Harold Vance Department of
PETROLEUM ENGINEERING
TEXAS A&M UNIVERSITY

A Geomechanical Analysis of Gas Shale Fracturing and its Containment

(RPSEA-DOE, Contract No. 10122-42)

Jihoon Kim, George Moridis, Ding Zhu

Texas A&M University

U.S. Department of Energy
National Energy Technology Laboratory
Mastering the Subsurface Through Technology, Innovation and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting
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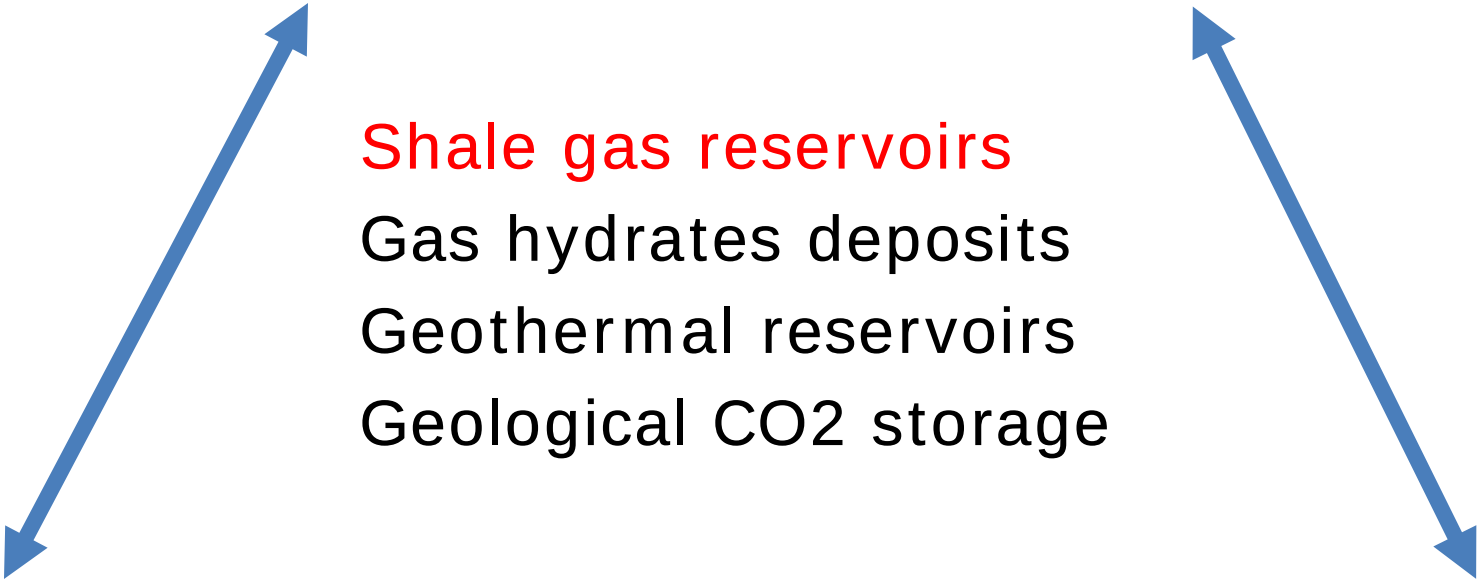
Coupled flow & geomechanics

Subsidence, Fracturing, Induced seismicity, EM



Shale gas reservoirs

Gas hydrates deposits

Geothermal reservoirs

Geological CO2 storage

Reservoir characterization

Joint inversion of geomechanics/geophysics

Heterogeneity

Interaction between hydraulic & natural fractures

Project Objectives (I)

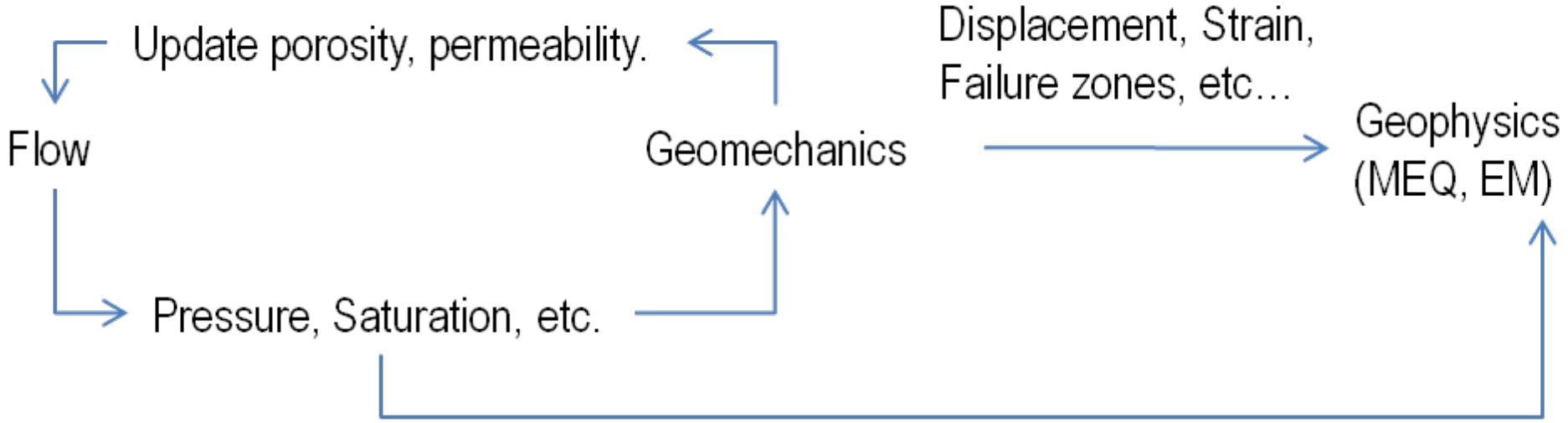
- Numerical and experimental study of in hydraulic fracturing (HF)
- Lab study: Understand the role of rock texture, fabric and deformation regime
  - Large block 3D hydraulic fracturing test
  - 3 Mid-size block test
  - Small sample test

Project Objectives (II)

- Develop rock strength/elasticity heterogeneity models that can be used for gas shale studies and field applications

- Implement experimental findings into numerical fracture simulation models with rock heterogeneity, discontinuity characteristics, and stress dependent rock properties
  - Planar fracture propagation in 3D
  - Non-planar fracture propagation

Framework of Numerical simulation



Geomechanics ⇒ MEQ, deformation (e.g., InSAR)

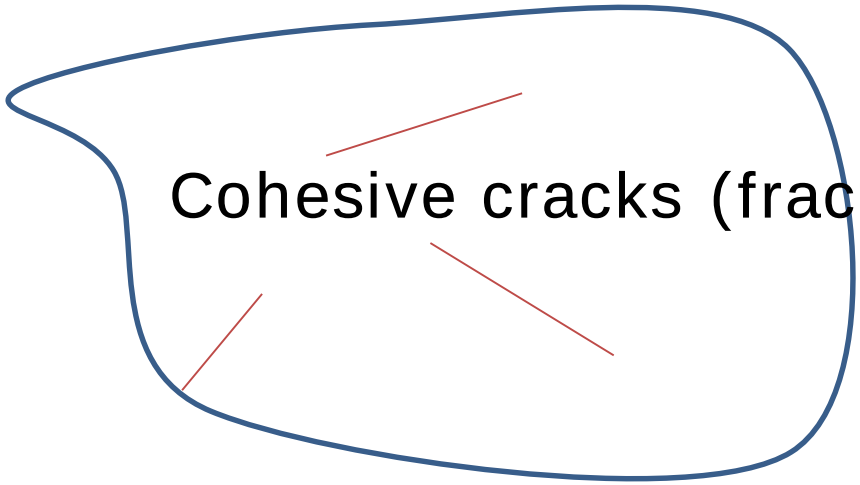
Flow ⇒ Electromagnetic survey

Different physics → different geophysics modeling

Non-planar fracture propagation
Cohesive zone model

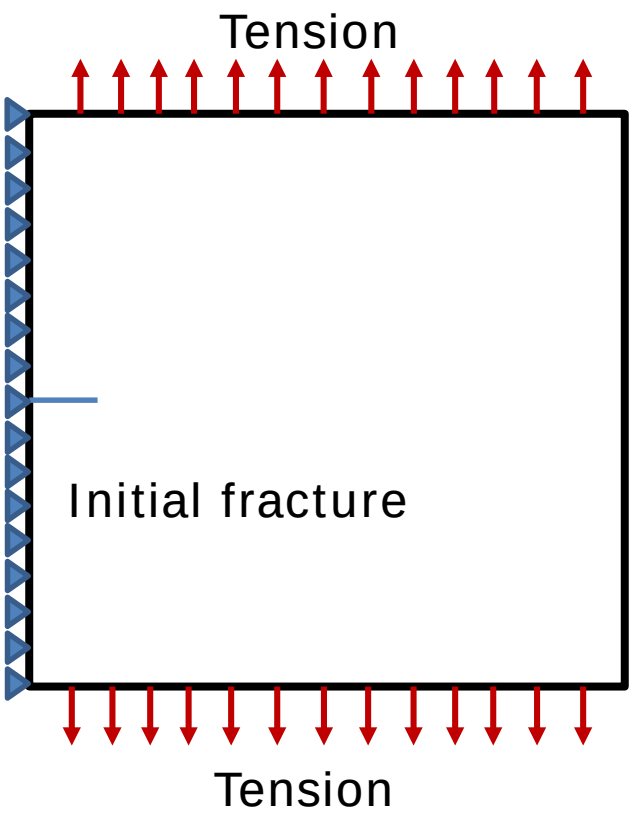
$$\mathrm{Div}\cdot\boldsymbol{\sigma}+\rho\mathbf{g}=0$$

