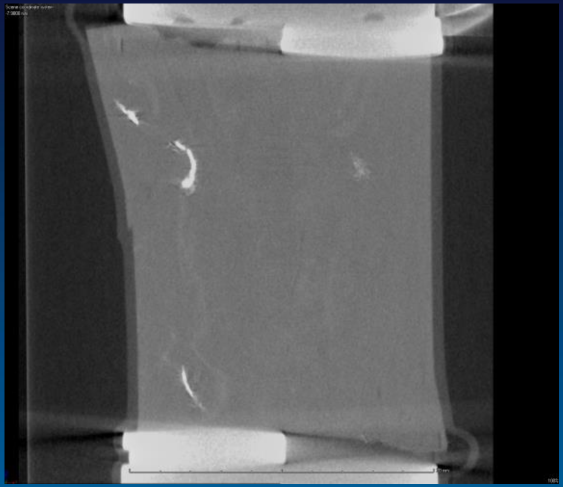
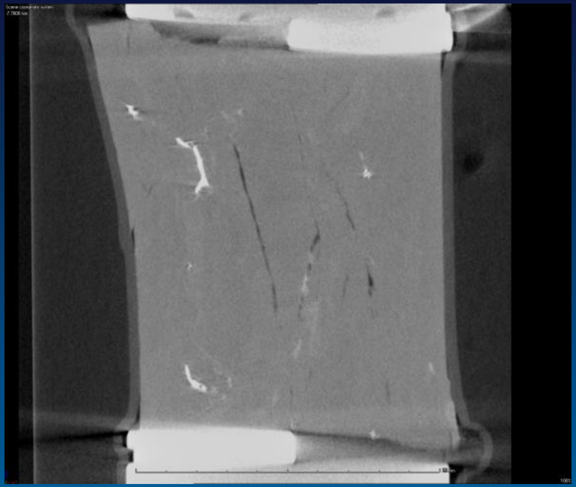
Wellbore and Seal Integrity

Experimental Studies of Fracture and Permeability of Shale Caprock

Project Number: LANL FE-715-16-FY17 Task 1

Project Manager: Josh Hull





Bill Carey, Mark Porter, and Luke Frash
Earth & Environmental Sciences
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U.S. Department of Energy
National Energy Technology Laboratory
2016 Mastering the Subsurface through Technology Innovation & Collaboration:
Carbon Storage & Oil & Natural Gas Technologies Review Meeting
August 16-18, 2016

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

- Impact of stress (mechanical and chemical) on wellbore and caprock integrity focused on role of CO_2-water
  - Experimental studies of the impact of mechanical stress on leakage processes
  - Experimental studies of the impact of CO_2 flow and reaction on leakage
  - Field studies of cement-steel-caprock samples obtained from CO_2-containing reservoirs
  - Numerical models to predict damage and leakage in wellbore and caprock seals

