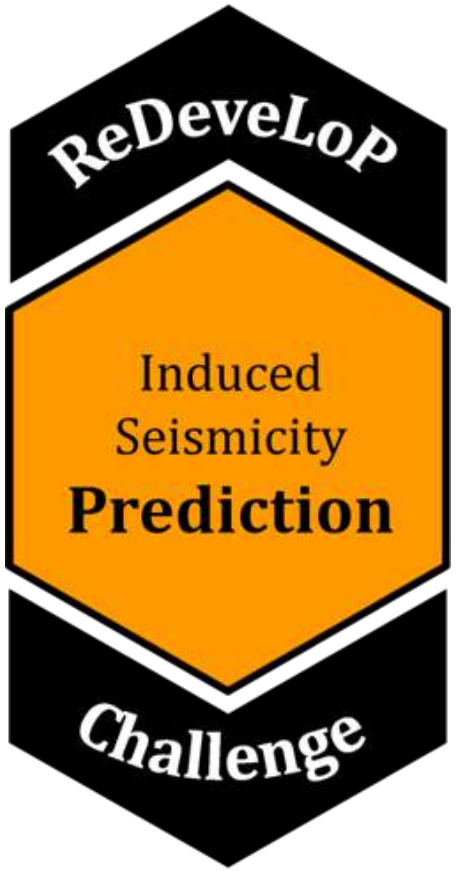
Induced Seismicity

Prediction and Mitigation



ReDeveLoP

Responsible **Deve**lopment of **L**ow-**P**ermeability Hydrocarbon Resources

Team 2 Challengers

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Induced Seismicity

- Earthquakes induced by humans = induced seismicity

- Various human activities can induce seismicity...

Mining

financialpost.com

Artificial Lake

ipsa-institut.com

Hydraulic Fracturing

wikihow.com

Research Questions

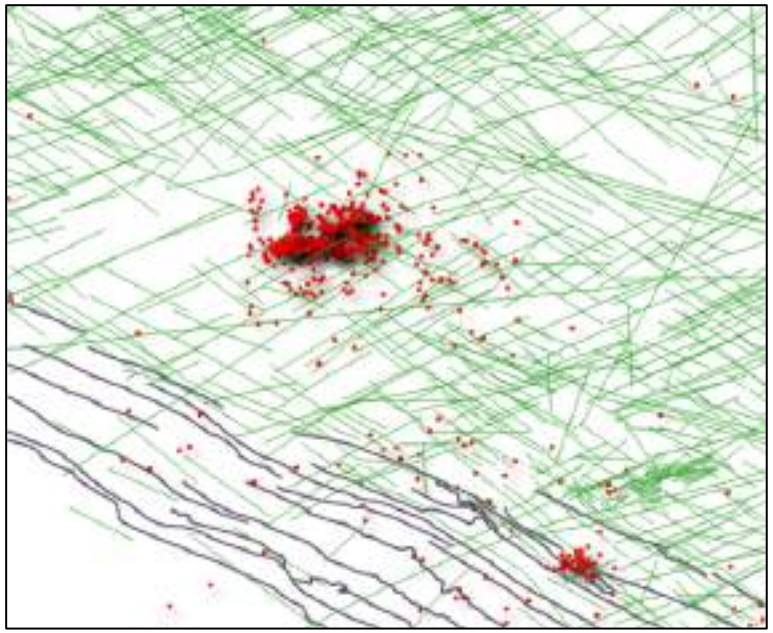
1. Is it possible to evaluate seismic hazard of a geological formation or region a priori?

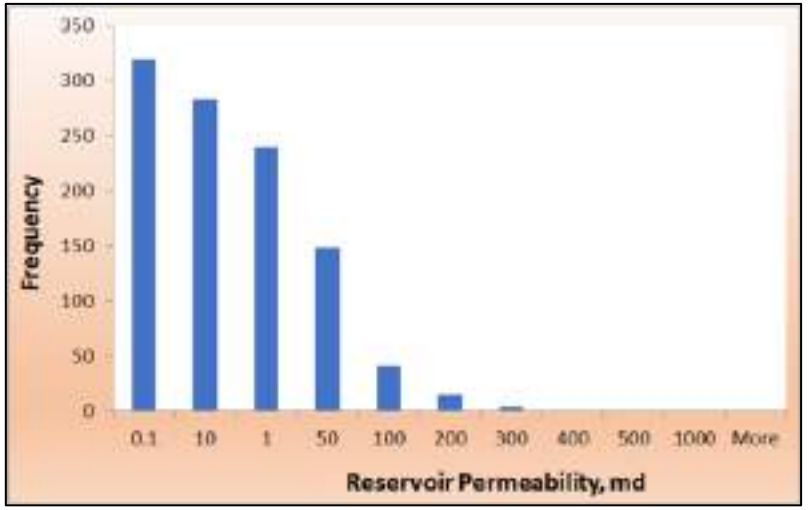
2. What mitigation techniques and strategies can reduce the severity of events of induced seismicity?

3. How can the answers to questions (1) and (2) help inform policy and regulatory decisions?

Induced Seismicity Requires 4 Primary Conditions

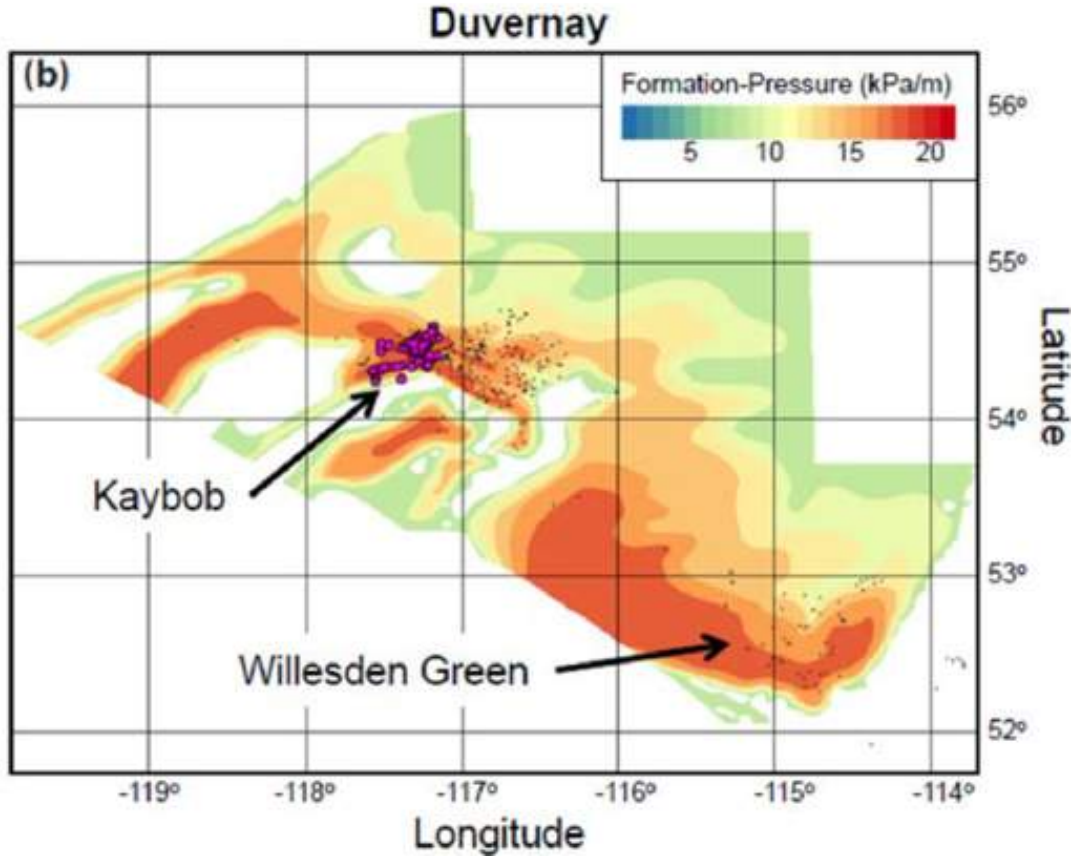
1. A pre-existing fault
2. A near critical stress environment
3. An injection source
4. A pathway for pressure diffusion and/or stress transfer





➢ *In this study, we determine the geological susceptibility to induced seismicity, in connection with these four parameters, through geomechanical modeling.*

