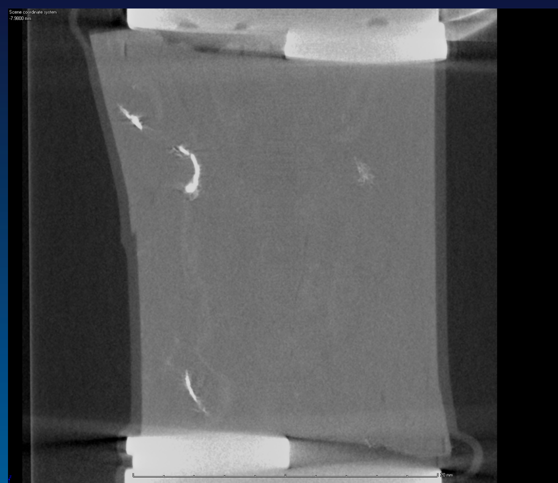
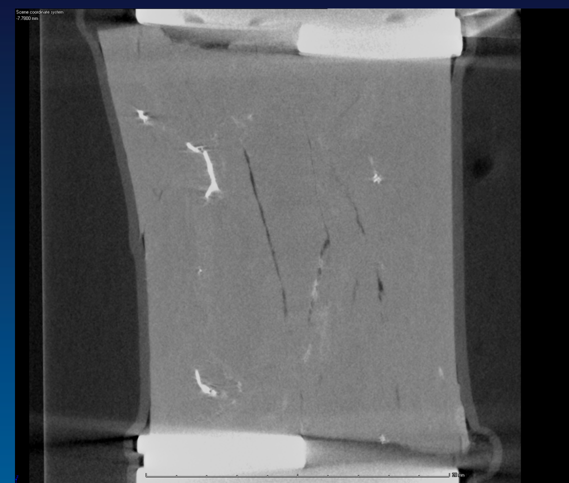
Wellbore and Seal Integrity

Experimental Studies of Fracture and Permeability of Shale Caprock

Project Number: LANL FE 10-003 Task 1





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Earth & Environmental Sciences

Los Alamos National Laboratory

U.S. Department of Energy

National Energy Technology Laboratory

Carbon Storage R&D Project Review Meeting

Transforming Technology through Integration and Collaboration

August 18-20, 2015

Motivation & Program Benefits

- Develop long-term predictive models for use in risk-based analyses of carbon storage systems
- What are the consequences of stress-induced damage to wellbore and caprock seals?
- Develop and validate technologies to ensure 99% storage permanence.

Goals & Objectives

- Integrate field, experimental and modeling methods to develop a fundamental understanding of how CO_2-water interactions in combination with in situ and applied stresses enhances or degrades the integrity of reservoir seals including caprock and wellbore systems
  - Field studies of cement-steel-caprock samples obtained from CO_2-containing reservoirs
  - Experimental studies of the impact of CO_2 flow on leakage through reservoir seals
  - Experimental studies of the impact of mechanical stress on leakage processes
  - Numerical models to predict damage and leakage in wellbore and caprock seals

Technical Status: Wellbore Systems

- Ordinary oilwell cement is a good barrier to CO_2 leakage
- Primary leakage concerns are damaged interfaces: steel-cement, cement-cement and cement-caprock
- Significant experimental and field evidence for self-healing processes that can mitigate leakage
- Important problems remain
  - Coupled steel-cement performance (corrosion)
  - Magnitude of leakage from damaged systems
  - Relation of mechanical stress to damage
  - Coupling of mechanical and chemical processes (long-term integrity)

Technical Status: Caprock

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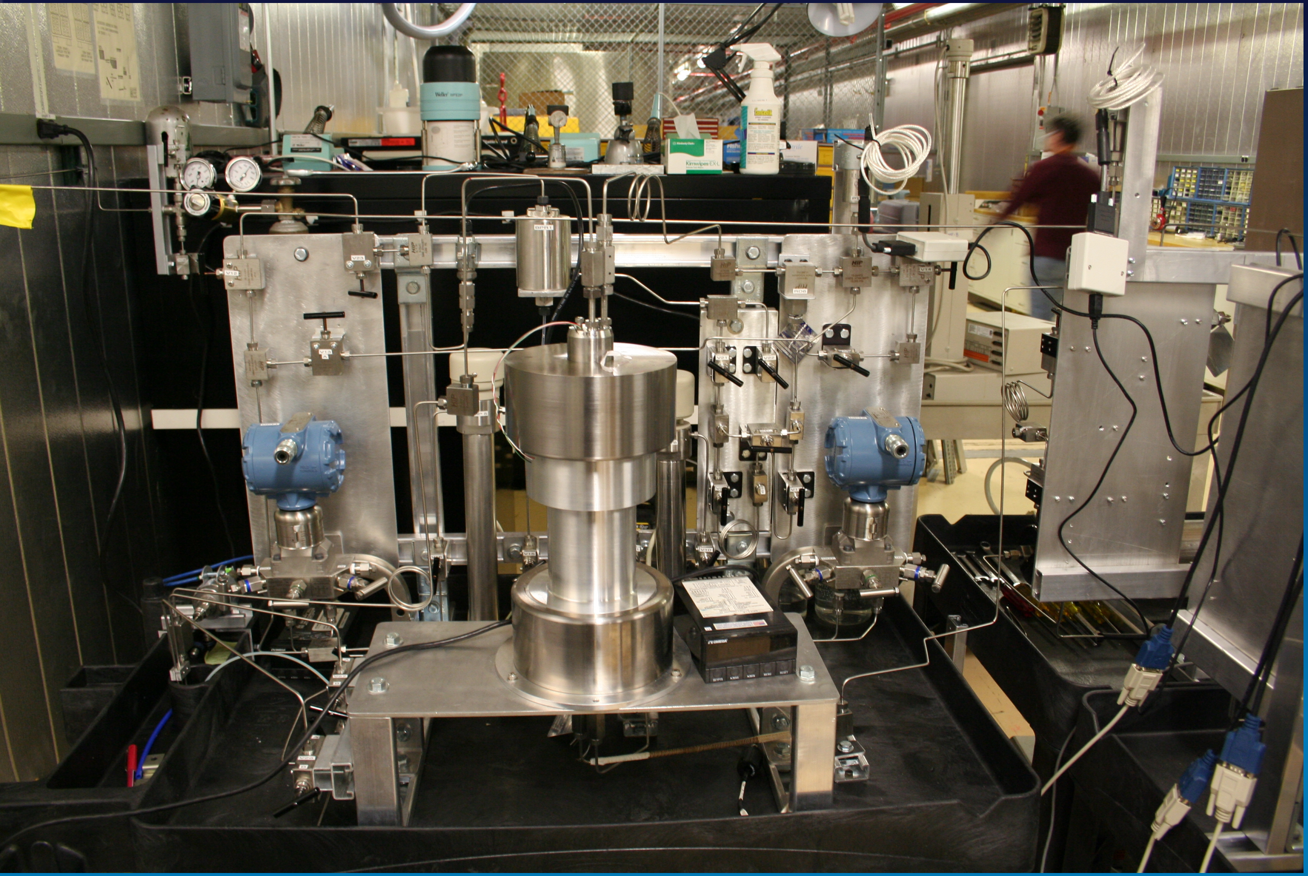
- Failure mechanisms
  - Insufficient continuity of low-permeability barrier
  - Lack of adequate capillary barrier
  - Fracture generation or reactivation
- Most previous laboratory work has focused on assessment of the capillary barrier
- Potential of induced seismicity to damage caprock is the primary motivation for our studies of caprock mechanical-hydrologic behavior
- Little previous work on *consequences* of fracture development in caprock

Technical Status: Caprock

- Our previous triaxial experiments of shale fracture-permeability behavior were conducted at low confining pressure [Carey et al. (2015) J. Unconv. O&G Res; Carey et al. (2015) ARMA; Carey et al. (2014) GHGT]
  - Experiments in compression = very low (< 0.1 mD) permeability
  - Experiments in direct shear
    - Across bedding = maximum of 30 mD
    - Parallel to bedding = maximum of 1 D
- Current work—method development/preliminary results
  - Hydraulic fracture technique
  - In situ fracture generation and imaging
  - High-pressure system behavior