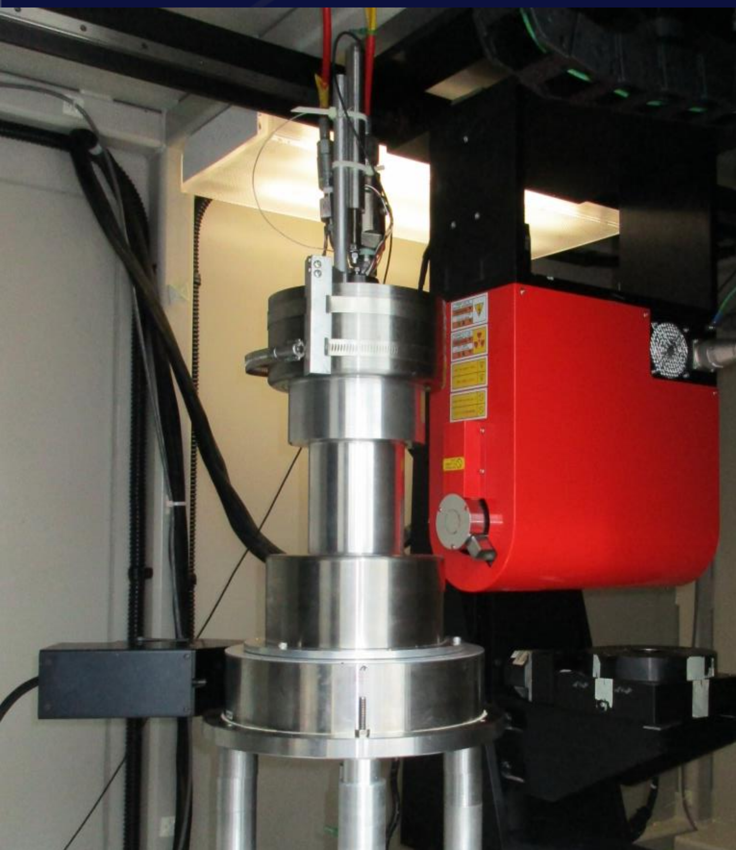
Technical Status

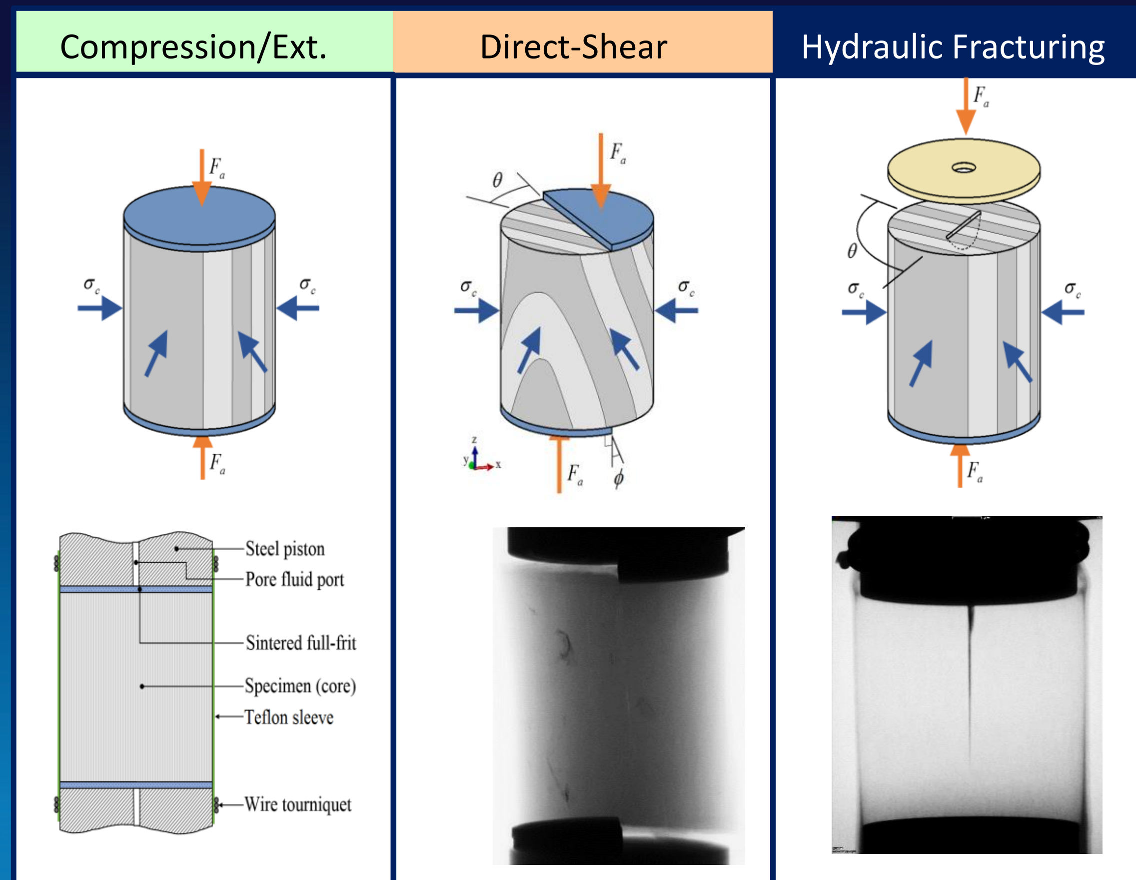
- Past focus has been *geochemistry* and *wellbore integrity*
- Culminated in several reviews completed on wellbore integrity
  - Carey, J. W. and Torsæter, M. (in review). Shale and Well Integrity. In Shale Science. John Wiley & Sons.
  - Carroll, S., Carey, J. W., Dzombak, D., Huerta, N., Li, L., Richards, T., Um, W., Walsh, S., and Zhang, L. (2016). Review: Role of Chemistry, Mechanics, and Transport on Well Integrity in CO_2 Storage Environments. Int. J. Greenhouse Gas Control, 49:149-160.
  - Carey, J. W. (2013). Geochemistry of Wellbore Integrity in CO_2 Sequestration: Portland Cement-Steel-Brine-CO_2 Interactions. In Geochemistry of Geologic CO_2 Sequestration, V. 77: pp. 505-539. Mineralogical Society of America.
- Profound change in conceptualization of wellbore integrity
  - Ordinary Portland cement and steel provide a seal for > decades in CO_2-environments
  - Leakage paths can be self-limiting due to precipitation and residual cement phase formation

Technical Status

- Current and new effort focused on *geomechanics* and *caprock*
- Based on advances in experimental capabilities
  - Combined triaxial coreflood and x-ray tomography
- Addresses the issue of induced seismicity and potential damage to caprock
  - Understanding *consequences* of fracture in caprock needed
  - Can shale accommodate deformation without leakage?