Geomechanical and Hydraulic Controling Parameters



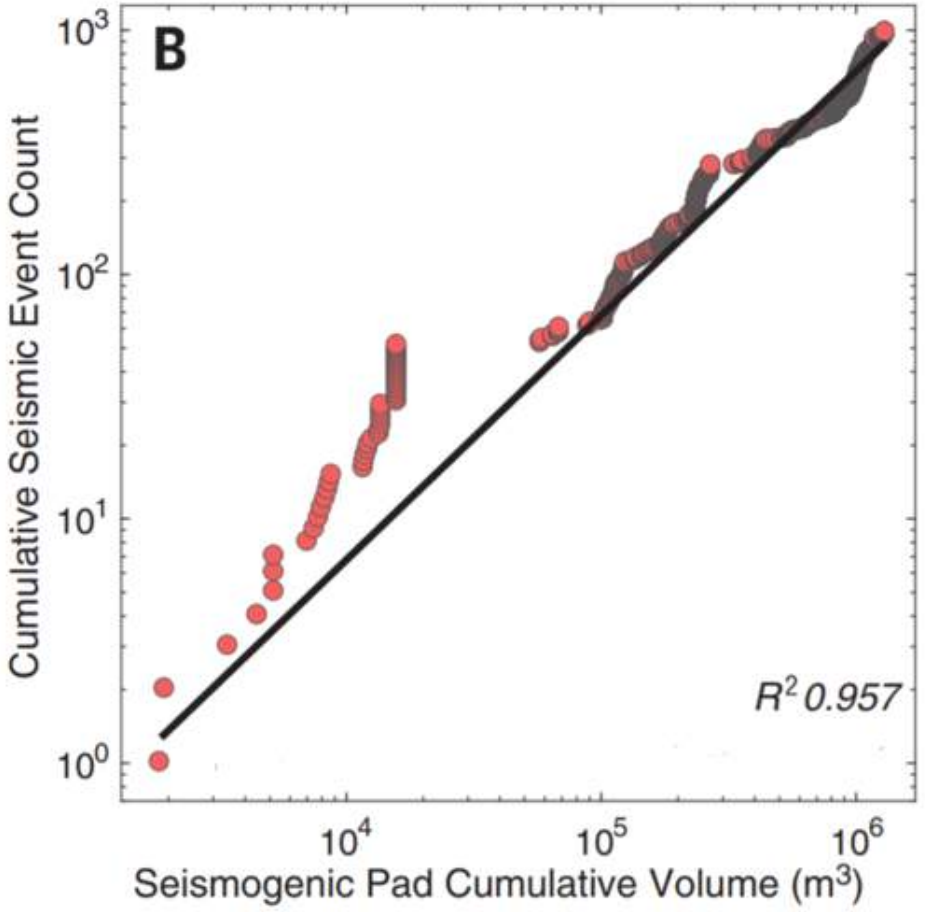
1. Proximity to crystalline basement
2. Formation overpressure
3. Minimum horizontal stress

Hydraulically fractured wells, induced earthquakes, and formation-pressure gradient - Eaton, 2017

Pawley et al., 2018 - Eaton, 2017

Geomechanical and Hydrological Controling Parameters

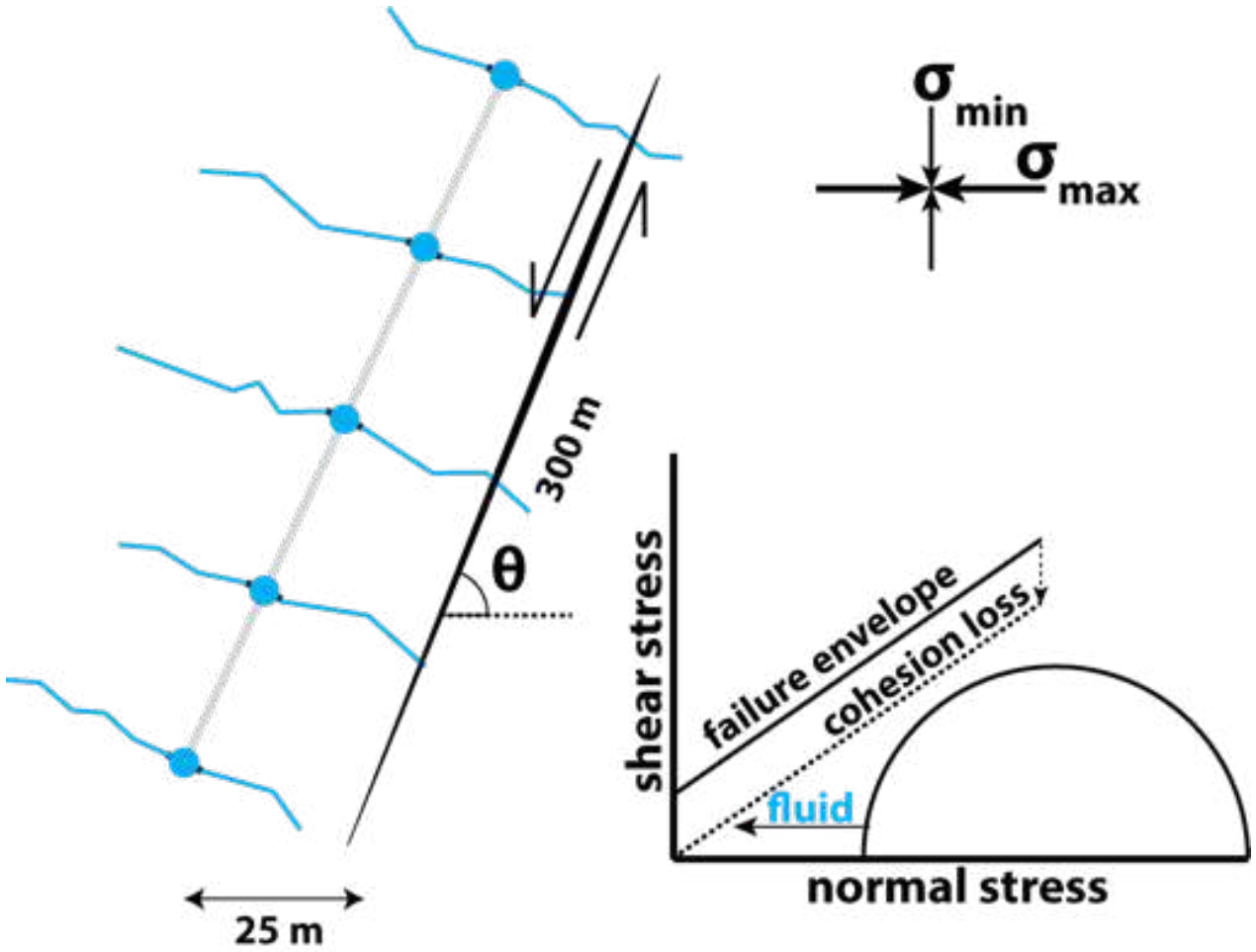
4. Proximity to reef margins
5. Lithium concentration
6. Rates of natural seismicity
7. Fluid injection volume (rate, pressure?)



