SAND2015-9503PE

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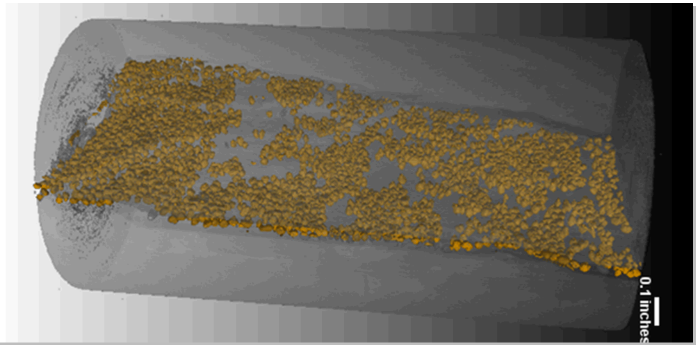
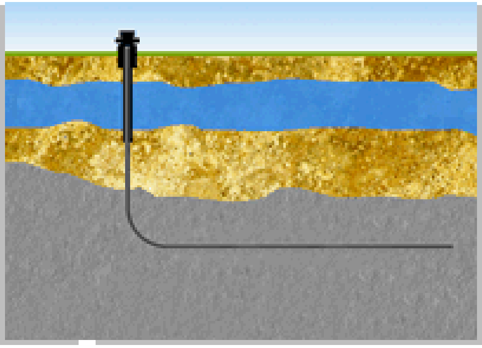
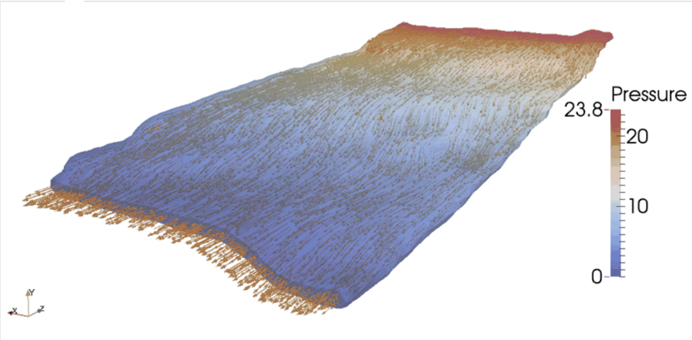






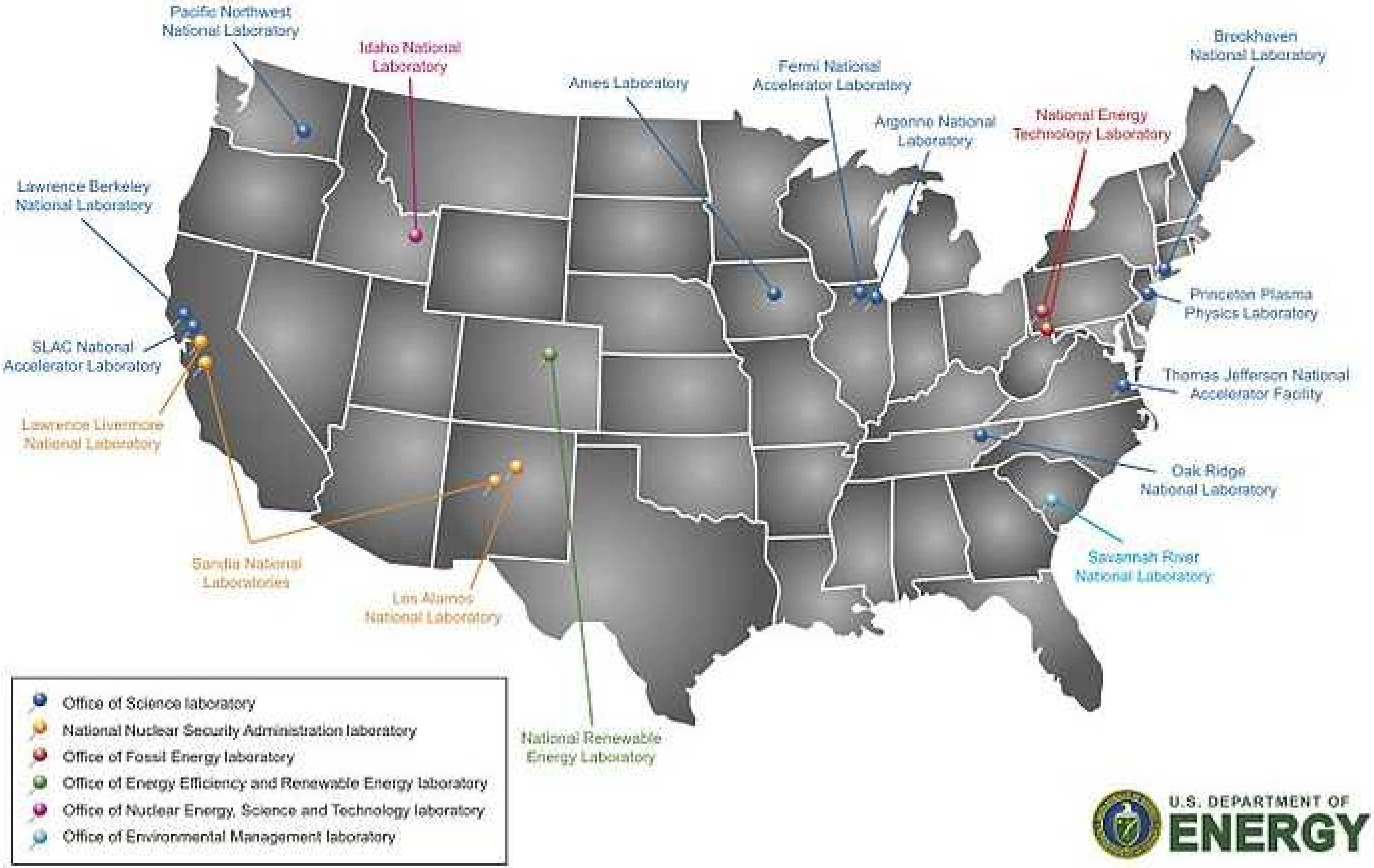
Hydraulic Fracture and Current Research at SNL

MD Ingraham

Introduction

- Sandia National Laboratory
- Geomechanics Lab and Capabilities
- Shale gas and hydraulic fracture
  - Hydrocarbon reservoirs
  - Conventional and Shale reservoirs
  - Hydraulic fracture of shale
  - Issues
    - Wastewater
    - Induced Seismicity
- Research at Sandia
  - Proppant Packs
  - Lab scale fracture and prop
  - Other

Department of Energy National Labs



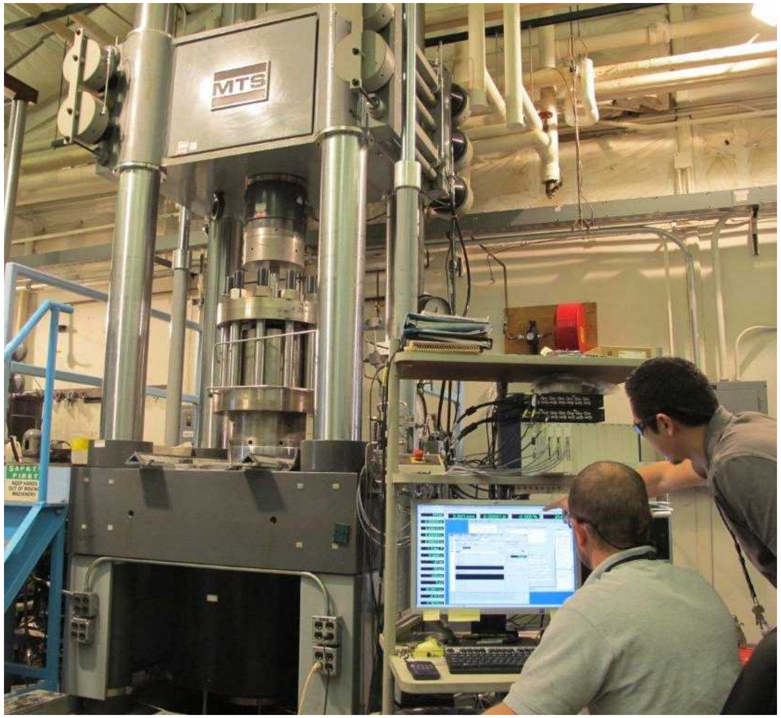
Sandia National Laboratory

Sandia National Laboratory

- ~11,000 employees (about the same size as Los Alamos)
- ~$2.6 billion annually
- Research areas
  - Nuclear Weapons – sustain secure and modernize the US nuclear arsenal
  - Defense Systems and Assessments – design and develop defense and national security capabilities
    - Microwave Scanners
  - **Energy and Climate** – Ensure secure and stable supply of energy and resources and protection of infrastructure
  - International, Homeland and Nuclear Security – Protection of nuclear material/assets, nuclear emergency response and nonproliferation

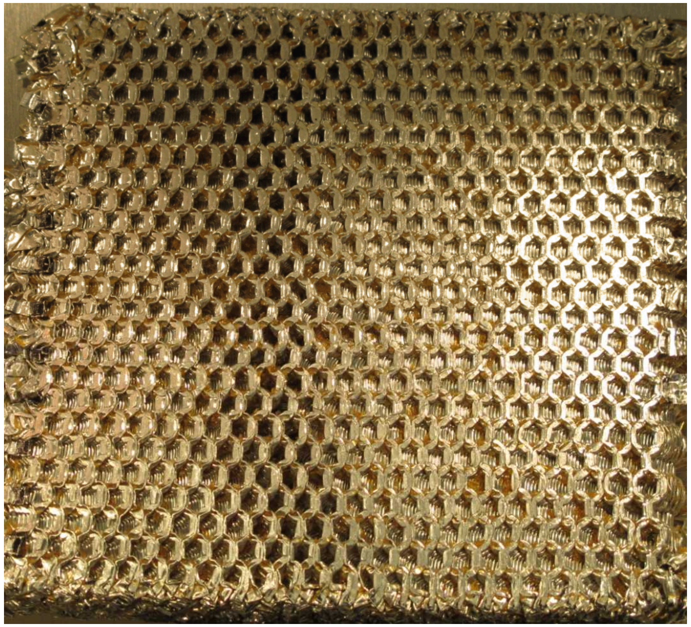
Geomechanics Facilities

- 4 Uniaxial frames with pressure vessels (<1,000,000 lbs, <145,000 psi)
- Axial-Torsional frame (220,000 lbs, 7400 ft-lbs)
- True Triaxial system (σ_2<14.5 ksi + σ_3)
- 10^{-10} /s < Strain rate < 10^{2} /s
  - Creep Frames
  - Split Hopkinson Bar
- -65°C < Temperature < 300°C



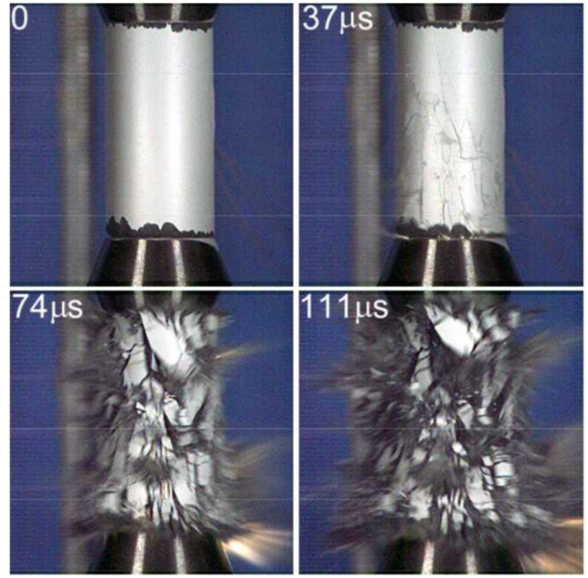
Materials Testing

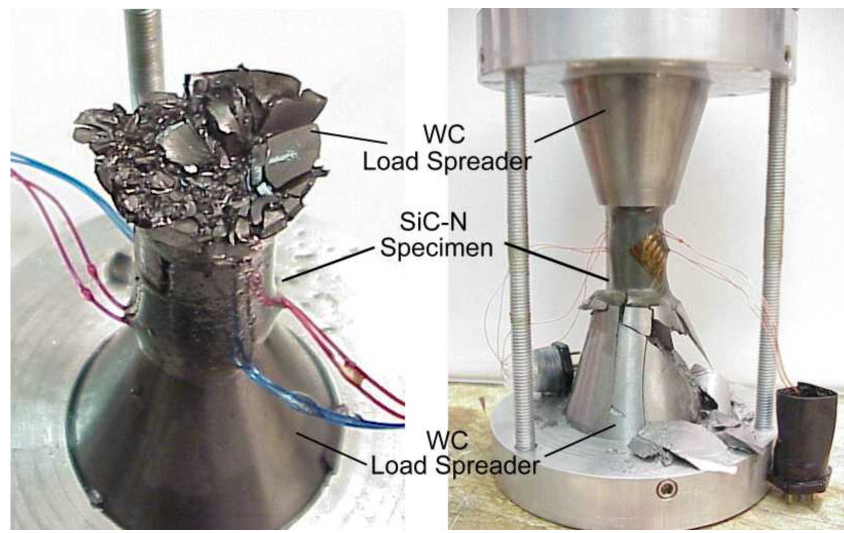
- 70% Geomaterials
  - Sandstone
  - Salt
  - Shale
  - Granite
  - Limestone
- 30% Engineering Materials
  - Bulk Metals
  - Honeycombs
  - Silicon Carbide
  - Ceramics
  - Carbon Composites



Materials Testing

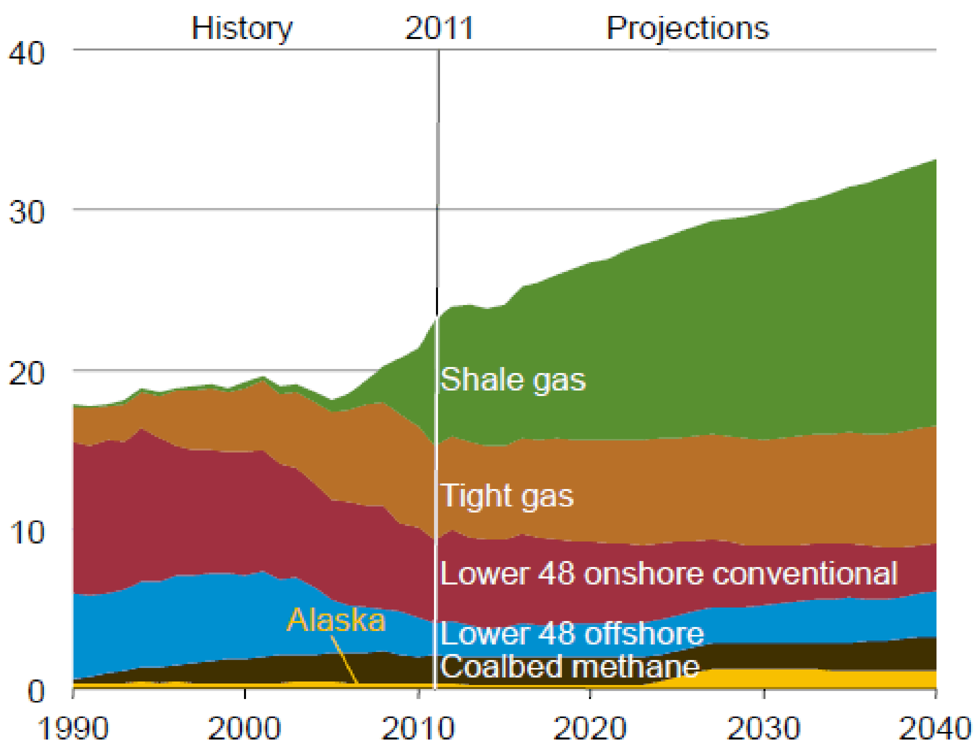
- Uniaxial
- Axial – Torsion
- Hydrostatic
- Axisymmetric
- True Triaxial
- Active and Passive Acoustics
- Impact (Hopkinson Bar)
- Creep





