Mitigation of Induced Seismicity that is Triggered by Hydraulic Fracturing

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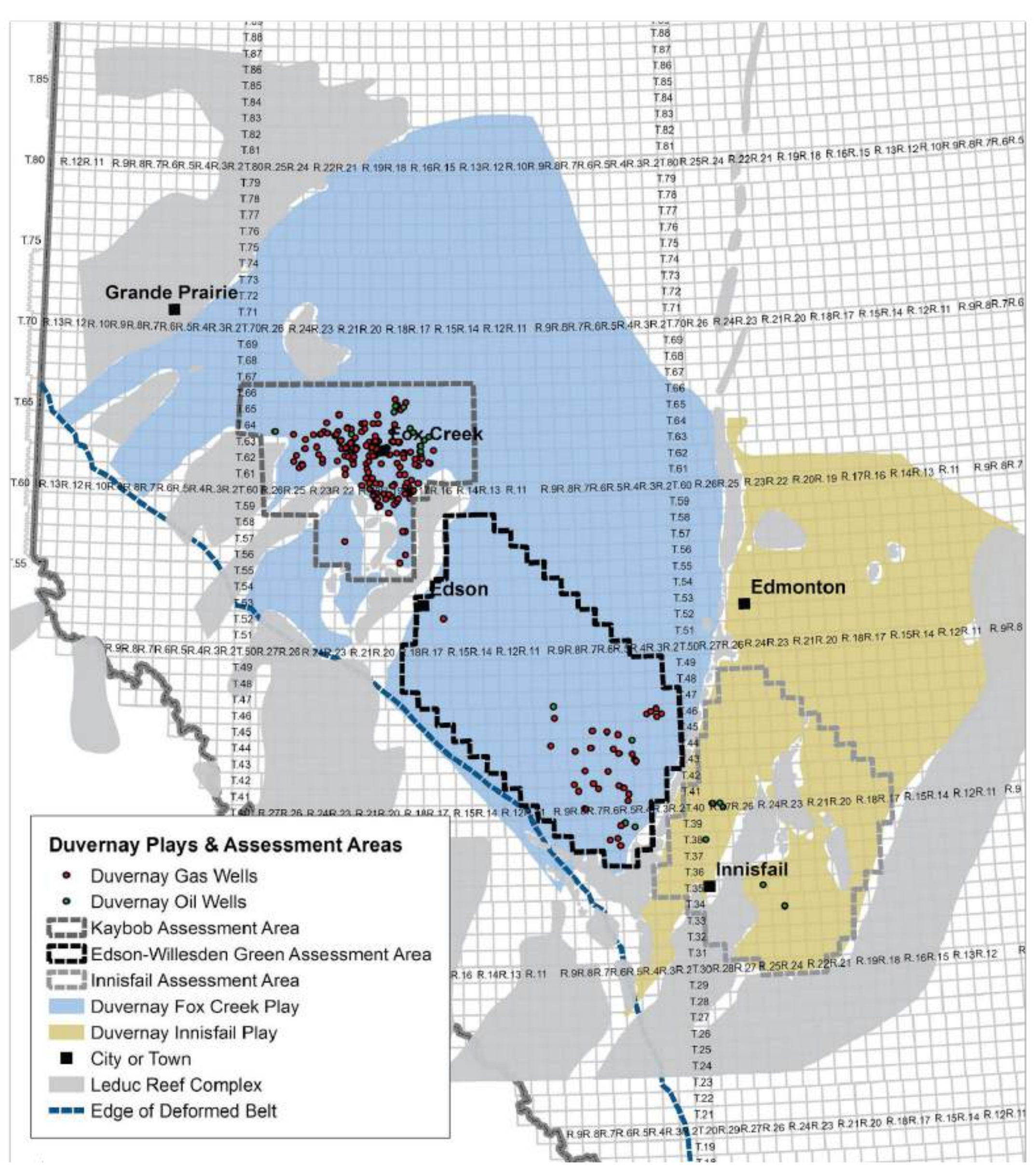
Introduction

We examine the current state of knowledge in evaluating hazards associated with hydraulic-fracturing induced seismicity; a particular focus is given to the Duvernay unconventional resource play in Alberta, Canada. The results of this study could be generalized for comparable unconventional resources in WCSB.

