Mechanistic Approach to Analyzing and Improving Unconventional Hydrocarbon Production FWP FE-772-16-FY17:

Tributary zone fractures (small-scale) contributions to hydrocarbon production in the Marcellus shale

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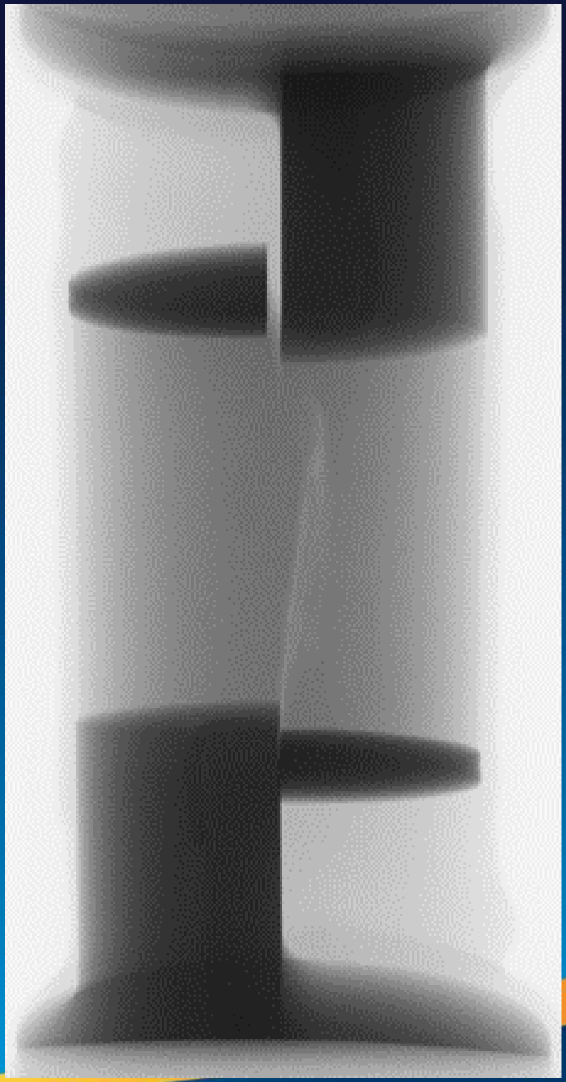
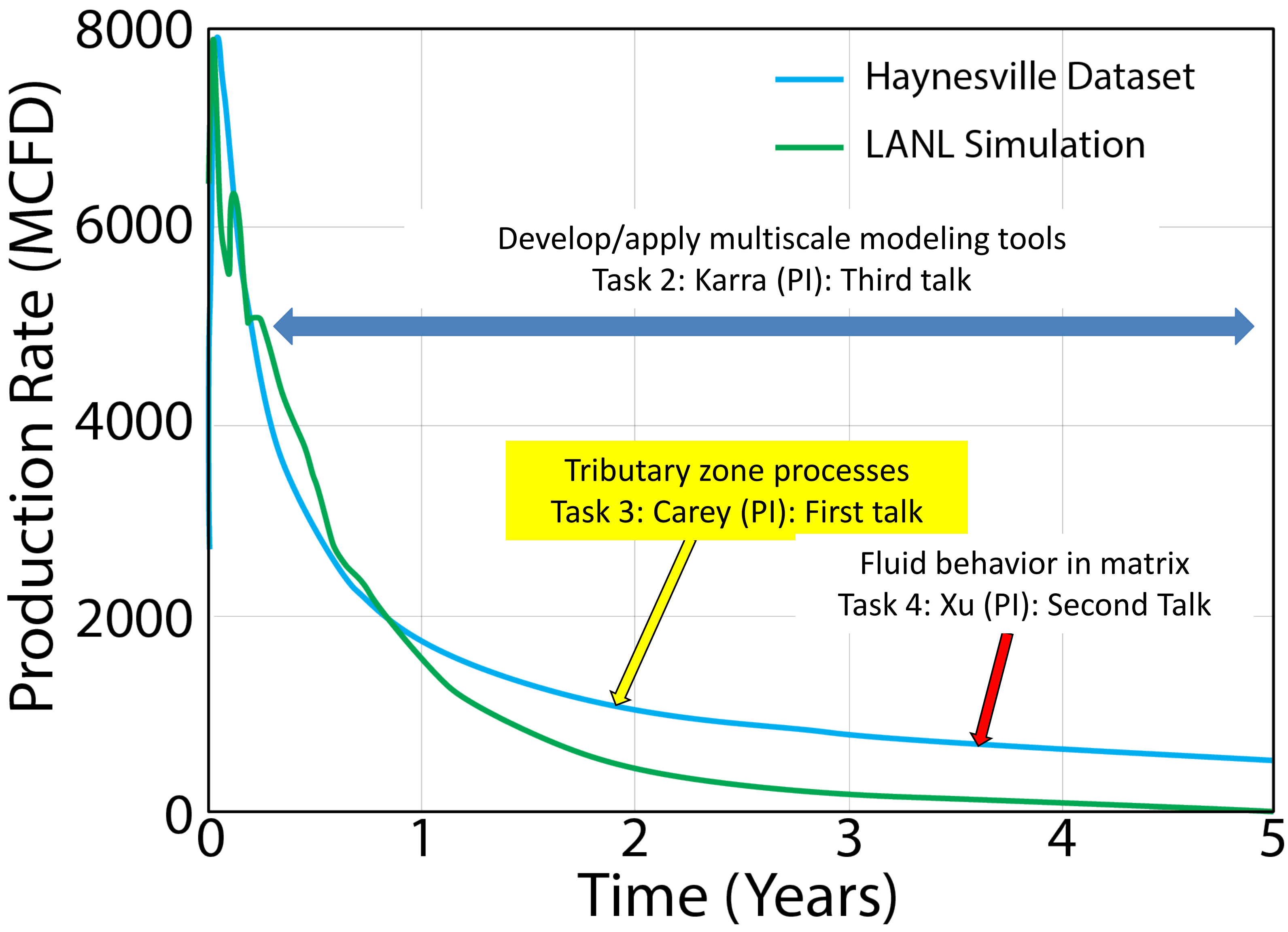