In Situ Tomography and Triaxial Coreflood Experiments



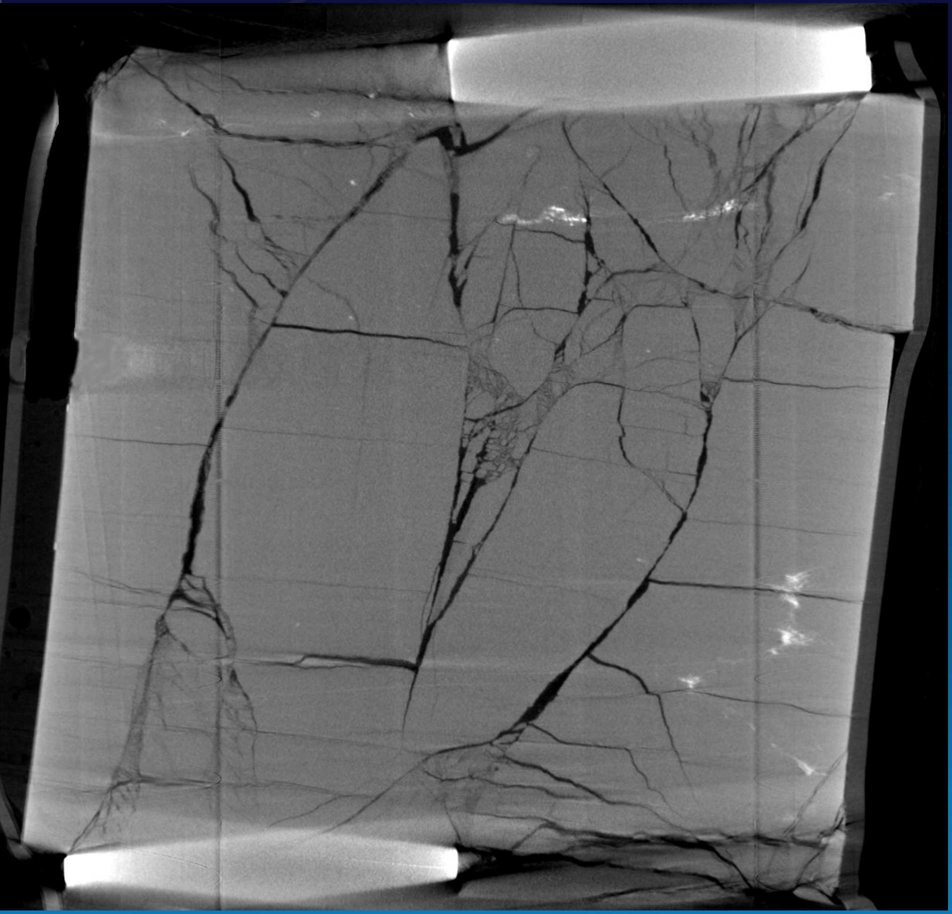


- Max Pressure: 34.5 MPa (5,000 psi)
- Max Axial Load: 500 MPa (70,000 psi)
- Max Temperature: 100 °C

Carey et al., J. Unconv. O&G Res., 2015; Frash et al. (in press) JGR; Frash et al. (submitted) Rock Mech. Rock Eng.

