Numerical and Experimental Analysis of Sheared Fractures Flows

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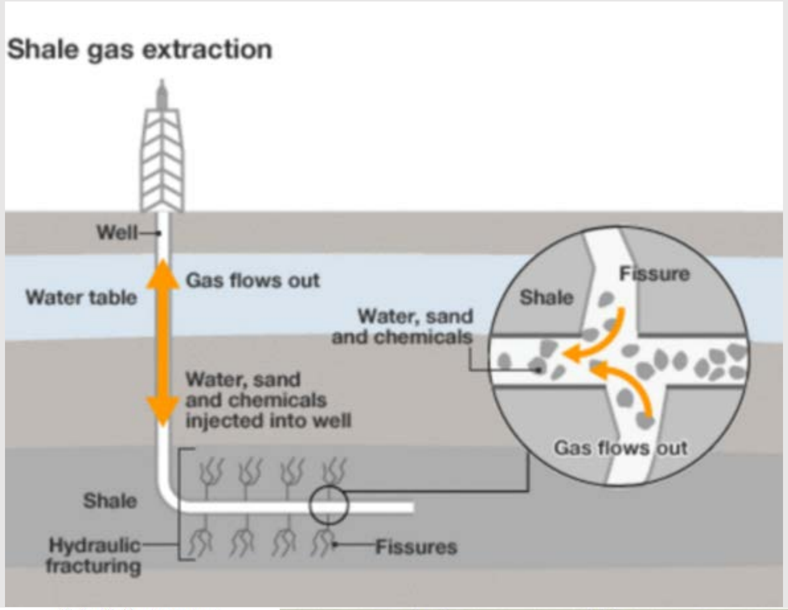
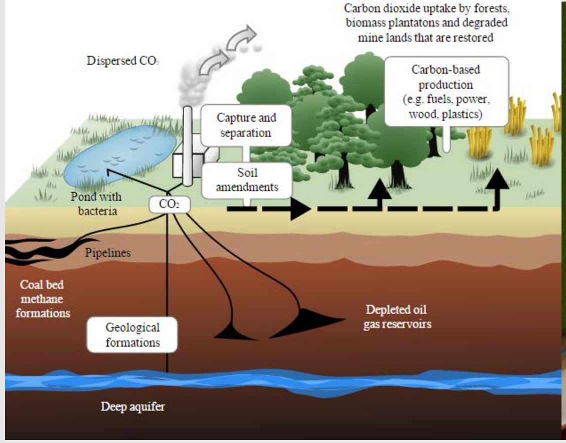
Outline

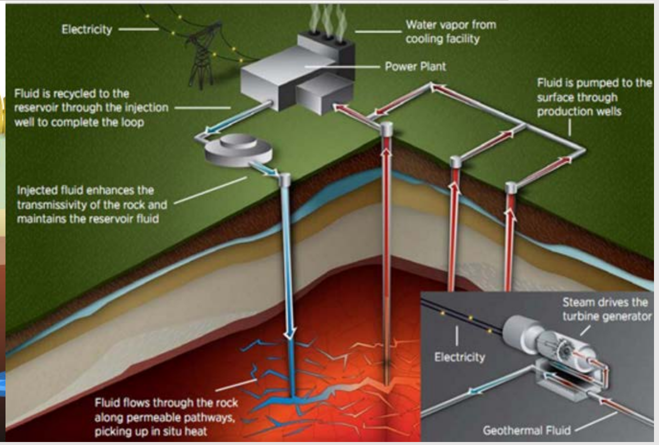
- Introduction
  - Fractures
  - Shearing
- Experimental Tests Rock Fractures at NETL in Morgantown
  - Preparing samples
  - Mechanical shearing
  - Computed tomography (CT) scan
  - Permeability measurement
- Numerical Simulations
  - Local Cubic Law (LCL) method and full Navier-Stokes simulations
  - Generating the geometry
  - Gridding
- Conclusions

Introduction

- ➢ Fractures are conduits in subsurface rocks
    - ➢ Unconventional oil and gas resources
    - ➢ Carbon sequestration reservoir
    - ➢ Enhanced geothermal system

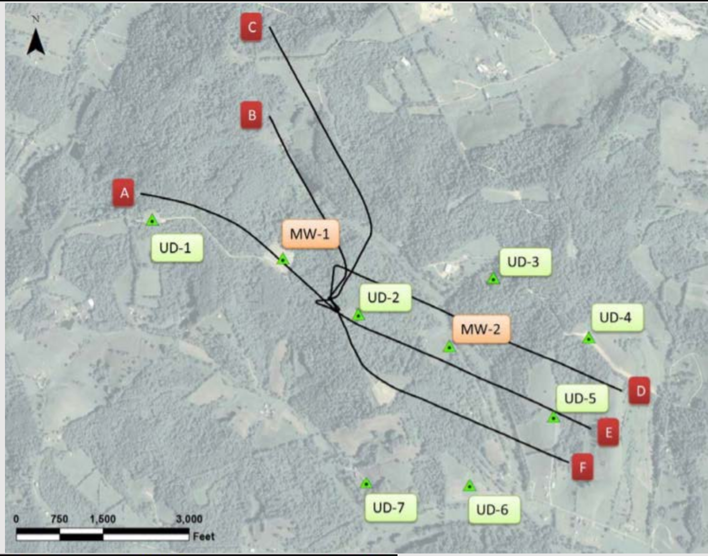


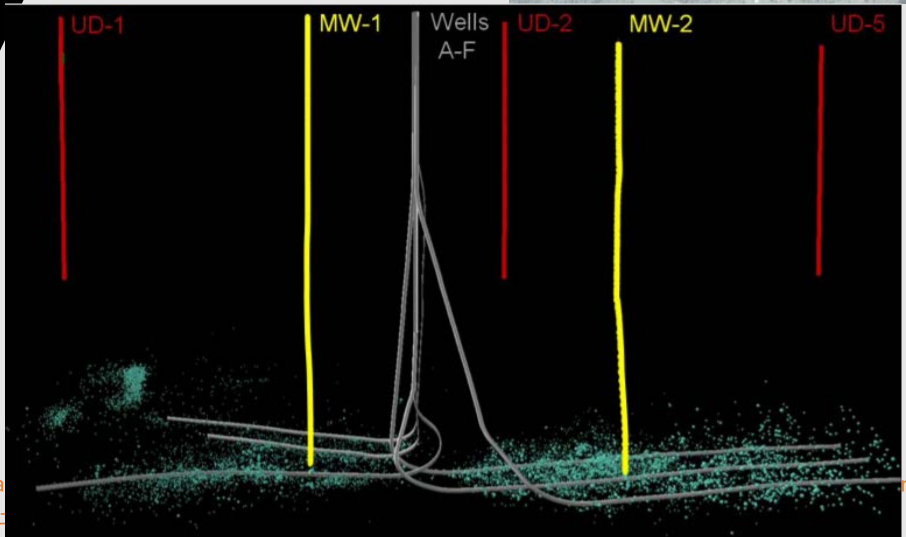




Introduction

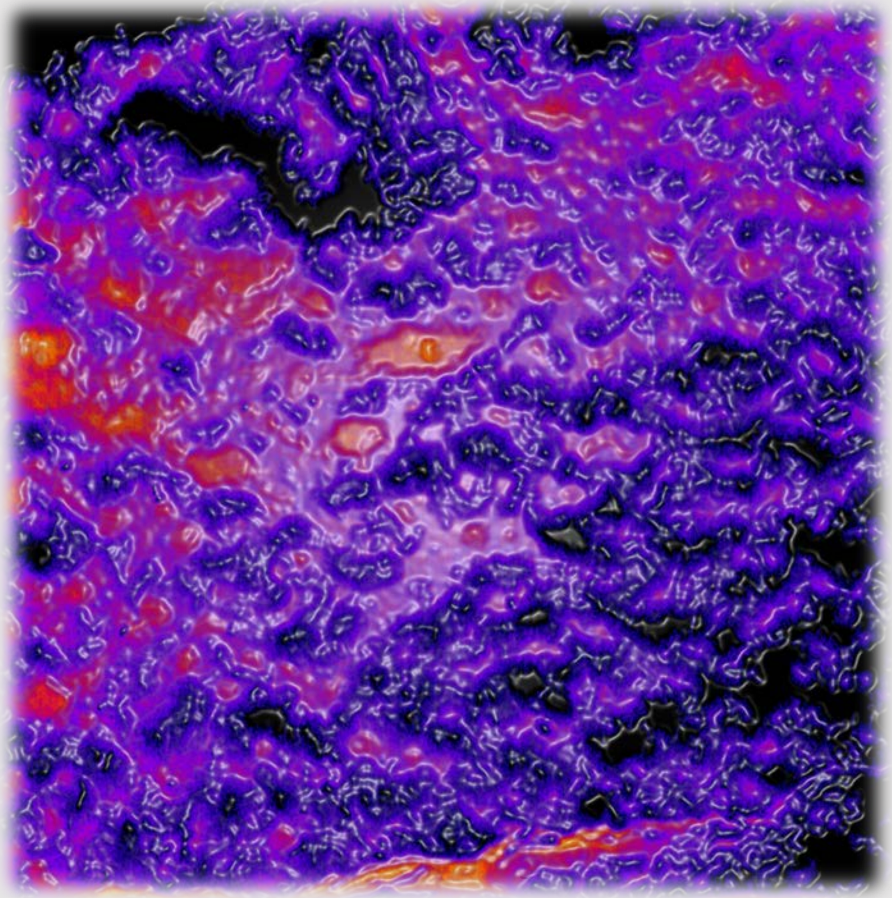
- Shearing is associated with micro-seismic events
  - Human Activities
    - Hydraulic fracturing
    - Enhance oil recovery
    - Geothermal operation
    - CO_2 Sequestration
  - Geometry changes
  - Evolution of fracture hydraulic properties