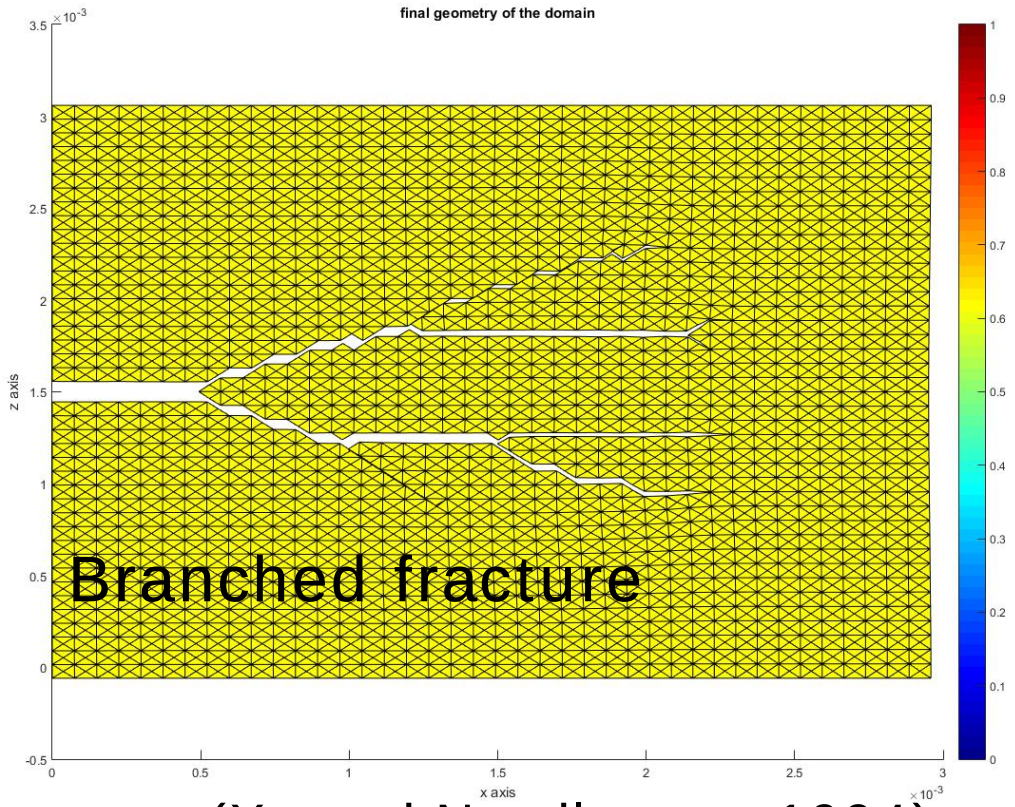
$$\int_{\Omega^e}\mathrm{Grad}^s\delta\mathbf{u}:\boldsymbol{\sigma}\,d\Omega-\int_{\Omega^e}\delta\mathbf{u}\cdot\mathbf{g}\,d\Omega-\int_{\Gamma_{\mathbf{t}}^e}\delta\mathbf{u}\cdot\bar{\mathbf{t}}d\Gamma_t+\int_{\Gamma_{coh}^e}\delta[\mathbf{u}]\cdot\mathbf{t}^c d\Gamma_d=0$$



Easy to implement under the finite element codes

Case 1-1: Single fracture (Verification)

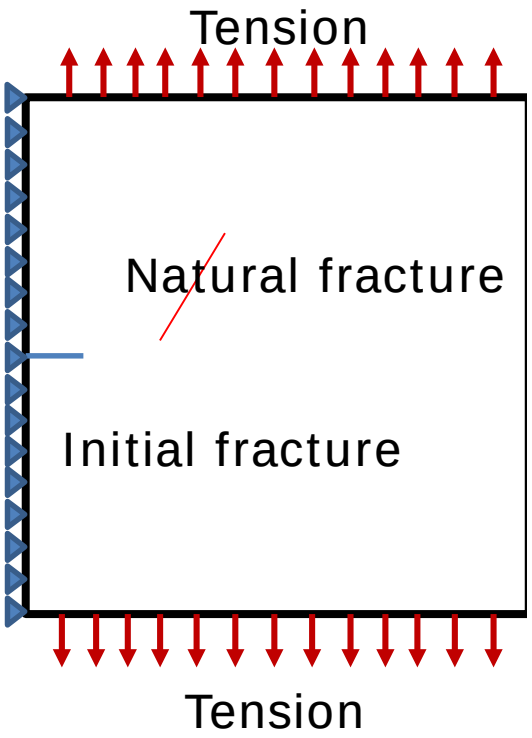


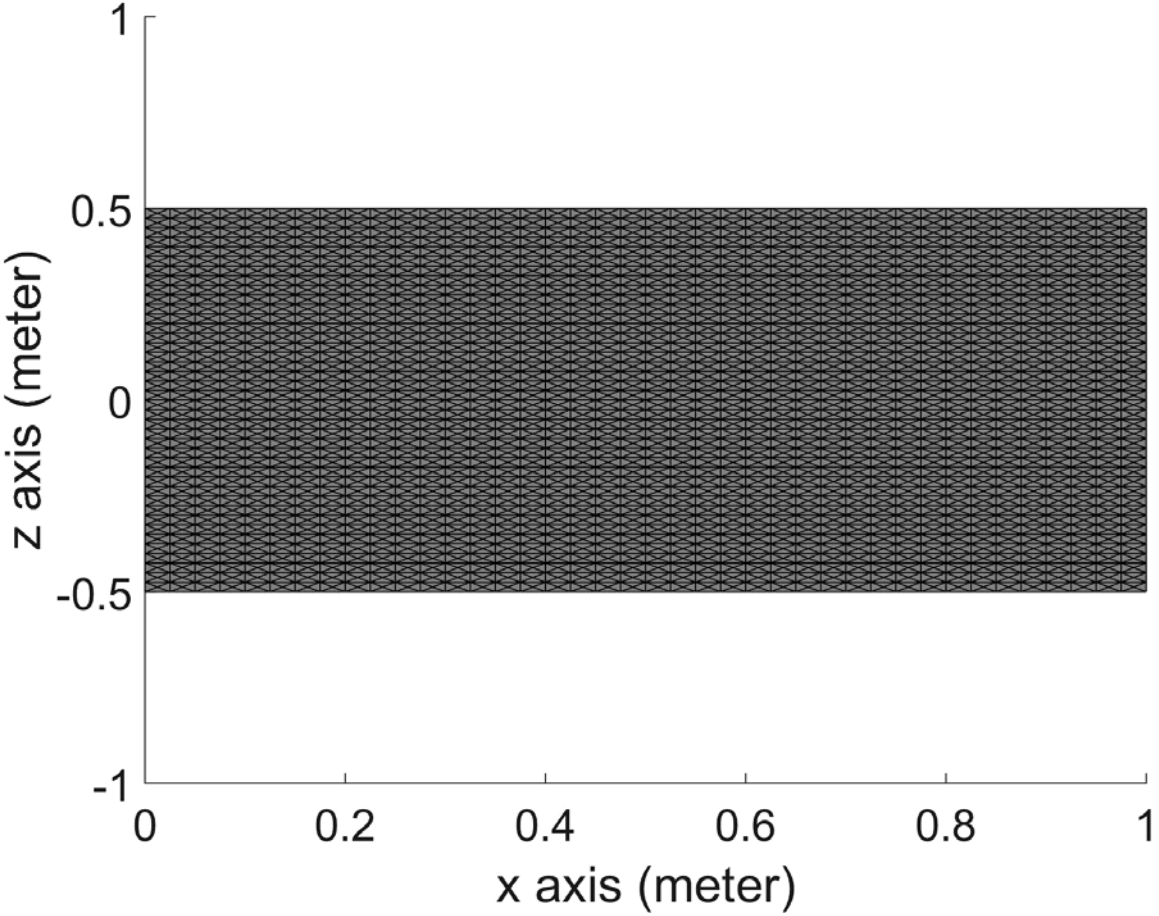


(Xu and Needleman, 1994)