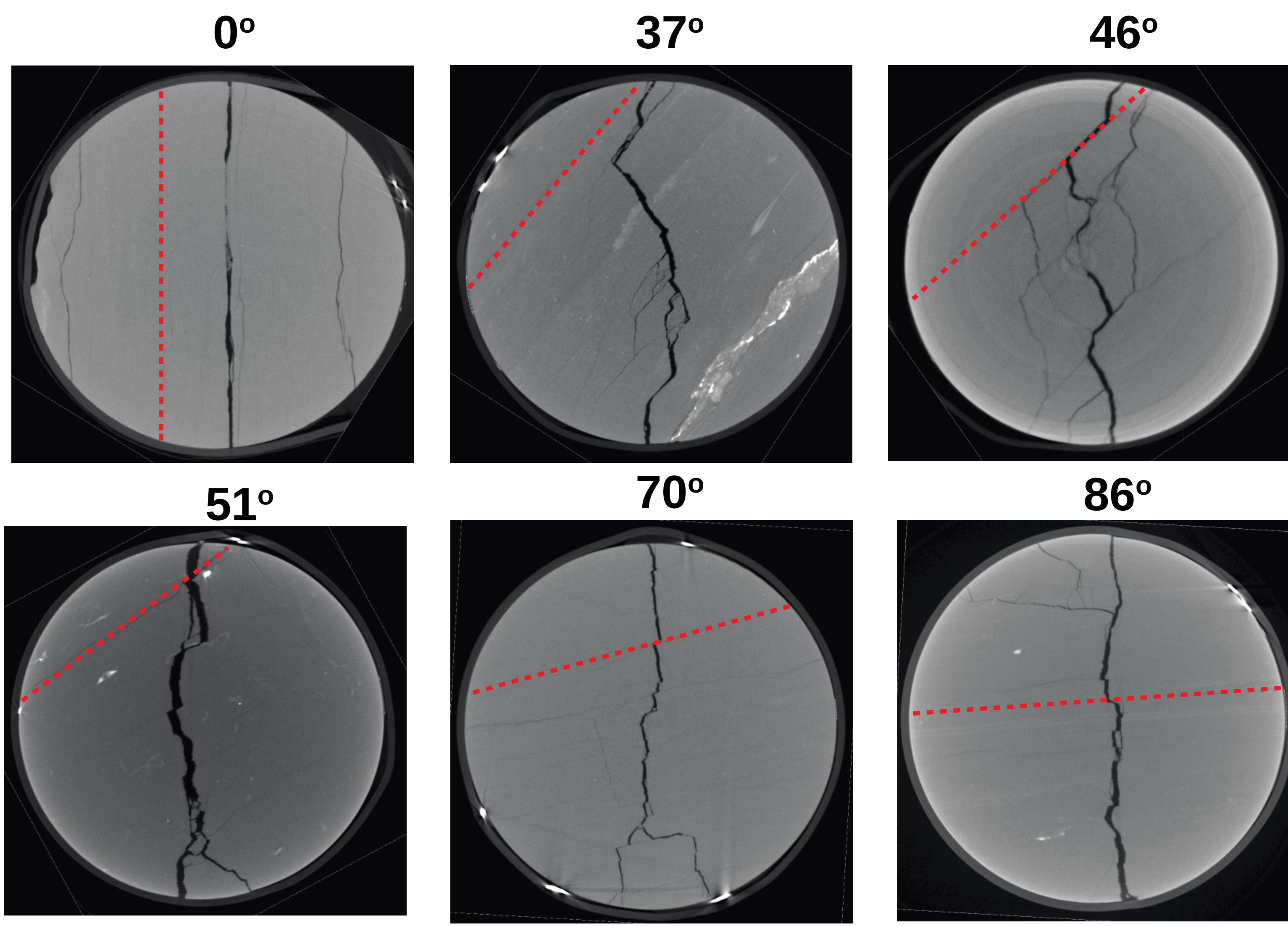
Low-Pressure Fractures

(Clay-bearing Utica shale)

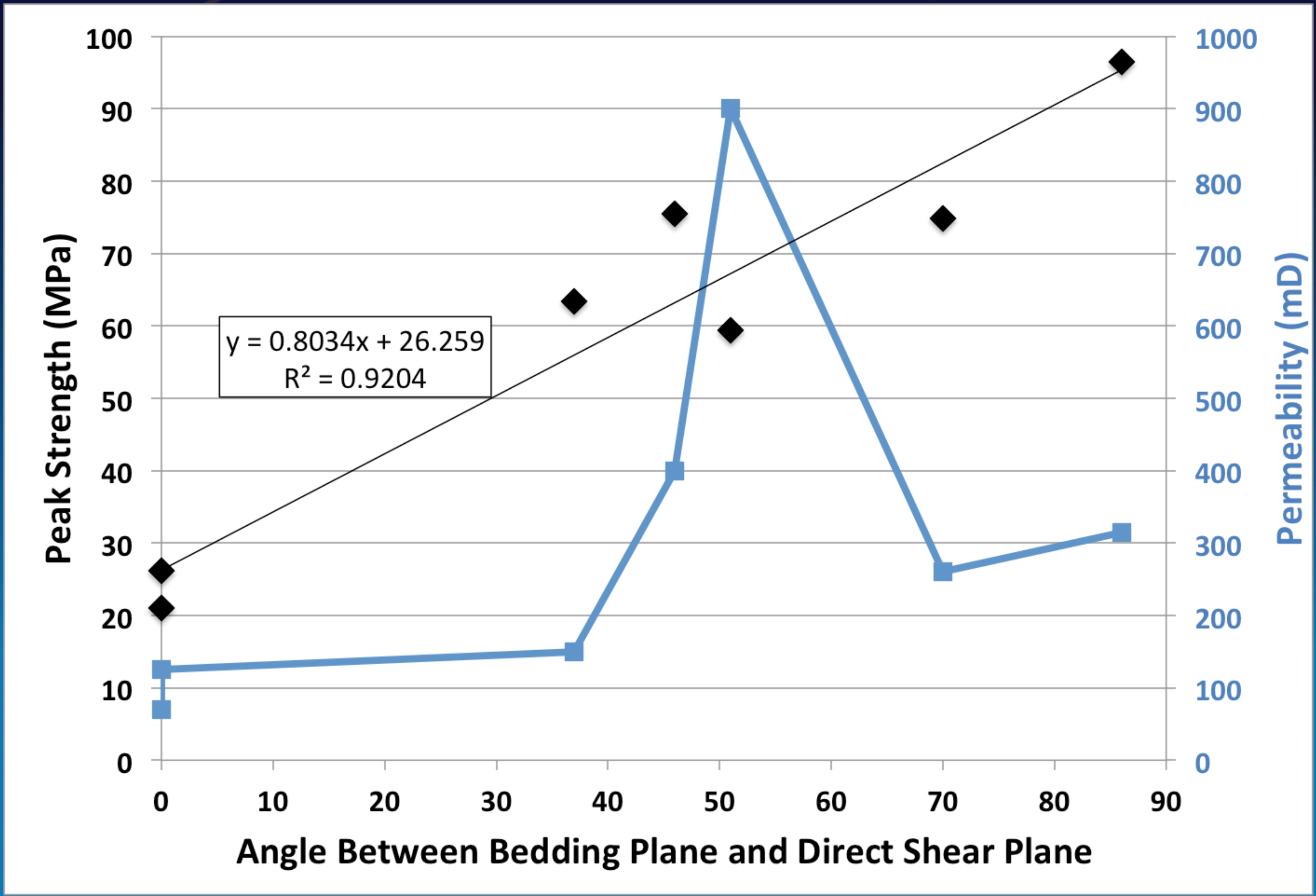


Large, clearly resolved fractures at low pressure (3.5 MPa)
Carey et al. (2015) J. Unconv. Oil & Gas Res.

