Numerical and Laboratory Investigations for Maximization of Production from Tight/Shale Oil Reservoirs

FP00008115

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Presentation Outline

Continue to work at multiple scales to quantify production-enhancing processes using parallel lab, imaging, and simulation capabilities

Area 1: Proppant Transport

- **Simulation** of fracturing and proppant transport
  - Investigate novel numerical and **other** methods
  - Incorporate proppant transport (and coupled geomechanics) into TOUGH+MCP
- **Laboratory studies** of proppant transport in fractures (and corners)
- **Expanded XRμCT visualization** of fractures and proppants
  - Understand role of **proppant shape** (reorganization)
  - Understand **creep/embedment** at higher temperatures
  - Micro-mechanical measurement of **matrix strength**
- **Coordination between simulations, lab-scale tests, and micro-scale visualization** (**validation and ground-truthing)**

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Area 2: Production Enhancement

- **Simulation studies** of production enhancement (reservoir scale):
  - Expand and use TOUGH+MCP: shale oil/gas all-purpose simulator
  - Gas injection (multiple species), thermal enhancement…
  - Effect of oil gravity vs. injection fluids
  - Ongoing compendium of **best and worst production strategies**
  - Effect of proppants → geomechanical coupling

- **Laboratory studies** of production enhancement:
  - Examine **anisotropic/heterogeneous** wetting media
  - Osmotic displacement (saline formations)
  - Technique combinations (pathwise) to avoid permeability jails
  - Targeted toward **verifying simulations**

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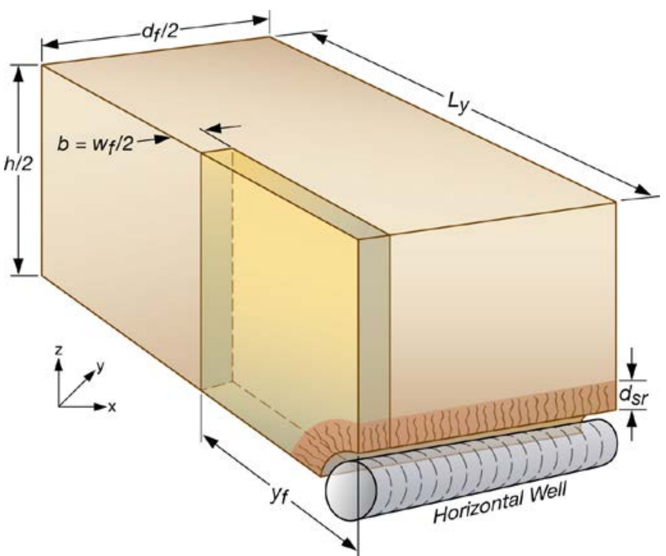
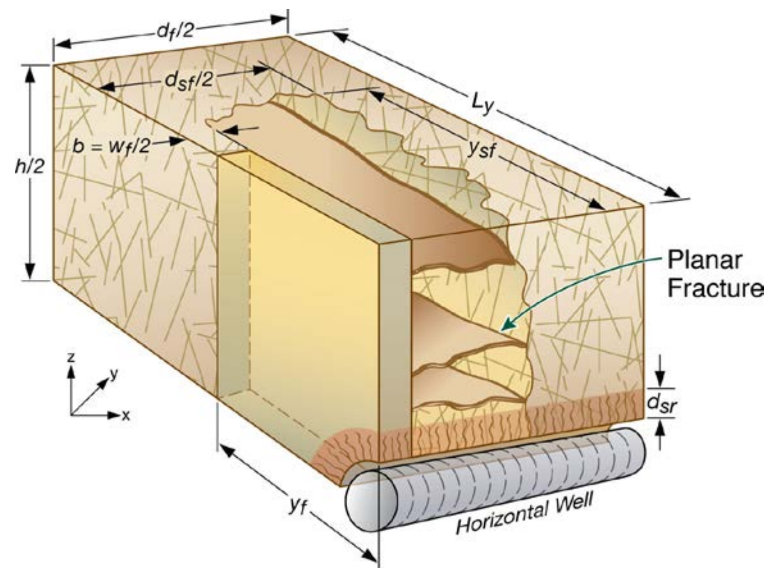
Reservoir Simulation Studies

TOUGH+OilGasBrine (formerly T+MCP) Code

- Conventional and tight/shale oil/gas, enhanced oil recovery, **fully compositional simulator, fully non-isothermal,** oil, H_2O, salt(s), up to 11 gas components ($C_{1\text{-}3}$, CO_2, N_2, H_2, etc.)
- **Enhanced oil physical properties relationships (viscosity, etc.)**
- Massively **parallel capabilities** (features merged with pTOUGH+)
- **Larger and larger simulation scope, more complex systems: 700,000 – 850,000+ elements and more (2 – 3 MM equations)**





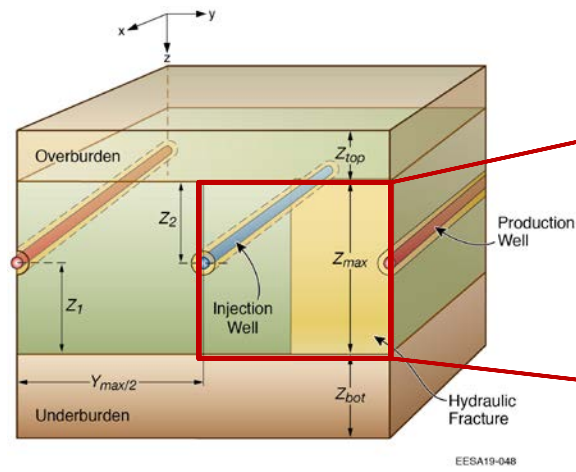
Reservoir Simulation Studies

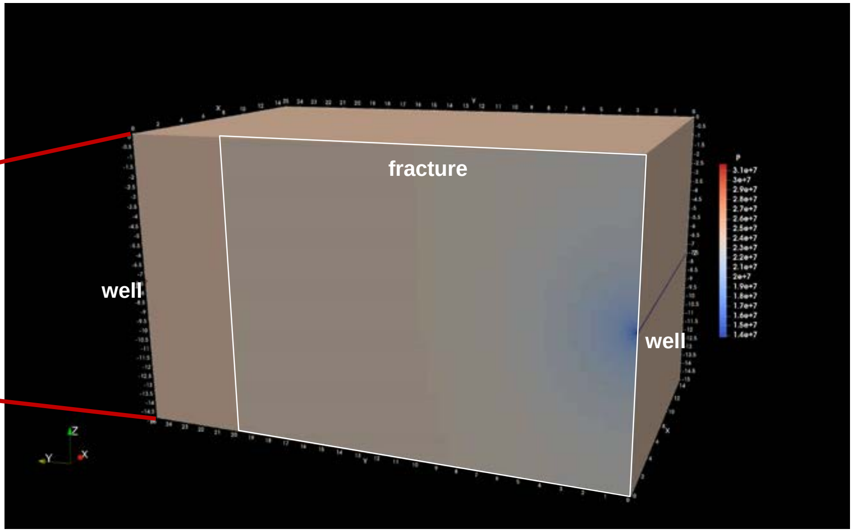
Shale oil system
2274 m (7460 ft)
1.1 μD - 5.5 μD
SRV Case

