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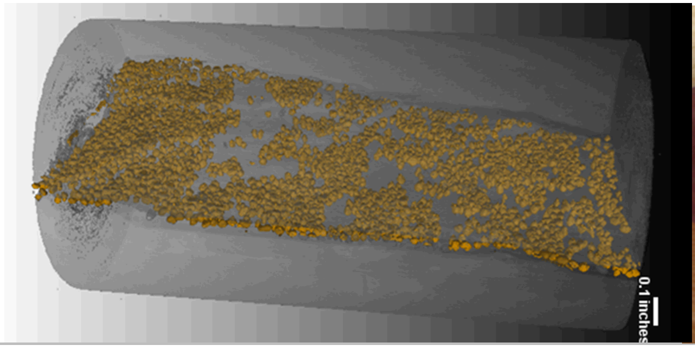

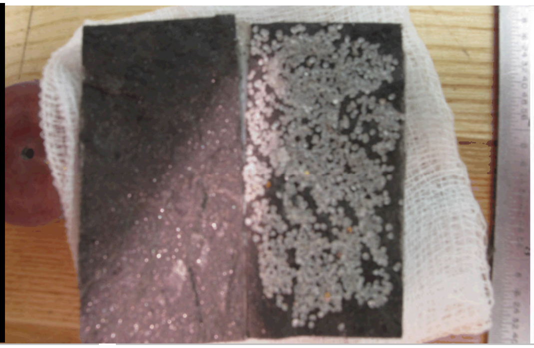

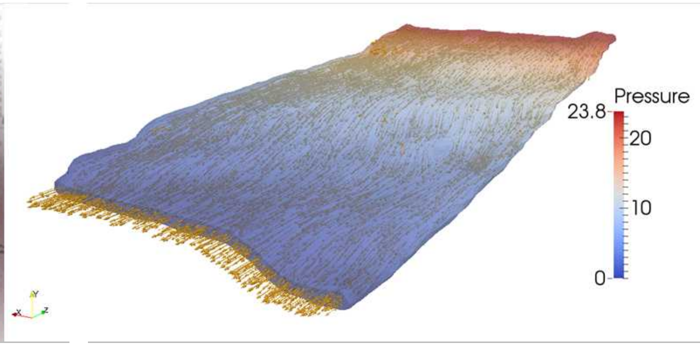

Effect of proppant on maintaining permeability in fractured shale: Status

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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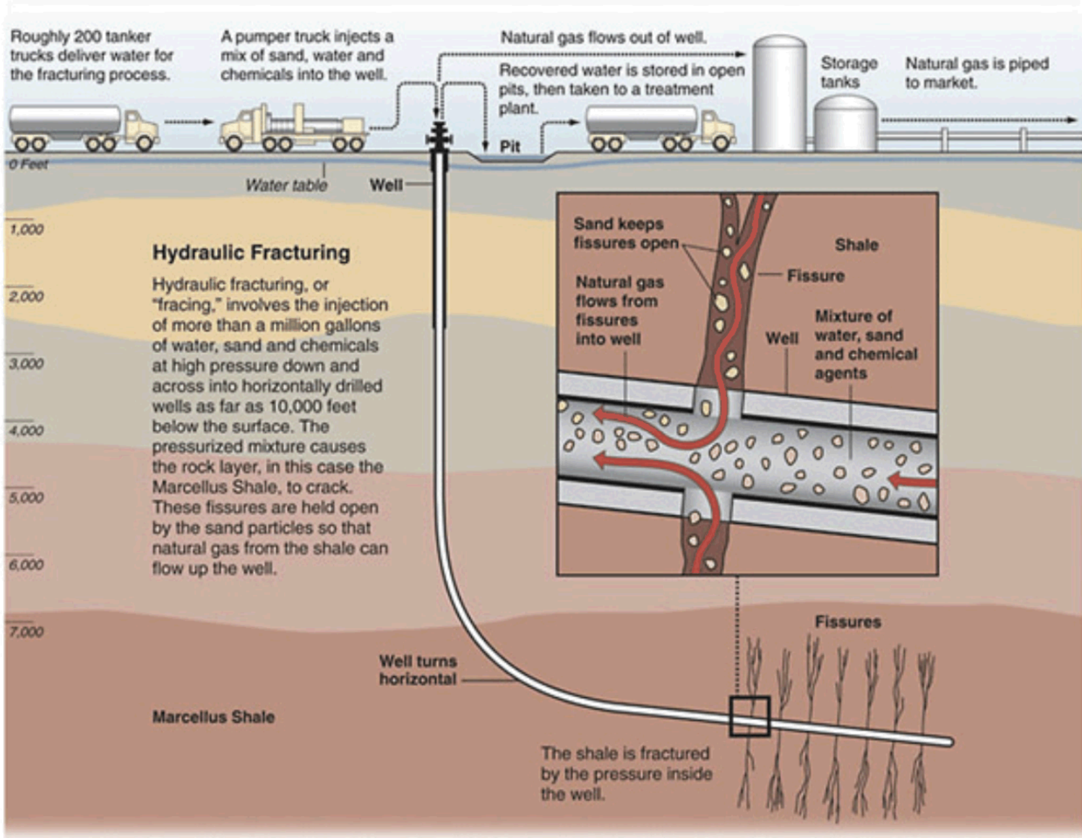
Outline

- Preliminary Testing
- Modeling of Preliminary Tests
  - Mesh Generation
  - Flow Results
- Fracturing System
- Experimental Results of Fracture Testing
- Conclusions
- Future Testing

