Project ESD14089:
Numerical and Laboratory Investigations for Maximization of Production from Tight/Shale Oil Reservoirs: From Fundamental Studies to Technology Development and Evaluation

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U.S. Department of Energy
National Energy Technology Laboratory
Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
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Presentation Outline

We have been using **multi-scale laboratory investigations** and **multi-scale numerical simulations** to:

- Identify mechanisms driving production from tight systems,
- Propose **new methods** for low-viscosity liquids production from tight/shale reservoirs
- Investigate a wide range of strategies, **identify promising ones**, and **evaluate their performance**

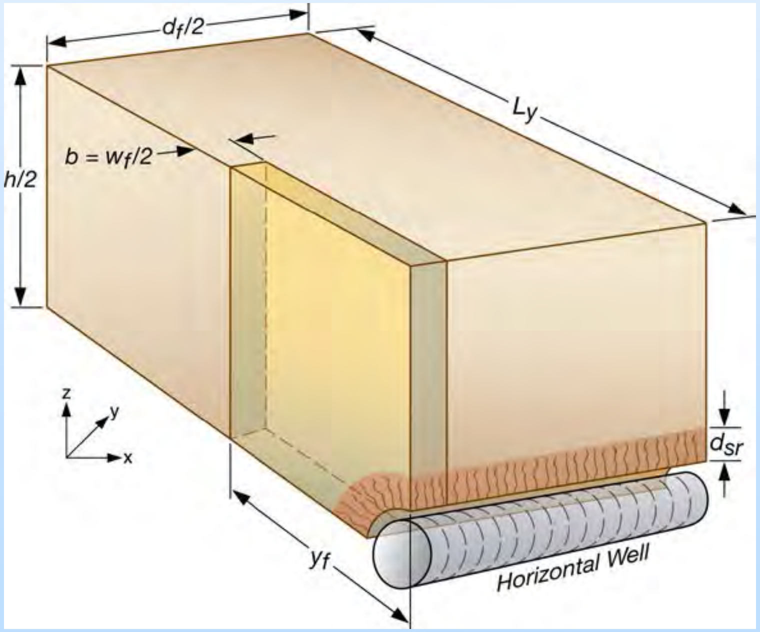
1. **Reservoir Simulation**
2. **Micro-scale laboratory studies**
3. **Core-scale laboratory studies**
4. **Fundamental Studies**

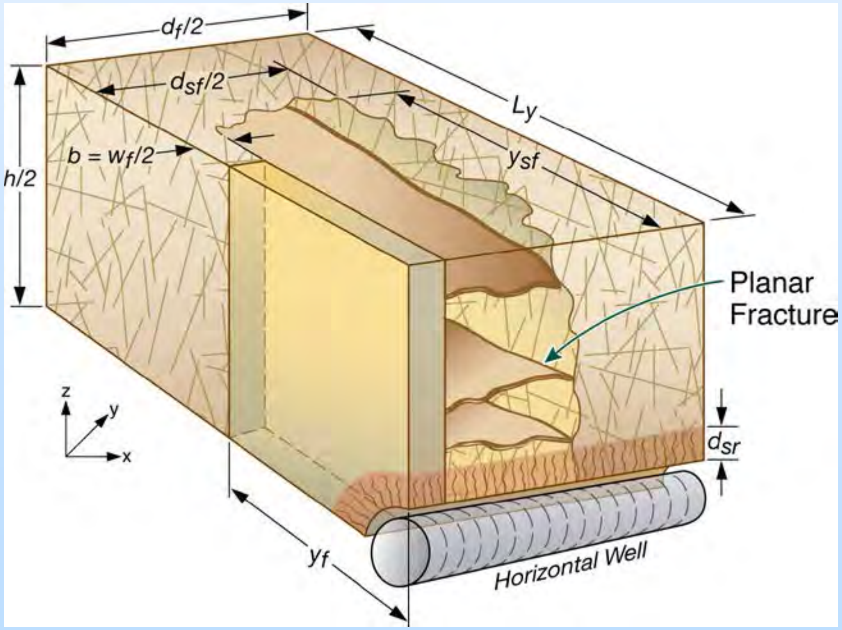
(validation)

1. Reservoir Simulation Studies

TOUGH+MultiComponentPhase (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+)





