Reservoir Geomechanics Modeling JIP-OU

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JIP Objective

- Develop & Apply Modeling Technologies for Reservoir Development & Stimulation Design:
  - Completions/Hydraulic fracturing
  - Fracture networks
  - Altered stress & Refrac analysis
  - Wellbore stability
  - DFIT in fractured reservoir
  - Inverse modeling of micro-seismic
  - Advanced rock mechanics testing

Using Rock Mechanics to Enhance Resource Development

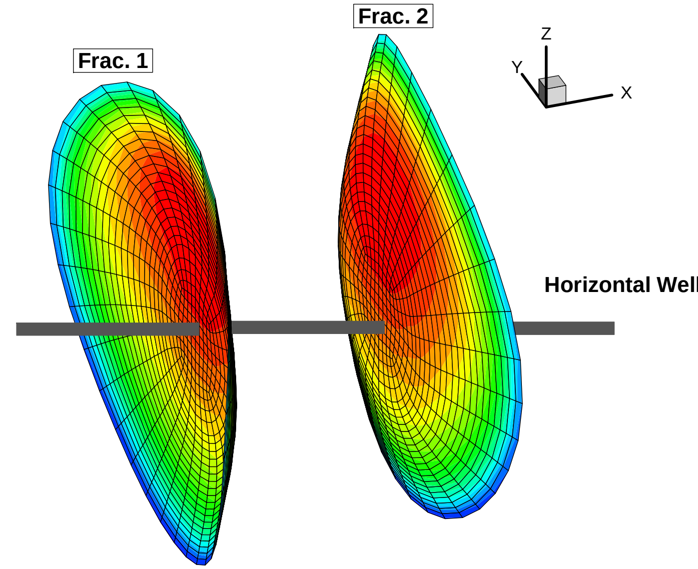
- **Technology Development**
  - Numerical/Theoretical modeling/Case studies
- **Technology Transfer**
  - Developing project-specific solutions
  - Student training (and train company personnel to use software)

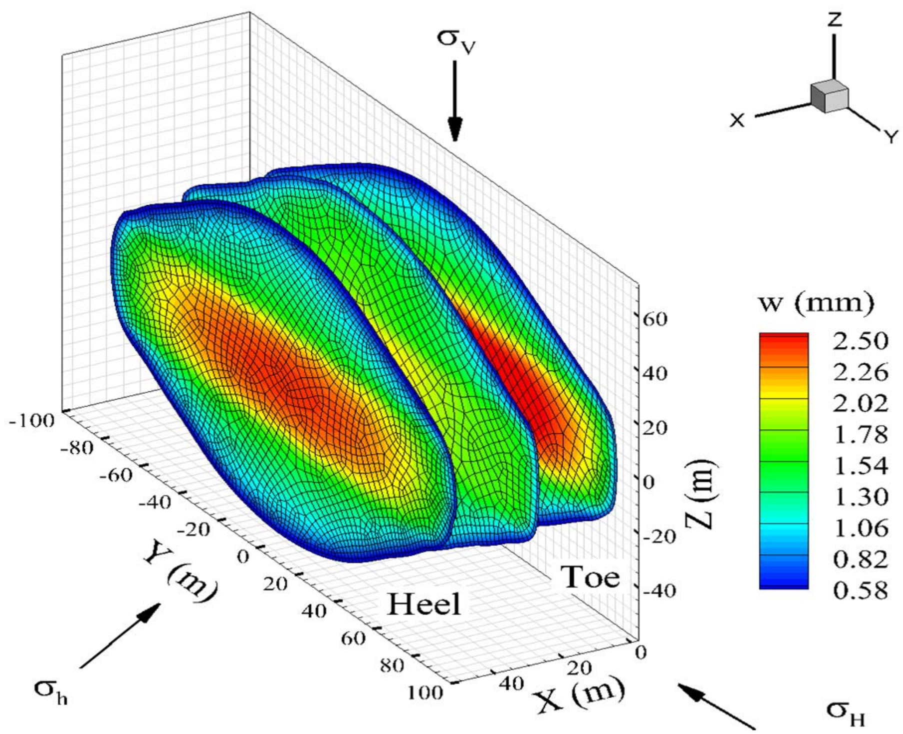
OU-JIP is the Leader in Hydraulic Fracture Modeling

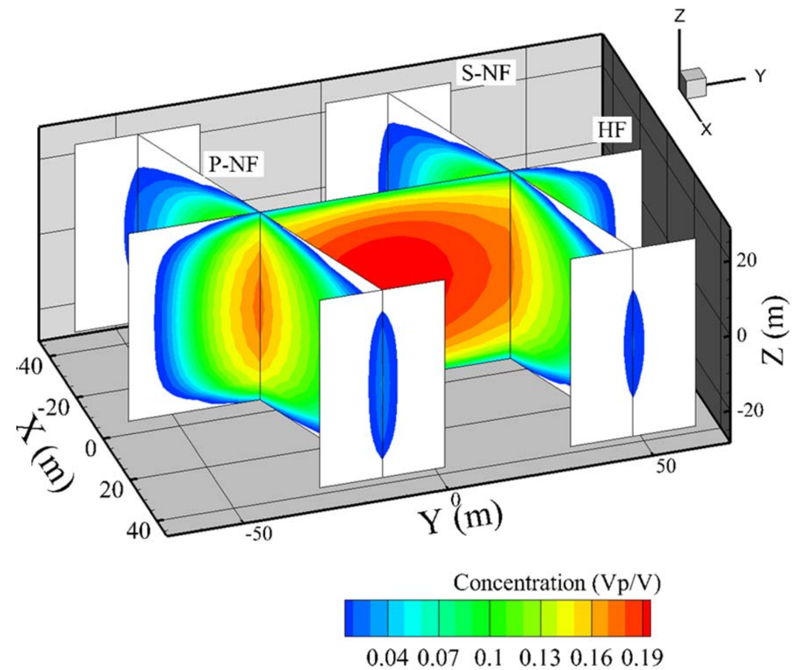
- State-of-the-art modeling
  - R3D multiple hydraulic fracture model capable of large-scale simulations
    - Multiple wells and multiple clusters, Rock mechanical anisotropy and toughness anisotropy, including height correction for stress shadow in anisotropic rock
    - Viscous and toughness regimes (first of its kind in the HF modeling community-progress ongoing)
    - Limited entry completions and perforation losses
    - Leak-off , Newtonian and non-Newtonian fluids
    - Pumping schedule, injection/shut-in cycles

Hydraulic Fracture Modeling

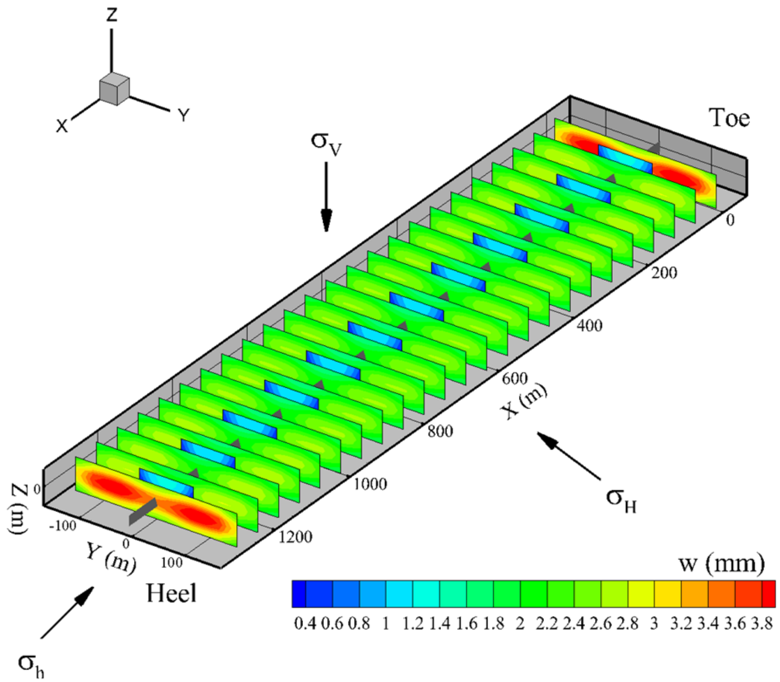
- 3D elastic/poroelastic DD hydraulic fracture model for multiple well and multiple clusters
- o Simulated simul- and zipper frac
- o Simulated refrac and parent/child well design
- o Proppant transport
- o 3D HF/NF