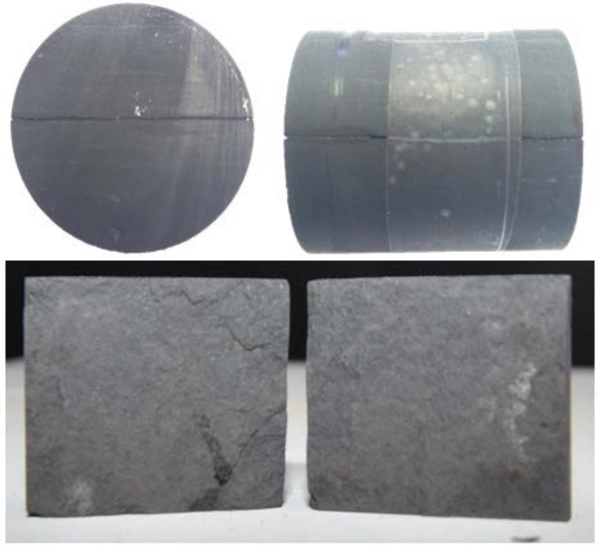
Hammack, R., Harbert, W., Sharma, S., Stewart, B., Capo, R., Wall, A.: An evaluation of fracture growth and gas/fluid migra … nsylvania. National Energy Tec
Laboratory: NETL-TRS-3-2014. https://www.netl.doe.gov/File%20Library/Research/onsite%20research/publications/NETL-

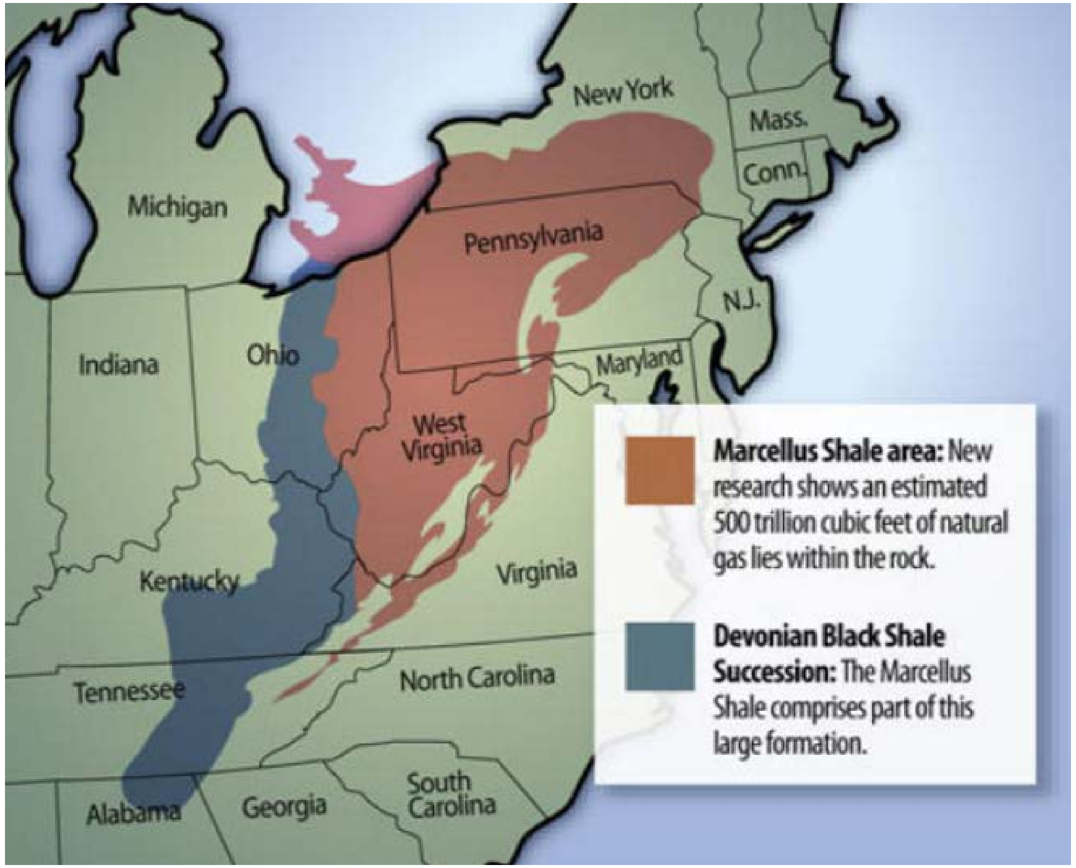
Experimental Section



Sample

- Sample
  - Marcellus shale
    - Giant unconventional resource of natural gas
  - 3.8 (cm) diameter, 3.8 (cm) length
  - No natural fractures
    - Mechanically fractured

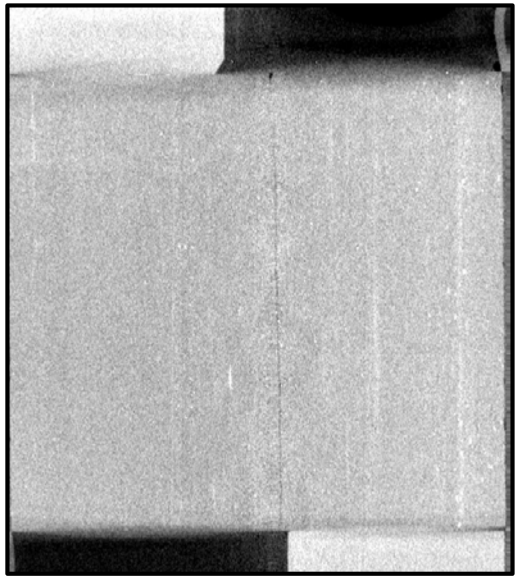


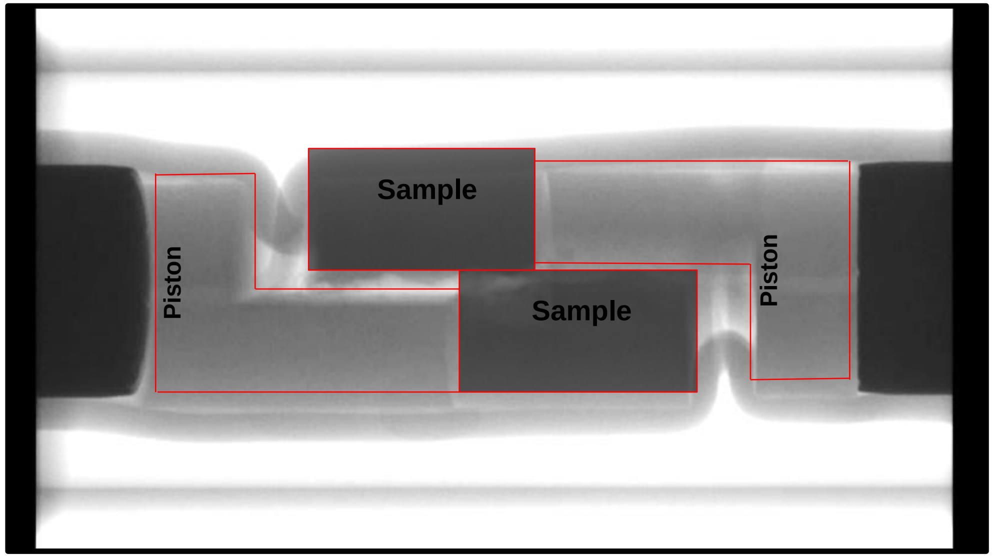


Shearing Apparatus

- Modified pistons within a Hassler core holder to shear fractured rocks in discrete steps
  - Total displacement of 4 cycles: 3.2 mm

- Industrial computed tomography (CT) scanning with 26.8 μm^3 resolution
  - Obtain the geometry of the fracture