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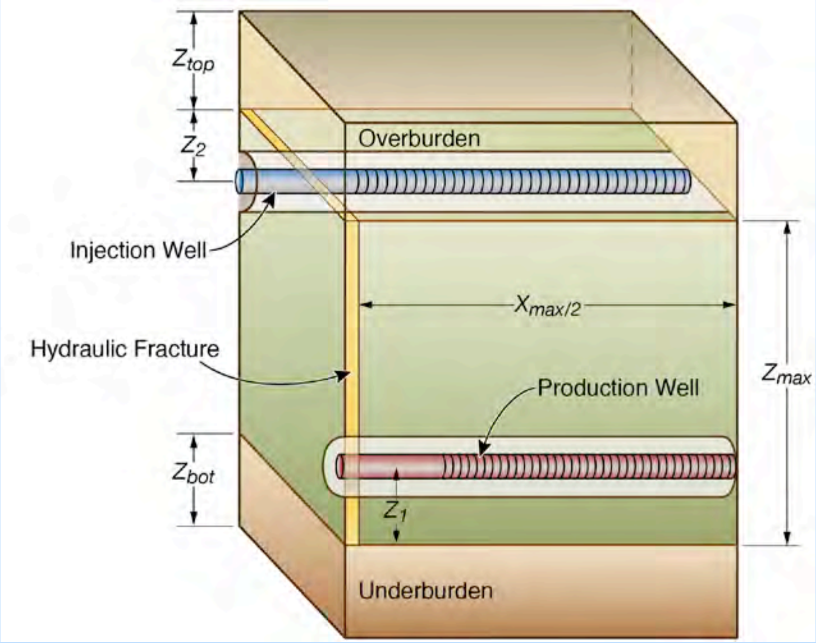
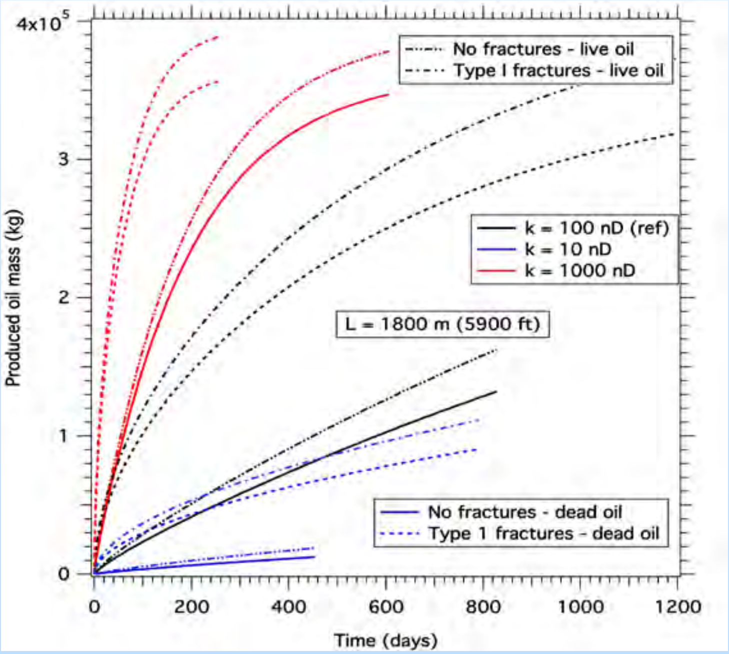
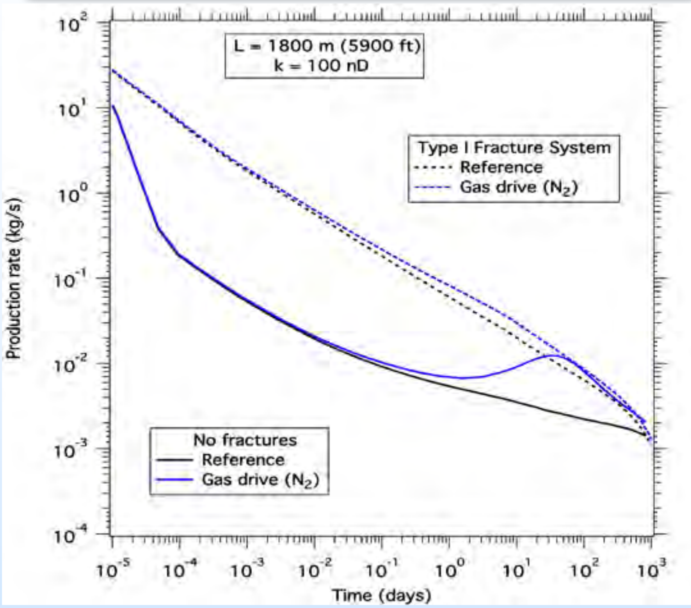


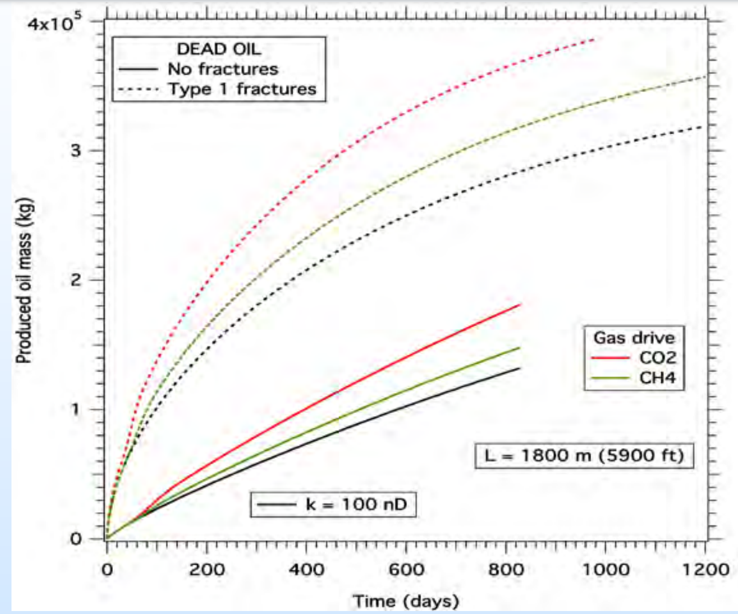


Shale Oil Production Simulation

Displacement: N_2 gas drive



Displacement: gas drive CO_2 vs. CH_4

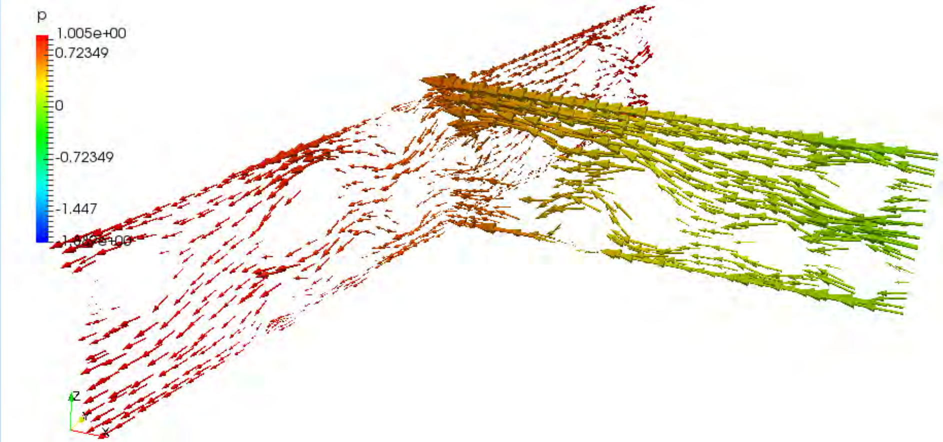


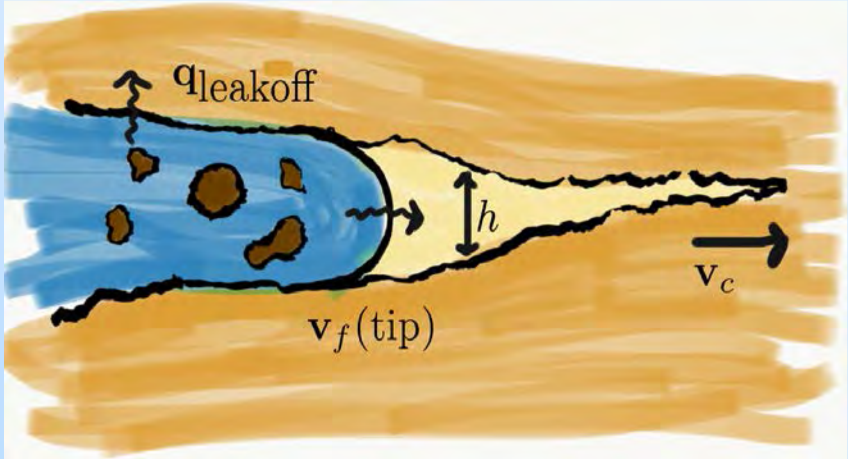
- **Continuous gas flooding**, **water-alternating-gas** (WAG) flooding
- **Injecting fluids** (CO_2 vs. N_2 vs. CH_4) for displacement/viscosity reduction
- **CH_4 vs. CO_2: effectiveness a function of oil gravity?**
- **Documenting effectiveness** of displacement techniques
- **What methods are inefficient or impractical?**