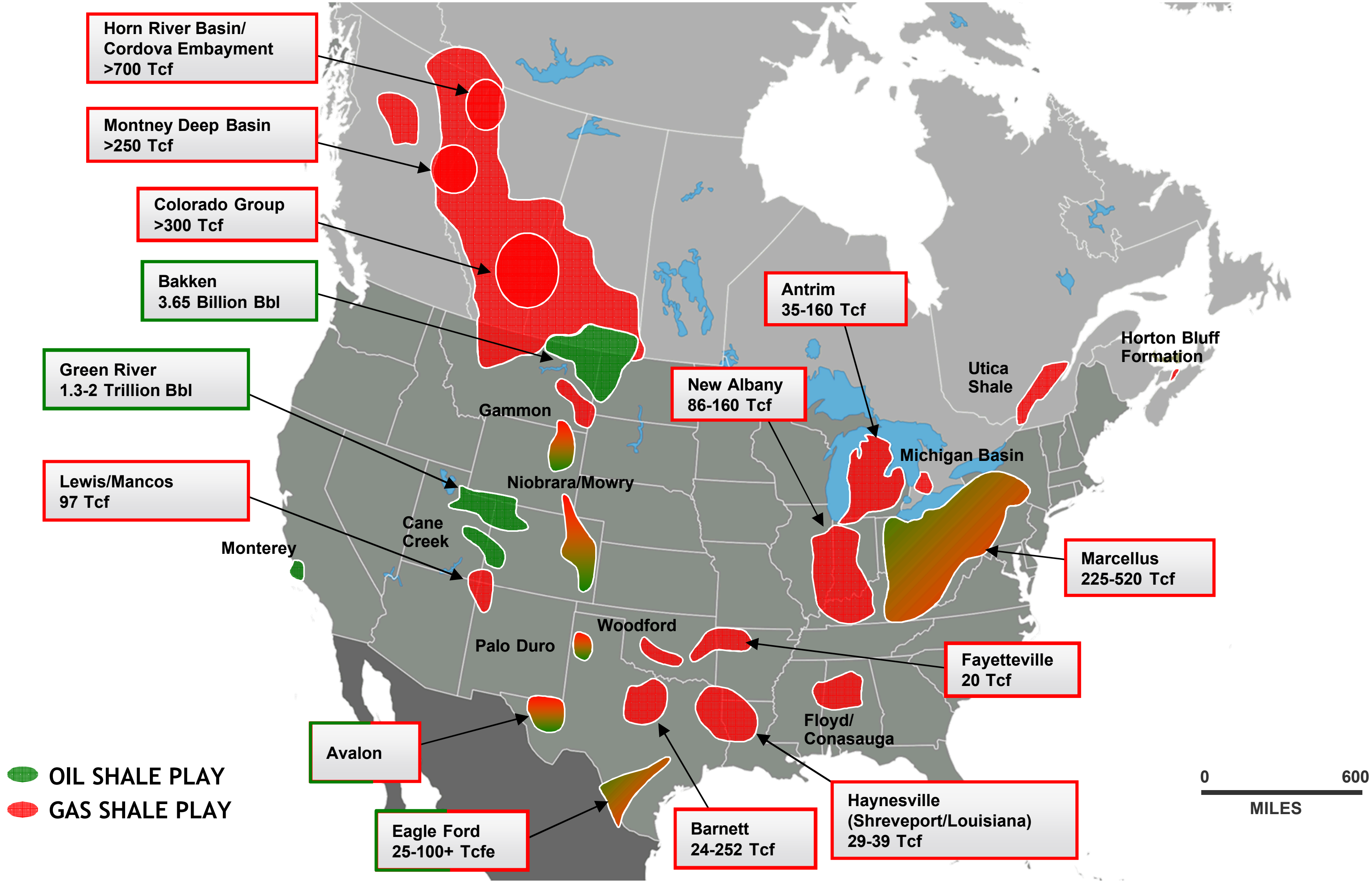
Materials Testing

Why do we care about Shale?



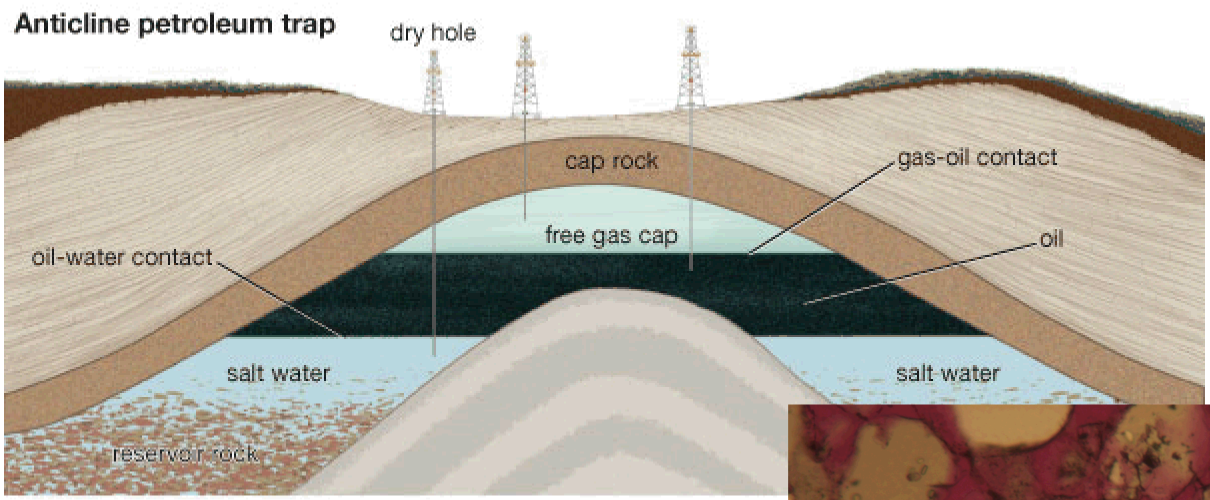
DOE annual energy outlook 2013

Shale Gas and Tight Oil Geomechanics



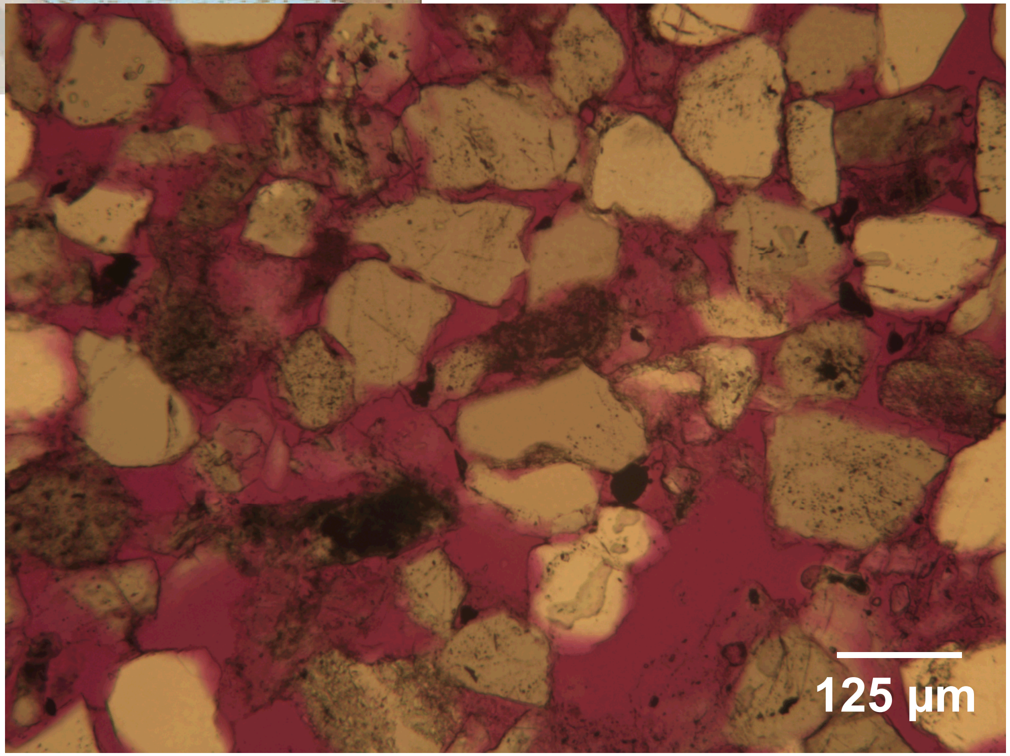
Slide courtesy of M. Zoback

Conventional Reservoirs



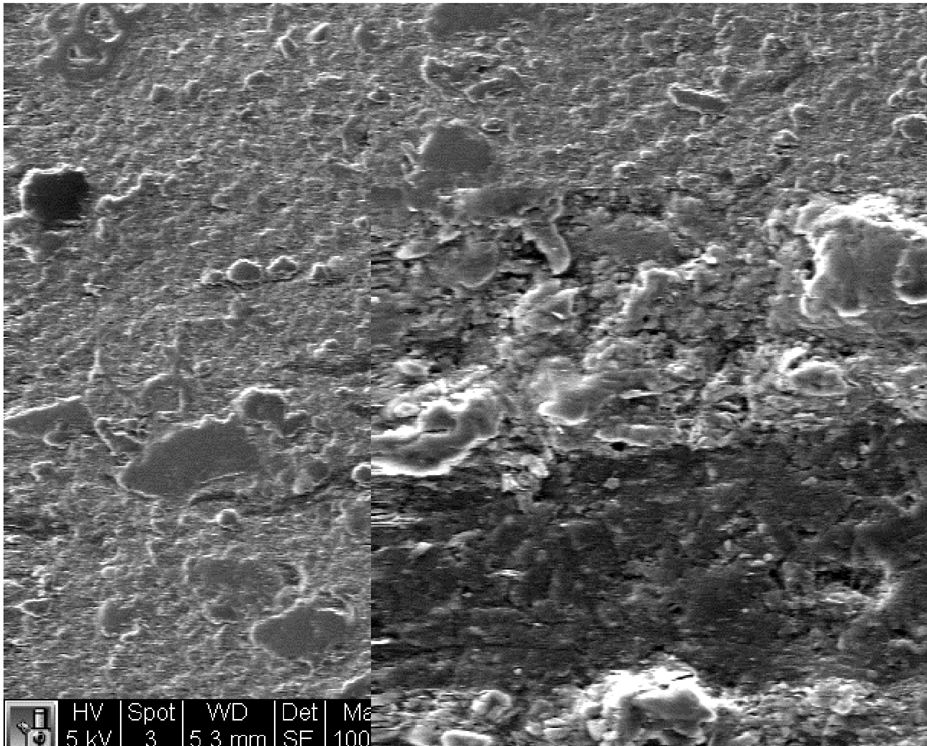
Typically Oil and gas are released from the source rocks and percolate through more permeable rocks until they are caught in a trap.

Traps are usually a highly permeable rock like sandstone overlaid by a low permeability rock like shale or salt.