U.S. Department of Energy

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

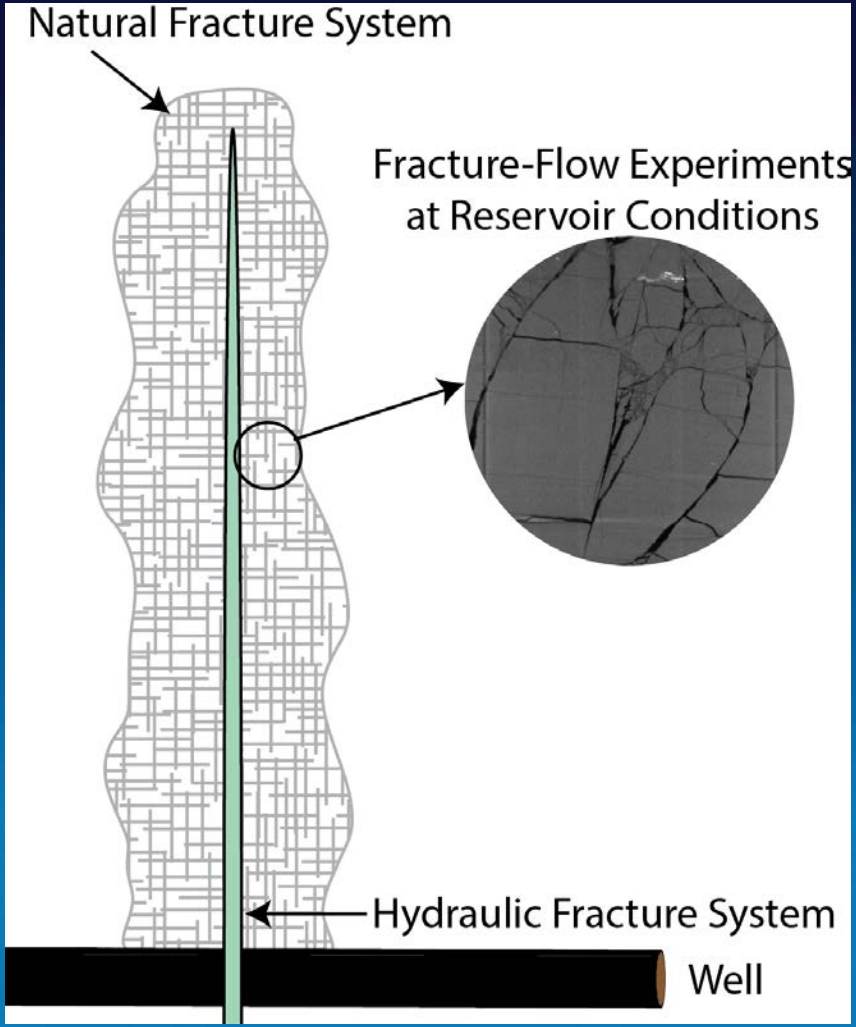
Overview of Project: Quantify Production Curve Processes



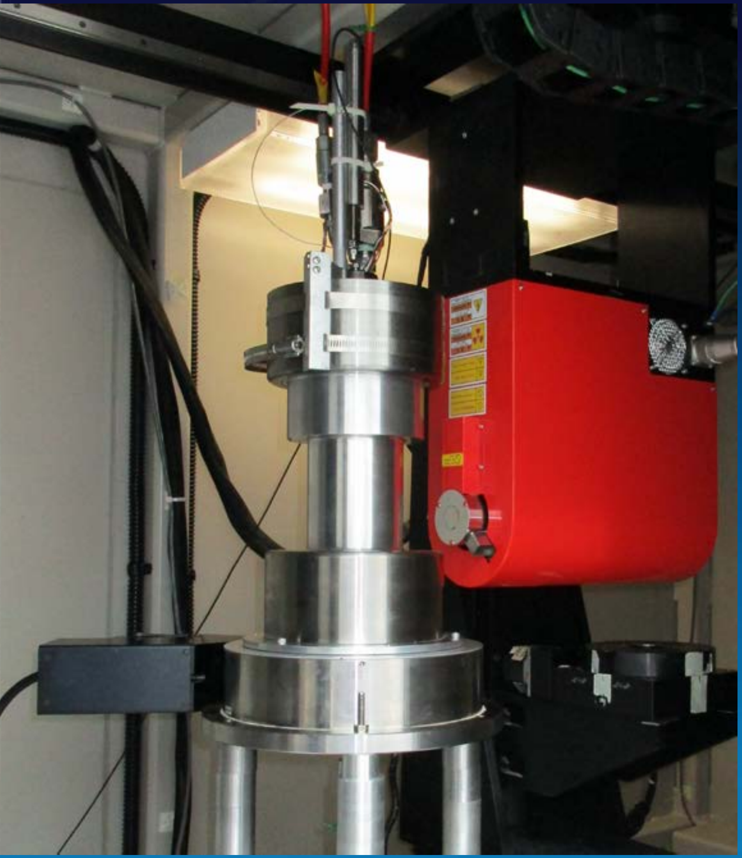
Technical Status:

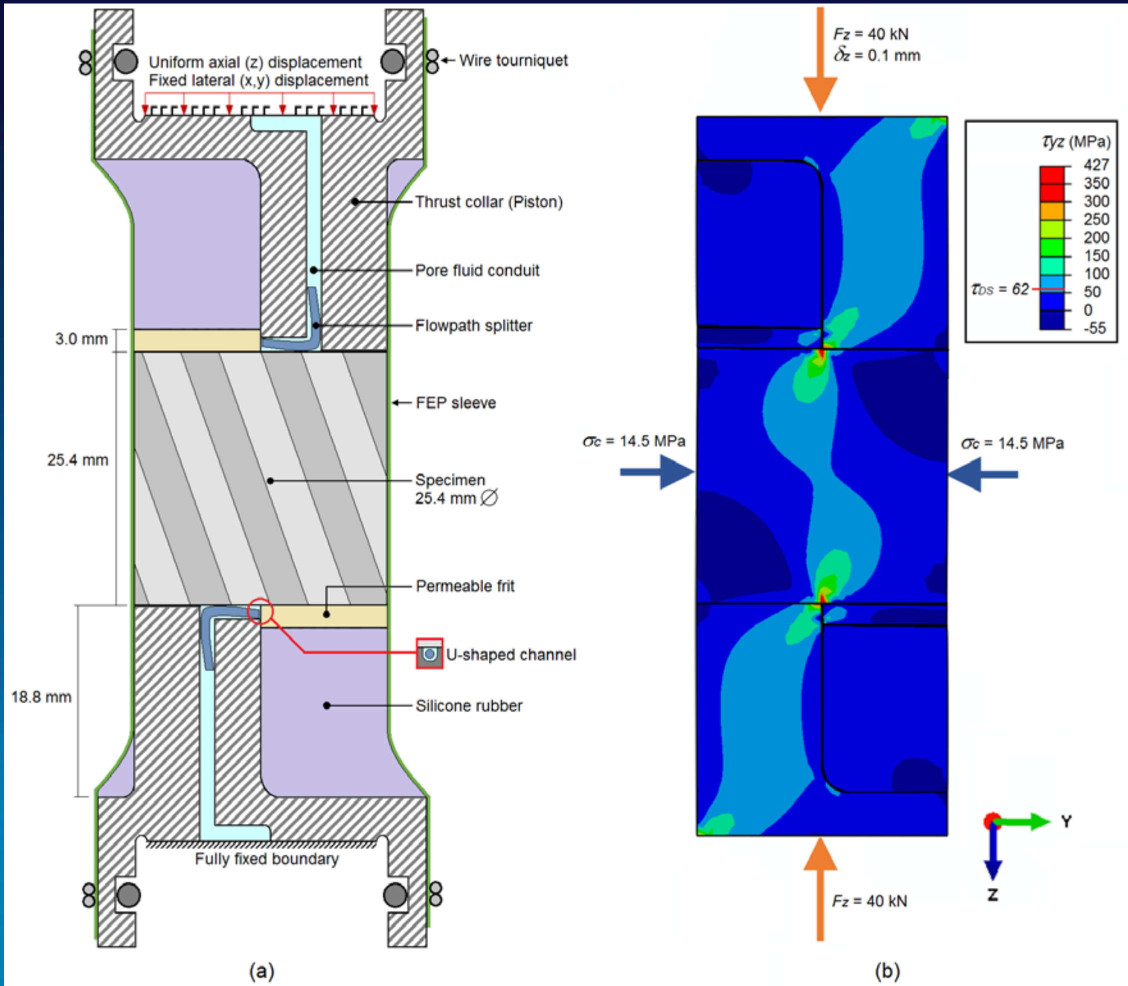
Fracture-permeability evolution of Marcellus shale