Approach & Methods: Experiments

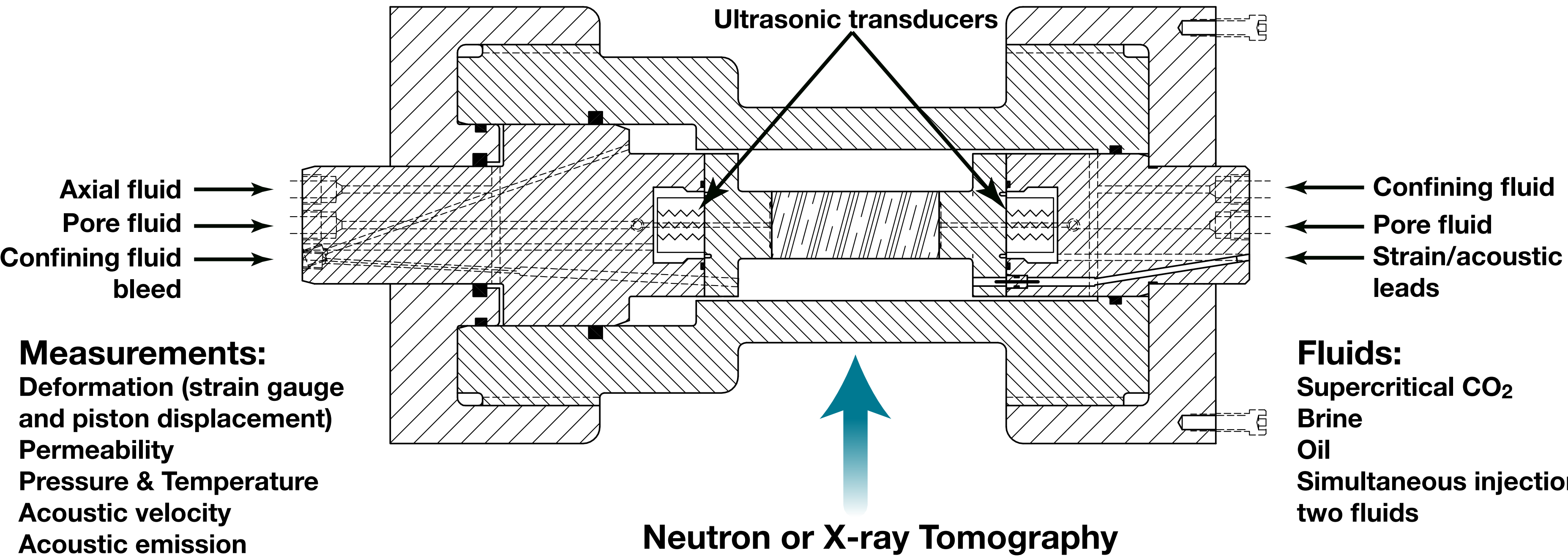


- Triaxial coreflood studies coupled with x-ray tomography
  - New and unique LANL capability
  - Deformation modes: Compression, direct shear, and tensile fractures
- Max Pressure: 5000 psi (34.5 MPa)
- Max Temperature: 100 °C

Carey et al., Journal of Unconventional Oil & Gas Resources, 2015

Approach & Methods: Experiments

Triaxial System: Independent Pore, Confining and Axial Pressure



Measurements:
- Deformation (strain gauge and piston displacement)
- Permeability
- Pressure & Temperature
- Acoustic velocity
- Acoustic emission
- Fluid samples

Fluids:
- Supercritical CO_2
- Brine
- Oil
- Simultaneous injection of two fluids

In Situ Tomography and Triaxial Coreflood Experiments

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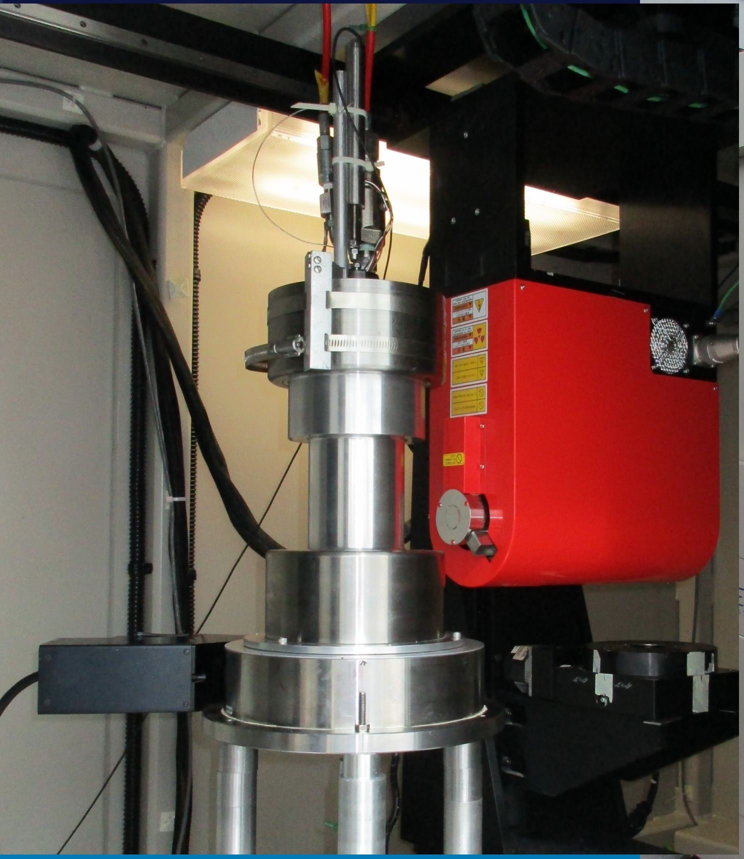
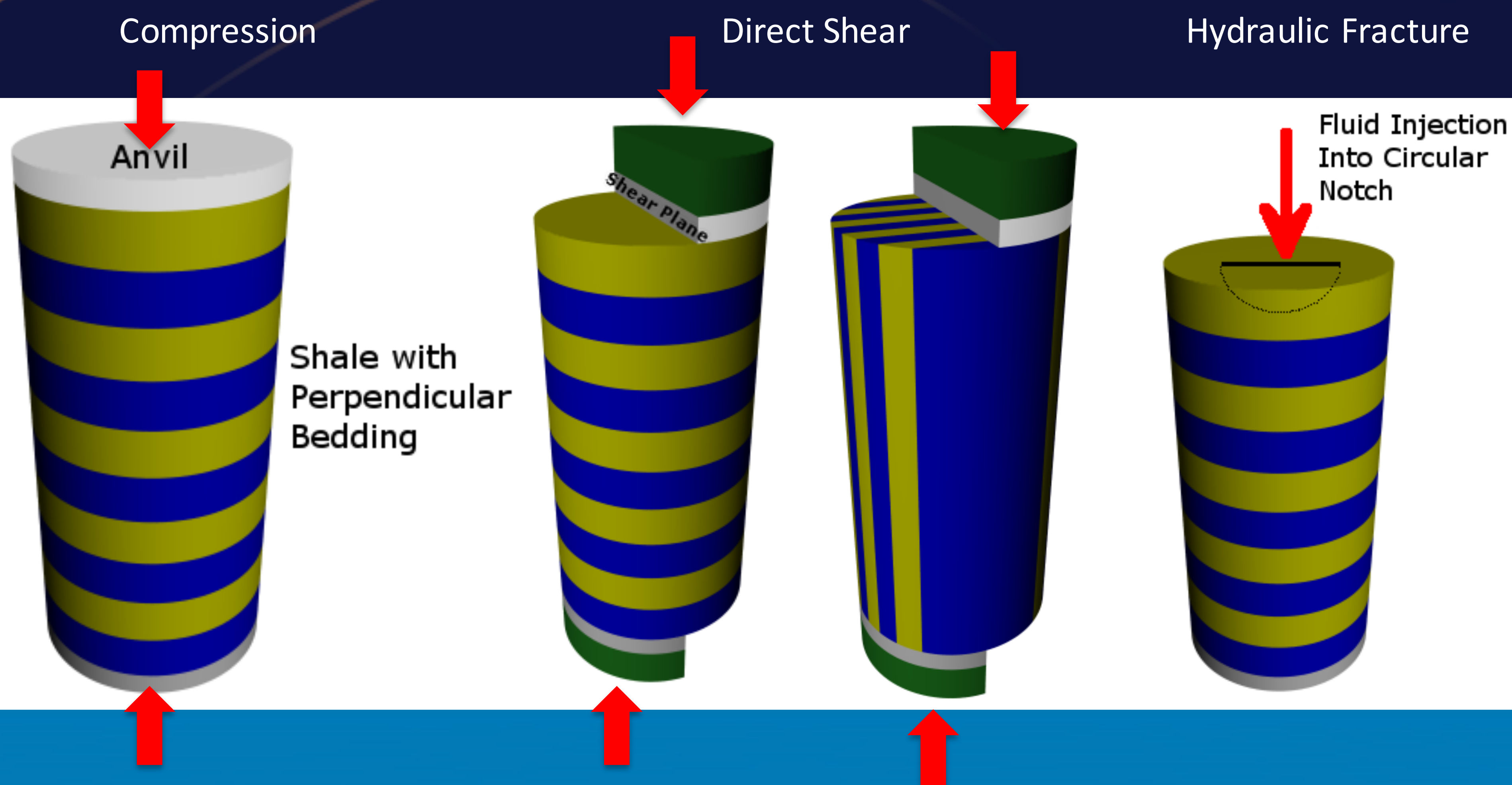