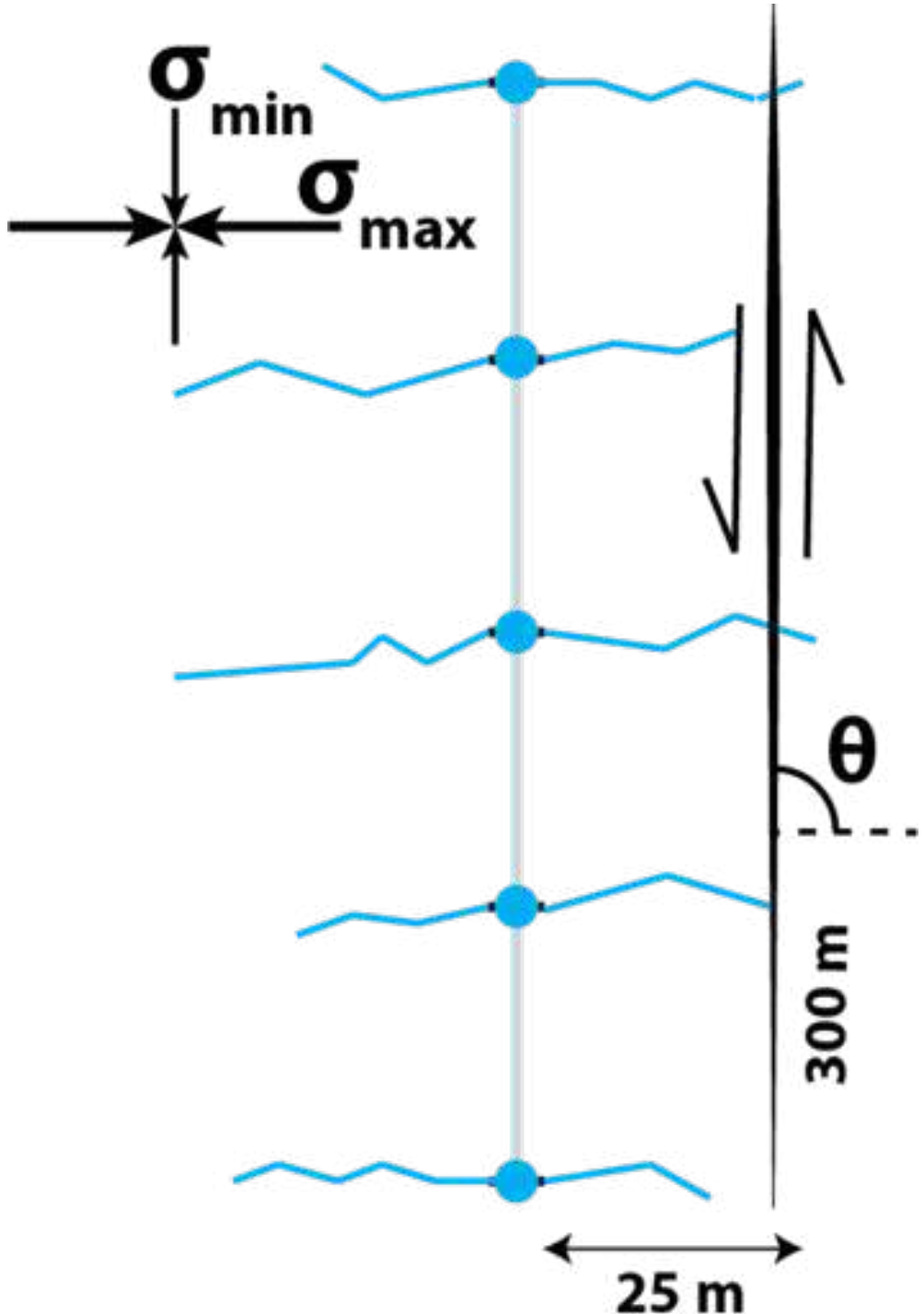
Number of earthquakes versus cumulative injection volume - Schultz, 2018

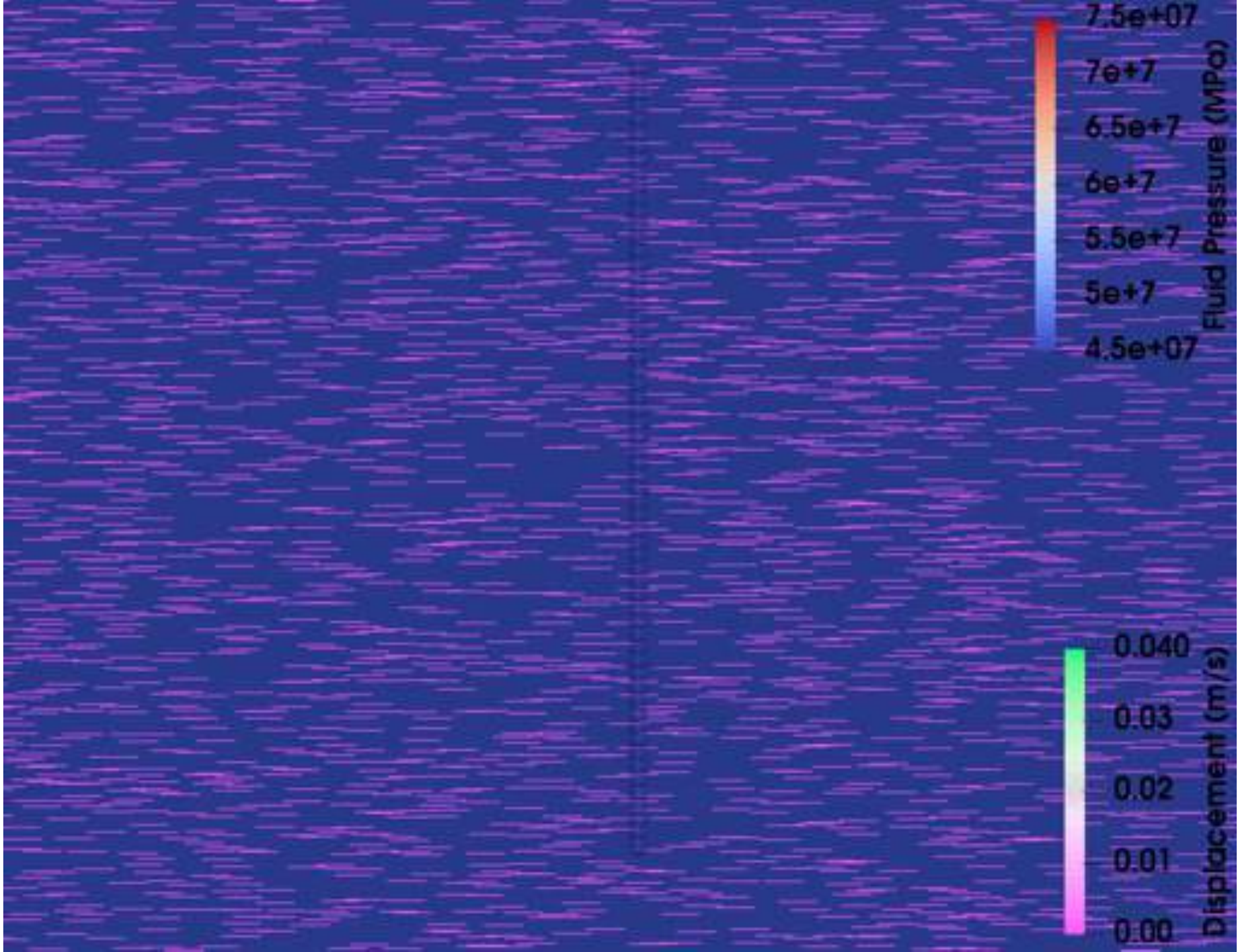
Pawley et al., 2018 - Schultz et al., 2018