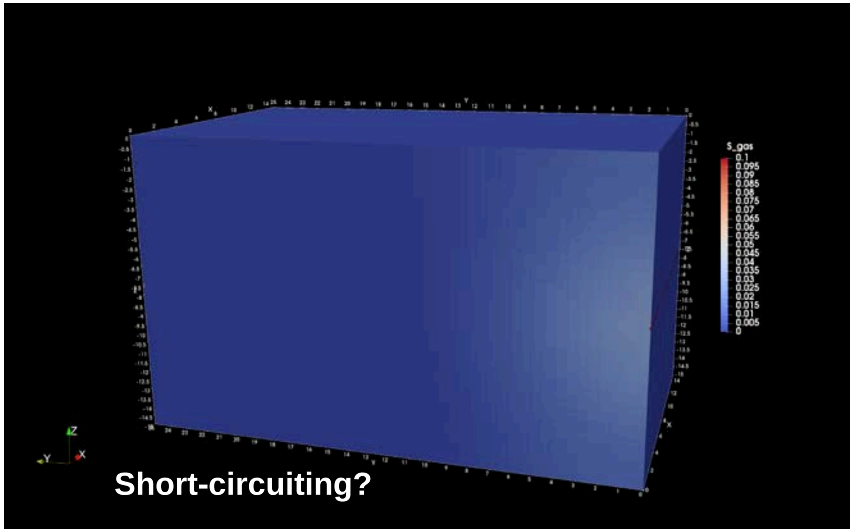
CH_4 Injection
(CO_2, N_2)

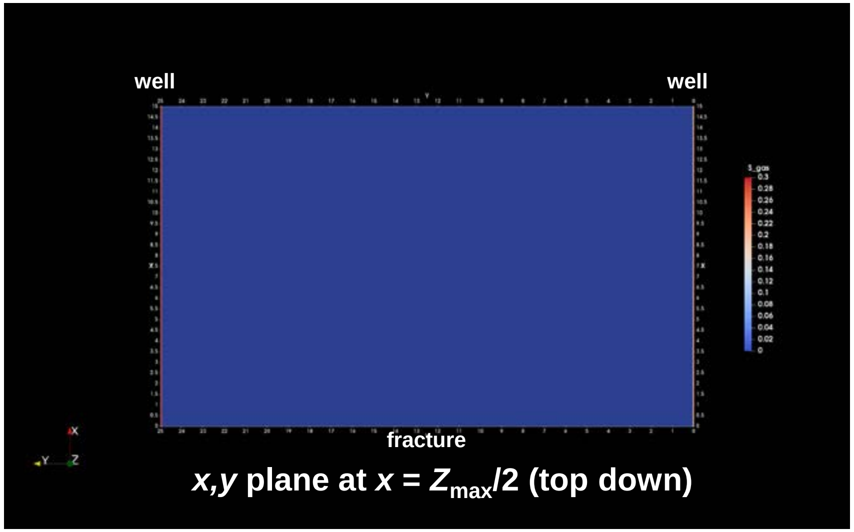
***P*, S_G evolution**

***t* = 3yrs**



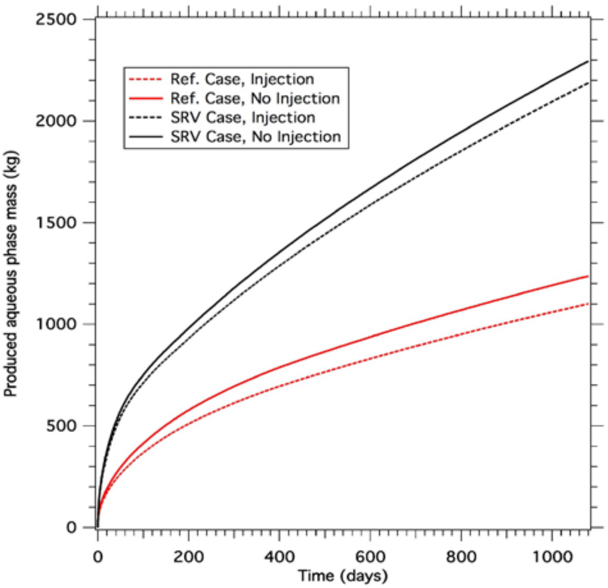






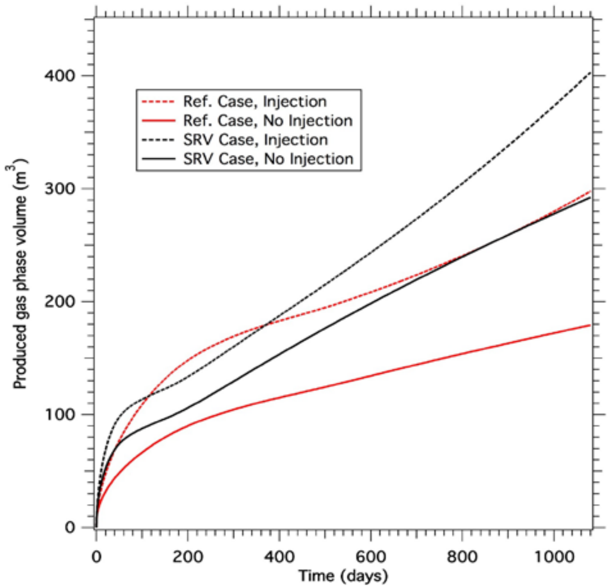
Reservoir Simulation Studies: Results

Water Production



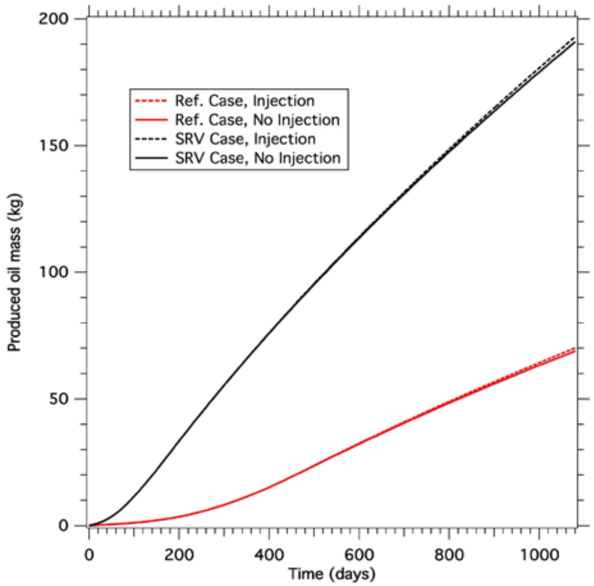
Effect of CH_4 injection:
- **Lower water production**
- Similar behavior for CO_2, N_2

Gas Production



Effect of CH_4 injection:
- **Higher gas production**
- Similar behavior for CO_2, N_2

Oil Production



Effect of CH_4 injection:
- **Practically no effect!**
- Similar behavior/results for CO_2, N_2

Unknown if this is a case-specific response or a general behavior, more research needed

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Reservoir Simulation Studies: Path Forward

- Performing **more complex** simulations
- **Coordinating with laboratory and visualization work**

- Two papers presented at the 2019 International Petroleum Technology Conference (Beijing):

Moridis, Reagan, Queiruga, "High-Definition Analysis and Evaluation of Gas Displacement EOR Processes in Fractured Shale Oil Formations," IPTC-19276

Moridis and Queiruga, "Interdependence of Flow and Geomechanical Processes During Short- and Long-Term Gas Displacement EOR Processes in Fractured Shale Oil Formations," IPTC-19421

- New abstract accepted for 2020 SPE Latin America and Caribbean Petroleum Engineering Conference (LACPEC):

Moridis, Reagan, Queiruga, "Evaluation Of The Effectiveness Of Continuous Gas Displacement For EOR In Hydraulically Fractured Shale Reservoirs," 19LACP-P-729-SPE.