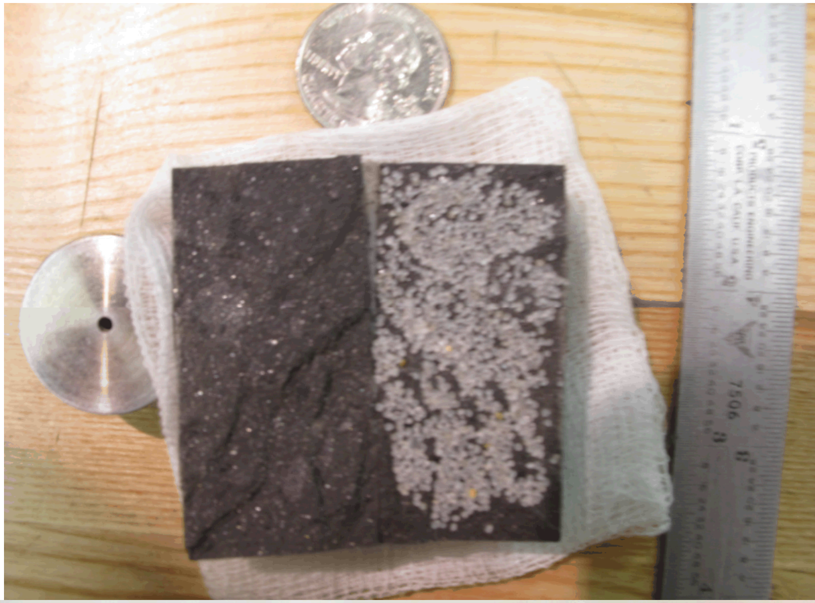


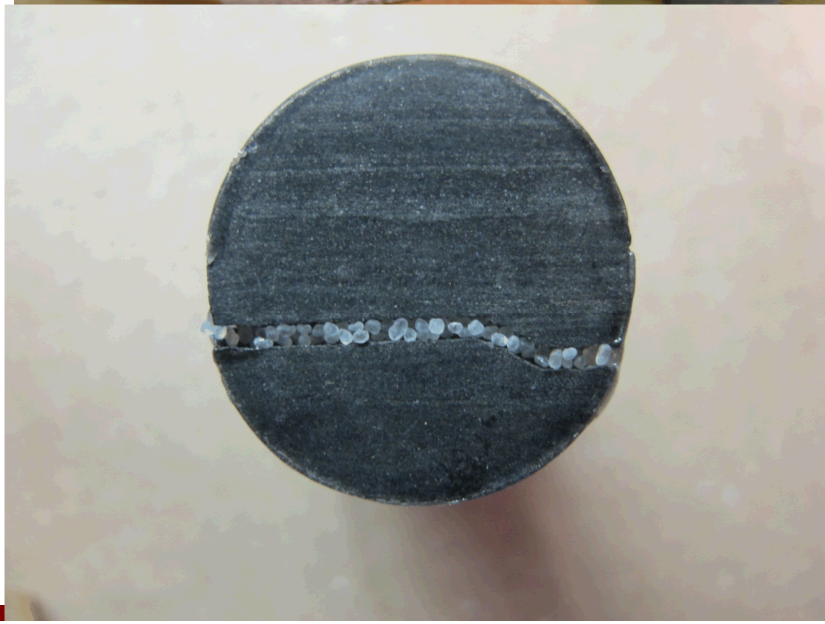
Graphic by Al Granberg

Goal: Develop a predictive model for proppant placement based off laboratory hydraulic fracture and proppant flow data to inform proppant selection and concentration to increase well production.

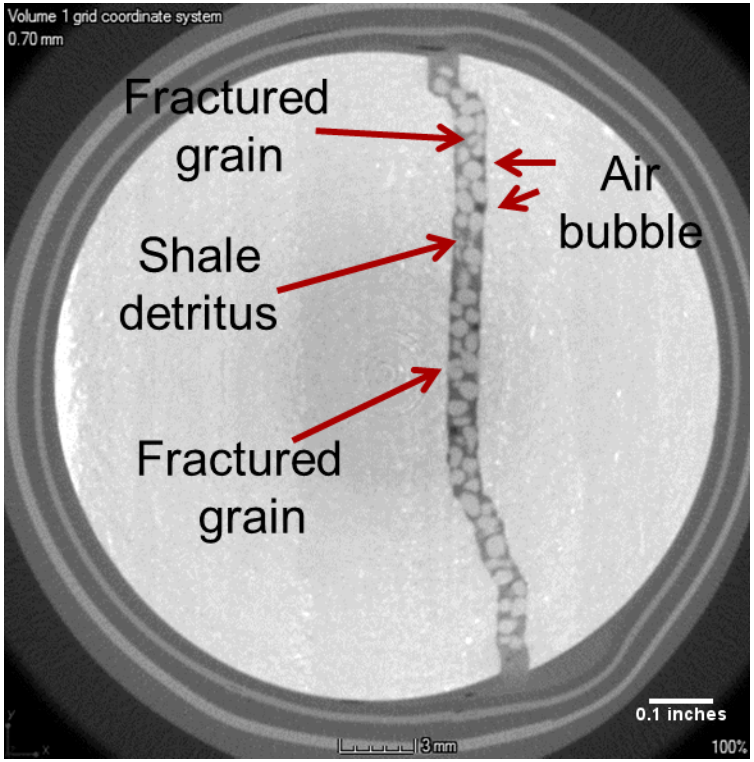
Preliminary Tests

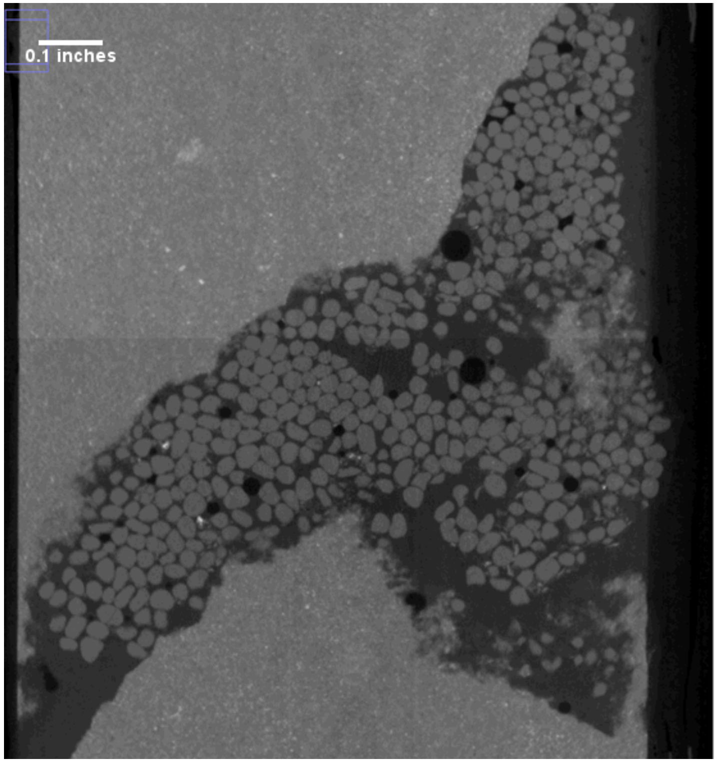
- Manually fractured shale with a monolayer of proppant placed into fracture
- Specimens reassembled and tested
  - 20-28 MPa Confining Pressure
  - 7 MPa Differential Stress
  - 75^{o} C
  - Flow was measured with water.
- Specimens were repeatedly loaded with micro-CT scans between loading cycles to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

