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Rupture Characteristics of Hydraulic Fracture Induced Seismicity

Schatzalp Induced
Seismicity Workshop
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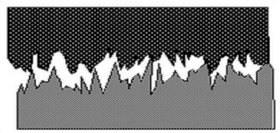
Motivation

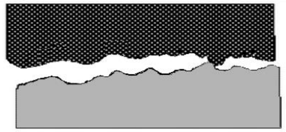
Understanding the rupture processes could help explain induced seismicity generation processes

- Fault behaviour
  - Perturbations in the local stress field
  - Degree of surface roughness, asperities and barriers to slip
  - Frictional stress of the rock and resulting rupture velocity
  - Influence of fluids and proppant
- Goal – to derive a picture of the types of faulting processes
  - We examine seismicity recorded over a wide frequency range associated with stimulations in Horn River formation NE BC.
    - Rupture characteristics
    - Scaling behavior

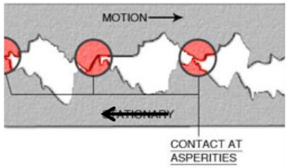


Rough
→ many small asperities breaking
→ high frequency energy signal

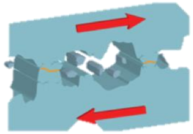
Fracture surface roughness

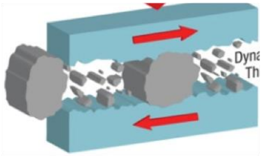


Smooth
→ few large asperities breaking
→ lower frequency energy signal

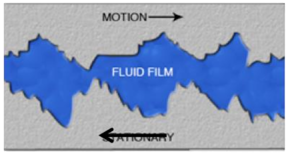


Most energetic asperity – resistance to sliding





Introduction of fluids and proppant



Fluids -> decrease in contact area and lubrication

Horn River Basin– Northeast BC

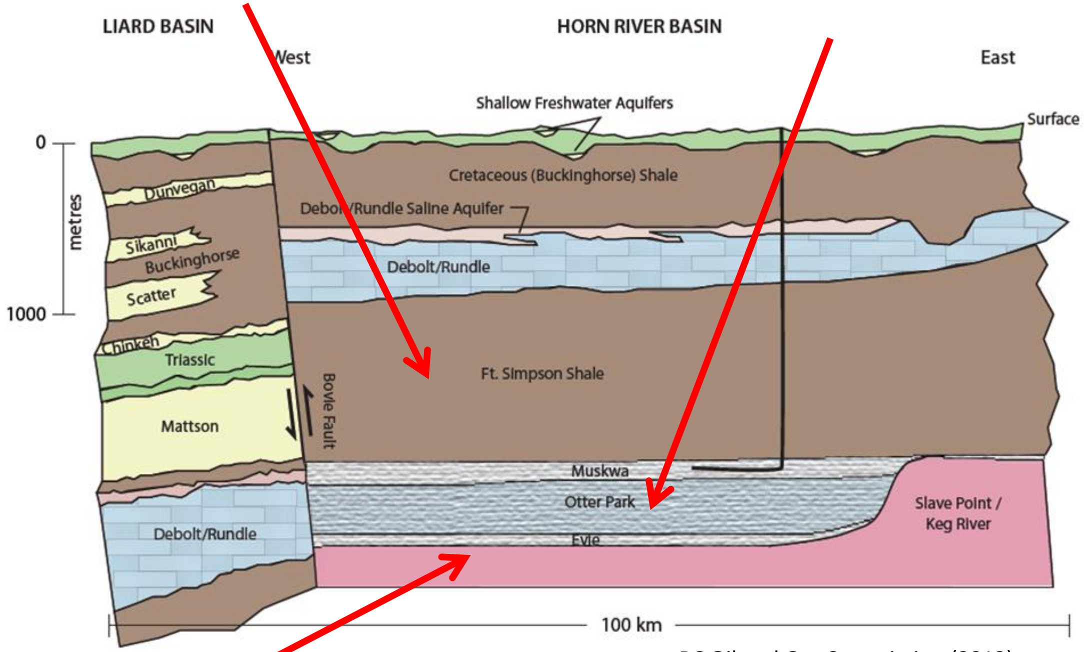
The Horn River Basin is a natural gas bearing shale in northeastern British Columbia, Canada

National Energy Board (2011)

