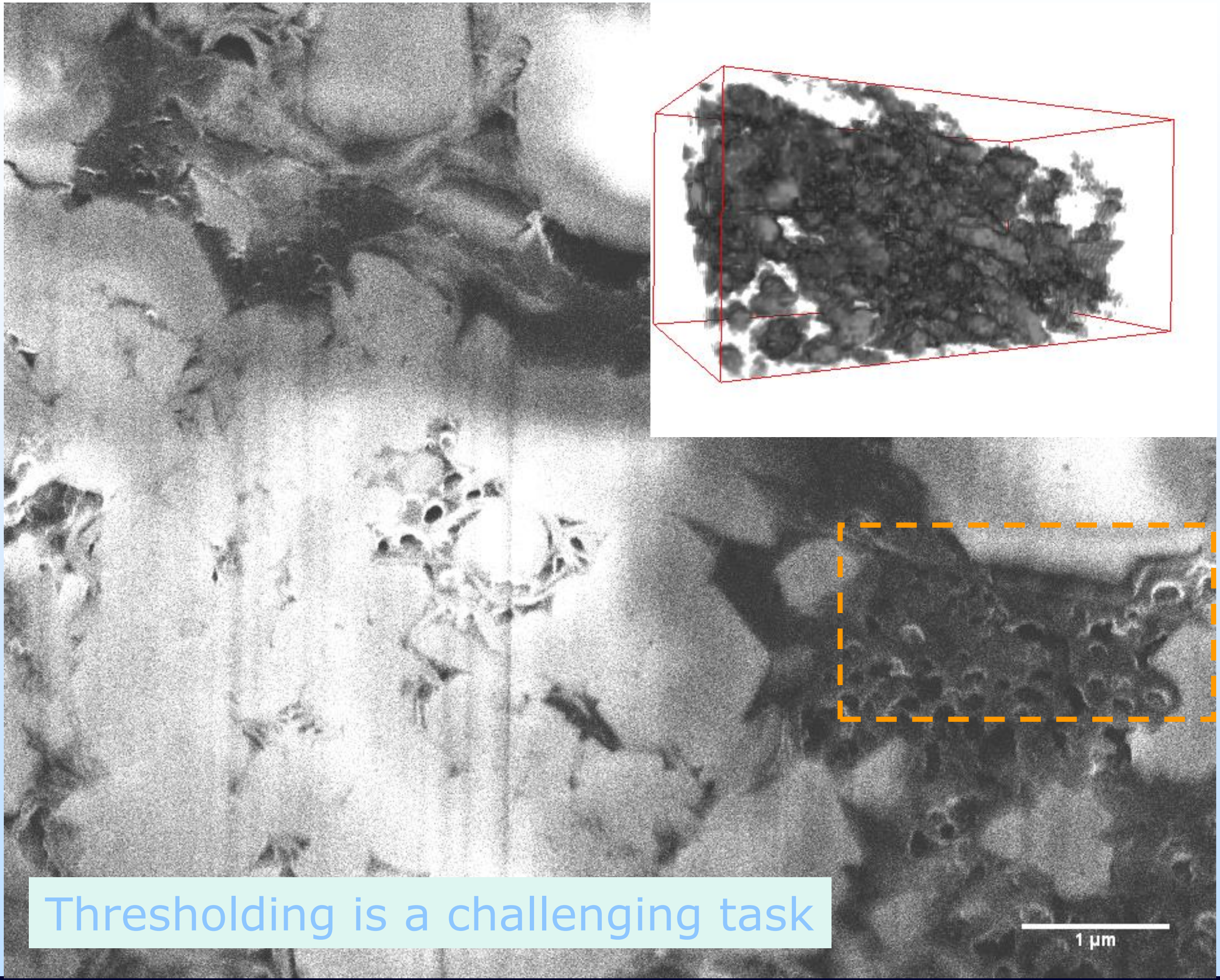
modified from Chalmers et al., (2012) and Nelson (2009)

3D reconstruction
15 × 11 × 14 micron^3

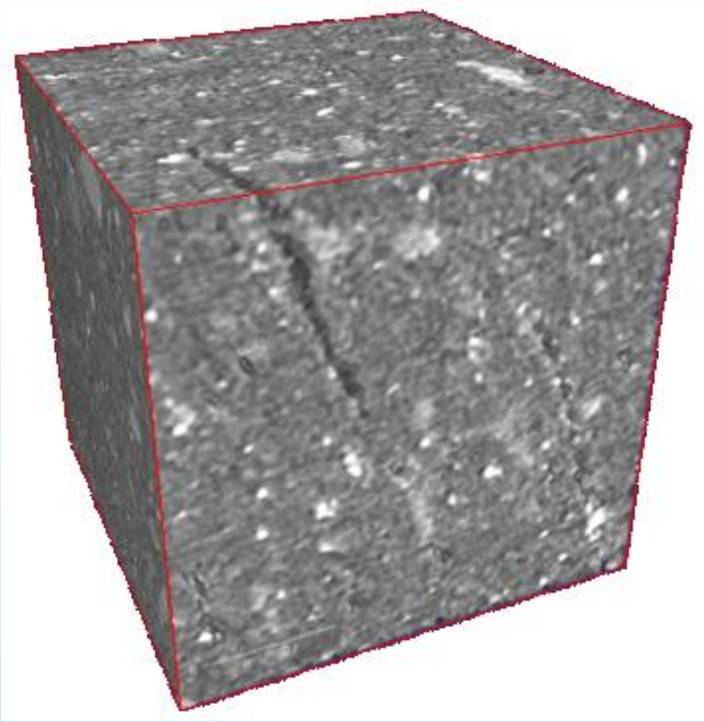


- Connected network of pores filled with kerogen
- Approximately 18% of the bulk volume
- Rich variety in a small volume