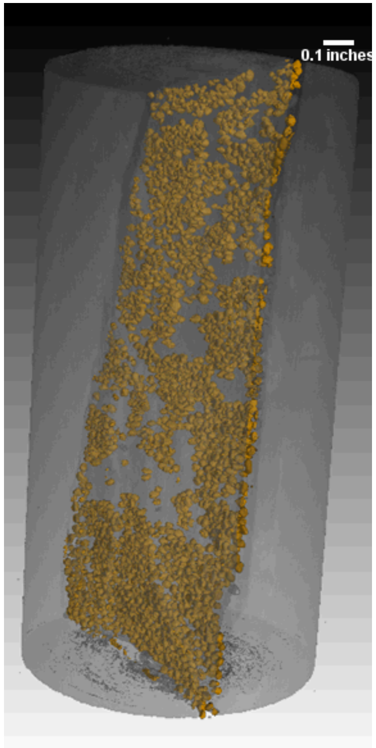




Preliminary Tests



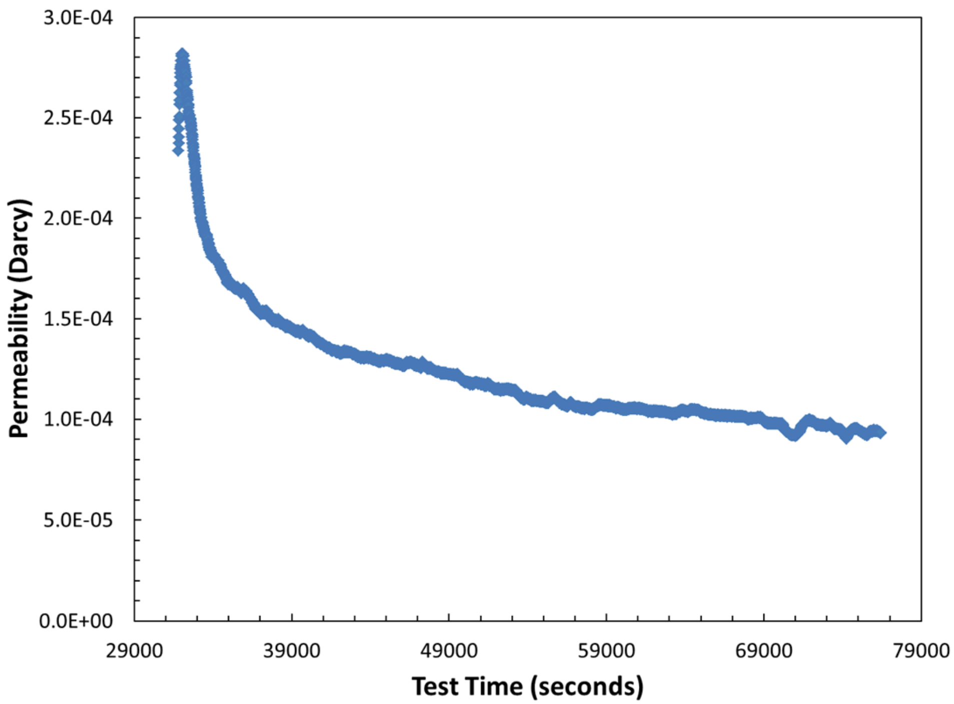


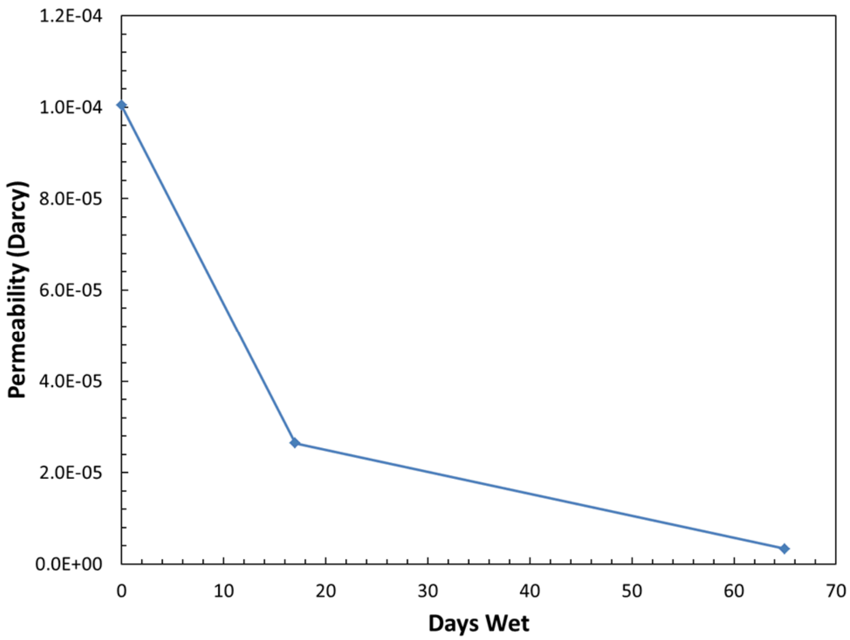


X-ray µCT data allows us to investigate the effects of the application of pressure, temperature, and pore fluids on cracks and proppant particles. Grain fracturing, embedment and shale fracturing was observed.

Preliminary Tests

- Swelling clays in shale appear to be causing significant permeability reduction purely by wetting the shale specimen.

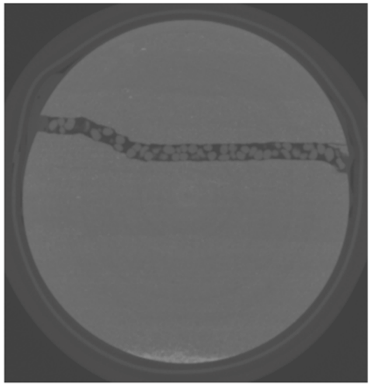




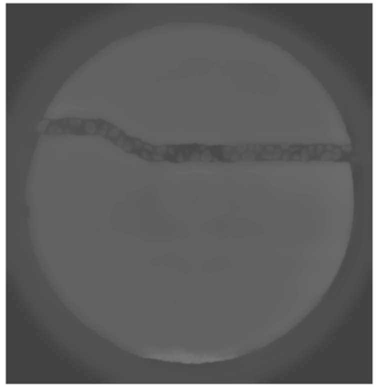
This could also be coupled with plastic deformation of the shale around the proppant particles, an effect seen in the CT images.