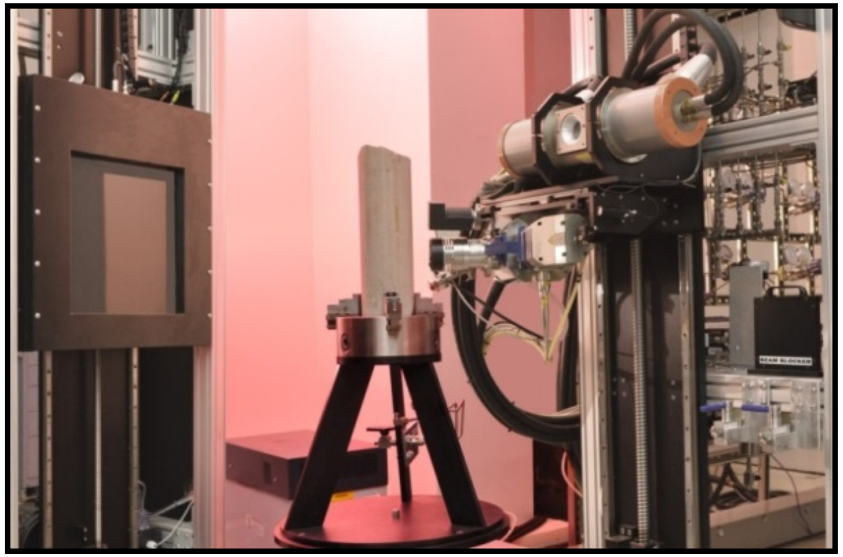
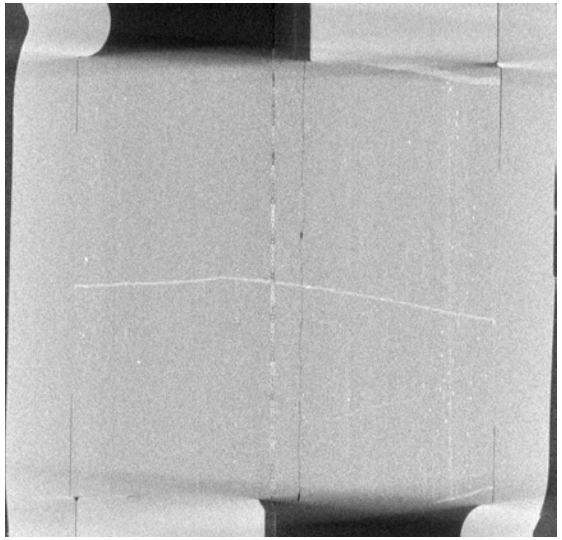
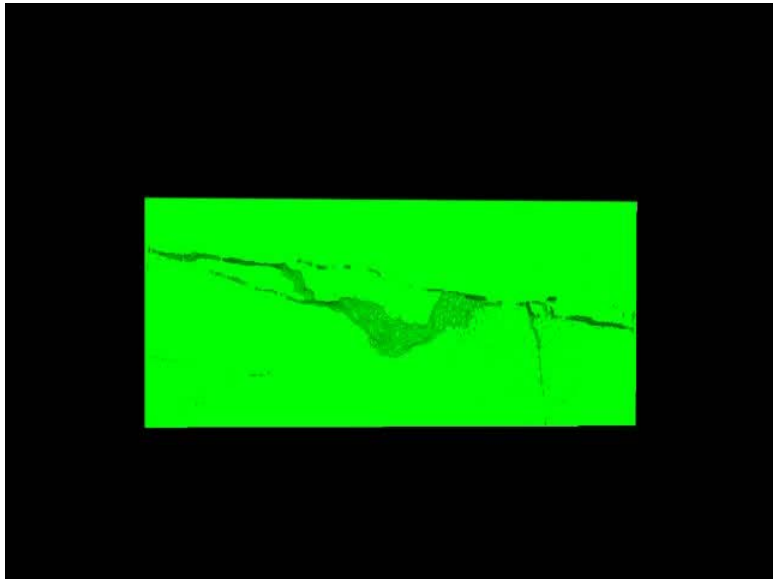
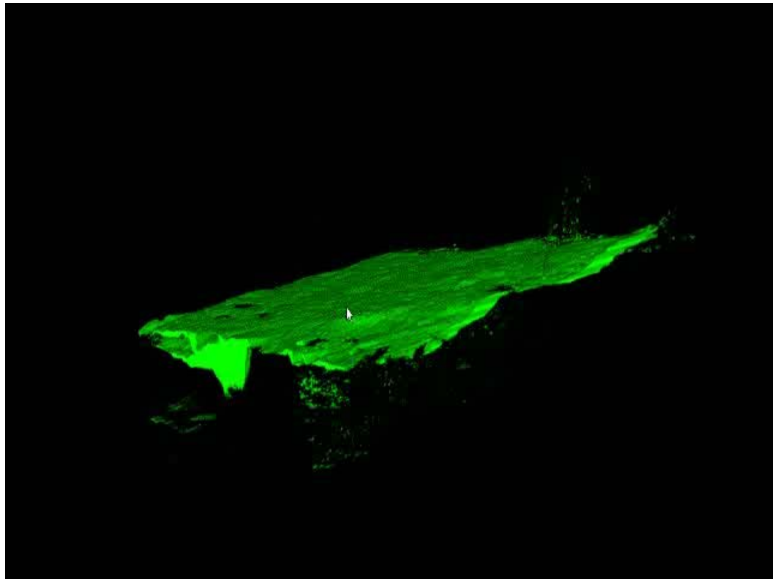


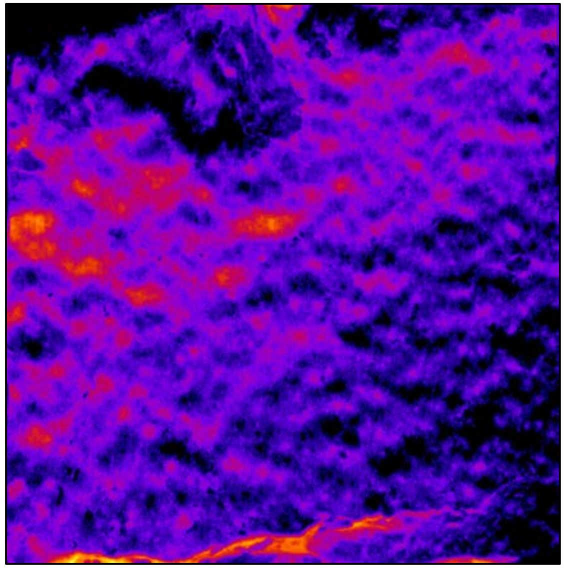
Image Processing

- CT scanning relies on capturing a large number of 2D x-ray
- Bulk matrix of rock was generated
- Fracture geometry was isolated via imageJ