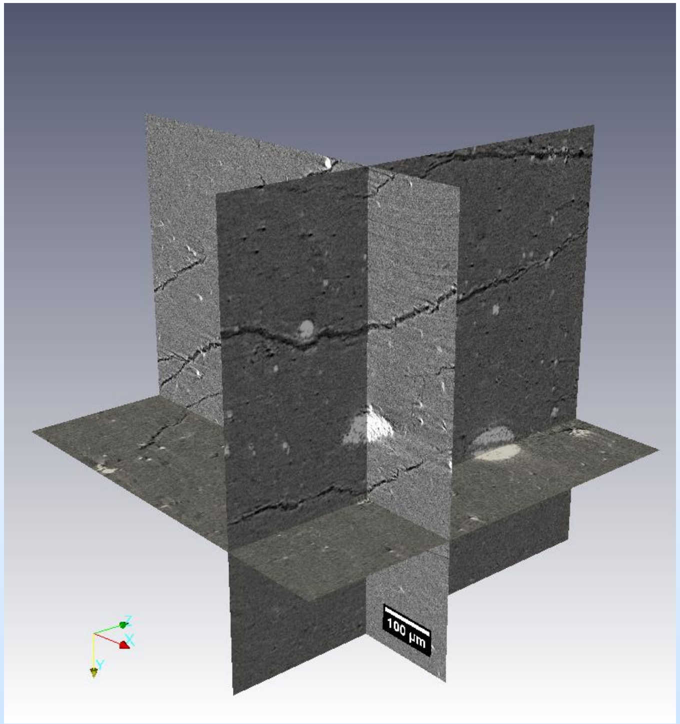
Pores in matrix and kerogen



MicroCT



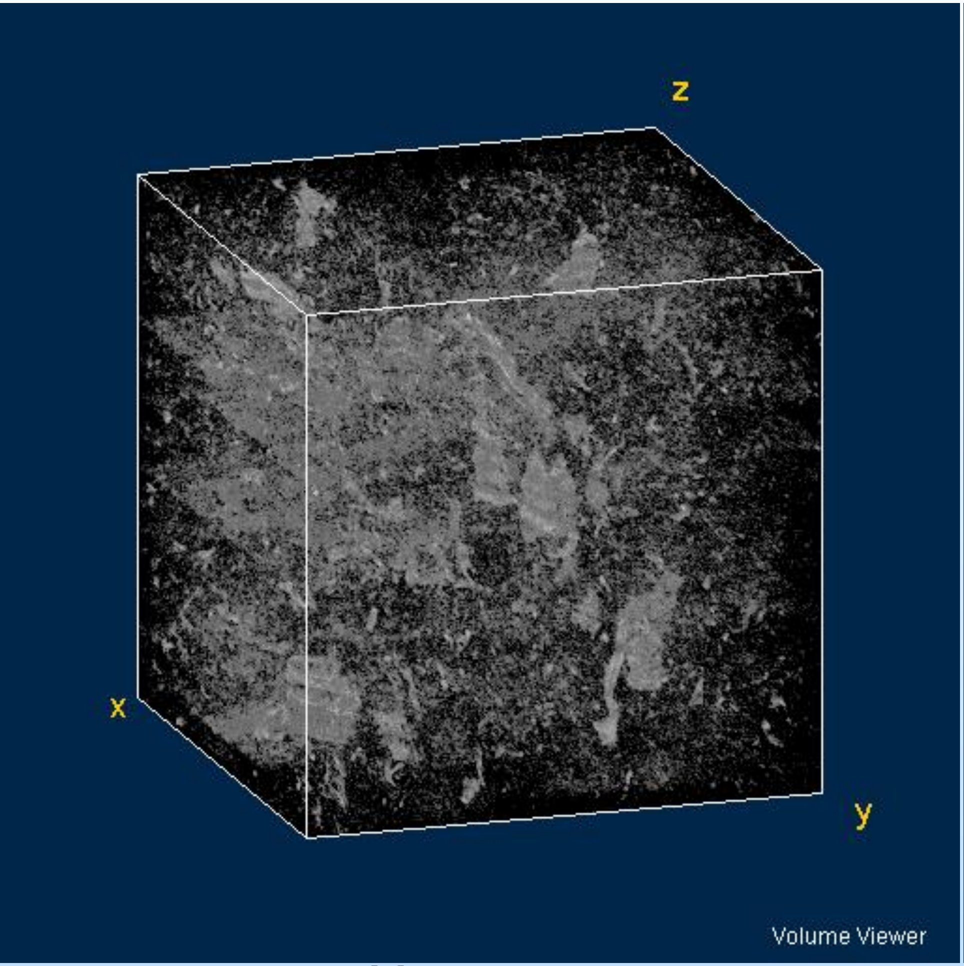
Stack of images of Barnett shale showing 3-D structure.

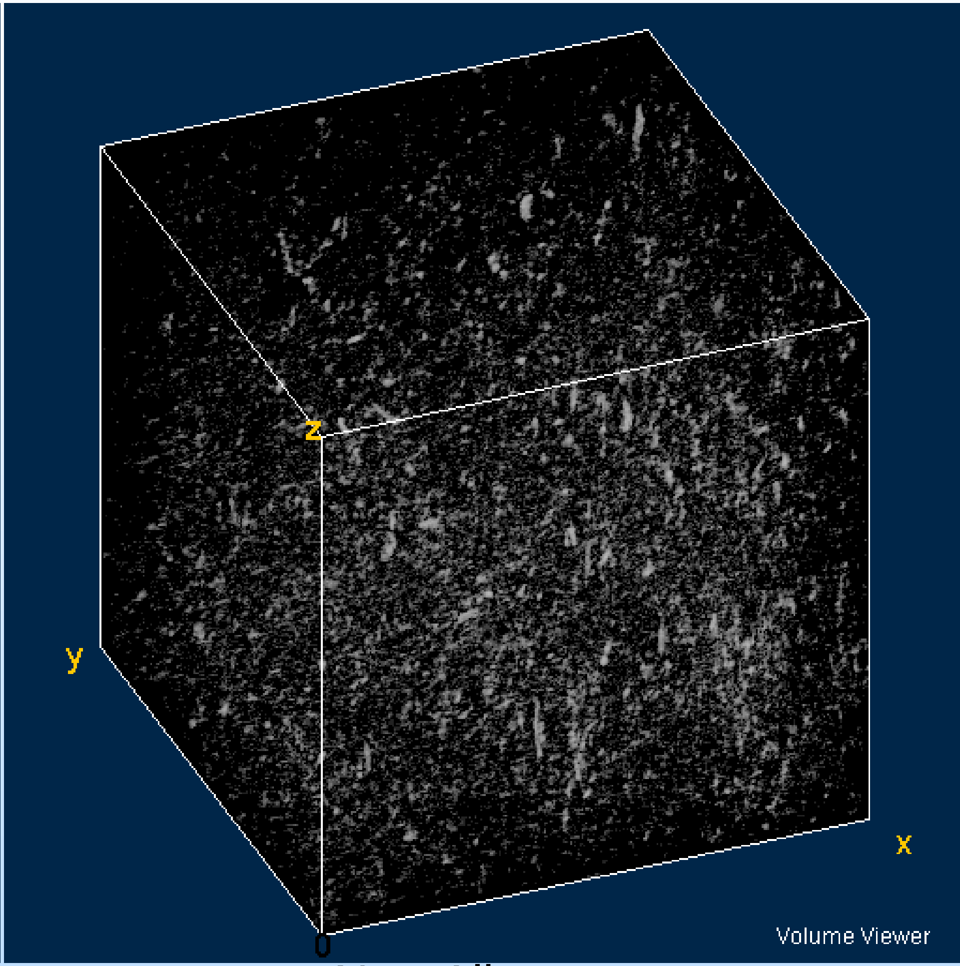


Stack of images of Marcellus shale showing 3-D structure and framboidal pyrite.

Micro-CT useful for identifying microfractures and anisotropy at the sub mm to micron+ scale

Example – Cracks and pores in Mancos and New Albany shale (~1mm scale)





Mancos

New Albany

Objectives

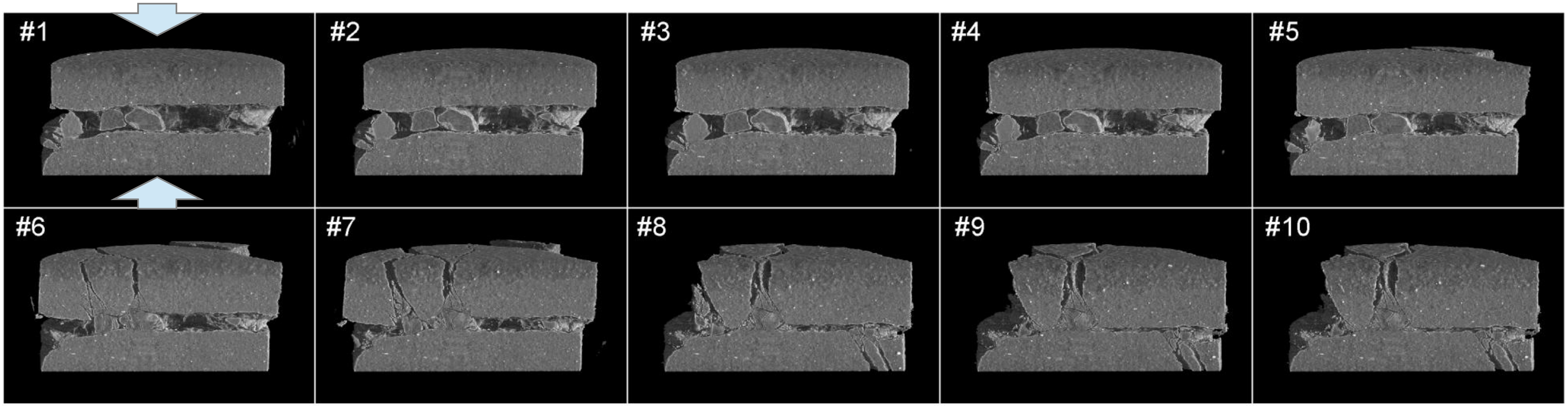
- Micro-scale Investigations
  - Proppant and fracturing
  - Effects of dissolved/free phase CO_2