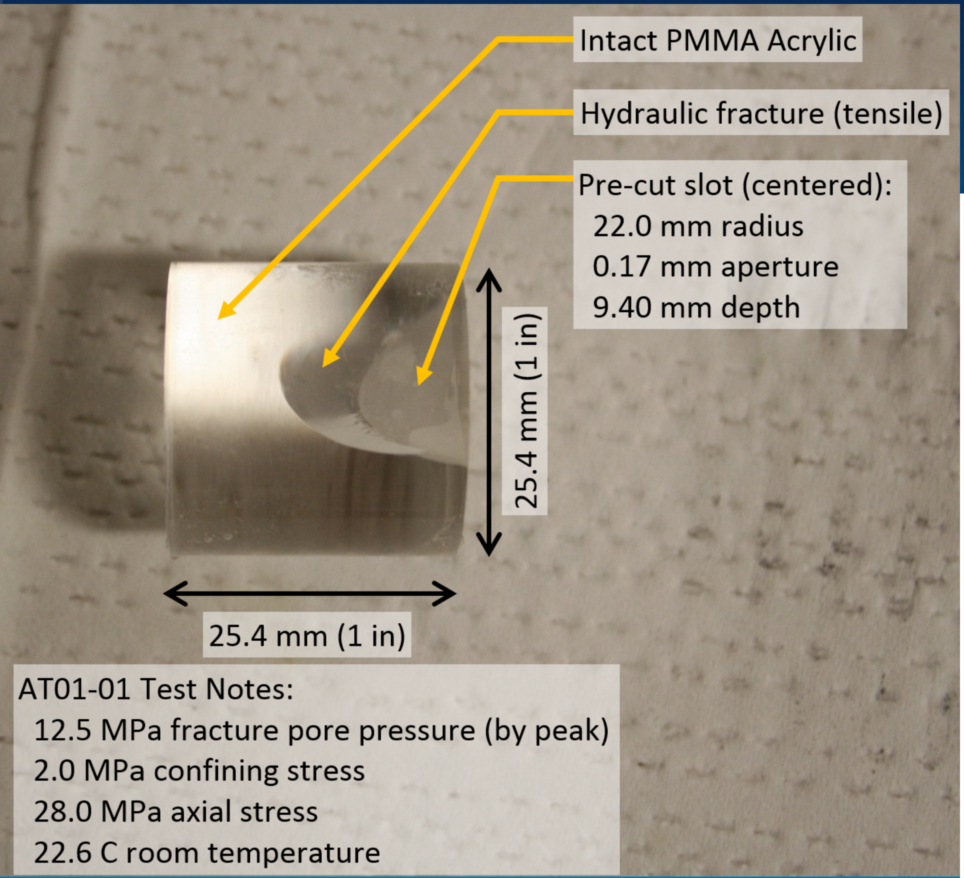
Fracture-Permeability Study Modes



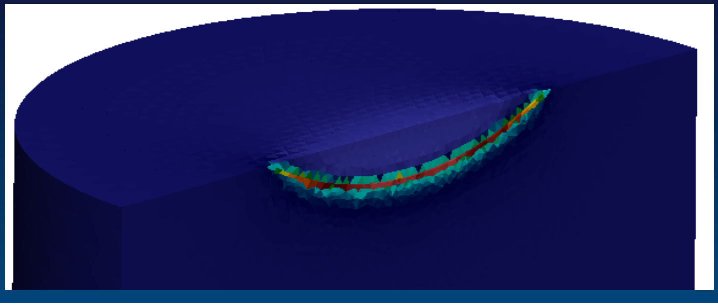
- Samples: Utica Shale
  - Courtesy of Chesapeake Energy
- Experiments at 20-45 ^{o}C and 3.4 - 22 MPa