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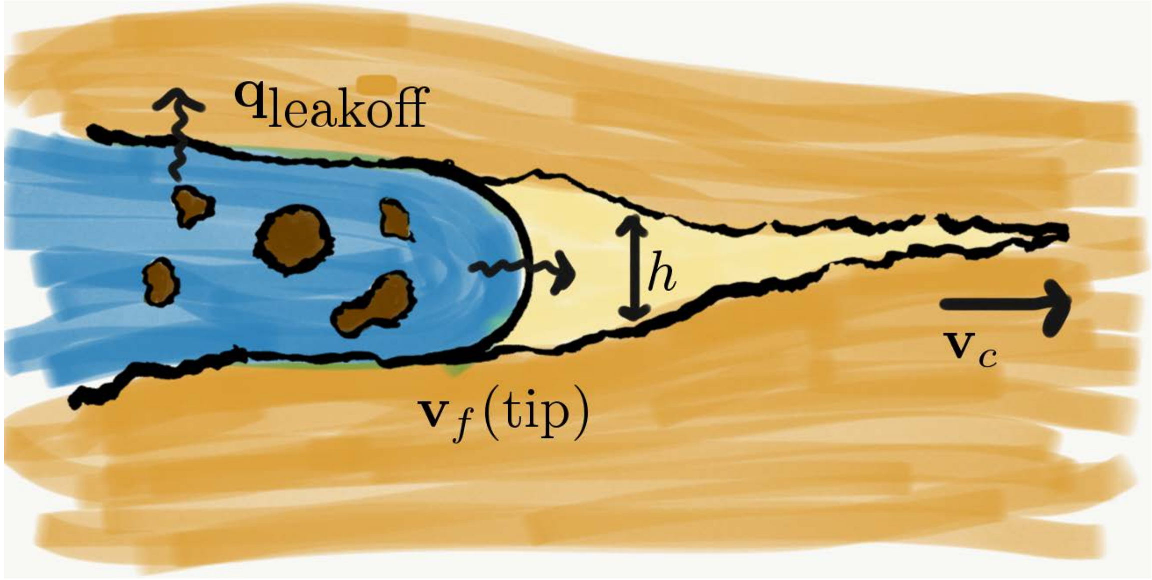
Proppant Transport Modeling

Goal: Develop predictive models for fracture and proppant transport at the reservoir scale

- Include proppant phase, fluid leak-off, fluid lag behind fracture tip, mechanical deformation, fracture propagation
- Couple to matrix flow and geomechanics models

Challenge: deriving theoretical or analytical relations is intractable



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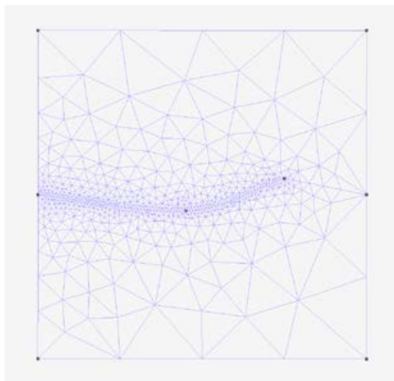
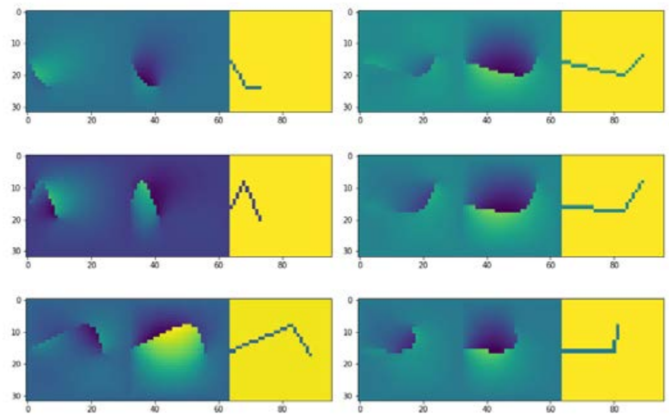
Proppant Transport: FractureDB

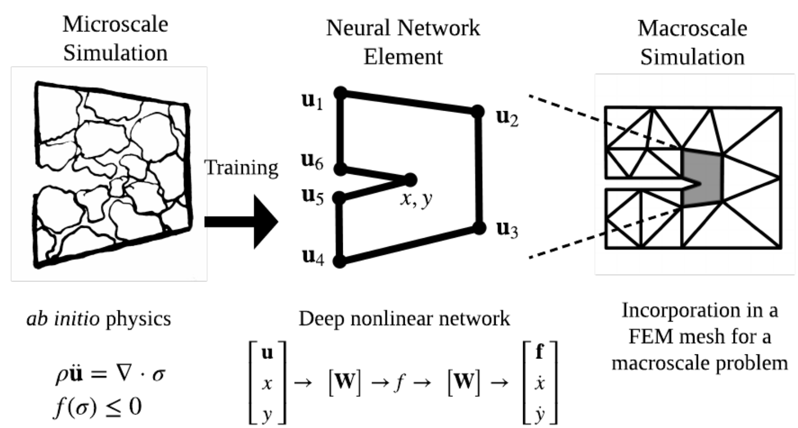
Test ML methods with synthetic dataset of randomly generated fractures

- Scripted FEM simulations generate 100s of realizations
- Open source: *https://github.com/afqueiruga/FractureDB*





- Dataset designed to work with "out-of-the-box" ML techniques (like MNIST or CIFAR)
- **Do regression for physically meaningful quantities instead of classification**
- **Evaluate ML methods quickly**



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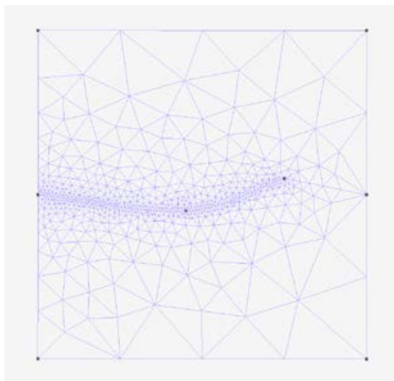
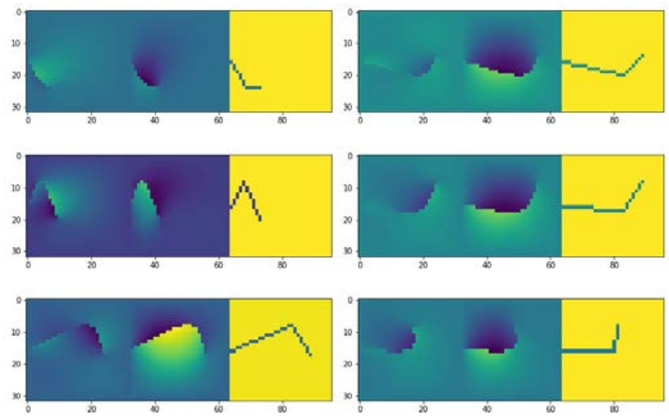
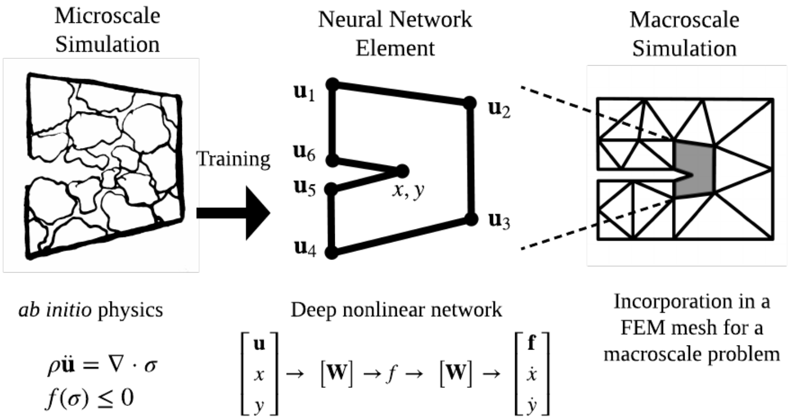