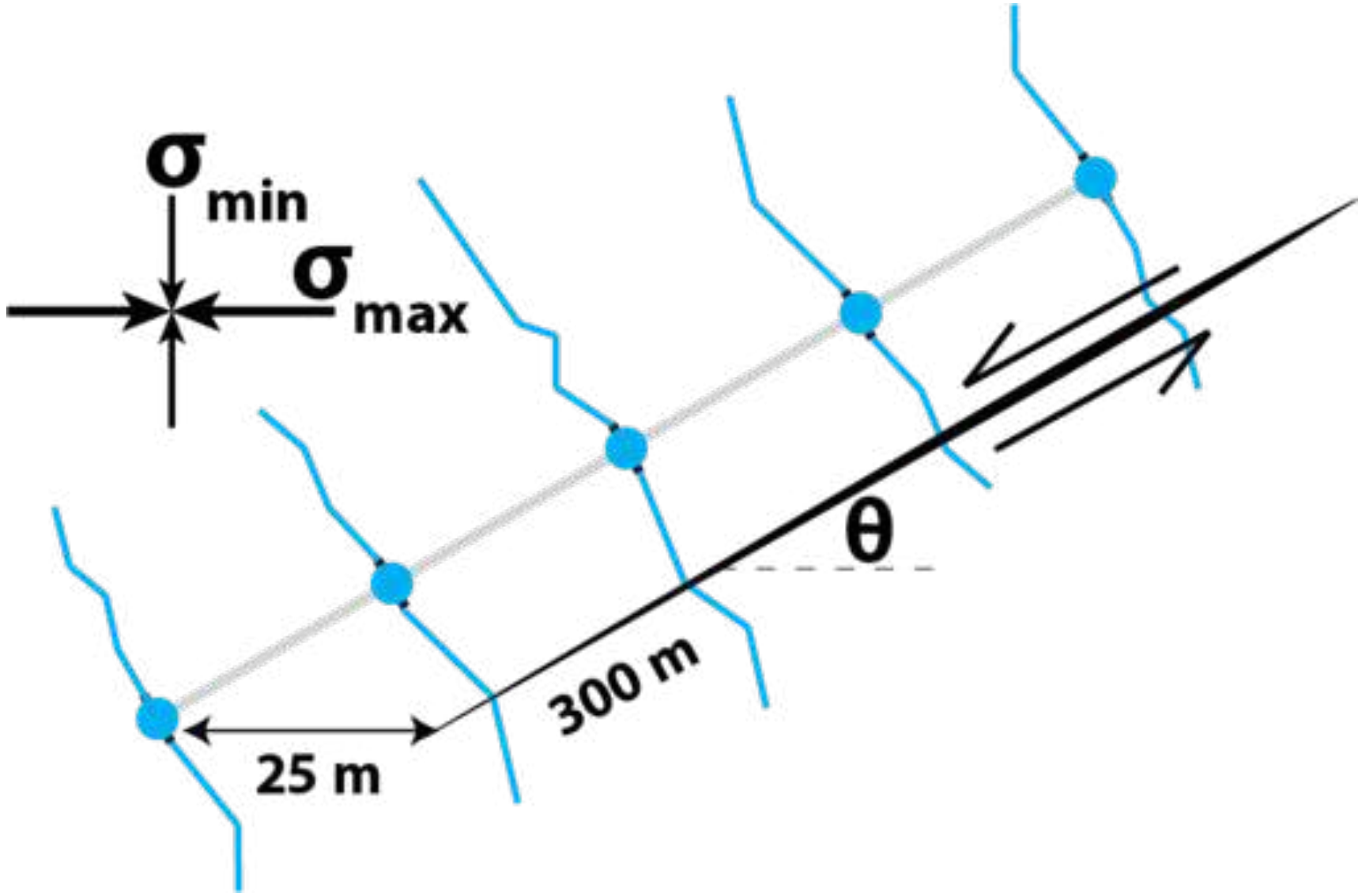
Finite-Discrete Element Method (FDEM)

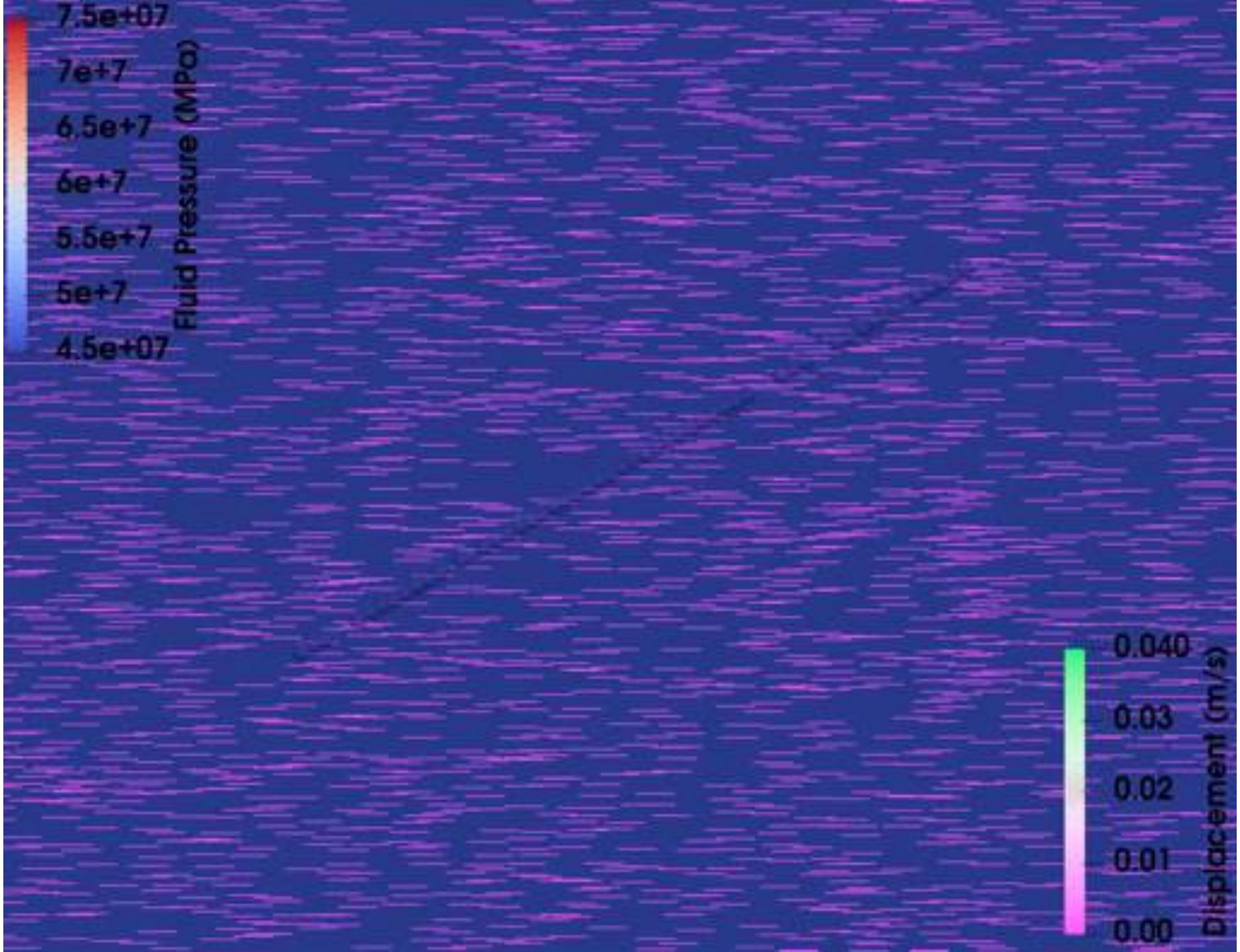


- Fault is broken (no cohesion), coefficient of friction μ = 0.6, fully fluid saturated
- Rock mass (shale) is fraturable, homogeneous and isotropic
- σ_{min}= 58 MPa, σ_{max}= 70 MPa, and pore pressure ρ_{pwp}= 54 MPa (Duvernay at 3km) (Lavoie et al., 2018)
- Fault orientation near critical θ = ∠ and stable θ = ⊥ from σ_{max}


σ min
σ max
θ
300 m
25 m


7.5e+07
7e+7
6.5e+7
6e+7
5.5e+7
5e+7
4.5e+07
Fluid Pressure (MPa)
0.040
0.03
0.02
0.01
0.00
Displacement (m/s)


σ min
σ max
θ
300 m
25 m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Fluid Pressure (MPa)
0.040
0.03
0.02
0.01
0.00
Displacement (m/s)

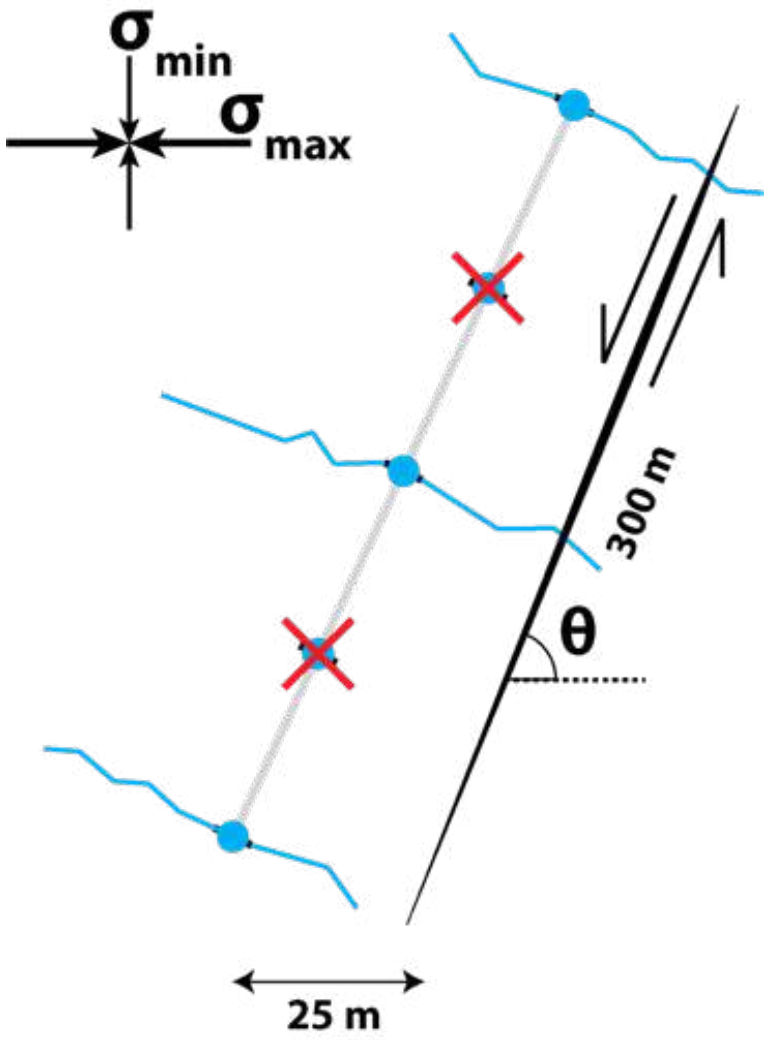
Geology - Fault orientation

- Fracture growth is hindered for the critically angled fault (θ=∠) relative to the stable fault (θ=⊥) orientation