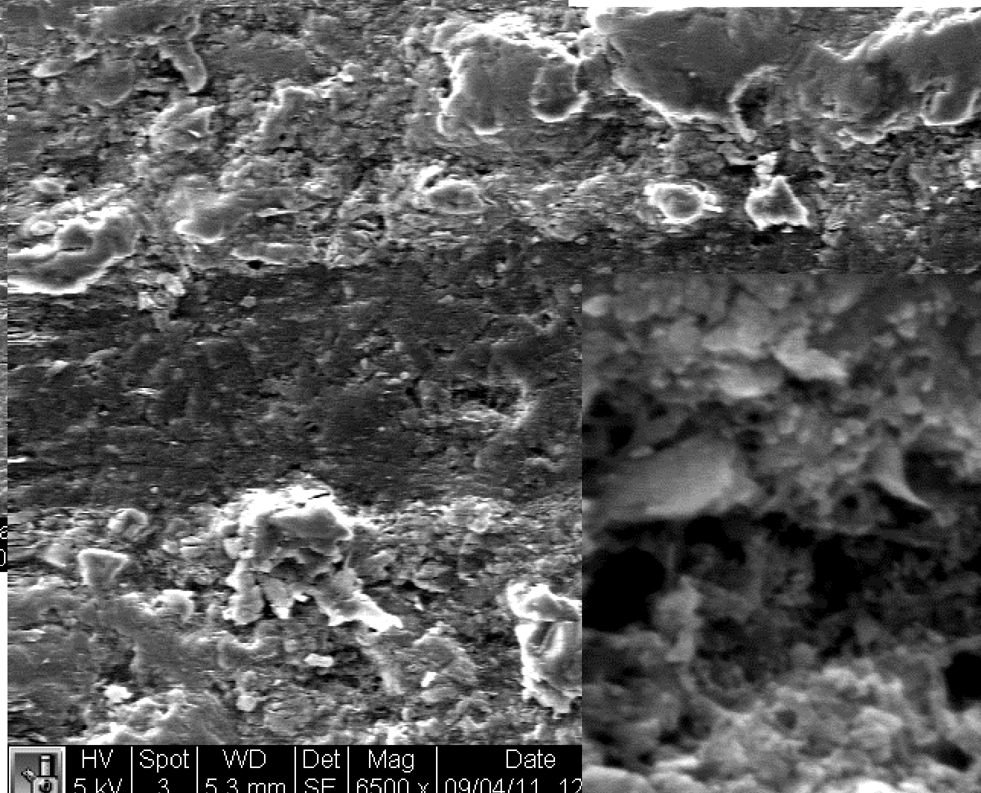


Eagle Ford Shale Pore Structure

Shale Permeability is a Million Times Smaller Than Conventional Reservoir

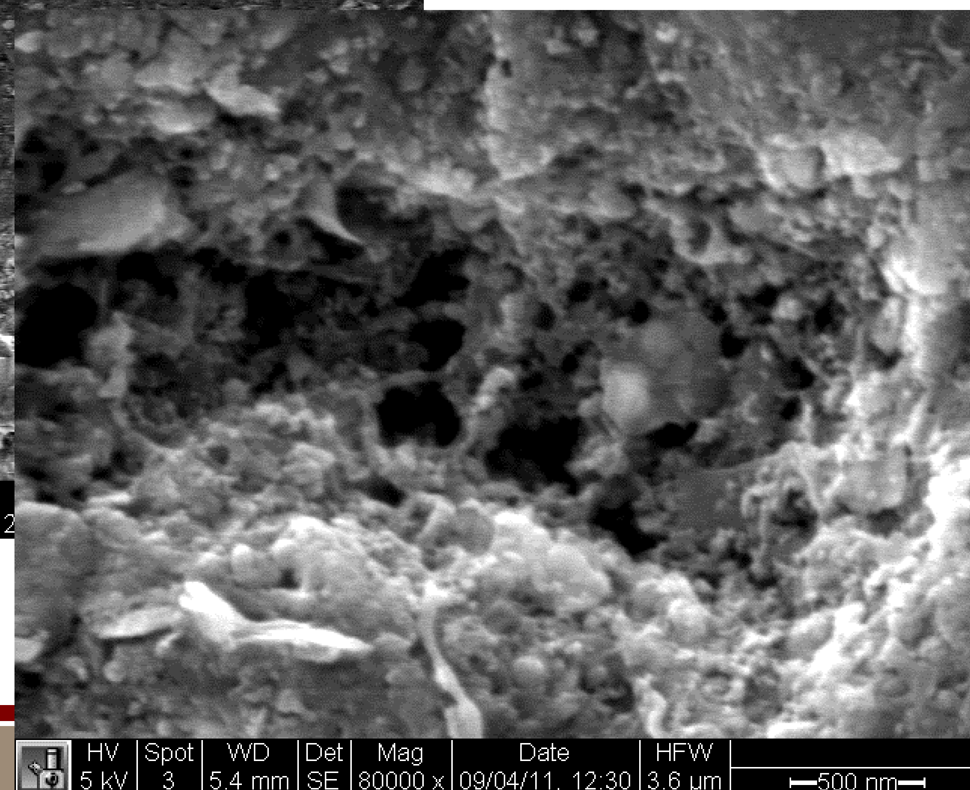


50μm



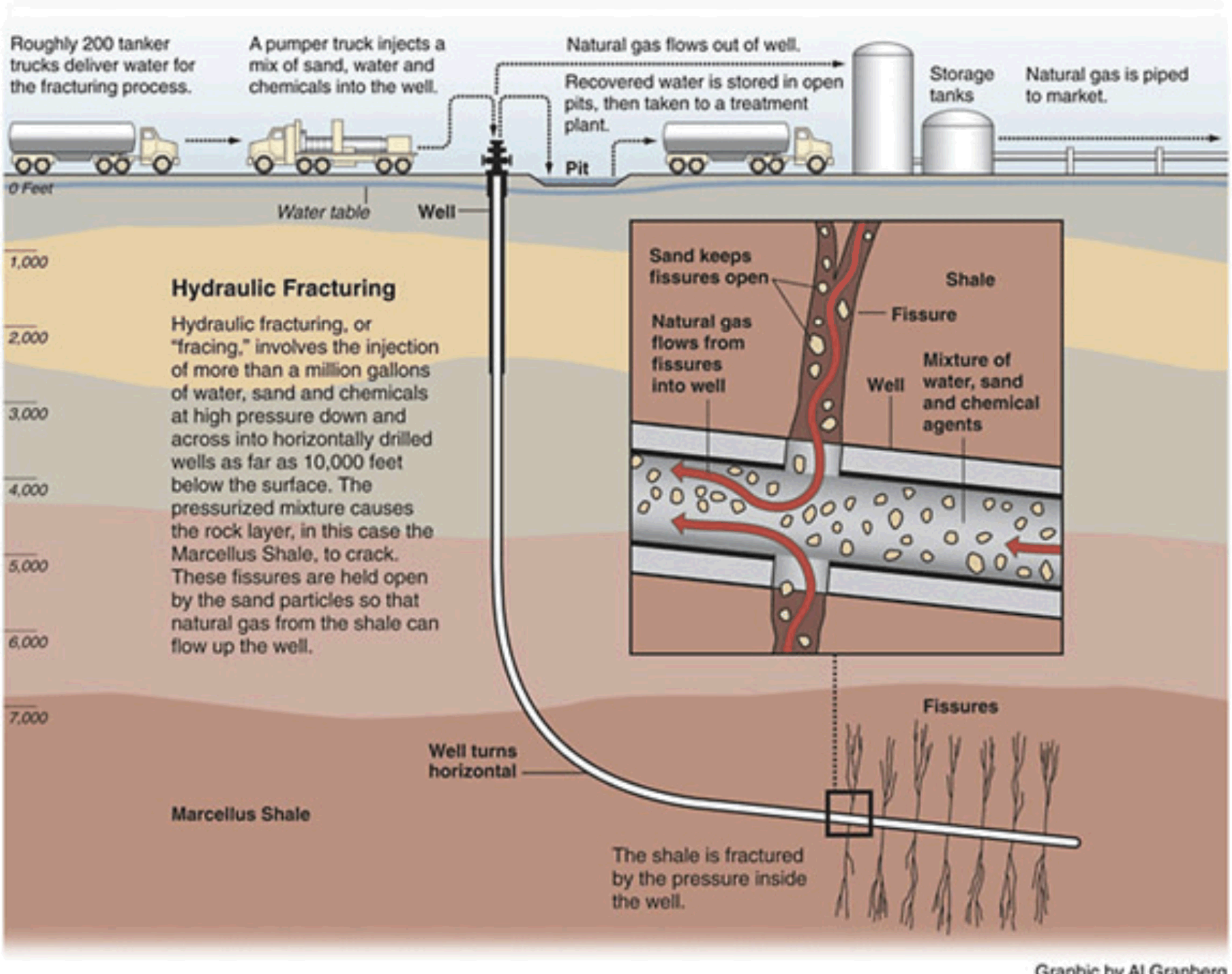
10 μm

500 nm



Slide courtesy of M. Zoback

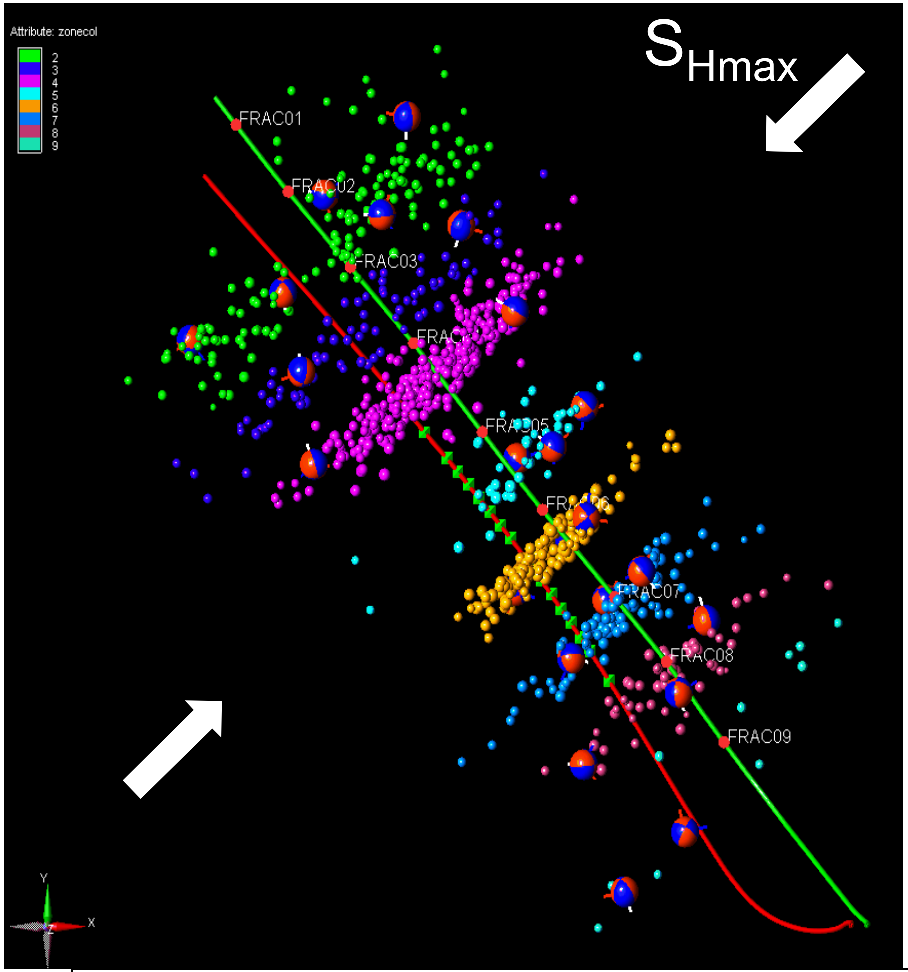
What is "Fracing"



Horizontal Drilling and Multi-Stage Fracing is a Large-Scale Industrial Process

Slide courtesy of M. Zoback

Multi-Stage Hydraulic Fracturing Works



Horizontal Drilling and Multi-Stage *Slick-Water* Hydraulic Fracturing Induces Microearthquakes (M ~ -1 to M~ -3) To Create a Permeable Fracture Network

Slide courtesy of M. Zoback

…A Long Way to Go

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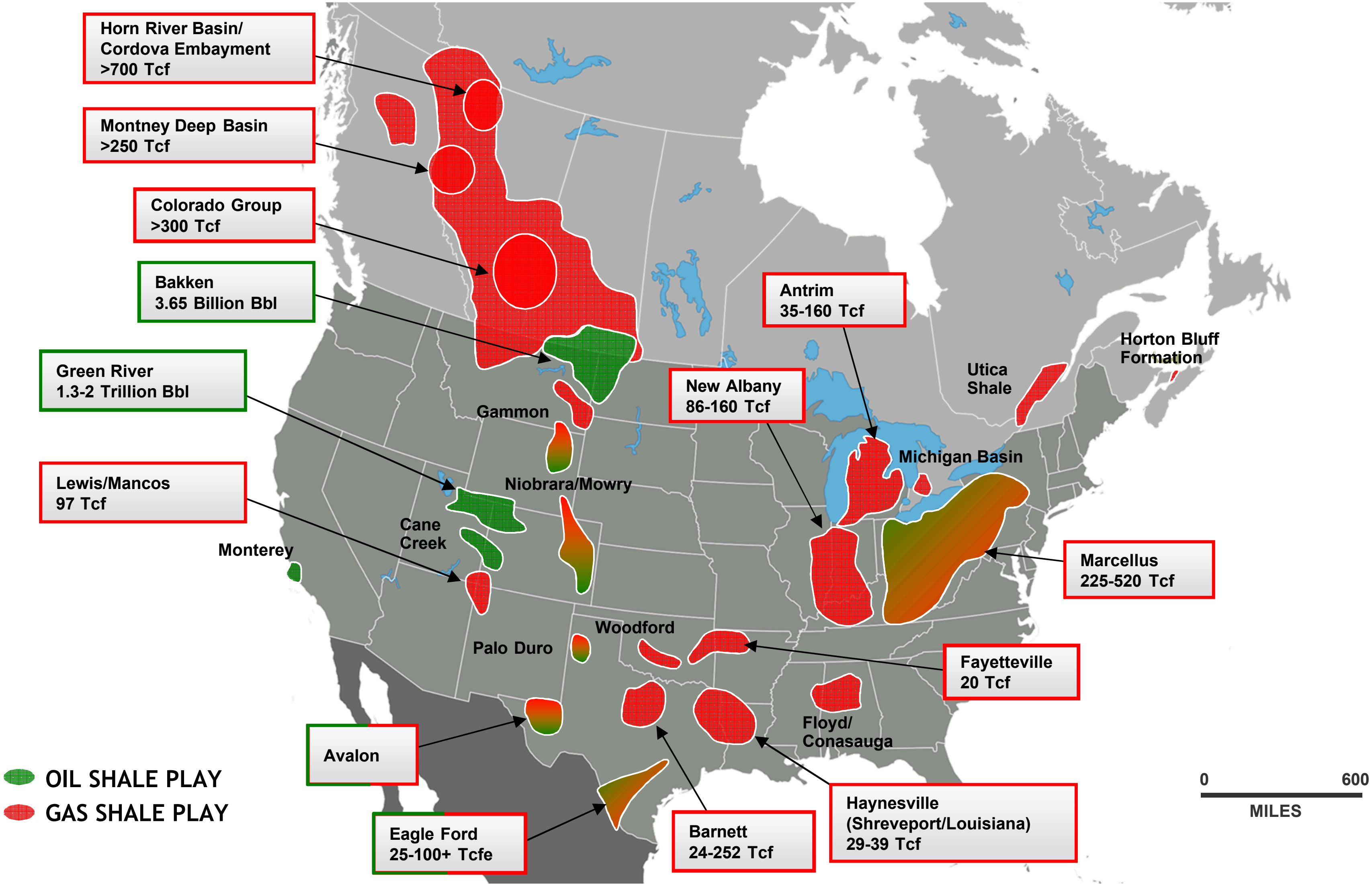

Slide courtesy of M. Zoback

Dry Gas ~25%

Petroleum Liquids ~ 5%

Hydraulic Fracturing is Controversial

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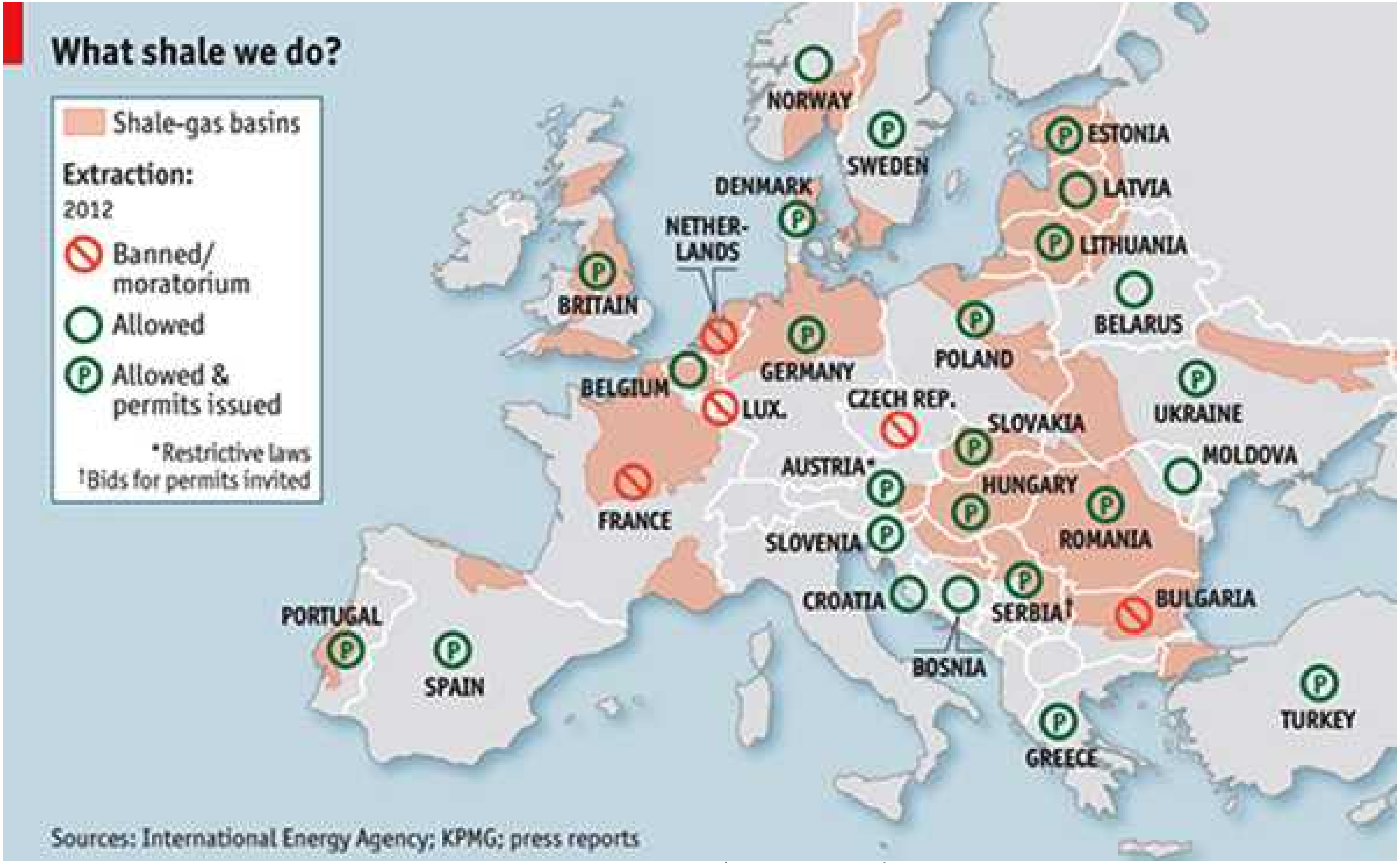