We aim to answer the following questions:
(1) What is the feasibility of quantifying geological susceptibility?
(2) With geomechanical modeling focus on:
a) Critical orientation of faults in respect to the minimum and maximum stresses.
b) Reactivation of fault due to stress / fluid pressure changes through hydraulic connectivity.
c) Effectiveness of suggested mitigation methods.

This study offers insight into practices to minimize the risk of future induced seismicity.

Geological Factors

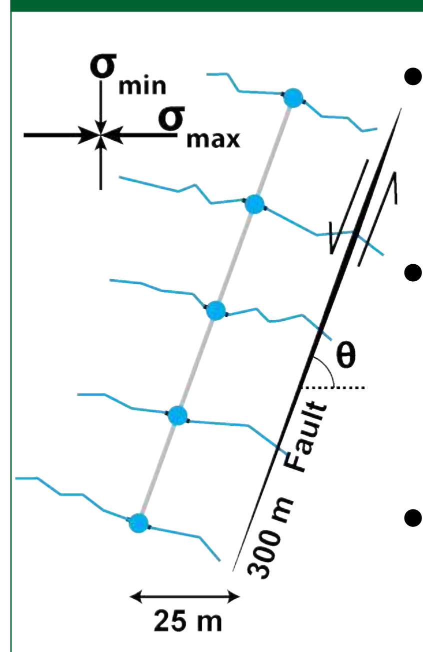


The Duvernay unconventional resource play is geographically divided into the West Shale Basin or Fox Creek play (shown in blue) and the East Shale Basin, or Innisfail play (shown in yellow). Figure from Preston et al. (2016).

It is possible to minimize the risk of induced seismicity by considering/quantifying geological and hydrogeological parameters:

- Pre-existing faults
- In-situ stress conditions
- Pathways for pressure diffusion and/or stress transfer
- Rock geomechanical parameters
- Proximity to crystalline basement
- Formation overpressure
- Proximity to reef margins
- Lithium concentration
- Rates of natural seismicity
- Fluid injection volume

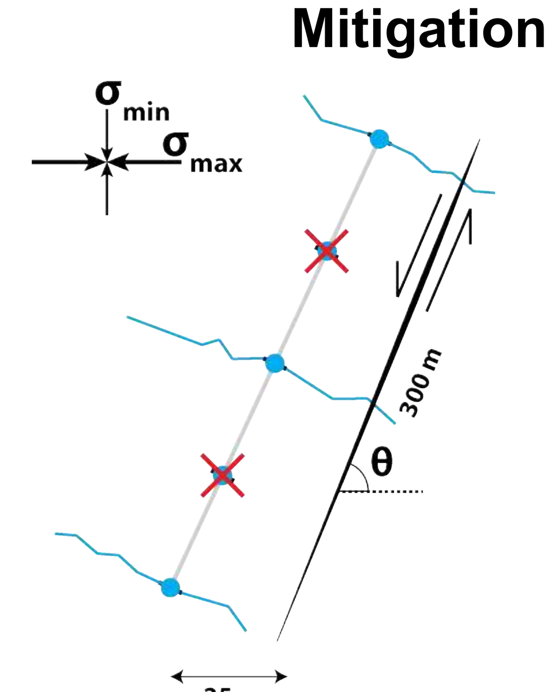
Geomechanical Models

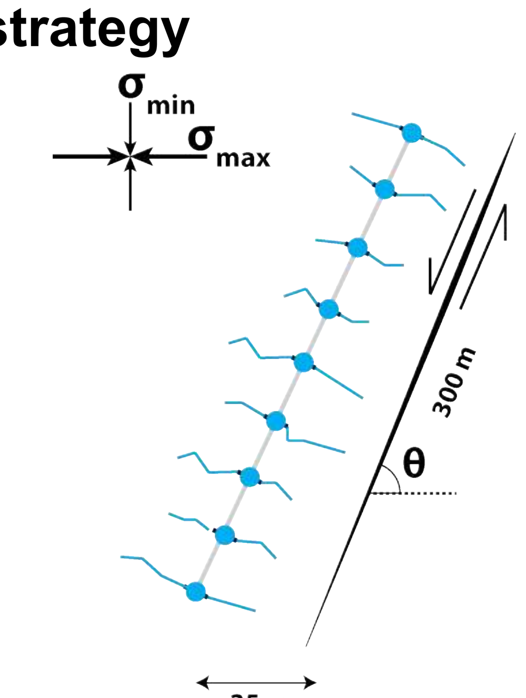


σ_{min}= 58 MPa σ_{max}= 70 MPa at ~3km (Lavoie et al., 2018)