Matched with the previous study

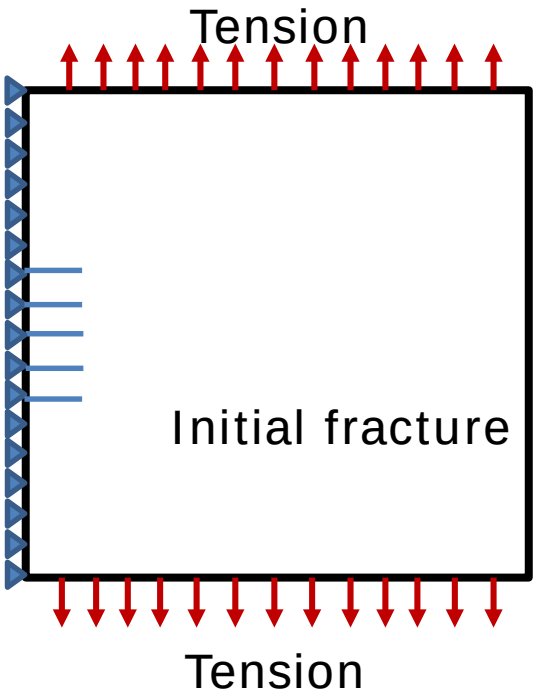
Case 1-2: Non-planar fracture propagation



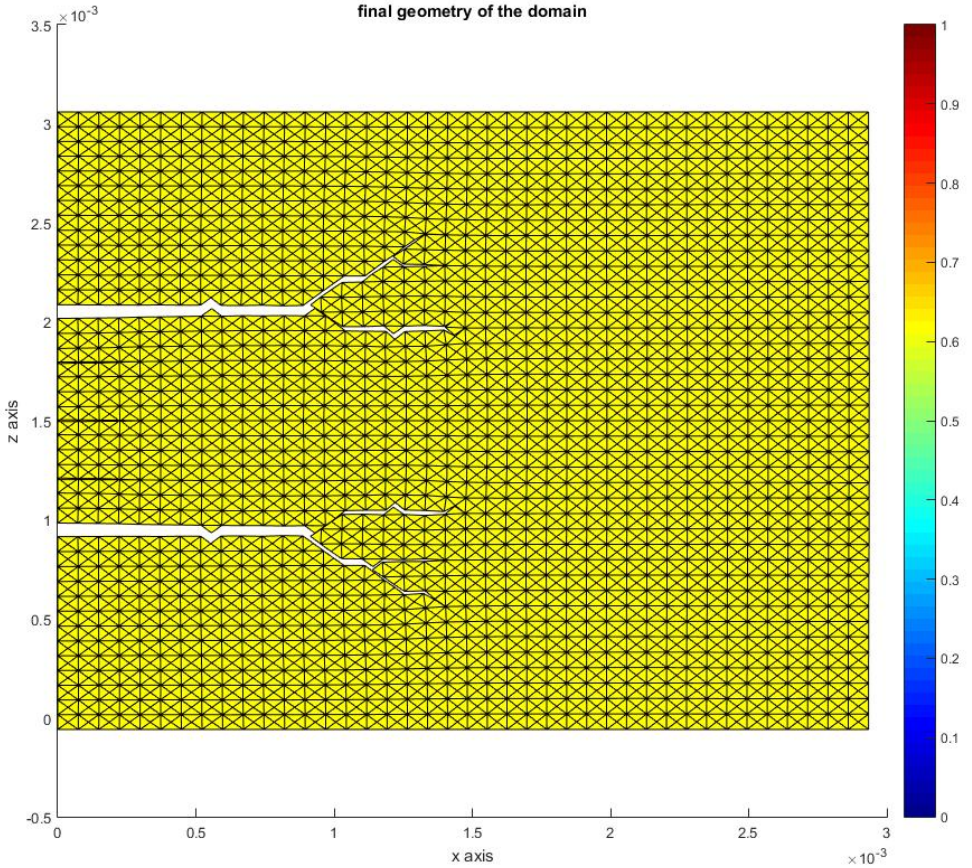


Natural fracture affects fracture propagation

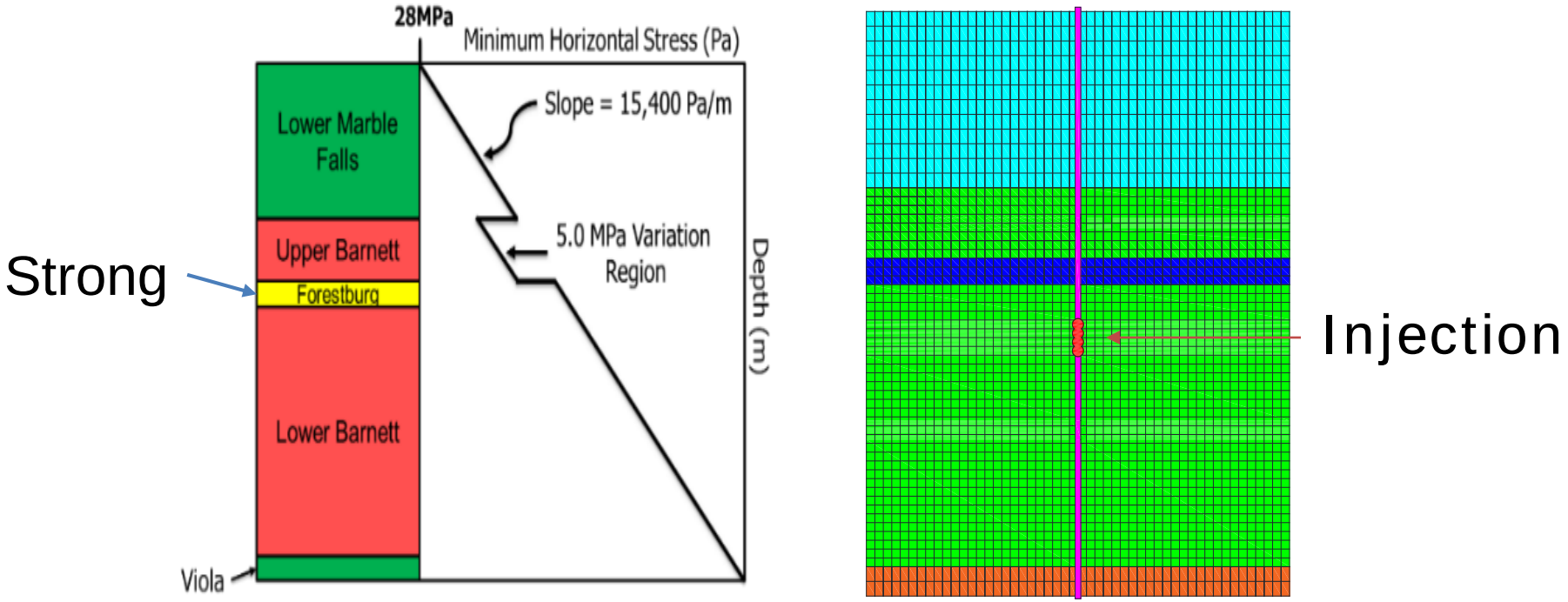
Case 1-3: Non-planar fracture propagation



Fractures interact each other.



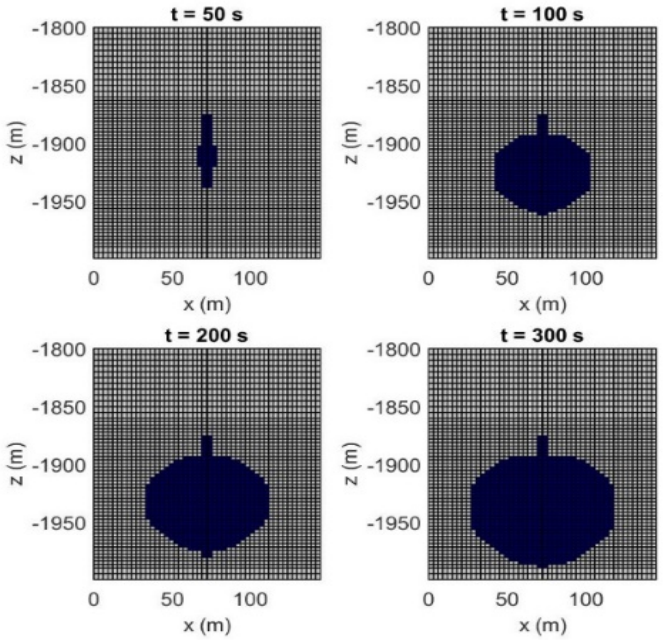
Case 2-1: 3D planar HF simulation

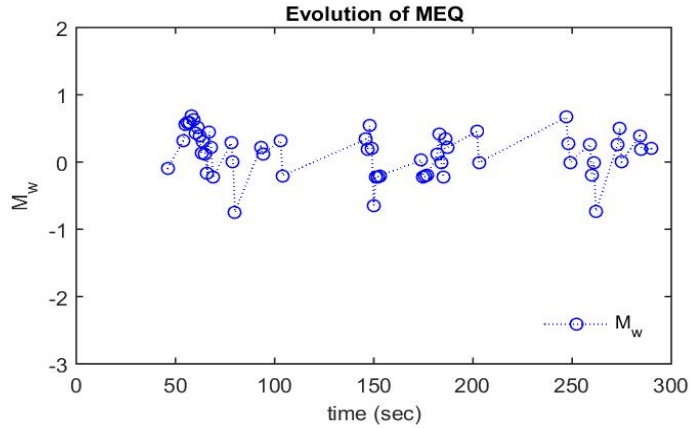


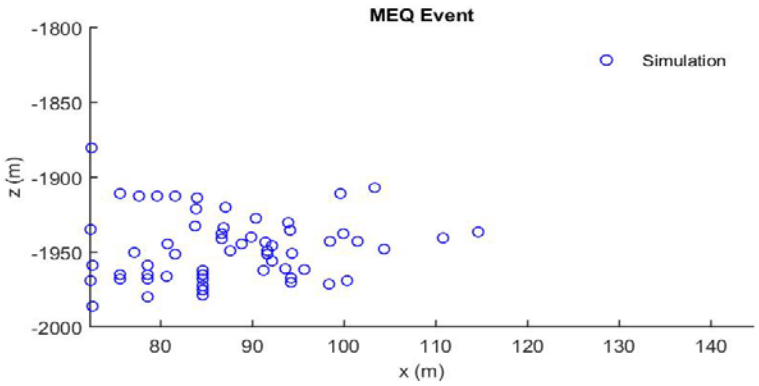
Layer heterogeneity (5 layers)