Mesh Generation

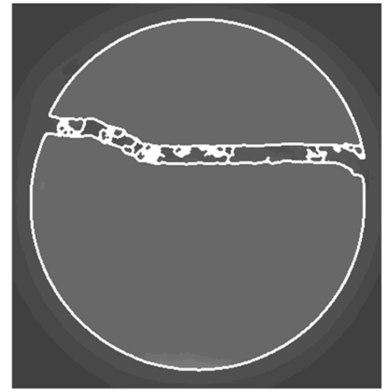
Goal: Convert grayscale image to segmented (binary) image



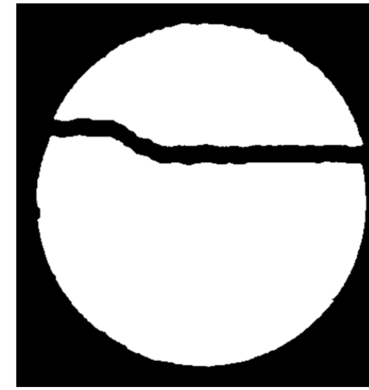
Original image



Bilateral filter
(remove noise, without losing edge sharpness)

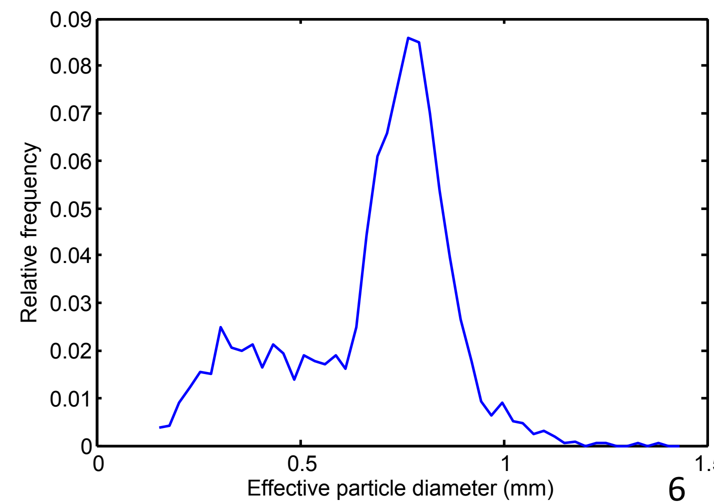


Canny edge detection
Combine with erode/dilate operations to connect edges

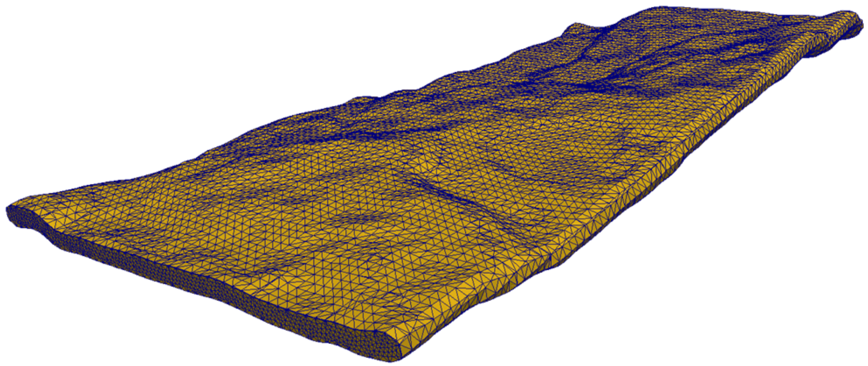


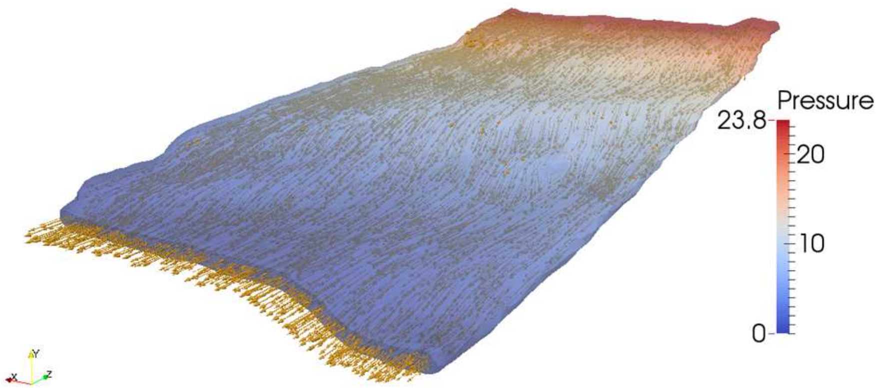
Flood fill to isolate regions of interest