- **Apply datasets obtained by laboratory and visualization tasks**
- **Models from real data**
- Incorporate new models into reservoir scale simulations

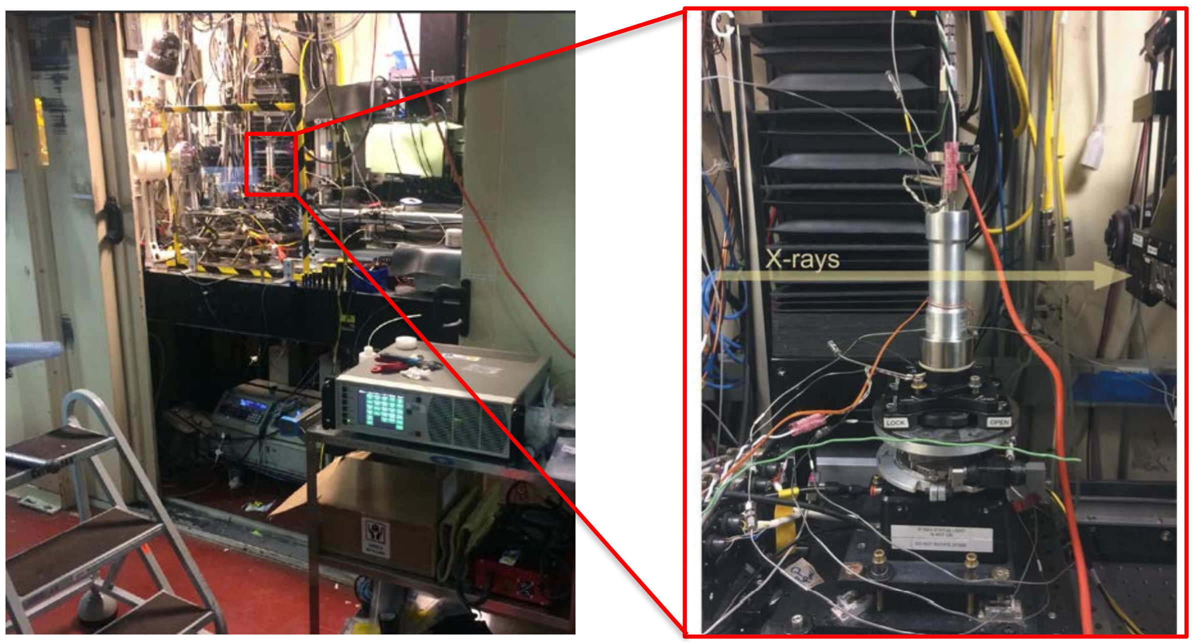


Proppant Visualization

Microscale parameters controlling the hydraulic properties of propped fractures in shales during closure

- We ran a series of in situ experiments closing propped fractures while imaging with synchrotron X-ray microCT (LBNL Advanced Light Source)
- **We have a unique laboratory apparatus: up to 24 MPa, up to 400 °C**

Voltolini, Marco, et al. "A new mini-triaxial cell for combined high-pressure and high-temperature in situ synchrotron X-ray microtomography experiments up to 400° C and 24 MPa." *Journal of synchrotron radiation* 26.1 (2019).



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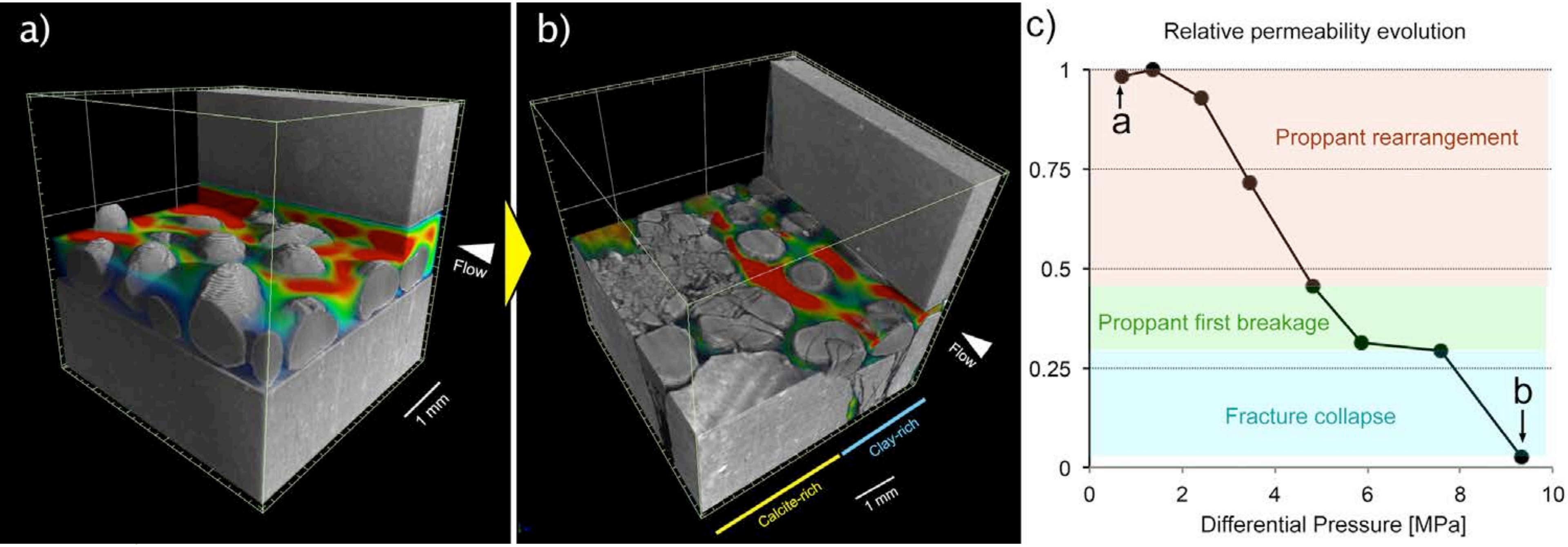
- Type of shale (Eagle Ford vs. Marcellus vs. Niobrara)
- Bedding direction (parallel vs. perpendicular)
- Proppant type (quartz sand vs. ceramic spheres)
- Single layer