EARTH & ENVIRONMENTAL SCIENCES

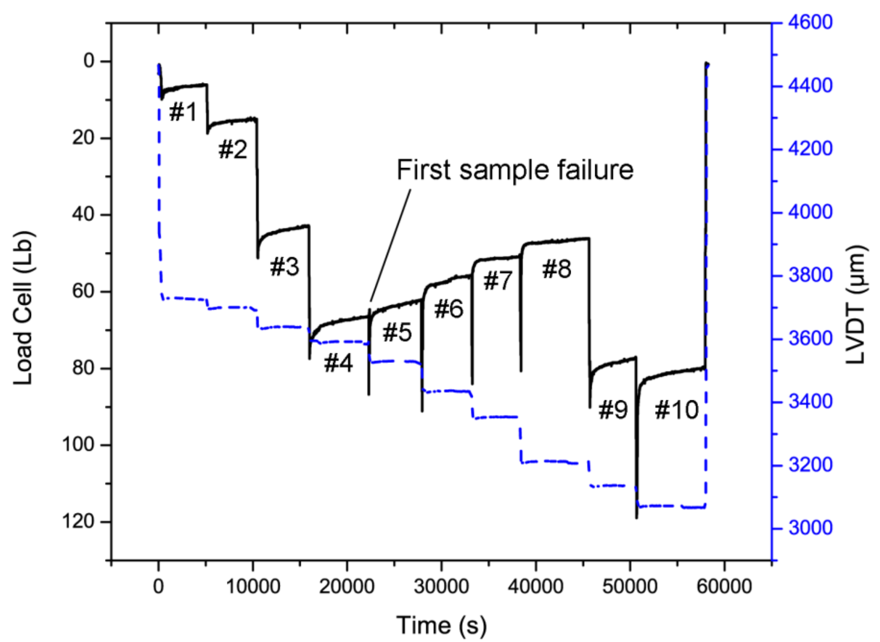
Closing a fracture: shale with proppant

BERKELEY LAB

3D rendering of the Mancos Shale sample (vertical cut) showing the evolution during uniaxial compression



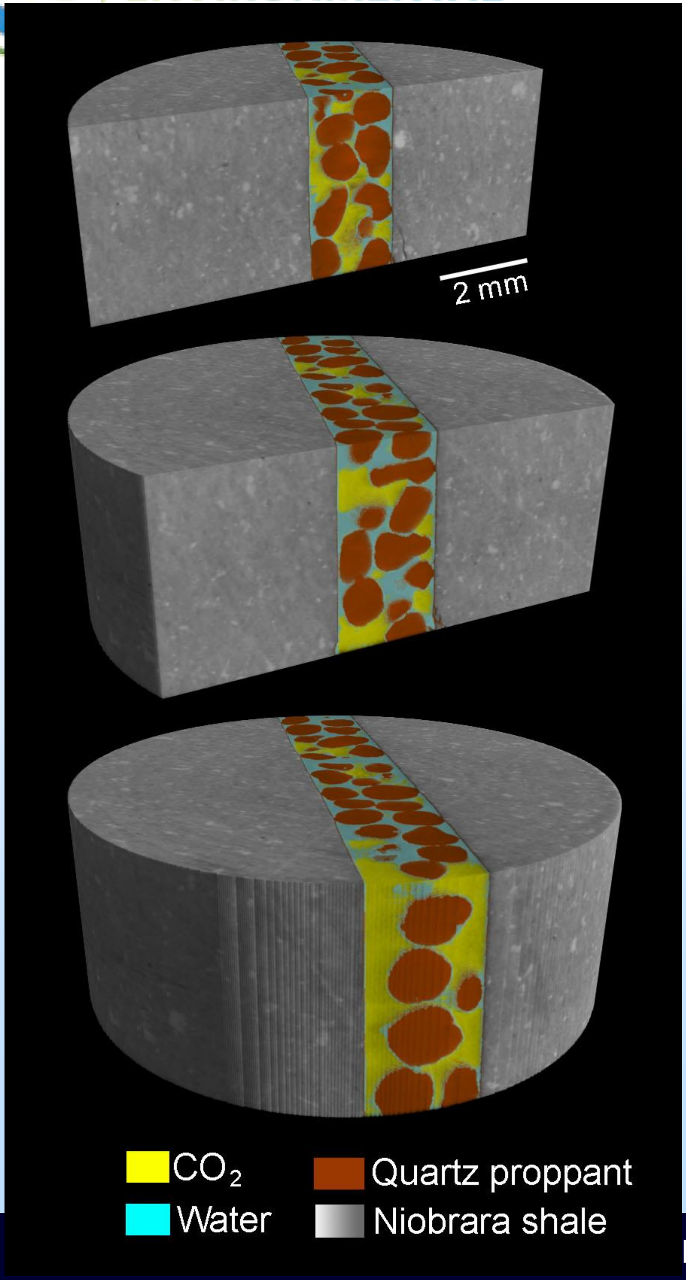
Load and verical stage displacement plots



Mancos Shale sample is fractured along the bedding direction (horizontal), filled with proppant (quartz sand + guar gel) under uniaxial compression (unconfined) to monitor the development of cracks.

Designing better hydraulic fracturing protocols

Sweeping a propped fracture with liquid CO_2

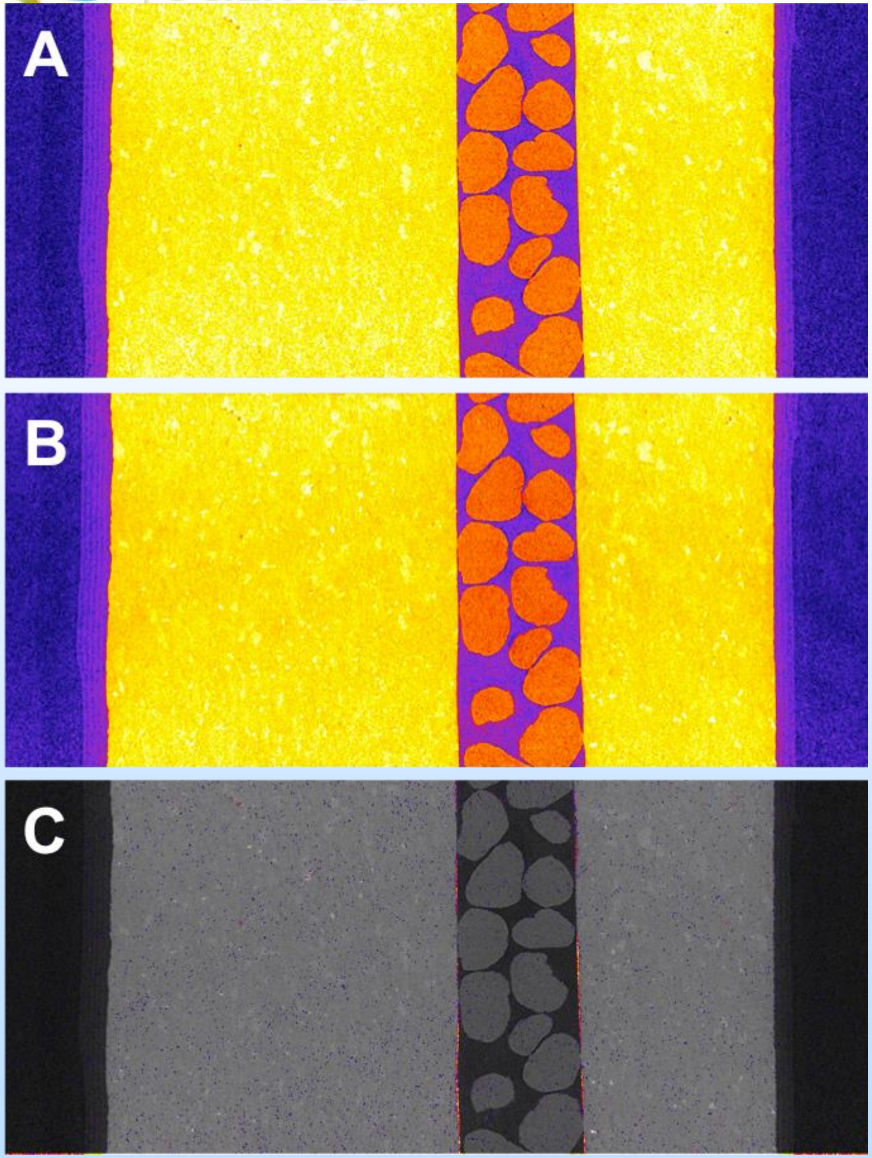


The sample was cut in half and filled with proppant (quartz sand).