- Natural, pre-existing fractures are critical to hydrocarbon production
- Permeability of natural fractures controls hydrocarbon production at mid- to long-term
- Measurement of permeability of newly created fractures as a function of effective stress
- Measurement of permeability of restimulated fractures
- Measurement of critical stress/depth of shear-fracture permeability for shales



Triaxial Direct-Shear Coreflood & Radiography + Tomography

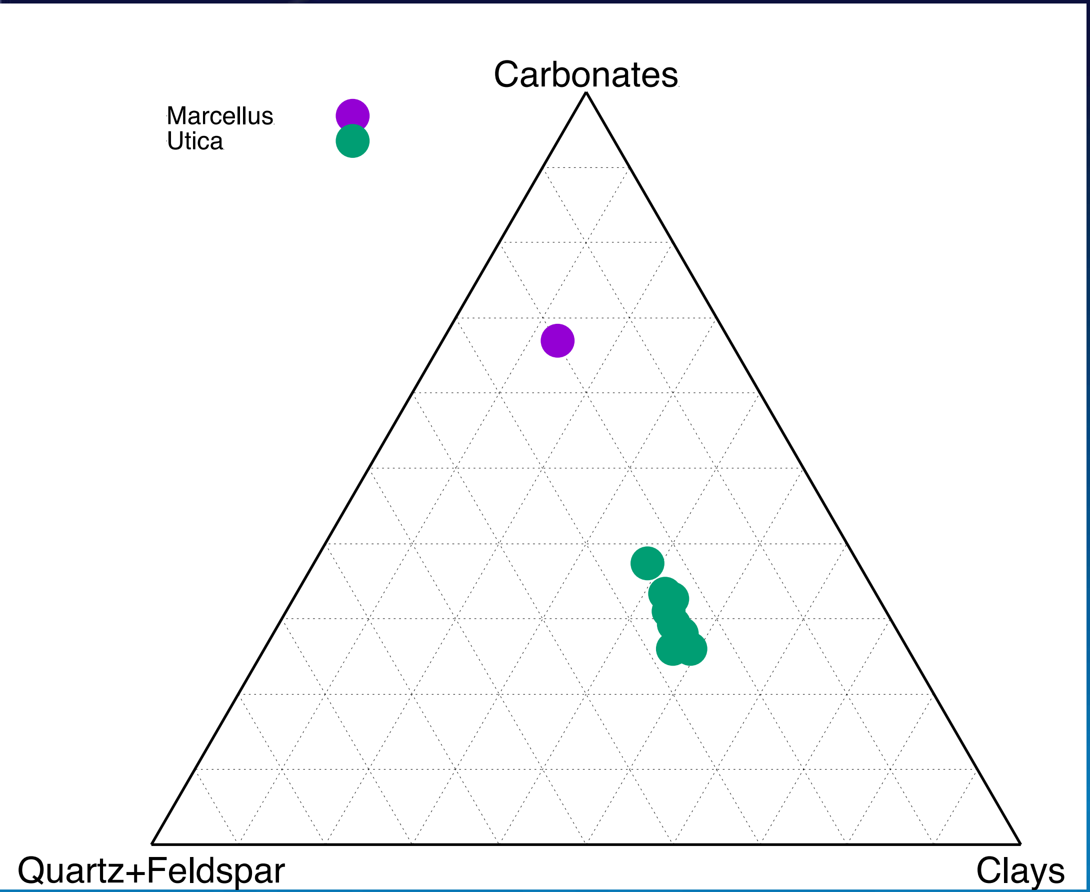




- Max Pressure: 34.5 MPa (5,000 psi)
- Max Axial Load: 500 MPa (70,000 psi)
- Max Temperature: 100 °C

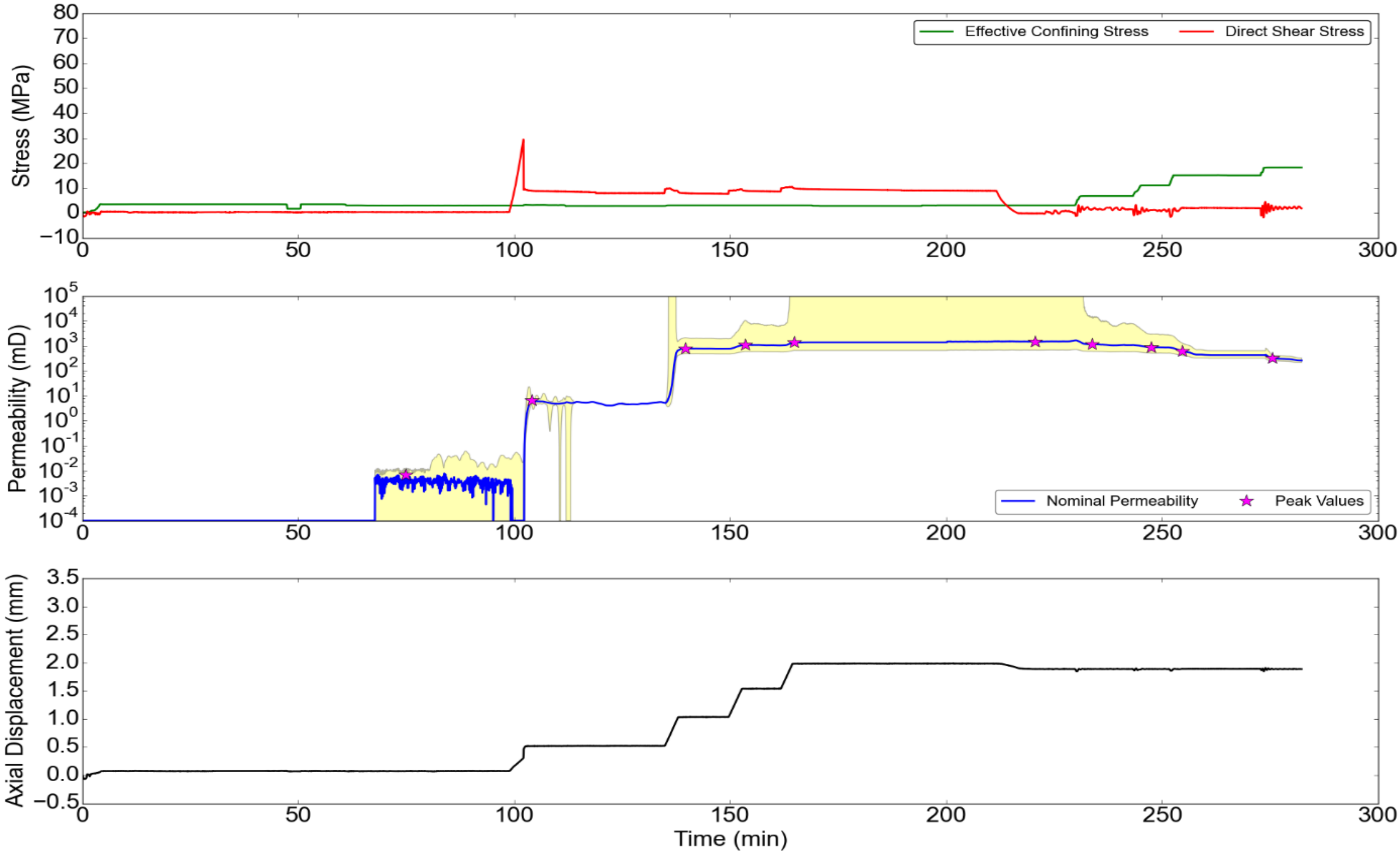
Carey et al., J. Unconv. O&G Res., 2015; Frash et al. (2016) JGR; Frash et al. (2017) IJGGC