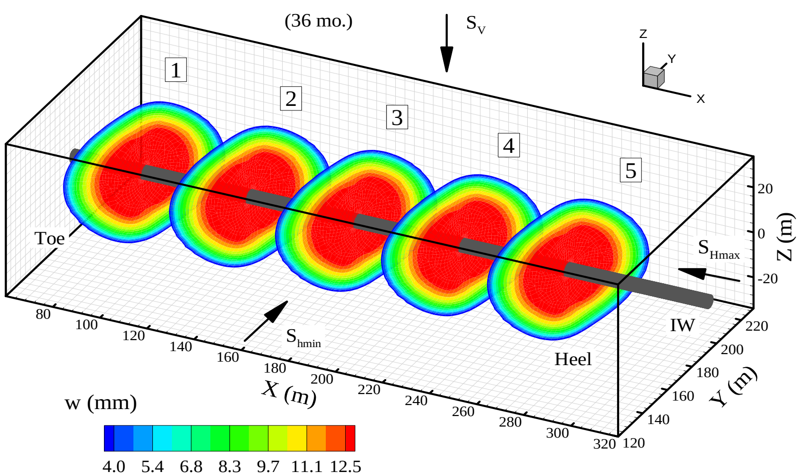


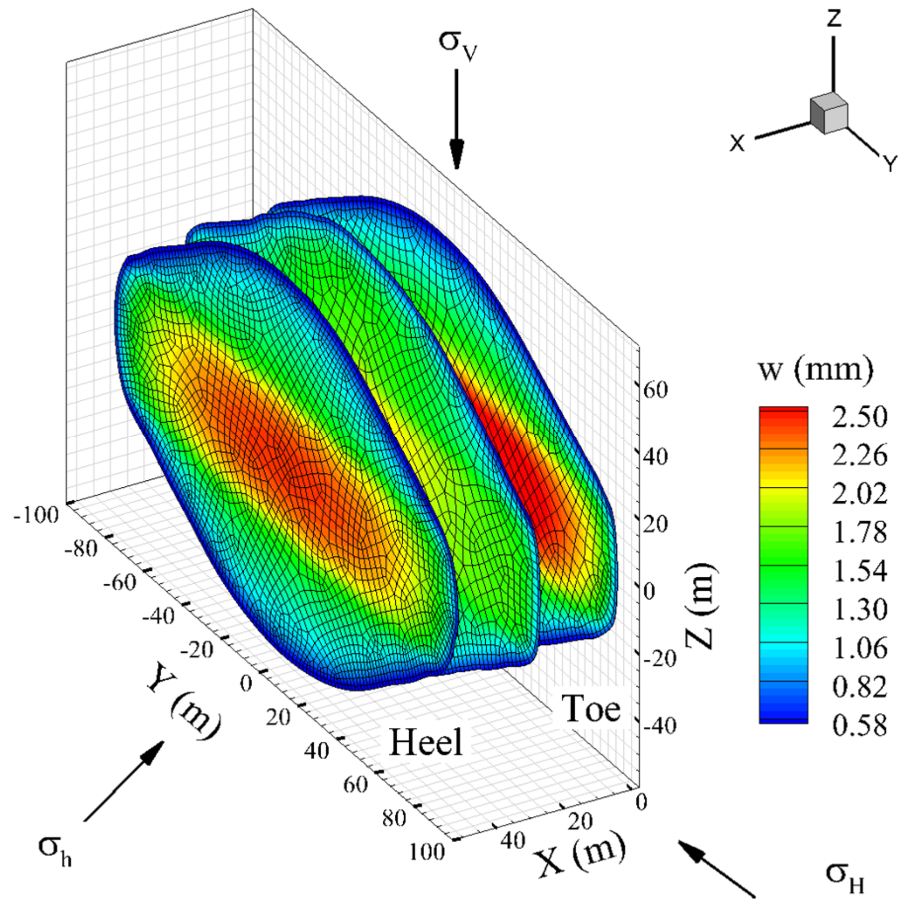




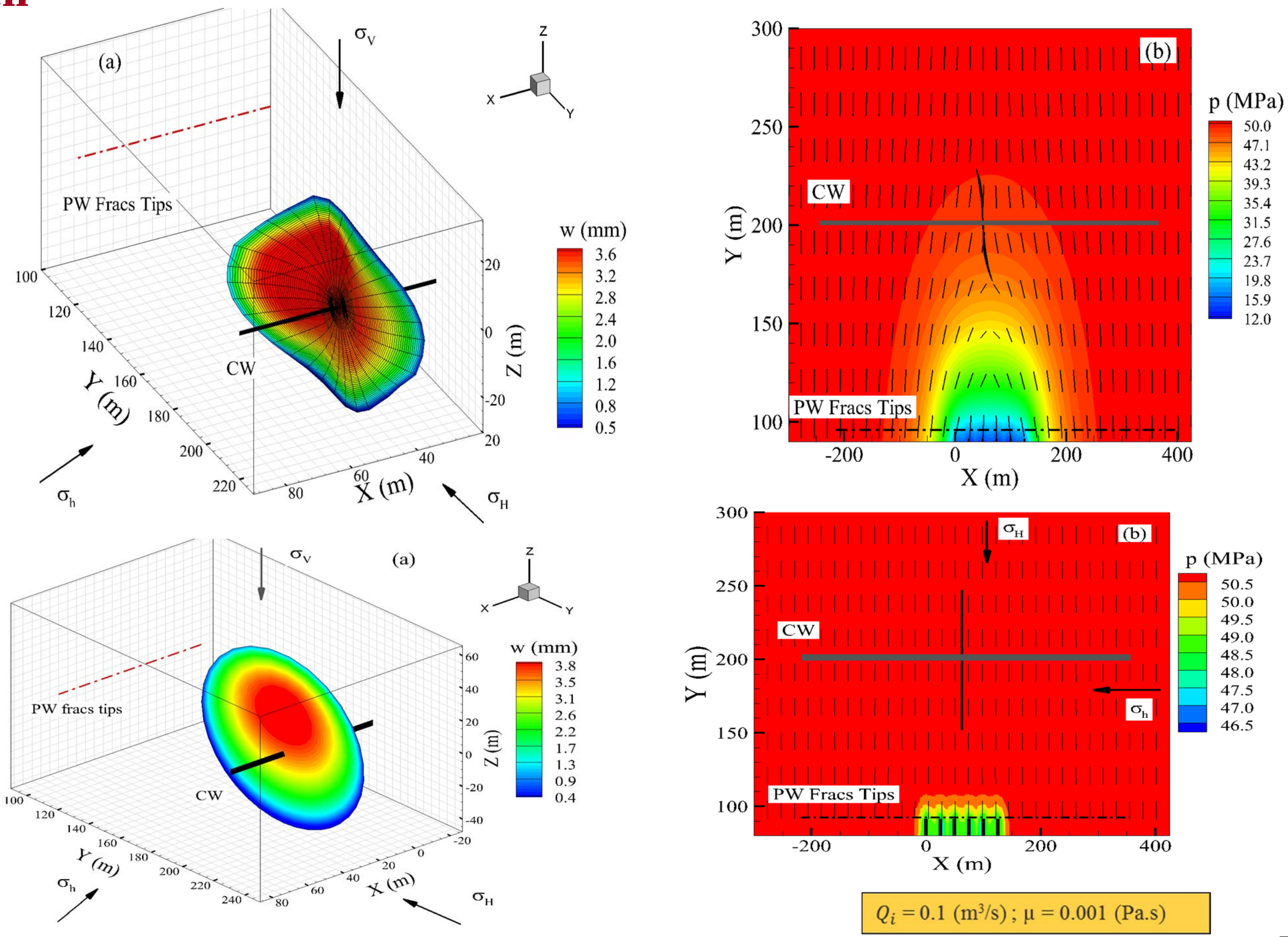
Hydraulic Fracture Modeling







Child Well Fracturing before Re-pressurization of "Parent" Well

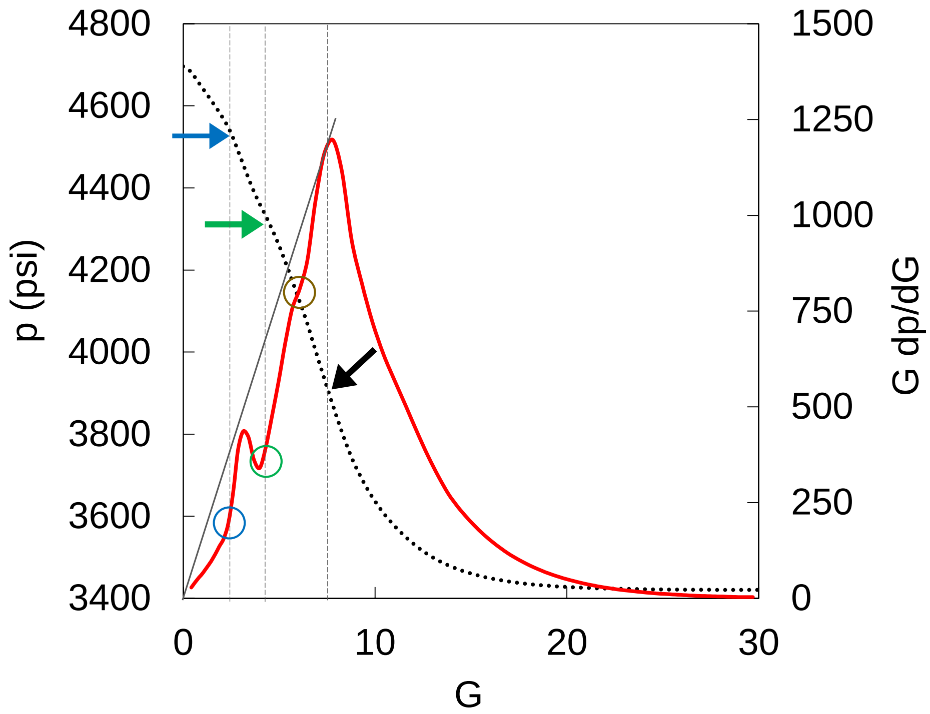


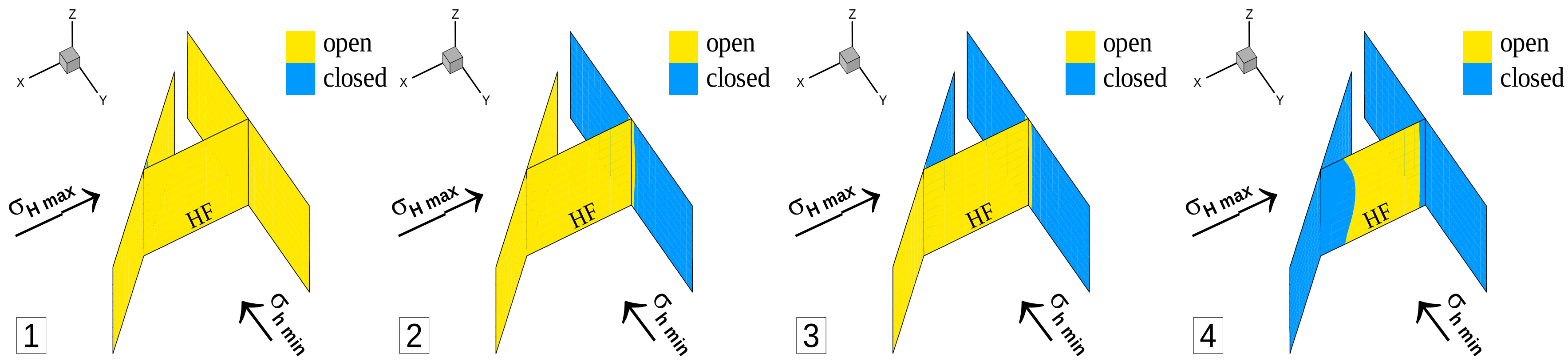
Q_i = 0.1 (m^3/s) ; μ = 0.001 (Pa.s)

Natural Fractures & DFIT

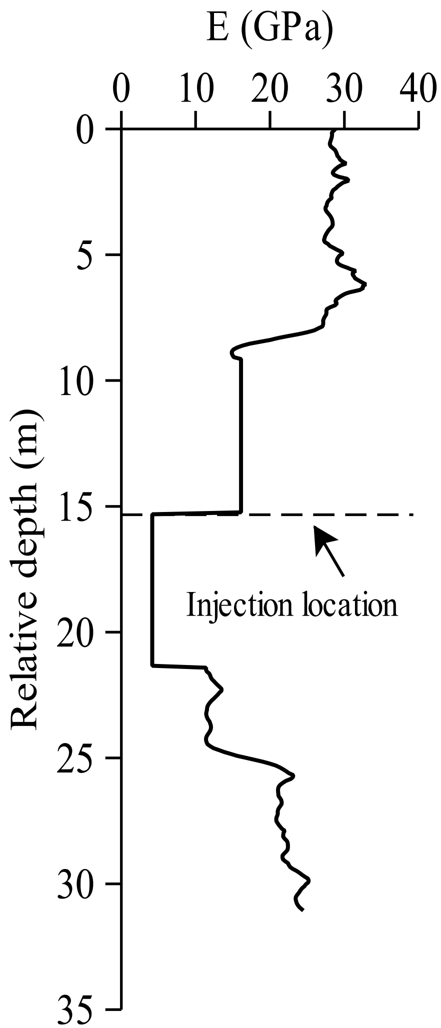
- It is likely HF intersects multiple NFs
- The closure behavior becomes complex
- The sequence of closure is reflected on the G-function plot