Low-Pressure Fractures and Bedding Planes

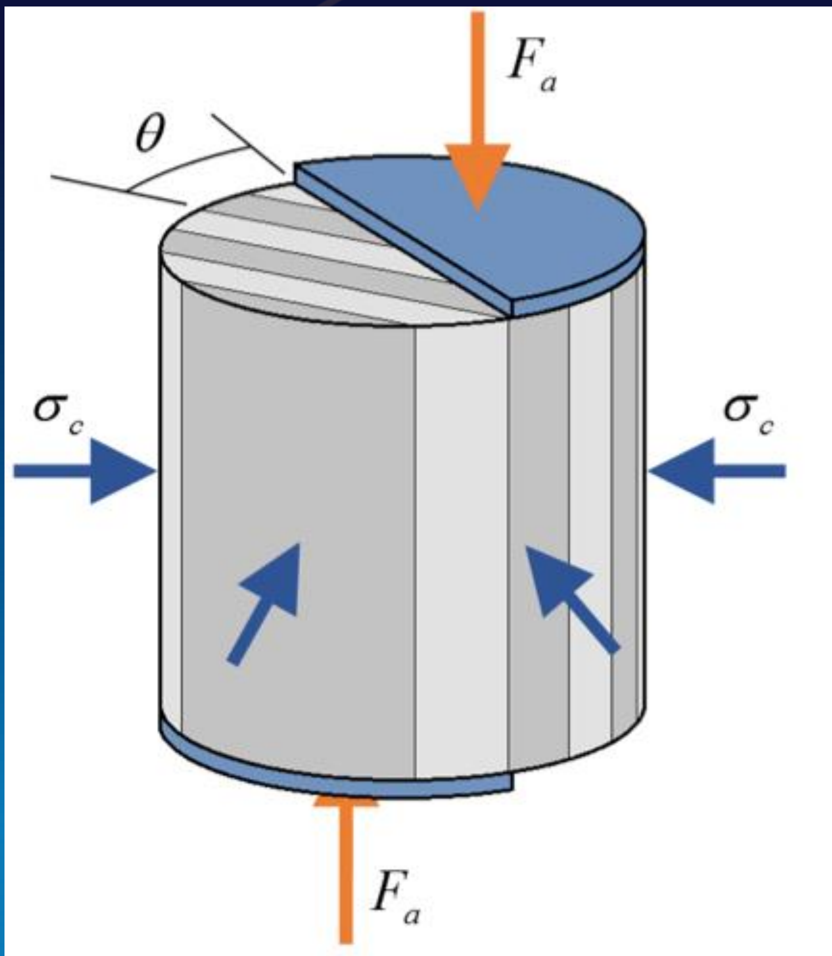


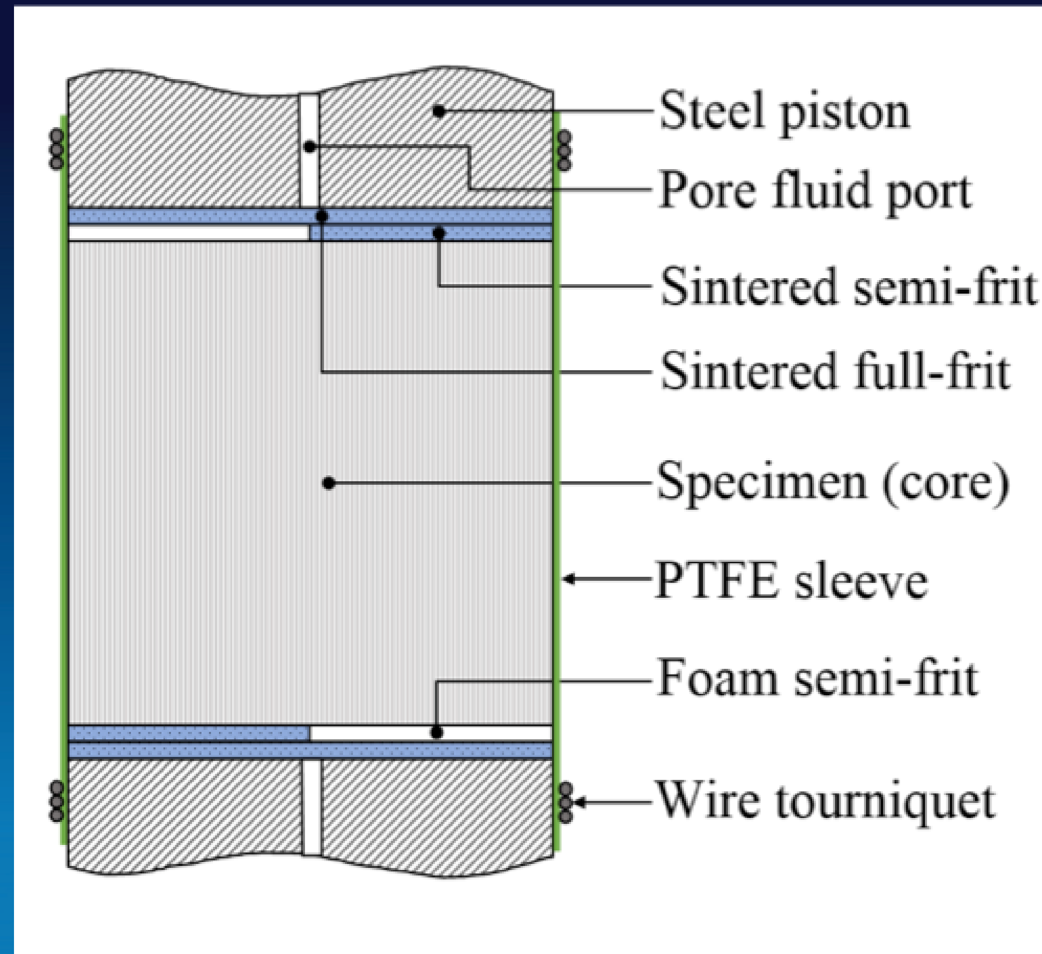