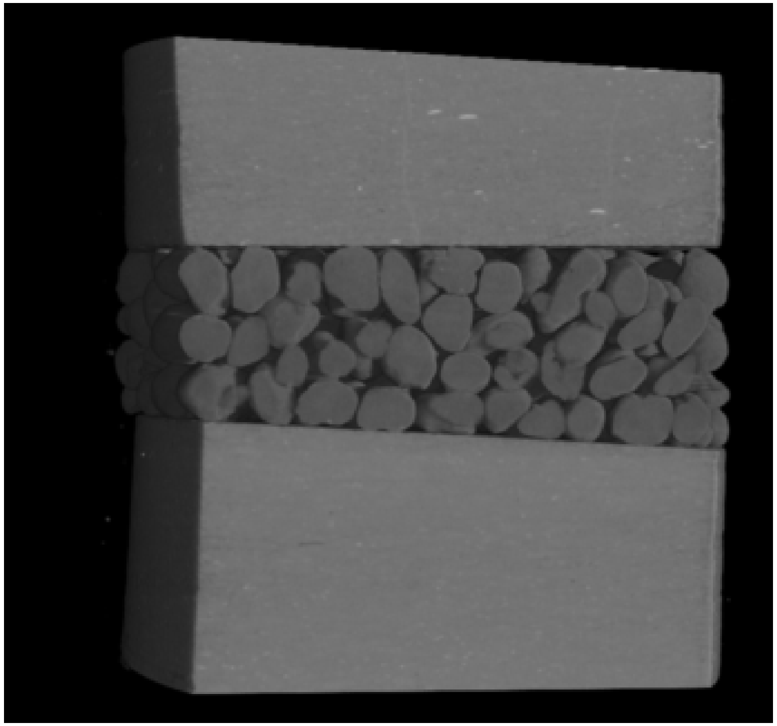
Rearrangement → Breakage → Collapse

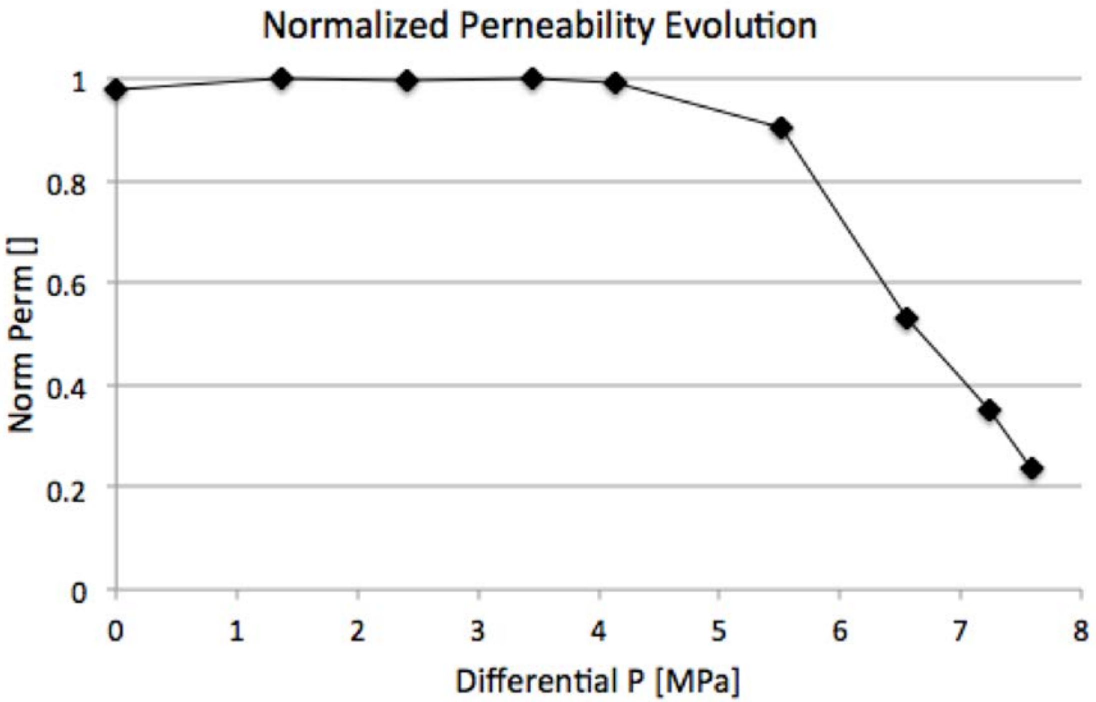


Proppant Visualization

Are these observations are still valid for the multilayer case?
Is rearrangement still so important?

No. Rearrangement changes flowpaths, but not permeability, which starts to decrease during proppant rupture (and significant aperture decrease).





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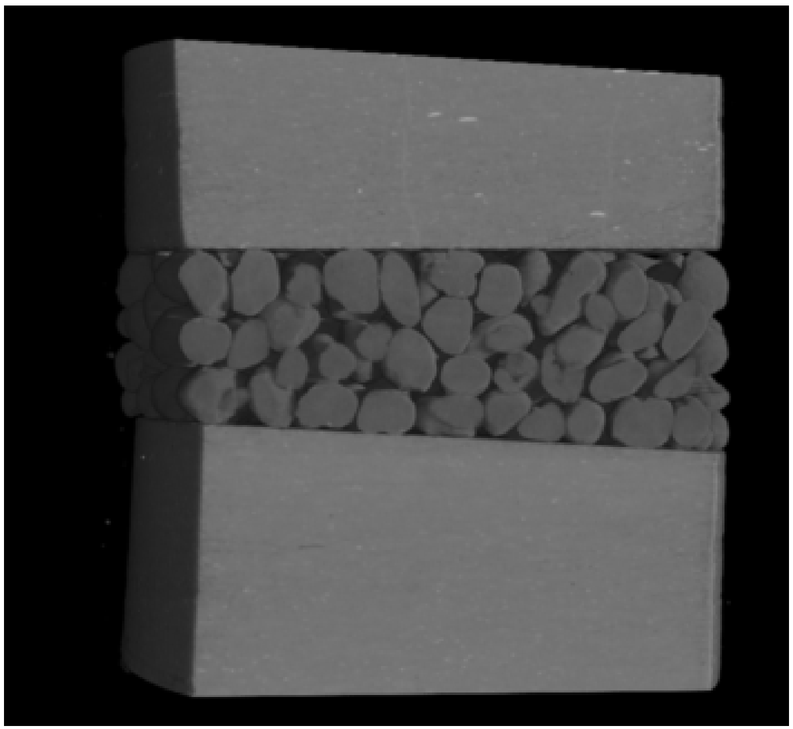
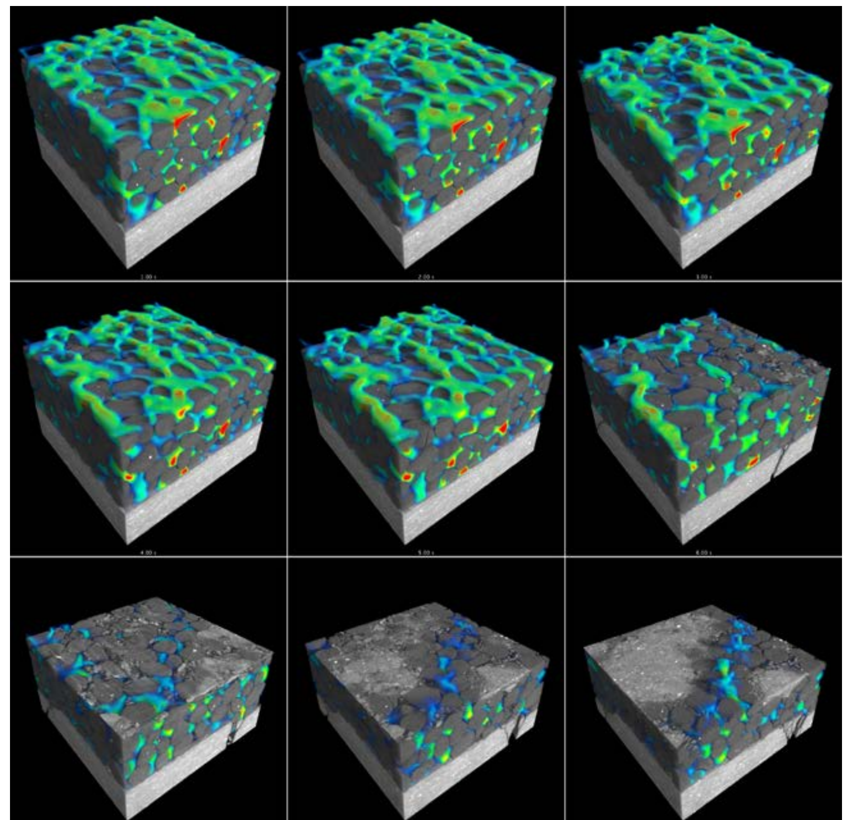