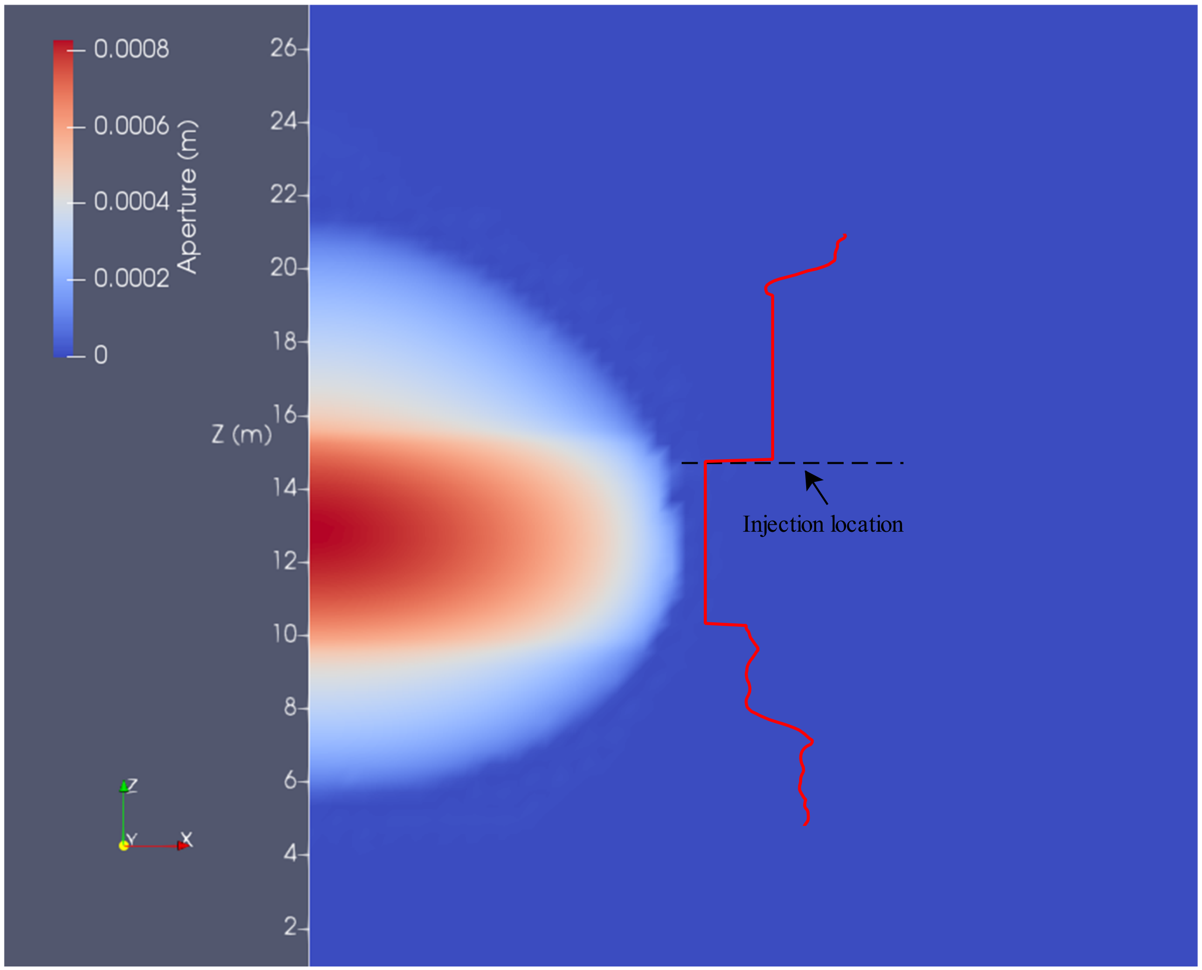
- Notice in Figure (3) the partial closure of the left NF indicating higher stress shadow on the left wing.





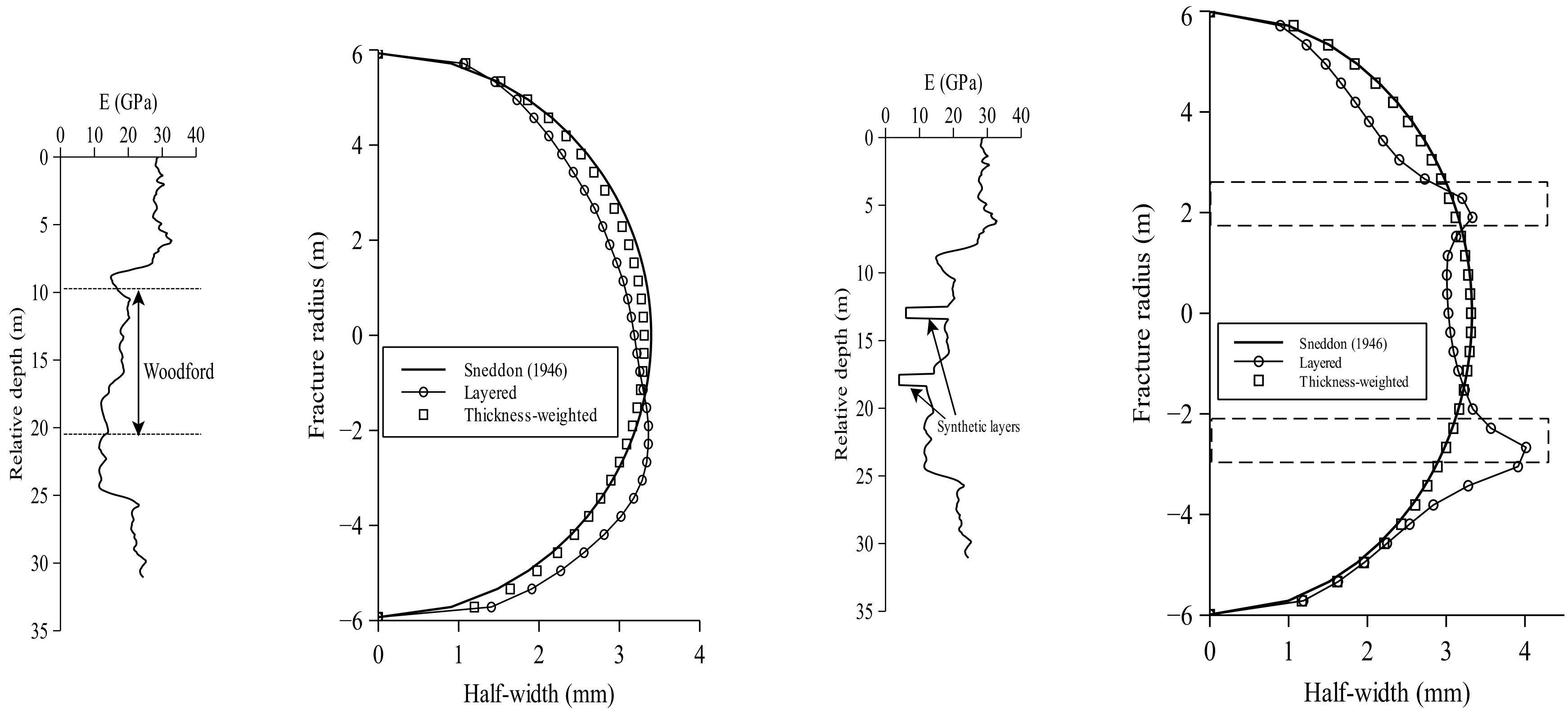
Influences of Layered Modulus (CZM)
Young's modulus contrast