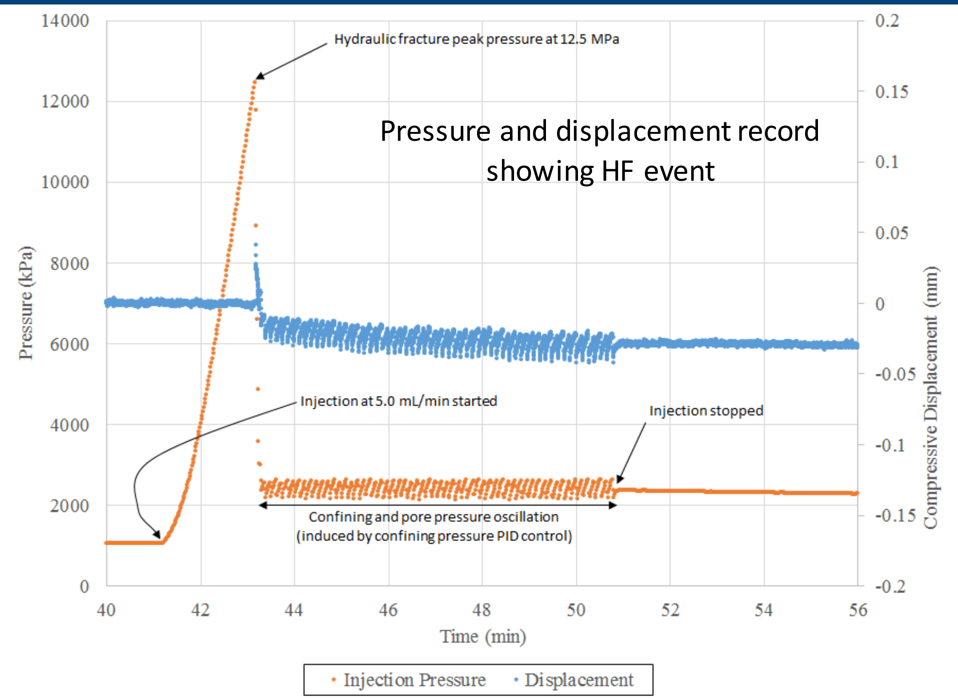
Hydraulic Fracture in Triaxial Device

Frash et al. (submitted) IJRMMS

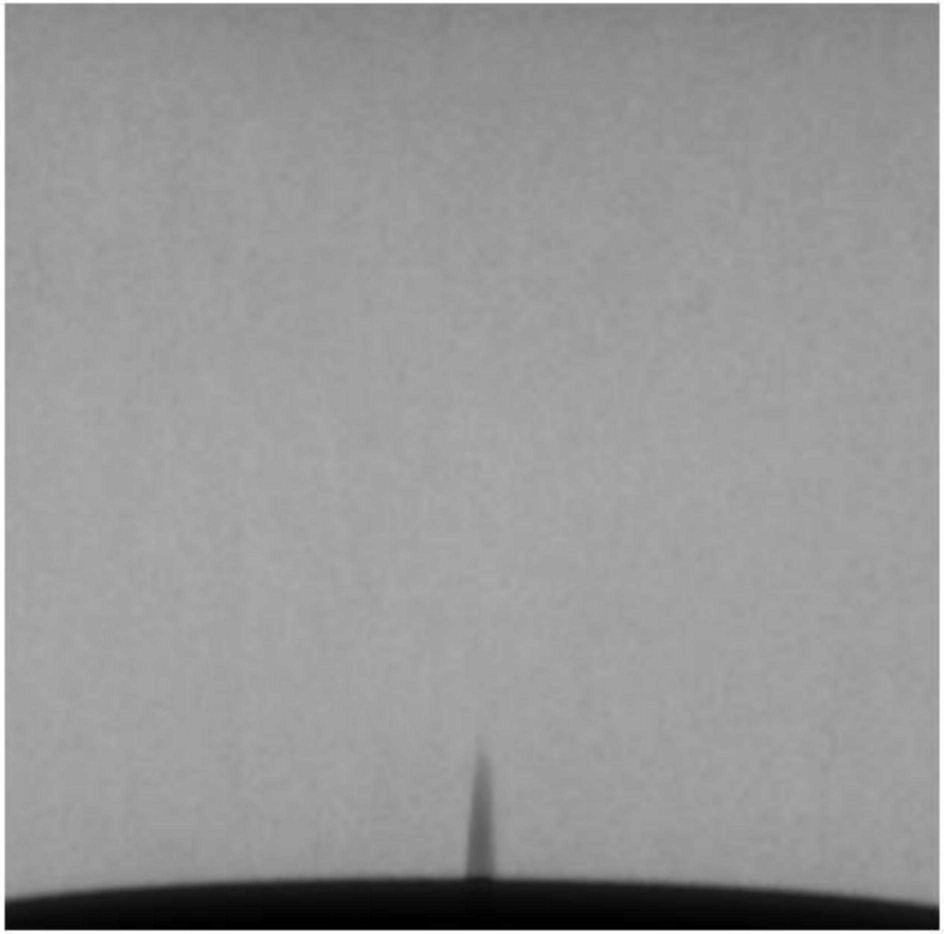


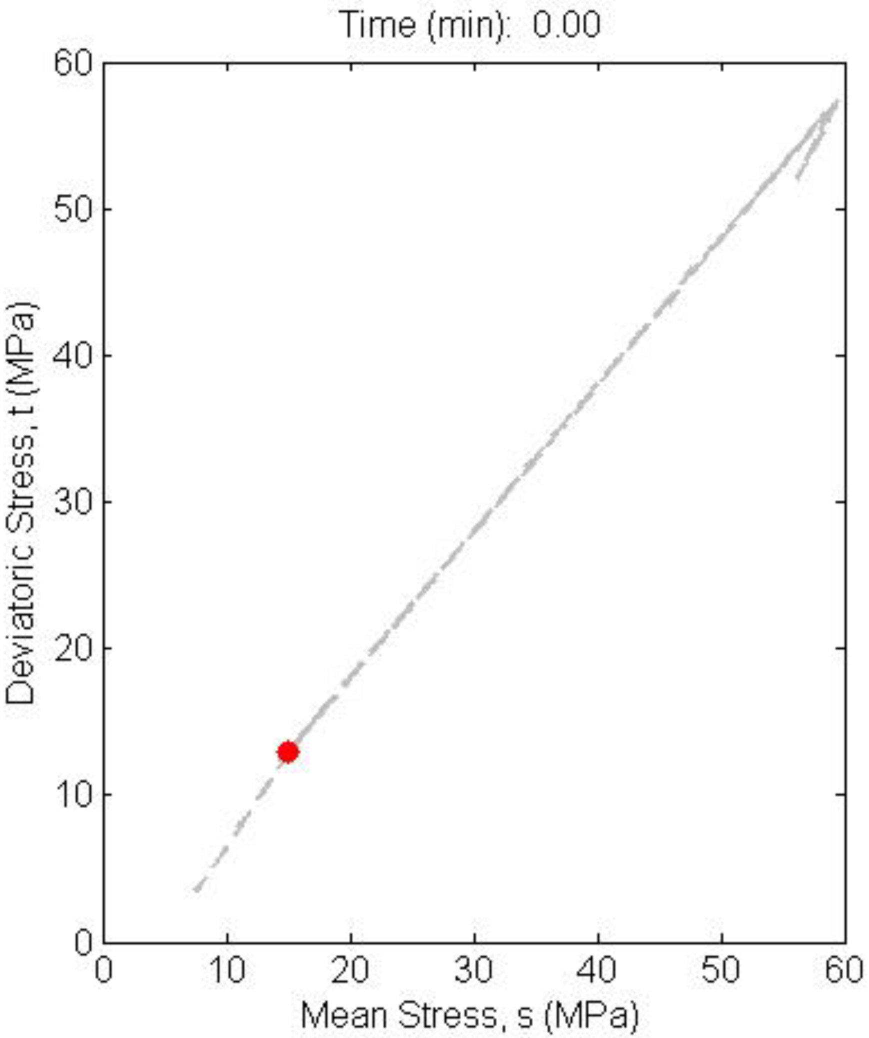
Numerical simulation of stress in slot



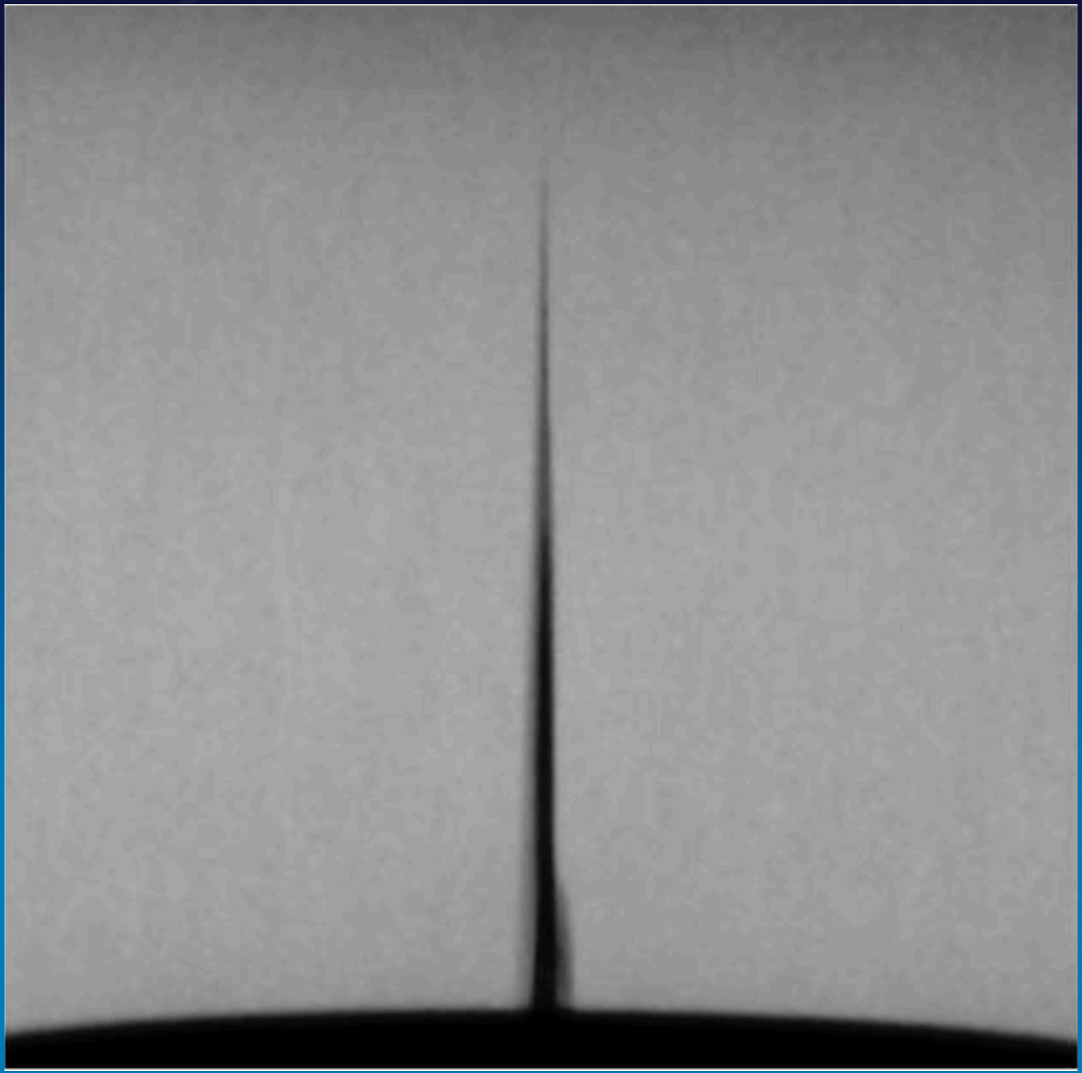


Hydraulic Fracture Acrylic