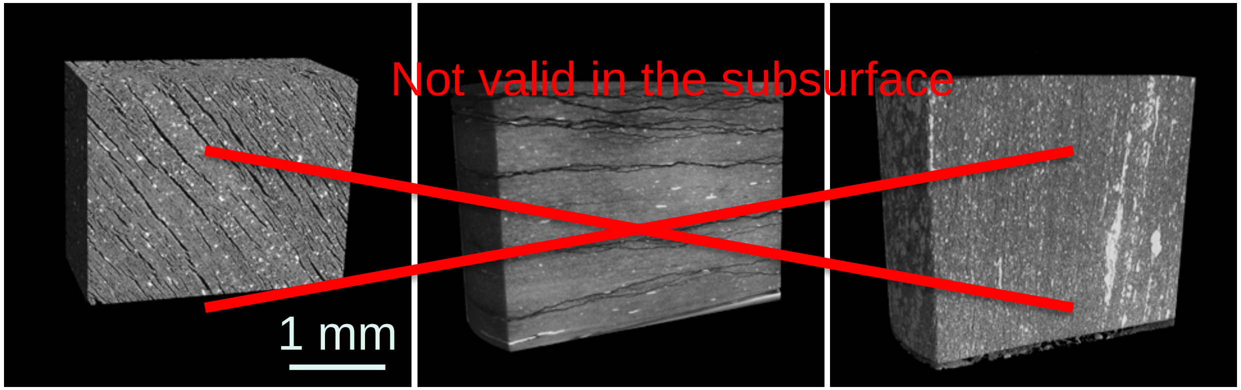
Proppant Visualization

- A new variable: **TEMPERATURE**. Role on proppant behavior?
- Shales very rich in organics have excellent potential, but a common problem is the fast closure of fractures

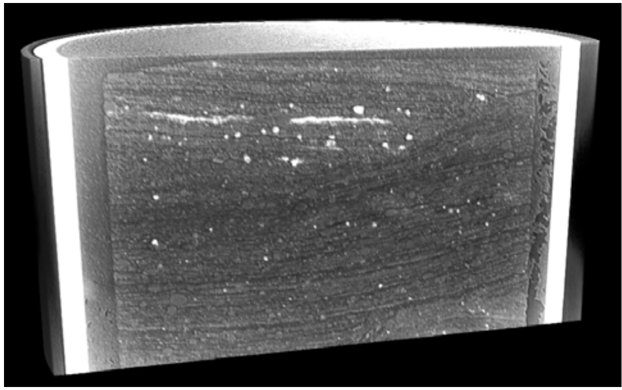
For the first time we have been able to observe this phenomenon

- Conventional experiments performed at unconfined conditions: **not realistic!**
- Sample in confined conditions behaves in a **completely different fashion**
- **A markedly plastic behavior is observed, with subsequent proppant embedment. Some microcracks heal.**

Unconfined samples (~400 °C)

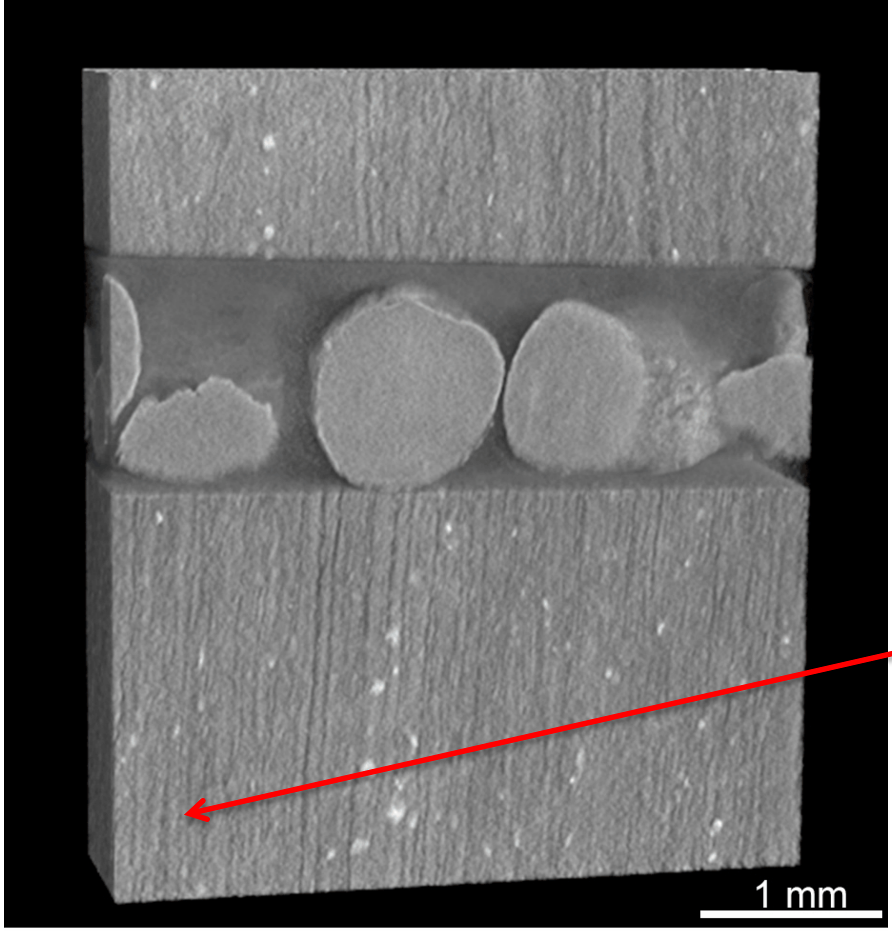


Confined sample (375 °C)



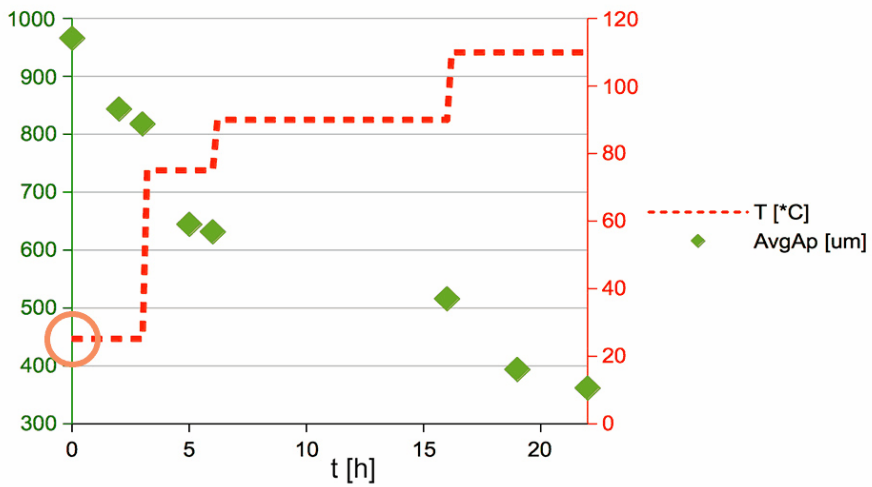
(Last frame is decompression)

HP/HT 4D SXR microCT measurement of a quartz sand propped fracture in Green River shale



Detail of the proppant displaying plastic embedment.

