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Induced Seismicity
Monitoring for Environmental Safety, Geohazards and Risk Evaluation in Unconventional Shale Reservoirs

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Outline

- Induced Seismicity Monitoring Effort
- Case Studies of Injection Induced Seismicity
- Coupled geomechanics and fluid flow modeling for stress alteration during hydraulic fracturing near vicinity of a fault
- Conclusions

Shale Reservoir Field Development and Production Challenges

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- Surface and ground water contamination and air pollution and geohazard risk evaluation are among the key environmental challenges attracts significant research for sustainable global development of shale reservoirs
- Microseismic data along with coupled geomechanics and fluid flow models and coupled experiments can provide significant understanding on the stress alterations and associated changes and identifying any induced seismicity potential

Geohazard Risk Evaluation

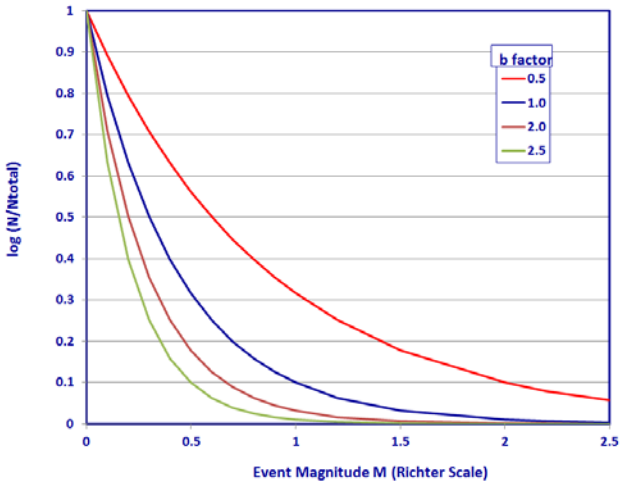
Gutenberg- Richter Law

- **Expresses the relationship between the magnitude and total number of earthquakes in any given region and time period of at least that magnitude**

$$\text{Log}\left(\frac{N}{N_{total}}\right) = a - b * M$$

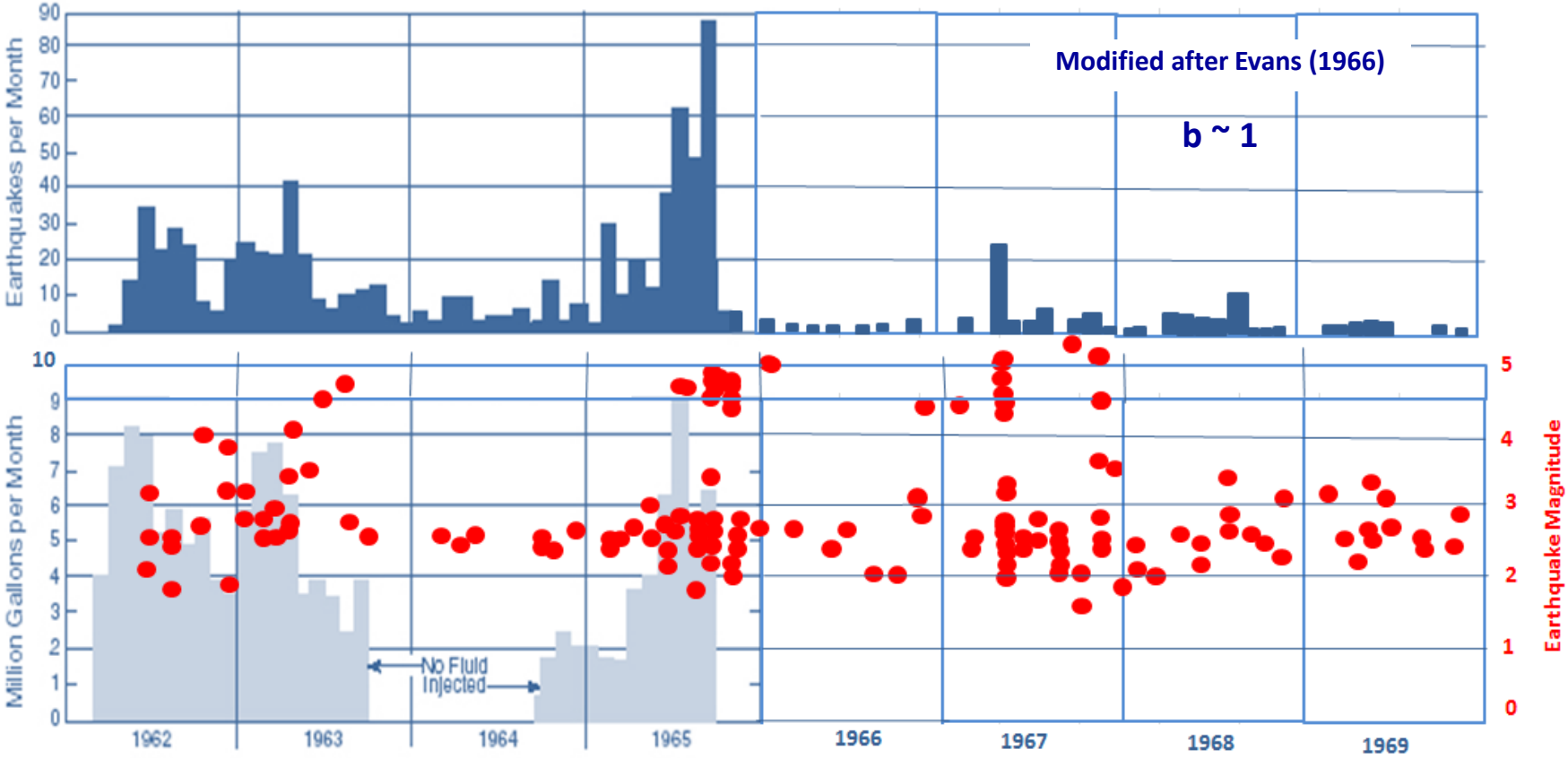
M is the event magnitude
b ~ 1.0 in seismically active regions
A indicates the total seismicity rate of the region.