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



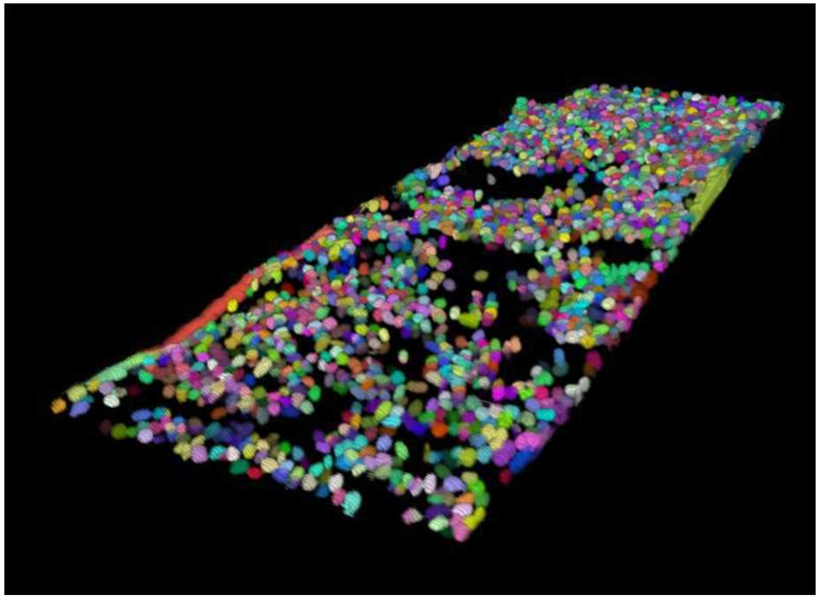
Mesh Generation

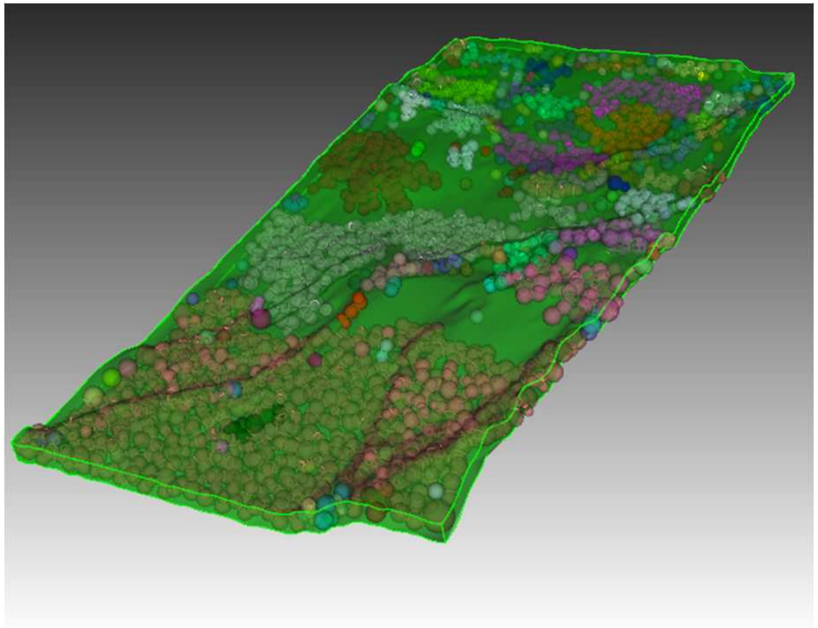




- Generate mesh of empty crack
  - Create bounding ‘net’ surfaces from CT
  - Use ‘nets’ to create volume
  - Mesh volume
- Resulting mesh contains approximately 150,000 elements
- Flow is measured to determine base line for the crack without particles.

Mesh Generation/Flow Results



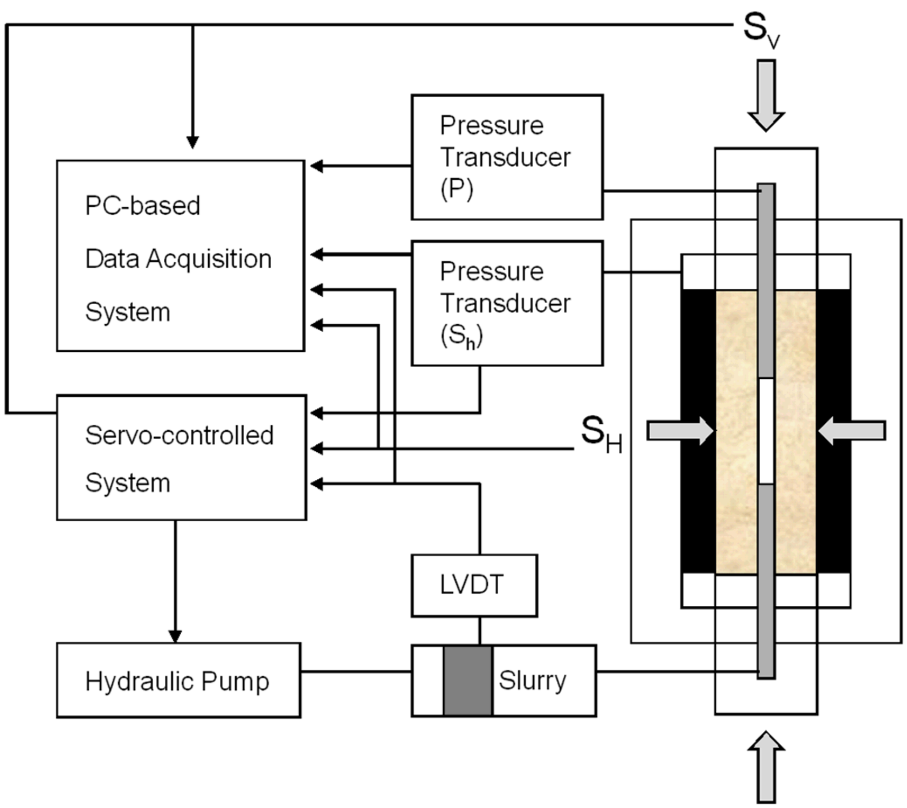


- Particles are identified by adaptive thresholding of the crack region (similar to determining crack space)
- Individual particles are identified with a 3D watershed algorithm

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)