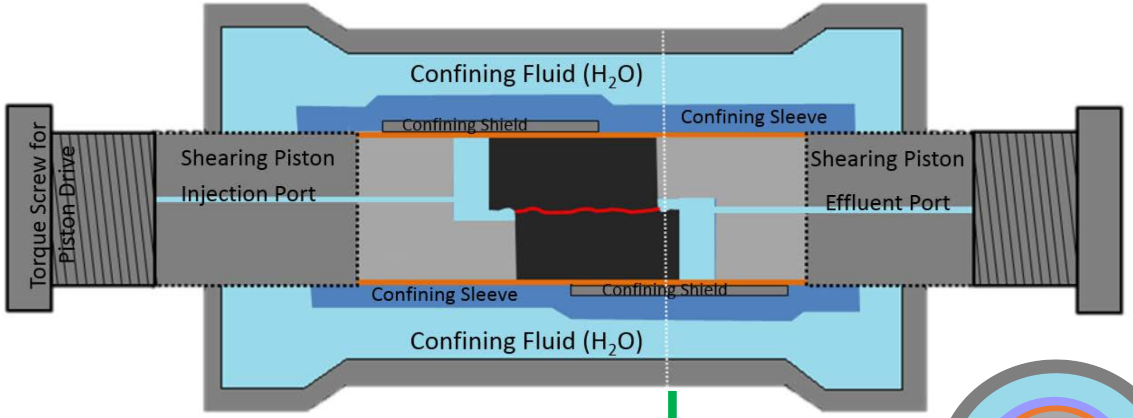






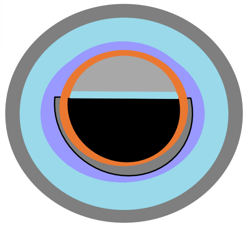
Permeability Measurements

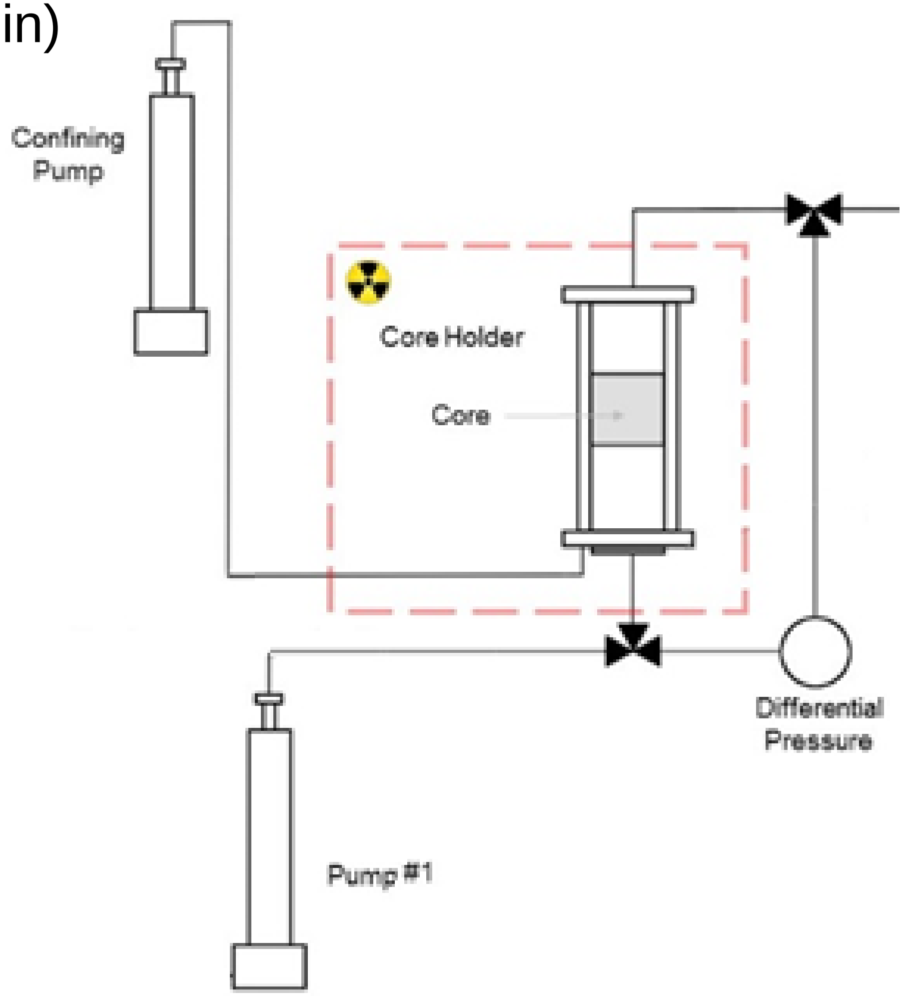
- Water fluid was injected with different flow rates (0-10 mL/min)
- Pressure drops were measured (0-2 MPa)



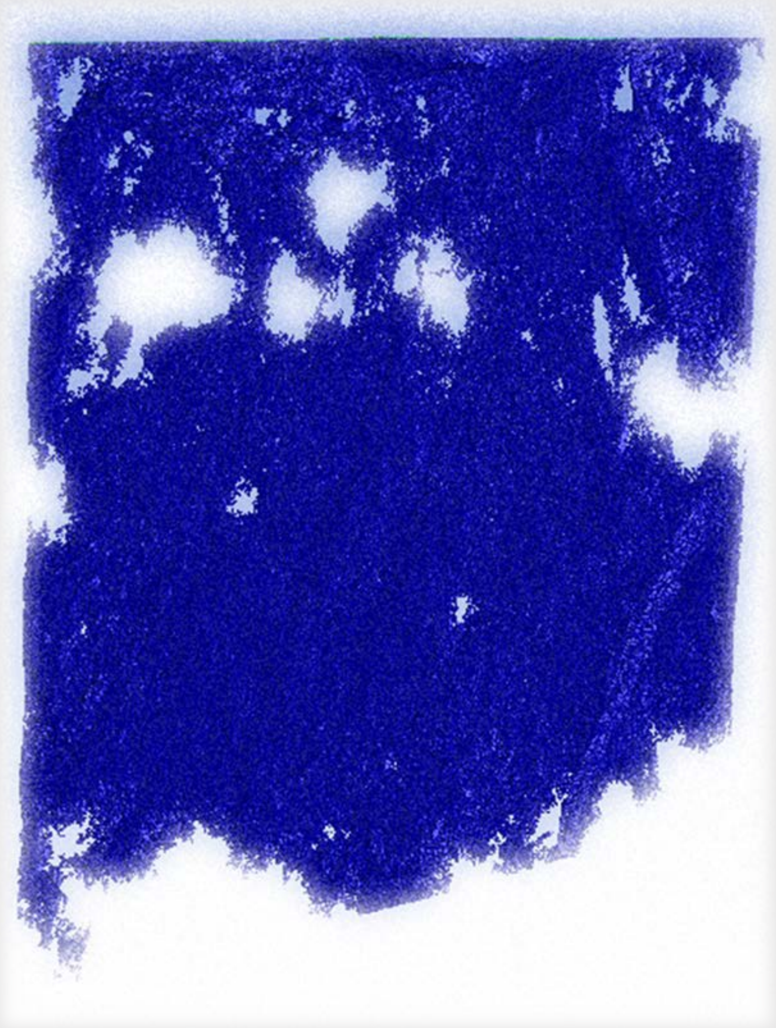
Schematic of current shearing apparatus with core

Crossectional view





Numerical Section



LCL Model & ANSYS-Fluent

- Cubic Law
  - Set of parallel plates
  - Obey the Cubic Law $\Delta p = \frac{12\ \mu L}{W {h_{eq}}^3} Q$
- LCL Model
  - Laminar creeping flow
  - Driven by a pressure gradient

Fractures have very rough and complex geometries

Navier-Stokes Equation → $0 = -\nabla P + \mu \nabla^2 u$

$$0 = -T_{x_{i,j}}(P_{i+1,j} - P_{i,j}) + T_{x_{i-1,j}}(P_{i,j} - P_{i-1,j}) - T_{z_{i,j}}(P_{i,j+1} - P_{i,j}) + T_{z_{i,j-1}}(P_{i,j} - P_{i,j-1})$$

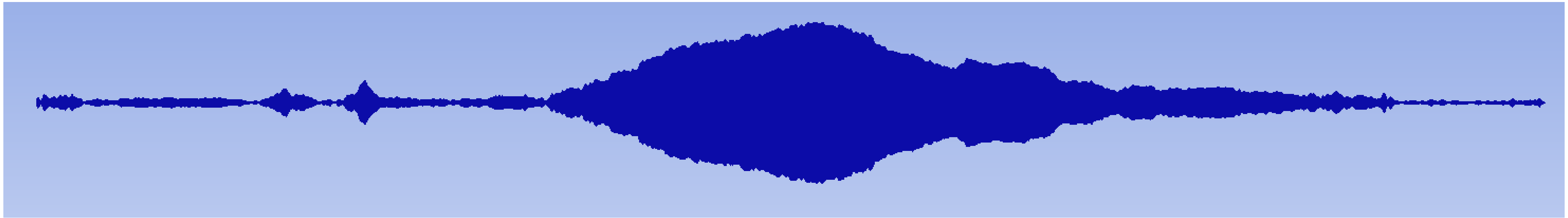
$$T_x = \frac{h^3 \Delta z}{12 \Delta x}$$

$$T_z = \frac{h^3 \Delta x}{12 \Delta z}$$

- ANSYS-Fluent Software
  - Solve Conservation of Mass and Momentum Equations

Generating Geometry

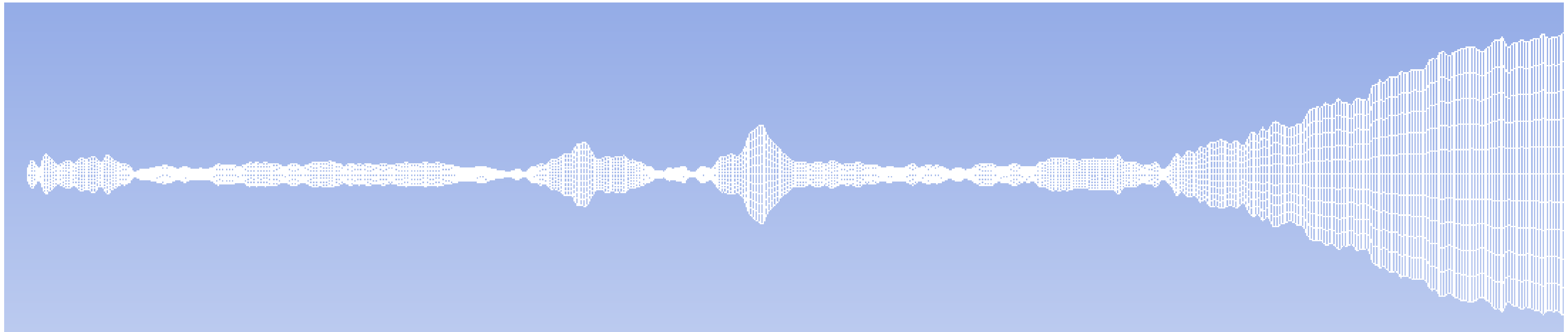
- Geometry
  - A 2D map of aperture values
  - No macroscopic undulation
  - The mid-surface is forced to be flat
    - Experimental shearing steps required the fracture to be planner
  - Reduced resolution map of fractures
    - 10x10 grids
    - The small scale features of the rough fracture
    - Need less computational time
    - Effect of scan resolution