- Stable fault (⊥) acts as a hydraulic conduit for fluids, critically angled fault (∠) acts as a fluid sink

- Greater displacement magnitudes occur for critically angled fault (∠), thus potentially greater chance of a fault slip

Mitigation of Fault Reactivation

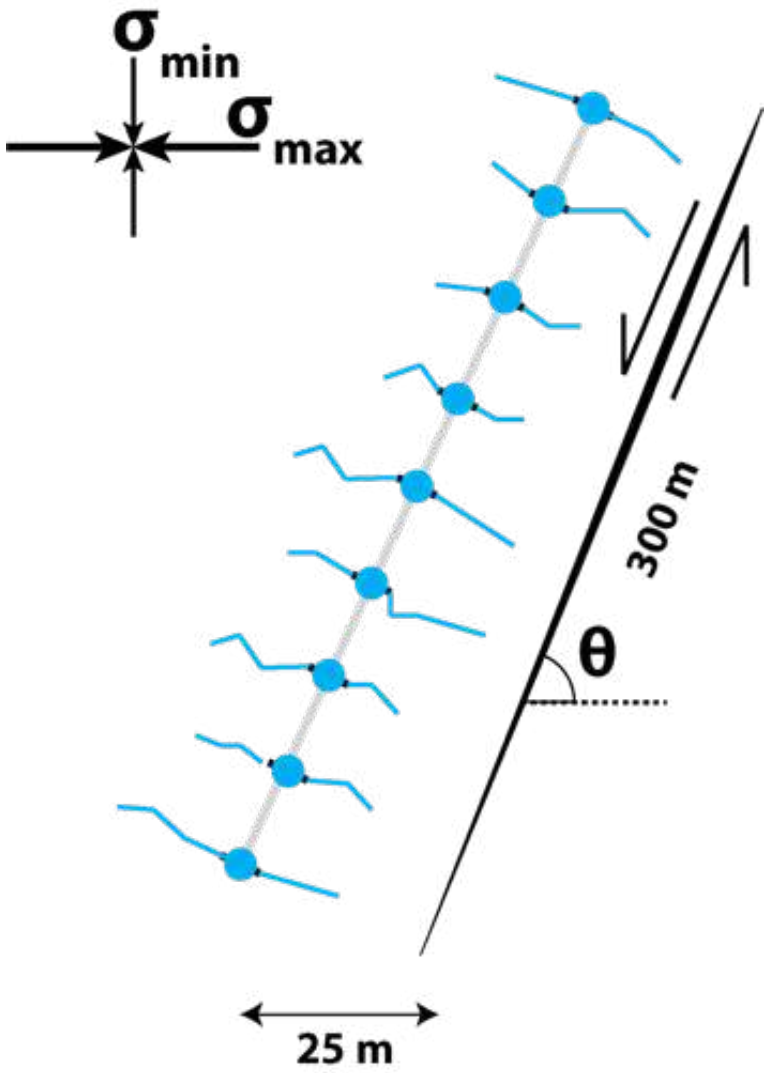


- Skip stages to reduces ↓ total injected volumes

❑ For stable fault (⊥): seismicity of model decreases ↓

❑ For critically oriented fault (∠): seismicity of model rather unaffected

Mitigation of Fault Reactivation



- Decrease the injection spacing to maintain total injected volumes & reduce fracture growth

❑ For stable fault (⊥): seismicity of model increase ↑

❑ For critically oriented fault (∠): seismicity of model slightly increase ↑

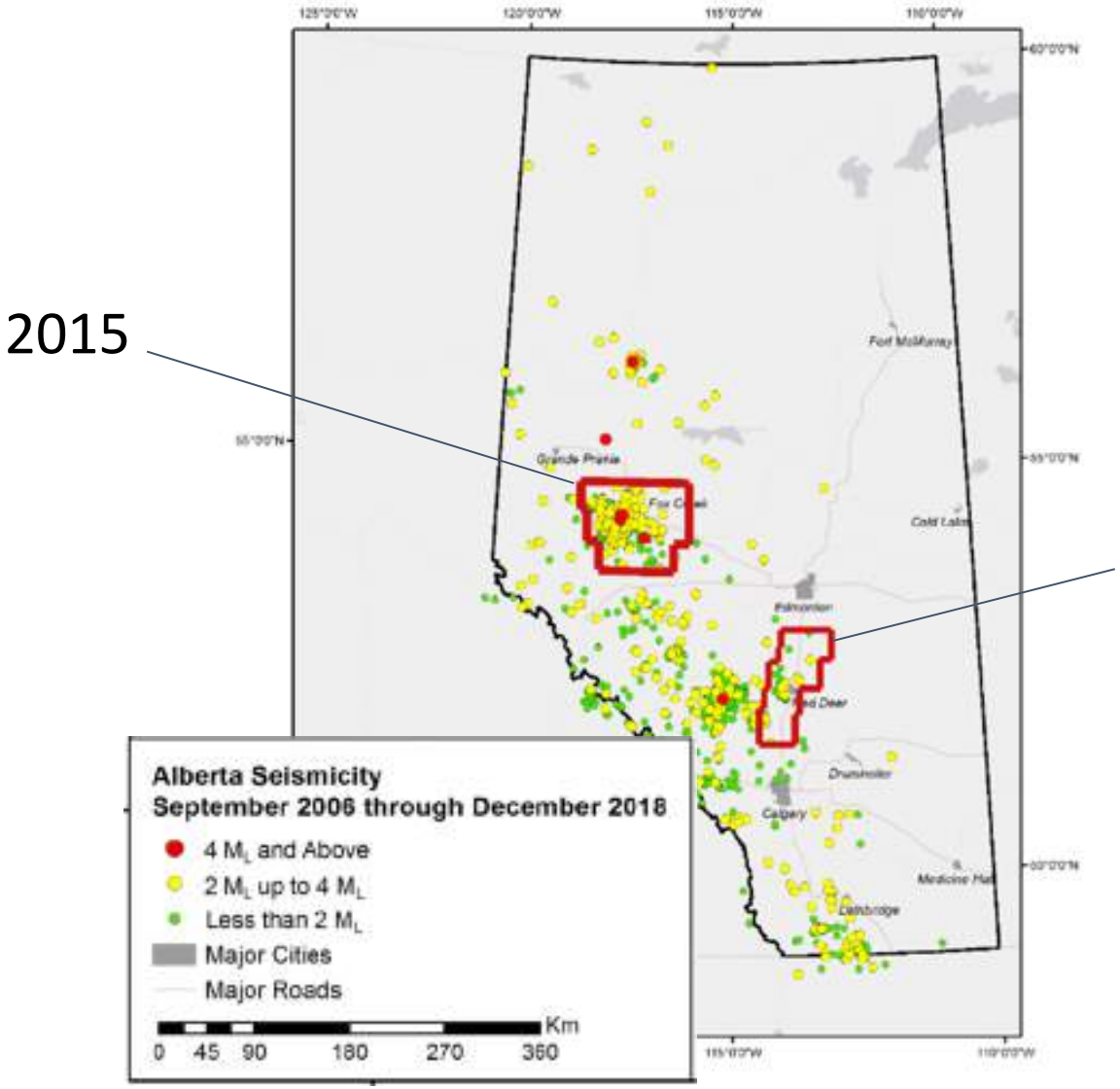
Policy Issues

- Events of induced seismicity may:
  - damage infrastructure and property
  - lead to wellbore integrity issues
  - cause public perception issues

- Balancing safety and the environment with regulatory burden

Current Regulatory Status

- Require pre-operation assessments, monitoring, and planning
- Apply in areas with history of induced seismicity



Adapted from Alberta Geological Survey, n.d.