- Model using 2D finite-discrete element method (FDEM) Irazu software
- Fault is broken (no cohesion), dry (no fluids), assume strike-slip fault (vertical), coefficient of friction μ=0.6
- Rock mass (shale) is fraturable, homogeneous and isotropic
- Baseline model with 5 injection points away from fault
- Fault orientation near critical θ =∠ (30° worst case) and stable θ =⊥ (90° best case) from σ_{max}

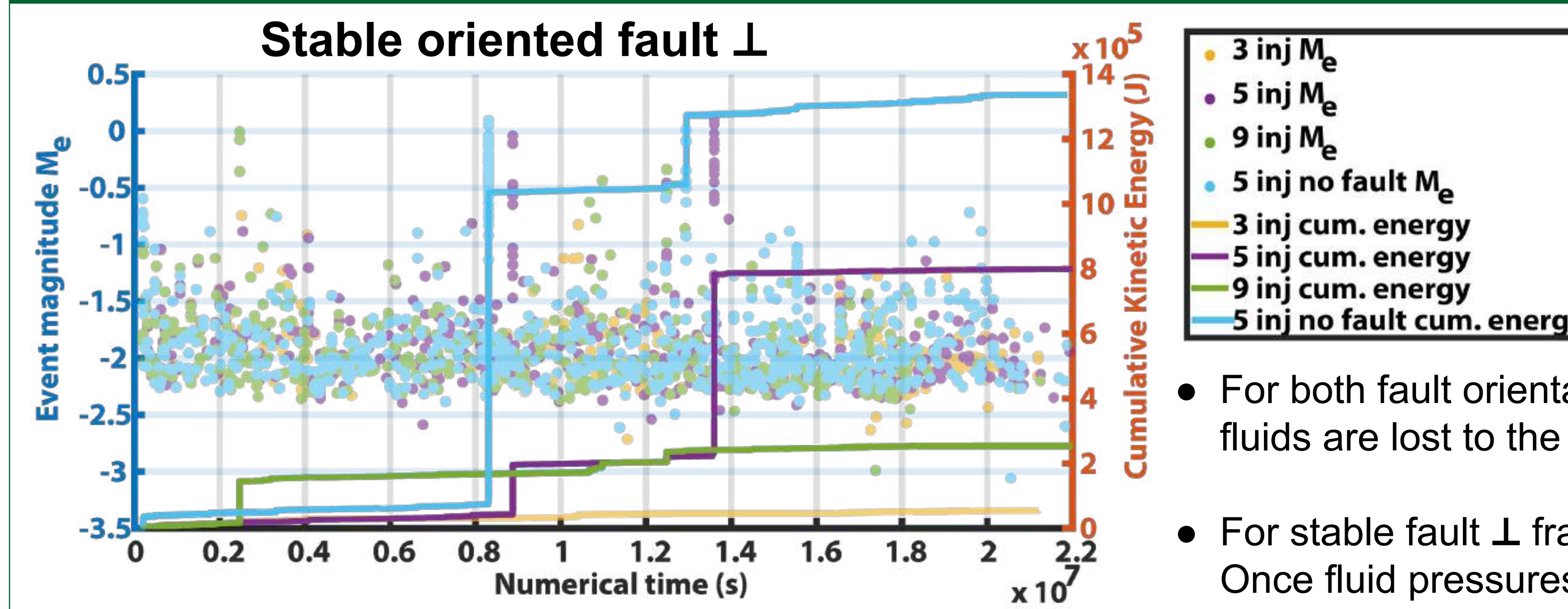
Mitigation strategy



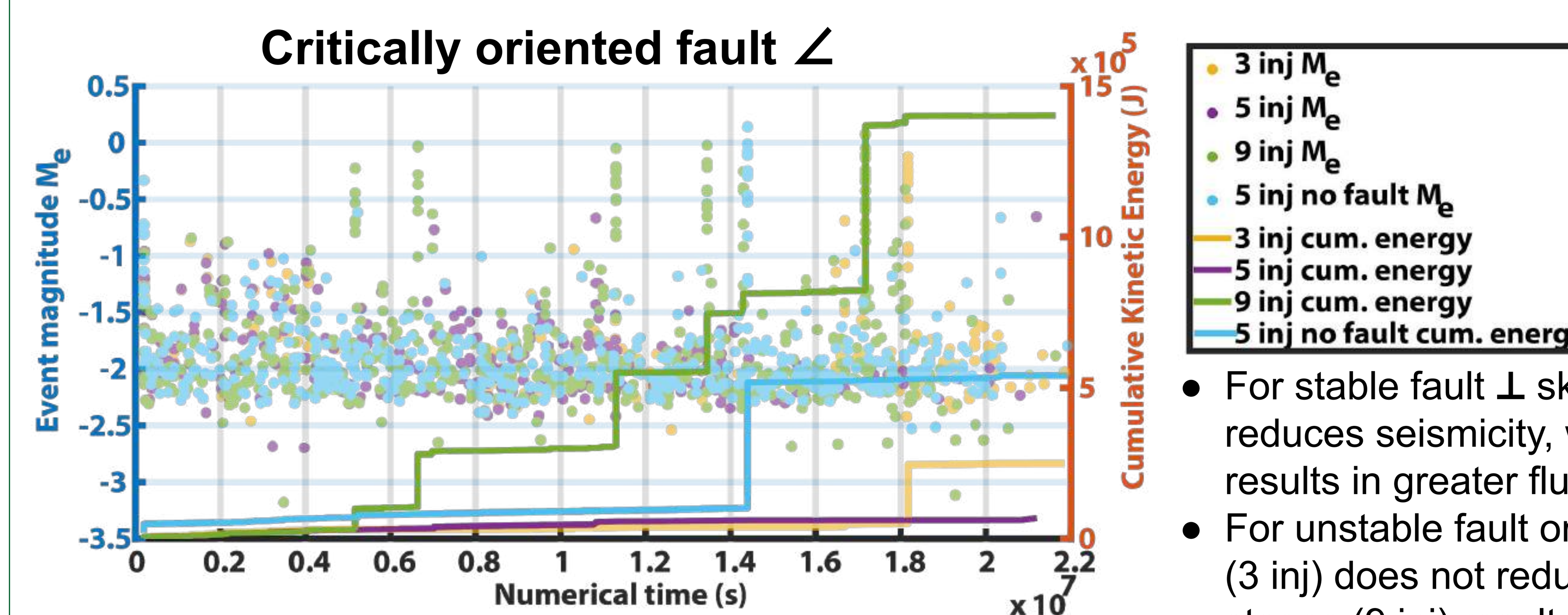


- Skip 2/5 stages to reduce ↓ total injected volumes
- Decrease injection spacing to maintain total injected volumes & reduce outward fracture growth

Fracture Growth and Simulated Microseismics



- Seismic energy is only considered from nucleation of new fractures within the intact rock mass.
- Greater seismic energy is indicative of a more efficient fracturing treatment.
- For both fault orientation (stable ⊥ and critical ∠) fluids are lost to the fault through fractures.
- For stable fault ⊥ fractures are arrested at the fault. Once fluid pressures within the fault are greater than σ_{min} fractures propagate across the fault.



- For unstable fault ∠ fractures are arrested and deviated. Once fluid pressure within the fault are greater than σ_{min} fractures propagate favorably from the edges of the fault.