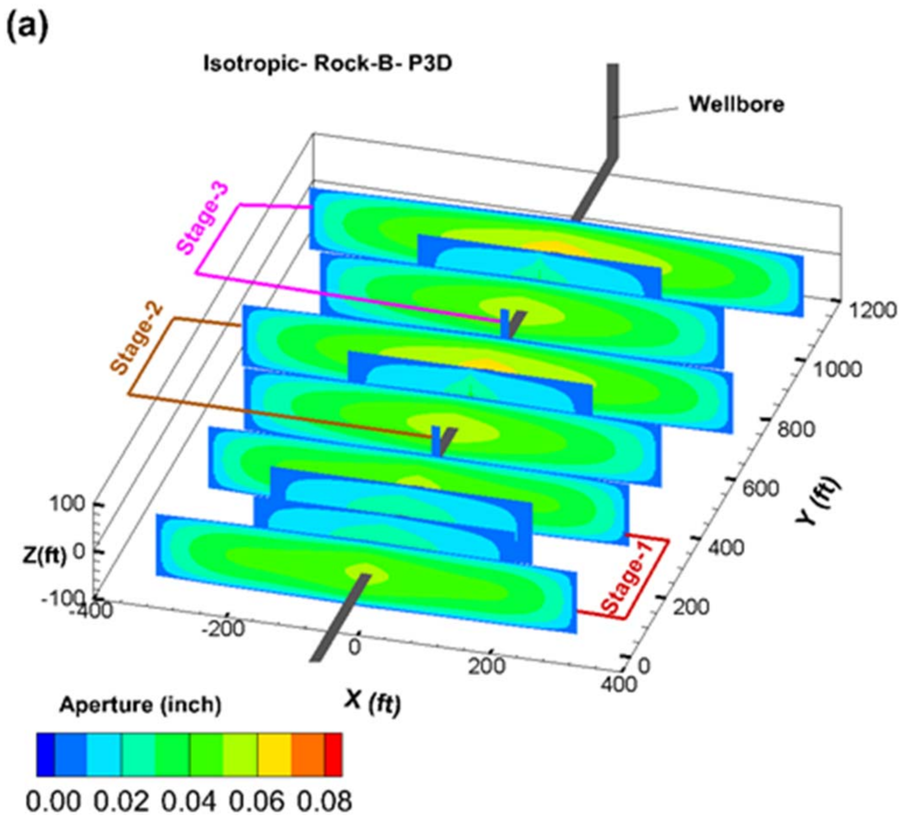


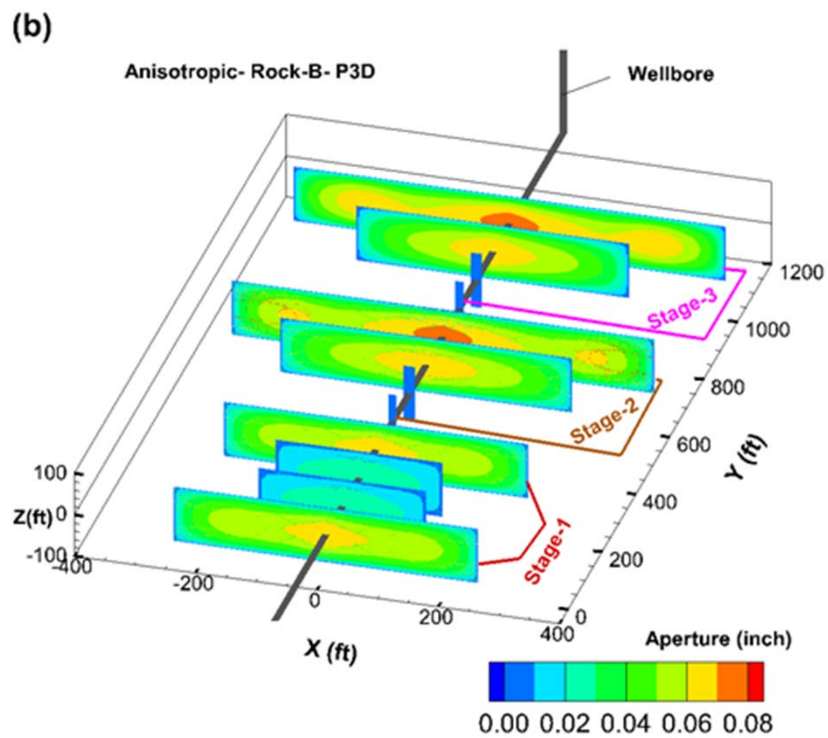
Aperture Profile

Fracturing in Layered Systems



P3D model for multi-stage fracturing in anisotropic formations

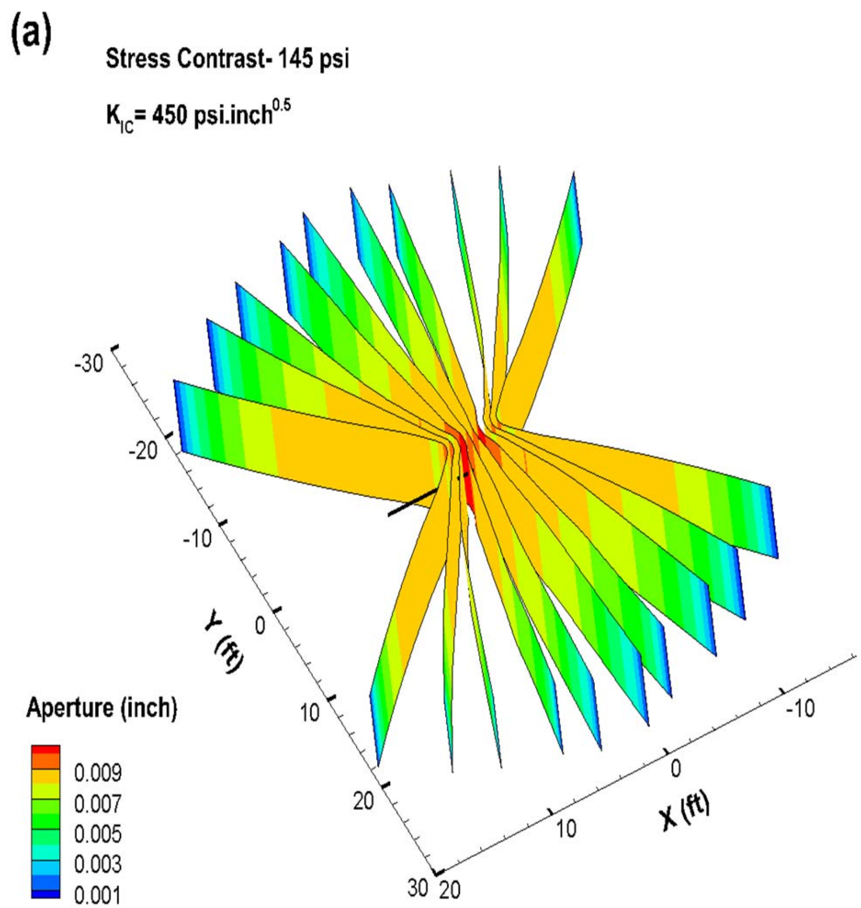




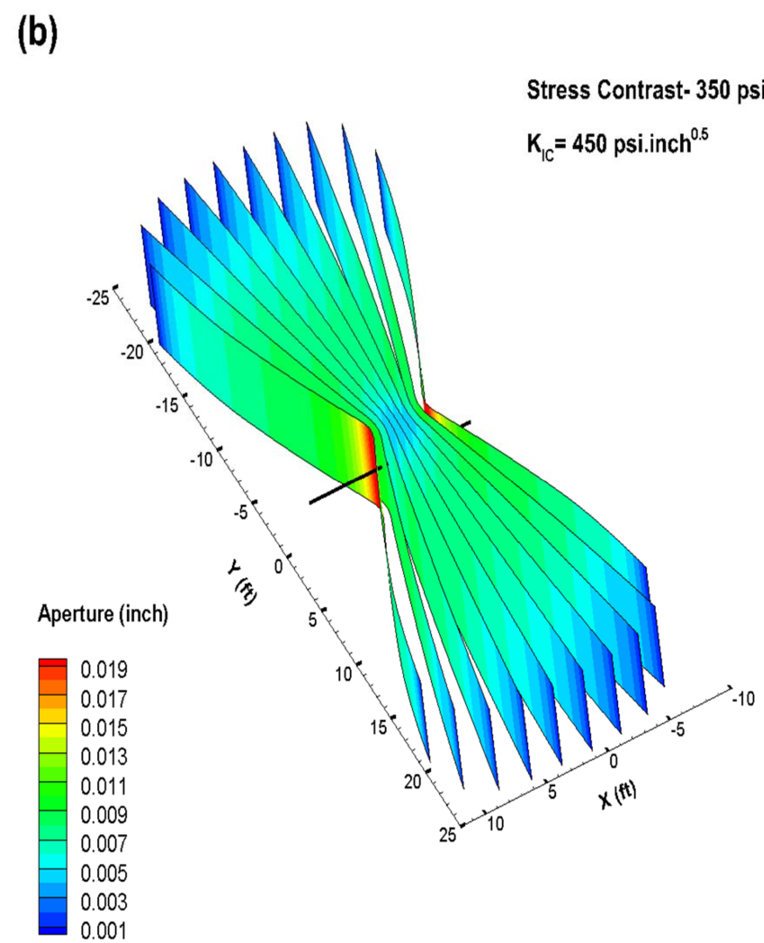
Effect of Fracture Toughness (K_{IC}=450 psi.inch$^{0.5}$)

$$\Delta\sigma = \frac{K_{IC}}{\sqrt{2\pi r}}$$

Stress Contrast- 145 psi



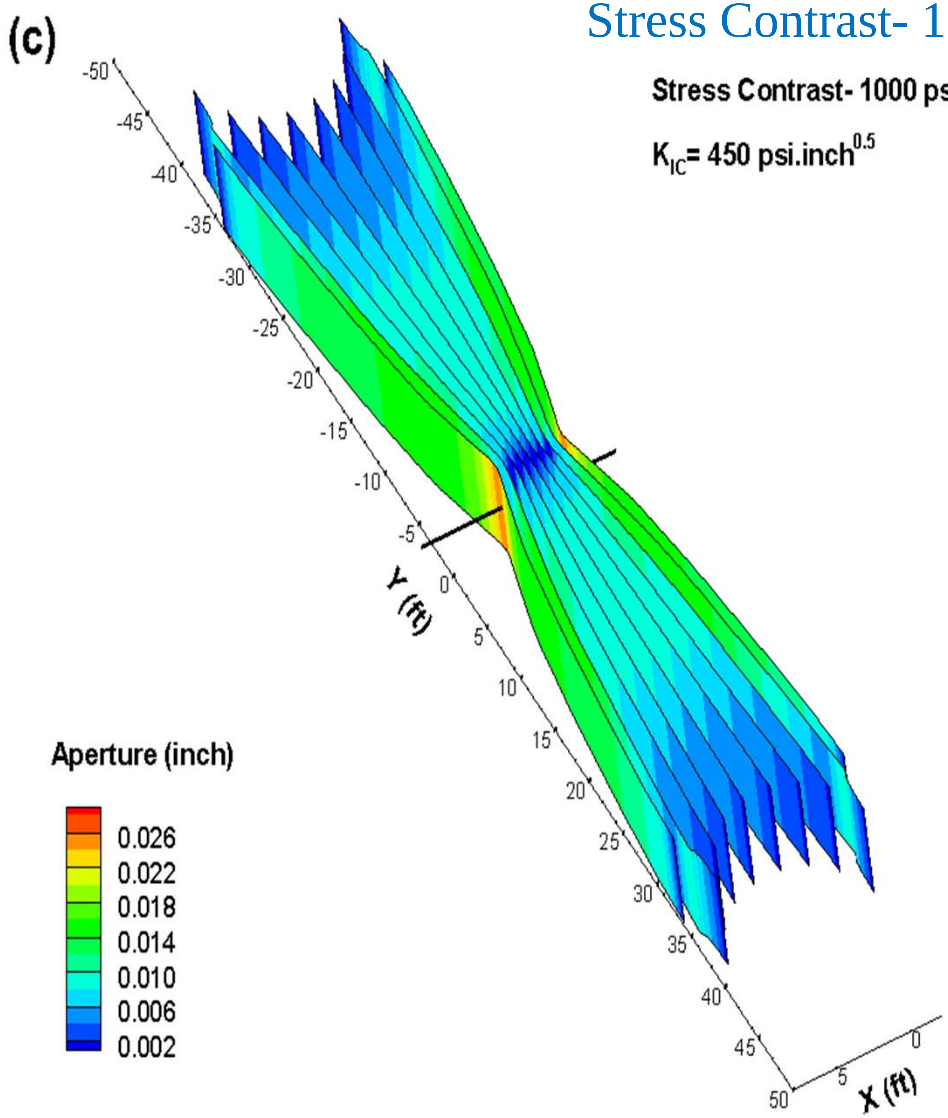
Stress Contrast- 350 psi



- Fracture coalescence is not observed in either stress contrast cases.
- When fracture curving is small, outer fracture dominate opening.

Effect of Fracture Toughness (K_{IC}=450 psi.inch$^{0.5}$)

Stress Contrast- 1000 psi



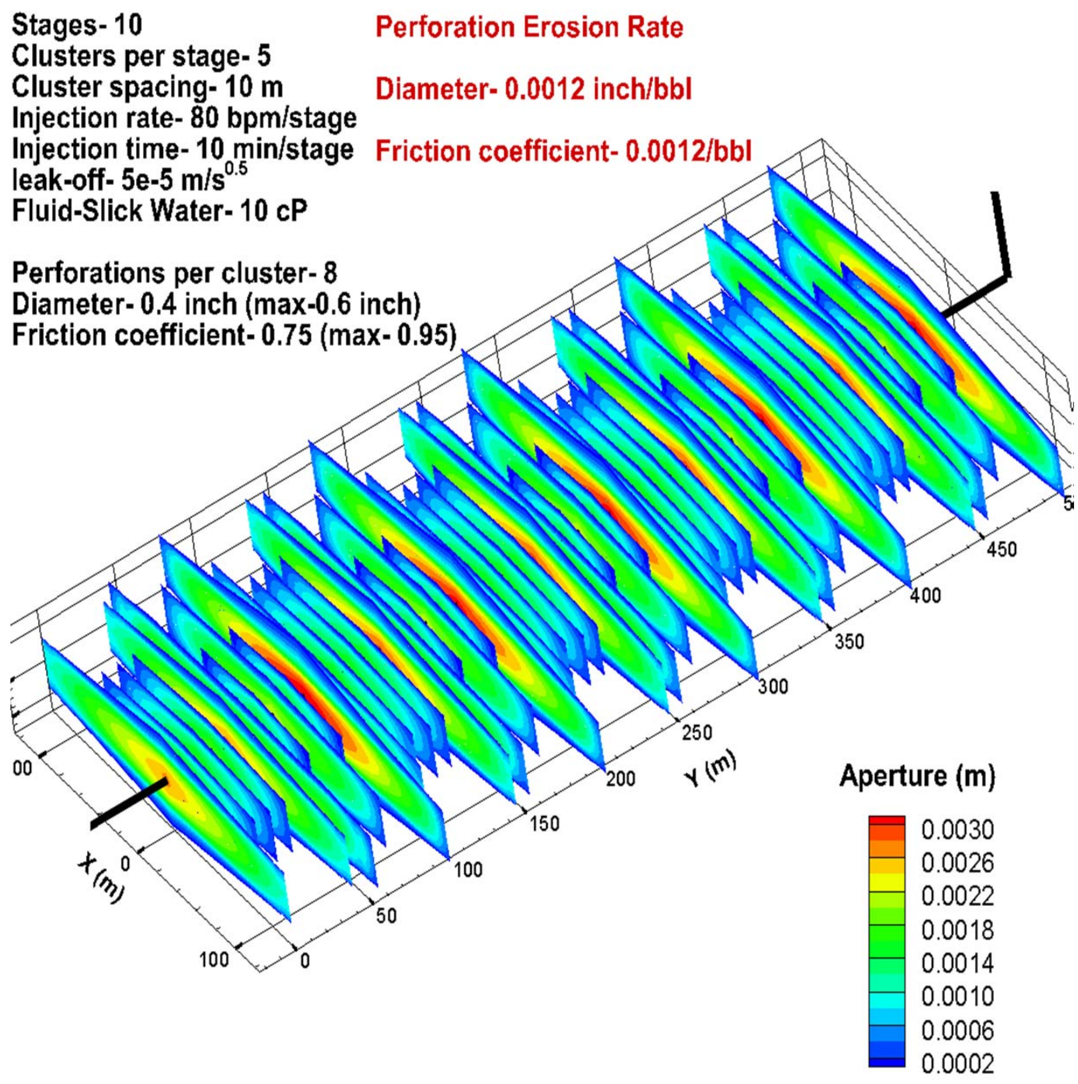
- Fracture coalescence not observed
- The six inner fractures grow 35 ft. in half length before termination
- Outermost fractures dominate opening

$$w(x)_{tip} \approx \frac{4K_{IC}(1-\nu^2)\sqrt{2x}}{\sqrt{\pi}E}$$

SPE - 194328-MS.