Policy Options

- Prediction:
  - establish minimum criteria for pre-operation risk assessments
  - explore proactively expanding regulations to reduce the risk of high impact events

- Mitigation:
  - minimize total injected volume as much as possible

Conclusions

- Evaluate geological and hydrological factors prior to starting operations to minimize risk of induced seismicity
- Mitigation for critically oriented faults (∠) is complicated and not as effective
- Explore evidence based policy opportunities

Acknowledgments

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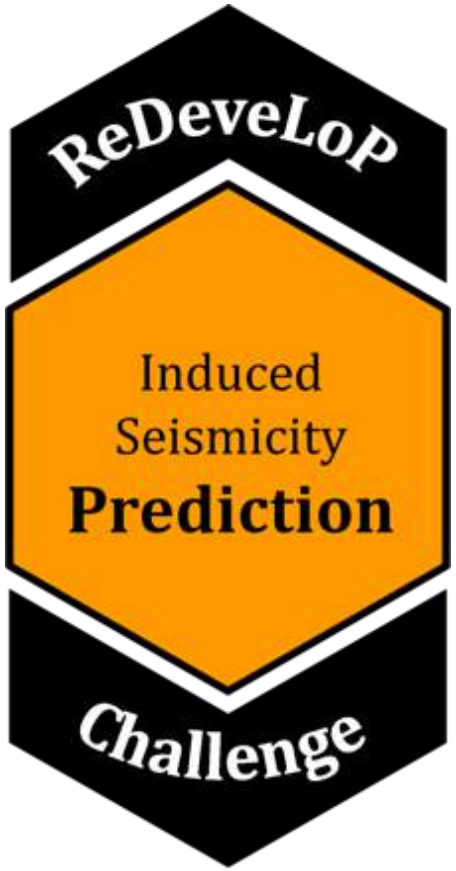
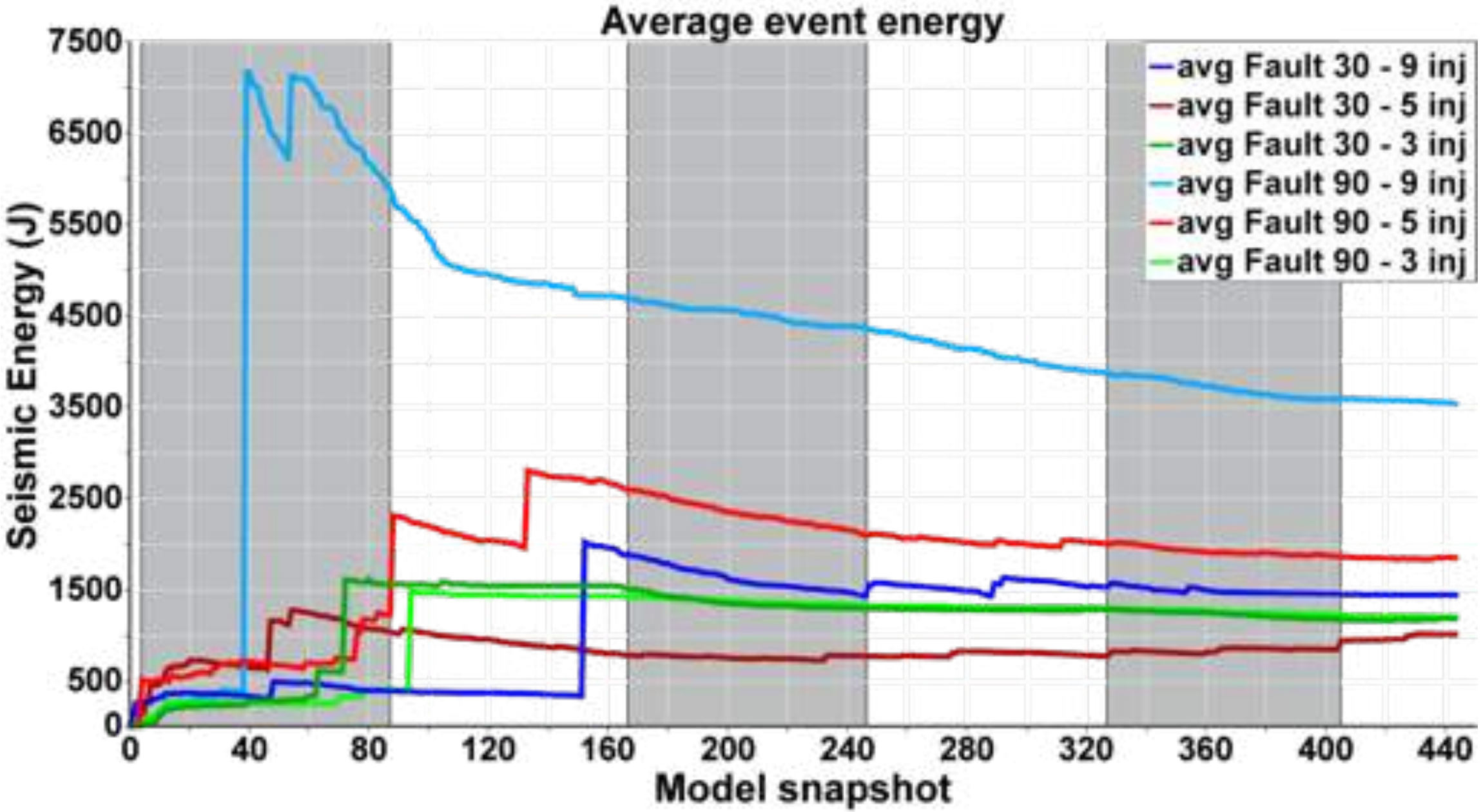
Thank you for your attention!