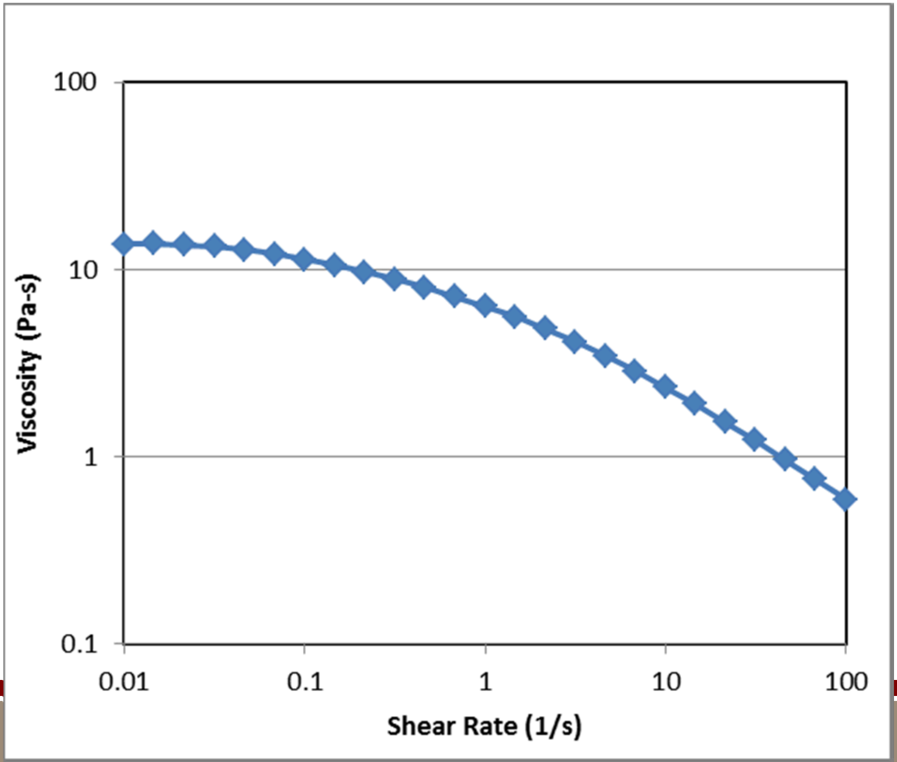
Fracturing System

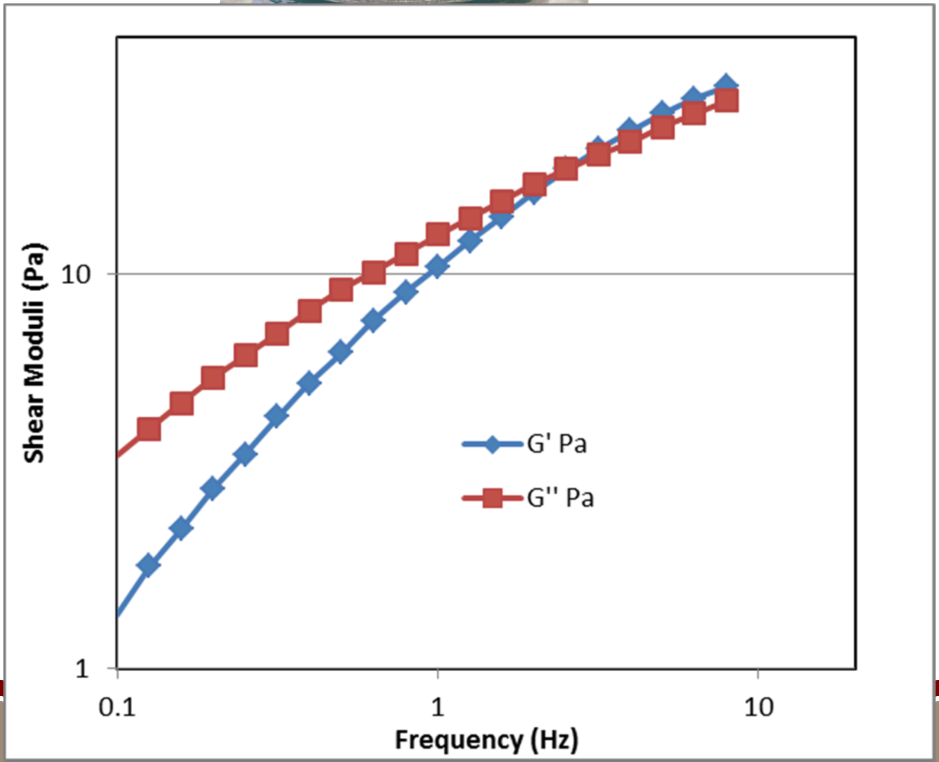
- Fracture is achieved by a 2 stage injection process
  - First 300 mL of water is injected at 20 mL/min
  - This causes the pressure to rise to the necessary level to generate the fracture
  - Then 200 mL of a guar mixture with 50-70 sieve sand is injected at a constant pressure level (this is done to avoid hitting the pressure limit of the pump as the thickened guar takes much more pressure to flow into the fracture.