Flowing with liquid CO_2 , 1100 psi pore pressure, and 1300 psi confining pressure. 36 ml of CO_2 were injected at 100 µl/min for 3.25 hours and 25 µl/min for 11 hours.

Niobrara shale matrix is shown in grey while the quartz sand proppant is shown in brown. The CO_2 and water phases are shown in yellow and blue respectively.

Effect of sweeping a propped fracture with liquid CO_2



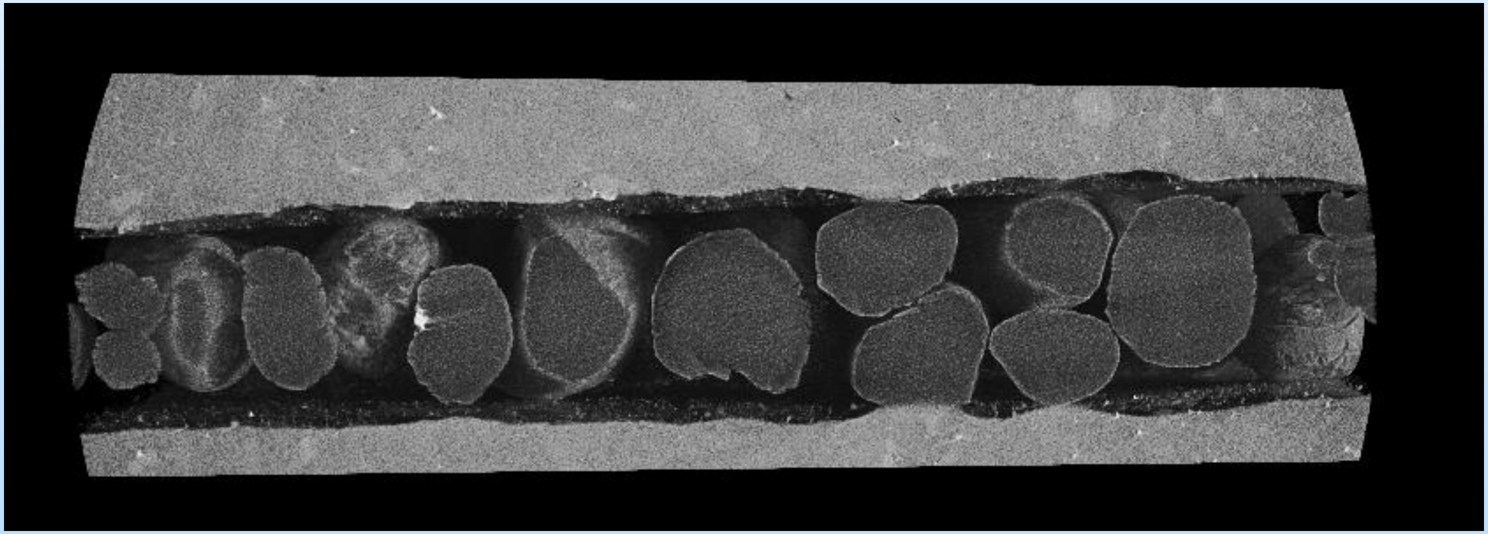
- Effect of the CO2 strongly limited by the trapped water.
- The trapped water and the two-phase flow also limit the transport of ionic species, thus *inhibiting the dissolution of the carbonates on the fracture surface*.
- Very limited modifications of the fracture surface. The proppant is effectively keeping the fracture open.

A – before
B - after liquid CO_2 injection.
C - shows modification (only 2-3 voxels).

Effect of sweeping a propped fracture with CO_2-saturated water

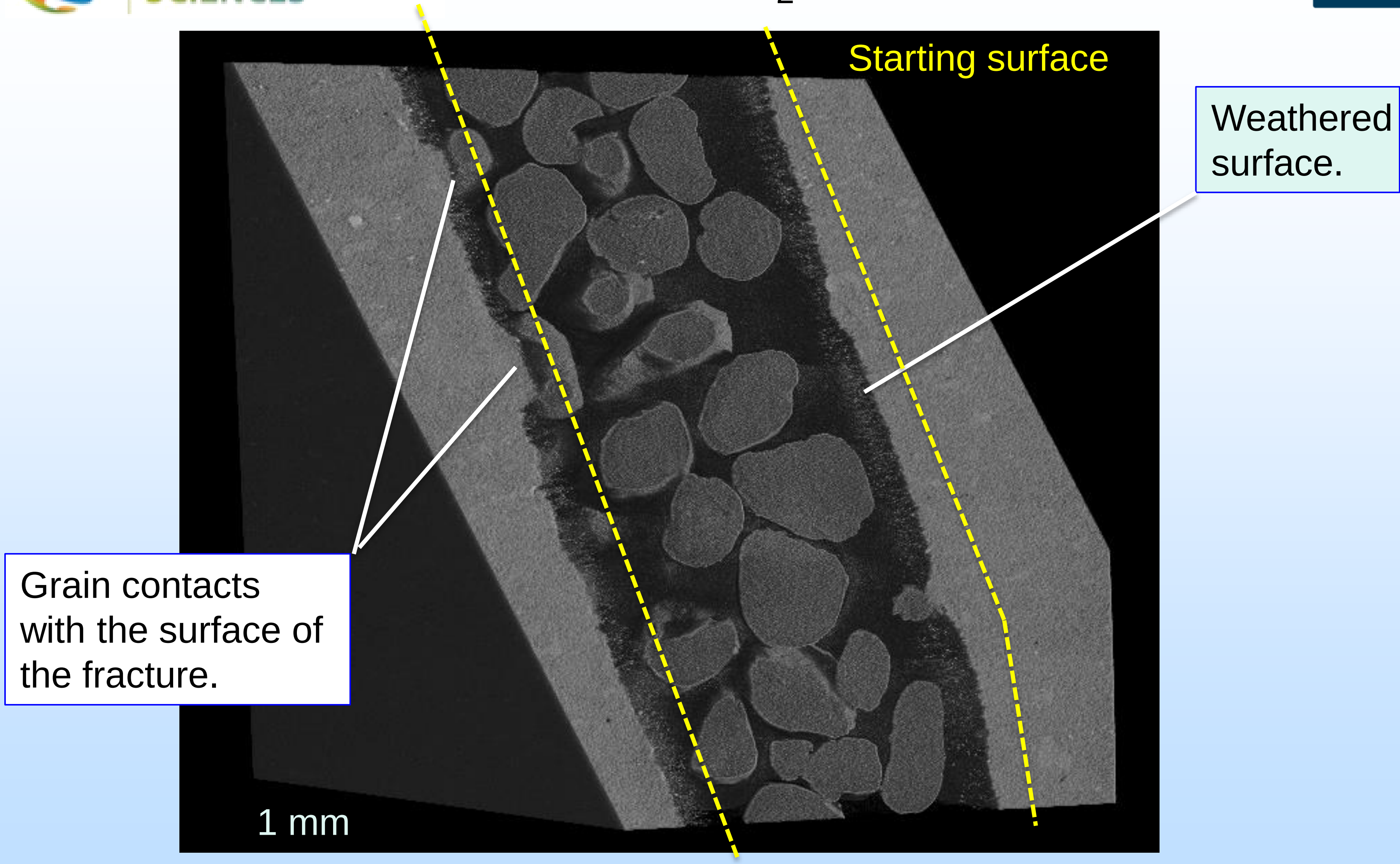
CO_2-saturated water will dissolve the carbonates and develop a weathered zone (as seen before), ***will the proppant embed in the mechanically weakened surface, therefore limiting its effect?***