- **For every magnitude 4.0 event there will be 10 magnitude 3.0 quakes and 100 magnitude 2.0 quakes. There is some variation with b-values in the range 0.5 to 1.5 depending on the tectonic environment of the region.**
- **During earthquake swarms, b-value can become as high as 2.5**



Injection and Production Induced Seismicity

Rocky Mountain Arsenal, Colorado



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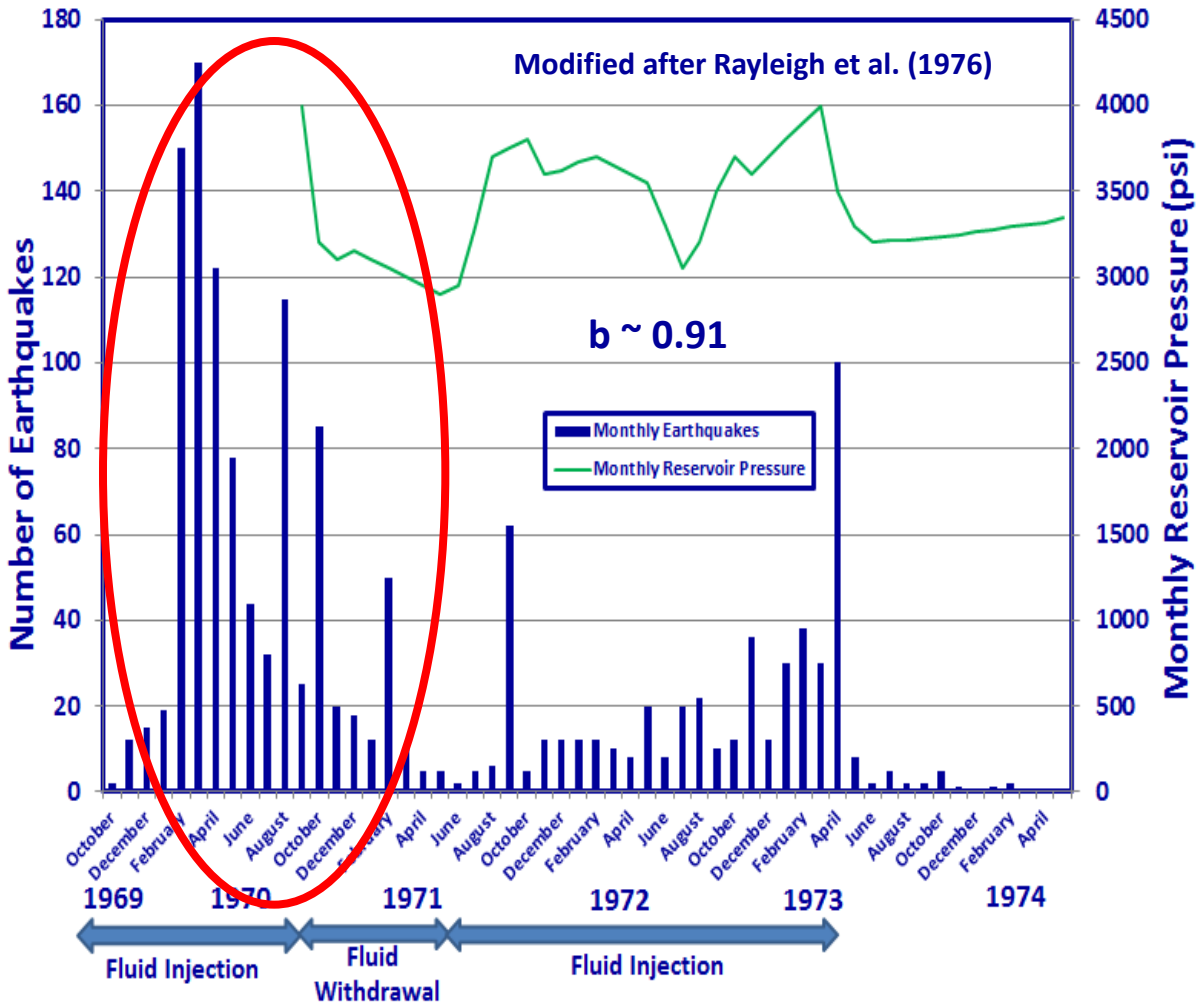
Injection and Production Induced Seismicity