Methodology



- Samples of Marcellus shale (outcrop) and Utica shale (core) and : 2.5x2.5 cm cylinders
- Confining pressure from 3.5 to 30 MPa (500 to 4300 psi)
- Room temperature
- Permeability from continuously injected water
- Fracture geometry continuously monitored with x-ray radiography

Low Confining Pressure: 3.5 MPa



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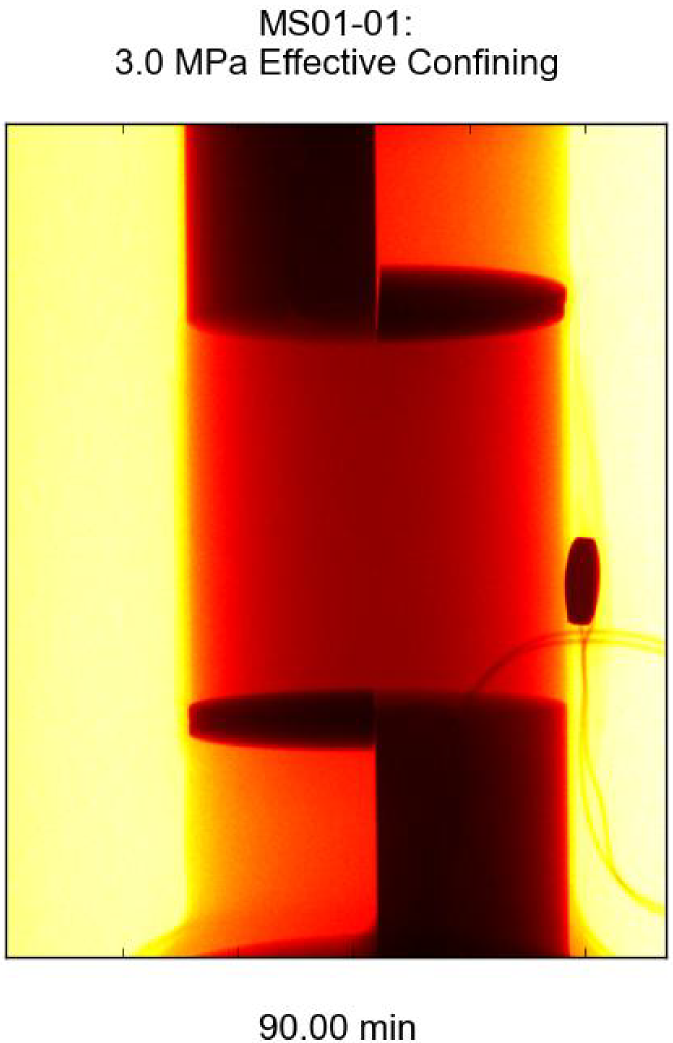
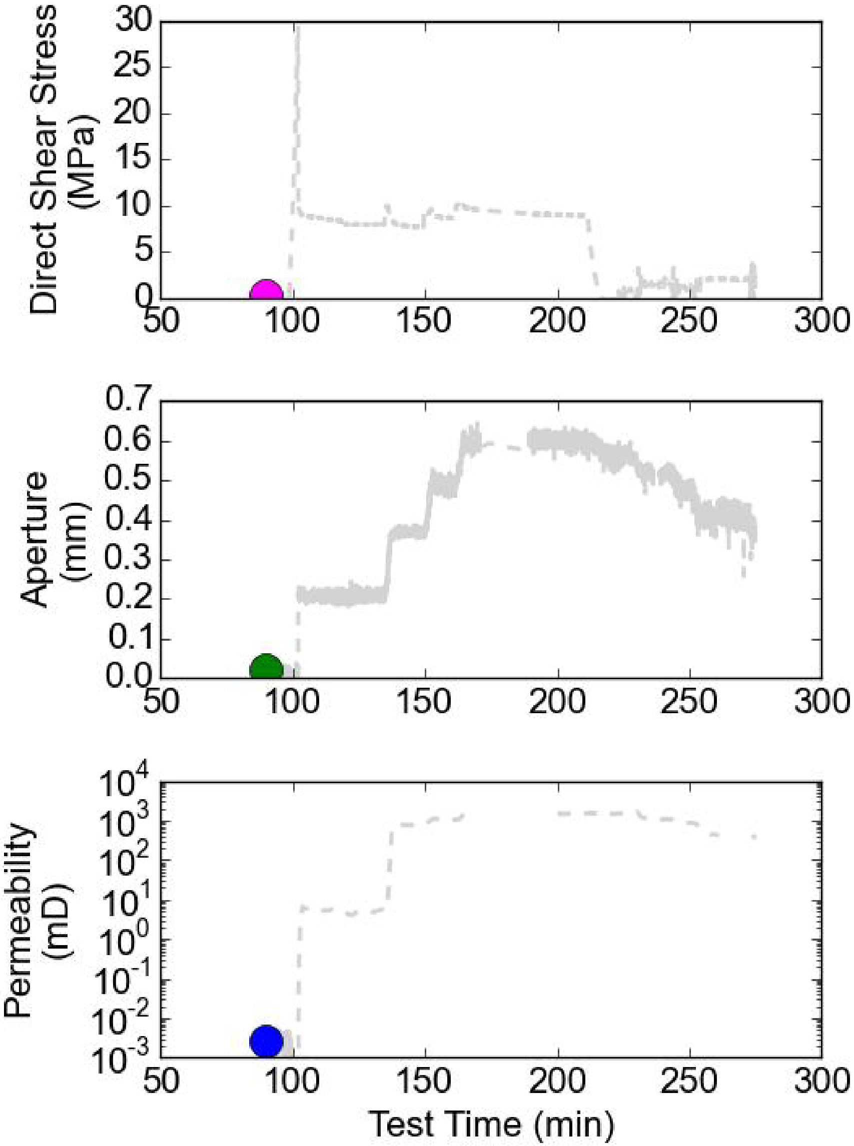
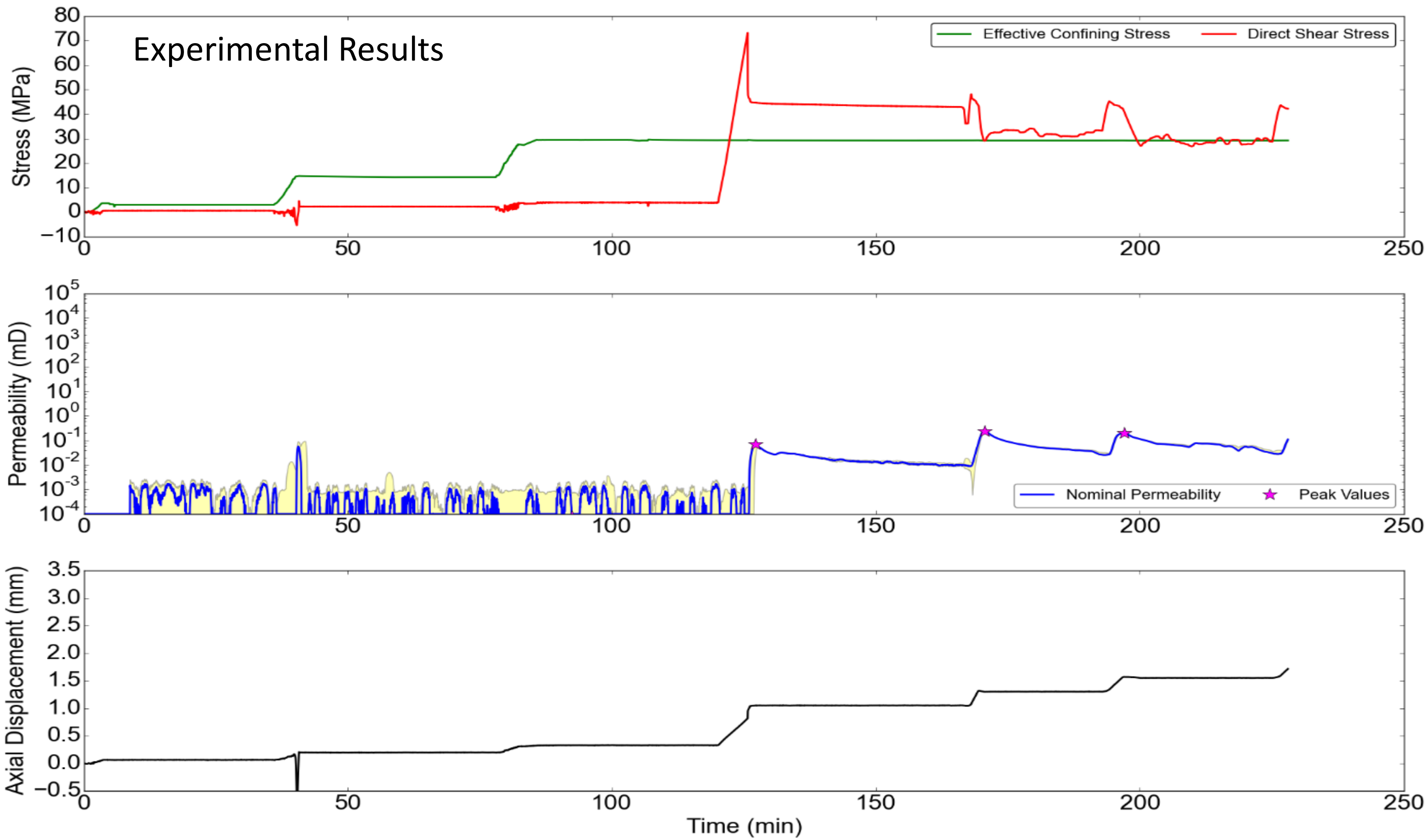