Fracture-Bedding Plane Relations



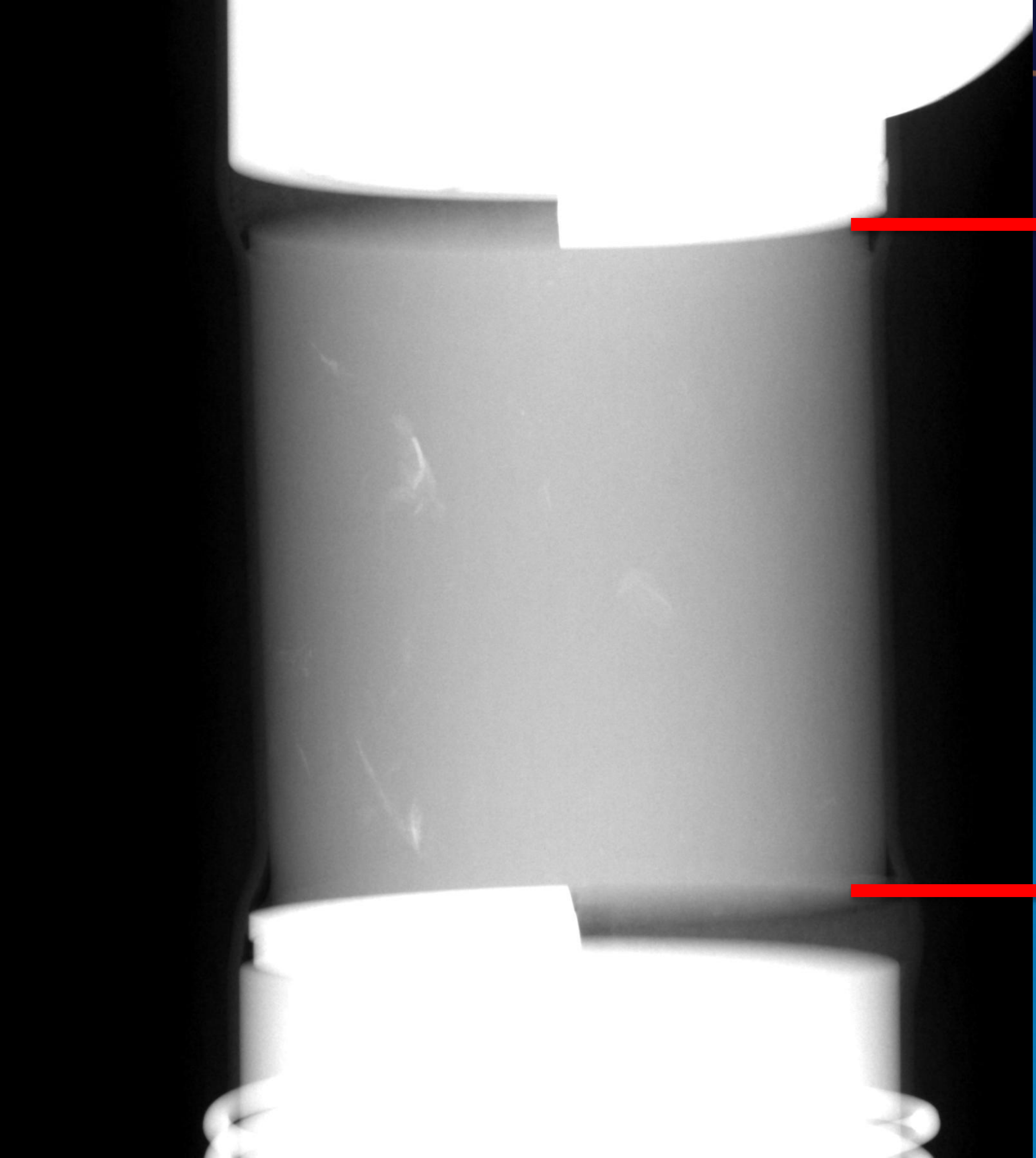
High-Pressure Fractures

(Clay-bearing Utica shale)