Proppant Transport Simulation

Analysis and Modeling of the Transport and Long-Term Fate of Proppants

- Developed numerical model of fluid flow and proppant transport
- Captures fluid lag and movement/embedment of proppants
- Effect of stresses on embedment of the proppants into the matrix
- Experimented with novel treatments of proppant modeling
- Determining the transport and fate of injected proppants and **resulting geomechanical behavior**





Proppant Transport Simulation

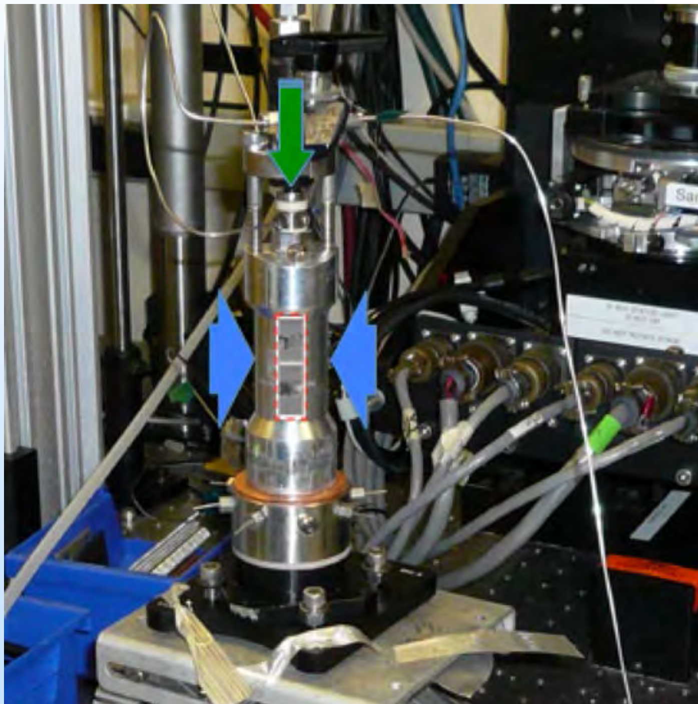
Proppant-laden fluid injection into a vertically oriented 10m fracture, color indicating pressure. Fluid interface is the 0-contour (thick line)

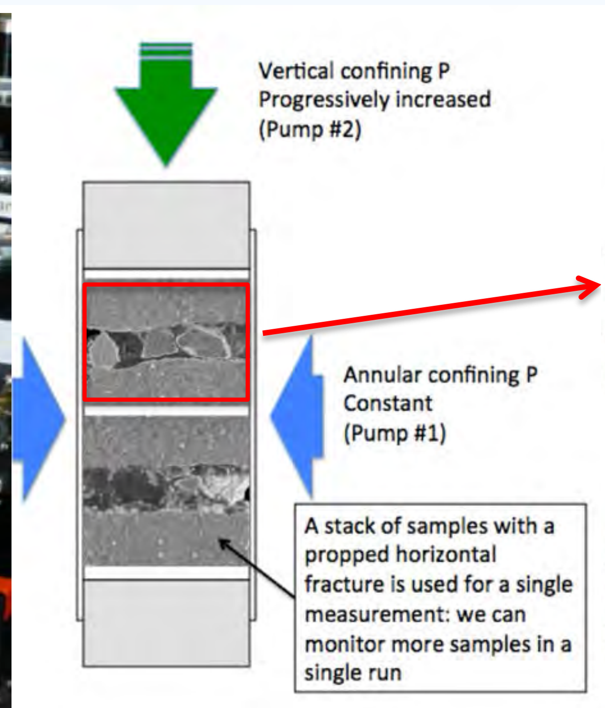
Proppant-laden fluid injection into a horizontally oriented 10m fracture, color indicating proppant density. Fluid interface is the thick line.

2. Micro-Scale Laboratory Studies

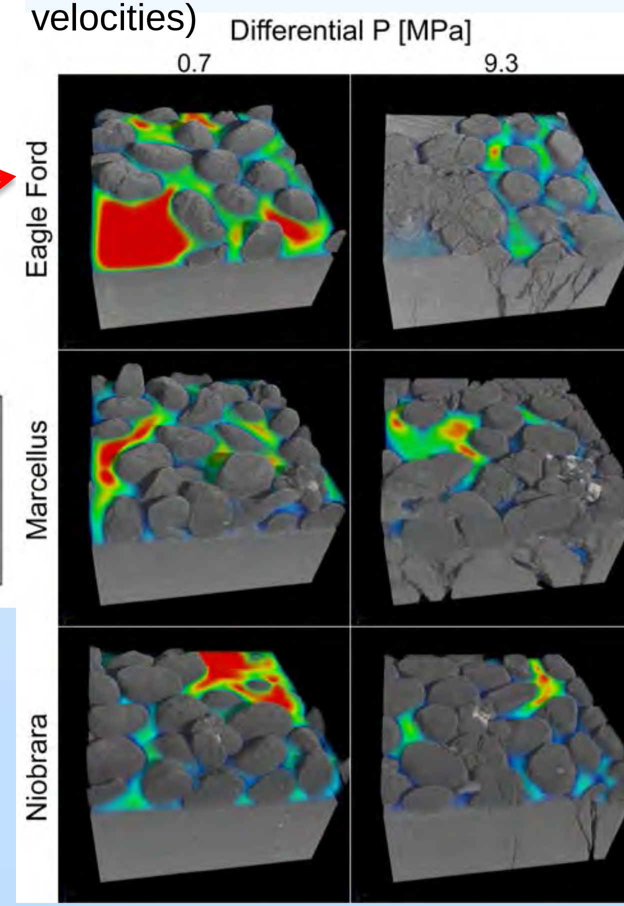
Sub-Microscopic-Scale Visualization Studies