Reservoir depth: 2500 m

Ft. Simpson: Barrier

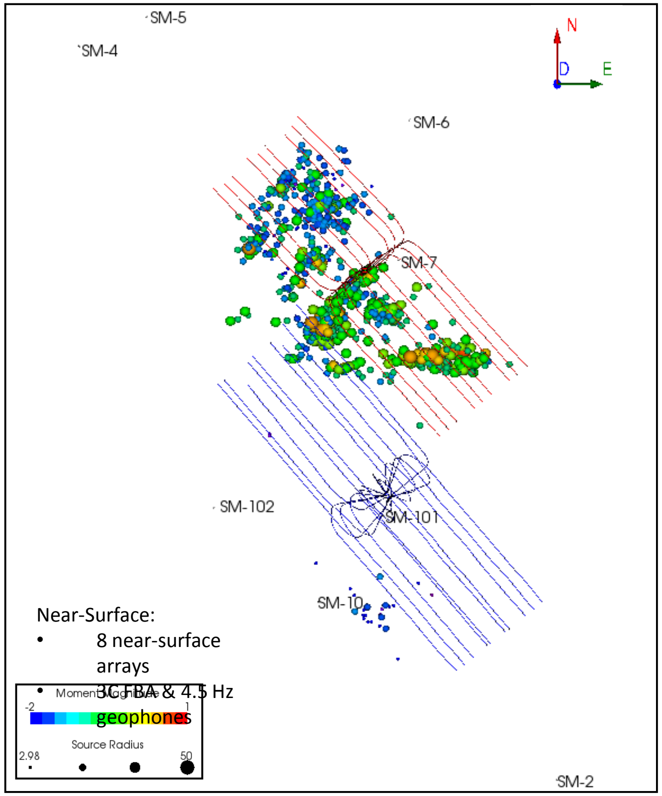
Target Formations: Muskwa, Otter Park and Evie



BC Oil and Gas Commission (2012)

Keg River: Barrier, Limestone

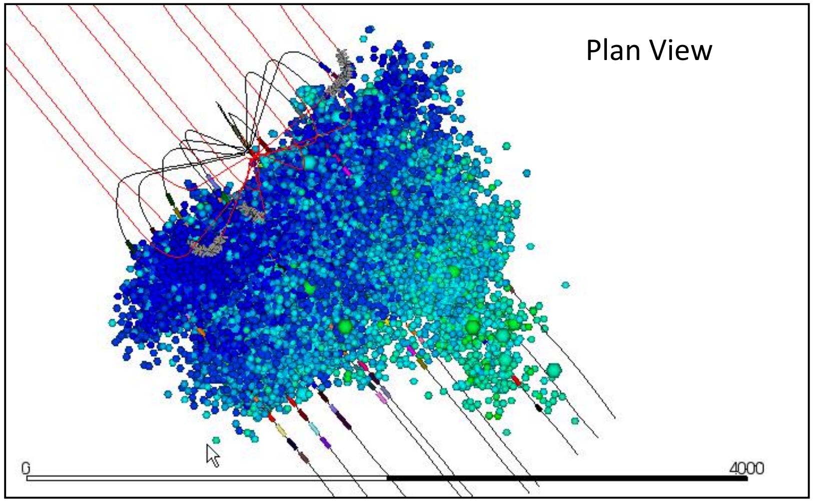
Seismicity



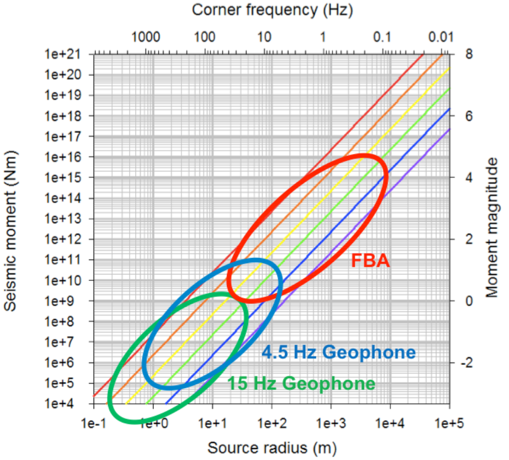
Near-Surface:

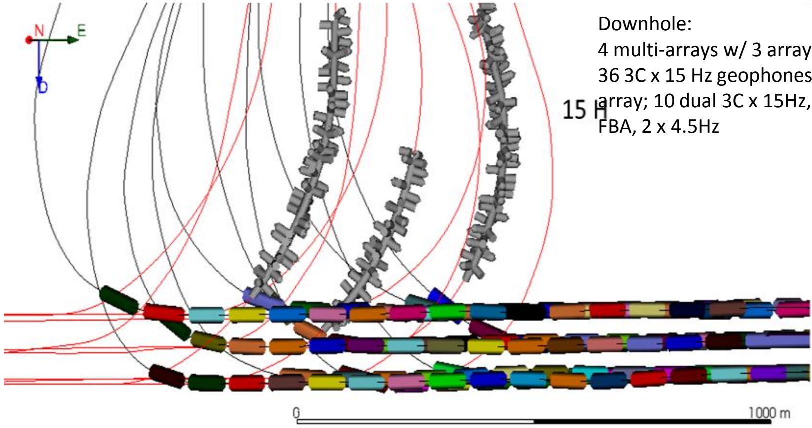
- 8 near-surface arrays
- 3C FBA & 4.5 Hz geophones