False-Color X-ray Radiography

High Confining Pressure: 30 MPa

Marcellus: Q+F=20%, Carbonate=67%, Clay=13%



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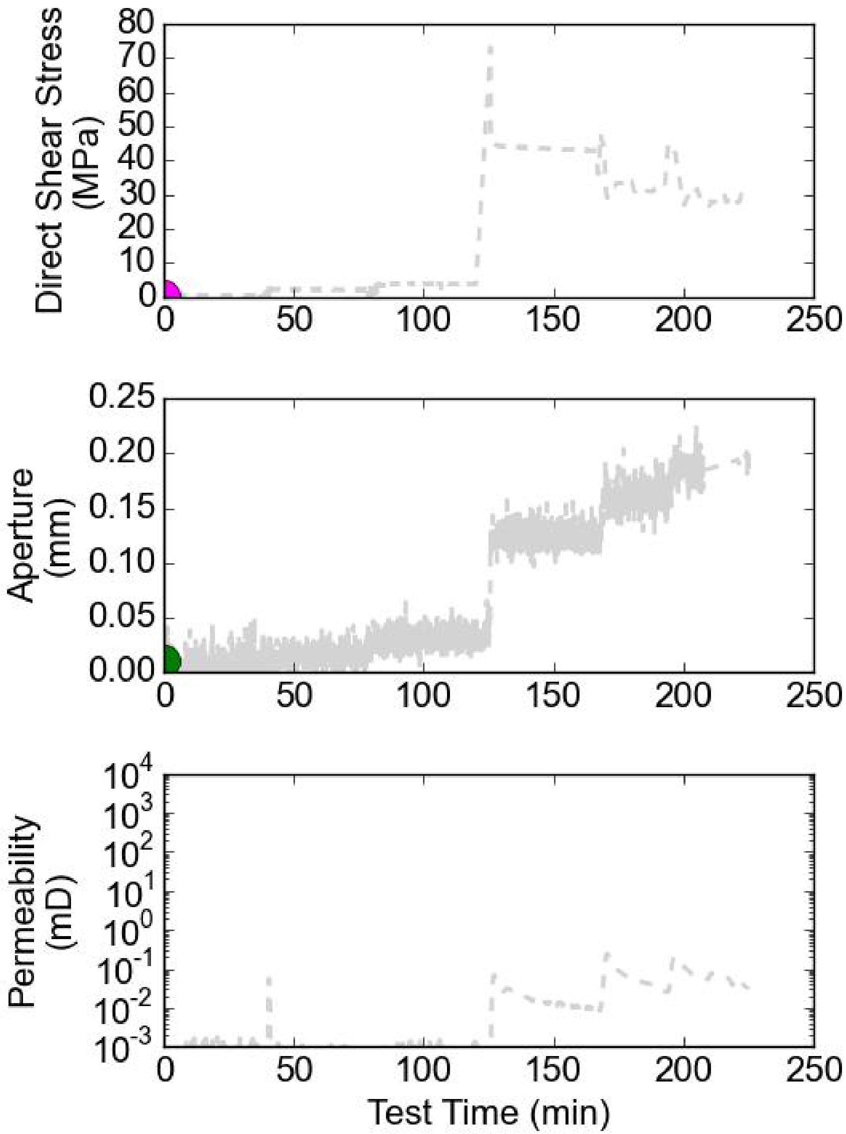