Brittle crack healing at high *T*



Aperture analysis, showing its dependence on *T* and *t* (see fracture closing at *T* = 110 °C)

Proppant Visualization: Path Forward

- Continuation of the work involving the role of proppant rearrangement in multilayers.
- Behavior as function of *T* & *t*: extract more information
  - Direct testing of **surface modification techniques** for better exploitation of plastic shales is now possible
- Fracture roughness?
  - Visualize the development of fractures at the microscale and examine role in proppant migration ("proppant accessibility")

Laboratory Studies

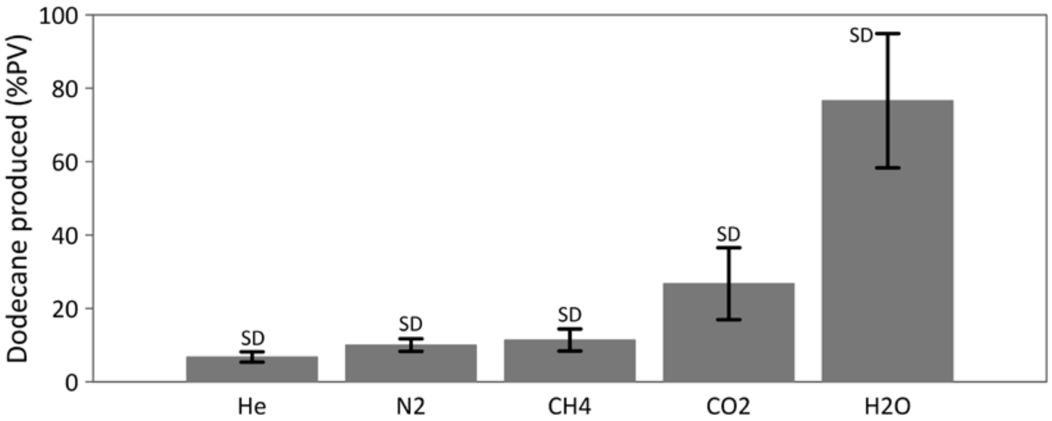
Objectives: Investigate and quantify differences in possible light tight oil (LTO) EOR techniques suggested by conceptual and numerical investigation

Fundamental Knowledge Gaps in Shale EOR

- What injection fluids are most (technically, economically) effective?
- How should they be applied?
- For what duration?
- For anisotropic shale?
- For mixed-wet shale?

Initial Study Findings

- > 60 tests performed to evaluate dodecane enhancement using N_2, CH_4, He, CO_2, and H_2O:
  - Mineral media (ceramic discs) used as test sample.
  - He performed poorly; N_2 outperformed He.
  - **CH_4 and CO_2 found to be highly effective. Mixtures of these two gases might be much more effective**.
  - H_2O surpassed other tested fluids.



- Dodecane enhancement using CH_4 outperformed both N_2 and He.
- CO_2 displacement produced a large fraction of the dodecane.
- Higher dodecane production using H_2O likely due to:
  - Water-wetting ceramic used.
  - Piston-like displacement of oil through larger ceramic pores (2.5 μm).

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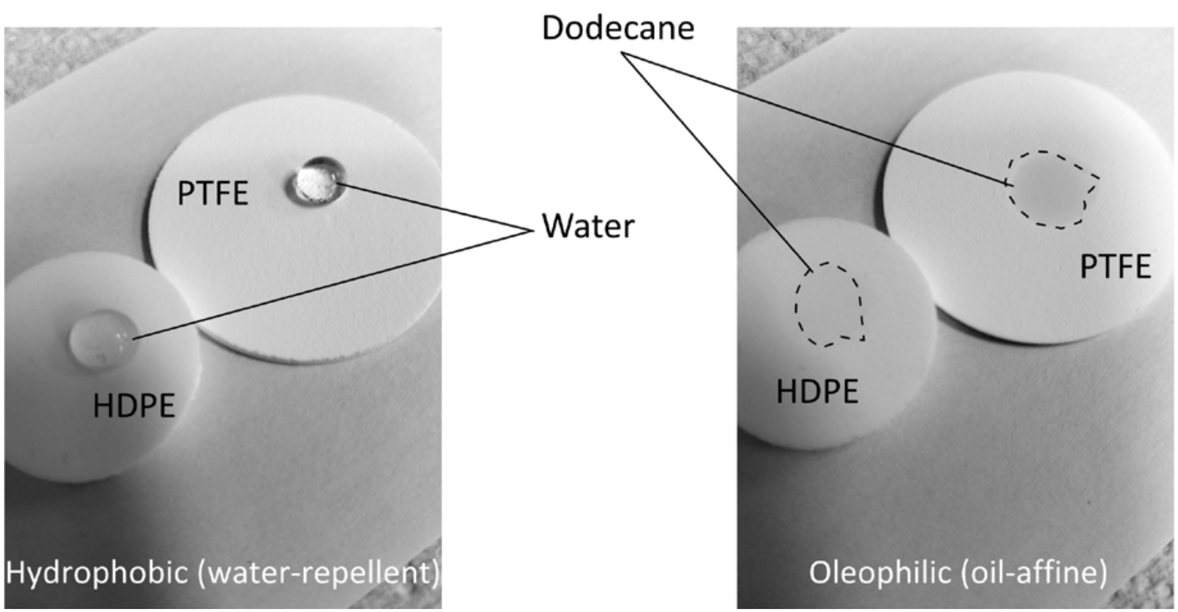
Laboratory Studies

Additional Process Modifications

- **Realistic, improved system for process evaluation:**
  - Use variable gas mixtures
  - Use samples with tight rock properties (porosity, pore structure, mineralogical anisotropy, and heterogeneous wetting media)
  - **Sample stack alternates water-wetting ceramic, oil-wetting materials**



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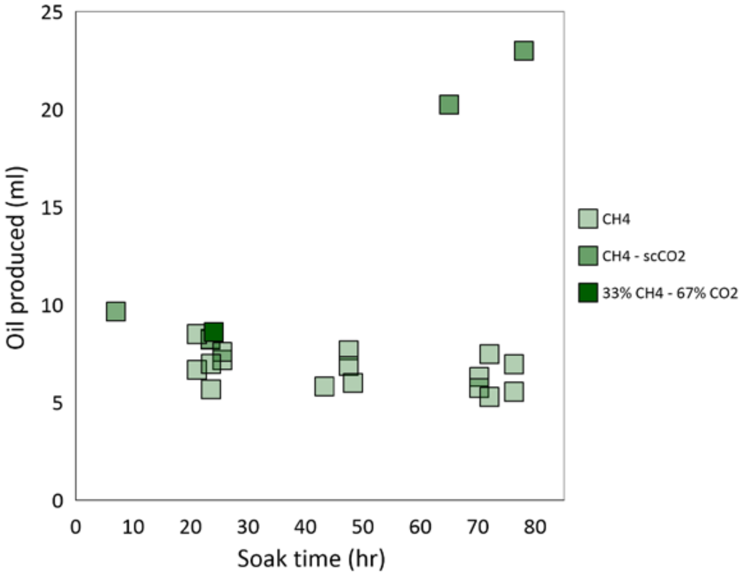
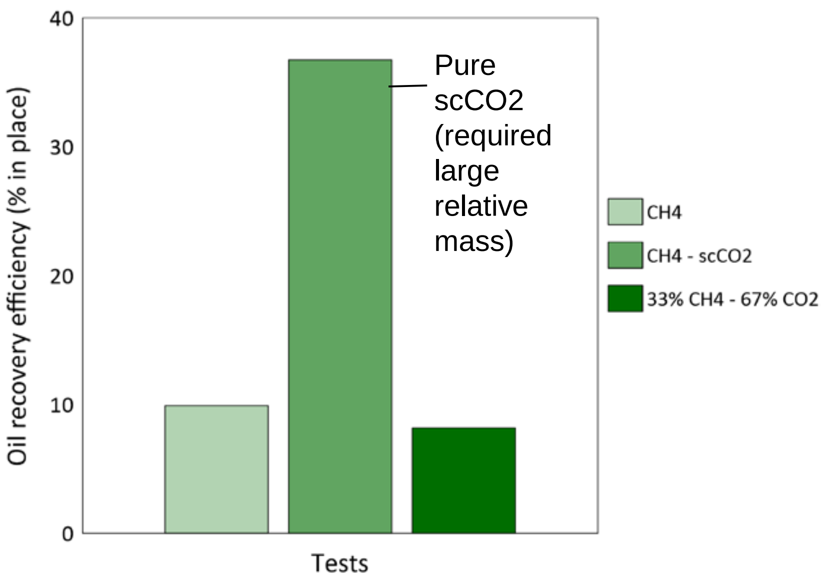
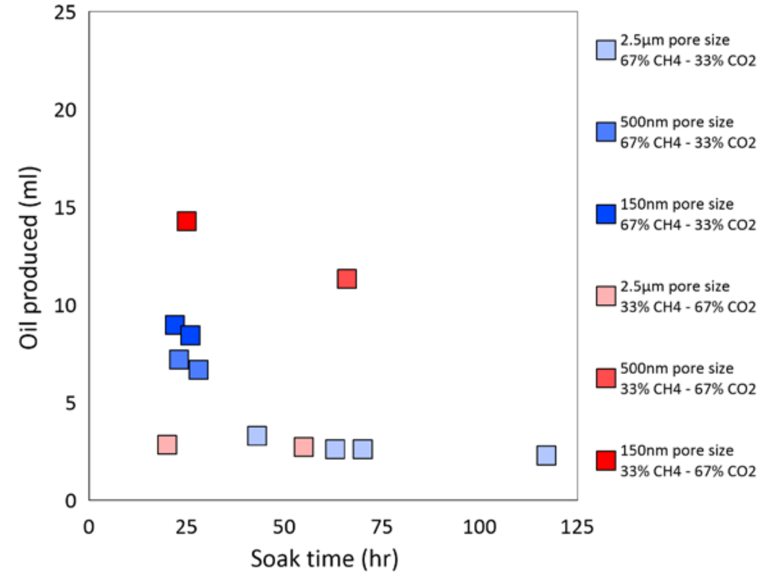
Anisotropic Media