sources | International Energy Agency; KPMG; press reports

Slide courtesy of M. Zoback

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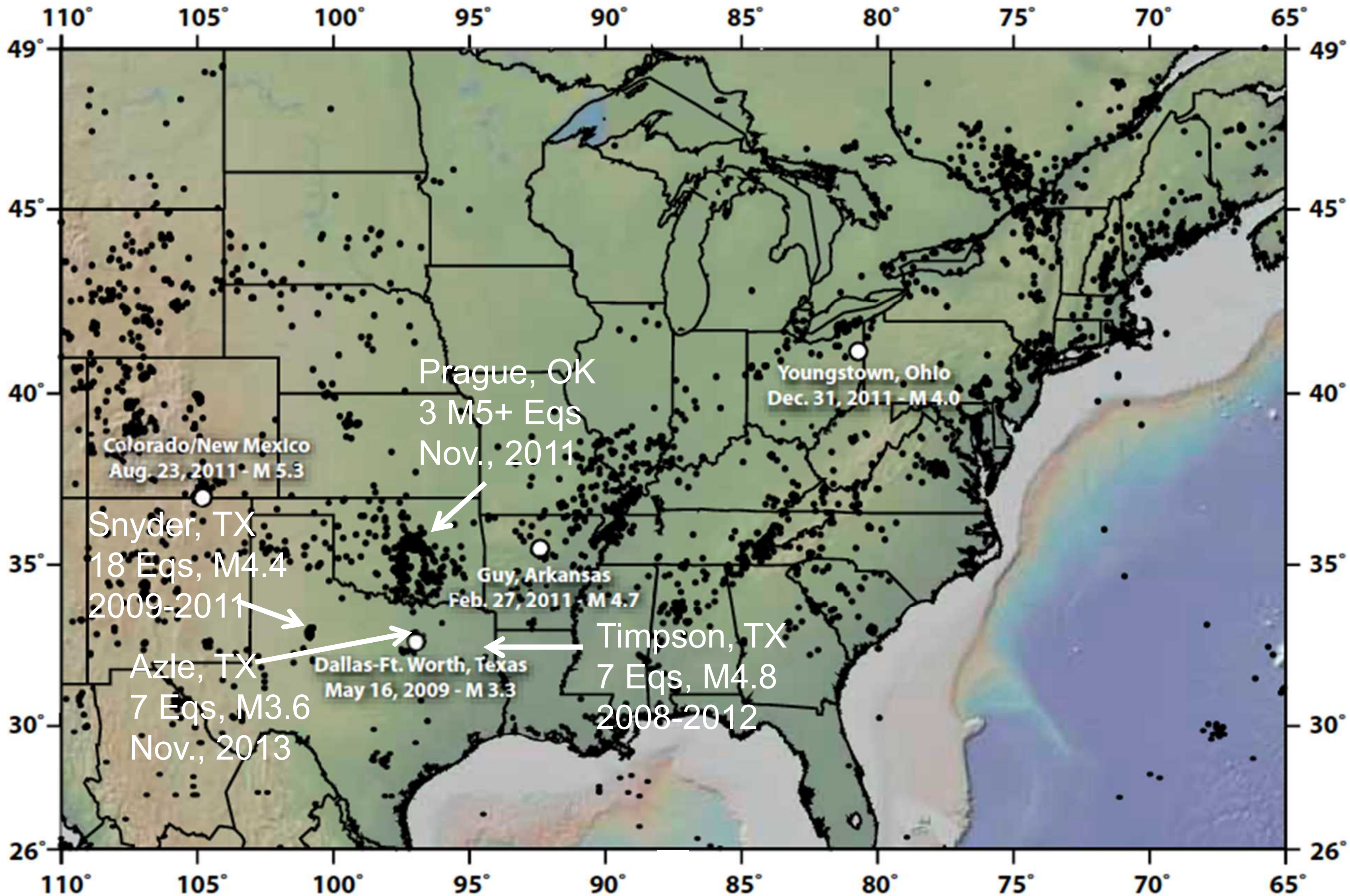
Environmental Issues

- Contamination at the surface
  - Spills at drill site and in transportation
- Land use and impact on those residing around well site
- Air Pollution
- Hydraulic Fracturing affecting well water?
  - Fracture
  - Casing leak
- Utilization of increasingly scarce water supply
- Leakage from wells
- **Flow-back water injection**
  - **Induced Seismicity**

Injection Triggered Seismicity



M.D. Zoback, Managing the seismic risk of wastewater disposal, *EARTH*, April, 2012, 38-43 (2012).

Correlation between injection and earthquakes

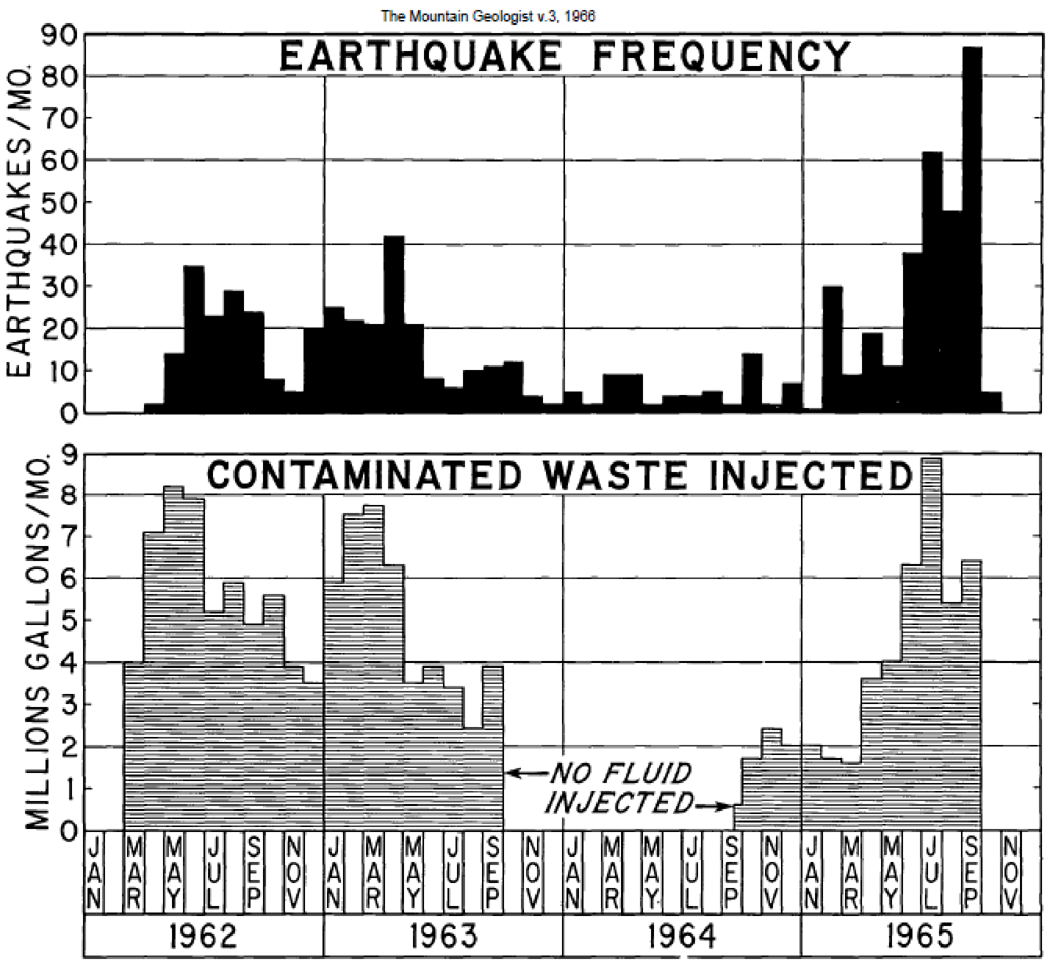
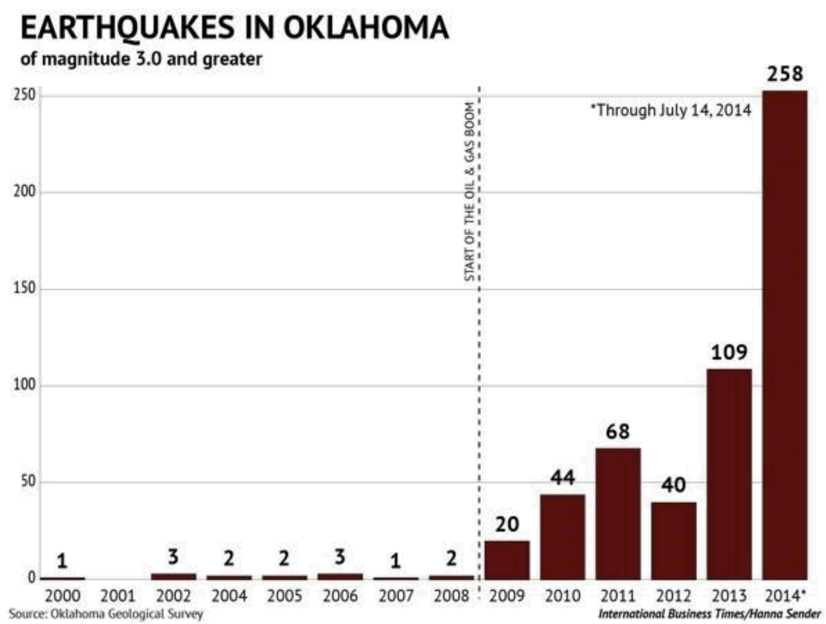


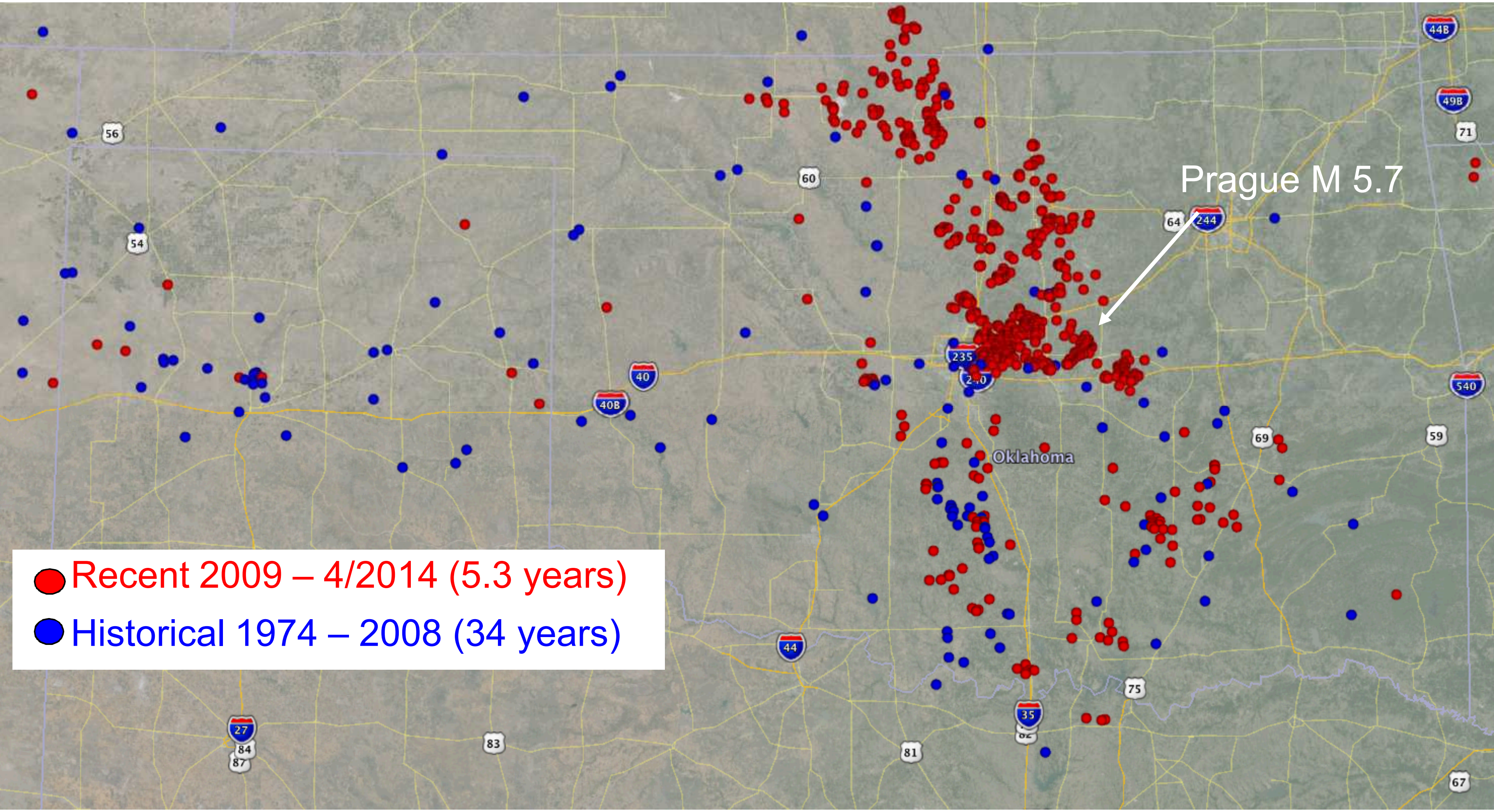
Figure 5. Upper half: number of earthquakes per month recorded in the Denver area.
Lower half: monthly volume of contaminated waste water injected into the Arsenal well.