- ~820 events with $< 0 < M < 2.9$ and hypocentre distance from 2550 to 10000 m.
- ~30,000 events with $M < 0$ within 1km of injection zones



Depth View



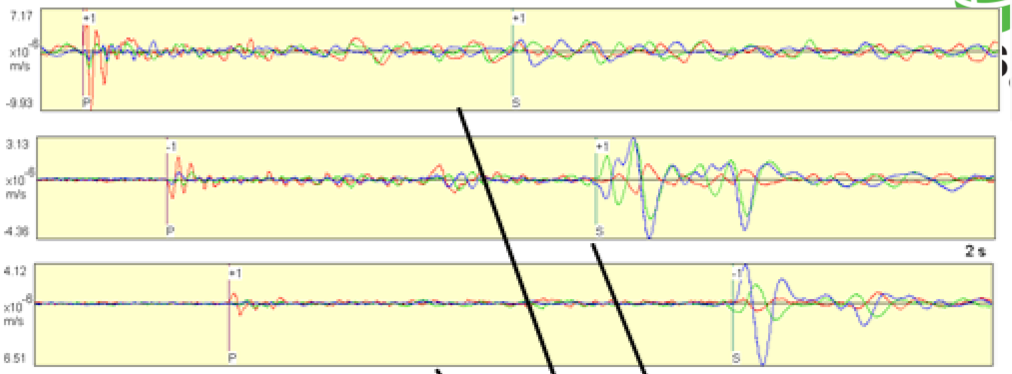


Downhole:
4 multi-arrays w/ 3 arrays; 24-36 3C x 15 Hz geophones, 1 array; 10 dual 3C x 15Hz, 2 3C FBA, 2 x 4.5Hz

Waveforms

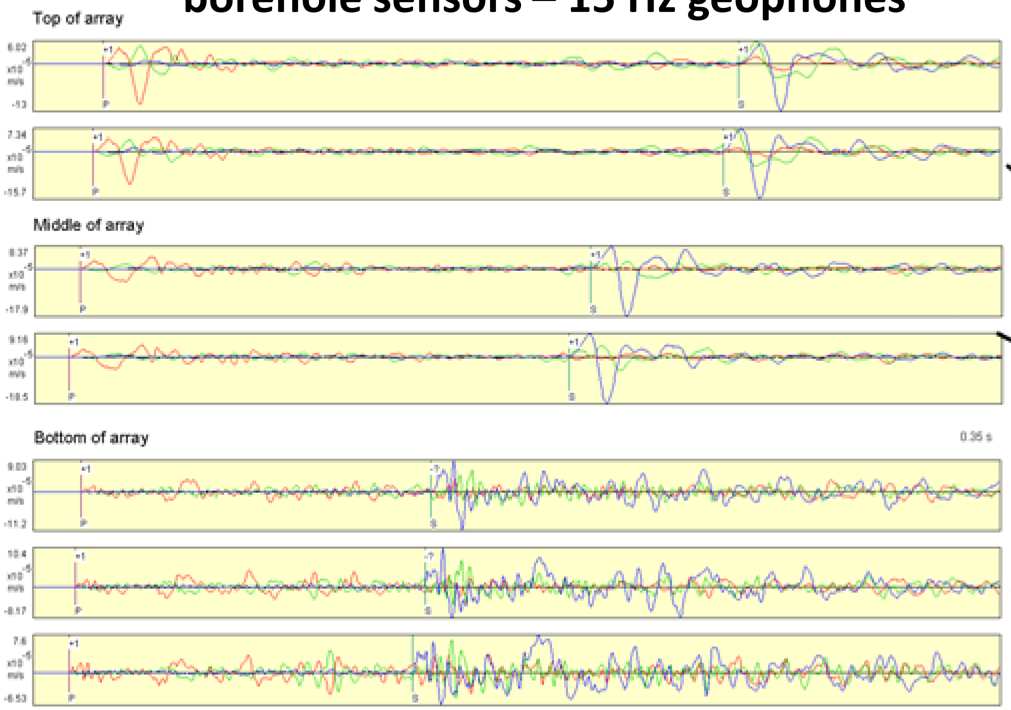
Example of waveforms from a M1 deep event recorded at borehole and near-surface geophone sensors.