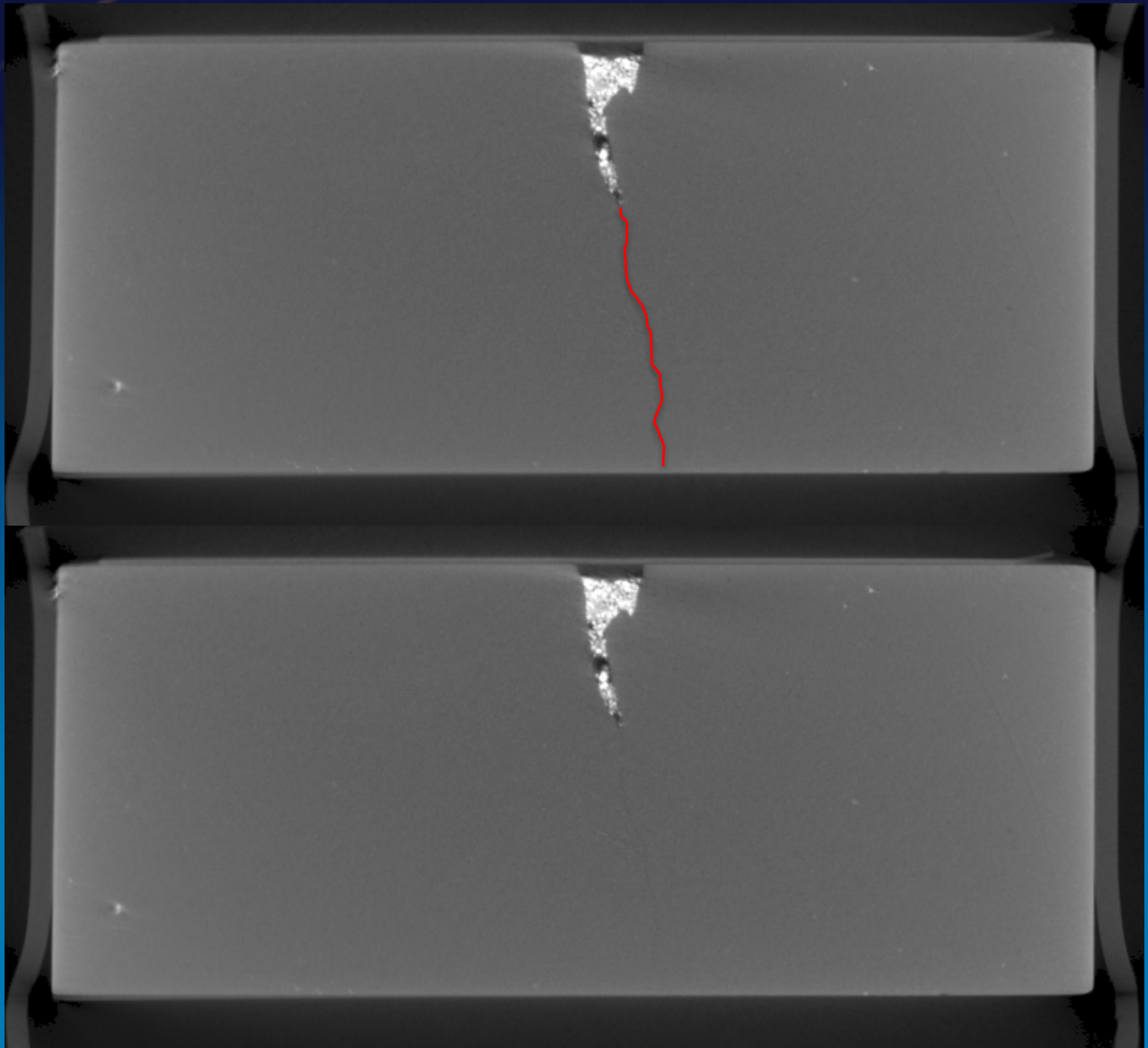


Hydraulic Fracture Acrylic

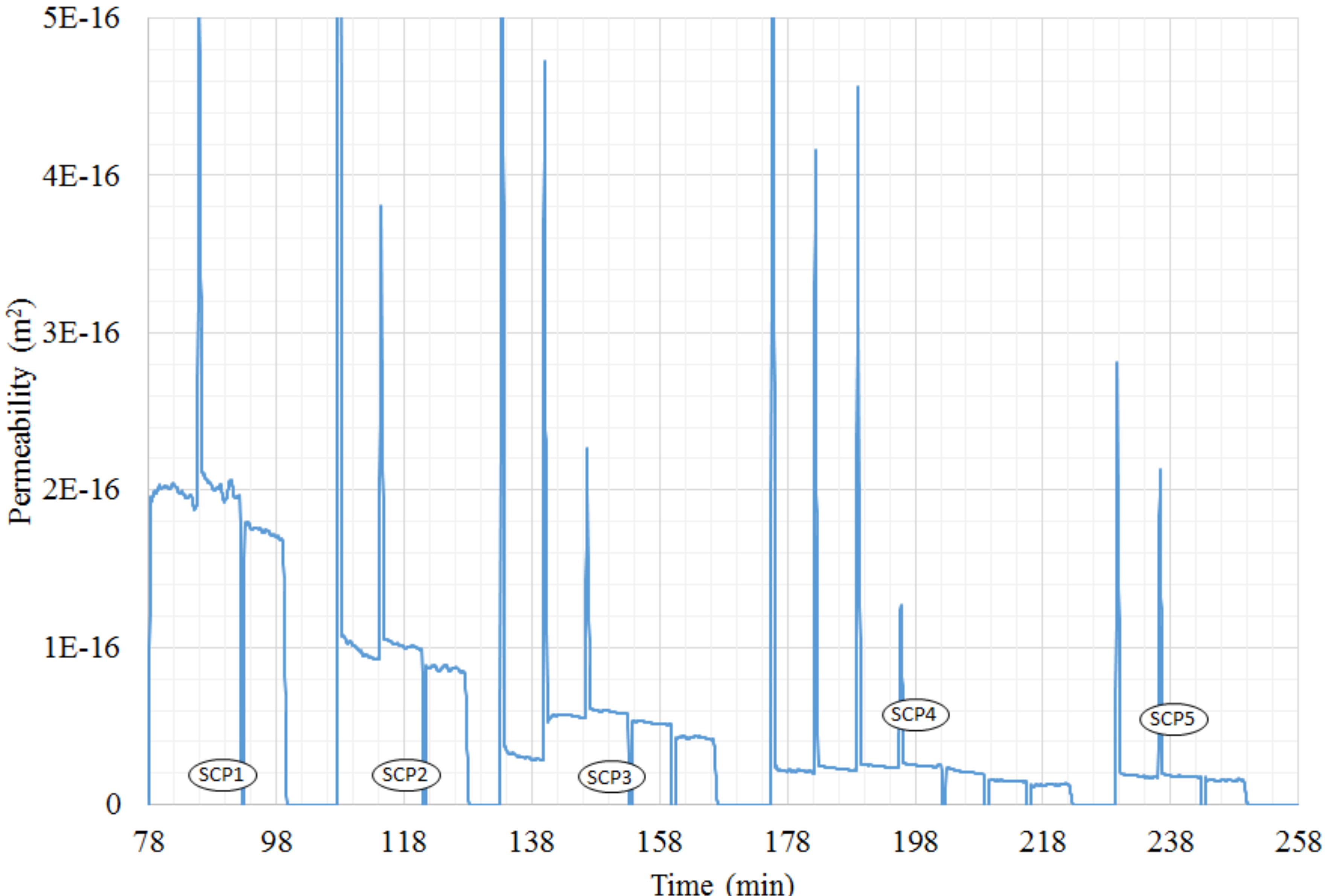


- Fracture initiated with combination of injection pressure and axial load
- $BaCl_2$ used as contrast agent
- Ambient temperature
- Confining = 2 MPa
- Axial = 116 MPa
- Injection = 25 MPa