Using in-situ XRμCT scanning at the LBNL Advanced Light Source to understand the role of proppant in the evolution of fractures in shales





Volume rendering of three shale samples, horizontally cut.
(in color, the calculated flow velocities)

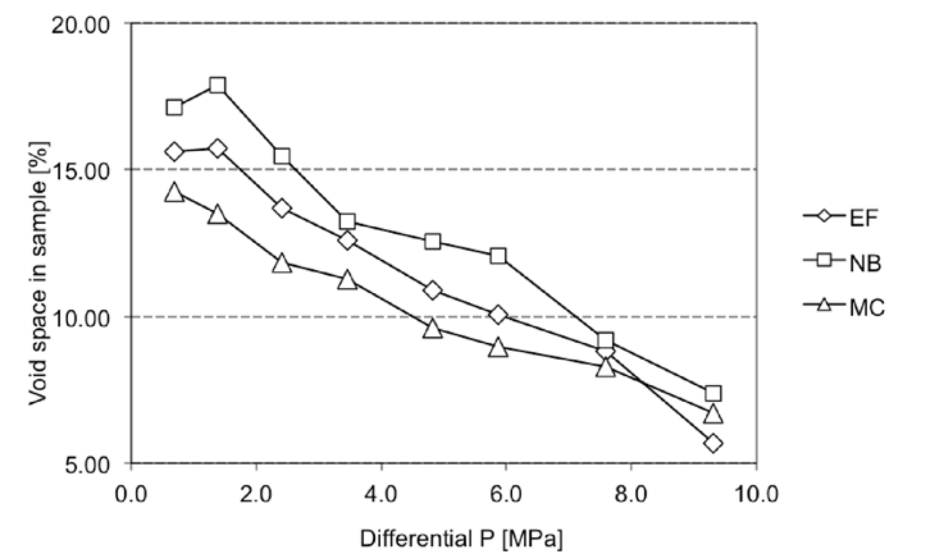


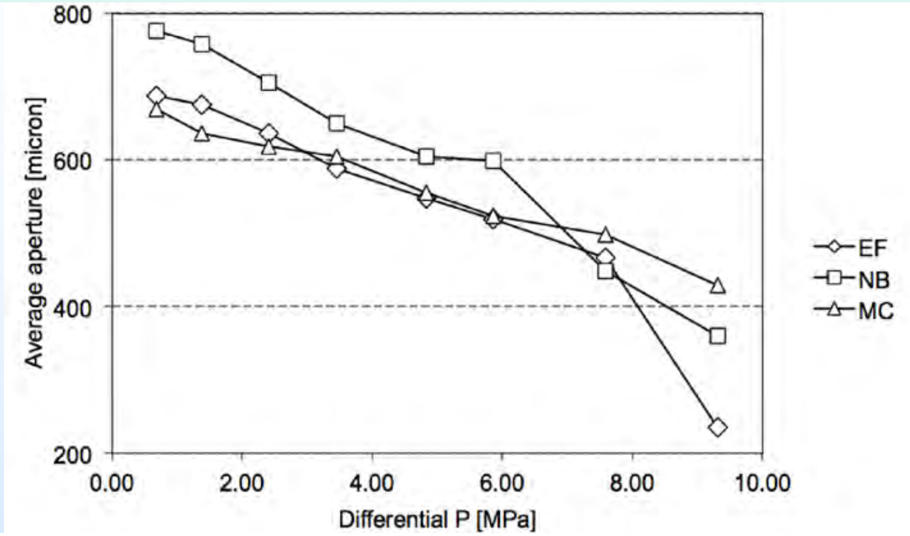
We are using this experimental approach to study the role of **shale type** (and microstructure)**, bedding orientation,** and **proppant type** on the evolution of fractures at the microscale during closure, and the impact on hydraulic properties.

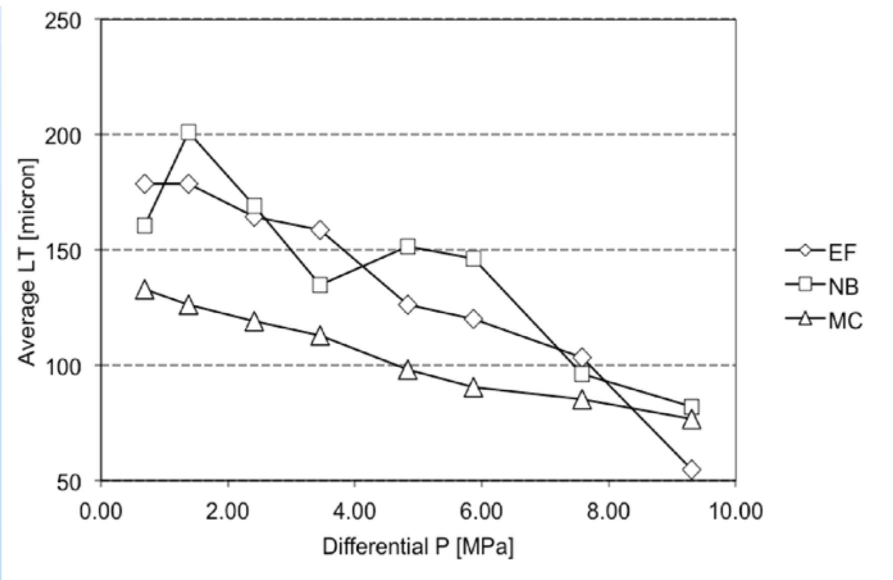
Three different oil shales: EF = Eagle Ford; NB = Niobrara; MC = Marcellus