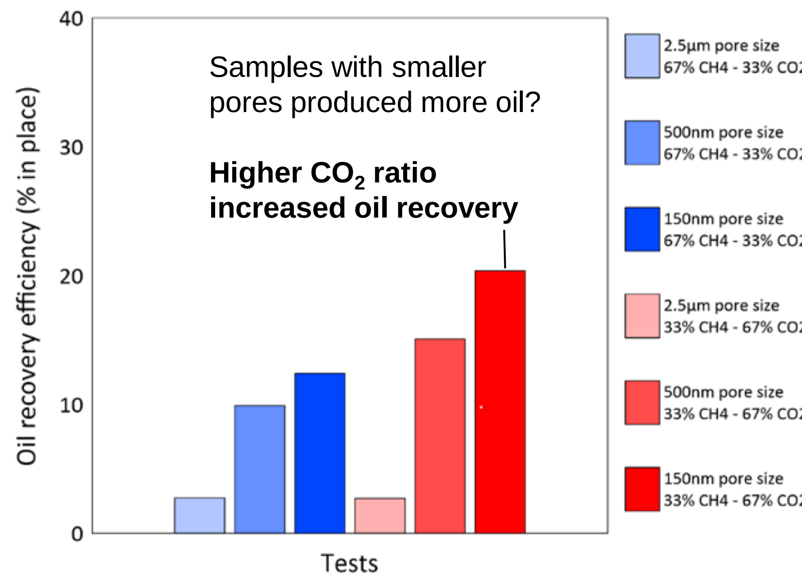
Old: Isotropic water-wet media
(ceramic discs only)





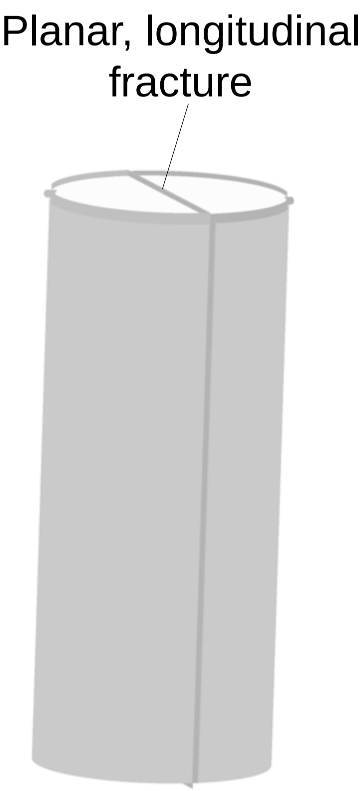
Anisotropic water-wet/oil-wet media
(ceramic discs and teflon)



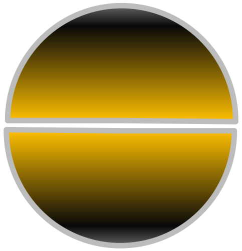


Laboratory Studies: Path Forward

- Using current setup, examine:
    - Enhancement techniques (gas expansion, fluid dissolution, diffusion).
    - Water/osmotic displacement.
    - **Observe processes using longer ceramic rods with longitudinal fracture**
    - **X-ray CT to monitor oil displacement processes.**



Ceramic rod
(4” L x 1.5” D)



Accomplishments to Date

We are continuing to use multi-scale laboratory investigations and multi-scale numerical simulations to:

- Identify mechanisms driving production from tight systems,
- Investigate a wide range of strategies, **identify promising ones**, and **evaluate their performance**
- **Understand proppants and proppant behavior**
- Understand the relationship to production enhancement

- **Building coordinated capabilities:** laboratory and simulation

Lessons Learned

- How to leverage unique LBNL capabilities to work at multiple scales
  - Simulators
  - Advanced Light Source
  - Laboratory
- Importance of laboratory visualization and verification studies
  - Validation and ground-truthing
  - Scaling between micro-, core-, and simulations

Synergy Opportunities

- Clear synergies are apparent in approaches, measurements, and analysis of data among similar project themes
- Synergies with fundamental oil and gas projects
  - Ongoing sharing of results and data
  - Cross-validation
- **Comparisons of results** obtained using the various approaches builds confidence in the results and the program

Appendix

Schedule & Budgets

Project Year	#1				#2				#3			
Quarter	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
Task 1: Project Management and Planning	M1											M6
Task 2: 3D Modeling of the Transport and Long-Term Fate of Proppants				M2				M4				
Task 3: Laboratory-Scale Studies of Proppant Transport				M2				M4				
Task 4: In-situ 4D X-ray micro-imaging of the evolution of propped fractures				M2				M4				
Task 5: Reservoir Simulation of Recovery-Enhancing Production Techniques						M3				M5		
Task 6: Laboratory-Scale Studies of Production Enhancement						M3				M5		

Budget: $400K in FY2019, $400K in FY2020 $400K in FY2021

Benefit to the Program

The objectives of the Program are to:

- Identify and accelerate development of economically-viable technologies to more effectively locate, characterize, and produce natural gas and oil resources, in an environmentally acceptable manner
- Characterize emerging oil and natural gas accumulations at the resource and reservoir level and publish this information in a manner that supports effective development
- Catalyze the development and demonstration of new technologies and methodologies for limiting the environmental impacts of unconventional oil and natural gas development activities

Benefit to the Program

Benefits:

- Increases in production (from a very low base, 5%)
- Identify and evaluate development improvement strategies
- Increases in reserve estimates
- Enhanced energy security

Project Overview

Goals and Objectives

By using multi-scale laboratory investigations (micro- to core-scale) and numerical simulations (from micro- to field-scale) to:

- Identify and quantify the mechanisms involved in hydrocarbon production from such tight systems,
- Describe the thermodynamic state and overall behavior of fluids in the nanometer-scale pores of these tight media,
- Propose new methods for low-viscosity liquids production from tight/shale reservoirs
- Investigate a wide range of such strategies, and identify the promising ones to quantitatively evaluate their expected performance

Success criteria

- Develop methods to compare a number of possible light tight oil production methods
- Identify and compare a number of possible light tight oil production methods

Organization Chart