Tensile Fracture in Shale

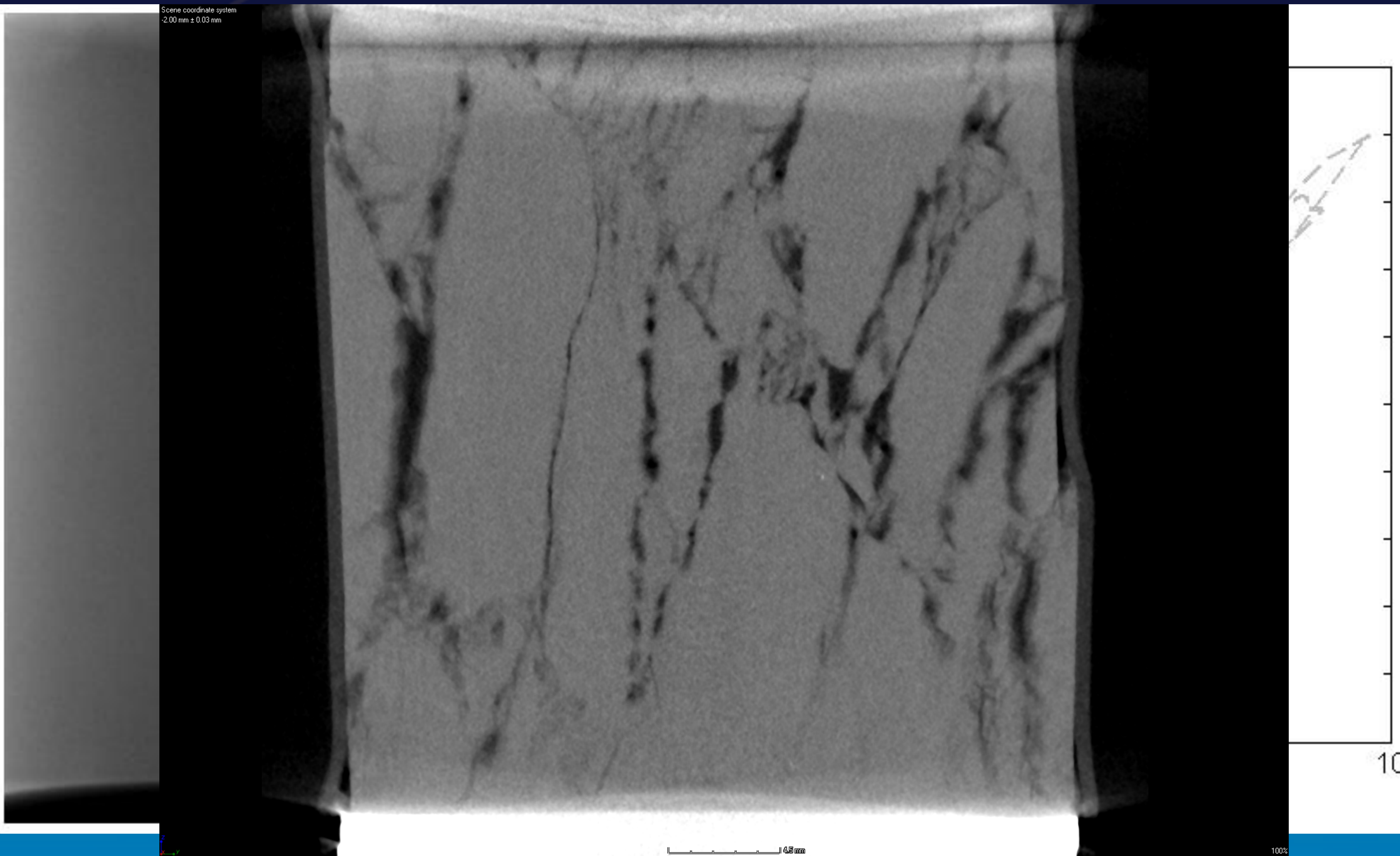


Permeability of tensile fracture



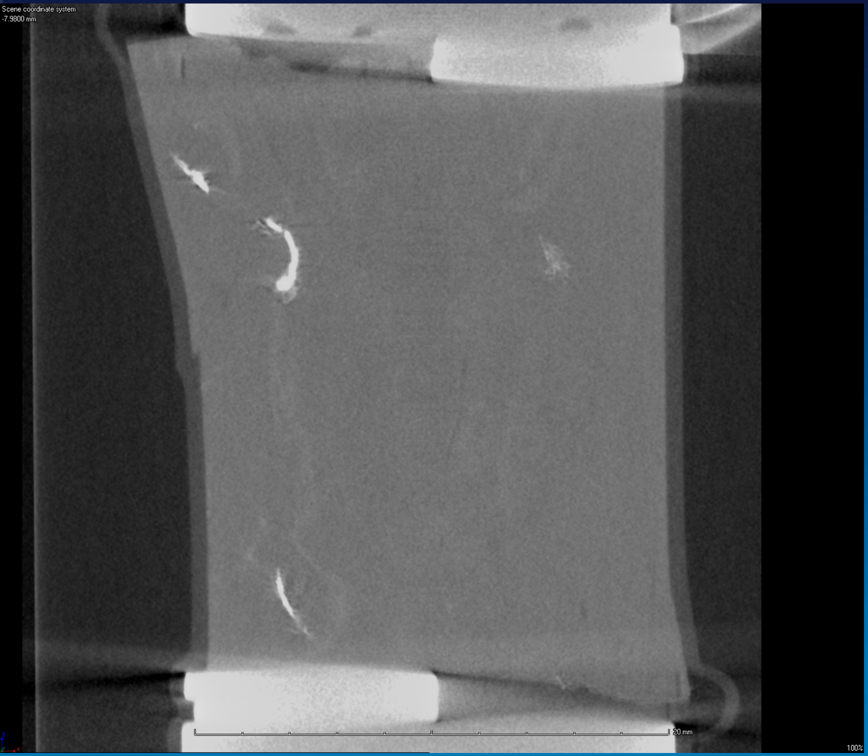
X-ray Videography of Shale

Direct Shear

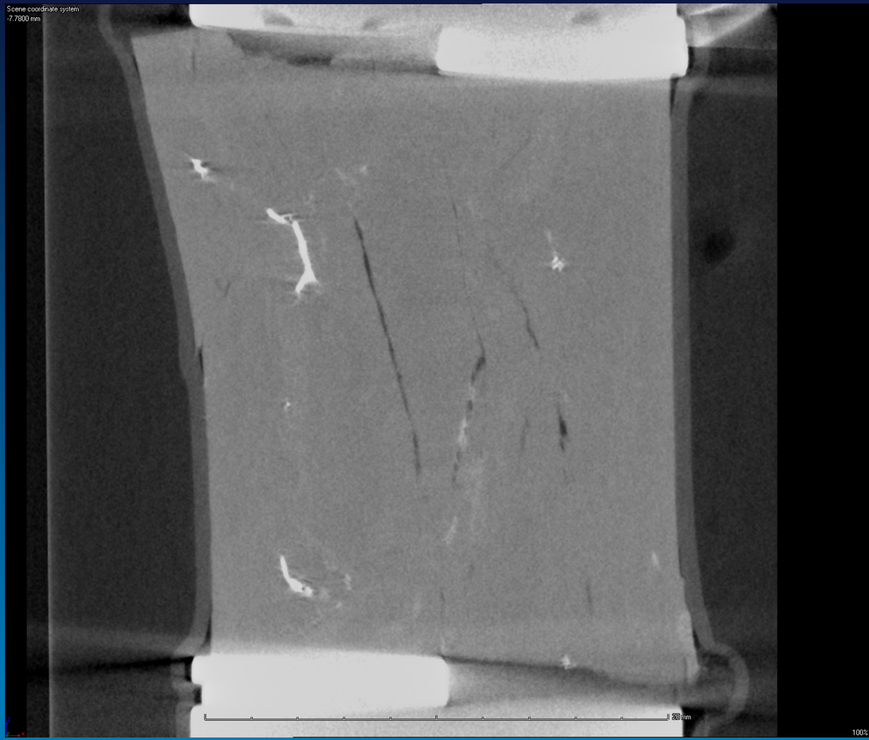


Fracture Apertures at In Situ Conditions: Direct Shear

22 MPa *In Situ Tomogram*

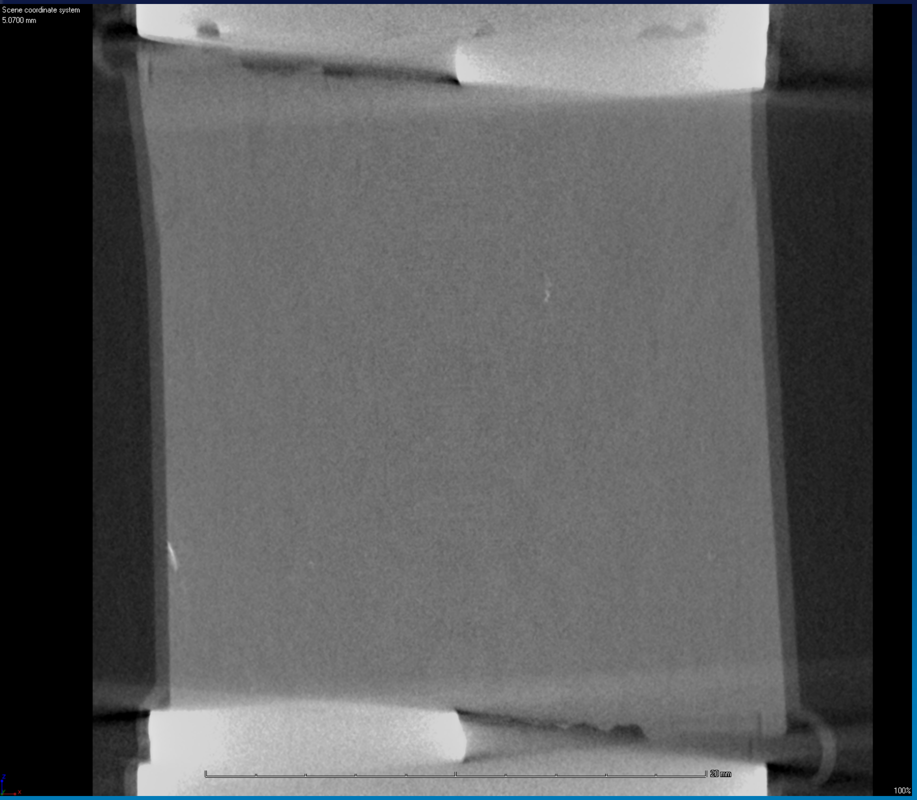


Lab Condition Tomogram

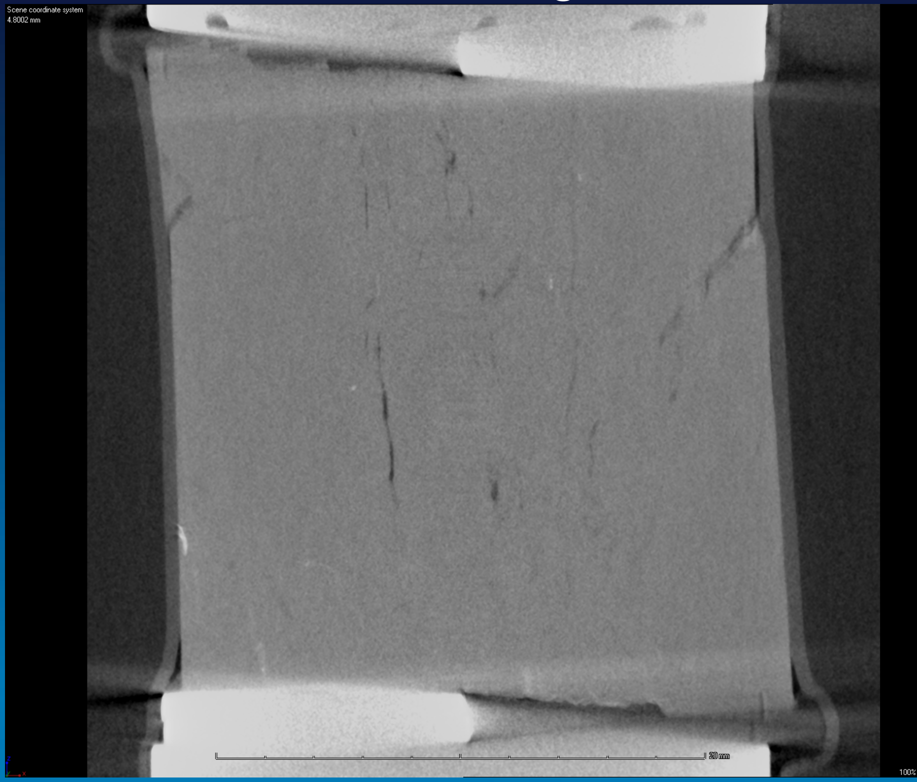


Fracture Apertures at In Situ Conditions: Direct Shear

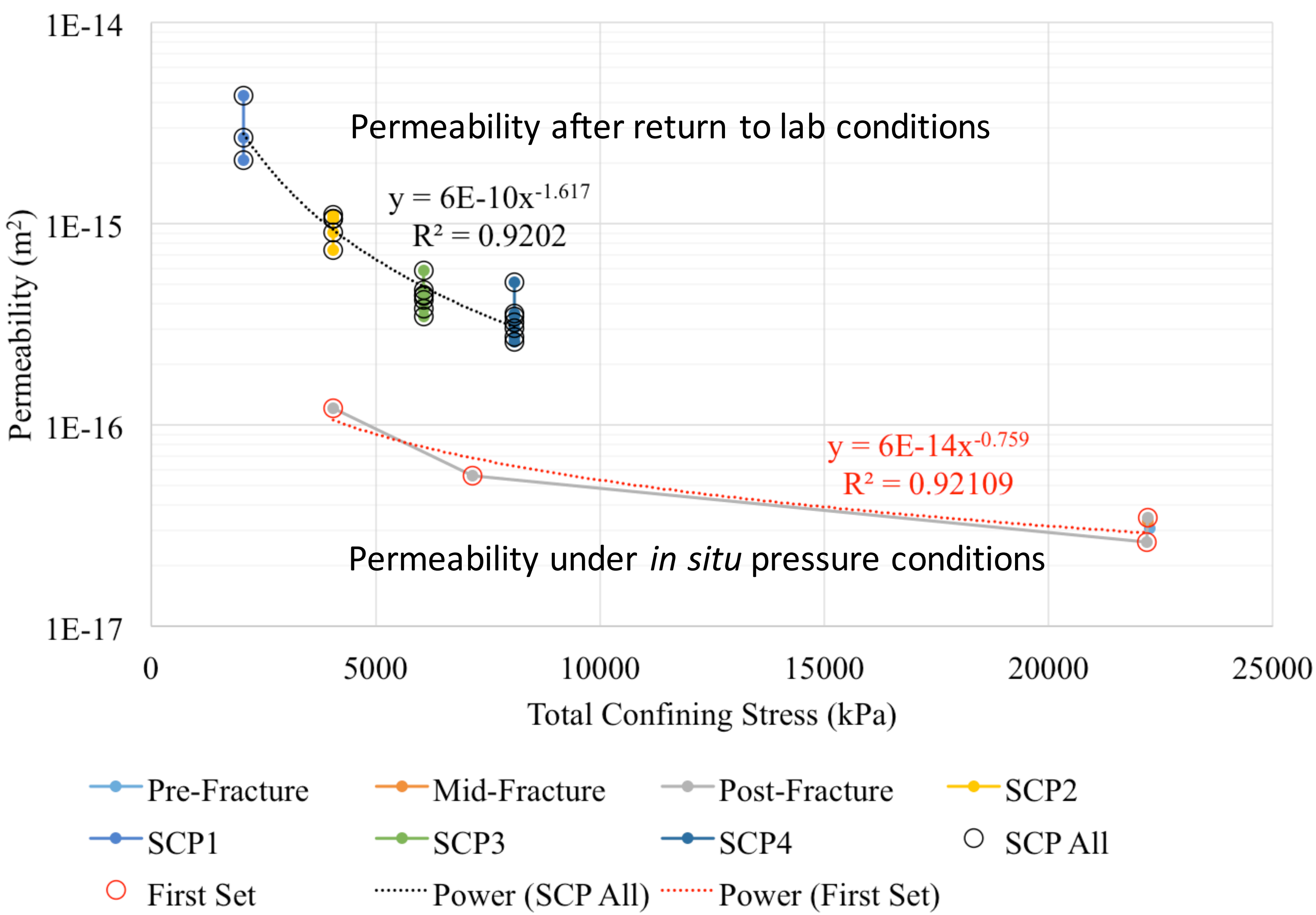
22 MPa *In Situ Tomogram*



Lab Condition Tomogram



Permeability Relations



Conclusions

- New experiments allow tensile (hydraulic) fracture studies in a triaxial coreflood device
  - Apertures small (15-20 µm)
  - Permeability measurements show values near 0.1 mD
- New experiments reveal *in situ* dynamics of fracture formation
  - Fracture propagation rates determined (order of 1-5 s)
  - Analysis of aperture-permeability relations in progress
- New experiments show significant changes in aperture during unloading
  - Permeability increases an order of magnitude
  - Formation of new fractures under investigation
- New experiments show much lower permeability of samples fractured at high confining pressure (22 MPa)