Marcellus Shale Radiography

Carbonate Facies

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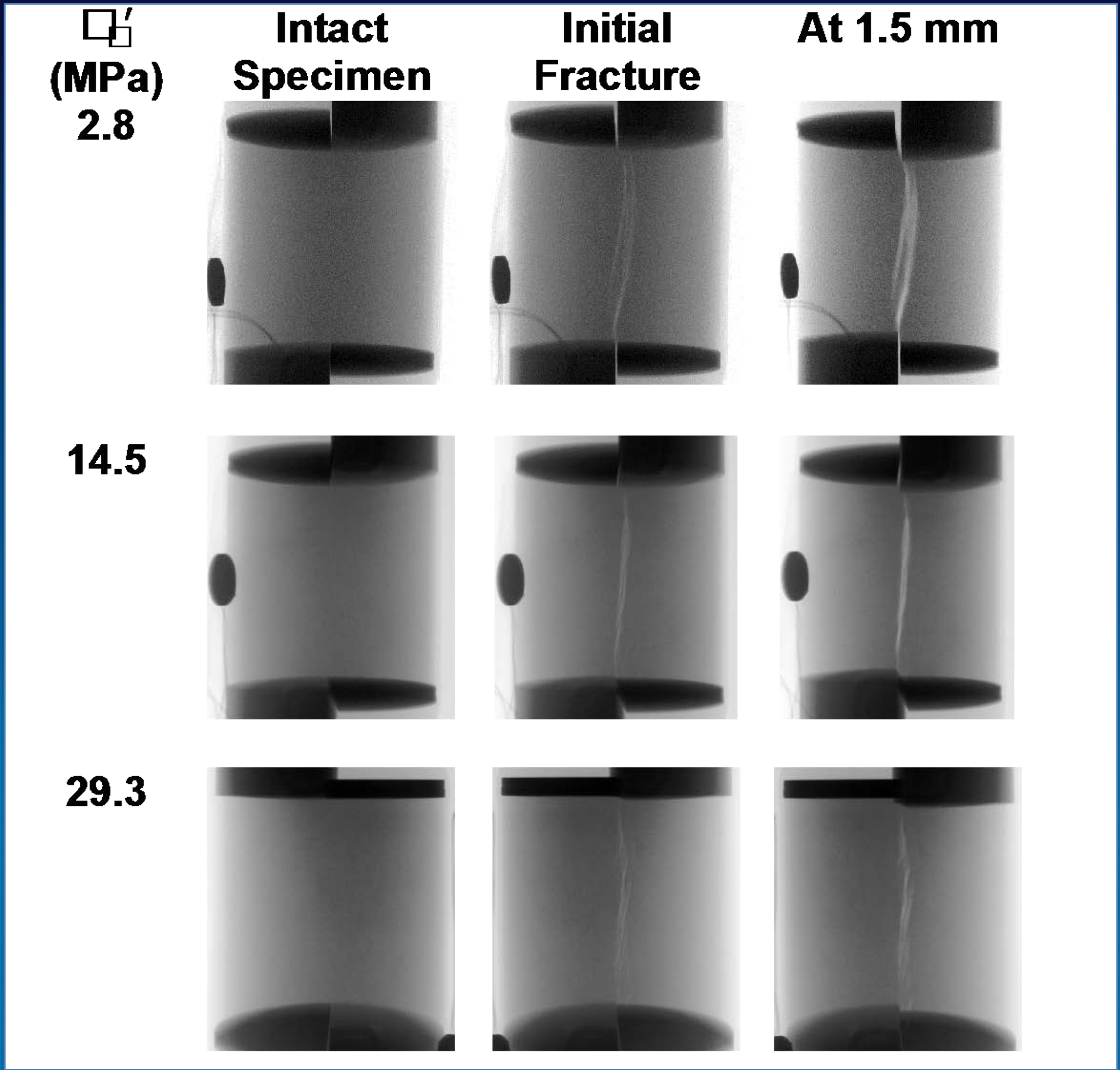
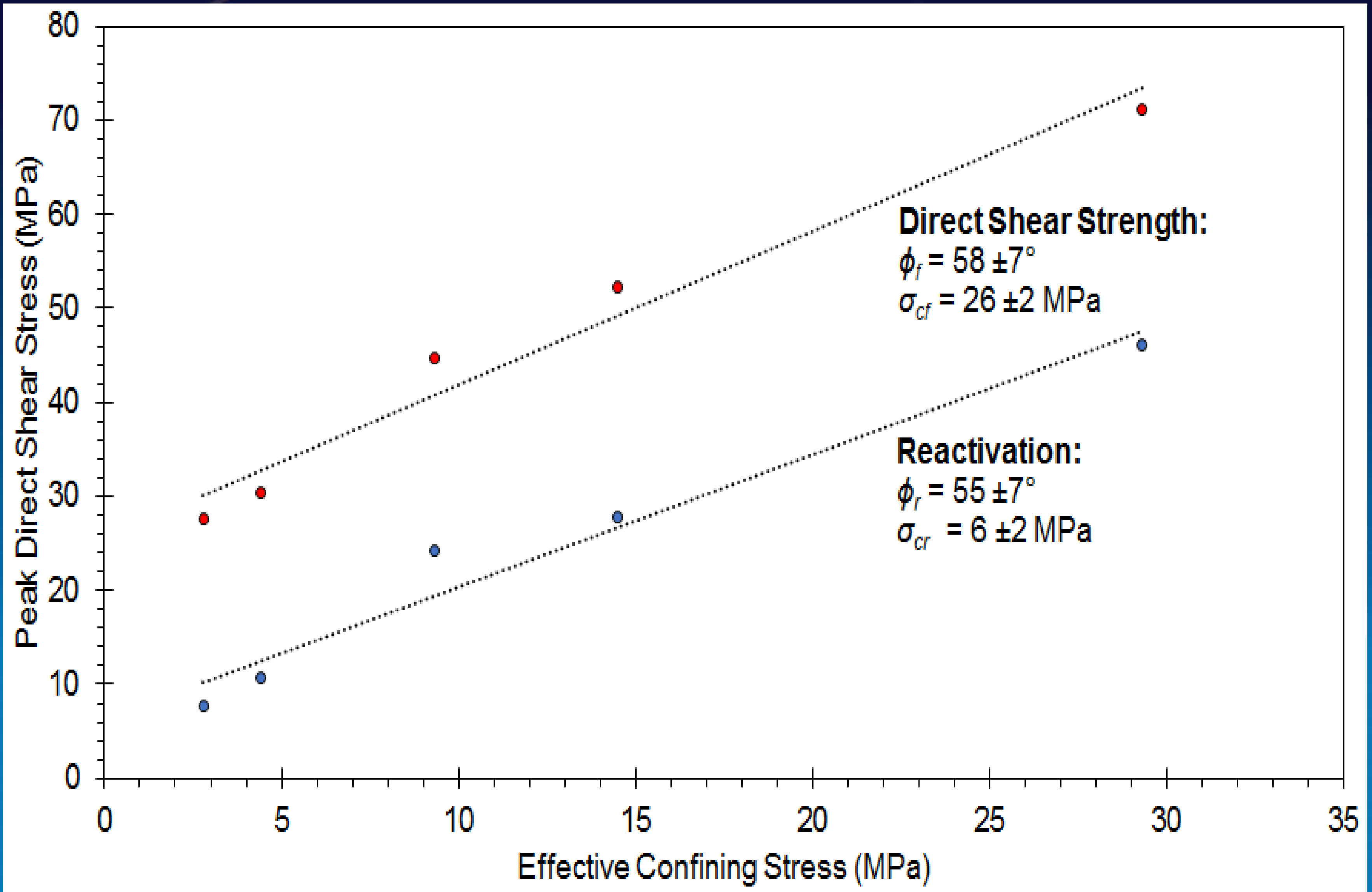
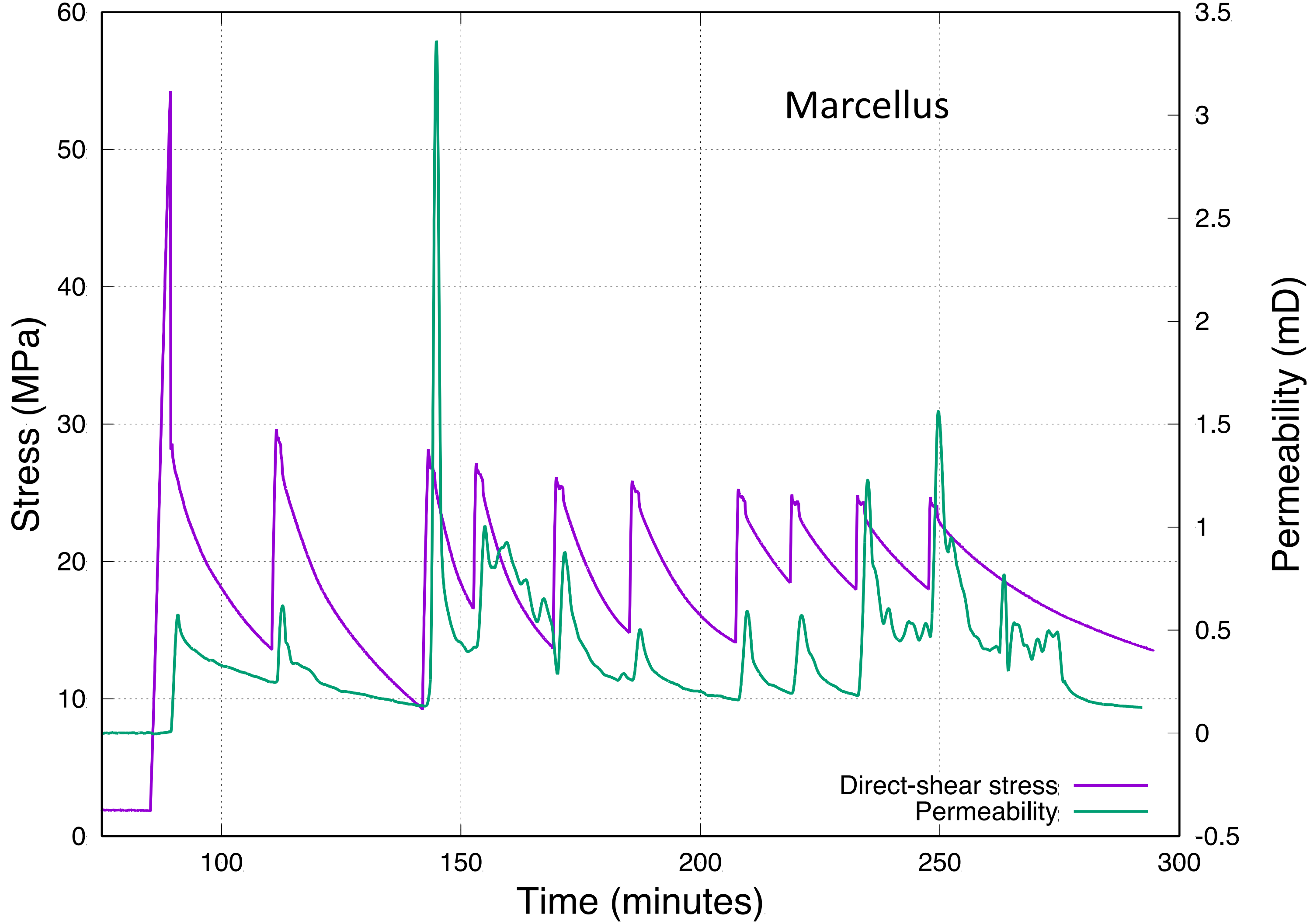