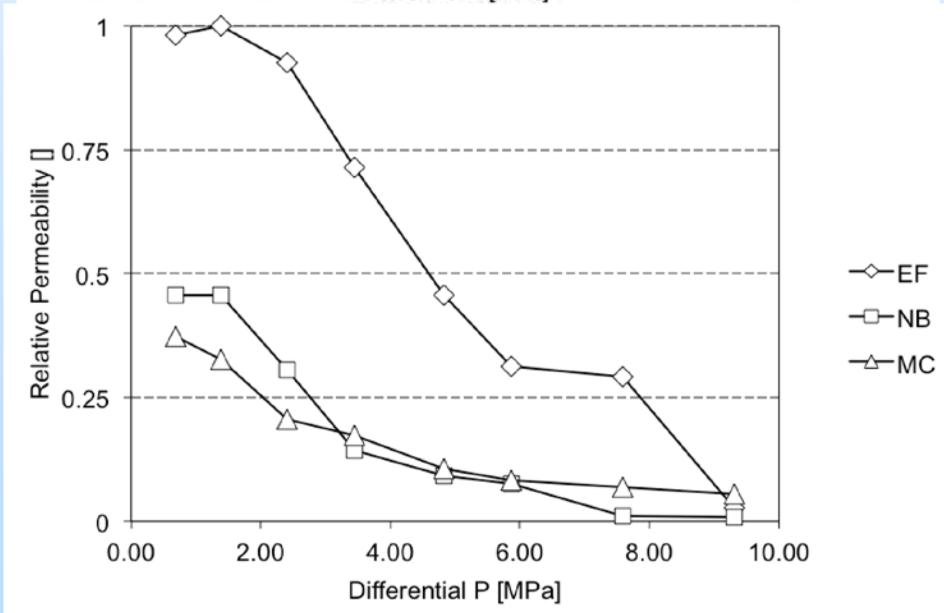
How morphological parameters (void space, average aperture of the fracture, and average local thickness) and relative permeabilities evolve during loading/closure.