Rangely Field Experiments, Colorado



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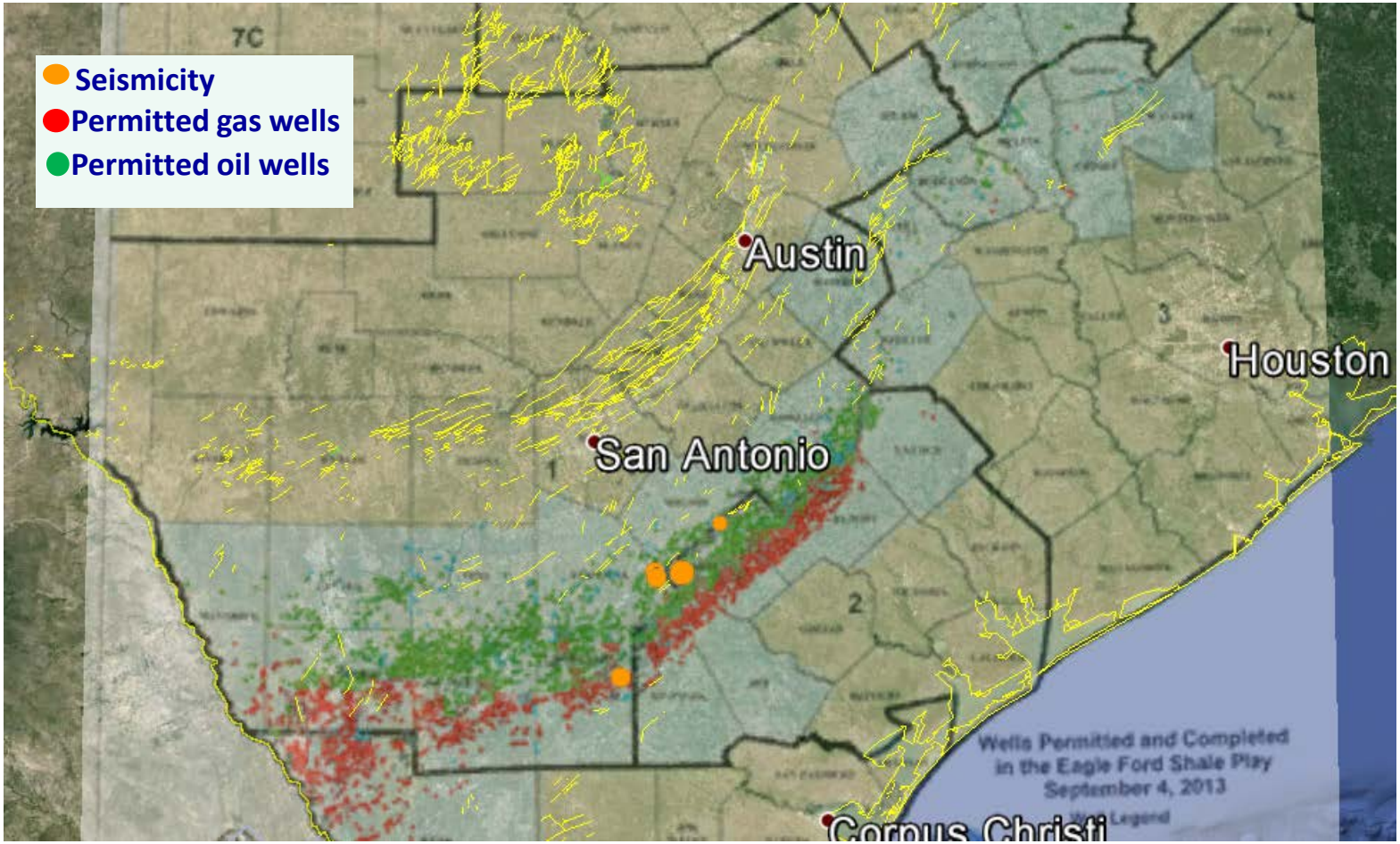
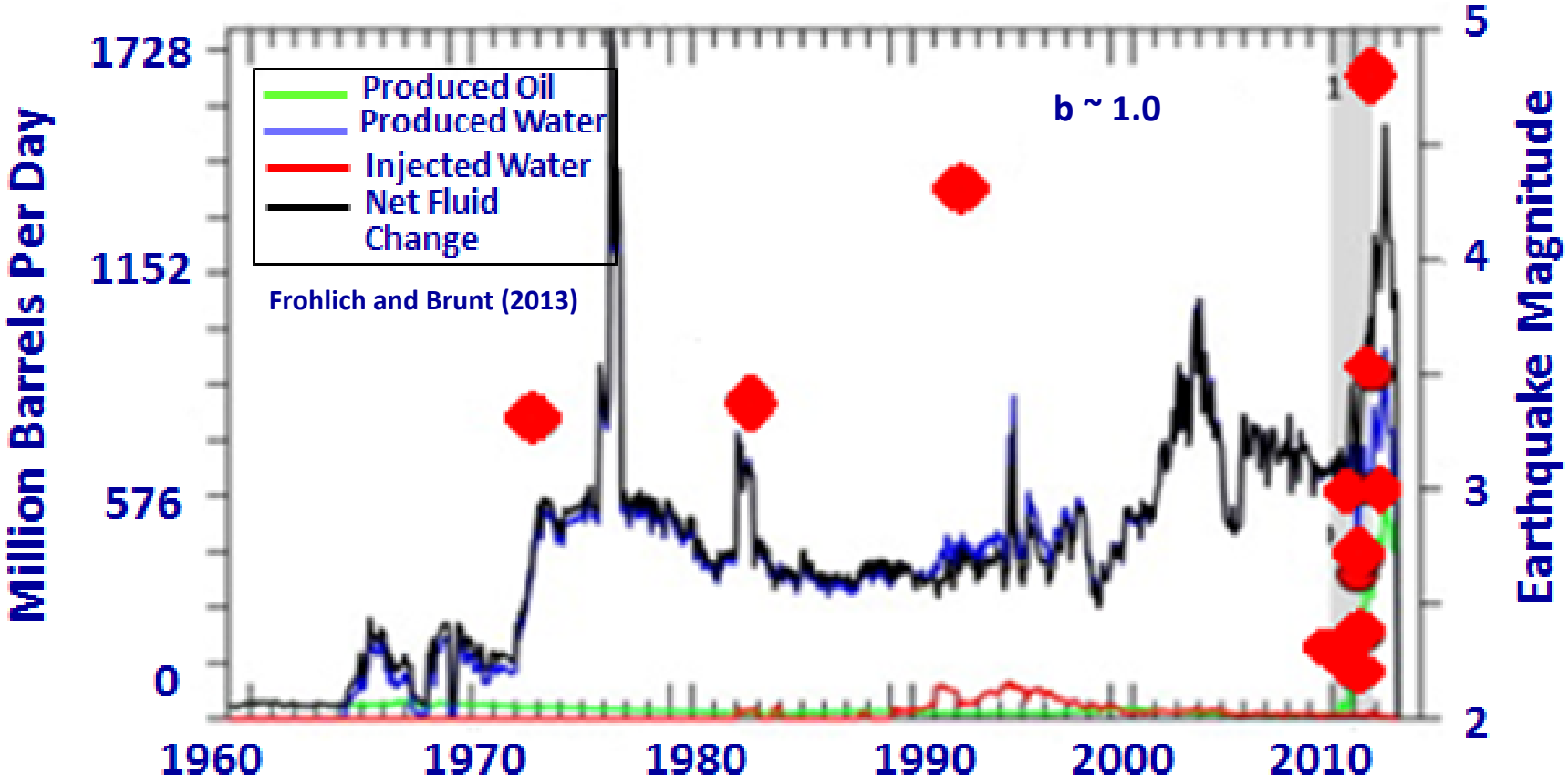
Induced Seismicity?



Modified after USGS, TRRC (2013)

Induced Seismicity?



Observed Mechanisms in Microseismic Data

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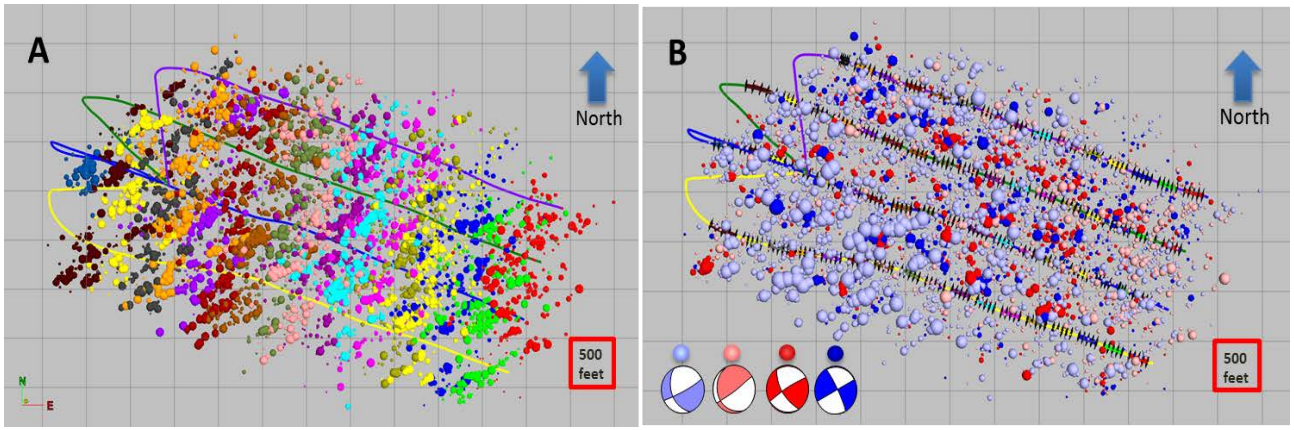
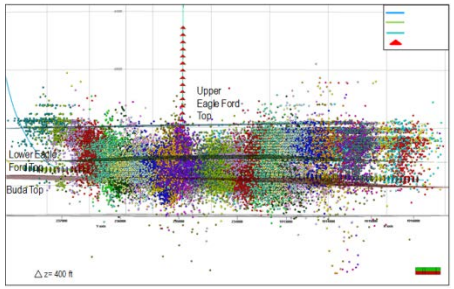
- There are four mechanisms occur in microseismic data
- Dip-slip failure occurs near the beginning of the treatment stage
- Strike-slip occurs near the end of the treatment stage
- The *b* value analysis not show distinct values for the different mechanism types