Evans, THE DENVER AREA EARTHQUAKES AND THE ROCKY MOUNTAIN ARSENAL DISPOSAL WELL, 1966

Recent and Historical Oklahoma Seismicity

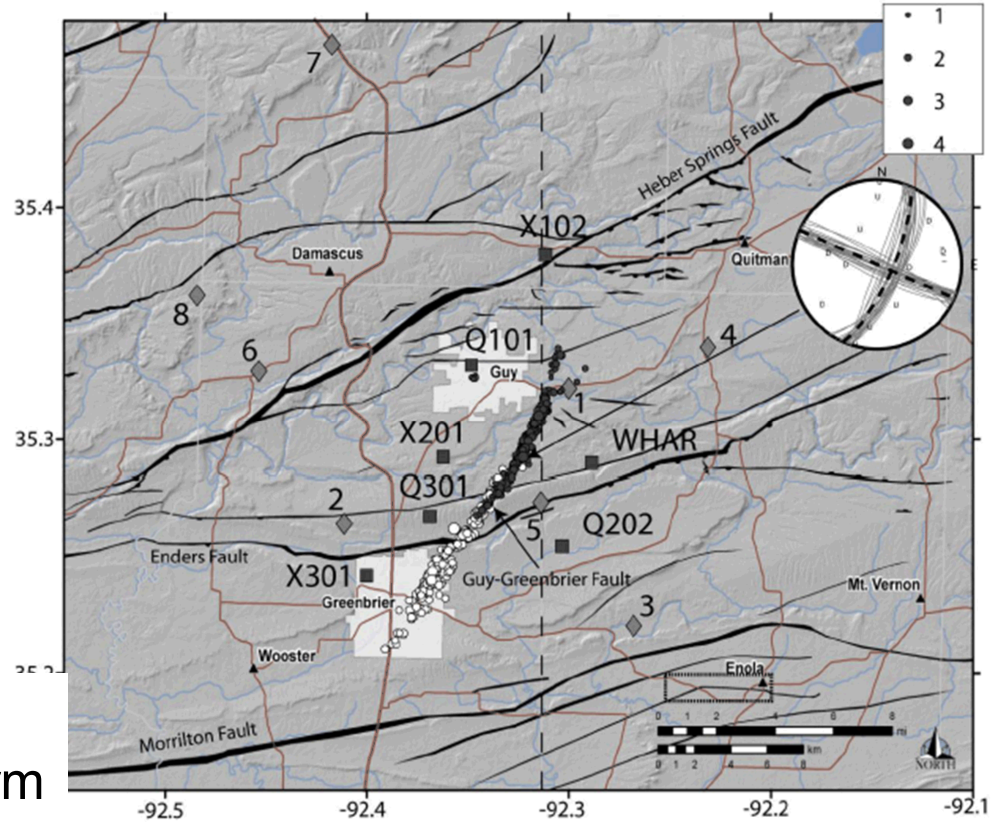
Sandia National Laboratories



OK Geological Survey - 40 fold increase in Seismicity

Slide courtesy of M. Zoback

Managing the Risk of Triggered Seismicity

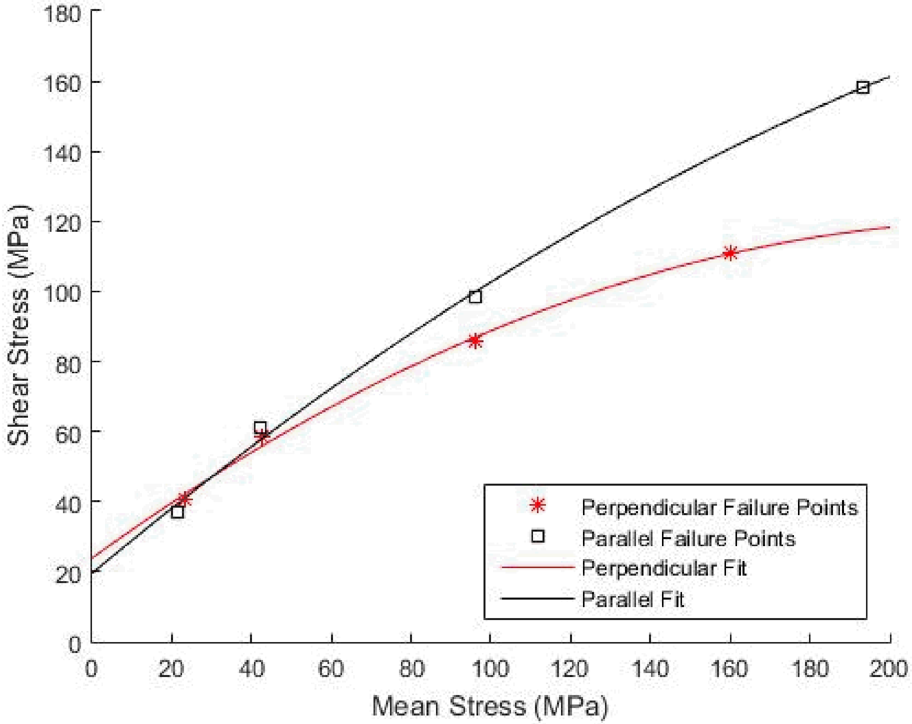


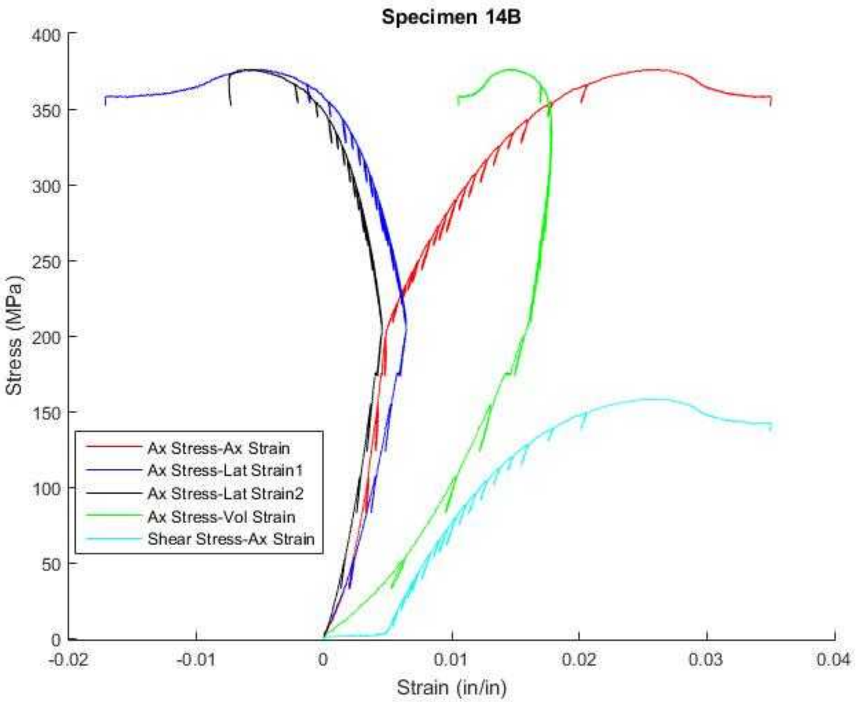
Guy Arkansas Earthquake Swarm

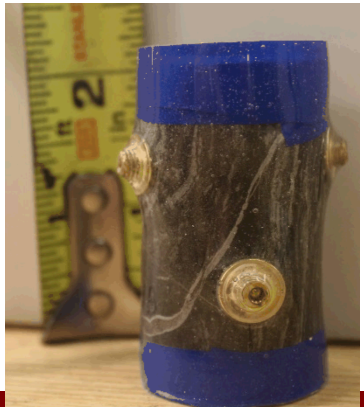
- Avoid Injection into Potentially Active Faults
- Limit Injection Rates (Pressure) Increases
- Monitor Seismicity (As Appropriate)
- Assess Risk
- Be Prepared to Abandon Some Injection Wells