***No clear morphological proxy for permeability*.**

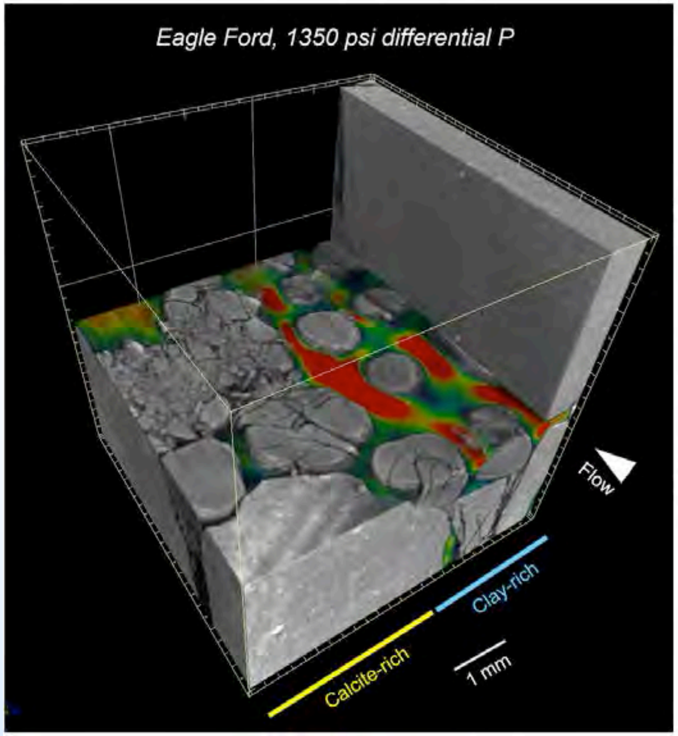


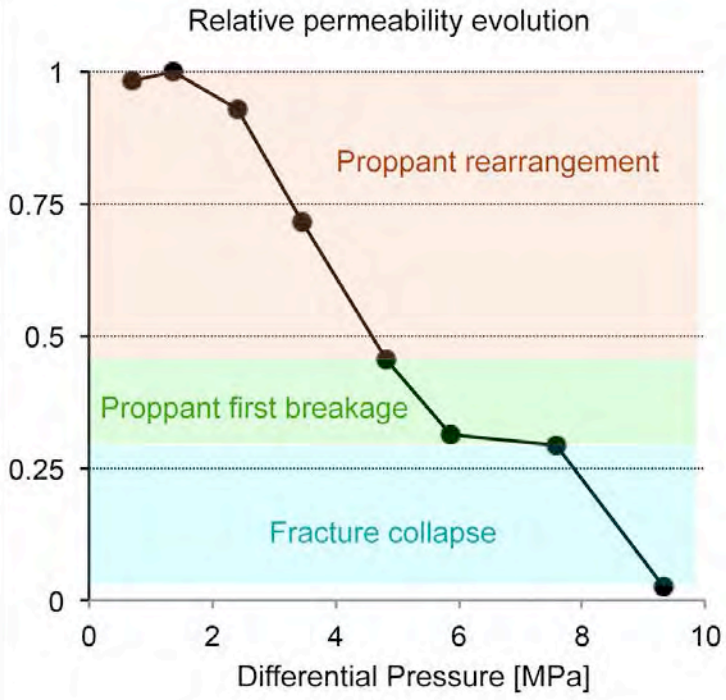




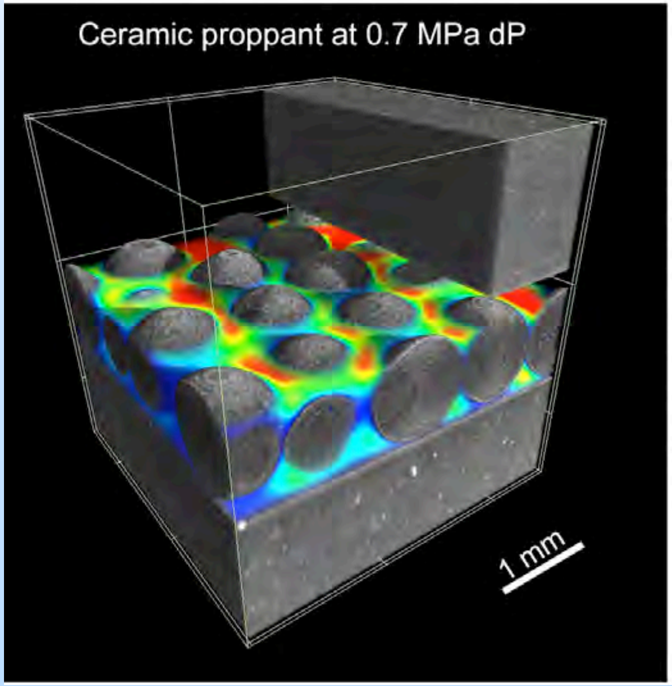


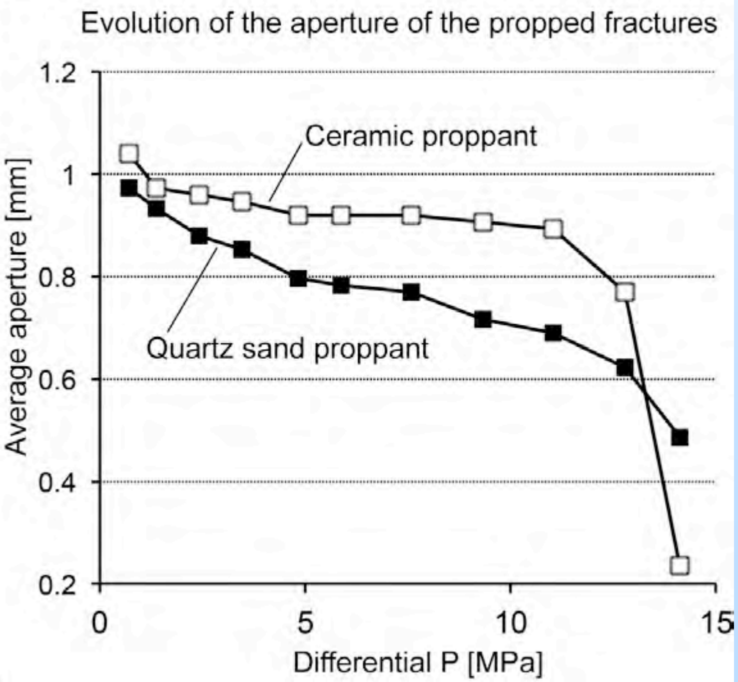
When using quartz sand, the **proppant rearrangement** has the largest impact on permeability.
(Flow velocity fields are in color)

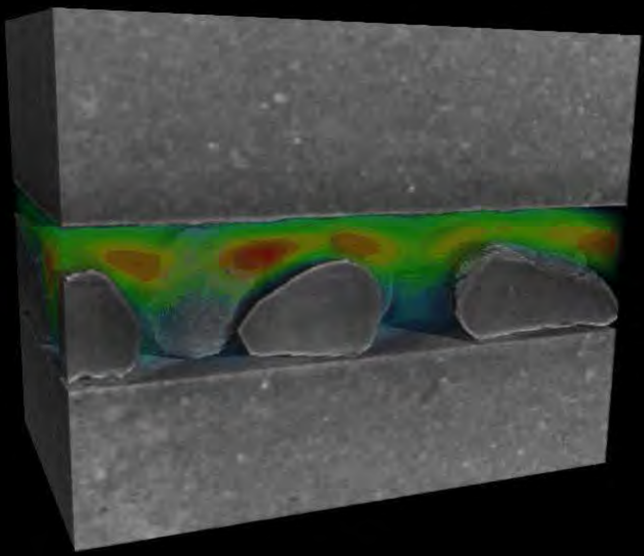


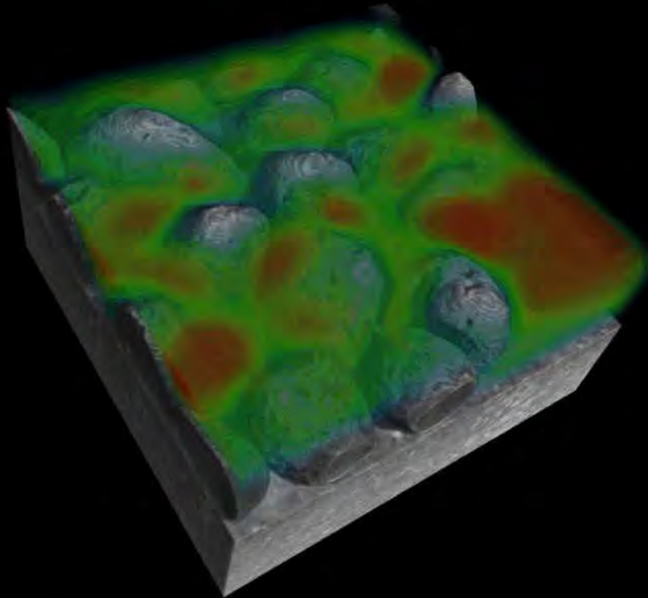


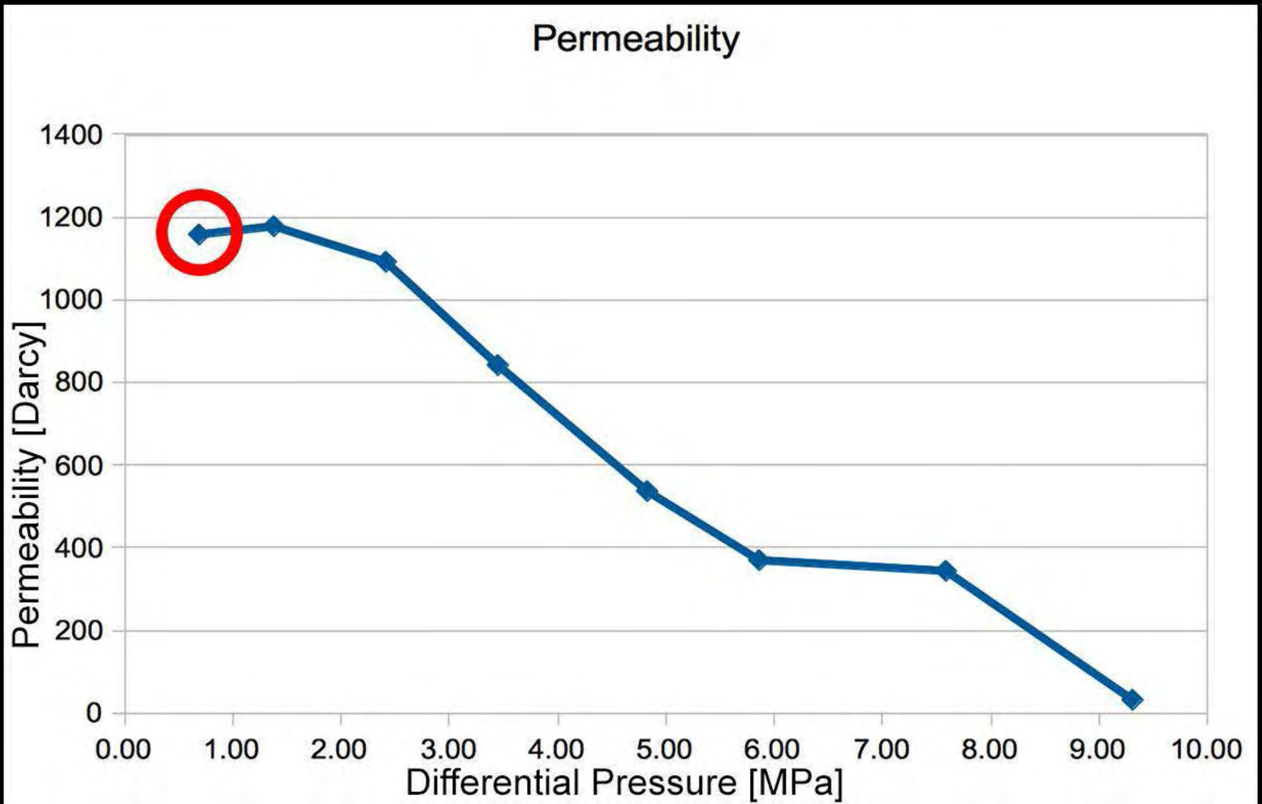
New experiment comparing **two different proppants**: ceramic proppant shows a much more stable fracture during loading, until the final collapse, and is not subject to significant rearrangement.