Stress heterogeneity (Upper Barnett)

Fracturing in Lower Barnett



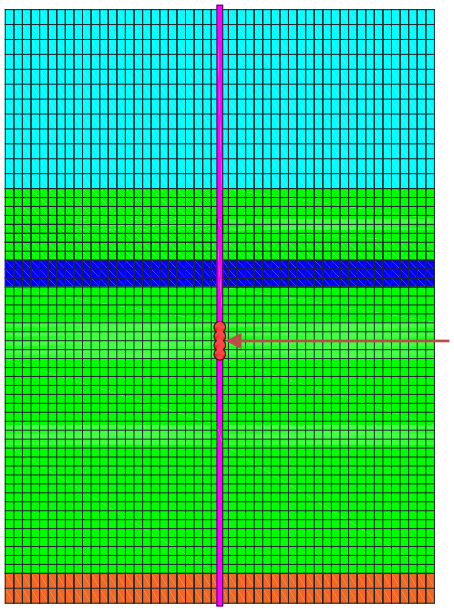




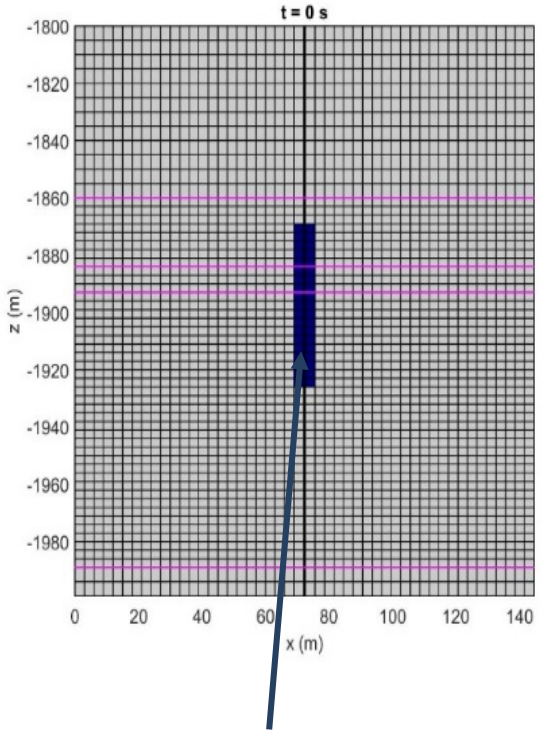
Moment magnitude calculated from geomechanics

Fracture cannot go through Forestburg (strong layer)

Case 2-2: Wellbore partially fractured



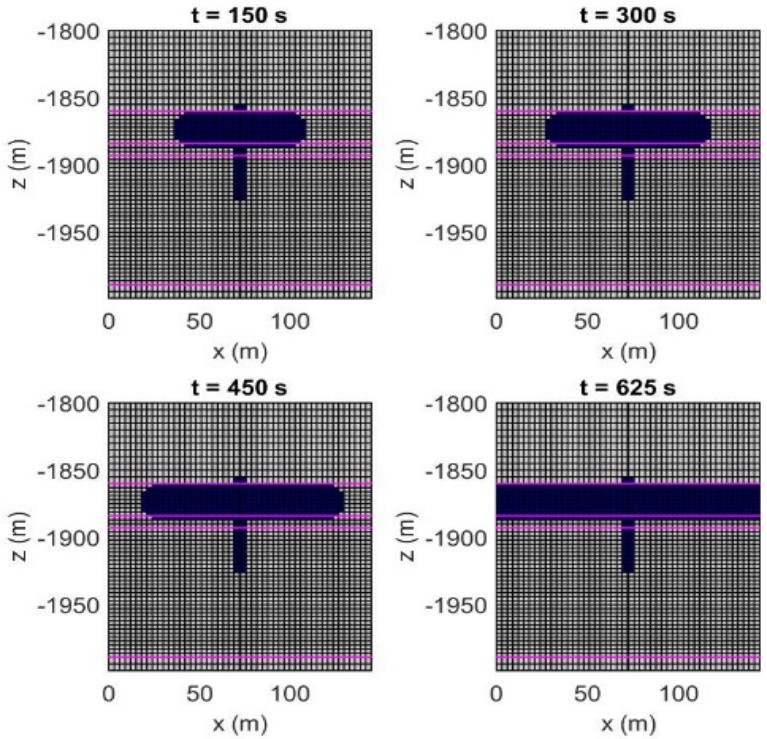
Injection

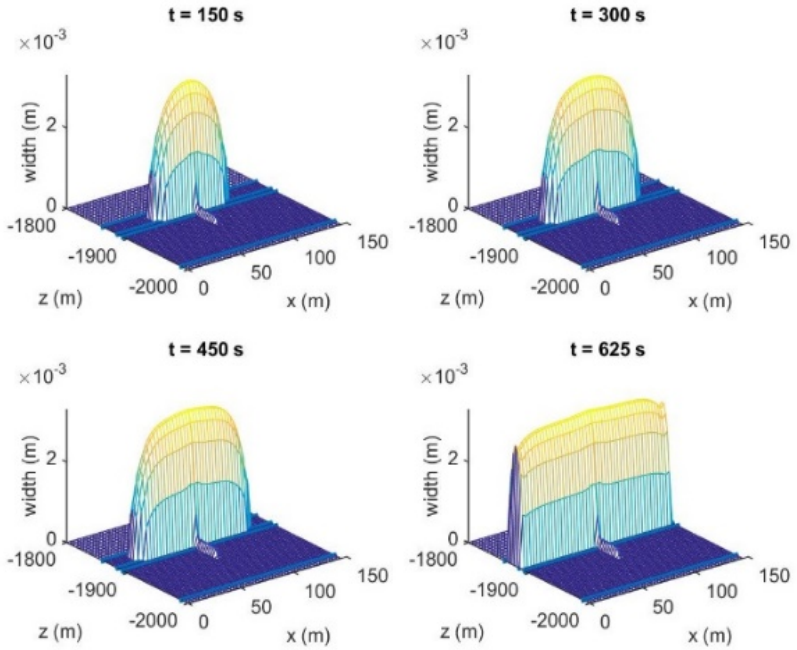


Assume wellbore to be partially fractured

This can happen because of incomplete wellbore cementing

Fracturing in Upper Layer

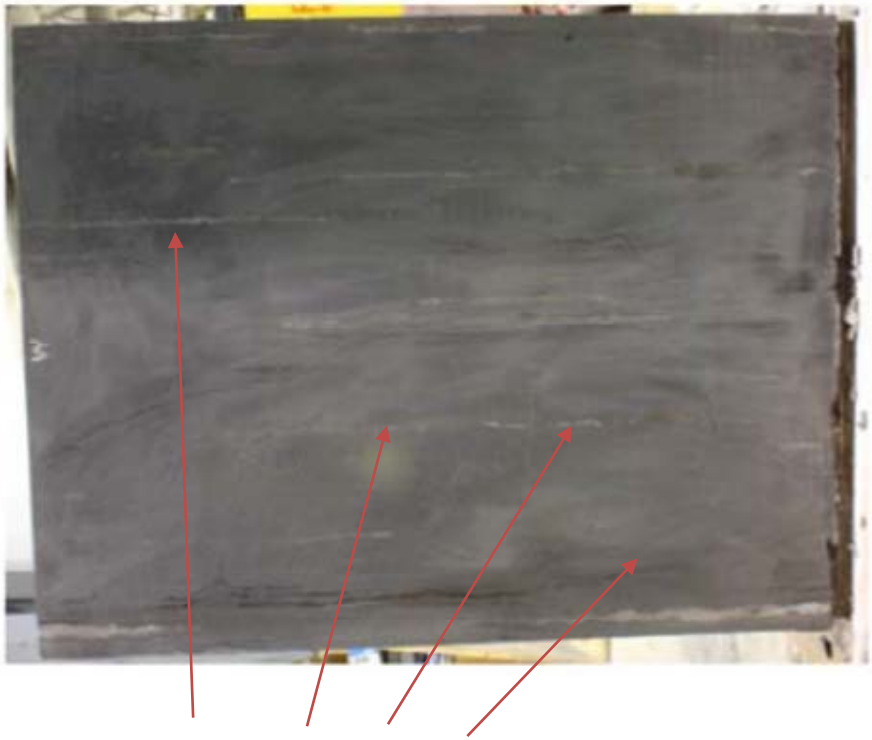




Fluid flows along the wellbore, as well.