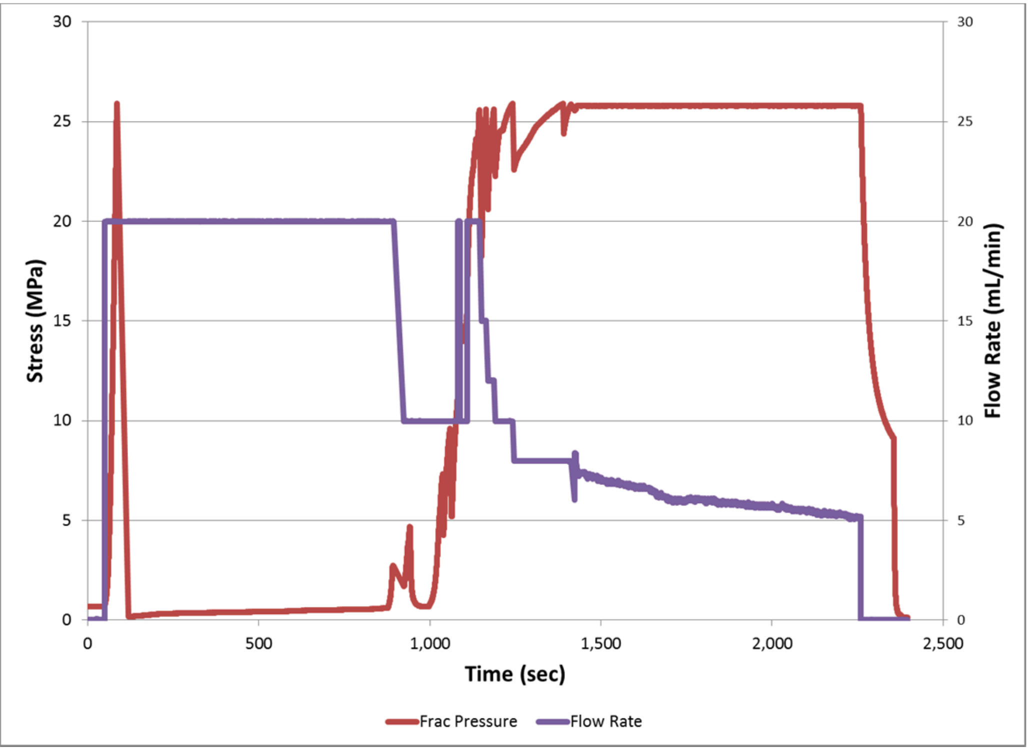
Guar Rheology

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

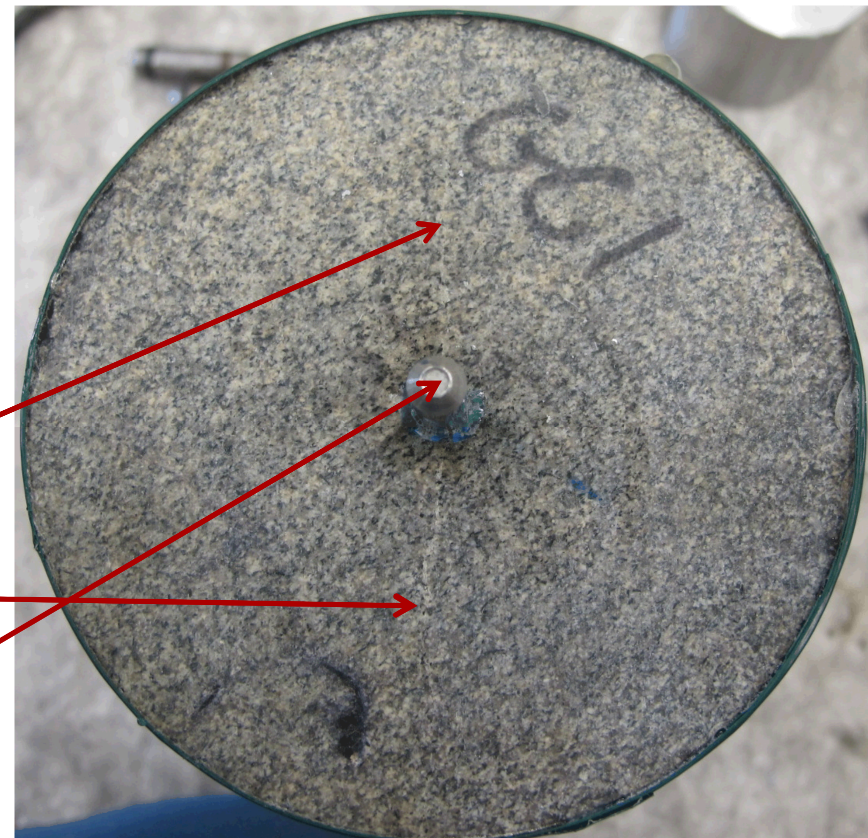




Experimental Results



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

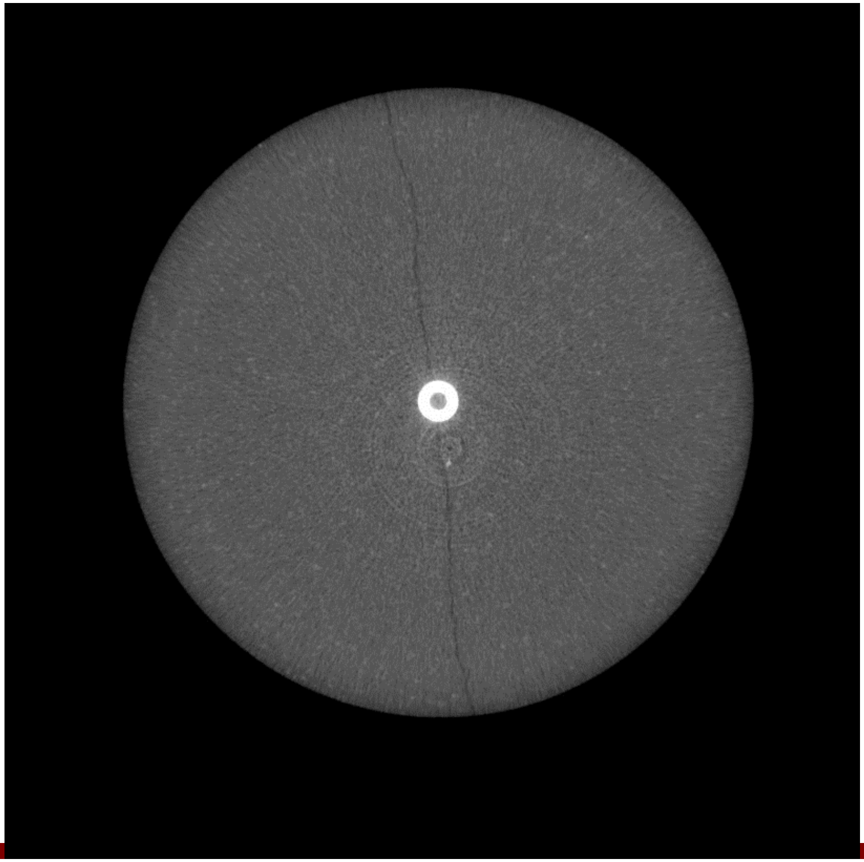


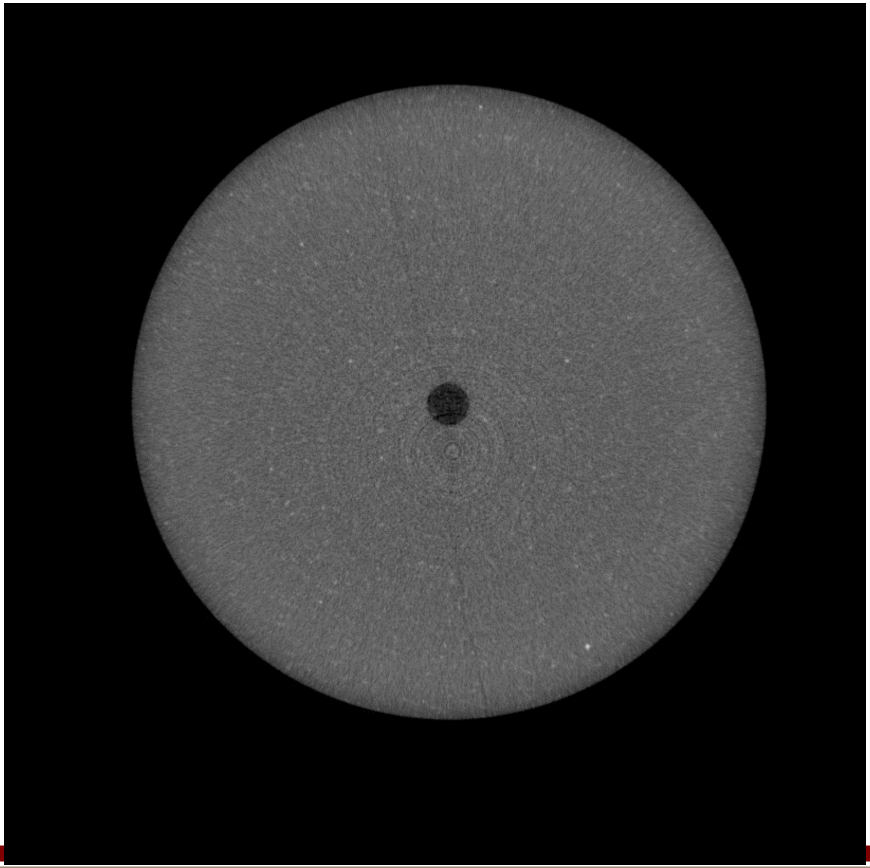
Hydraulic Fracture

Proppant packed into borehole.