Evolution of permeability during the forced closure of the fracture

Simulated Stokes flow velocity fields (colors)

Identified/quantified events **controlling flow properties** of the sample

Proppant rearrangement shows the largest impact.

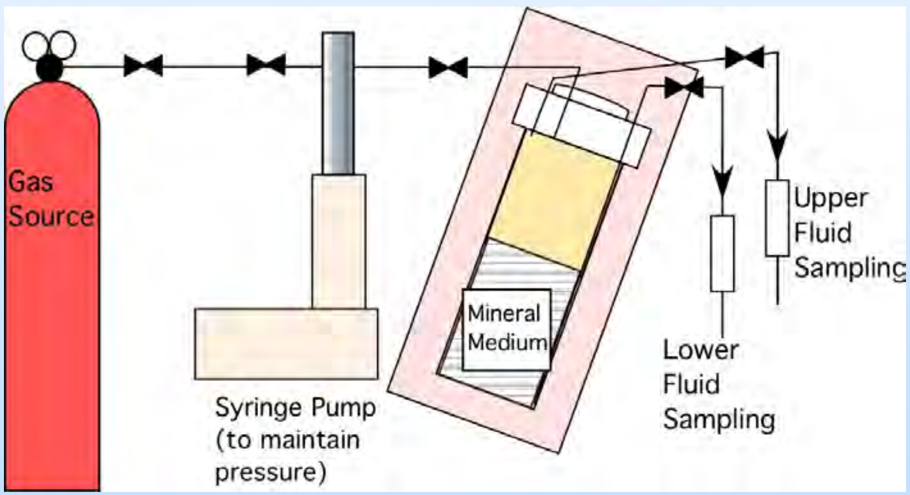
Similar behavior is present in all samples.