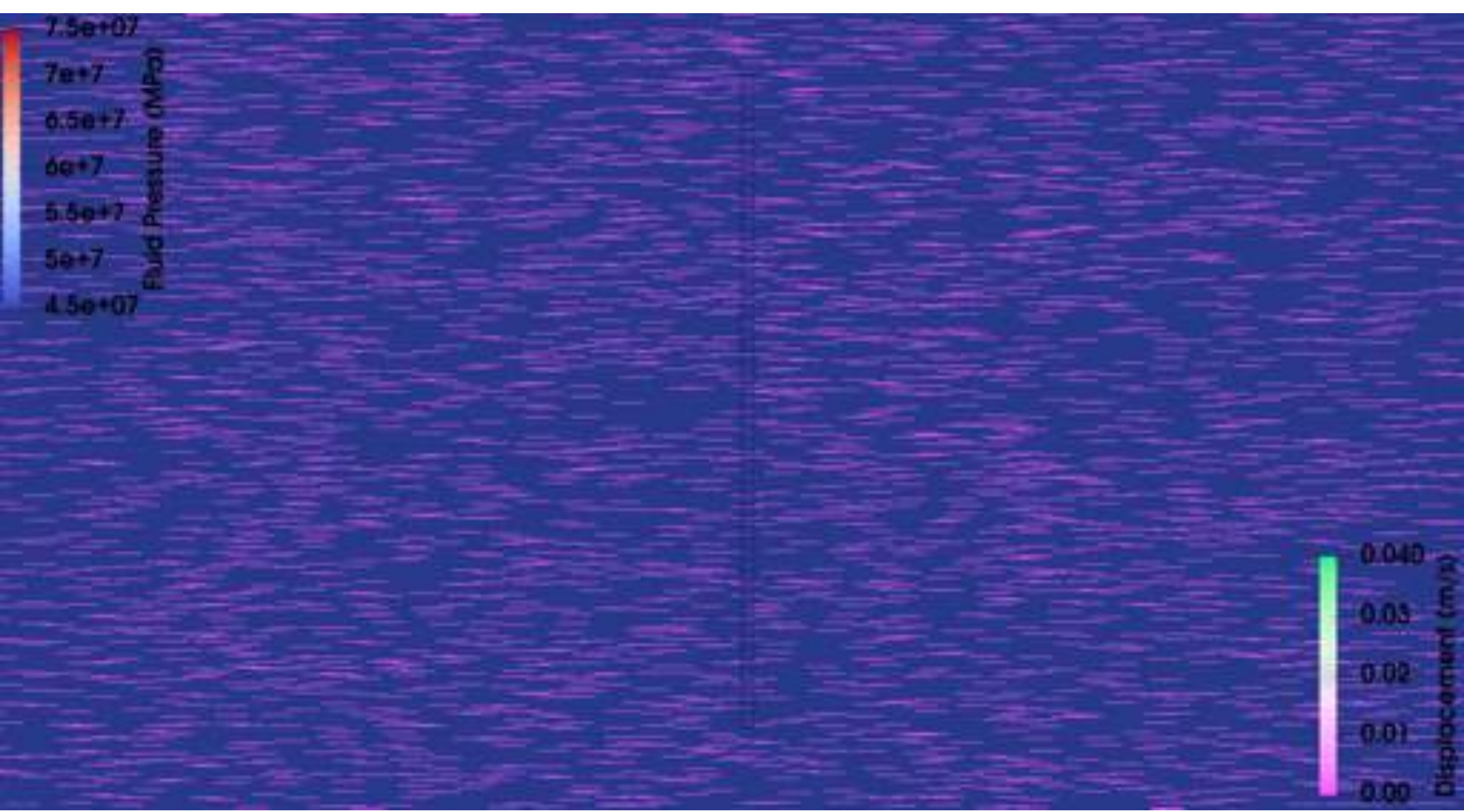


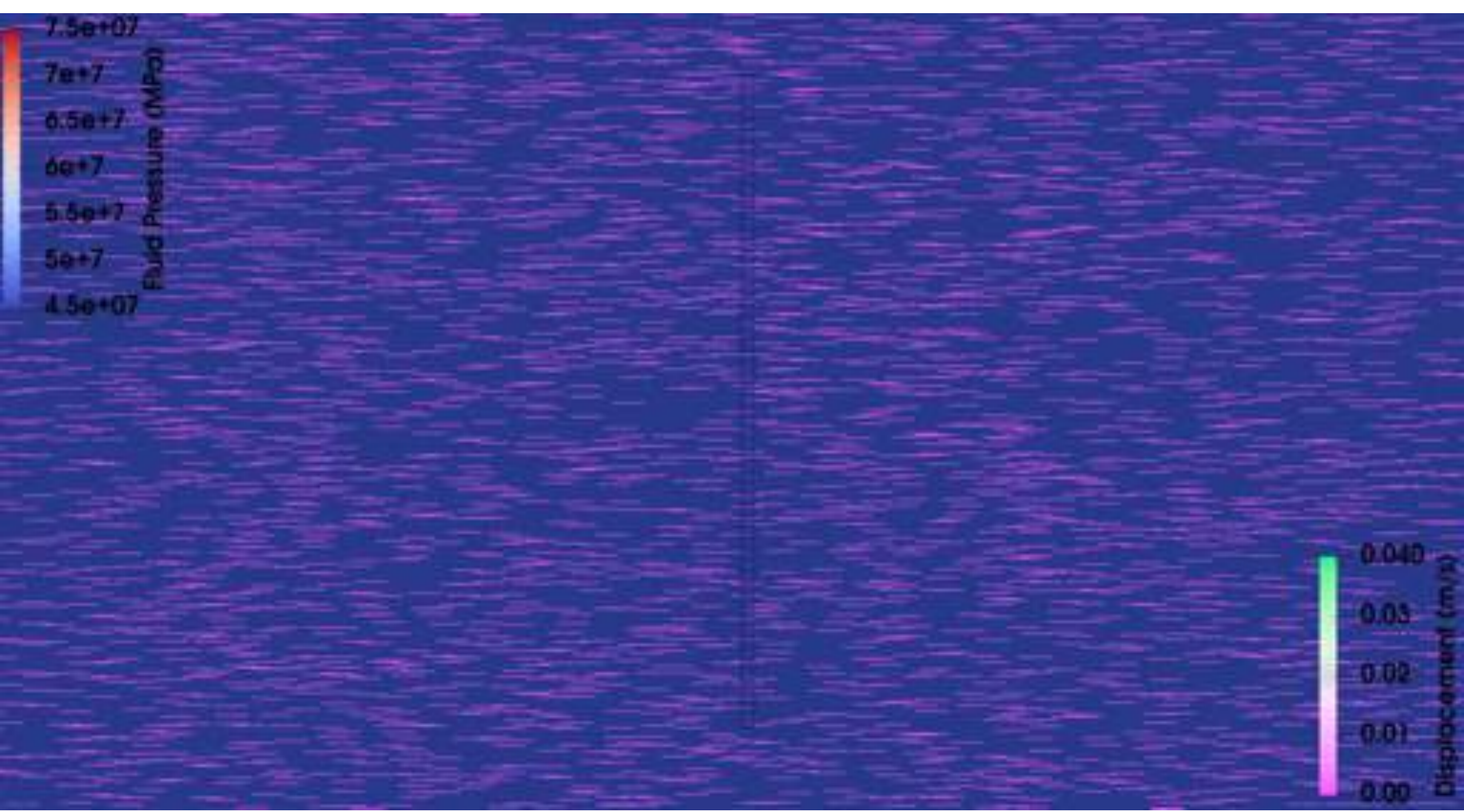
¿ Questions ?

References

1. Lavoie, V., Willson, S. M., Sturm, C., Lee, J., Purdue, G., & Dempsey, D. (2018, August). A Method to Assess Potential Induced Seismicity Hazard With Application to the Duvernay. In *52nd US Rock Mechanics/Geomechanics Symposium*. American Rock Mechanics Association.
2. Alberta Geological Survey, n.d., Earthquakes in Alberta, https://www.ags.aer.ca/activities/earthquakes-in-alberta
3. Pawley, S., Schultz, R., Playter, T., Corlett, H., Shipman, T., Lyster, S., & Hauck, T. (2018). The geological susceptibility of induced earthquakes in the Duvernay play. Geophysical Research Letters, 45, 1786–1793.
4. Eaton, D. (2017). Dynamics of Fault Activation by Hydraulic Fracturing in Overpressured Shales. 79th EAGE Conference and Exhibition.
5. Scientific Review of Hydraulic Fracturing in British Columbia (2019). British Columbia Minister of Energy, Mines, and Petroleum Resources.


Average event energy
Seismic Energy (J)
7500
6500
5500
4500
3500
2500
1500
500
0
0
40
80
120
160
200
240
280
320
360
400
440
Model snapshot
avg Fault 30 - 9 inj
avg Fault 30 - 5 inj
avg Fault 30 - 3 inj
avg Fault 90 - 9 inj
avg Fault 90 - 5 inj
avg Fault 90 - 3 inj