Rapid 3D Multi-frac

- R3D incorporates fracture height growth
- Fracture Mechanics
- Leak-off, viscous, toughness regimes
- Comparison with benchmark solutions
- Realistic stress shadow
- Perforation erosion
- Fast without compromising physics

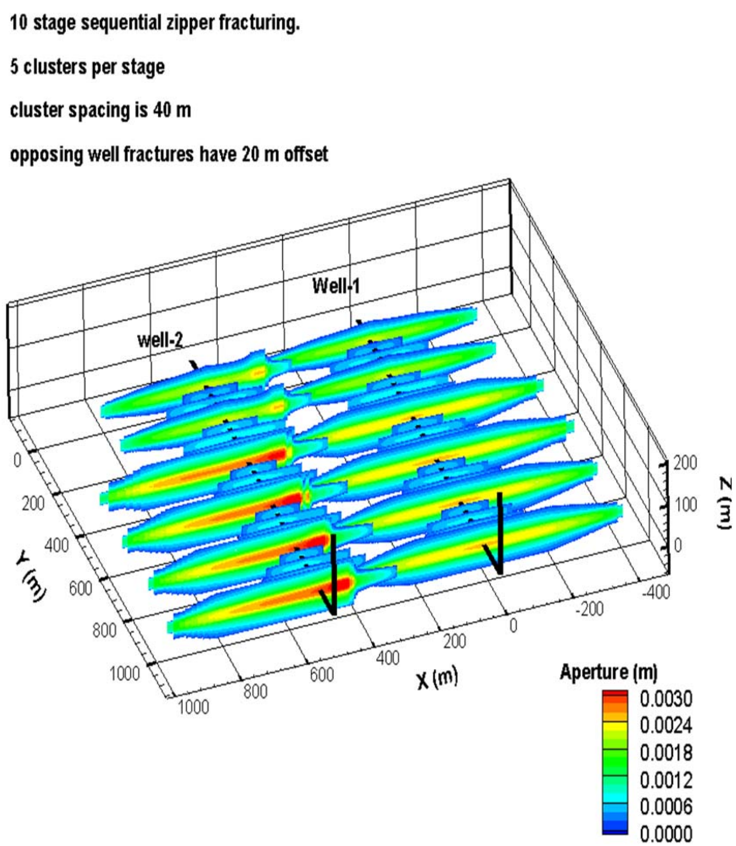


Capabilities of R3D

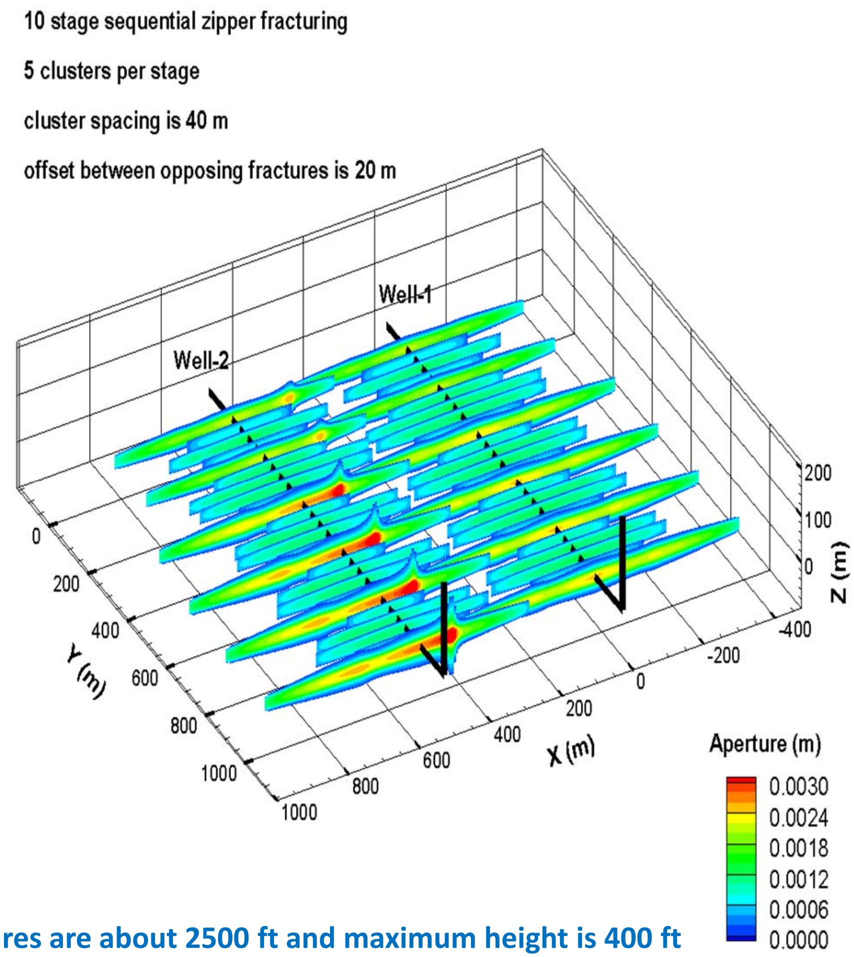
Simulation time 10-30 minutes on a desktop

50 bpm/stage, toughness=1

(Excess barrier stress- 145 psi)



(Excess barrier stress- 220 psi)



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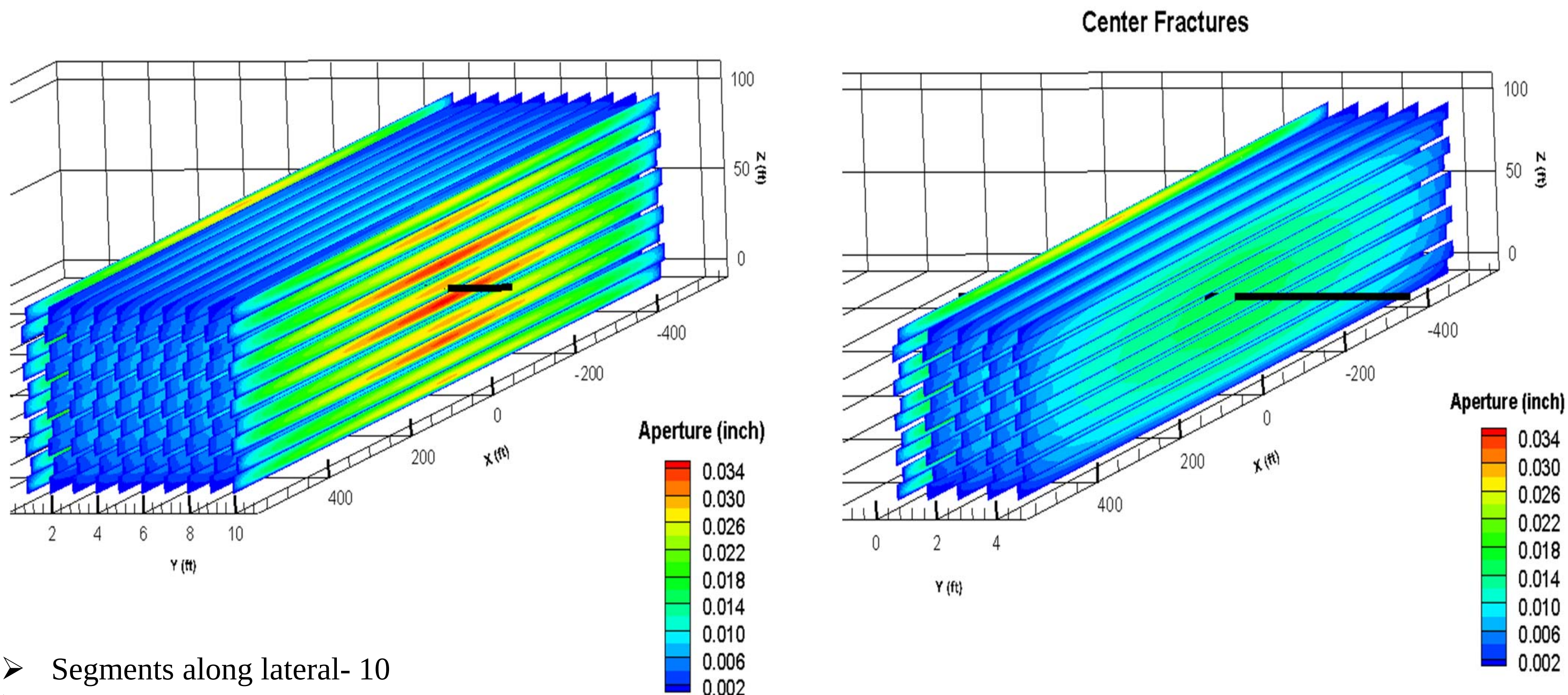
closer to

The longest fractures are about 2500 ft and maximum height is 400 ft

SPE - 194328-MS

P3D Simulation of Multiple Fracture Strands from a Perforation Cluster-1

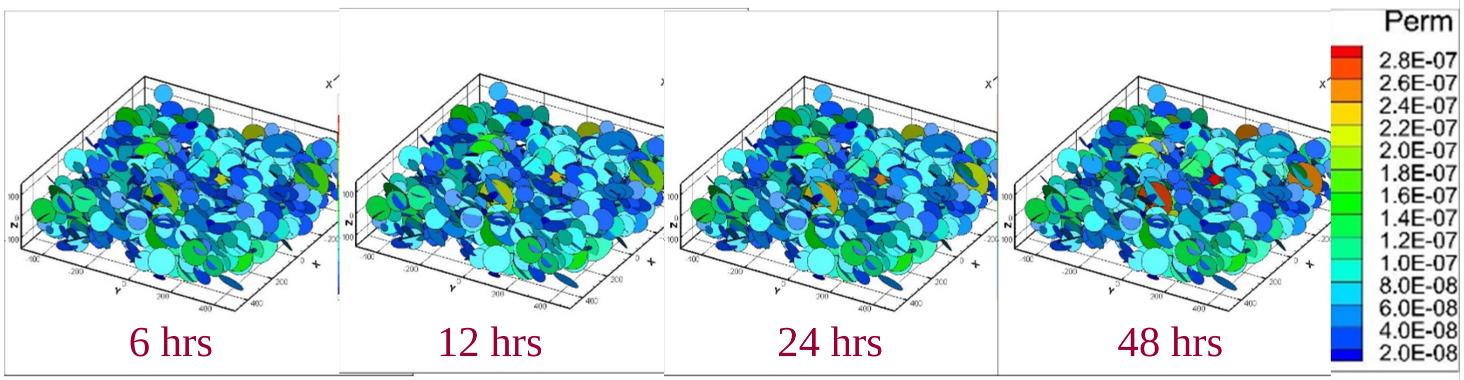


- Segments along lateral- 10
- Segments along vertical- 10
- Total segments- 100
- Segment height- 10 ft.
- Spacing 10% of height- 1.0 ft.