Accomplishments

- Measurements of fracture-permeability behavior of shale for
  - Compression
  - Direct shear
  - Tensile fractures
- Study of fracture permeability behavior as function of confining pressure
- Development of hydraulic fracture methodology
- Development of *in situ* tomographic methodology
- First images of fracture apertures at *in situ* conditions
- First video radiography of fracture formation at reservoir conditions

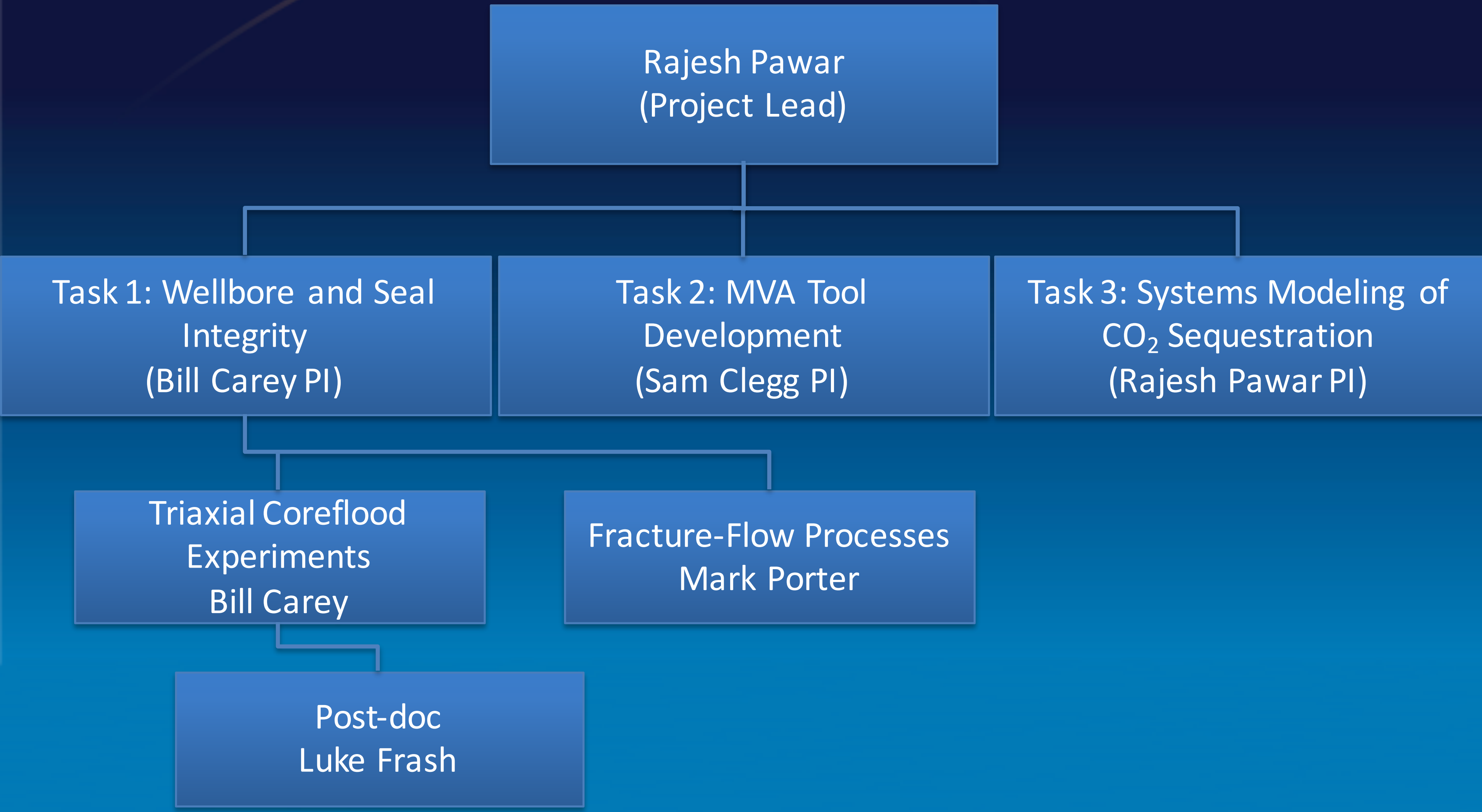
Synergy

- Good opportunities with teams working on geomechanics and induced seismicity of storage reservoir systems
  - We can provide information/data on fracture-permeability behavior
  - We need information on stress conditions and failure modes of the caprock
- Good potential collaborations with teams developing strain/stress monitoring tools for reservoirs and wellbore systems
- Good opportunities with teams focused on risk assessment studies of caprock and wellbore systems

Project Summary

- Cement and caprock exhibit a certain amount of resilience when damaged because of plastic (non-brittle) deformation, mechanical recovery (creep), and chemical reactions
- High pressures encountered at typical storage conditions (> 1 km depth) are a significant advantage for recovery from damaged-induced fractures
- The consequences of induced seismicity on caprock depends on fracture-permeability behavior with significant work left to define the parameters that limit or enhance leakage

Appendix: Org Chart



Appendix: Gantt Chart

Task	SubTask	FY14	FY15	FY16	FY17
Wellbore/Seal Integrity	Field Studies of Wellbore Integrity from Analog Sites	Concluded			
	Experimental Geochemistry Studies of Wellbore and Caprock Integrity	Concluded			
	Numerical Geochemistry Modeling Study of Wellbore Integrity	Concluded			
	Experimental geomechanics of wellbore and caprock integrity including fracturing		30% complete		
	Computational geomechanical studies of wellbore integrity		15% complete		

Appendix: Publications 2014/2015

Supported in total or in part by this project

- Carey, J. W., Lei, Z., Rougier, E., Mori, H., and Viswanathan, H. S. (2015). Fracture-permeabilty behavior of shale. Journal of Unconventional Oil and Gas Resources, 11:27–43. doi: 10.1016/j.juogr.2015.04.003.
- Carey, J. W., Rougier, E., Lei, Z., and Viswanathan, H. S. (2015). Experimental investigation of fracturing of shale with water. In 49th US Rock Mechanics/Geomechanics Symposium, 28 June-1 July 2015, San Francisco, CA USA.5
- Carey, J. W., Mori, H., Brown, D., and Pawar, R. (2014). Geomechanical behavior of caprock and cement: Plasticity in hydrodynamic seals. Energy Procedia, 63:5671–5679.
- Kelkar, S., Carey, J. W., Dempsey, D., and Lewis, K. (2014). Integrity of pre-existing wellbores in geological sequestration of CO_2–assessment using a coupled geomechanics-fluid flow model. Energy Procedia, 63:5737–5748.
- Carey, J. W. (2013). Geochemistry of wellbore integrity in CO_2 sequestration: Portland cement-steel-brine-CO_2 interactions. In DePaolo, D. J., Cole, D., Navrotsky, A., and Bourg, I., editors, Geochemistry of Geologic CO_2 Sequestration, volume 77 of Reviews in Mineralogy and Geochemistry, chapter 15, pages 505–539. Mineralogical Society of America, Washington, DC.