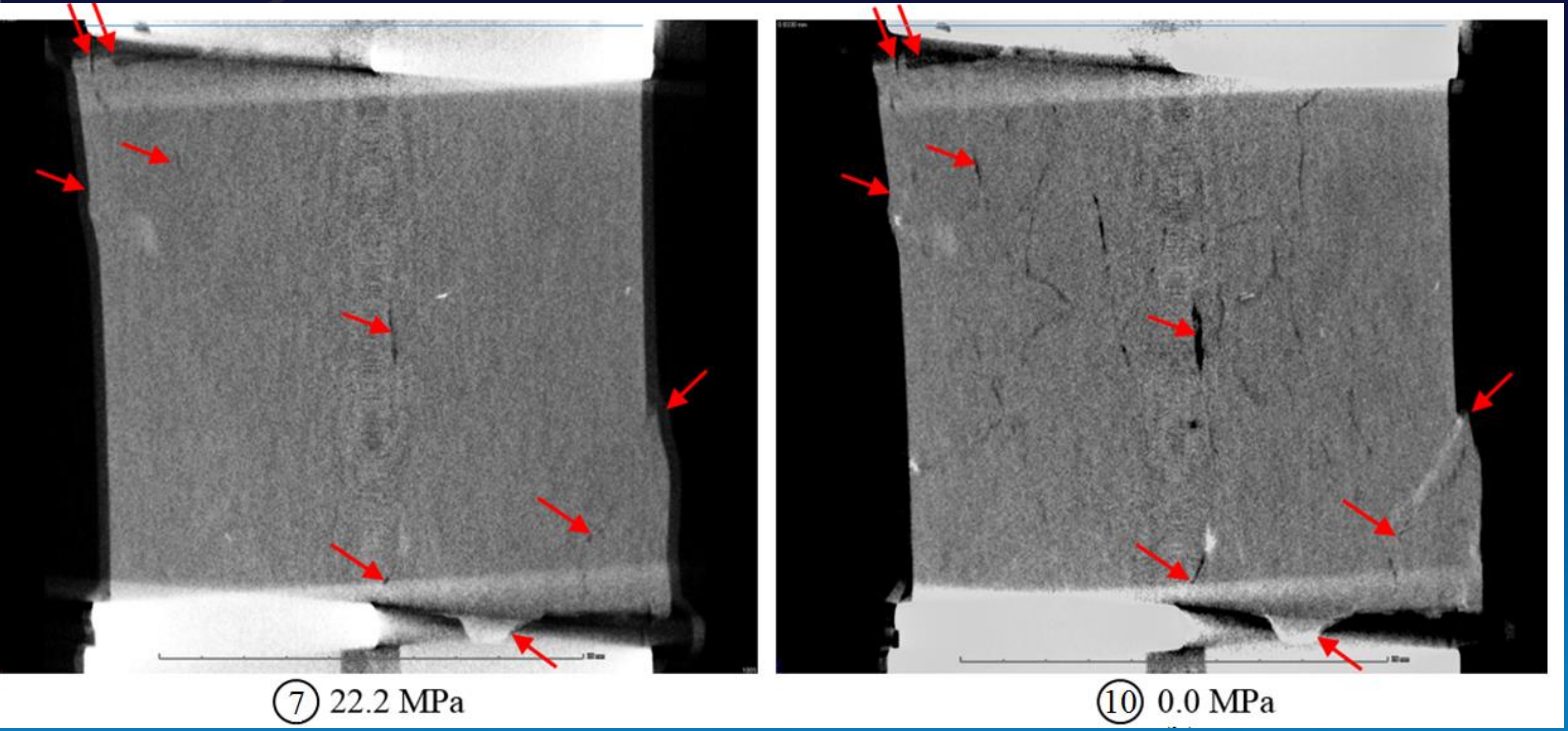
X-ray Radiography Video at 22.5 MPa …



X-ray Radiography Video at 22.5 MPa (3250 psi) Utica shale (clay-bearing) Video represents about 30 minutes