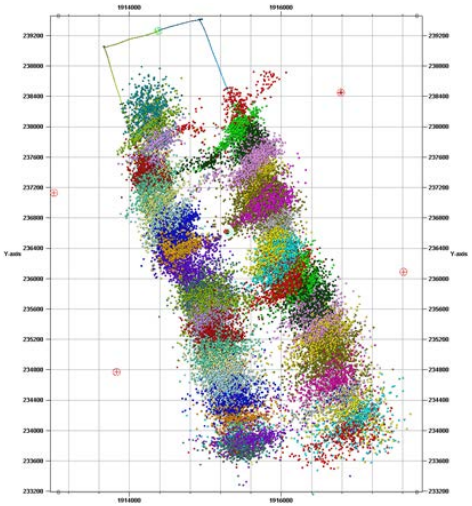


Marcellus Shale, West Virginia

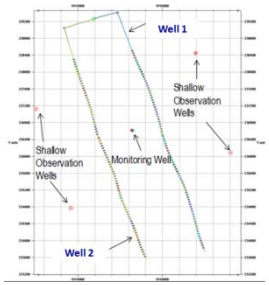
Microseismic Inc. (2013)

Eagle Ford Microseismicity
Oil Window

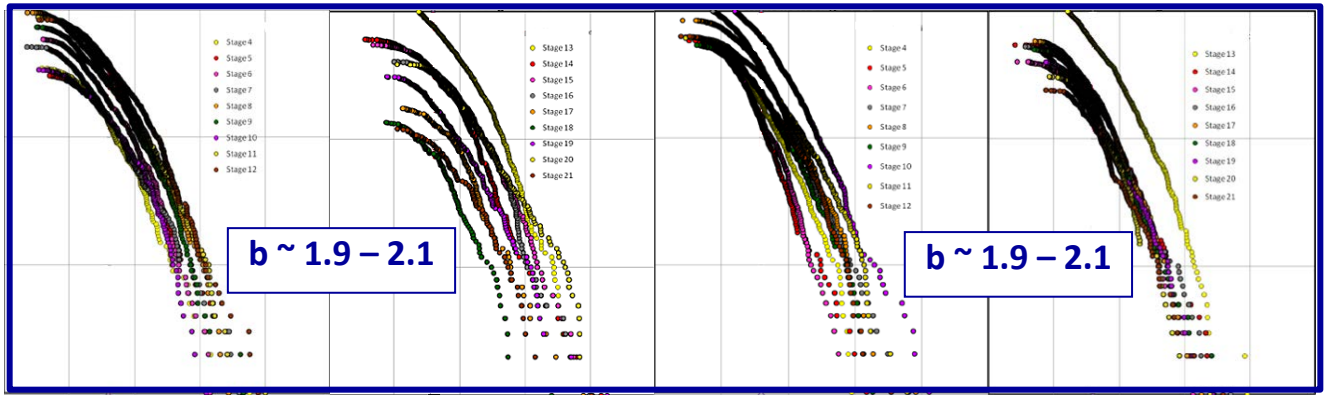




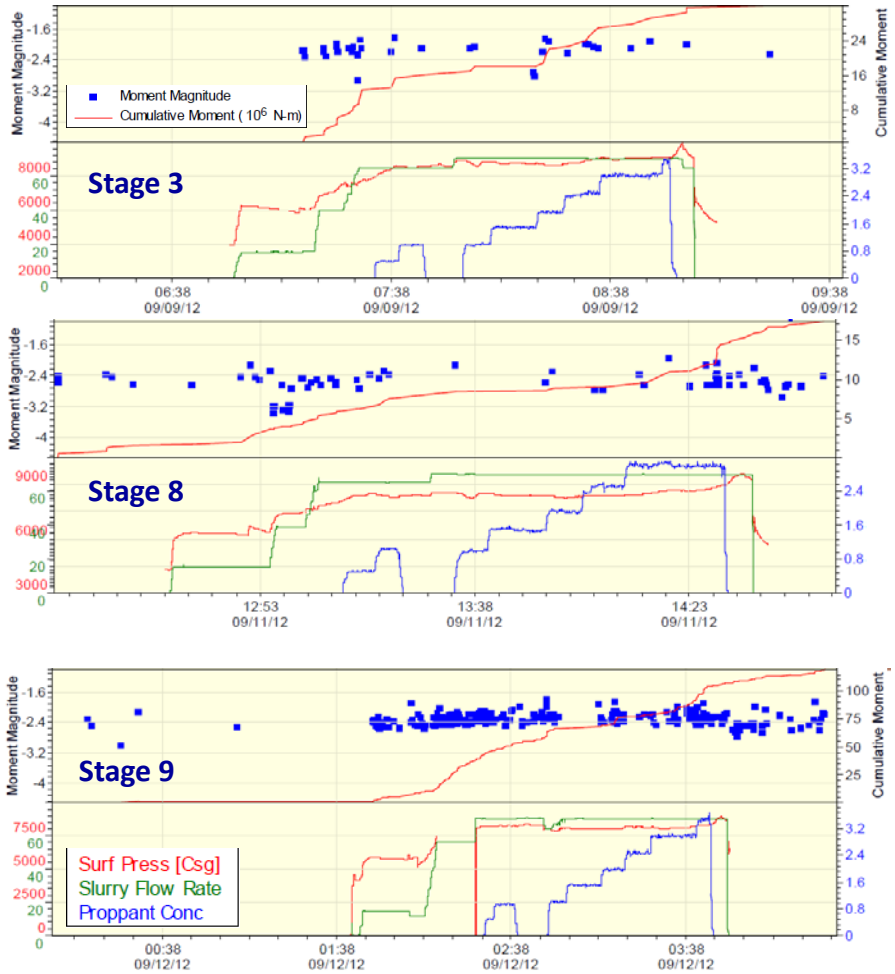
- An array of 51 geophones with 15 m between each sensor
- Crosslinked gel with 20/40 proppant