Upper Barnett fractured while fluid is injected at Lower Barnett

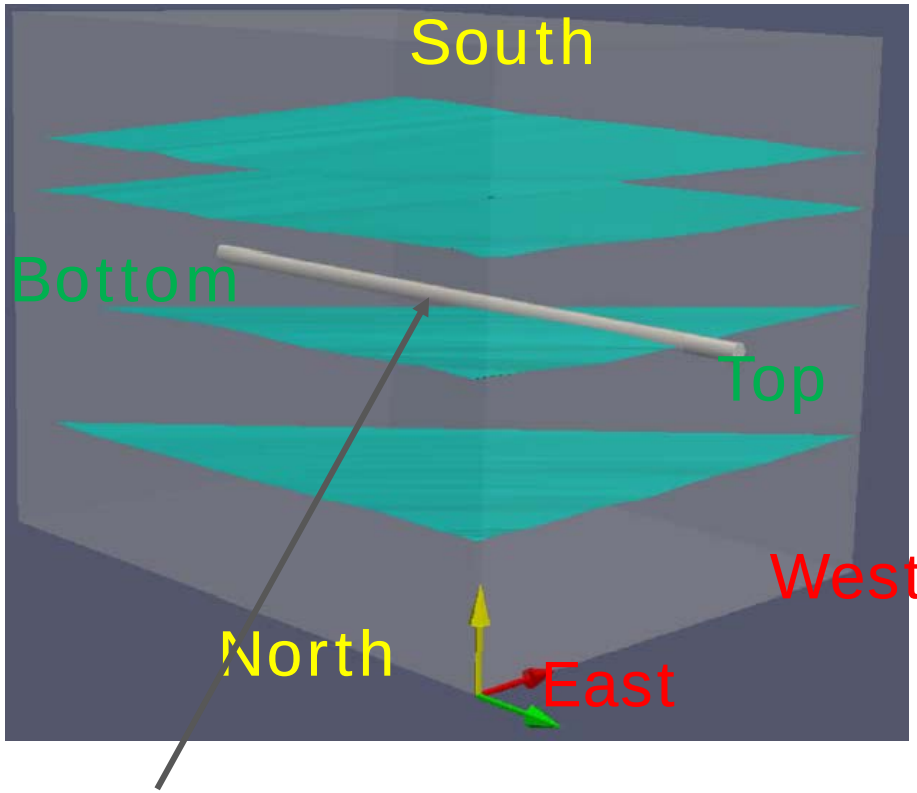
Experiment: Large block test



Fabrics & natural fractures

Niobrara-Mancos shale
28’’X28’’X36’’(0.71X0.71X0.91m^3)

Experiment: Big block test



Horizontal well

NF 1 σ_V=6000psi (41.37MPa)

NF 2 σ_H=4500psi (31.03Mpa)

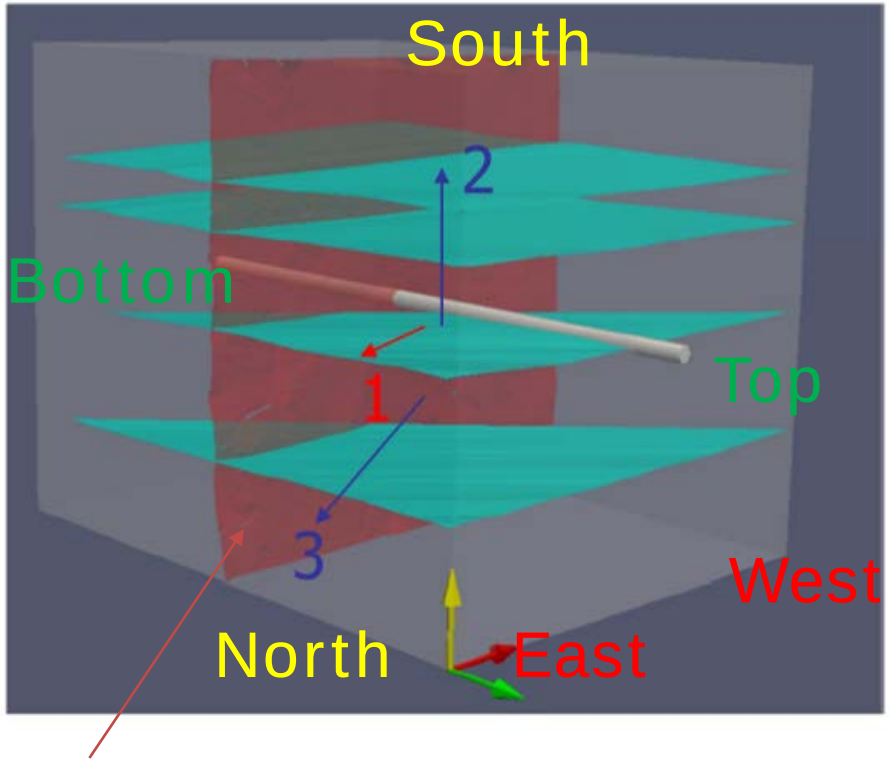
NF 3 σ_h=4000psi (27.58MPa)

NF 4

30mL/min of Glycerin (800cp)

σ_h perpendicular to bedding planes, natural fractures, horizontal well

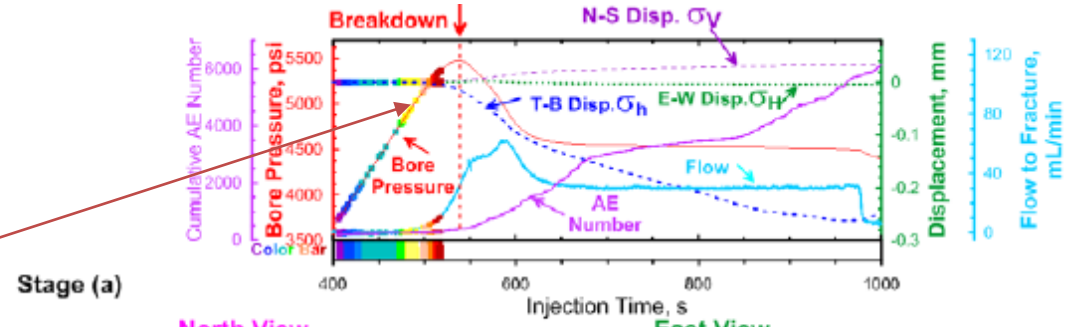
Fracture propagation



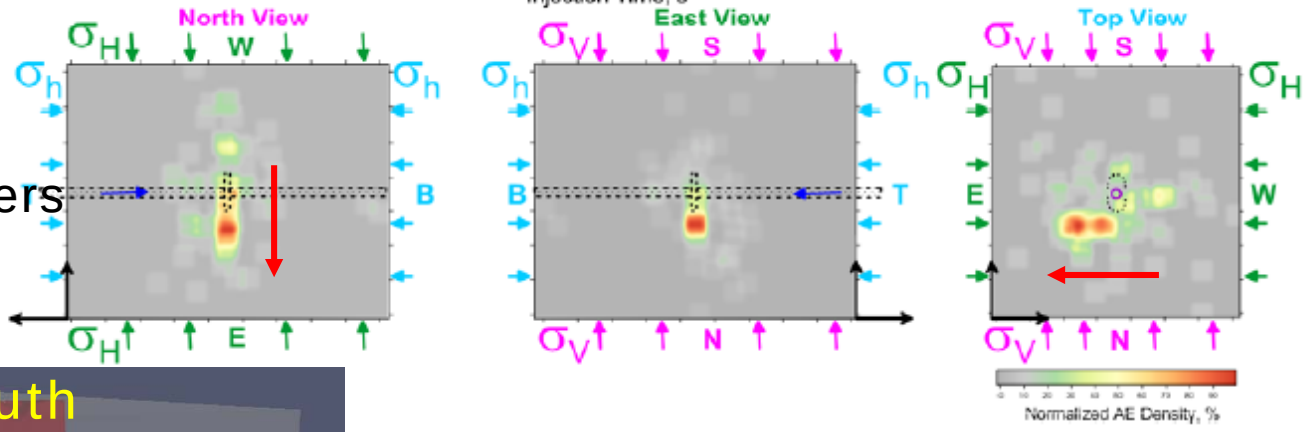
Hydraulic fracture formation perpendicular to HW