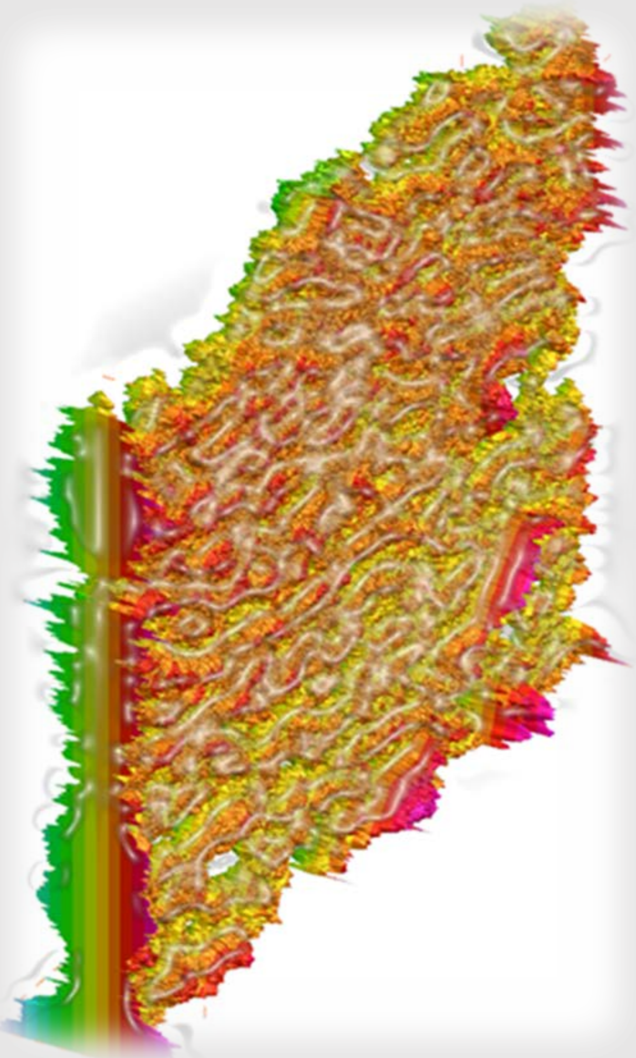
Gridding

- Gridding (LCL and ANSYS-Fluent)
  - Each point of the aperture maps was transferred into a rectangular cell
  - No internal refinement for LCL
  - Internally refined for ANSYS-Fluent for accuracy and convergence

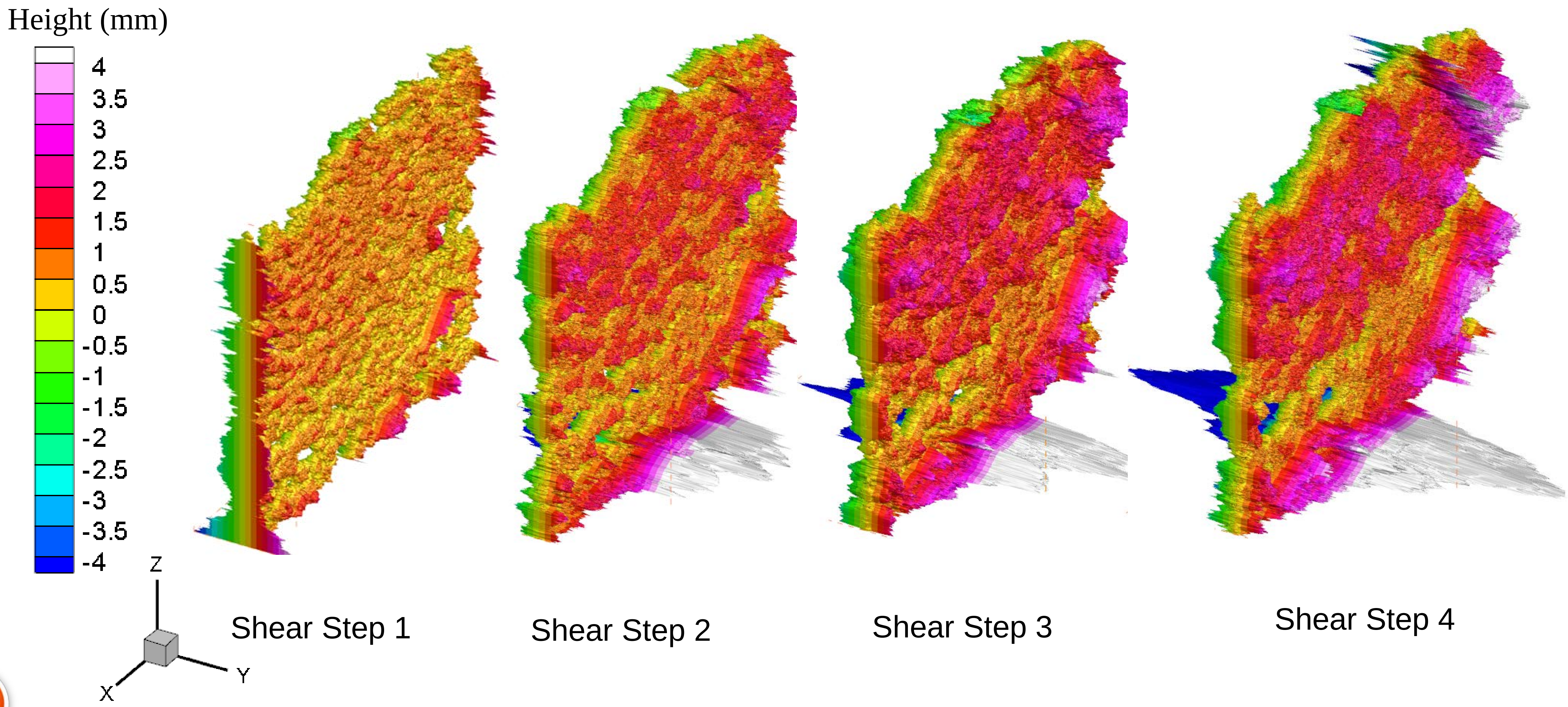
Case (N_x N_y N_z)	Number of elements	CPU time (min)	Obtained pressure drop (Pa)	Pressure drop difference %
(1 1 1)	13,690	0.23	134.45	-
(1 5 1)	68,450	0.50	372.10	176.76
(1 10 1)	136,900	1.08	394.85	6.11
(2 20 2)	1,095,200	12.45	399.40	1.63
(4 40 4)	8,761,600	240	402.90	0.88



Results



Aperture Maps



Shear Step 1

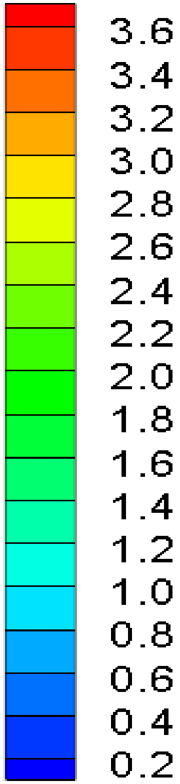
Shear Step 2

Shear Step 3

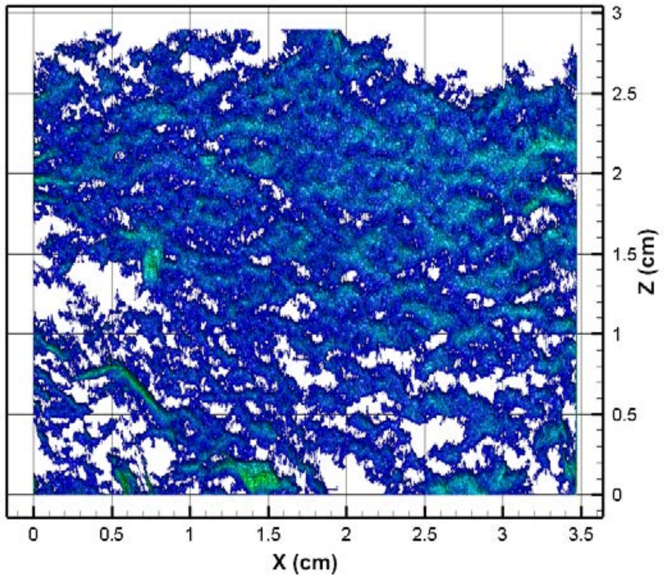
Shear Step 4

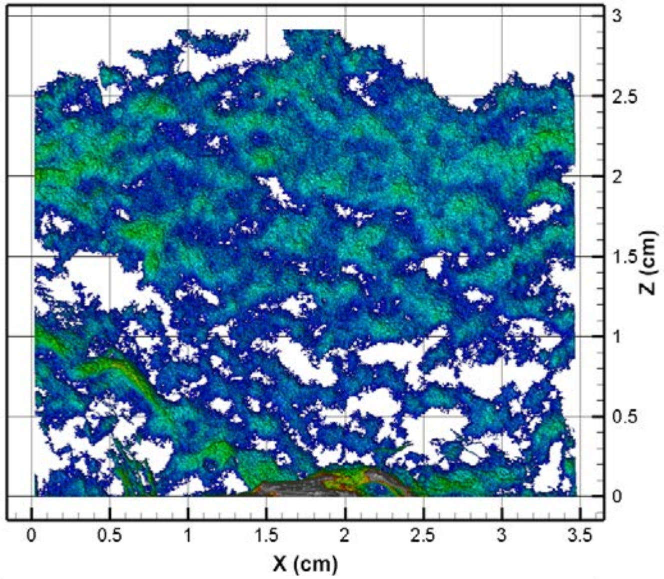
Aperture Maps

Height (mm)