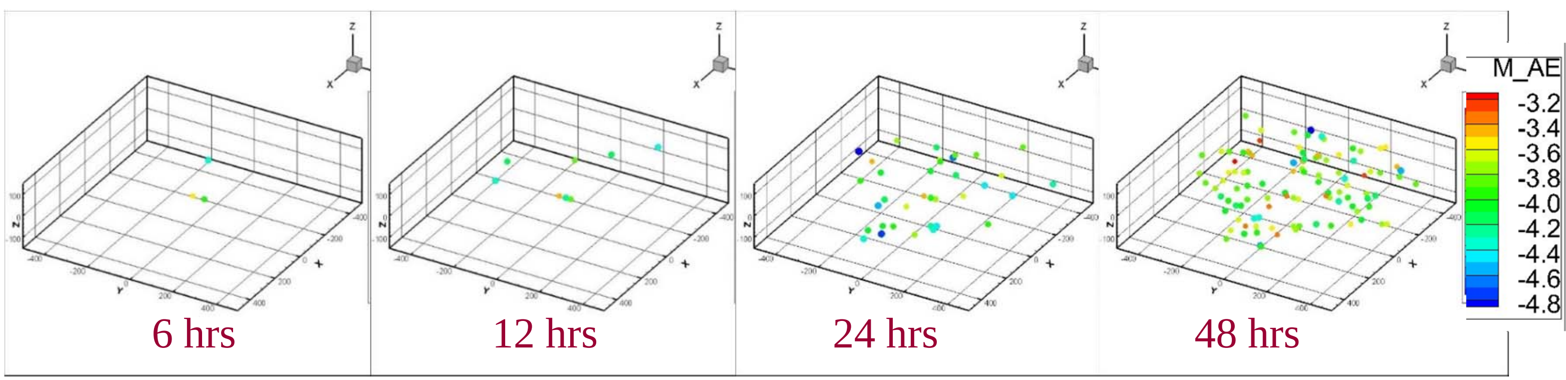
- Maximum opening of outer fractures- 0.034 inch .<< conventional single frac model (0.085 inch)
- Maximum opening of inner fractures- 0.015 inch
- Majority fractures have opening less than 50% of outer most fractures
- Predicted fracture half- length is 515 ft.<< conventional single frac model (1050 ft)

Shear Stimulation in 3D Network

- Fracture Permeability Increase
  - fluid injection successfully improves the permeability of interconnected fractures



- Injection Induced seismicity
  - fractures slip in shear and induce micro-earthquakes
  - confirms that the fracture network is successfully stimulated by injection

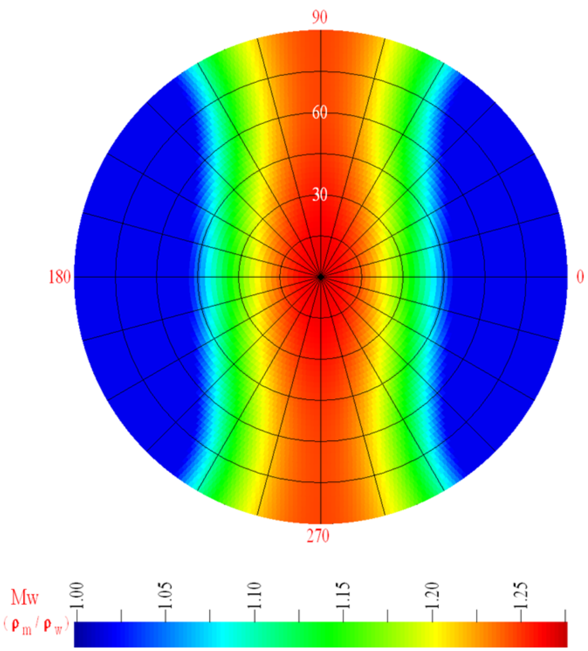


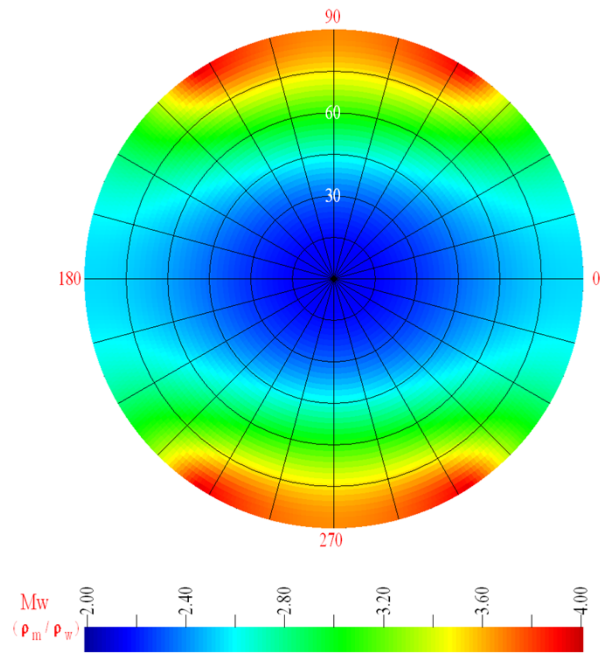
3 MEQs | 8 MEQs | 35 MEQs | 140 MEQs

Wellbore Stability Model Features

- Stable trajectory design using optimum mud-weight definition based on the most complete and theoretically robust thermo-chemo-poroelastic modeling
- In addition to mud weight, the impact of temperature, and mud chemistry on shale stability as a function of time can be considered
- Drucker-Prager failure criterion

Critical Mud Weight Based on the Elastic Model: (a) Critical Low Mud Weight; (b) Critical High Mud Weight





σ_H

29

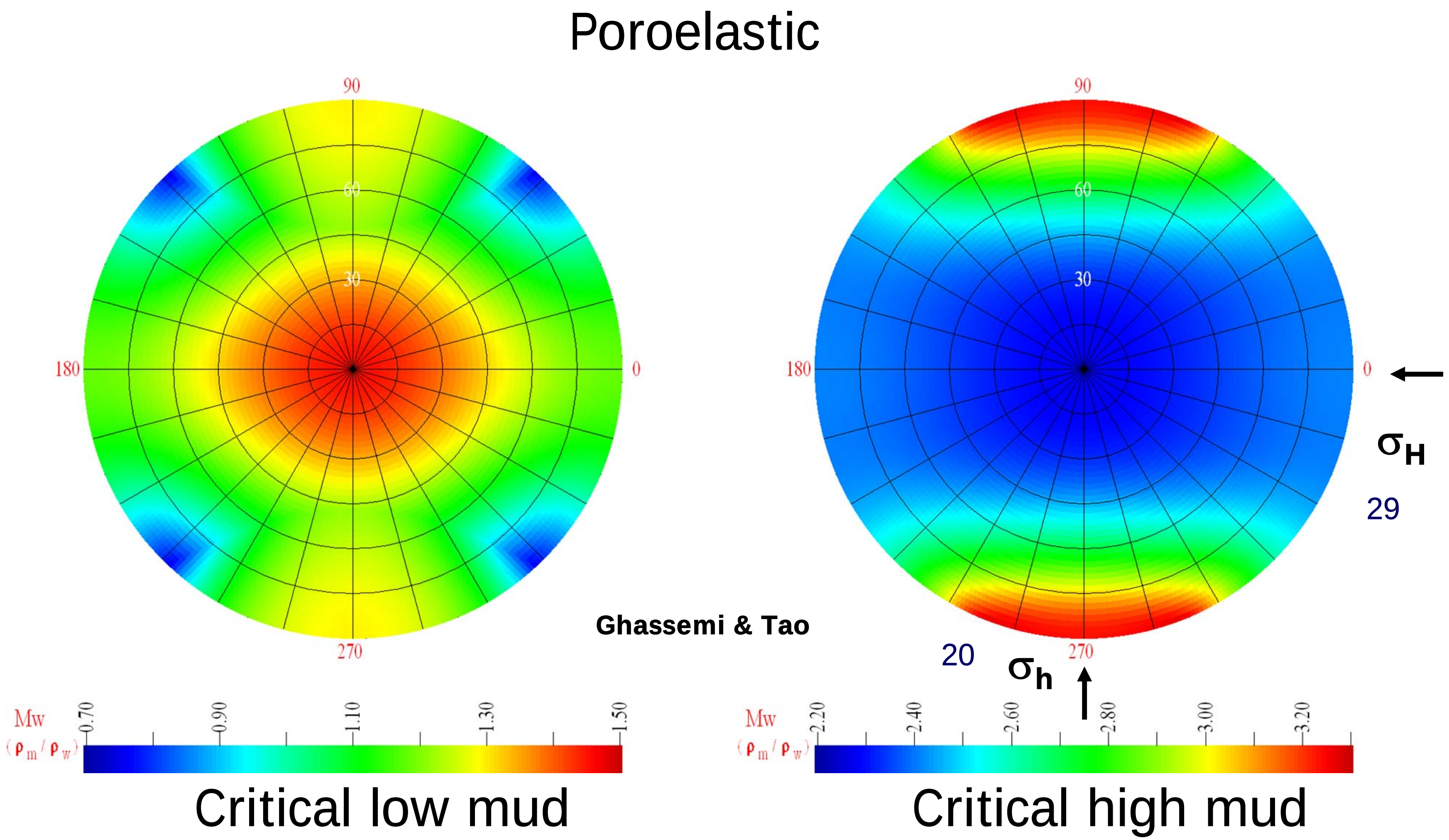
Ghassemi & Tao

20 σ_h

Critical low mud

Critical high mud

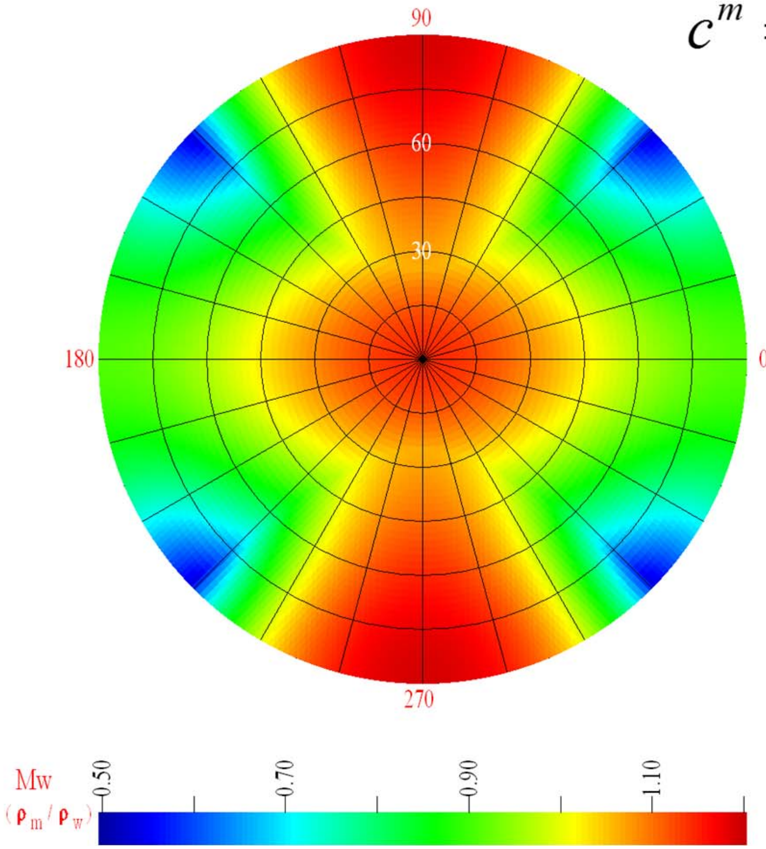
Mud weight for wells with variable inclination (0-90) and orientation (0-360), 1 hr



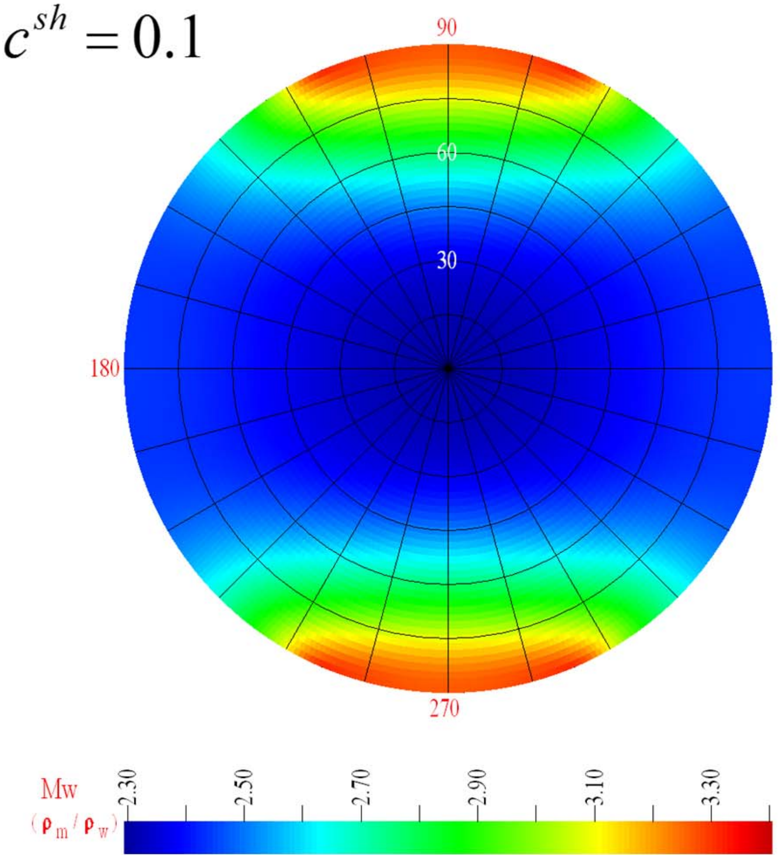
Mud weight for wells with variable inclination (0-90) and orientation (0-360), 1 hr