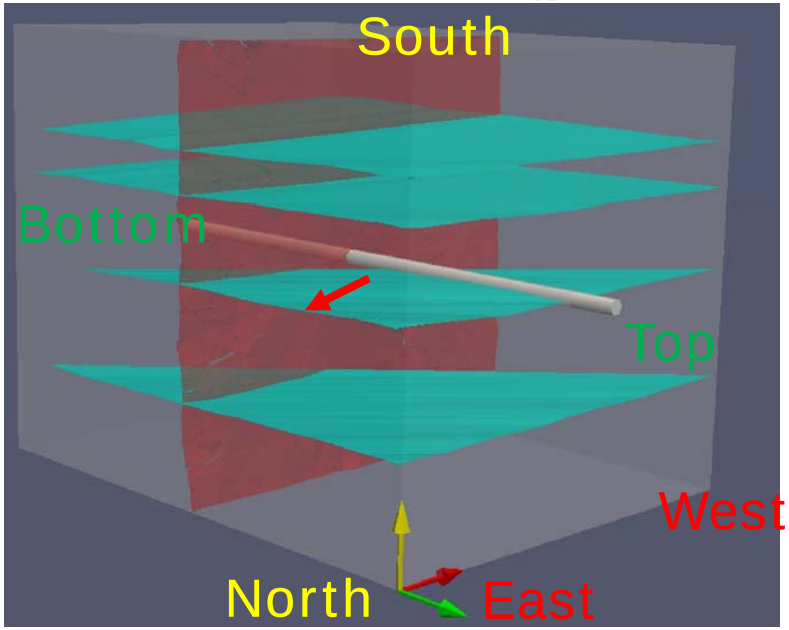
Stage (a)

Pressure



Density of Acoustic Emission hypocenters



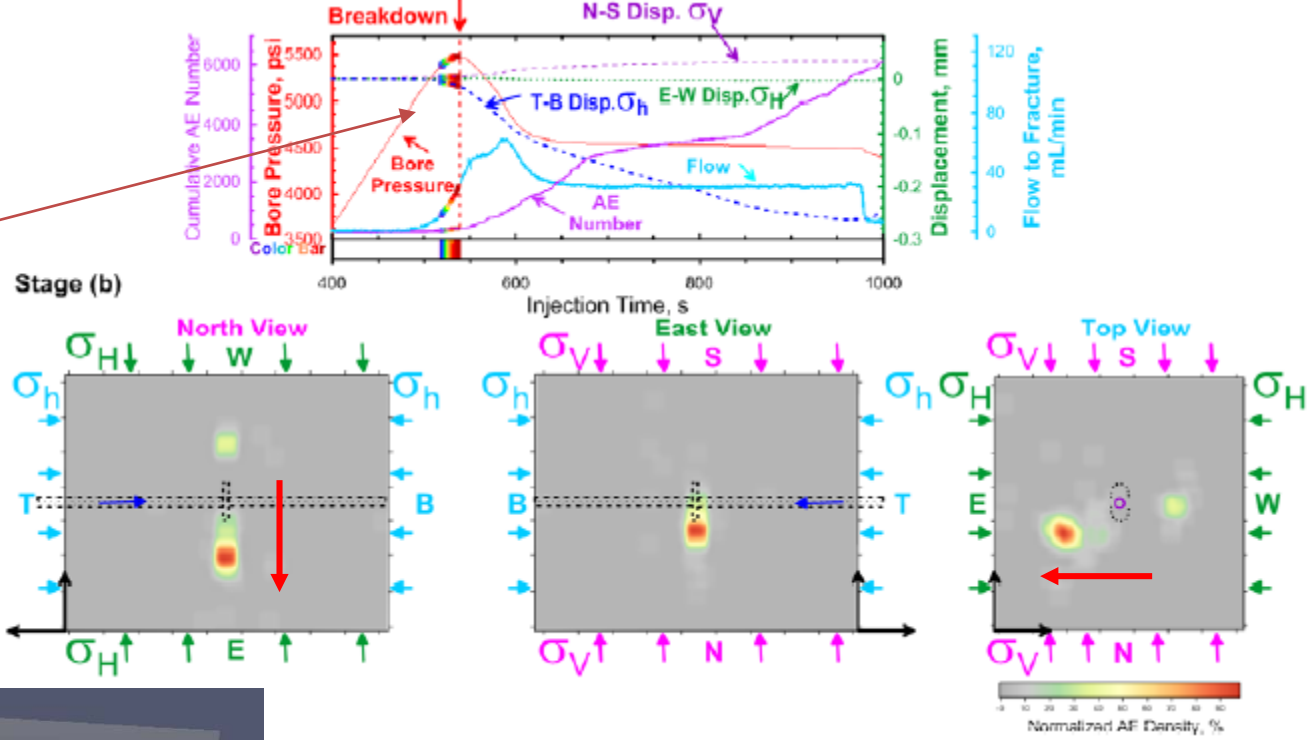


Fracture propagates to East, possibly interacting with NF3.

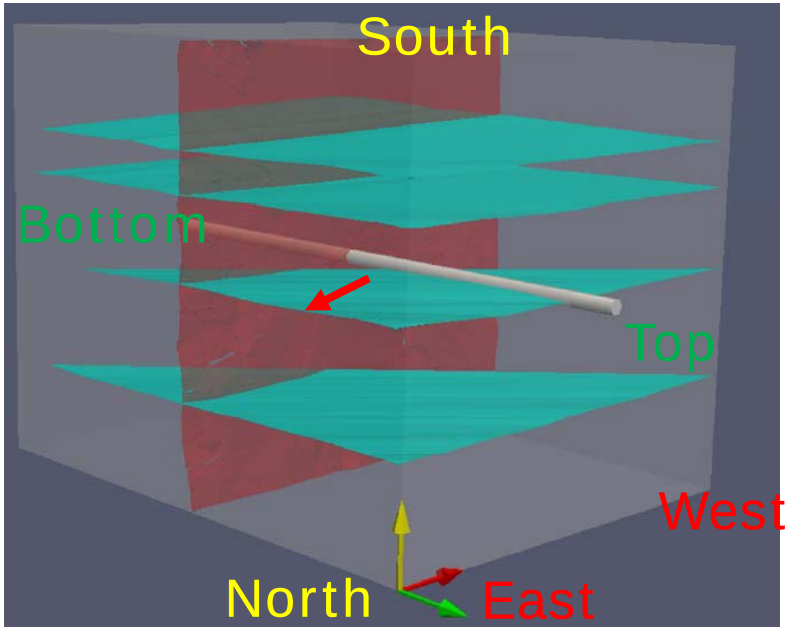
Pressure still builds up

Stage (b)