Marcellus Shear Strength

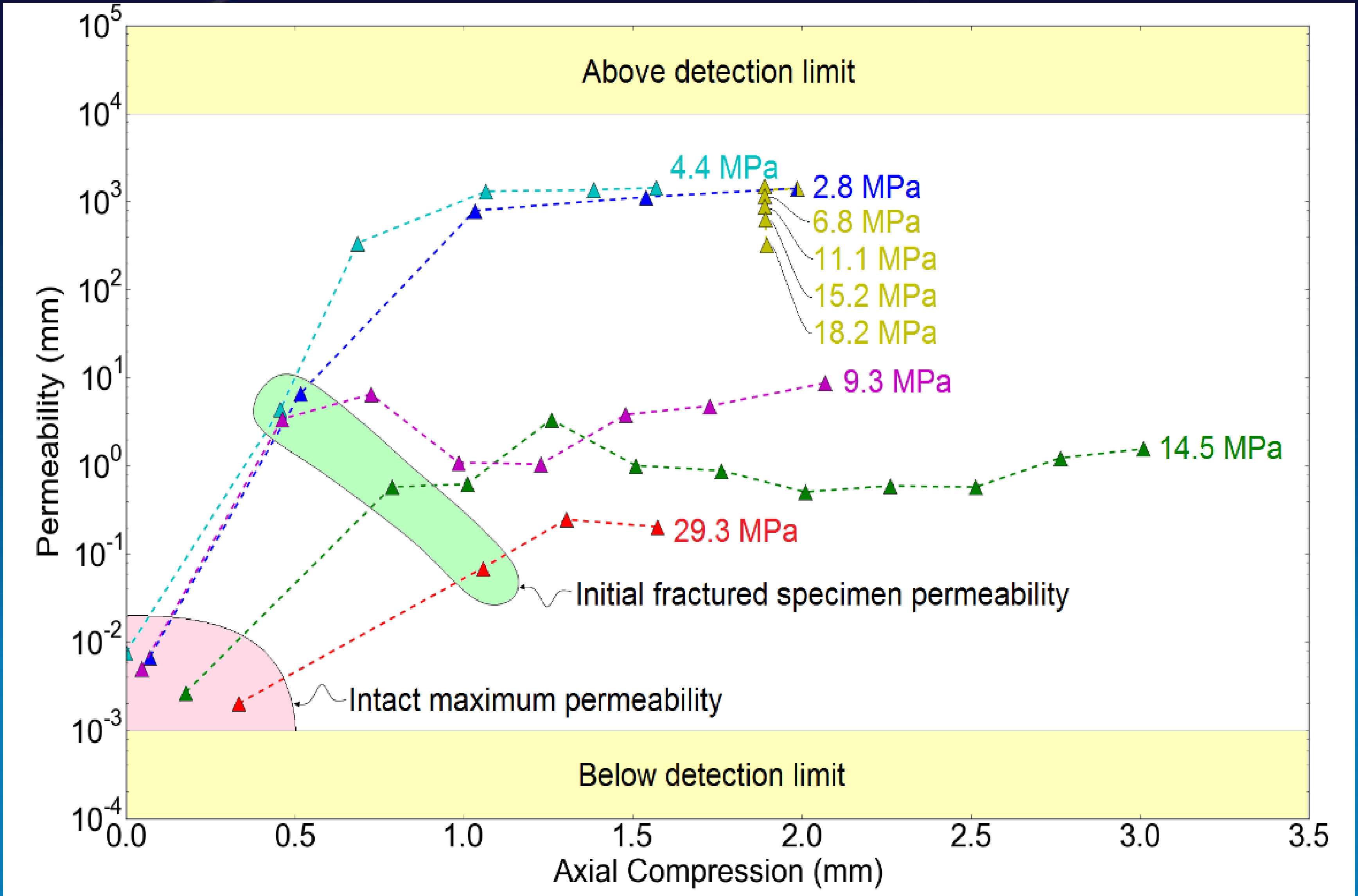


Permeability and Restimulation



Marcellus Shale Summary

Carbonate Facies



Accomplishments to Date

- Developed an experimental system capable of simultaneously measuring and visualizing fracture-permeability relations
- Measured permeability of shear fractured Utica and Marcellus shale
  – Transition from high permeability at shallow depths (brittle) to low permeability at greater depth
- Measured hydrocarbon production with high-P/T microfluidics system
  – Significantly enhanced production with the use of soluble fracturing fluid (supercritical CO_2)