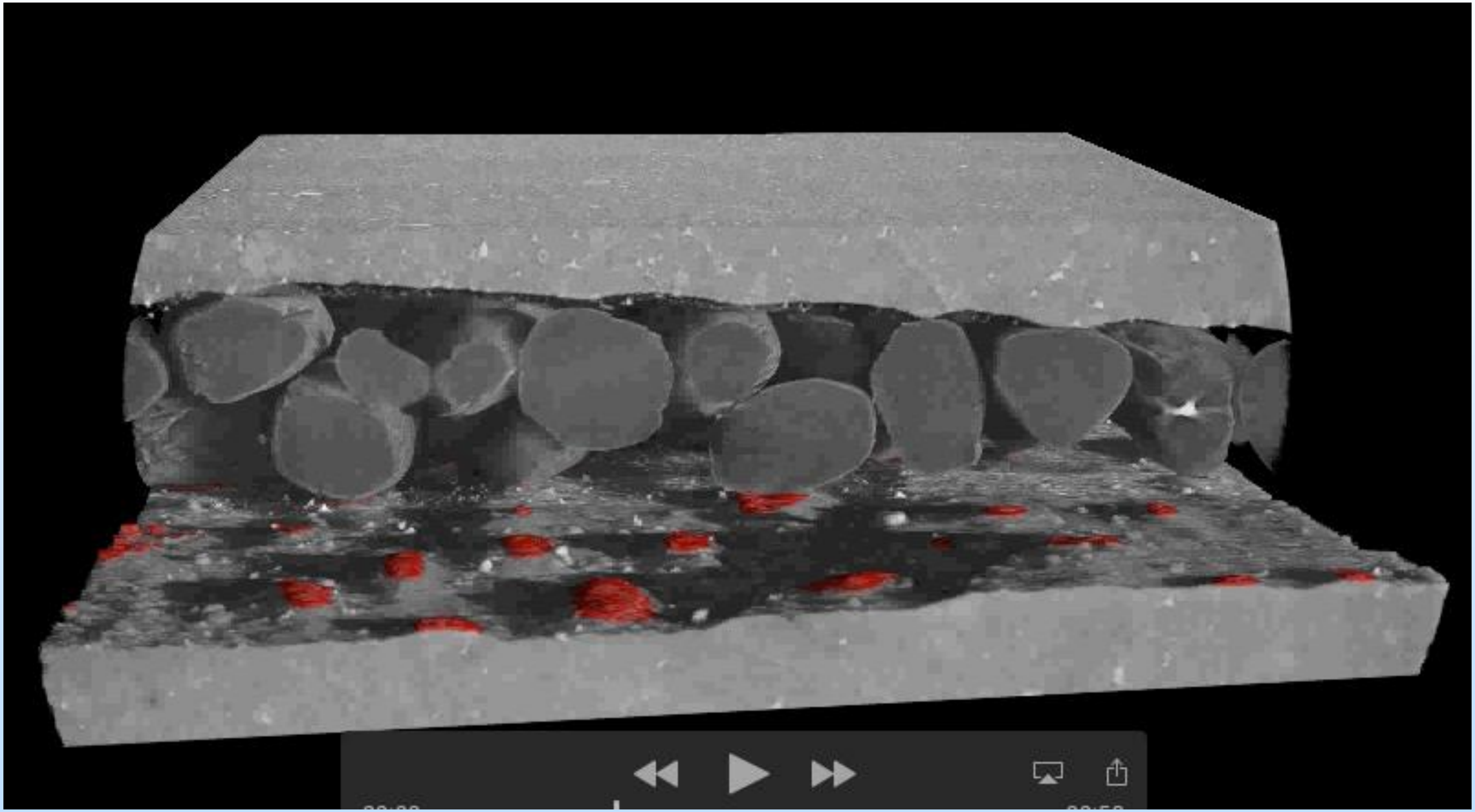
1100 psi pore pressure, 1300 psi confining pressure, 35 ml of CO_2 saturated water flowed at 25 µl/min (fast flow to induce homogeneous dissolution).
Synchrotron X-ray microCt performed after the flow.



Volume rendering of a cutout of the fracture in the sample.

Effect of sweeping a propped fracture with CO_2-saturated water



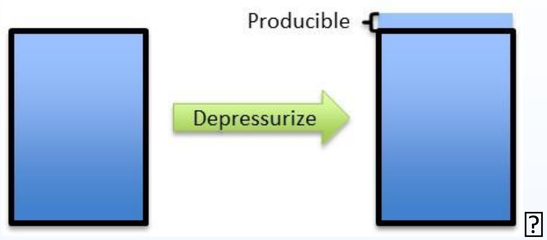


Objectives

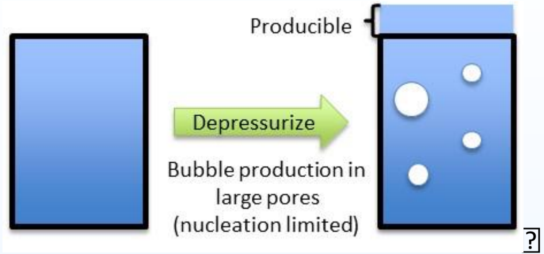
- Core scale investigations
  - Investigate and quantify differences in possible light tight oil (LTO) production techniques suggested by conceptual and numerical investigation
  - Provide feedback to simulations

Techniques to Examine

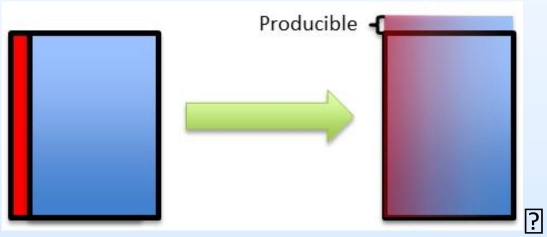
- Depressurization (Baseline)
- Depressurization with gas expansion
- Fluid dissolution into oil and production
- Water-flood
- Surfactant flood
- Imbibition/Osmotic displacement