Slide courtesy of M. Zoback

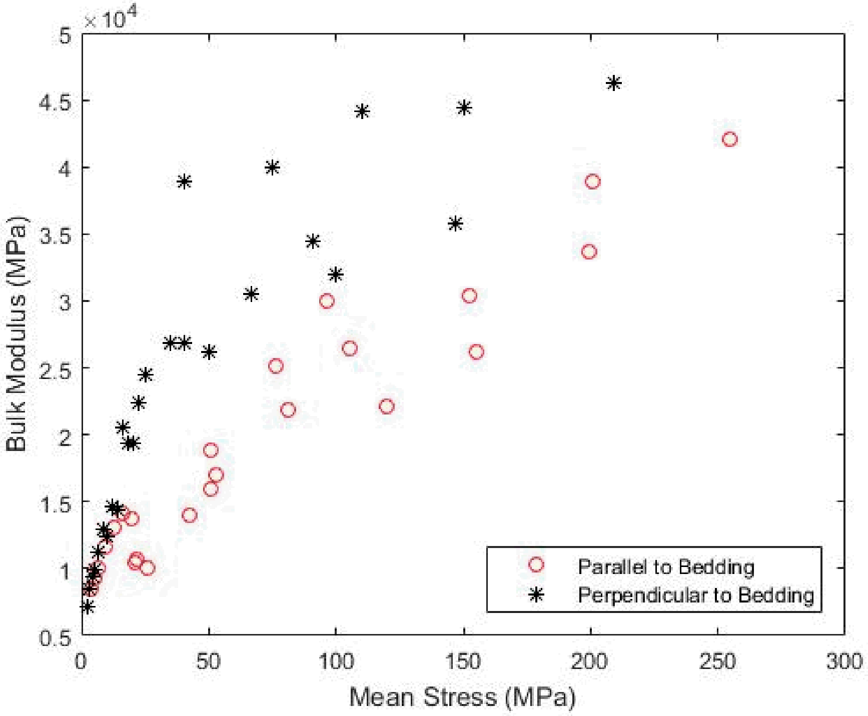
Mechanical Characterization of Shale

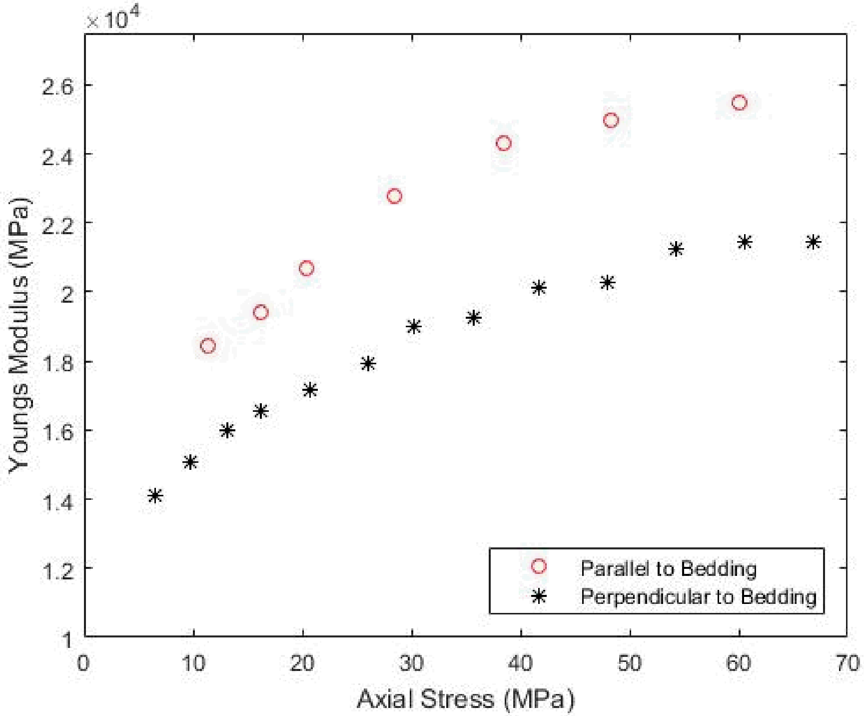






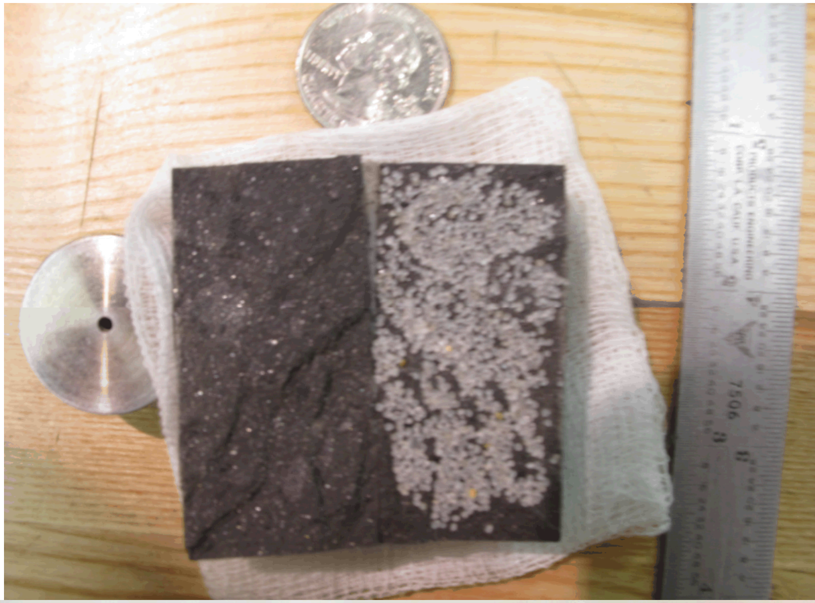
Evolution of material properties

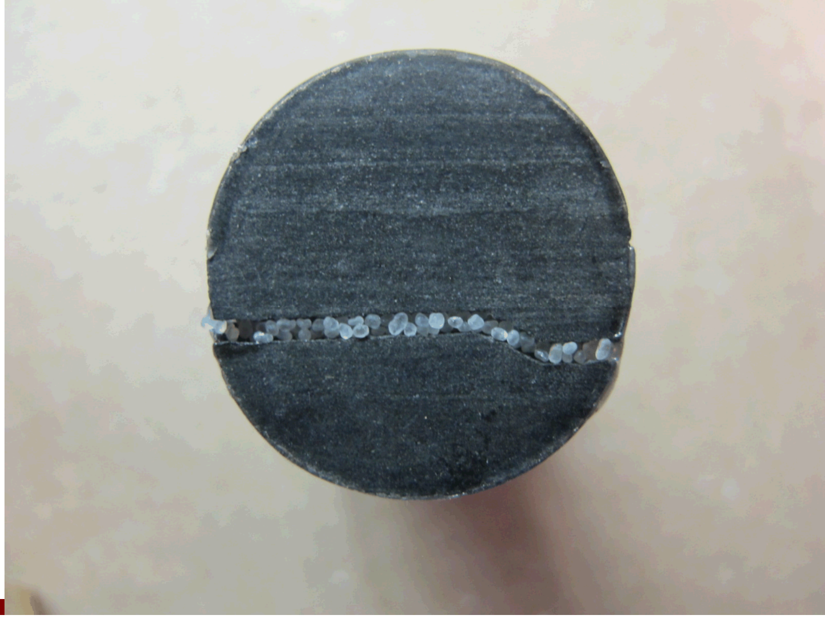




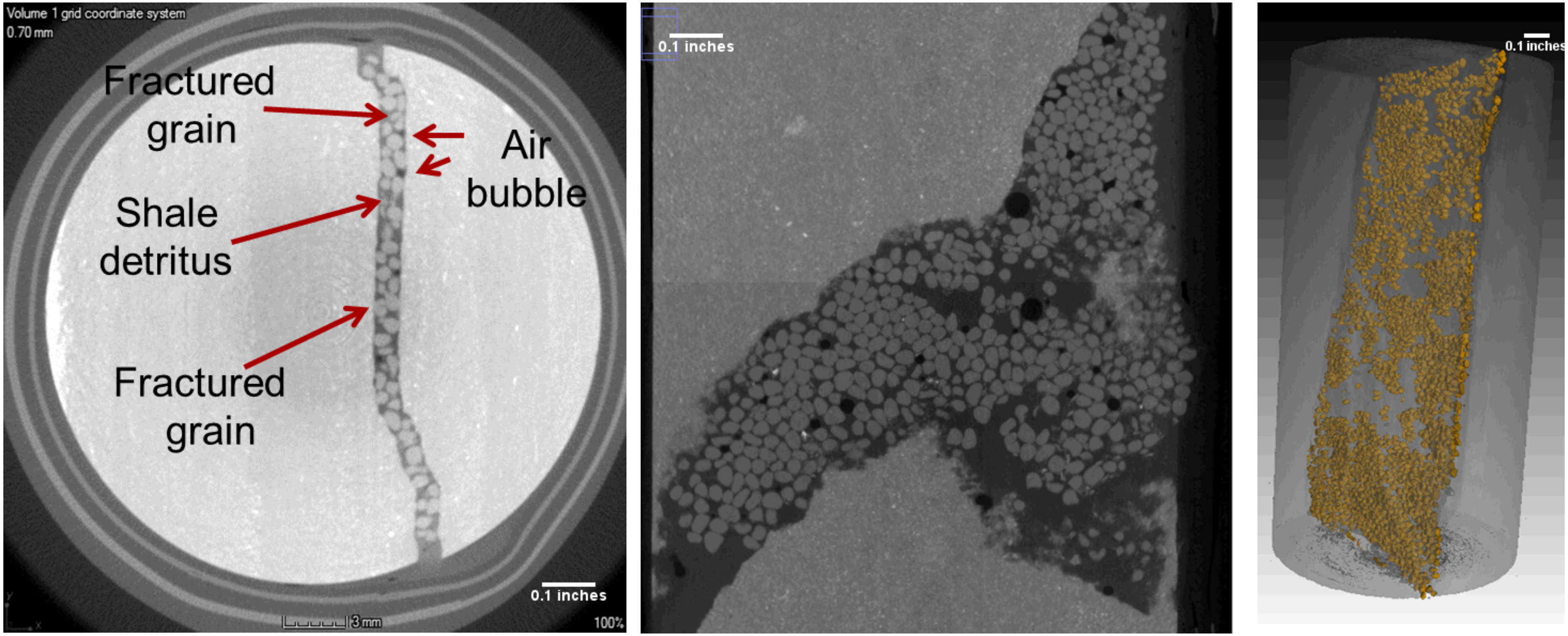
Manual Fracturing Tests

- Manually fractured shale with a monolayer of proppant placed into fracture
- Specimens reassembled and tested
  - 20-28 MPa Confining Pressure
  - 7 MPa Differential Stress
  - 75° C
  - Flow was measured with water.
- Specimens were repeatedly loaded with micro-CT scans between loading cycles to monitor shale and proppant behavior





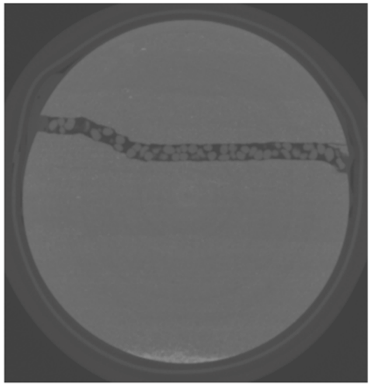
Manual Fracturing Tests



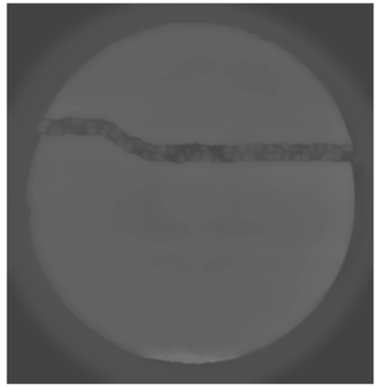
X-ray µCT data allows us to investigate the effects of the application of pressure, temperature, and pore fluids on cracks and proppant particles. Grain fracturing, embedment and shale fracturing was observed.

Mesh Generation from CT data

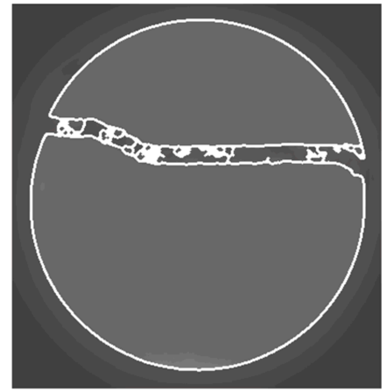
Goal: Convert grayscale image to segmented (binary) image



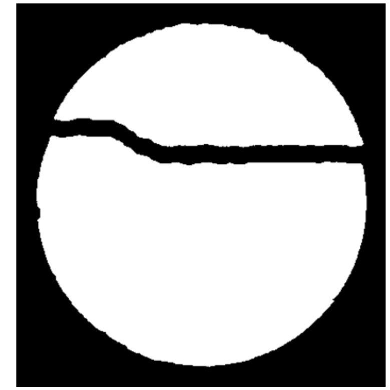
Original image



Bilateral filter
(remove noise, without losing edge sharpness)

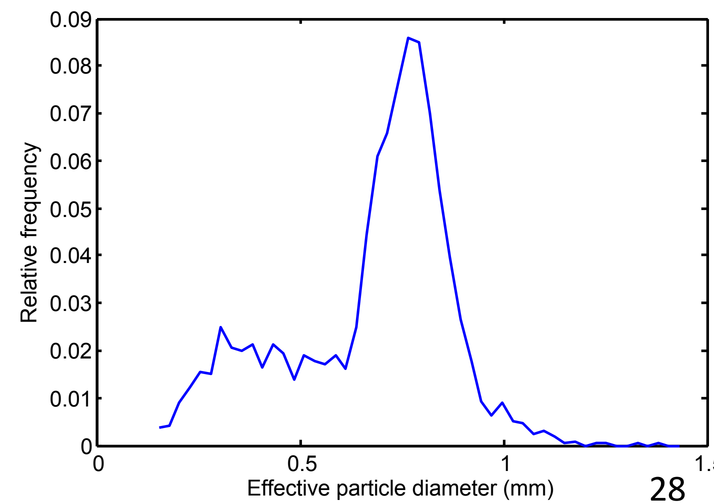


Canny edge detection
Combine with erode/dilate operations to connect edges

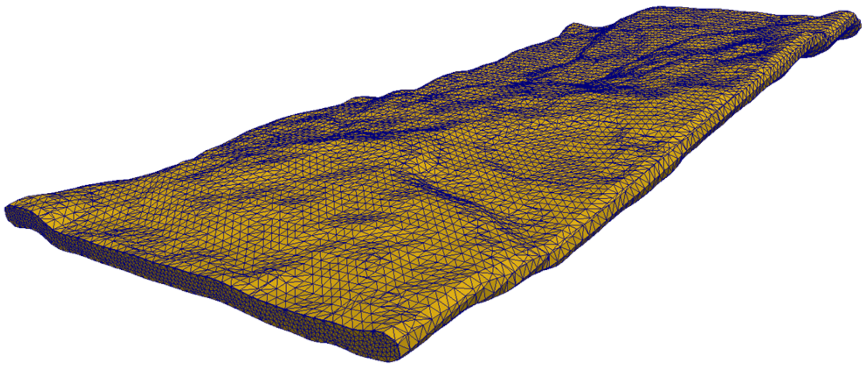


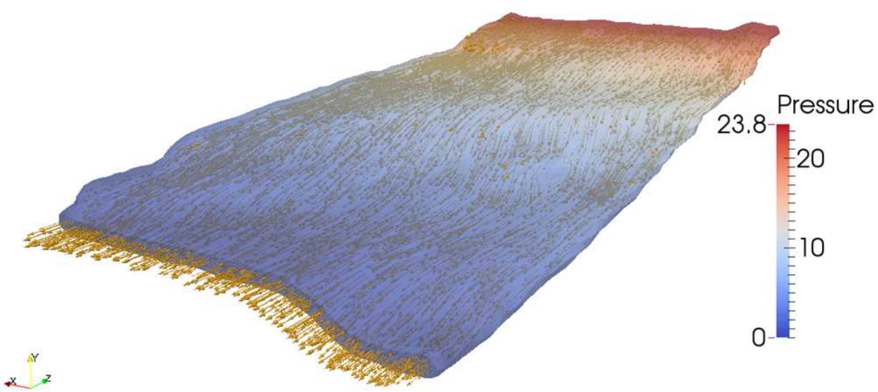
Flood fill to isolate regions of interest

Slight changes in thresholding result in ~60% decrease in permeability, use known particle size to scale thresholding



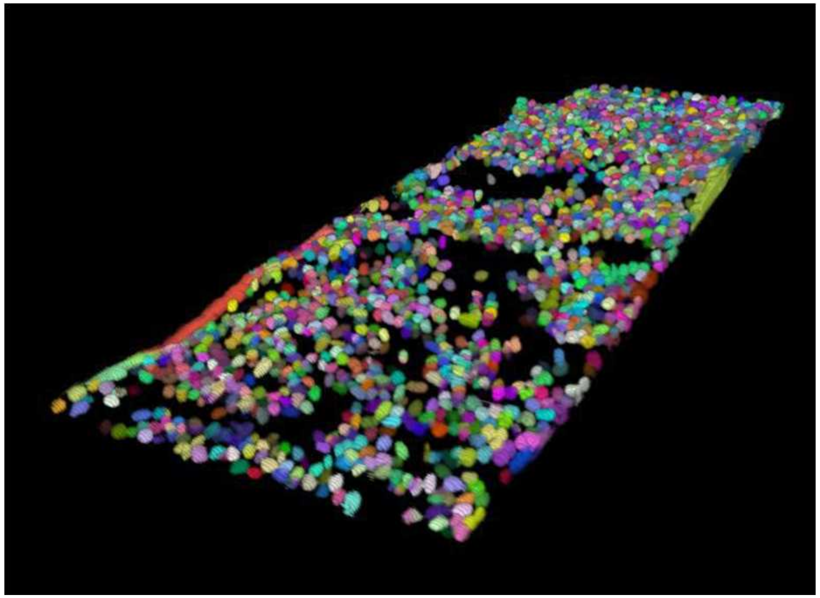
Mesh Generation

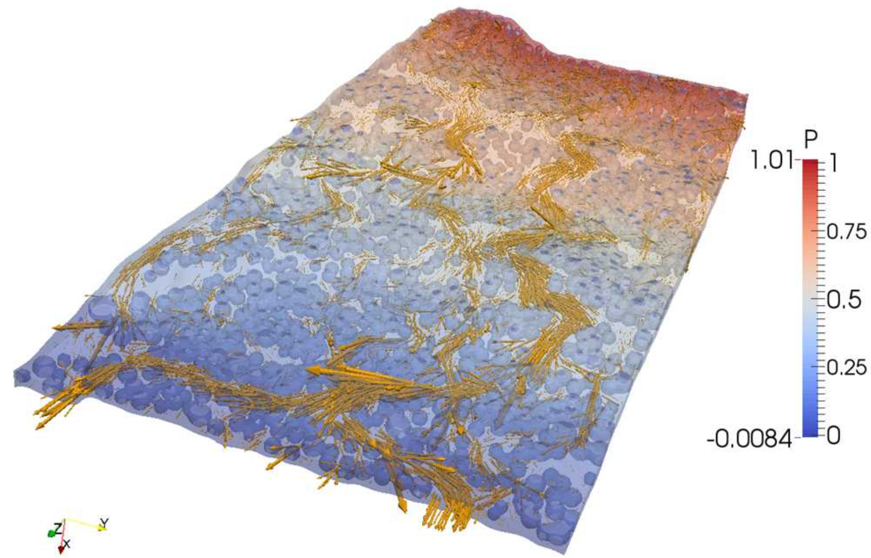




- Generate mesh of empty crack
  - Create bounding ‘net’ surfaces from CT
  - Use ‘nets’ to create volume
  - Mesh volume
- Resulting mesh contains approximately 150,000 elements
- Flow is measured to determine base line for the crack without particles.

Mesh Generation/Flow Results





- Particles are identified by adaptive thresholding of the crack region (similar to determining crack space)
- Individual particles are identified with a 3D watershed algorithm

Combine particle size and location information with crack geometry by generating spheres at appropriate locations → possible to generate high-quality mesh that accounts for particles: (Still in progress)