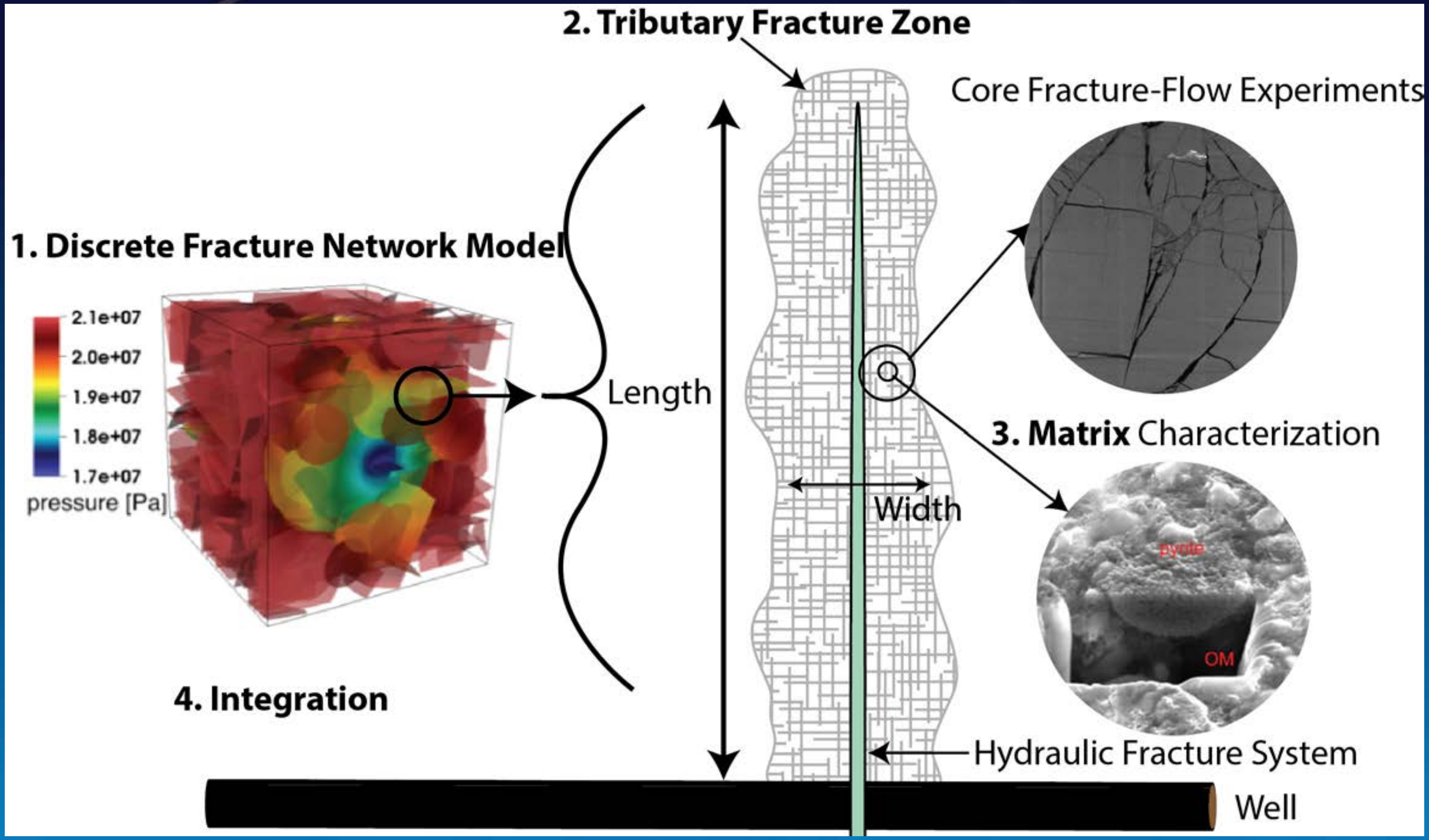
Lessons Learned

- Fracture permeability a strong function of effective stress
  - Changes in effective stress are less impactful
  - Restimulation of fractures can be short-lived
- Previous tectonic and burial history may control fracture productivity
- Impact of lithology (clay vs. carbonate vs. quartz) has not yet been determined
- Impact of heterogeneity (bedding, pre-existing fractures) has not been determined
- Big challenge: net behavior of heterogeneous shale

Synergy Opportunities

- Marcellus Shale Energy and Environment Laboratory: Work with MSEEL core
  - USEEL and Permian Basin projects also represent good collaboration opportunities
- National Risk Assessment Project: Analysis of leakage risk from caprock
- SubTER: Permeability manipulation
- Other projects in Oil and Gas Fundamental Science Portfolio
  - Emphasizing geochemistry (SLAC), nanopore interactions (Sandia), hydraulic fracturing propagation (LBNL)
- Caprock studies for CO_2 sequestration: Colorado School of Mines, NETL, UT-Austin
- Fracture behavior and stress/strain: Penn State, Clemson, UT-Austin

Project Summary



- Developed fracture permeability data for tributary fracture zone
- Input data for hydrocarbon production from Hongwu's matrix project
- Output results to Satish's discrete fracture network model of reservoir behavior

Appendix

Benefit to the Program

- Measurement of the permeability and multiphase flow behavior in small-scale fractures comprising the tributary fracture zone
- Improving the efficiency of hydraulic fracturing through production curve analysis
- Determination of key mechanisms controlling unconventional oil and gas migration
- Development of tools to analyze production cures and thereby enhance hydrocarbon production

Project Overview
Goals and Objectives

- Quantification of fracture-network permeabilities
  – Use state-of-the-art facilities to measure and characterize permeability at reservoir conditions
- Determine influence of reservoir stress conditions on fracture permeability
  – Fracture-permeability as a function of the conditions of fracture formation (i.e., depth) and as a function of changing stress conditions (potential effect of fracture closure)
- Multiphase fluid flow processes
  – Use high P/T microfluidics system to directly observe and characterize multiphase flow in fractures

Organization Chart

Los Alamos
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EST. 1943

- George Guthrie (Project Lead)
  - Task2: Field-Scale Reservoir Analysis (Satish Karra, PI)
  - Task 4: Fracture Experiments (Bill Carey, PI)
    - Triaxial Direct-Shear Experiments
      Bill Carey
      - Staff
        Luke Frash
    - Multiphase Flow Processes
      Bill Carey
      - Post-doc
        Phong Nguyen
  - Task 5: Shale Matrix Properties (Hongwu Xu, PI)

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Gantt Chart

		Phase 1			Phase 2			
			FY15		FY15	FY16		
Task		Q1	Q2	Q3	Q4	Q5	Q6	
3.1	Project Management							
3.2	Sample Acquisition							
3.3	Fracture Generation							
3.4	Fracture Characterization							
3.5	Fracture Permeability							
3.6	Fracture Penetration							
3.7	Fracture Surface Area							
3.8	Integration							
	Cost	$78k	$78k	$78k	$78k	$78k	$78k	$468k

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Publications 2016/2017

Supported in total or in part by this project

- Frash, L. P., J. W. Carey, T. Ickes, and H. S. Viswanathan (2017) Caprock integrity susceptibility to permeable fracture creation, International Journal of Greenhouse Gas Control, 64, 60 – 72.
- Frash, L. P., J. W. Carey, T. Ickes, M. L. Porter, and H. S. Viswanathan, Permeability of fractures created by triaxial direct shear and simultaneous x-ray imaging, in 51th US Rock Mechanics / Geomechanics Symposium held in San Francisco, CA, USA, 26-28 June 2017, p. 5, 2017.
- Carey, J. W., Frash, L. P., and Viswanathan, H. S. (2016). Dynamic Triaxial Study of Direct Shear Fracturing and Precipitation-Induced Transient Permeability Observed by In Situ X-Ray Radiography. In 50th US Rock Mechanics/Geomechanics Symposium held in Houston, Texas, USA, 26-29 June 2016.
- Frash, L. P., Carey, J. W., Ickes, T., and Viswanathan, H. S. (2016). High-stress triaxial direct-shear fracturing of Utica shale and in situ X-ray microtomography with permeability measurement. Journal of Geophysical Research.
- Jiménez-Martínez, J., Porter, M. L., Hyman, J. D., Carey, J. W., and Viswanathan, H. S. (2016). Mixing in a three-phase system: Enhanced production of oil-wet reservoirs by CO2 injection. Geophysical Research Letters, 43:196-205.