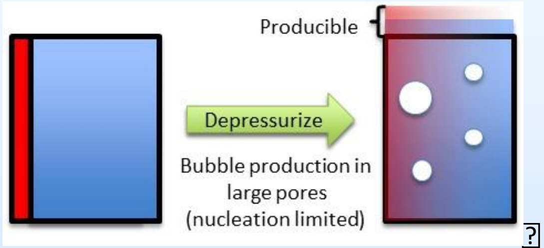
Depressurization



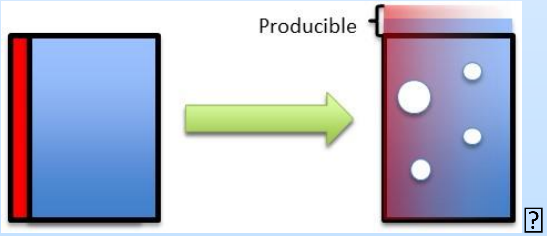
Depressurization with gas



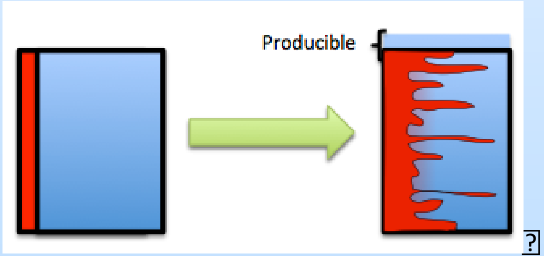
Fluid dissolution into oil



Dissolution with depressurization



Surfactant

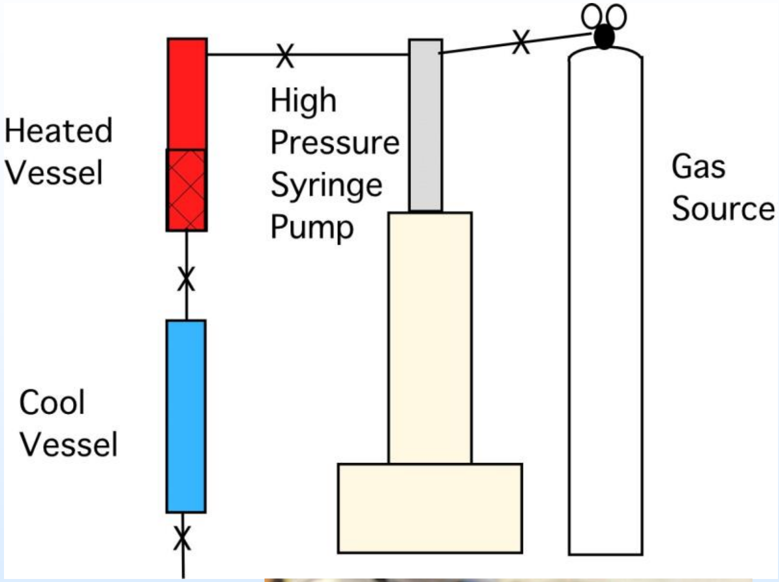


Imbibition/Osmotic

Combinations

Oil extraction from natural sample

- $scCO_2$ extraction from Niobrara shale sample - Warm supercritical CO_2 was applied for a week, and then slowly drained into the cool vessel. The vessel was depressurized through water. After venting, the vessel mass was slightly greater and the water developed a “clean” oil sheen.
- Only semiquantifiable (exact oil composition of shale will vary by location.
- Very small mass of oil extracted (> the error) but pressure vessels are heavy and the error is related to the total mass
- **Not** an ideal test method



Experiment Considerations

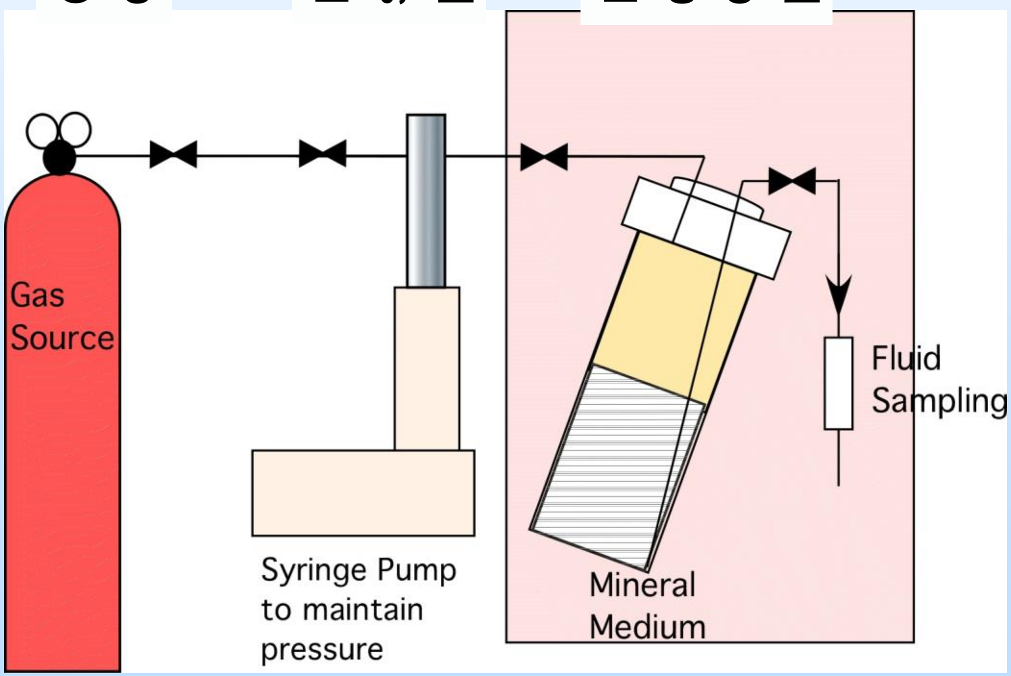
Condition	Real System	Preferred Experimental System
Oil mass vs. error	Low producible oil/volume – hard to quantify	Optimize oil mass/volume
Oil type	Multicomponent, aged (for samples)	Dodecane (low vapor pressure, known properties)
Porespace	Poorly understood (particularly connectivity)	High ϕ well studied ceramics
Wettability	Poorly understood (heterogeneous wetting)	Water-wetting surfaces (can control)
Starting conditions	Unknown, difficult to establish/quantify	Allows specified starting conditions
Duration	Long-term	Test duration ~ weeks