Pressure



Density of Acoustic Emission hypocenters

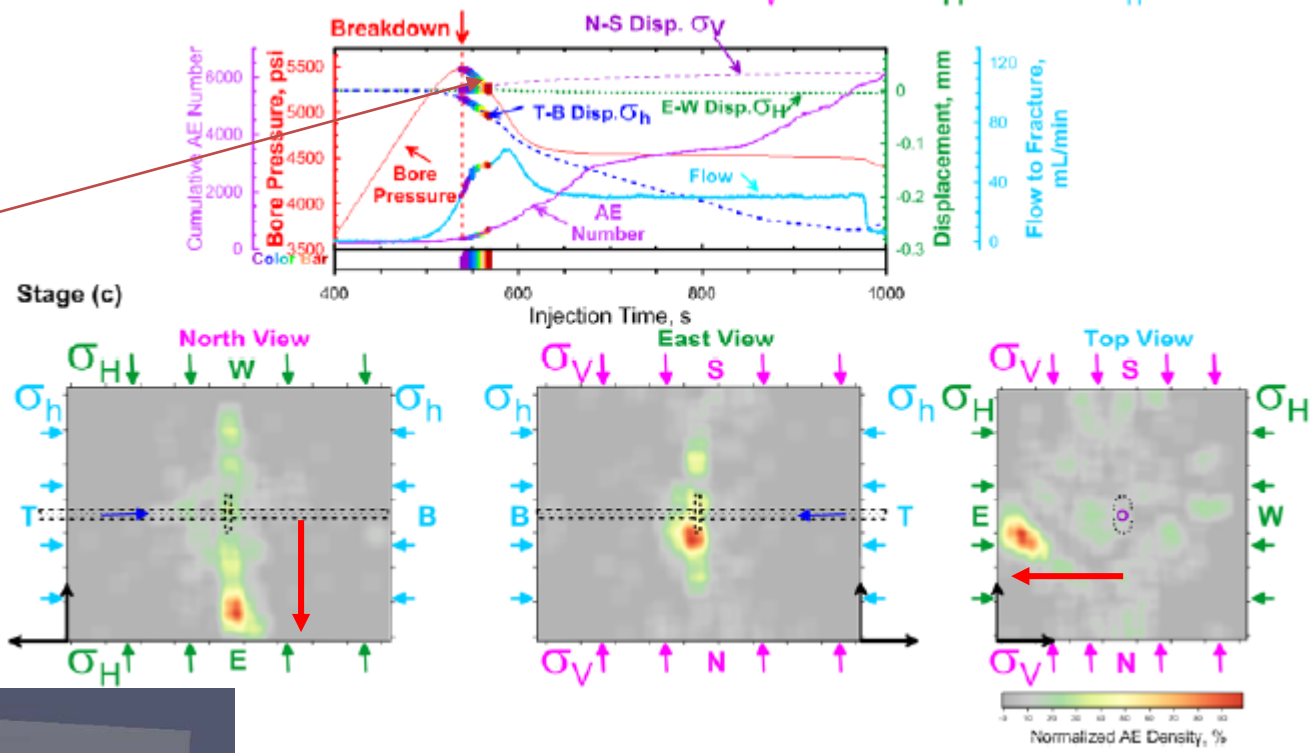


Fracture still propagates to East

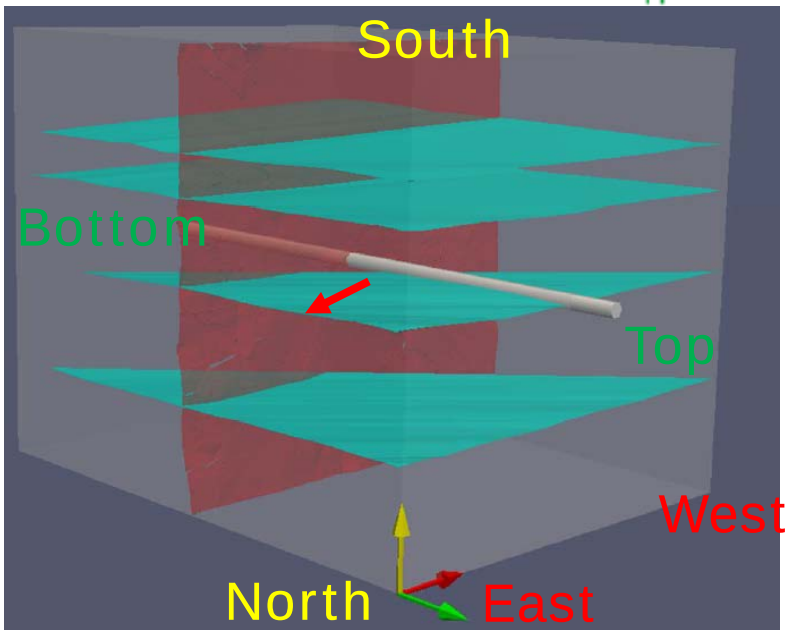
Not too fast before breakdown

Stage (c)

Pressure



Density of Acoustic Emission hypocenters

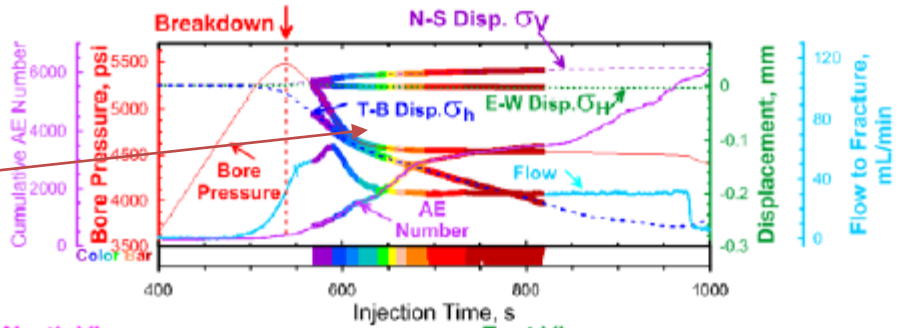


After breakdown, Fracture still propagates to East fast

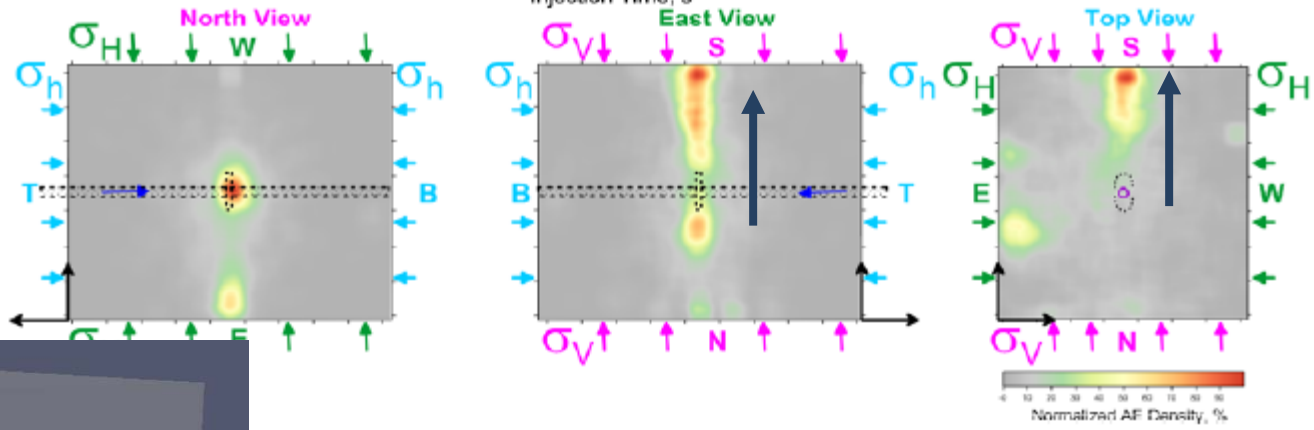
Pressure decreases because fracture volume increases fast

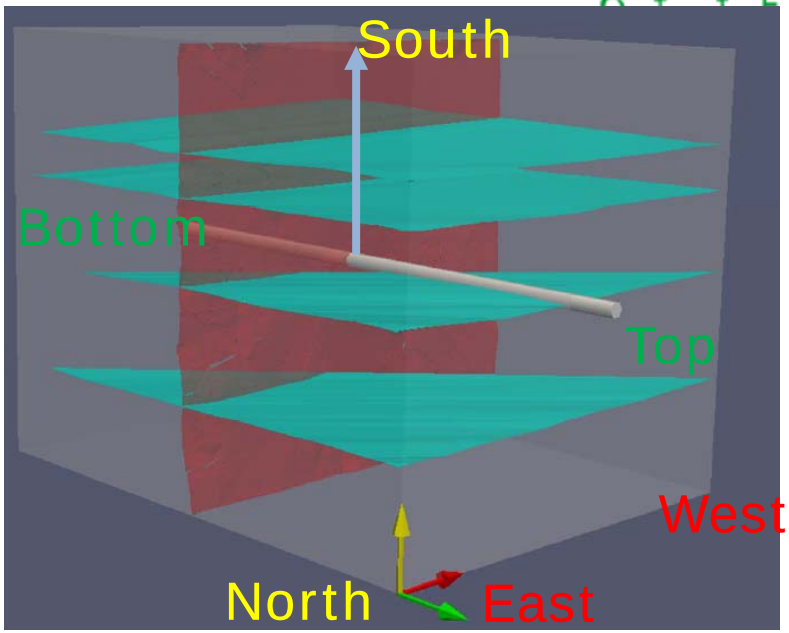
Stage (d)