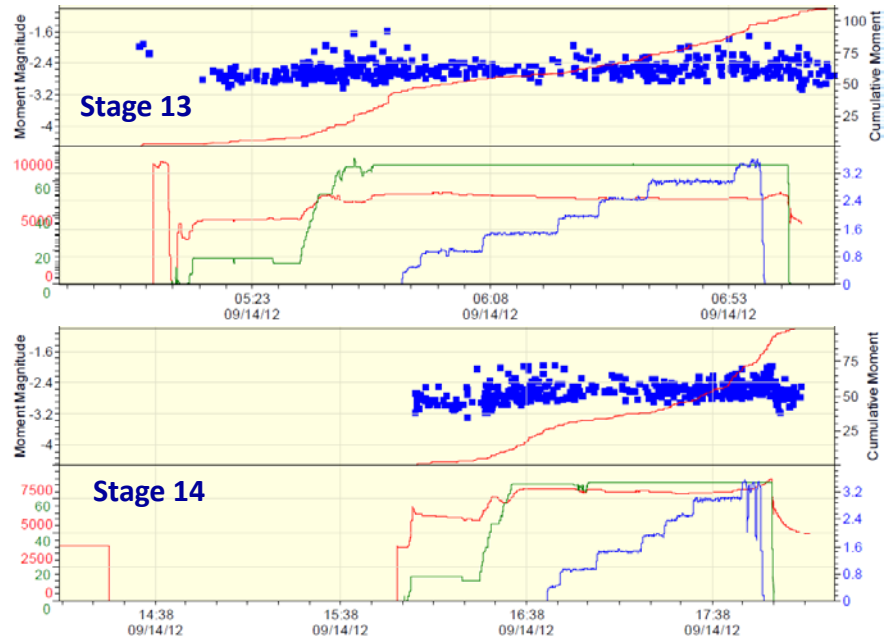


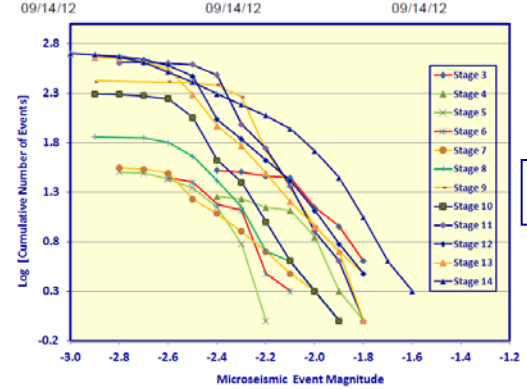
Horizontal Well #1 **Horizontal Well #2**



Eagle Ford Microseismicity
Gas Window







b ~ 2.0 – 2.8

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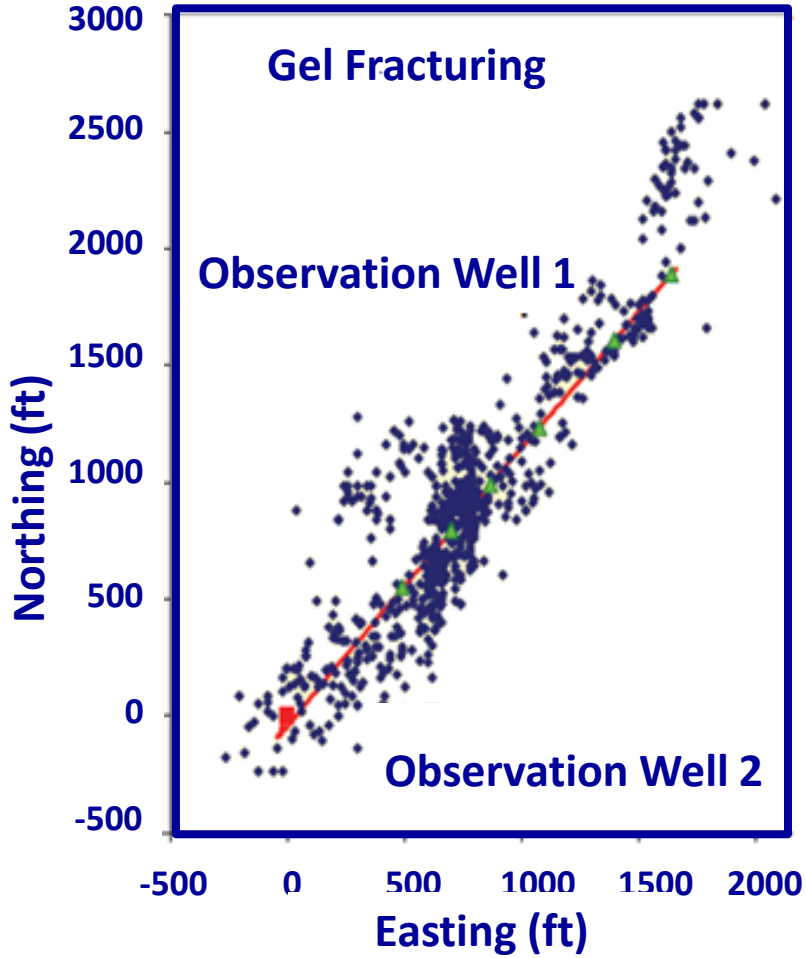
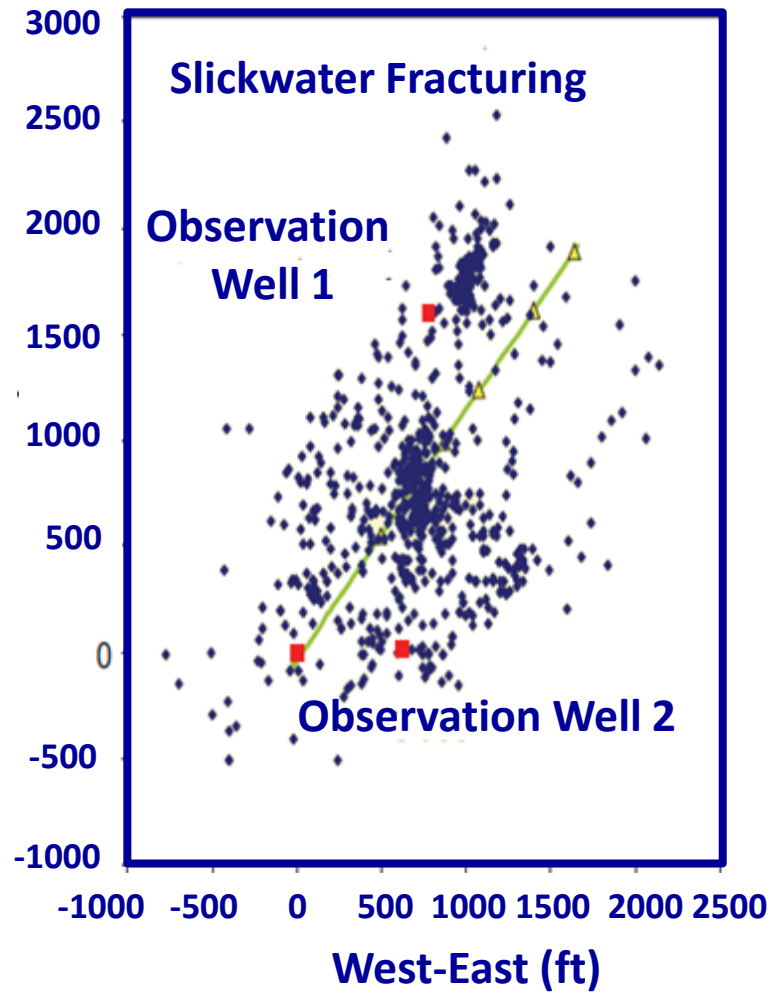
Stress Alteration and Injection Fluid Effect on Critically Stressed Fracture Induced Microseismicity