Simulation-based study

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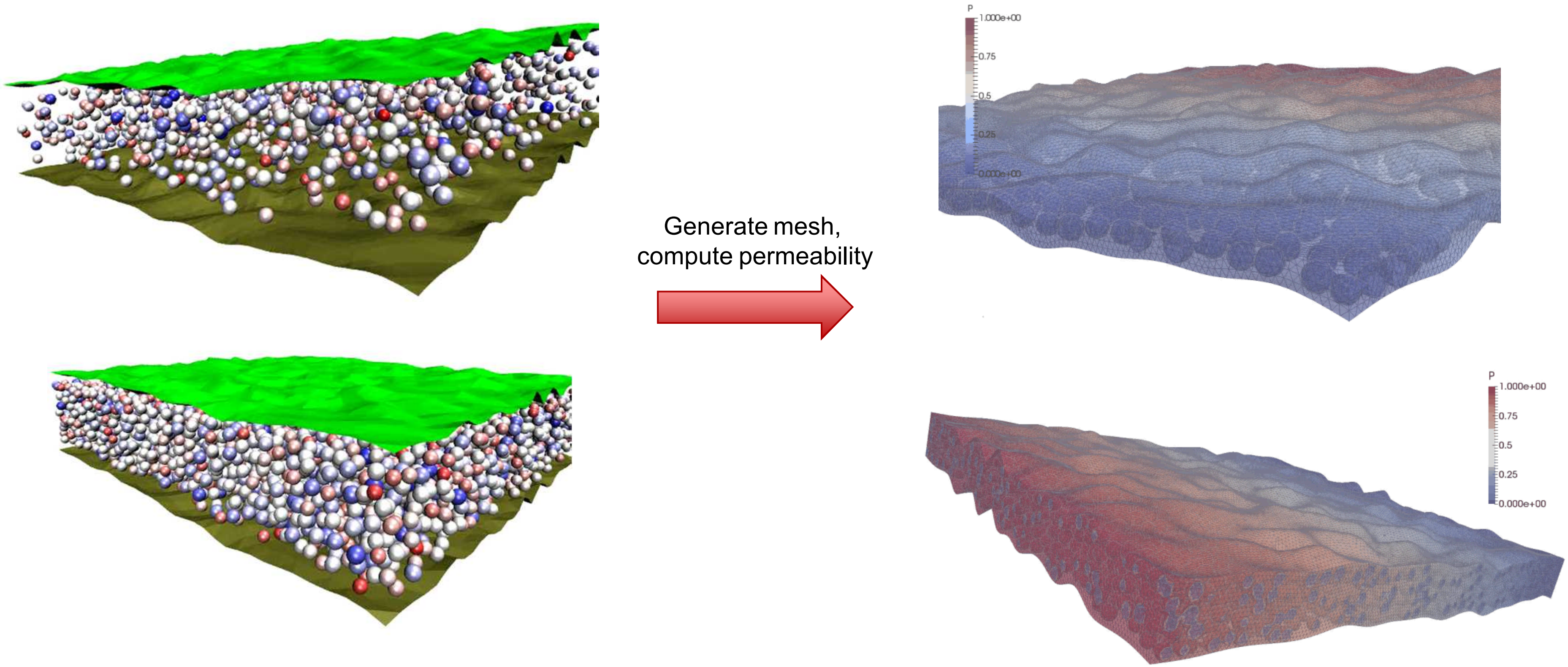
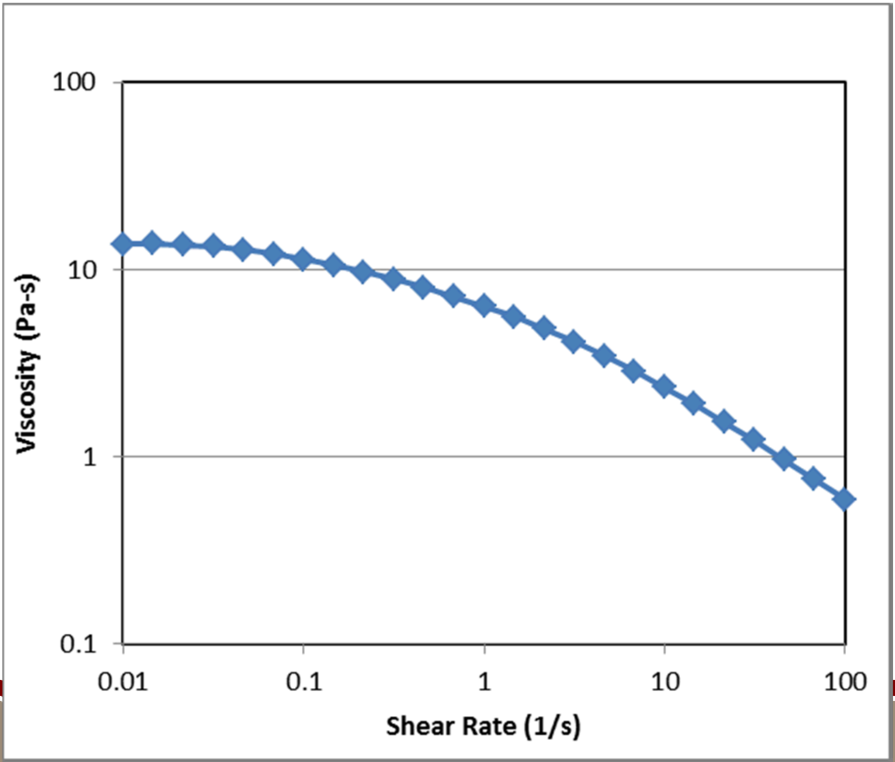
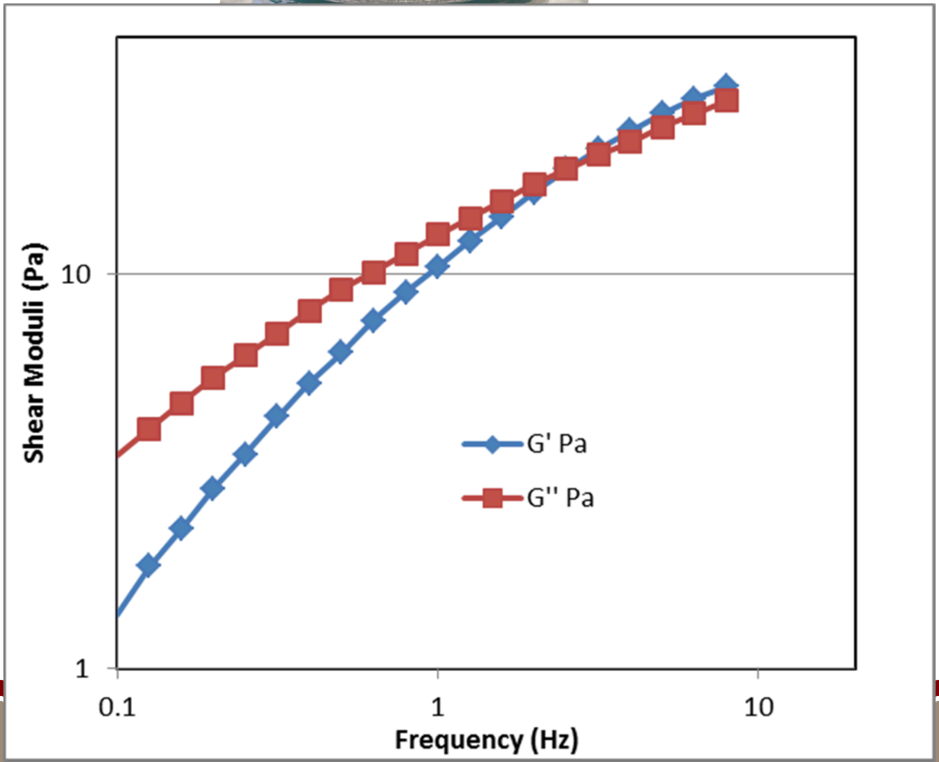


- Computer-generated crack geometries with controlled tortuosity
- Particle placement is somewhat artificial (compression w/ periodic boundaries), but here we are only interested in final placement of particles
- Large number of simulations underway to study combined effects of particle size distribution, particle arrangement, number of particle layers and crack tortuosity on crack permeability and flow patterns
- Potentially analyze particle stress distribution → use simulations to find optimal particle characteristics that maximize permeability, minimize stress

Guar Rheology

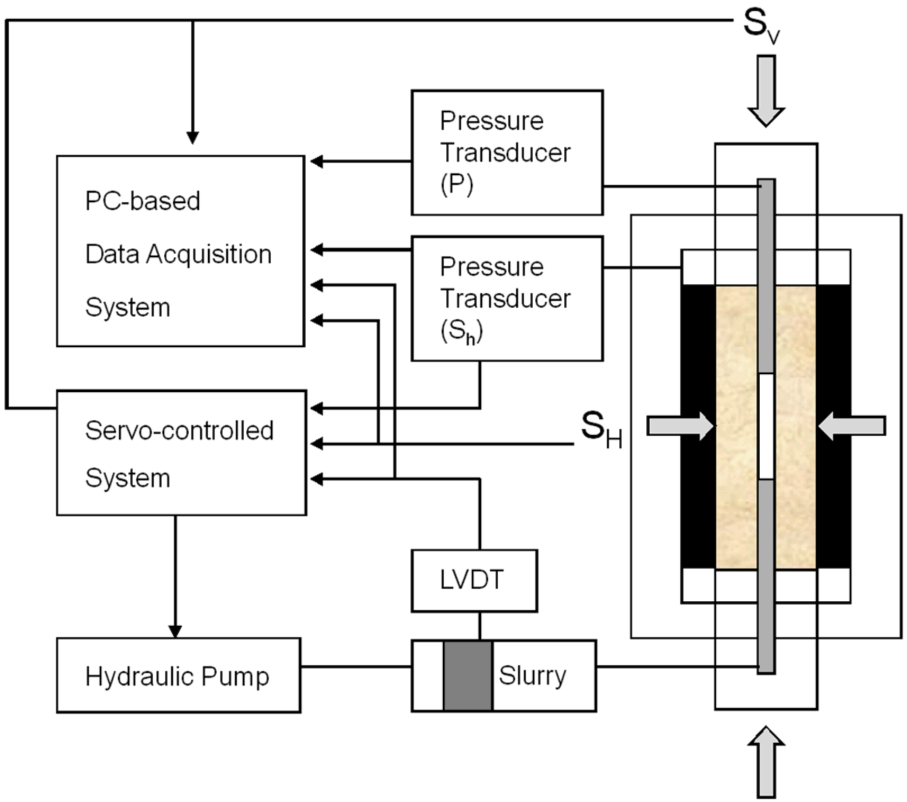
- Zero Shear Viscosity 13.7 Pa*s
  - Approximately that of molasses
- Strongly shear thinning
- Pronounced Viscoelasticity
- Guar based mixture



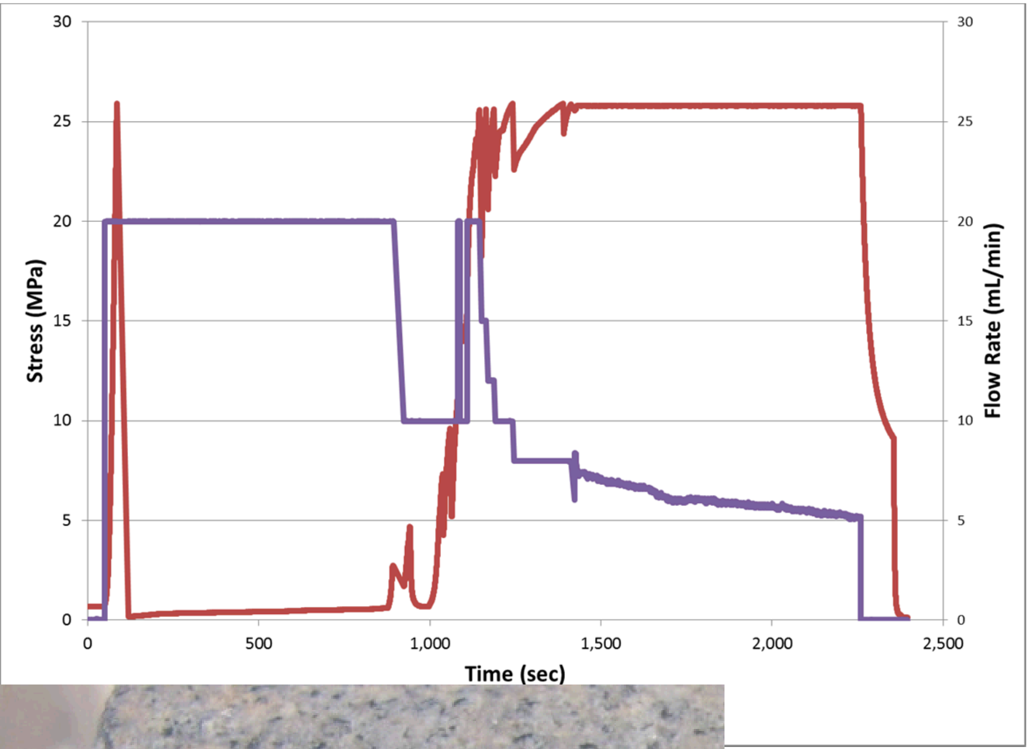


Fracturing System

- Fracture is achieved by a 2 stage injection process
  - First 300 mL of water is injected at 20 mL/min
  - This causes the pressure to rise to the necessary level to generate the fracture
  - Then 200 mL of a guar mixture with 75 +/-10 µm aluminum oxide (now silicon carbide) is injected at a constant pressure level (this is done to avoid hitting the pressure limit of the pump as the thickened guar takes much more pressure to flow into the fracture.

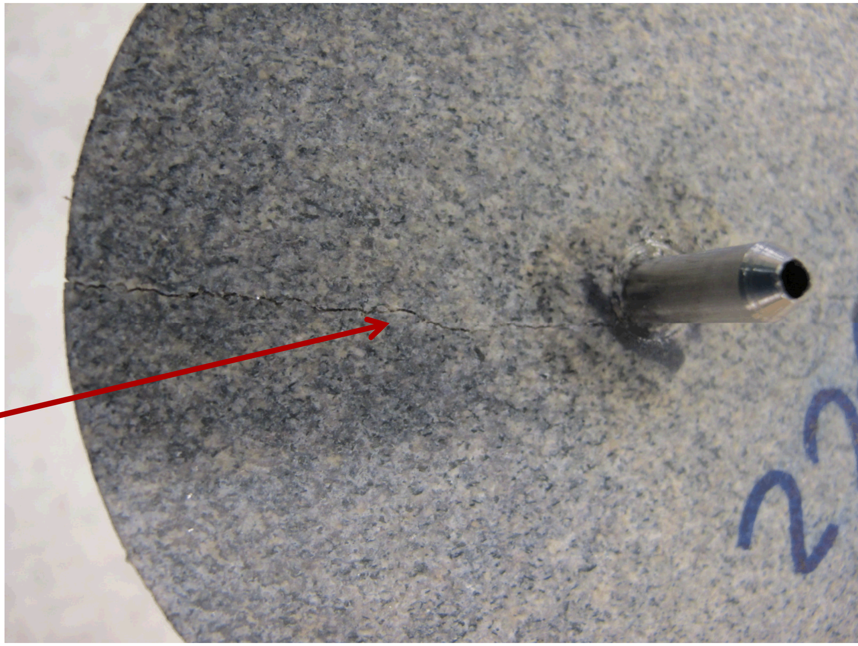


Experimental Results



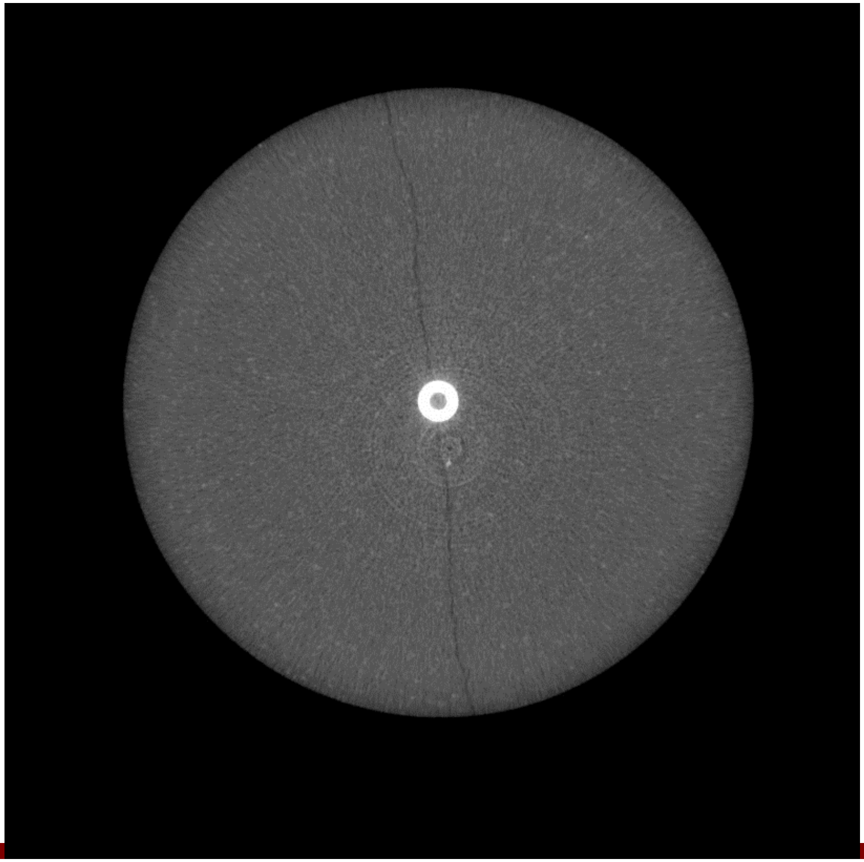
- $\sigma_H = 3.5$ MPa
- $\sigma_V = 7.0$ MPa