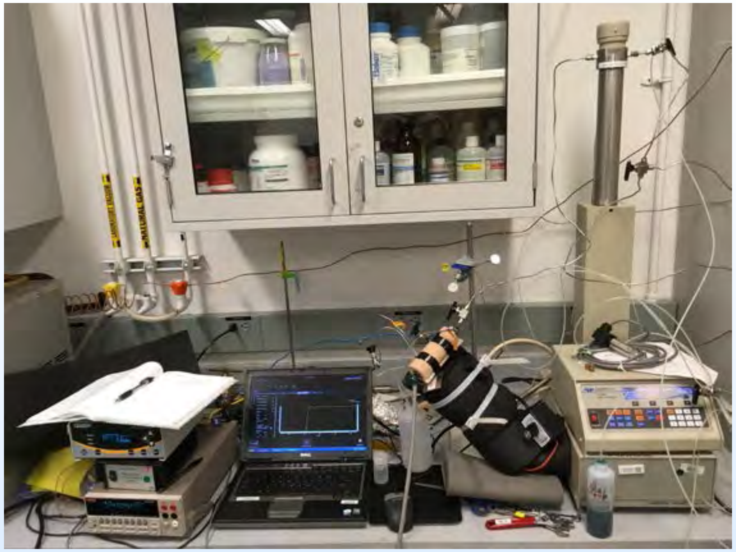
3. Core-Scale Laboratory Studies

Gas or fluid of choice

High-pressure syringe pump for pressure control

Porous ceramic disks in layers inside commercial pressure vessel



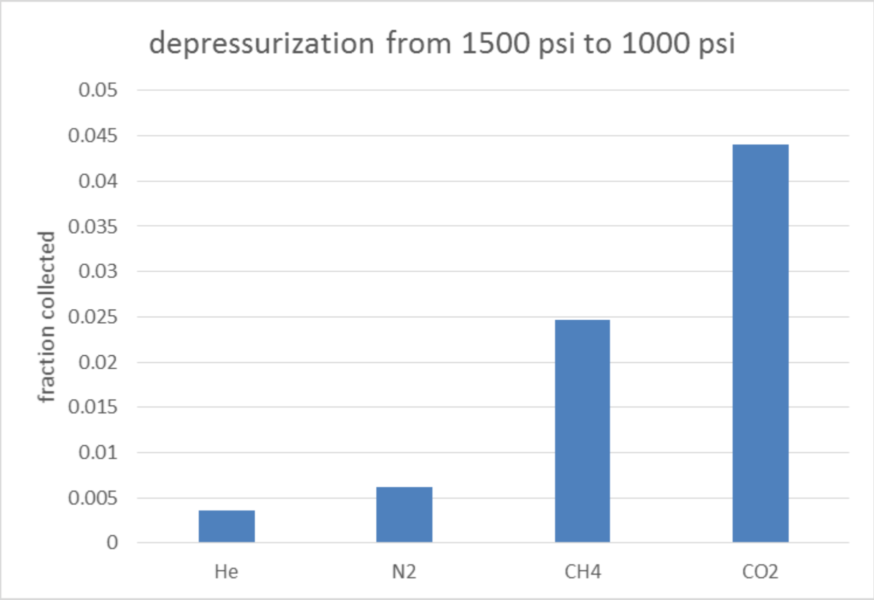


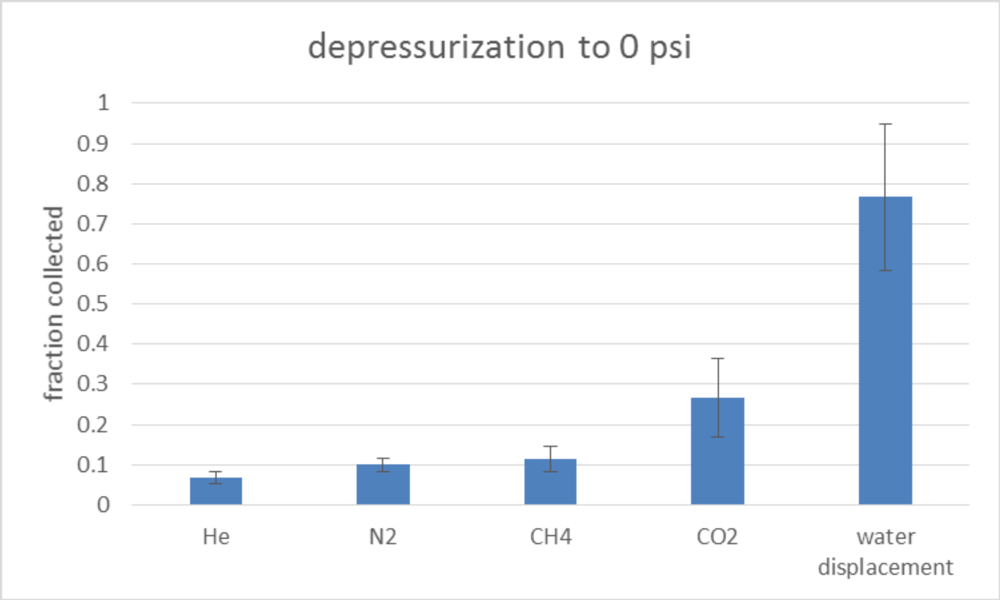
- Mineral medium: **porous ceramic disks**
- **Dodecane** as hydrocarbon phase
- **Depressurization, fluid dissolution, displacement, surfactants, etc.**
- Drain under pressure and collect/quantify the produced oil.
- **62 tests examining production-enhancing processes**

3. Core-Scale Laboratory Studies

Highlights:

- Performed **62 tests** to evaluate gas dissolution, depressurization, and imbibition
- **$scCO_2$ > CH_4 > N_2 > He**, but water was best
- CO_2 mass injected >> other gases
- **Oil gravity?**





Accomplishments to Date

We have used **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**

Phases I and II Complete:
Developed Parallel Capabilities
to Quantify Production Enhancement

Lessons Learned

- How to leverage unique LBNL capabilities (simulators, ALS, laboratory) to work at multiple scales
- Importance of laboratory visualization and verification studies
  - Validation and ground-truthing
  - Scaling between micro-, core-, and simulations

- Difficulties in scaling from molecule (nano-) to micro-scale using existing capabilities

Paths Forward

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

Area 1: Proppant Transport

- **Simulation studies** of proppant transport in fractures
  - Incorporate **proppant transport** (and existing capabilities in coupled geomechanics) into **TOUGH+MCP**
  - **New:** Investigate numerical methods for fracture propagation
- **Laboratory studies** of proppant transport in fractures (and corners)
  - Hand-in-hand **coordination with simulations**
- 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)**

Paths Forward

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

Area 2: Production Enhancement

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

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

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
- Seed Knowledge Management platform with results, data, and insights

Appendix

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

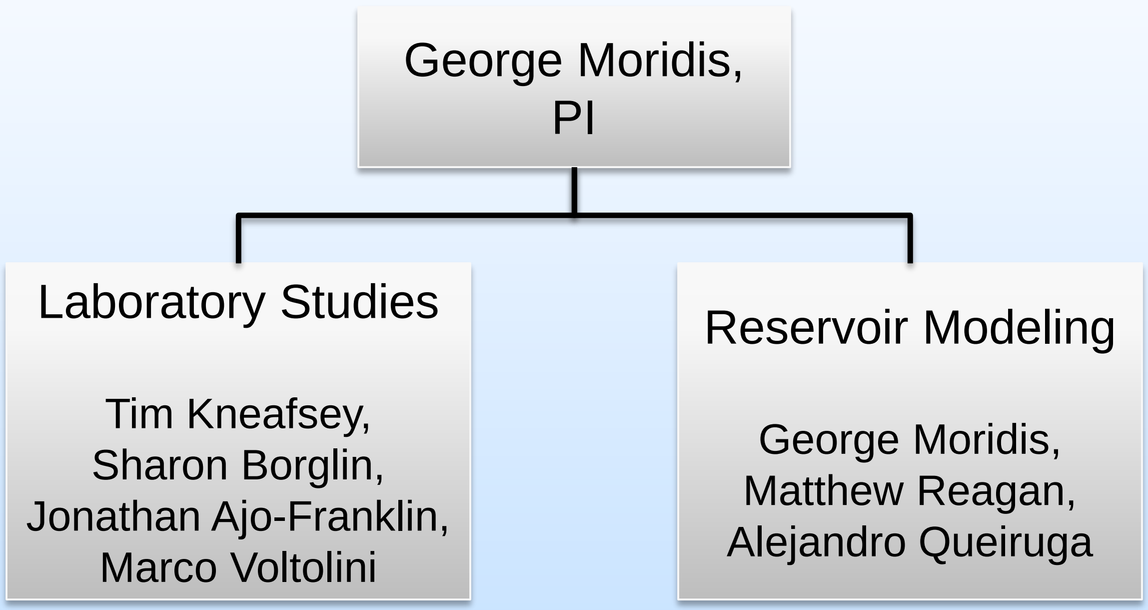
By using multi-scale laboratory investigations (nano- to core-scale) and **numerical simulations (from molecular to field-scale) to:**

- 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



Gantt Chart

Budget Period	#1				#2			
Quarter	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Task 1: Project Management and Planning	M1							M1
Task 2: Continuation of evaluation of enhanced liquids recovery		**M2**				M3		
Task 3: 3D Analysis and Modeling of the Transport and Long-Term Fate of Proppants				M4				
Task 4: Multi-scale laboratory studies of system interactions			**M5**		M6			
Task 5: Molecular simulation analysis of system interactions				M7				