Warpinski et al. (2005)

3rd Generation Coupled-Geomechanics-Flow Characteristics Laboratories

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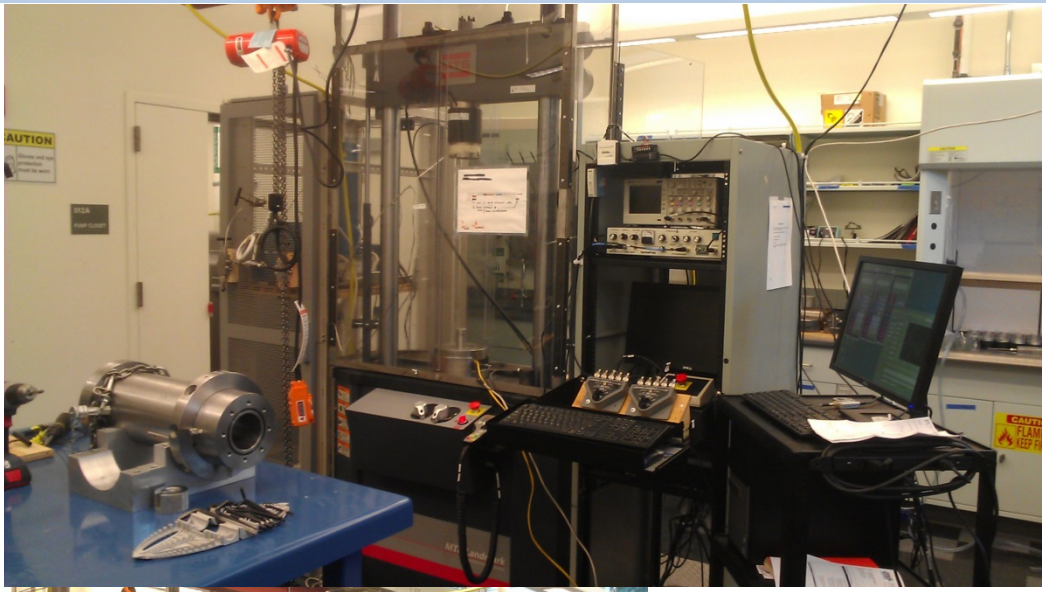

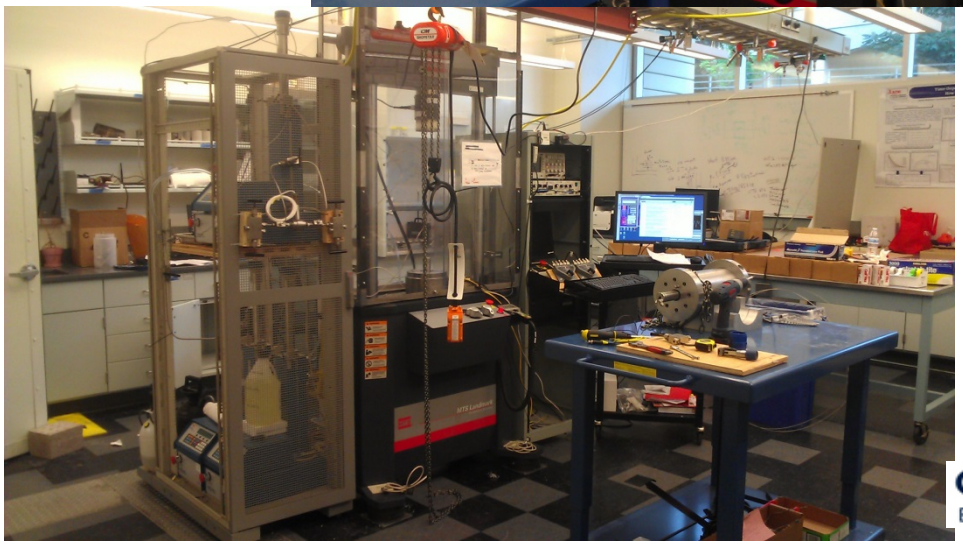

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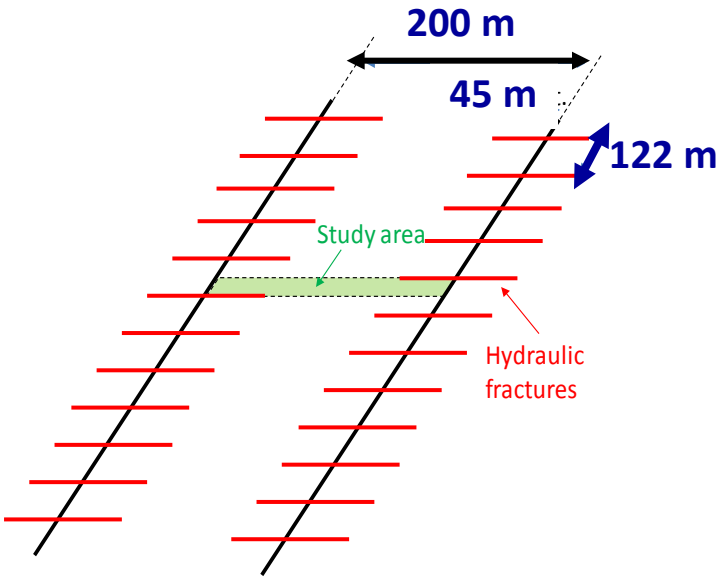
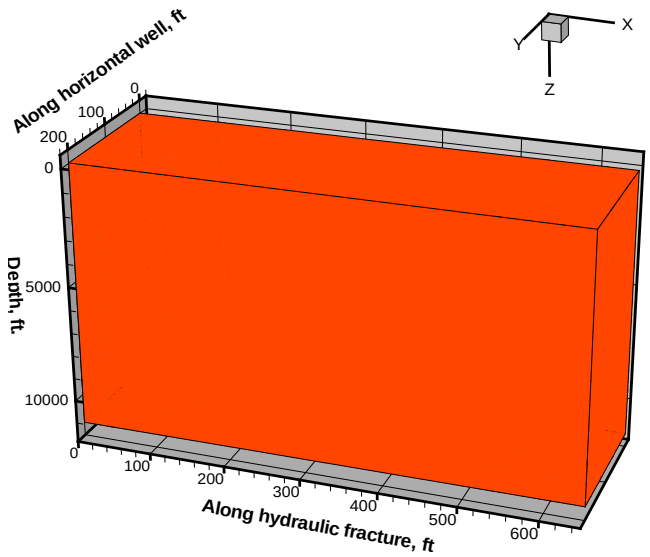
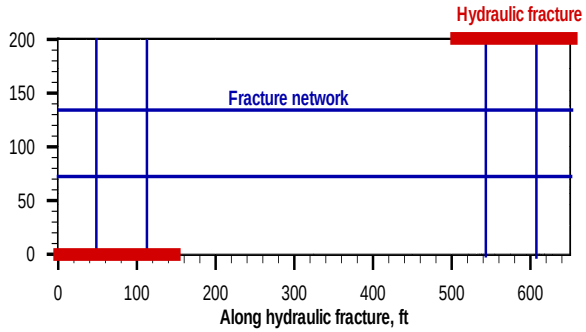
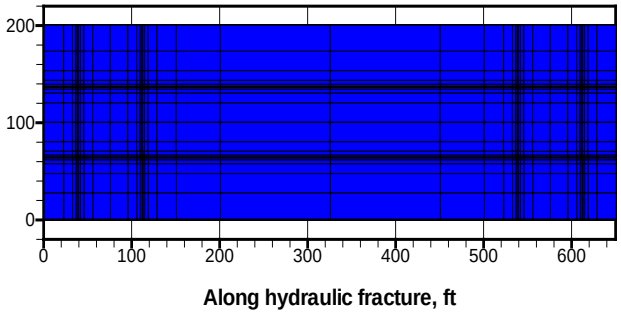
Stress and Velocity Alteration Caused by Hydraulic Fracturing