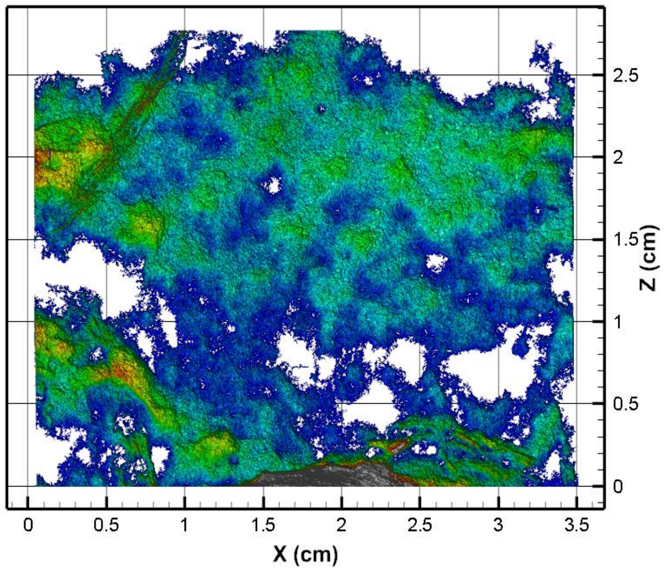
Shear Step 1

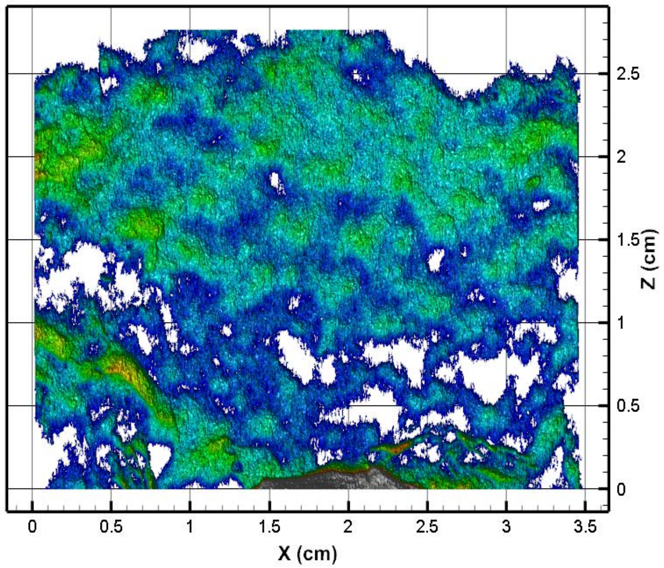




Shear Step 2

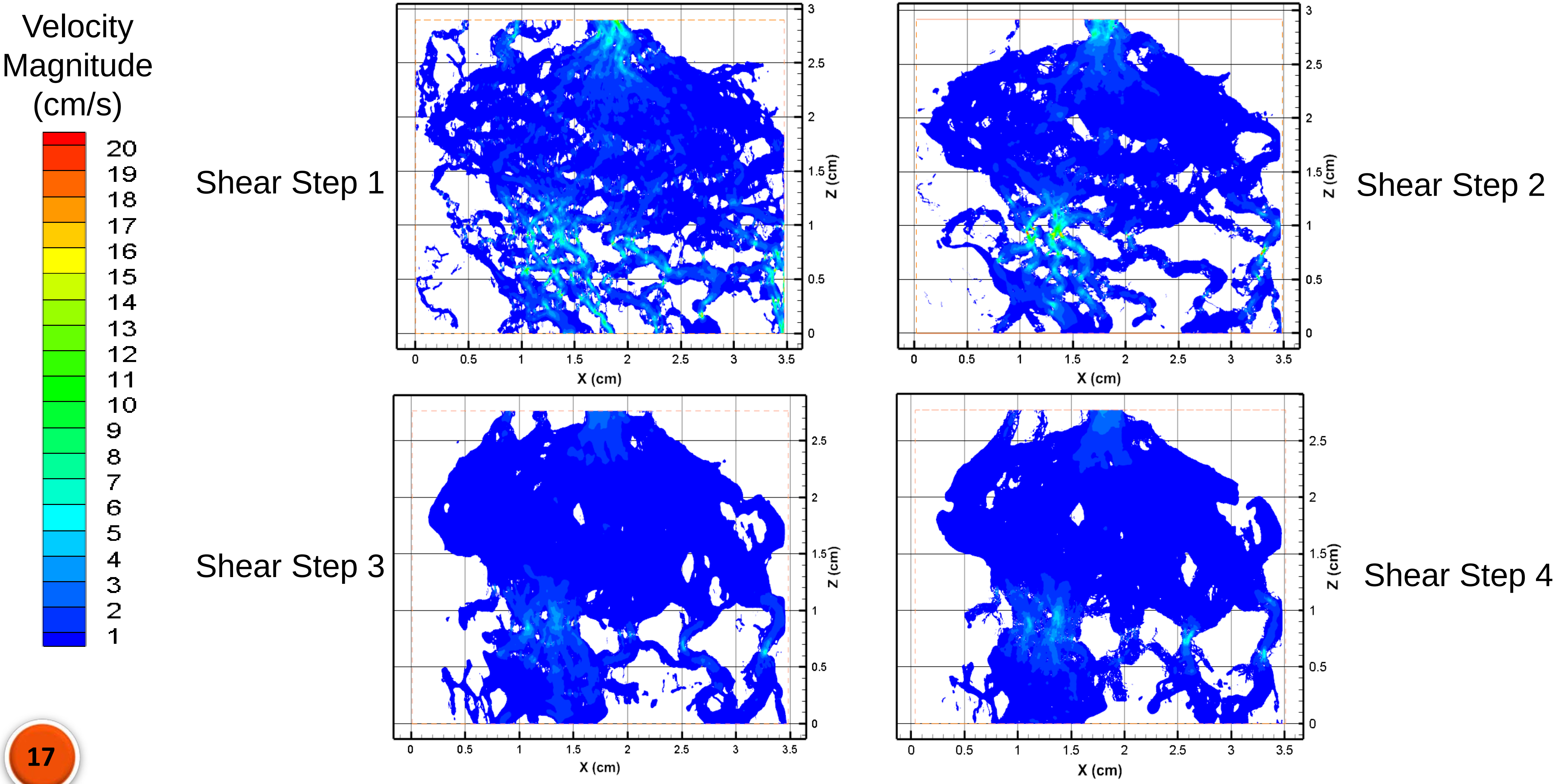
Shear Step 3





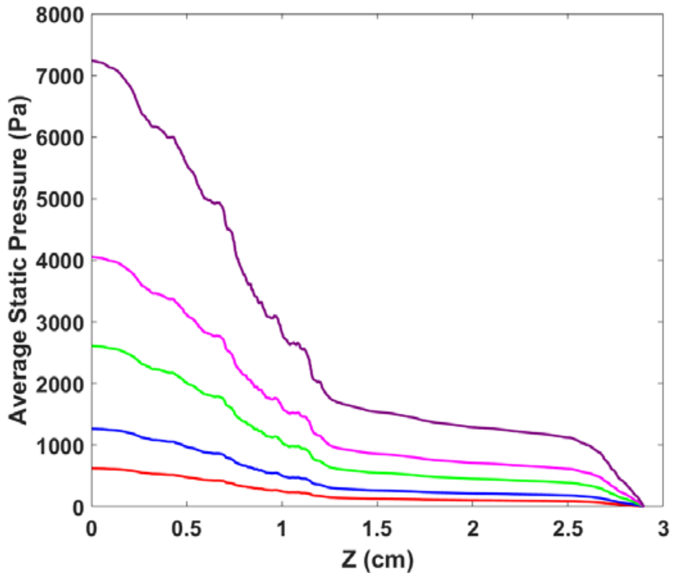
Shear Step 4

Velocity Contours

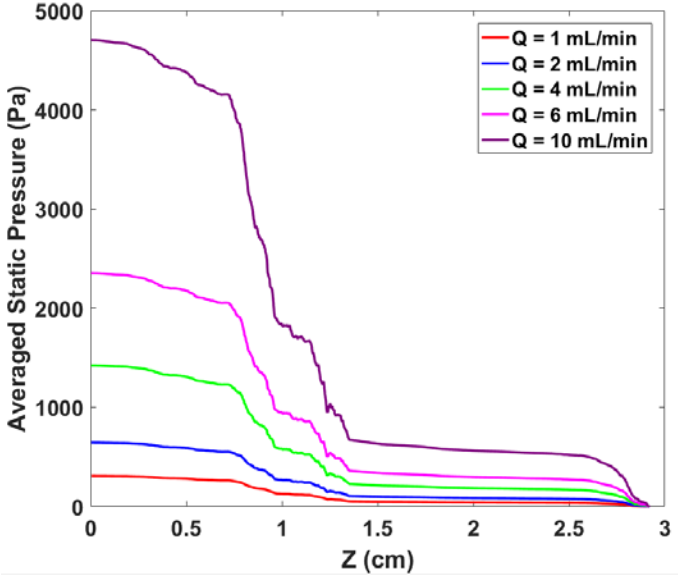


Pressure Drops

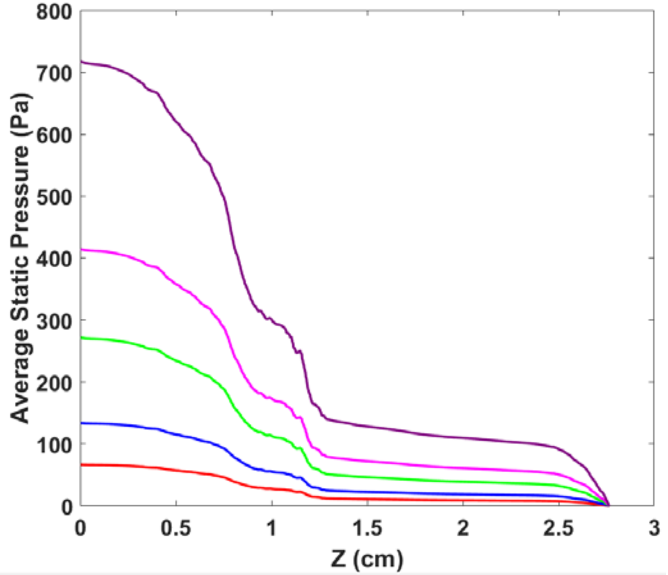
Shear Step 1



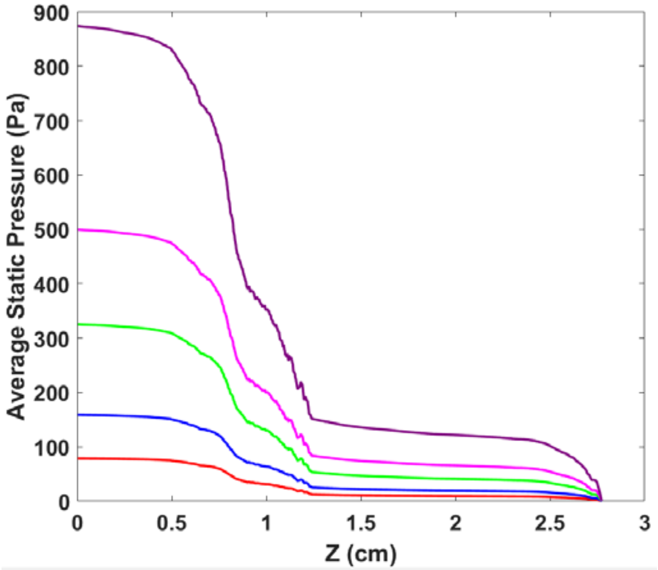
Shear Step 2



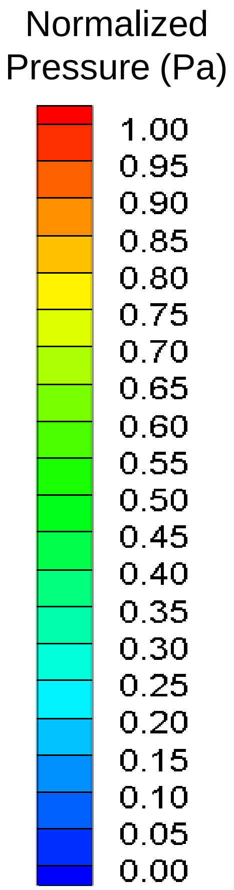
Shear Step 3



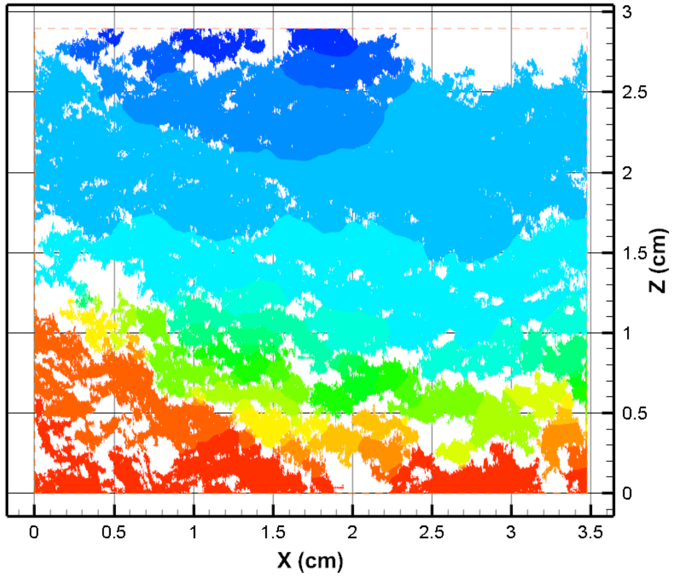
Shear Step 4



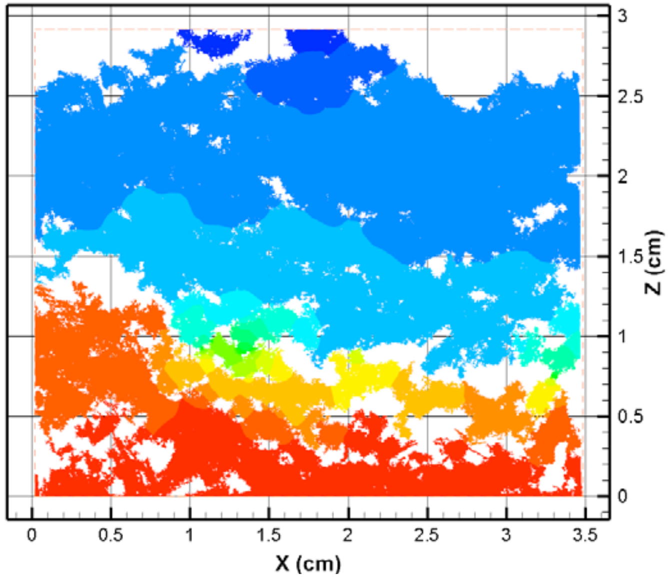
Normalized Pressure Contours



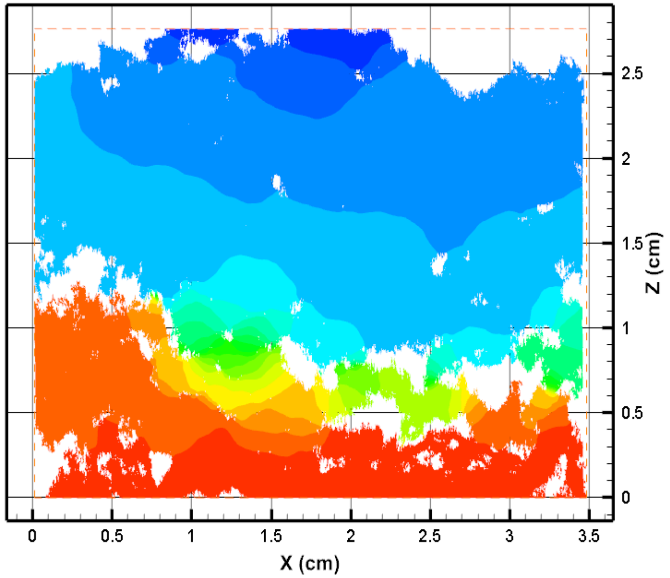
Shear Step 1



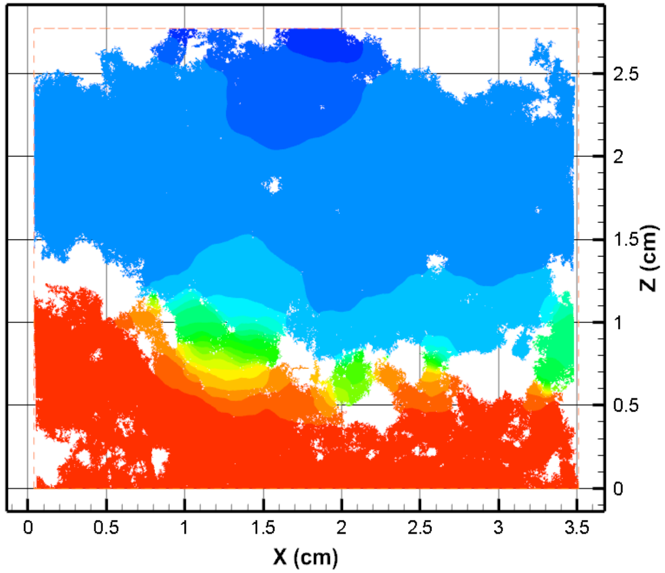
Shear Step 2



Shear Step 3

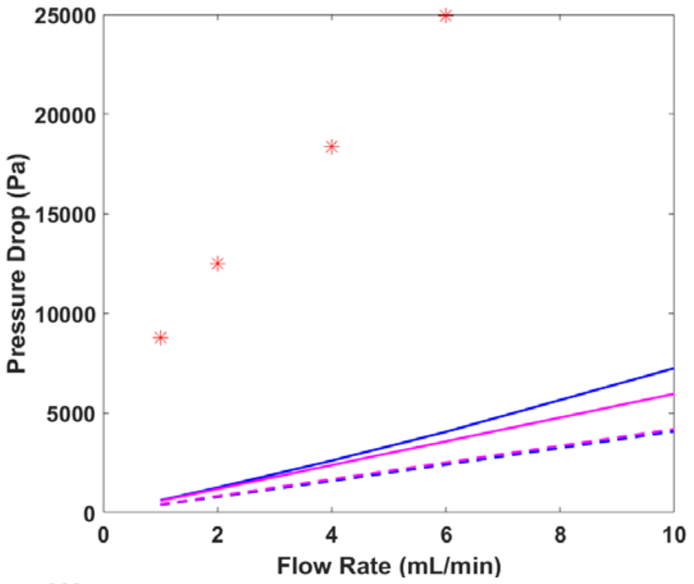


Shear Step 4

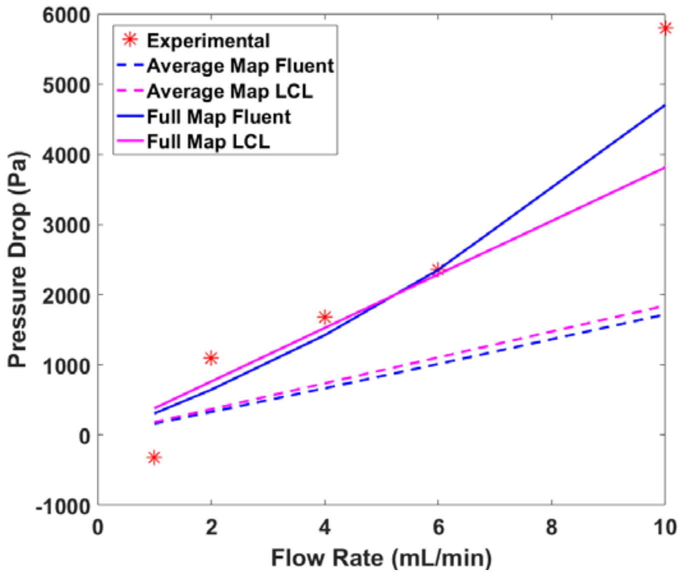


Comparison

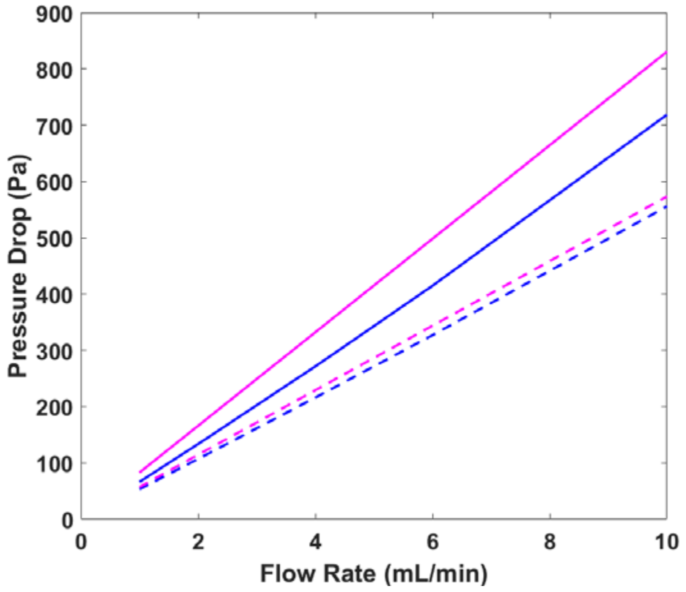