Chemo-poroelastic

$c^m = 0.2 \; c^{sh} = 0.1$



Critical low mud

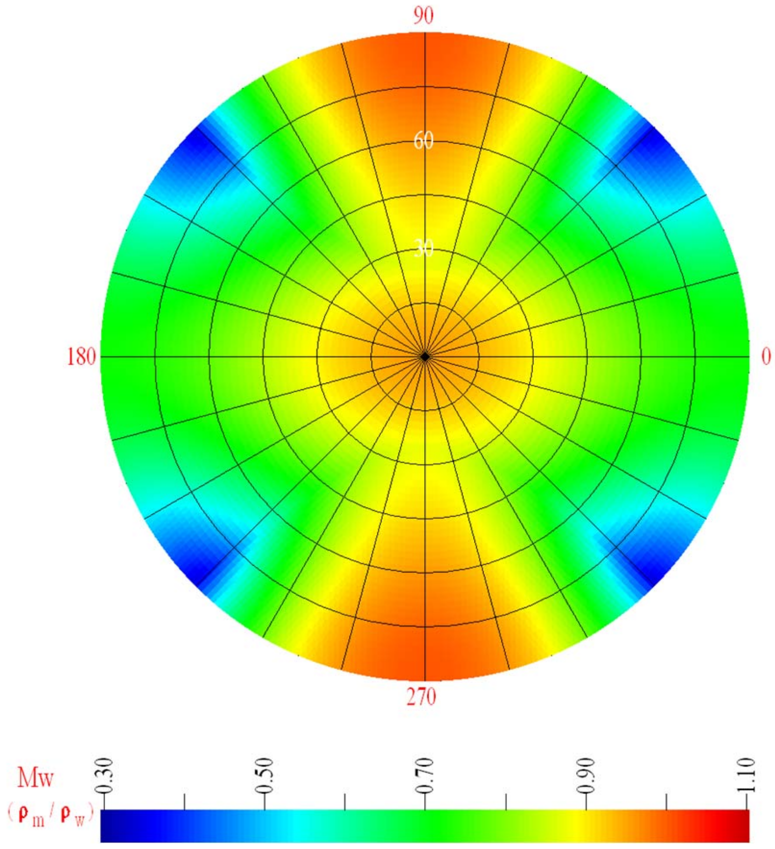


Critical high mud

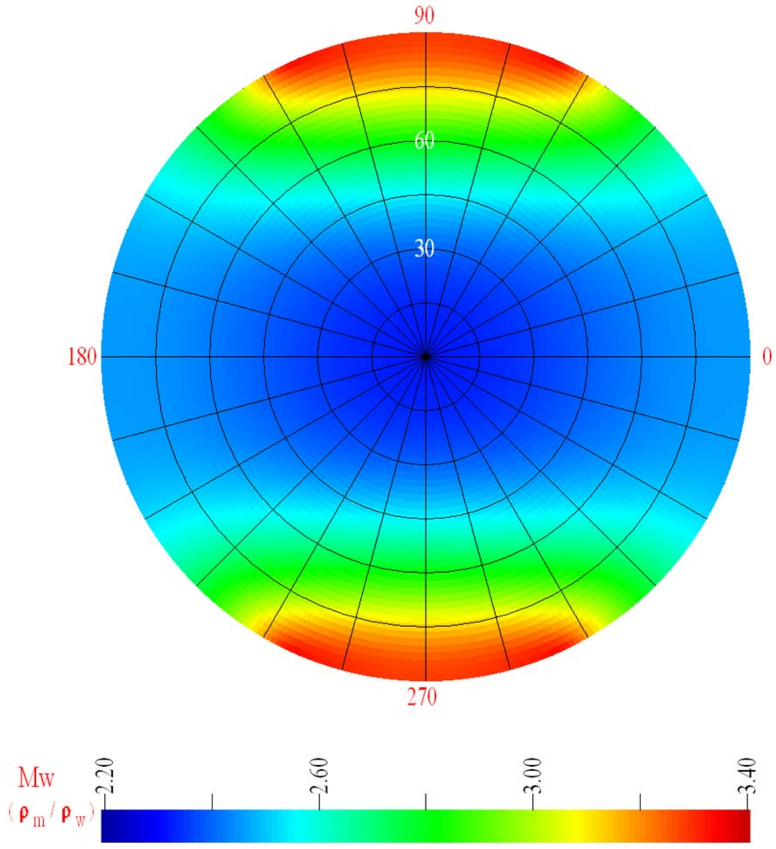
Mud weight for wells with variable inclination (0-90) and orientation (0-360)