Tutuncu (2012)









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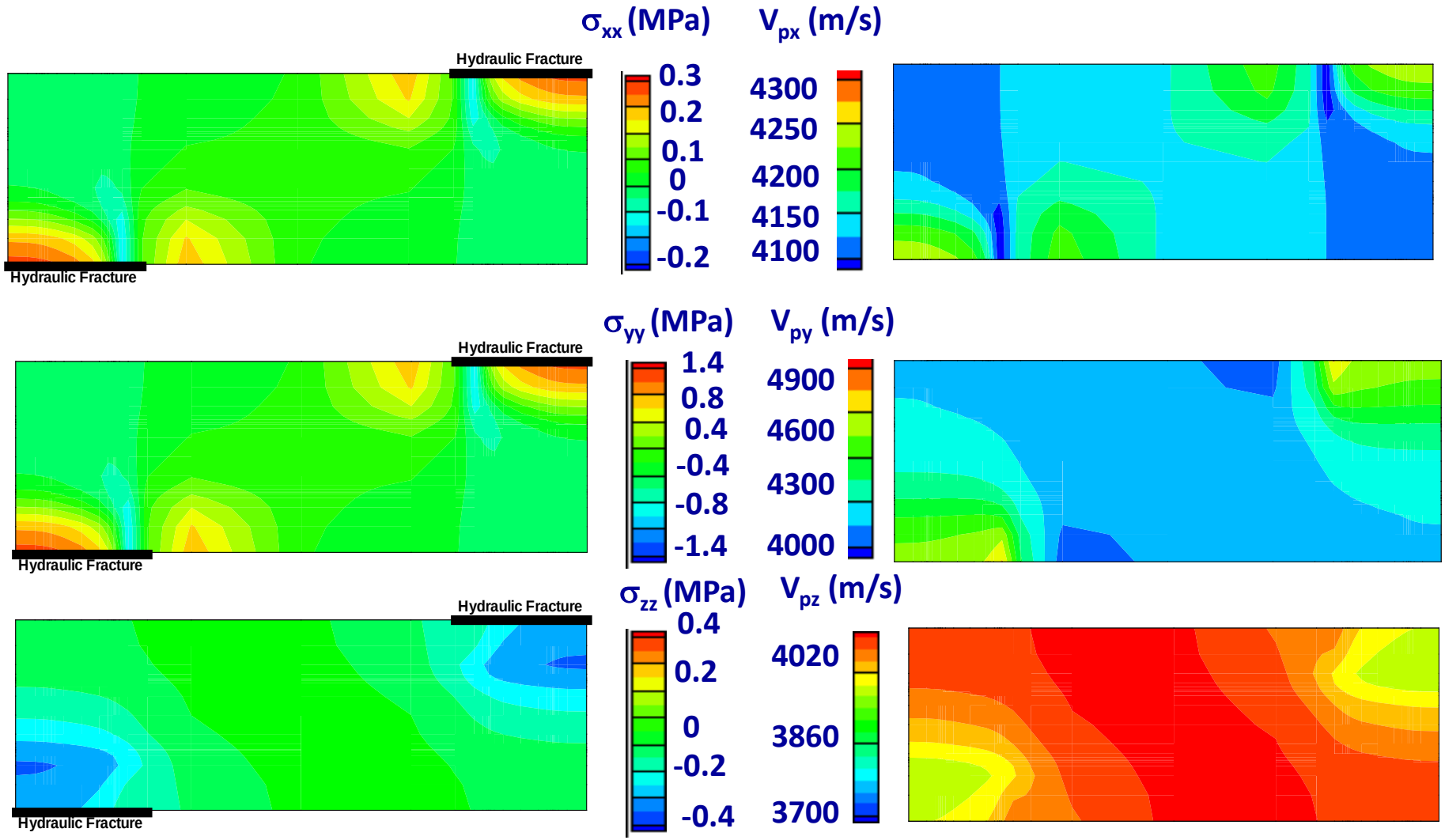
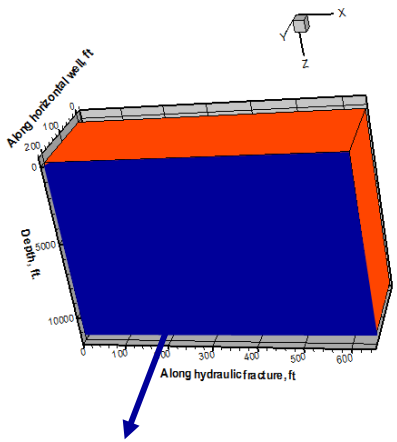
Stress and Velocity Alteration Caused by Hydraulic Fracturing Fluid Injection

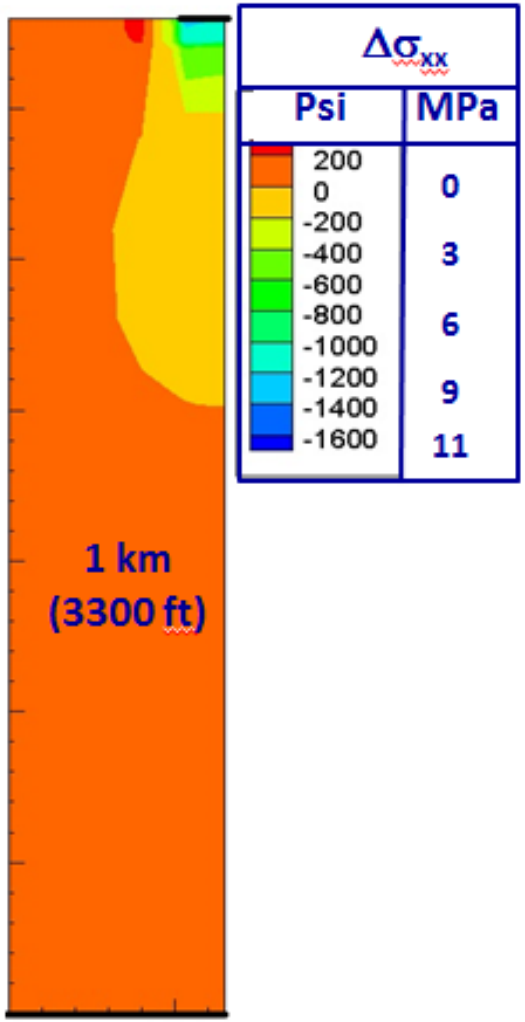
Tutuncu (2012)