Shear Step 1



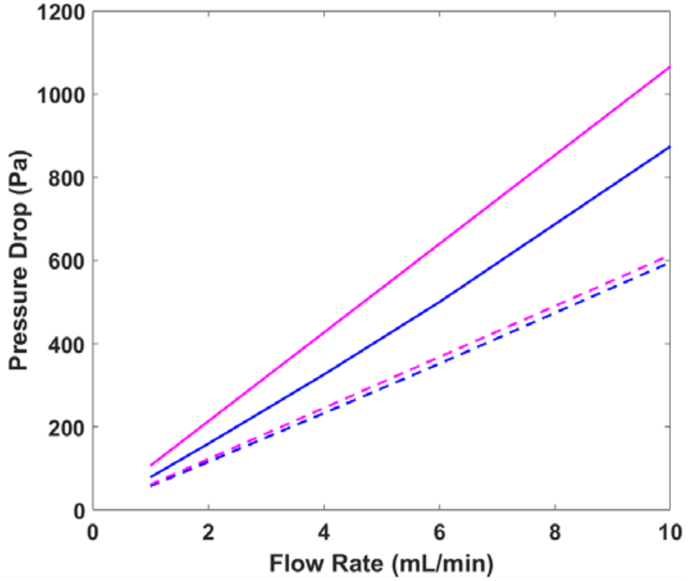
Shear Step 2



Shear Step 3



Shear Step 4



Summary

- A sheared Marcellus shale fracture was studied experimentally.
  - Sheared at different steps.
  - Permeability was measured at different flow rates.
  - The fracture was CT scanned at a high-resolution of 26.8 µm.
  - Geometry of the fractures was captures at each step.

- Low-resolution representations of the CT scans were created at 268 µm (average map).

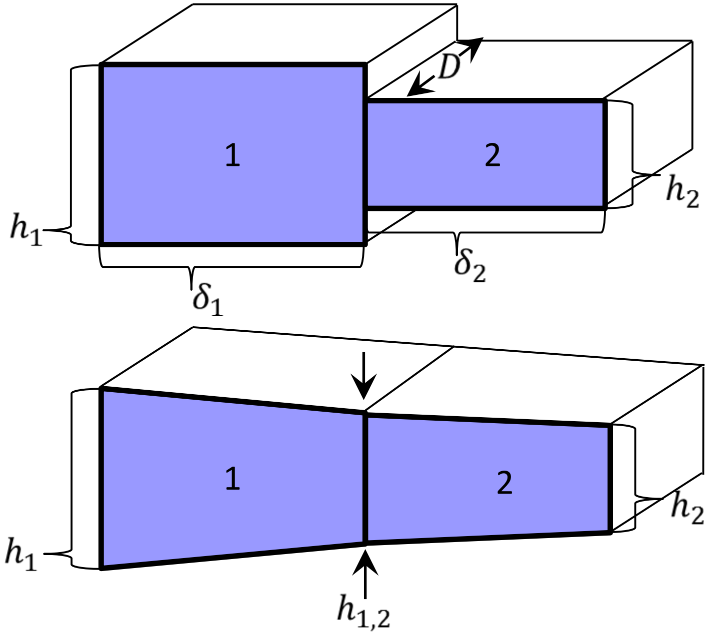
- The fracture flows were studied numerically using the LCL method and full Navier-Stokes simulations for both the average and full maps.

Conclusions

- Shearing increased the average aperture
  - The corresponding pressure drops and average flow velocities decreased.
- Good agreement was observed between the results for the average map fractures.
- Small deviation was observed for the full map fractures.
- Pressure drops of the average map fractures was smaller compared to those of the full map fractures.
  - Important effects of small scale surface roughness on increasing the fracture pressure drops.

Local Cubic Law Simulations

Grid Block Transition:



Local Cubic Law:

$$Q = \frac{(h_{1,2}^3 \cdot D)}{(12 \cdot \mu)} \cdot \frac{\Delta P_{1,2}}{\delta_{1,2}}$$

Stokes Tapered Plate Correction:

$$\delta_{1,2} = \frac{\delta_1 + \delta_2}{2} \qquad \tan(\theta_{1,2}) = \frac{|h_1 - h_2|}{\delta_{1,2}}$$

$$h_{1,2}^3 = \left[\frac{2 \cdot h_1^2 \cdot h_2^2}{h_1 + h_2}\right] \cdot \left[\frac{3(\tan(\theta_{1,2}) - \theta_{1,2})}{\tan^3(\theta_{1,2})}\right]$$

This method strongly tends towards the smaller aperture

Brush, Thomson. April 3, 2003. Fluid Flow in synthetic rough-walled fractures: Navier-Stokes, Stokes and local cubic law simulations.