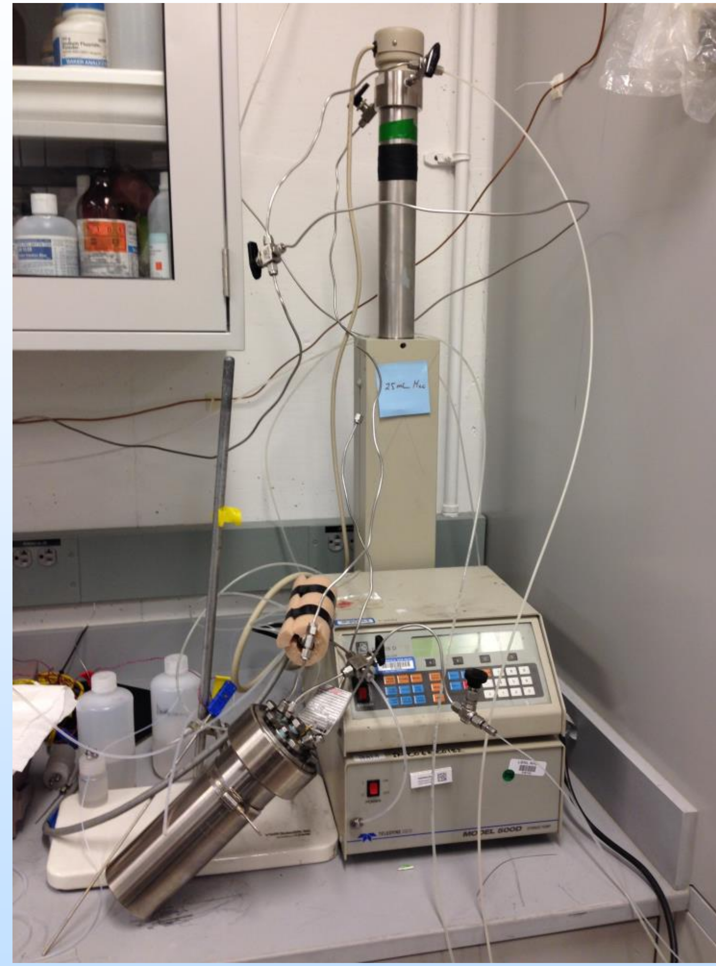
System for Process Evaluation

Gas or fluid of choice

High-pressure syringe pump for pressure control

Porous ceramic disks in layers inside commercial pressure vessel

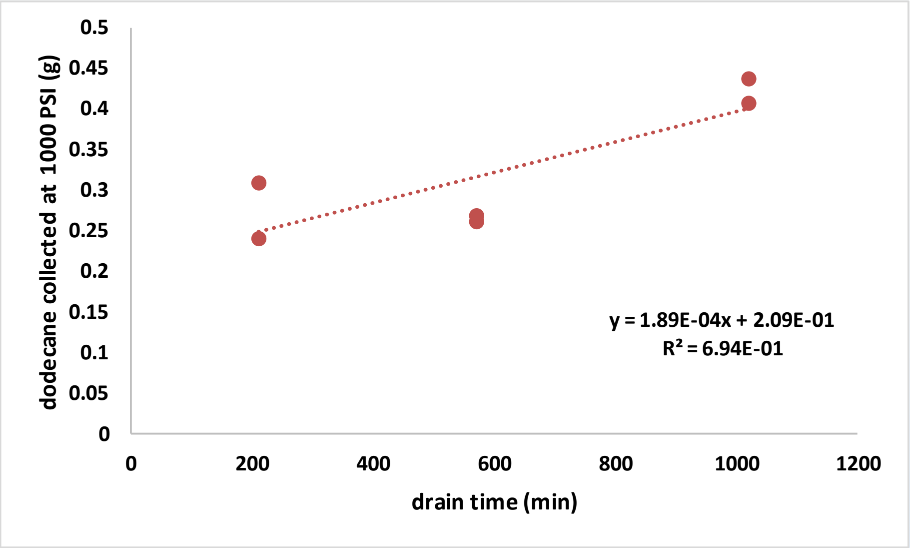




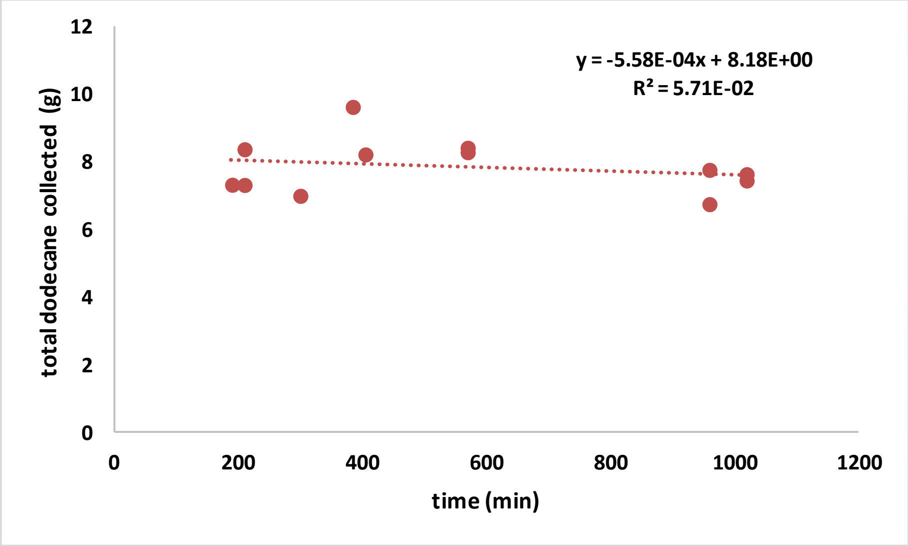
Measurement System and Process

Use mineral medium (water-wetting porous ceramic disks)

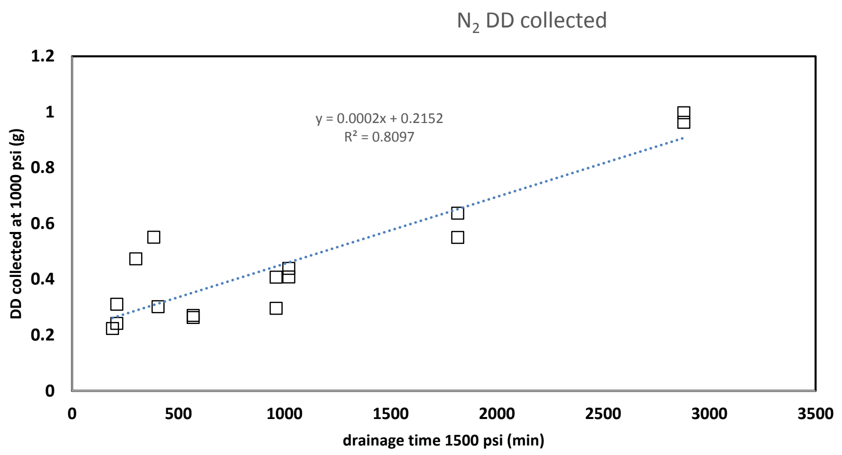
- Precondition with water vapor
- Vacuum/pressure-saturate with oil (1500 psi)
- Drain oil from system under pressure until no more oil is produced. (N_2, CH_4, He, used so far – CO_2, H_2O, mixed processes next)
- Change the test variable (depressurize, dissolution, soak time, fluid type...)
- Drain under pressure and collect/quantify the produced oil.
- Alter variables and repeat drainage.



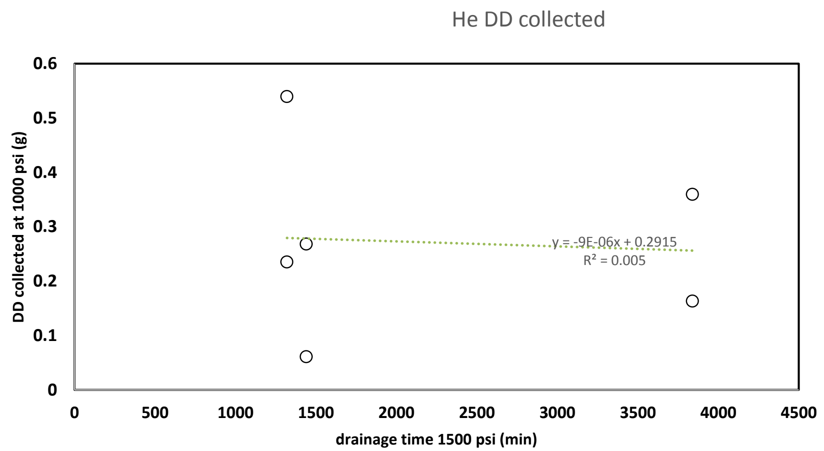
Oil produced in the first depressurization (1500 psi to 1000 psi) versus the initial drainage (nitrogen-dodecane contact) time.



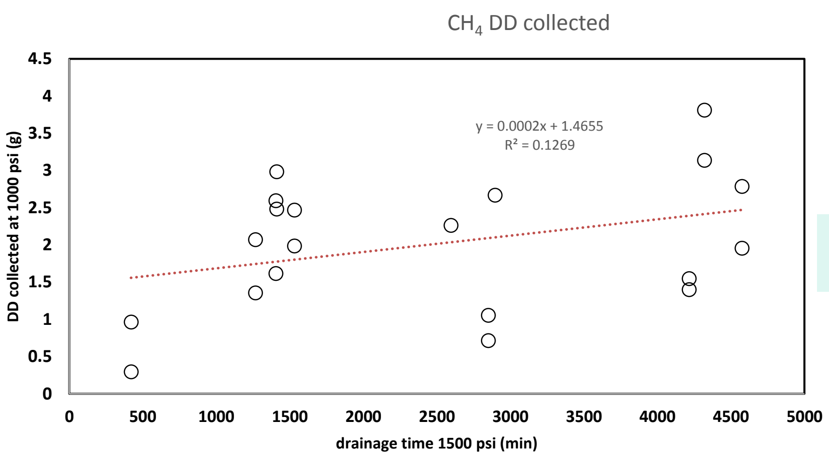
Total oil produced over all depressurizations (1500 psi to 0 psi) versus the initial drainage time.