Experimental Results

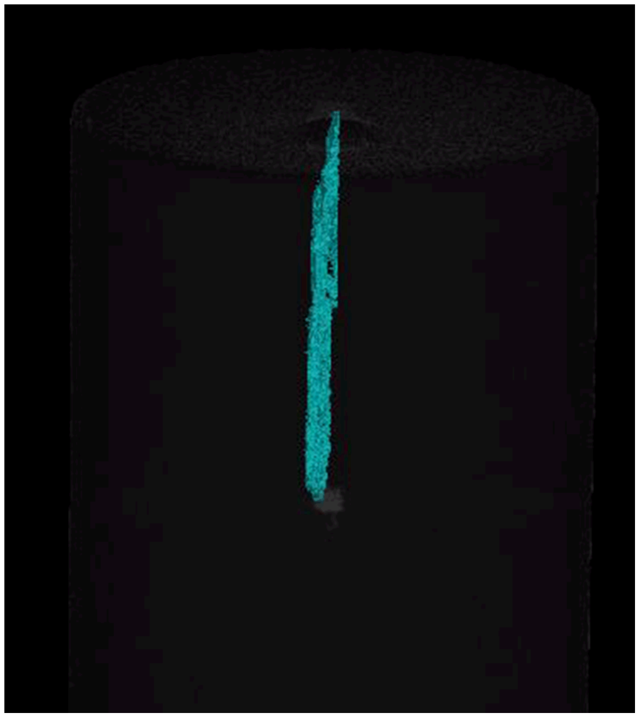
- Fracture shows noticeable opening on the order of 1-4 voxels (1 voxel is a 0.007" cube)
- Fracture extends below the end of the borehole.

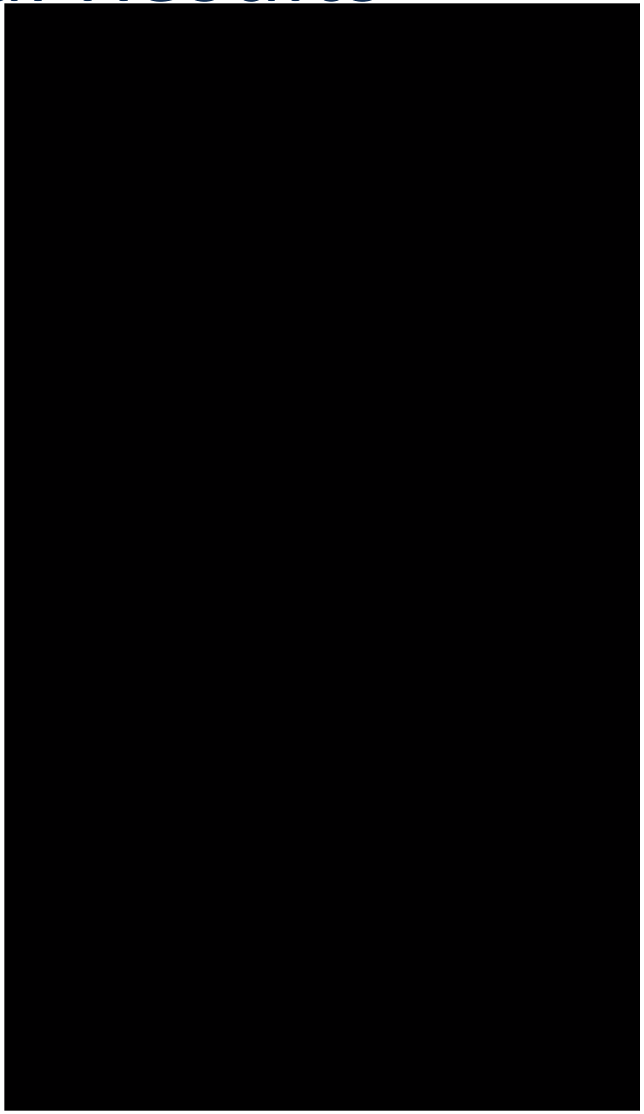


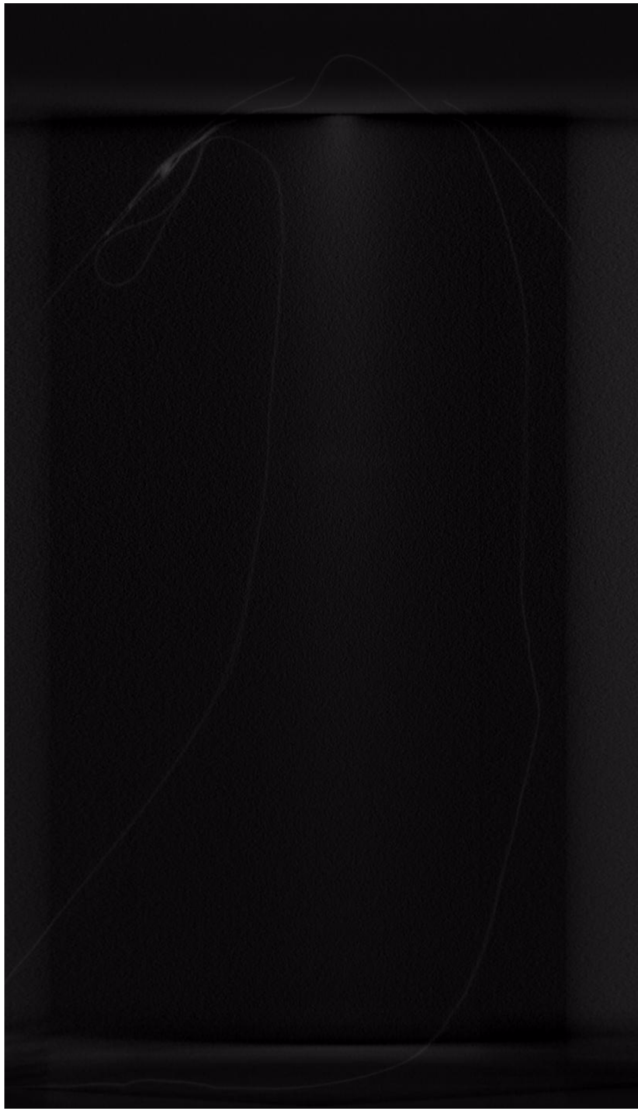


Experimental Results

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







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

Continued Testing

- Planning subsequent proof of concept tests
  - Larger open borehole
  - 3 Stage Frac
  - 100/170 Sand/Aluminum Oxide to assist in CT visibility
- Frac tests on Shale will proceed in spring

CT System Description

- Comet MXR-451HP/11
  - 400kV, 3.8mA
- Perkin Elmer XRD1620 X-ray Detector
  - DRZ Scintillator
- North Star Imaging Data Acquisition
  - 150 minute scan
- Volume Graphics VG Studio MAX
  - Reconstruction and 3D rendering