7.5e+07
7e+7
6.5e+7
6e+7
5.5e+7
5e+7
4.5e+07
Fluid Pressure (MPa)
0.040
0.03
0.02
0.01
0.00
Displacement (m/s)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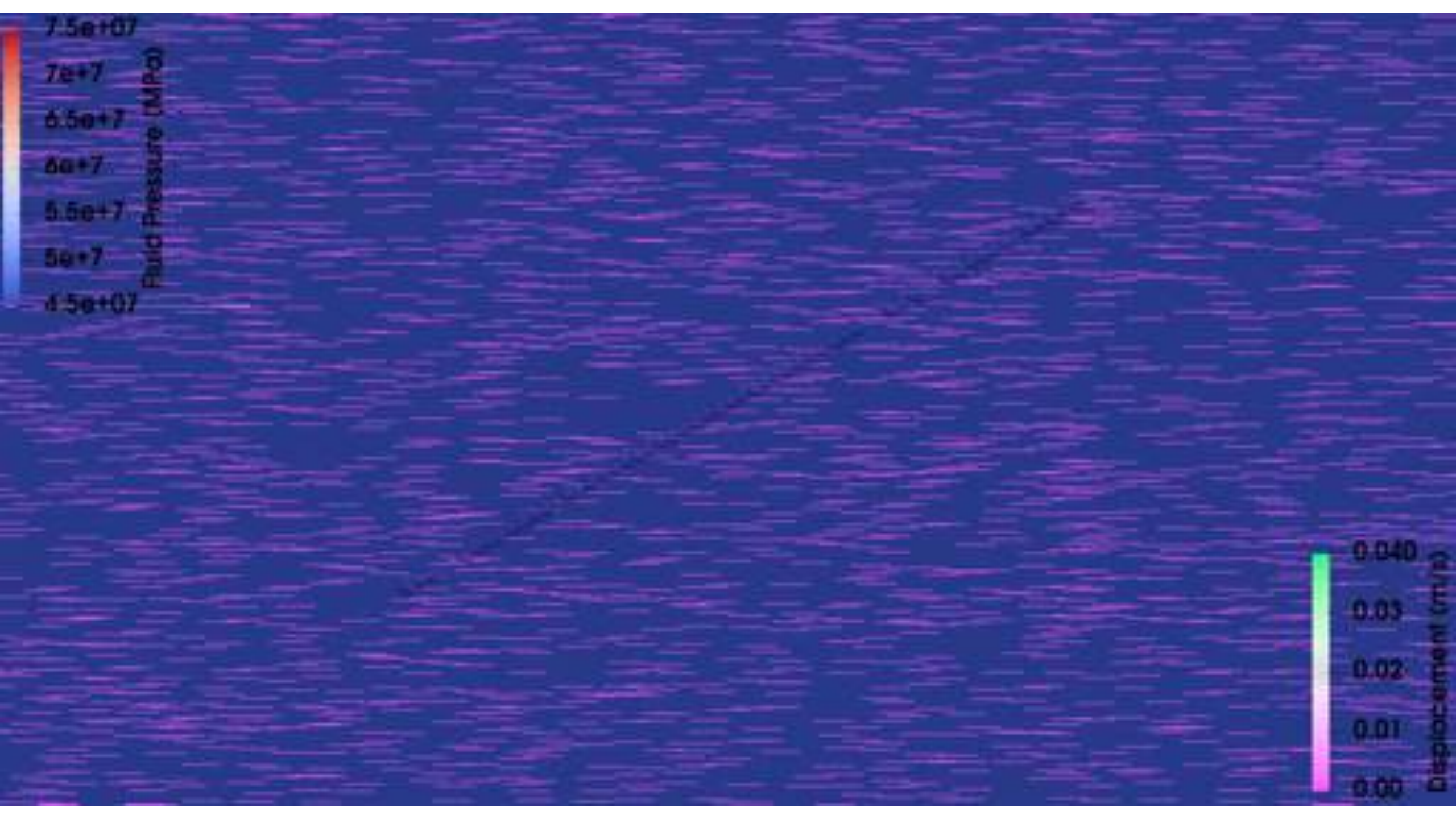
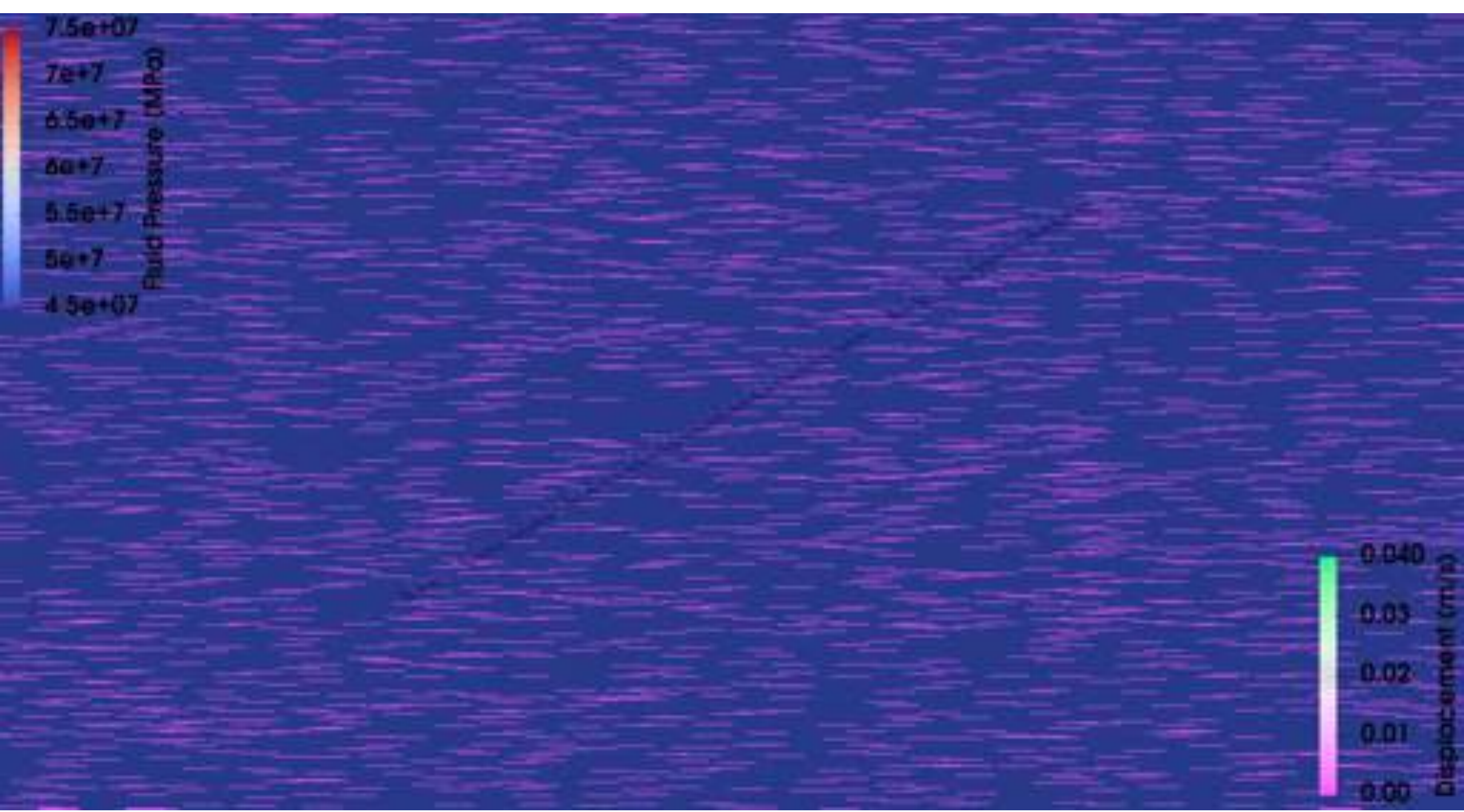
7e+7
6.5e+7
6e+7
5.5e+7
5e+7
4.5e+07
Fluid Pressure (MPa)
0.040
0.03
0.02
0.01
0.00
Displacement (m/s)


7.5e+07
7e+7
6.5e+7
6e+7
5.5e+7
5e+7
4.5e+07
Fluid Pressure (MPa)
0.040
0.03
0.02
0.01
0.00
Displacement (mm)


7.5e+07
7e+7
6.5e+7
6e+7
5.5e+7
5e+7
4.5e+07
Axial Pressure (MPa)
0.040
0.03
0.02
0.01
0.00
Displacement (mm)

Energy-Magnitude Relation

logE = 4.8 + 1.5M
giving the energy E in joules
from the magnitude M.

Magnitude	Energy in joules	Notes
-3.0	2	1 kg dropped 20 cm
-2.0	63	
-1.0	2000	100 kg person jumps down 2 m
0.0	6.3×10^4	
1.0	2.0×10^6	
2.0	6.3×10^7	Only felt nearby
3.0	2.0×10^9	Energy from 50 litres of petrol
4.0	6.3×10^{10}	Often felt up to 10's of miles away
5.0	2.0×10^{12}	Energy from 50 000 litres of petrol
6.0	6.3×10^{13}	3.3 Hiroshima-size A bombs
7.0	2.0×10^{15}	
8.0	6.3×10^{16}	1–2 earthquakes this size each year
9.0	2.0×10^{18}	Total annual energy use of UK

British Geological Survey - Earthquake Magnitude Calculations
https://www.bgs.ac.uk/discoveringGeology/hazards/earthquakes/magnitudeScaleCalculations.html

Regulatory Challenges

Fracking connection probed in 4.6-magnitude earthquake near Sylvan Lake

RYAN RUMBOLT Updated: March 4, 2019

https://calgaryherald.com/news/local-news/red-deer-hit-with-earthquake-monday-morning