- For stable fault ⊥ skipping stages (3 inj) greatly reduces seismicity, while increasing stages (9 inj) results in greater fluid loss into the fault.
- For unstable fault orientation ∠ skipping stages (3 inj) does not reduce seismicity, while increasing stages (9 inj) results in reduced fluid loss.

Pressure perturbations

- The table below summarizes the maximum fluid pressures at and around the fault at the end of all injections.

Model	Stable oriented fault ⊥	Critically oriented fault ∠
3 injections	57.0 MPa	61.0 MPa
5 injections	59.2 MPa	60.4 MPa
9 injections	58.4 MPa	58.5 MPa
5 injections no fault	60.3 MPa	59.7 MPa

- Higher pressure perturbations would shift the Mohr circle towards the failure envelope with critically oriented faults more likely to fail.

Conclusion

- For stable faults ⊥, fractures will propagate across the fault once fluid pressures within the fault overcome σ_{min}.
- For unstable faults ∠, fractures will deviate along the fault. Once fluid pressures overcome σ_{min} fractures will preferably propagate from the edges of the fault.
- For stable faults ⊥, minimizing fractures contact area with the fault results in less fluid loss and less pressurisation of the fault.
- For unstable faults ∠, decreasing injection spacing results in fewer contact area with the fault due to short and deviated fracture growth near the fault.

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