Nitrogen

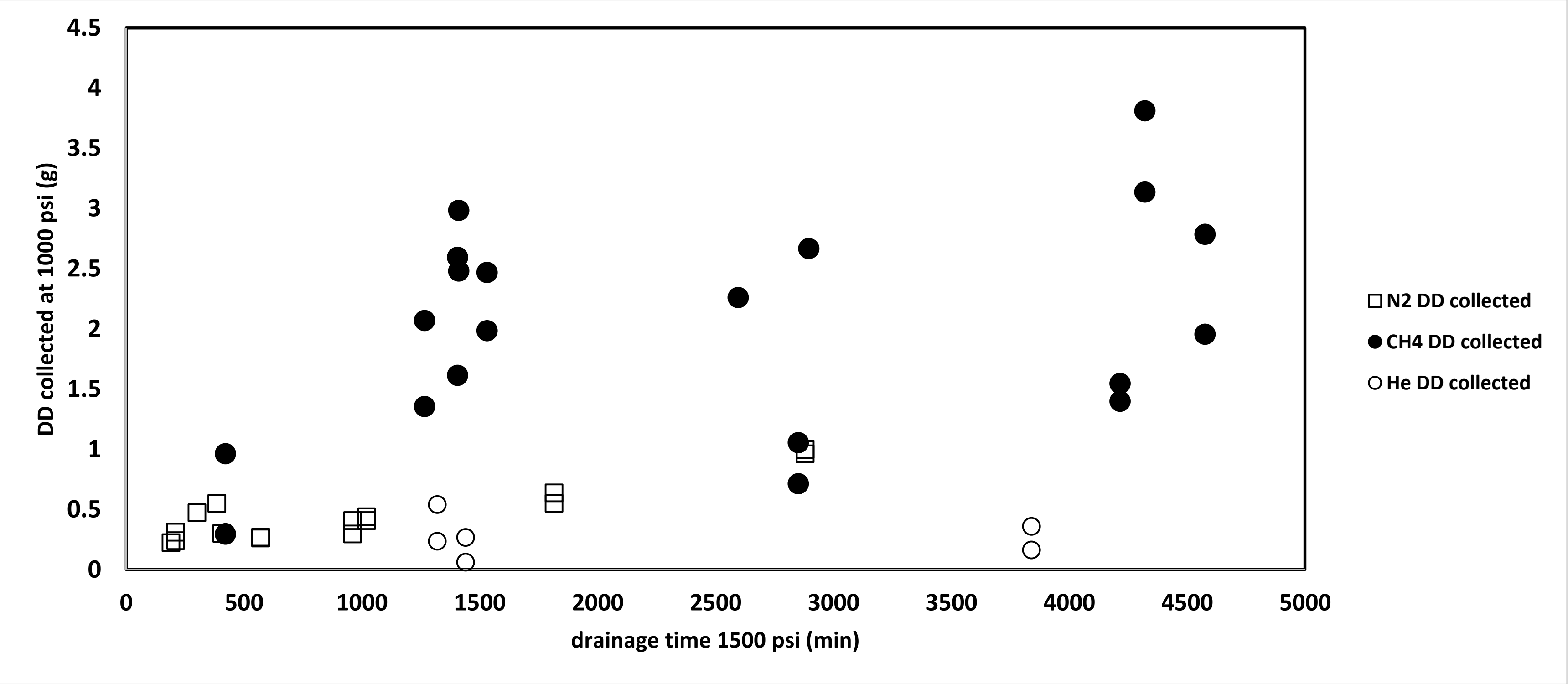


Helium



Methane

Effect of gas type

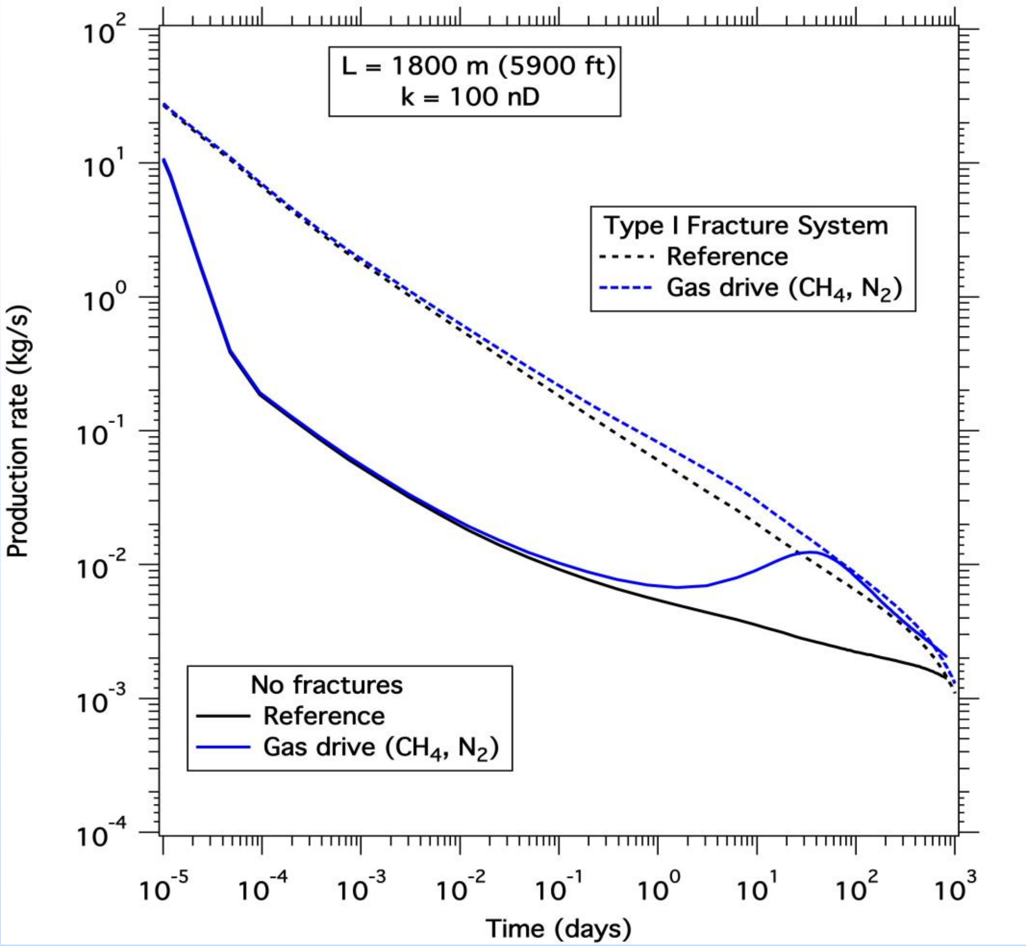


SHALE OIL PRODUCTION

REFERENCE CASE

Displacement process: gas drive

No discernible difference between N_2 and CH_4 (latter not affecting the oil properties); re-evaluating basic equations



Need for supporting lab studies – inadequate physics

Accomplishments to Date

- Developed tool and observed proppant crushing at microscale
- Examined effects of dissolved and supercritical CO_2 at microscale
- Built 2 process evaluation experimental setups and performed 44 tests to evaluate gas dissolution/depressurization
- Research currently on hold

Next Steps

- $scCO_2$ $dissolution_L$/displacement
- Water displacement (imbibition into water-wet media)
- Osmotic displacement (imbibition driven by water activity differences)
- Anisotropic/heterogeneous wetting media
- Sensible technique combinations (examine and avoid permeability jails)
- MicroCT observations of important processes

Synergy Opportunities

- Clear synergies are apparent in approaches, measurements, and analysis of data among similar project themes. Comparisons of results obtained using the various approaches builds confidence in the results and the program.

Summary

- Key Findings
  - system designed for process evaluation
  - methane>nitrogen>helium in producing LTO
  - processes related to proppant crushing observed
  - shale wall dissolution observed in propped system
- Lessons Learned
  - system optimization
- Future Plans
  - continue examining and quantifying processes and their effects to enhance LTO production.

Appendix

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

Organization Chart

George Moridis, PI

Laboratory Studies

Tim Kneafsey, Sharon Borglin, Jonathan Ajo Franklin, Marco Voltolini

Reservoir Modeling

George Moridis, Matt Reagan

Fundamental Molecular Studies

Glenn Waychunas

Gantt Chart

Budget Period	#1			#2		
Quarter	Q1	Q2	Q3	Q4	Q5	Q6
Task 1: Project Management and Planning	X					
Task 2: Definition of metrics and methodology for screening production strategies	X					
Task 3: Evaluation of enhanced liquids recovery using displacement processes			X			
Task 4: Evaluation of enhanced liquids recovery by means of viscosity reduction			X			
Task 5: Multi-scale laboratory studies of system interactions						X
Task 6: Molecular simulation analysis of system interactions					X	
Task 7: Evaluation of enhanced liquids recovery by means of increased reservoir stimulation, well design and well operation scheduling						X
Task 8: Evaluation of combination methods and of new strategies						X

Bibliography