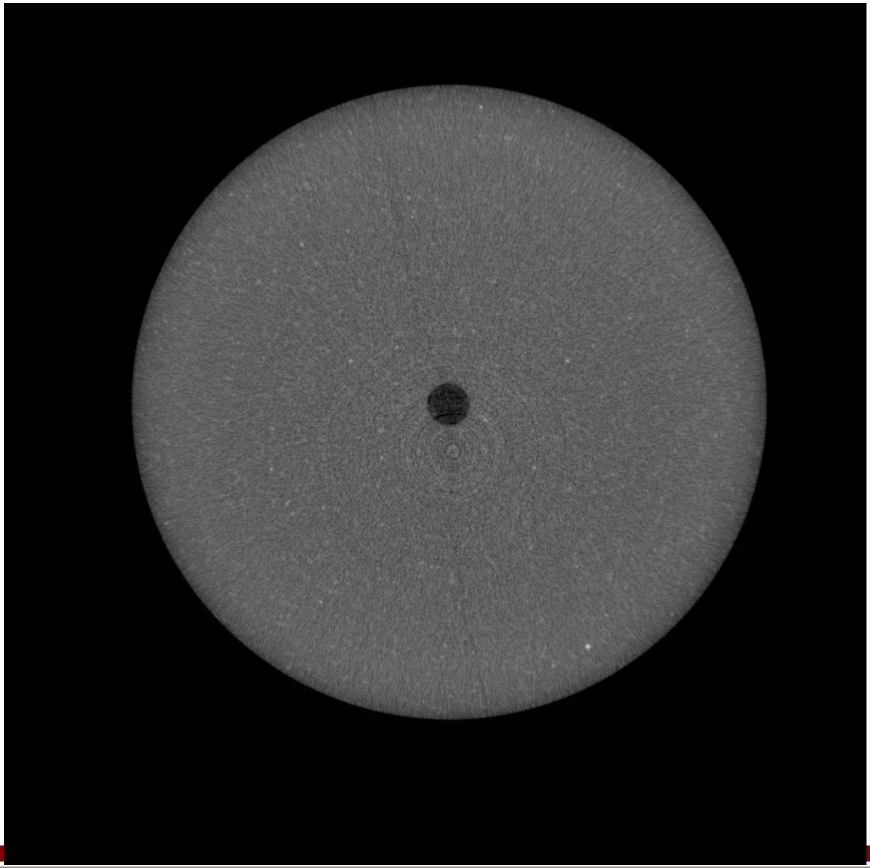
Hydraulic Fracture



Experimental Results

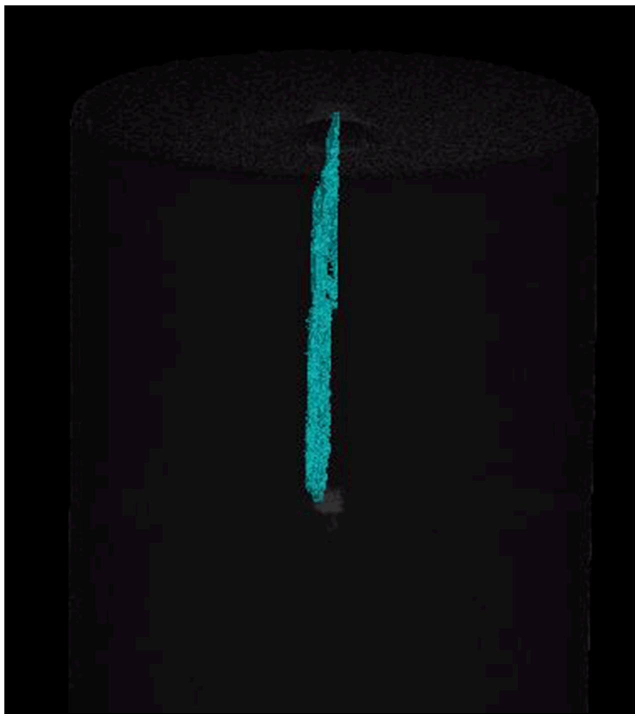
- Fracture shows noticeable opening on the order of 1-4 voxels (1 voxel is a ~0.007” on a side cube)
- Fracture extends below the end of the borehole.

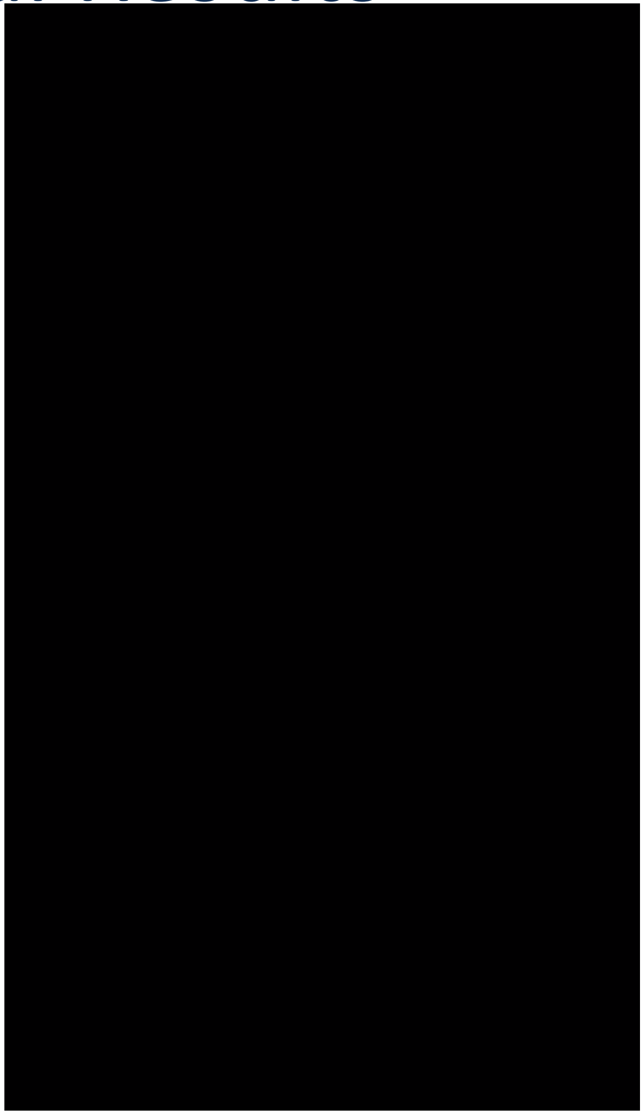


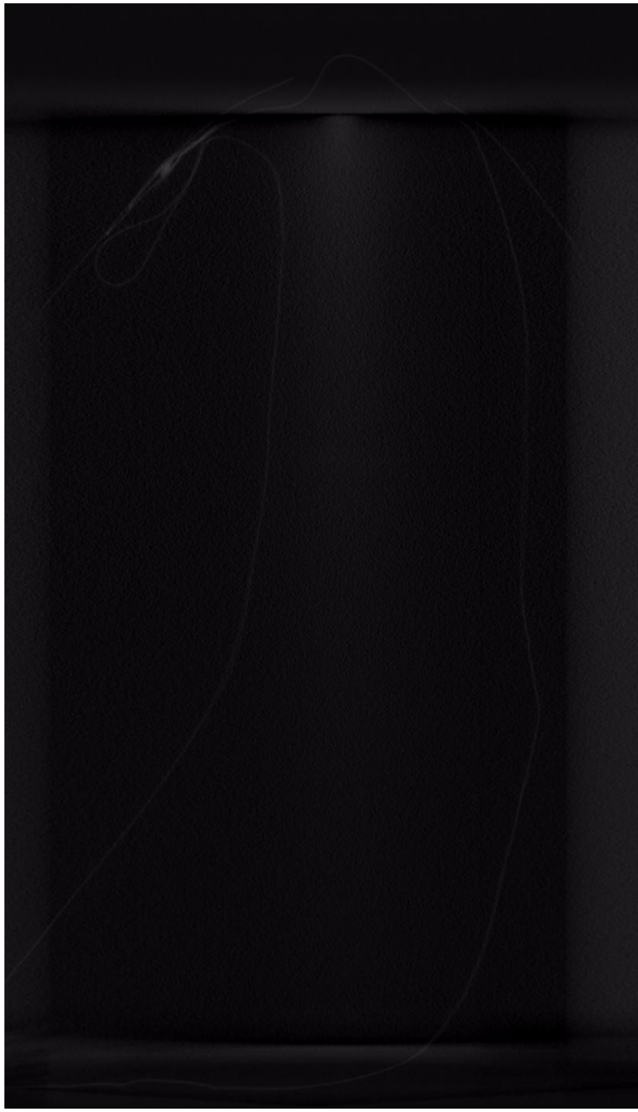


Experimental Results

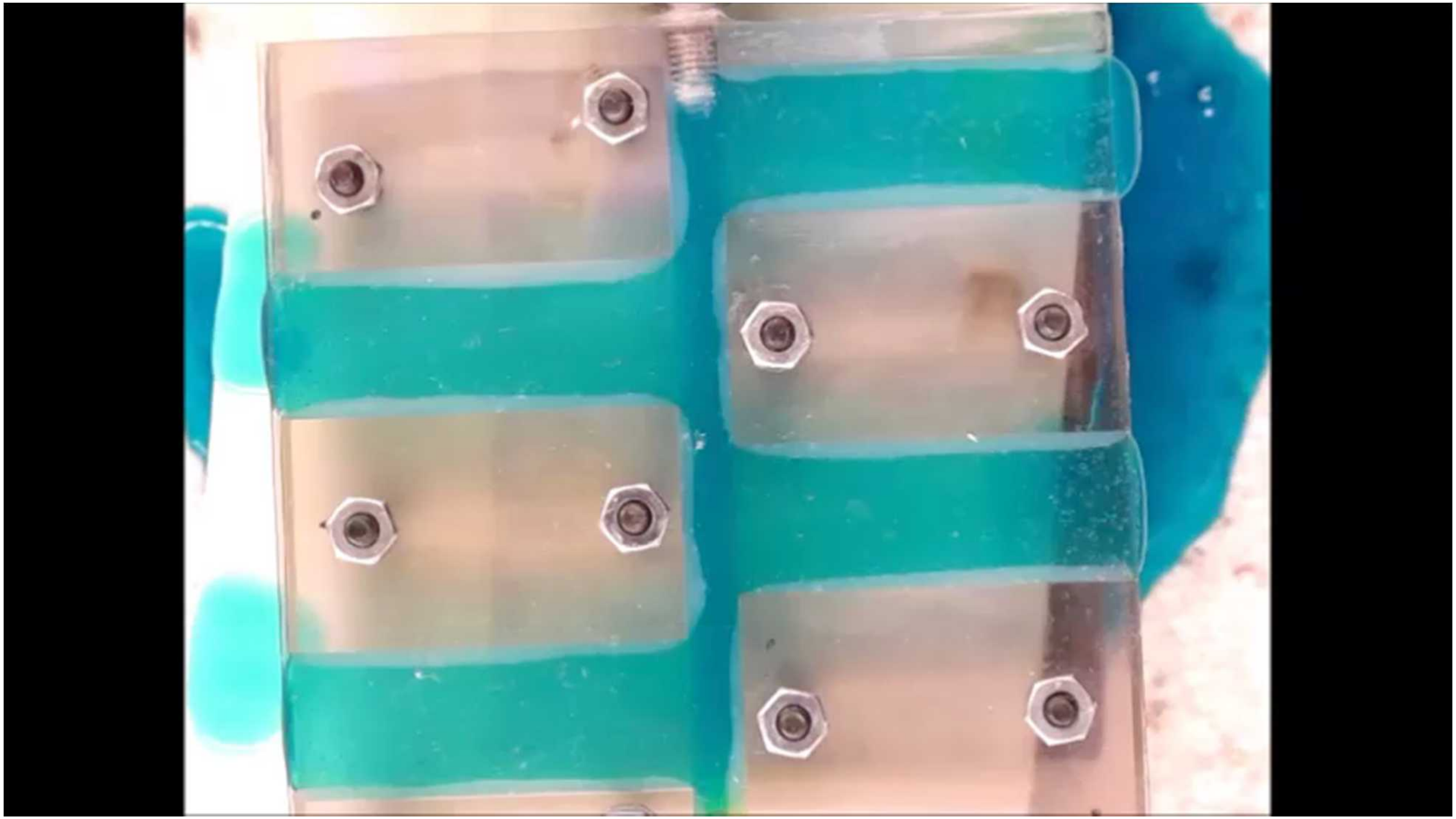
- As expected crack is roughly planar
- Crack bifurcates in a few places





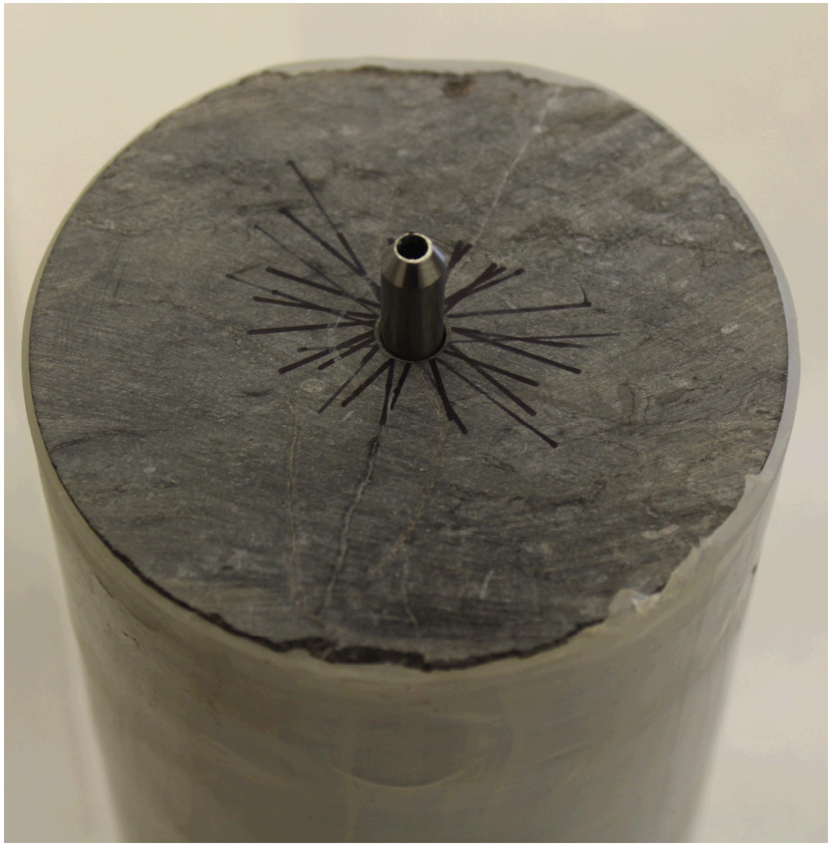


Flow Cell Testing



Future Testing

- Marcellus Shale from a newly exposed outcrop in Pennsylvania
- Fractured under extensile stress conditions to generate “disk on string” style fracture
- Subsequent proppant injection with silicon carbide particles (~75 µm)



Conclusions

- CT Scans have been invaluable in determining proppant shale interactions
- 2 Stage water frac is very effective at generating fractures with relatively high permeability
- Proppant size is extremely important in effectiveness of propping fractures
- With high resolution scans developing representative meshes from CT images is still difficult
- Flow simulations on said meshes is computationally expensive
- Proppant shale interaction has been investigated