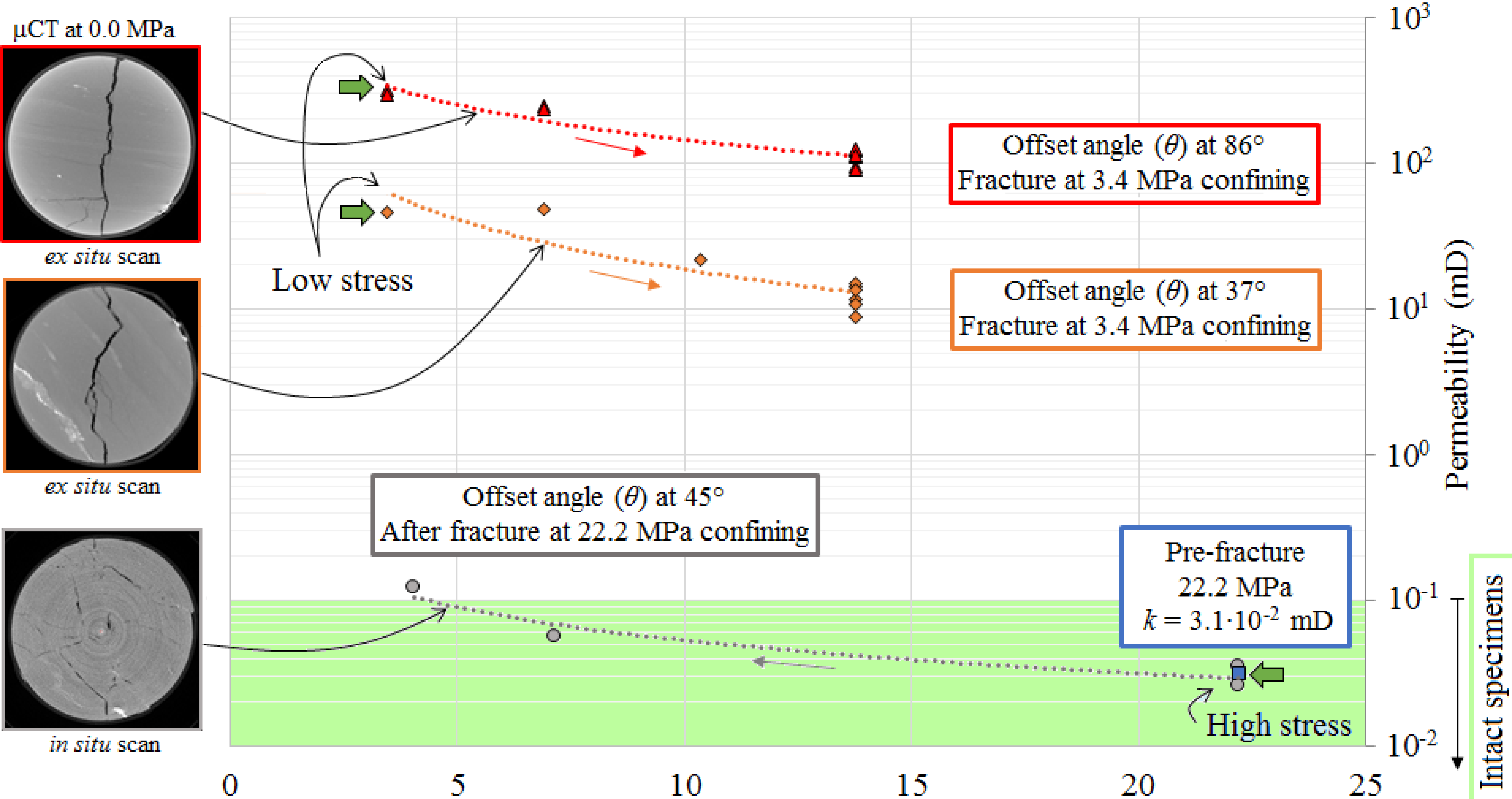
Frash et al. (2016) JGR

In situ Tomography



Fractures open on decompression
Frash et al. (2016) JGR

Depth-Permeability Relations



Frash et al. (2016) JGR

Conclusions

- Suitable caprock will accommodate deformation without developing substantial leakage pathways (Carey et al. 2015; Frash et al. 2016)
- This is consistent with oil and gas experience and the concept of a critical state deformation (Carey et al. 2016)
  - Transition from dilation to compaction during shearing
- Risk of potential caprock leakage is a function of depth and caprock mineralogy and structure (heterogeneity, bedding, pre-existing fractures)
- We should move beyond the generic use of caprock $\Rightarrow$ low permeability rock without further consideration

Accomplishments

- Measured fracture-permeability behavior of Utica shale using direct-shear methods and determined permeability as a function of confining pressure
- Demonstrated use of *in situ* tomography to characterize fracture apertures at reservoir conditions
- Demonstrated use of video radiography to analyze fracture formation at reservoir conditions
- Review article submitted on shale and well integrity
- Our work is focused on developing a risk-based analysis of the potential for induced seismicity to damage caprock and cause leakage of CO2.
  - Our work on Utica shale shows that good quality caprock can absorb significant deformation without developing significant leakage pathways

Synergy

- Excellent opportunities to collaborate on geomechanics and induced seismicity of storage reservoir systems
  - Penn State study of rheology of fracture slip (D. Elsworth)
  - UT-Austin study of reservoir seal geomechanics (P. Eichhubl)
  - LBL study of *in situ* fault slip (J. Birkholzer)
- Excellent opportunities to collaborate on well integrity problems
  - Clemson study of strain/stress measurement in wells (L. Murchoch)
  - LLNL study of thermal stresses in wells (J. Morris/P. Roy)
  - NETL studies of well integrity (N. Huerta/B. Kutchko)
- Many other projects are closely allied to work here (reservoir geomechanics, well integrity studies, etc.)

Acknowledgements

- Support and funding from DOE-Fossil Energy program
  - FE-715-16-FY17
  - Joshua Hull, Karen Kluger and Traci Rodosta

- Colleagues at Los Alamos
  - Rajesh Pawar and George Guthrie

Appendix: Org Chart

Appendix: Gantt Chart

Task	SubTask	FY15	FY16	FY17
Wellbore and Seal Integrity	1.2 Experimental Study of Fracture-Permeability Behavior of Seal Materials	40%		
	1.2.1 Development of theoretical framework		60%	
	1.2.2 Fracture-permeability behavior of caprock	30%		
	1.2.3 Fracture-permeability behavior of wellbore materials		20%	
	1.3 Computational Study of Fluid Flow through Pre-existing Flow Pathways	20%		

Appendix: Publications 2015/2016

Supported in total or in part by this project

- Carey, J. W. and Torsæter, M. (in review). Shale and Well Integrity. In Shale Science. John Wiley & Sons.
- Frash, L. P., Carey, J. W., Ickes, T., and Viswanathan, H. S. (in press). High-stress triaxial direct-shear fracturing of Utica shale and in situ X-ray microtomography with permeability measurement. Journal of Geophysical Research.
- 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.
- Carroll, S., Carey, J. W., Dzombak, D., Huerta, N., Li, L., Richards, T., Um, W., Walsh, S., and Zhang, L. (2016). Review: Role of Chemistry, Mechanics, and Transport on Well Integrity in CO_2 Storage Environments. International Journal of Greenhouse Gas Control, 49:149-160.
- Carey, J. W., Lei, Z., Rougier, E., Mori, H., and Viswanathan, H. S. (2015). Fracture-permeability 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.