$c^m = 0.2 \; c^{sh} = 0.1$

Chemo-thermo-poroelastic $T^m = 85^\circ C \; T^{sh} = 95^\circ C$

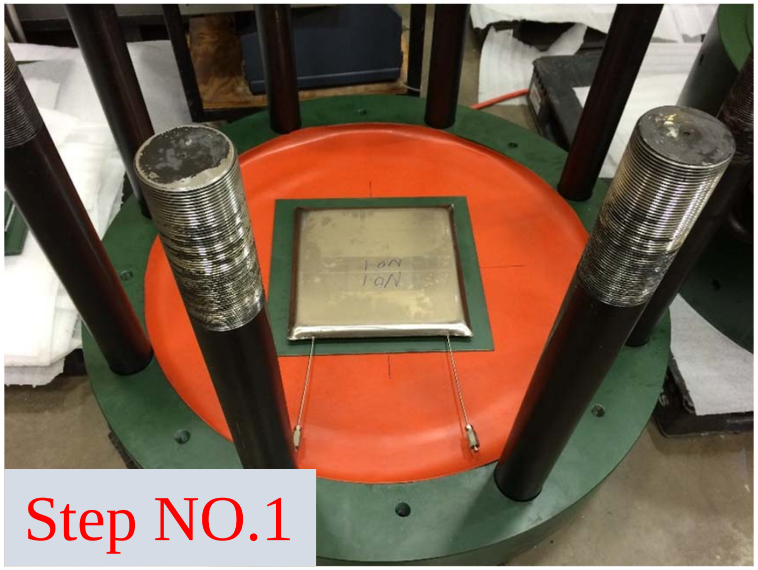


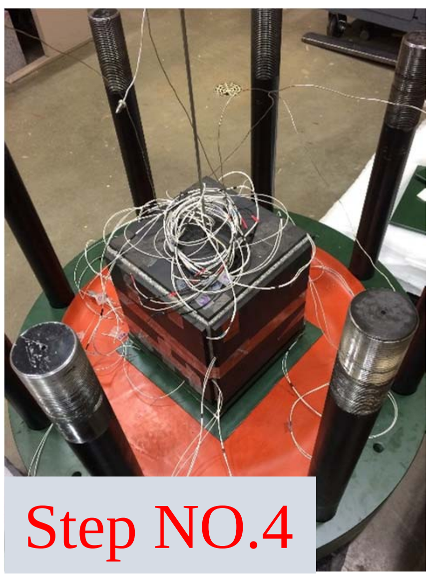
Critical low mud

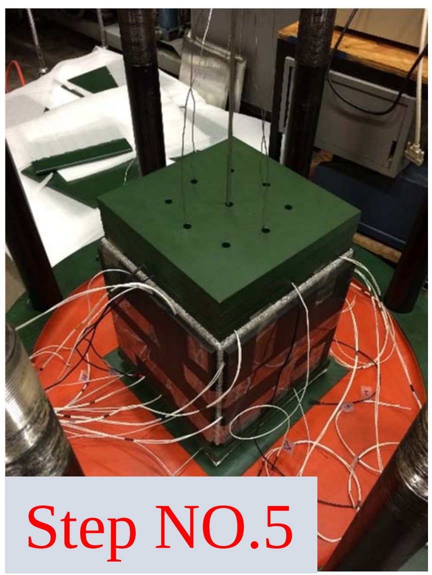


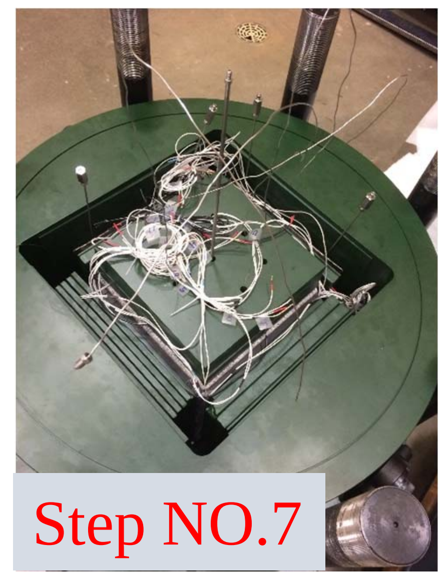
Critical high mud

Block HF Tests



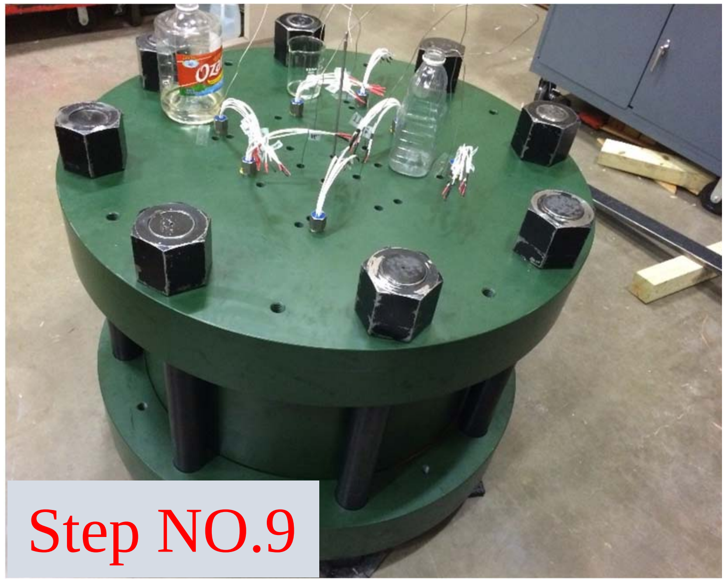






Test Assembly Procedure -continued

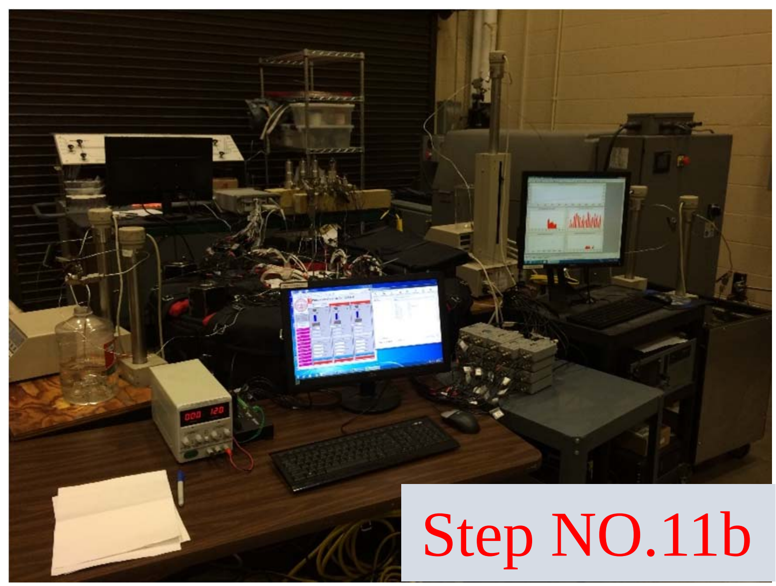
Step NO.8



Step NO.9

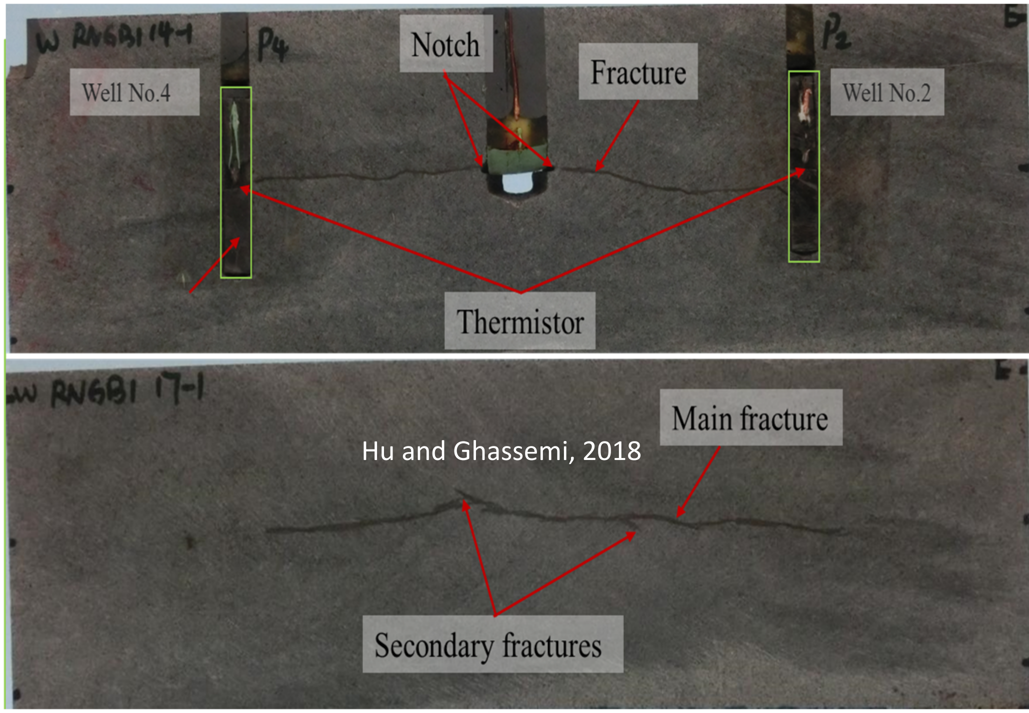
Step NO.10

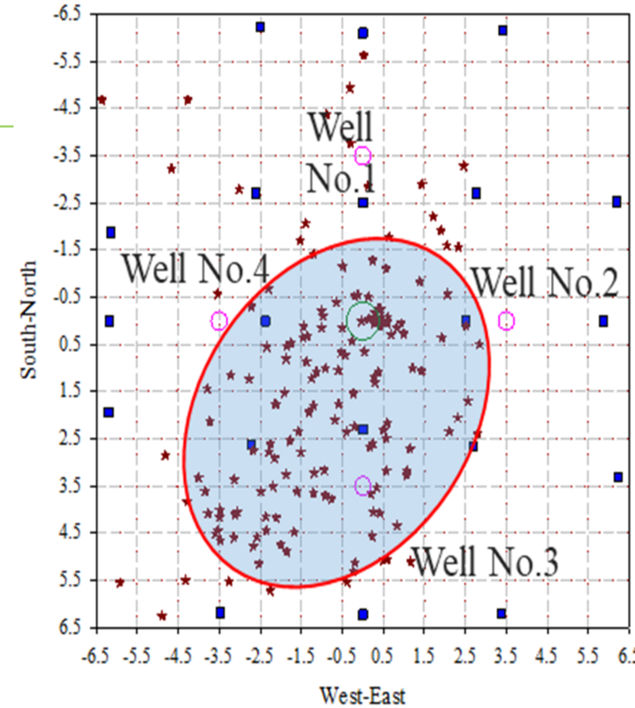
Step NO.11a

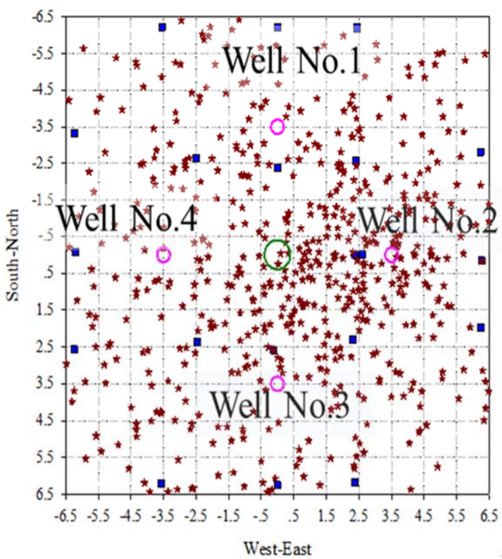


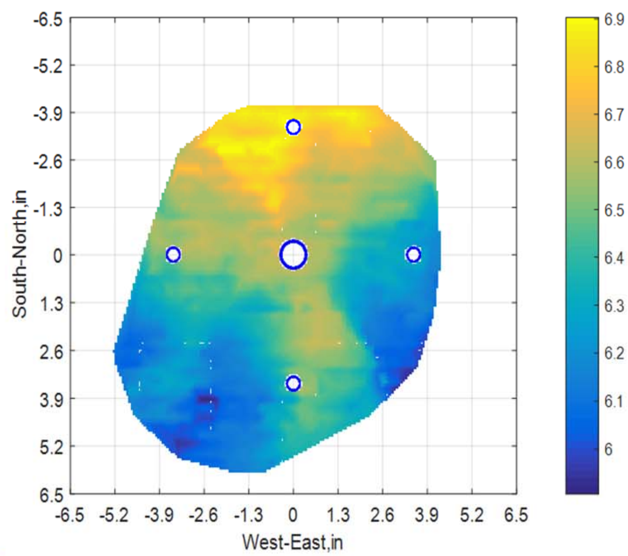
Step NO.11b

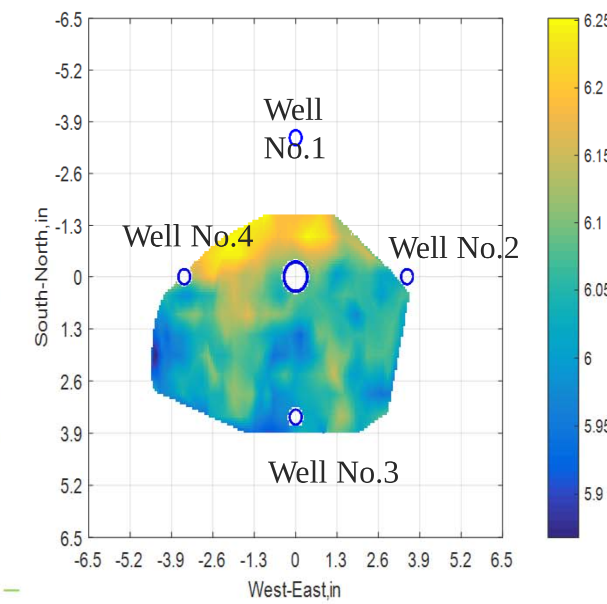
Test results- Induced fractures







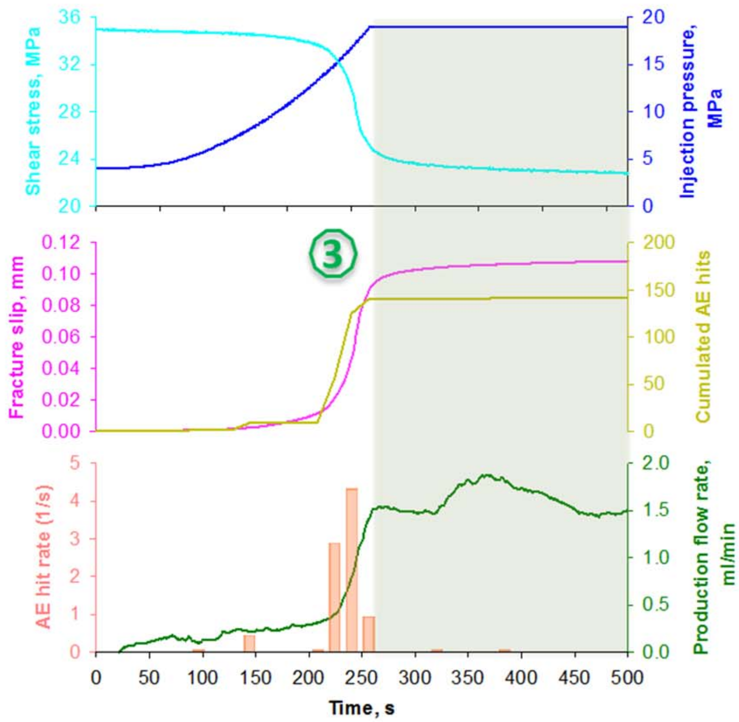


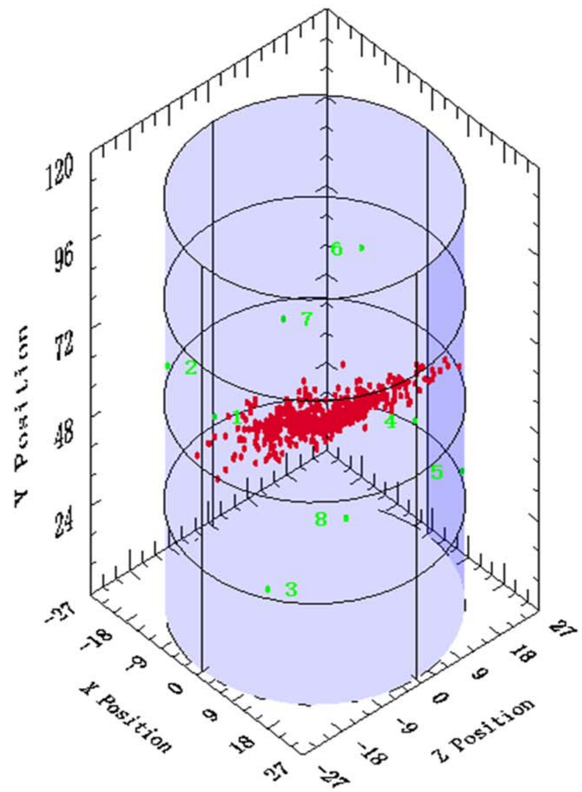


Left: MTS 810; Right: MTS 315

MTS 816 Direct Shear & Triaxial System (Back View)

Triaxial-injection Test with Acoustic Emission





Other Lab Capabilities

- True triaxial cell
- Rock scratch system
- Complete stress-strain curves
- Proppant embedment and consolidation
- Formation elasticity/strength sensitivity to fluids (i.e. chemo-poroelastic and rock weakening effects)
- Advanced poroelastic
- PVC
- Creep testing
- Fracture toughness
- Shear testing of natural fractures and bedding planes
- Testing under temperature up to 200C

Deliverables

- **Deliverables**

- 3D multiple hydraulic fracture modeling (BEM)
- 3D modeling of multiple fractures and re-frac, frac hit analysis
- 3D poroelastic DFIT considering HF/NF
- R3D HF model rapid large-scale completion optimization
- 3D FEM (CZM, Damage, etc.) for height growth
- Model applications to specific cases per request
- Advanced rock mechanics testing
- Student site visit program to help software use

Cost, Schedule

- Platinum membership ($100K/yr)
  - To attract new members, Platinum membership fee is reduced to $50K/year for a period of 2-years, and previous years' late fees are reduced to $100K total.
  - $100K due upon joining
- Reports on each task/project (approximately every 4 months)
  - If the need to disclose proprietary information arises, a separate confidentiality Agreement will be executed between the parties
  - University grants to each Sponsor a non-exclusive, royalty-free license to use any Invention