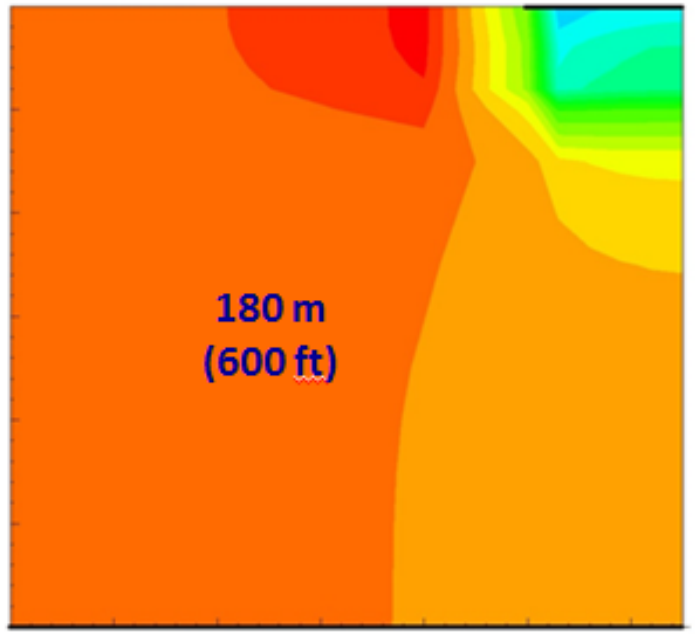


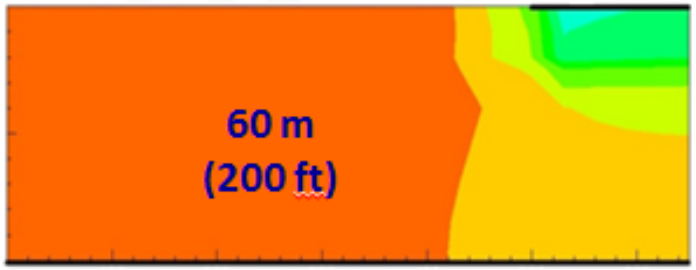
Stress Alteration as A Function of Fault Proximity to Injection Well

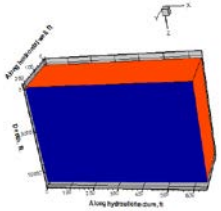
Tutuncu and Bui (2013)





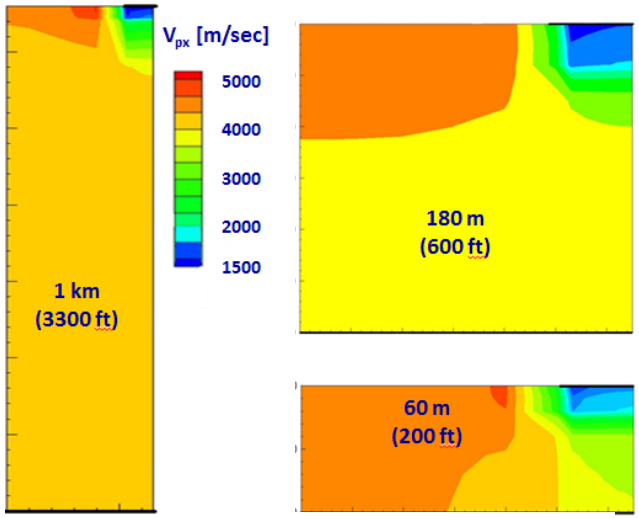


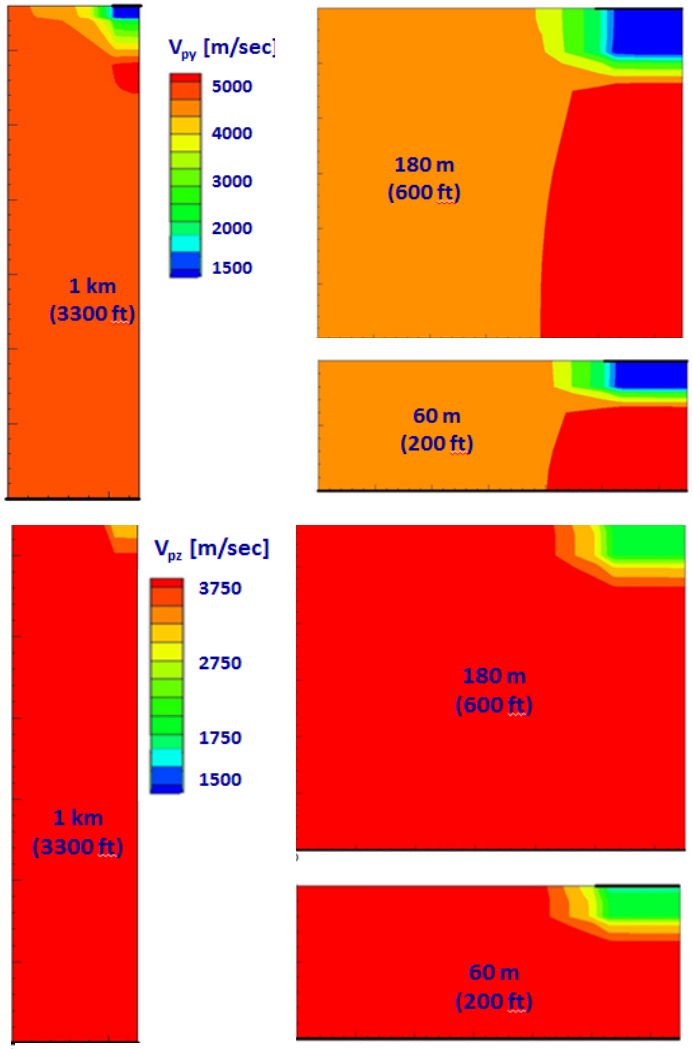




Velocity Alteration as A Function of Fault Proximity to Injection Well

Tutuncu and Bui (2013)





Conclusions

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- Injection and production induced stress alteration introduces variations in the formation geomechanical properties that may increase potential risk for induced seismicity in the area
- Further research is ongoing using coupled geomechanics, acoustic emission and fluid flow experiments and modeling with various fluids to capture these alterations and associated induced microseismic activity relation
- Operators, regulators and academia should work in full collaboration to verify the distinct differences between the waste disposal processes and hydraulic fracturing operations and a continuous monitoring methodology should be implemented for better evaluation of the time dependent geohazard risks.

Thank You

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