Pressure



Density of Acoustic Emission hypocenters





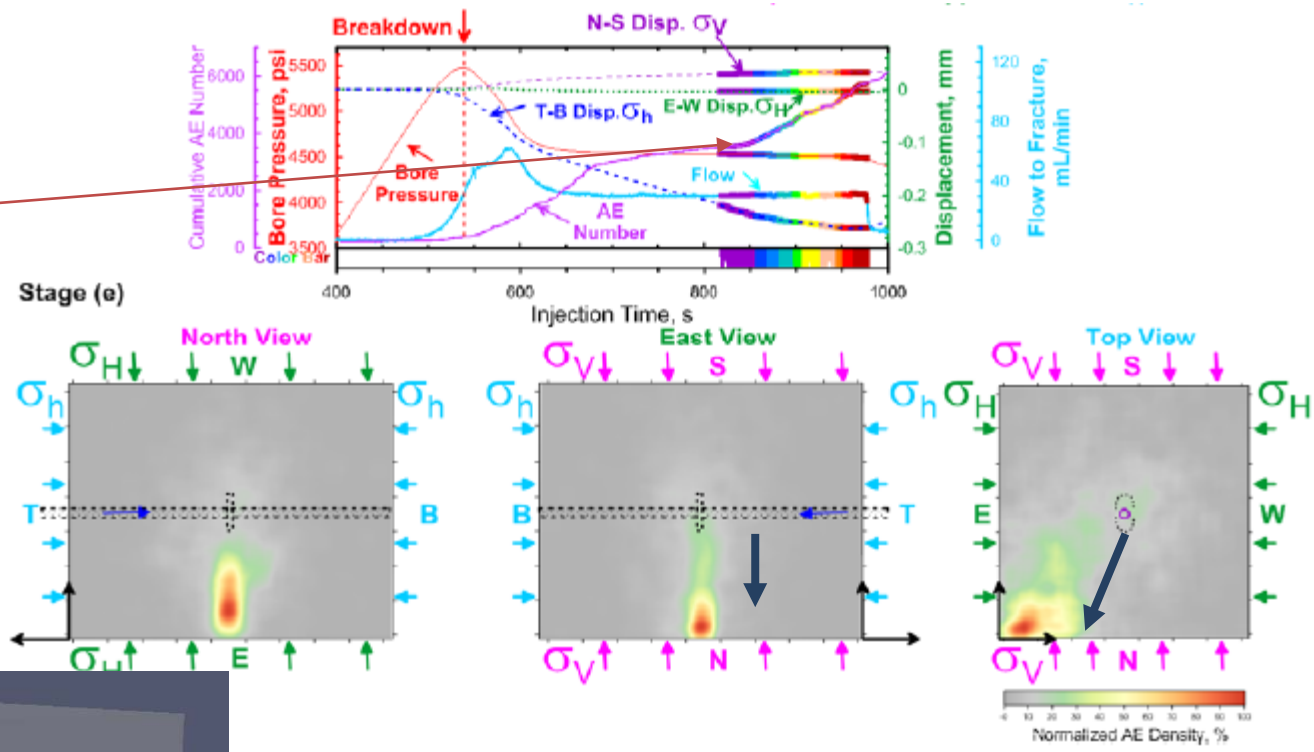
Fracture propagates to South

Pressure becomes constant

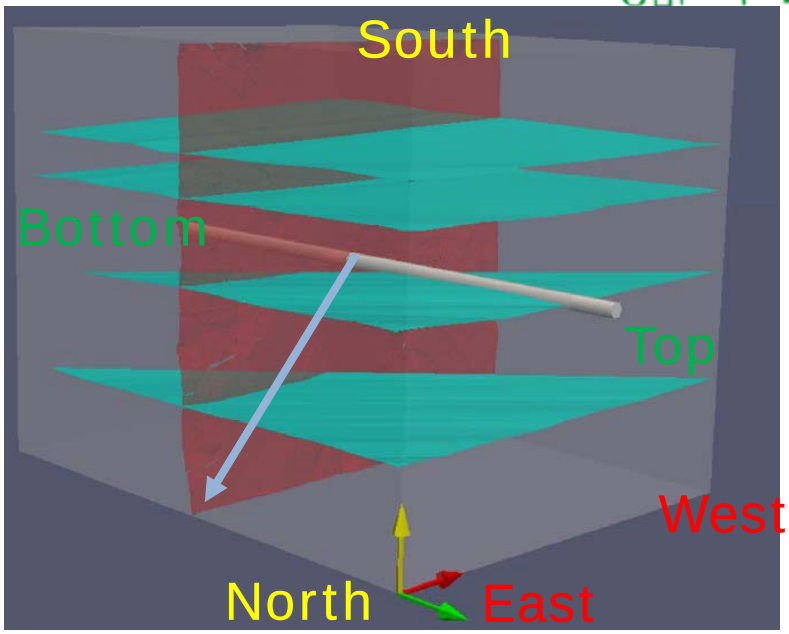
Fracture does not seem to interact with other NF's

Stage (e)

Pressure



Density of Acoustic Emission hypocenters



Fracture propagates to North/East

Pressure is still constant

Ongoing 3 mid-size block tests

Niobrara-Mancos shale
11''X11''X15''(0.28X0.28X0.38m^3)

1000cp Glycerin

Maximum stress limit:
3500psi (24.13Mpa)

σ_V =3500psi
σ_H =1500psi
σ_h =1000psi

Ongoing mid-size block tests

Test	Fluid type	Injection rate	Purpose
MB1	1000cp Glycerin	30mL/min	Size effect between LB &MB Stress heterogeneity
MB2	Lower viscosity	15mL/min	Effects of viscosity & injection rate
MB3	1000cp Glycerin	30mL/min	Introduce natural fractures

Will be done by August

Accomplishments to Date

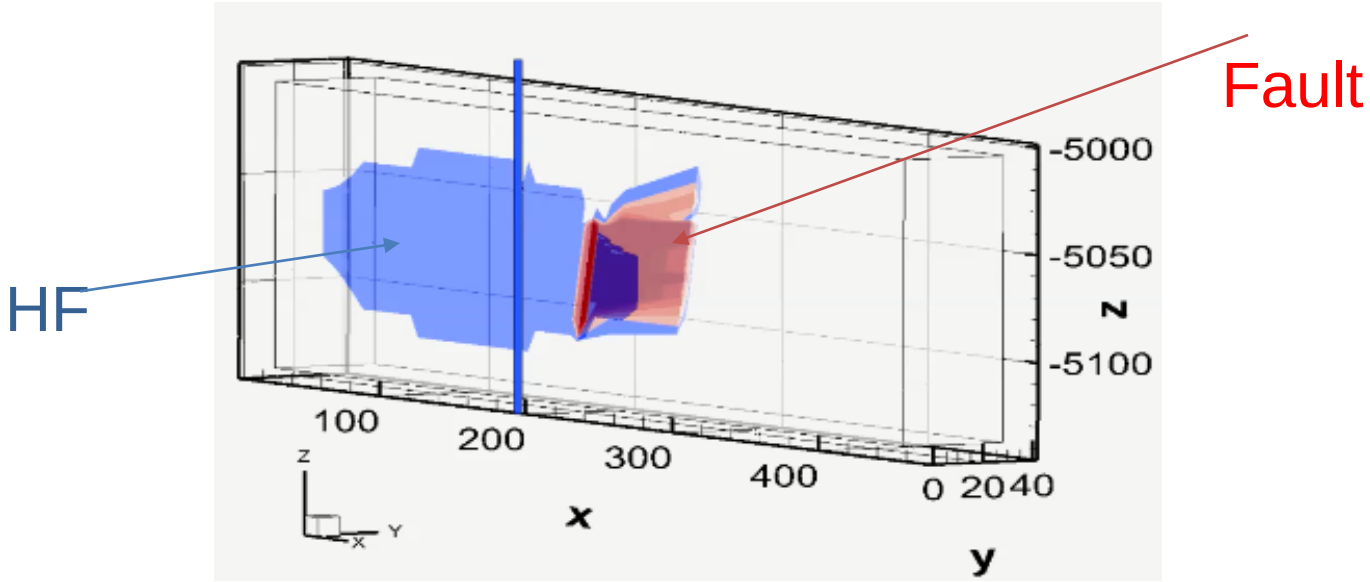
- Lab tests
  - ✓ Large block test completed
  - ✓ Mid-size block test to be completed by August
  - ✓ Small block test done 95%
- Numerical simulation
  - 3D Planar fracture propagation completed
  - Non-planar fracture propagation completed 95%

All tasks will be accomplished by the end of September

Synergy Opportunities

This developed simulator can be used for CO2 storage, gas hydrate deposits, geothermal reservoirs, Shale gas

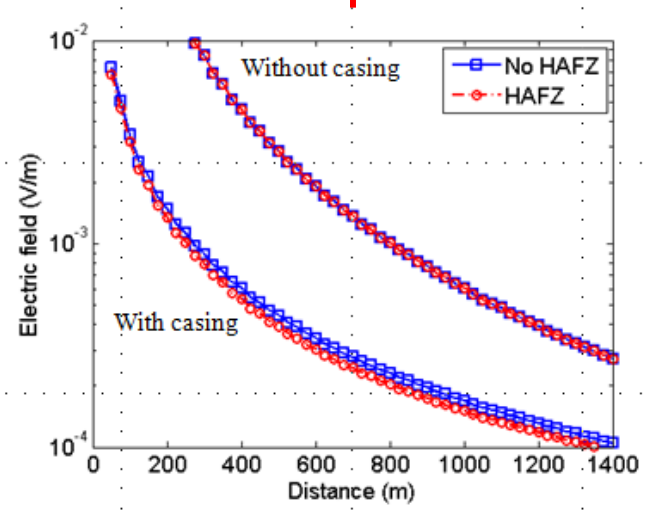
- Fault activation/interaction with natural fractures



Synergy Opportunities

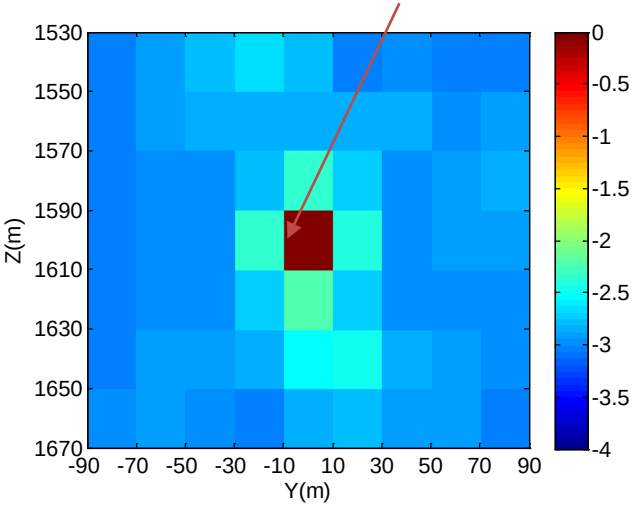
- Joint analysis/inversion of **flow / geomechanics / geophysics**, e.g.,

EM responses



Constrained Geomech/EM optimization

Imaged HF



- Well stability
  - ➢ Subsidence, Wellbore failure

Summary

- Developed a coupled flow-geomechanics simulator of hydraulic fracturing
- HF propagated, perpendicular to HW
- Identified the role of pre-existing fractures
- Found importance of heterogeneity