near-surface sensors – 4.5 Hz geophones

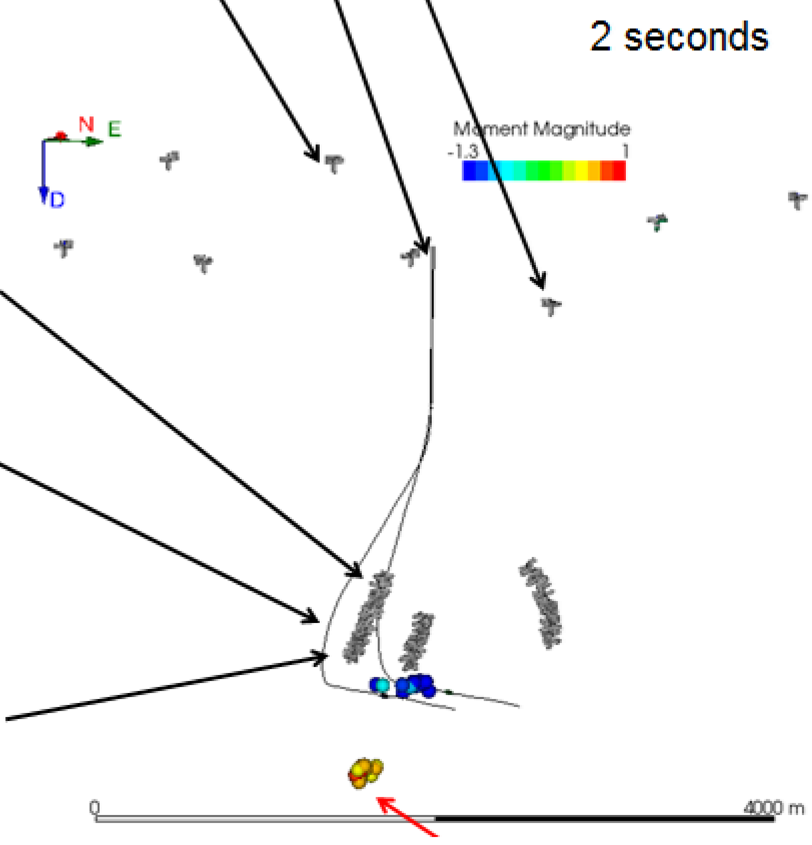


2 seconds

borehole sensors – 15 Hz geophones

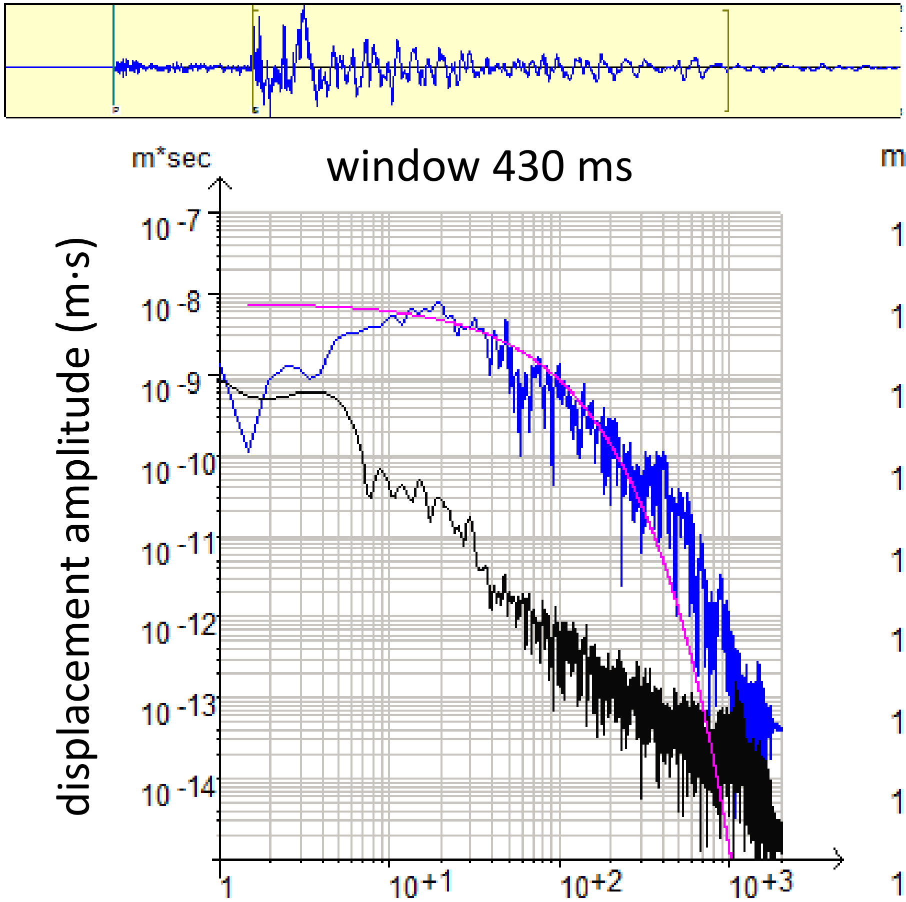


0.35 seconds



M1

Signal Comparison

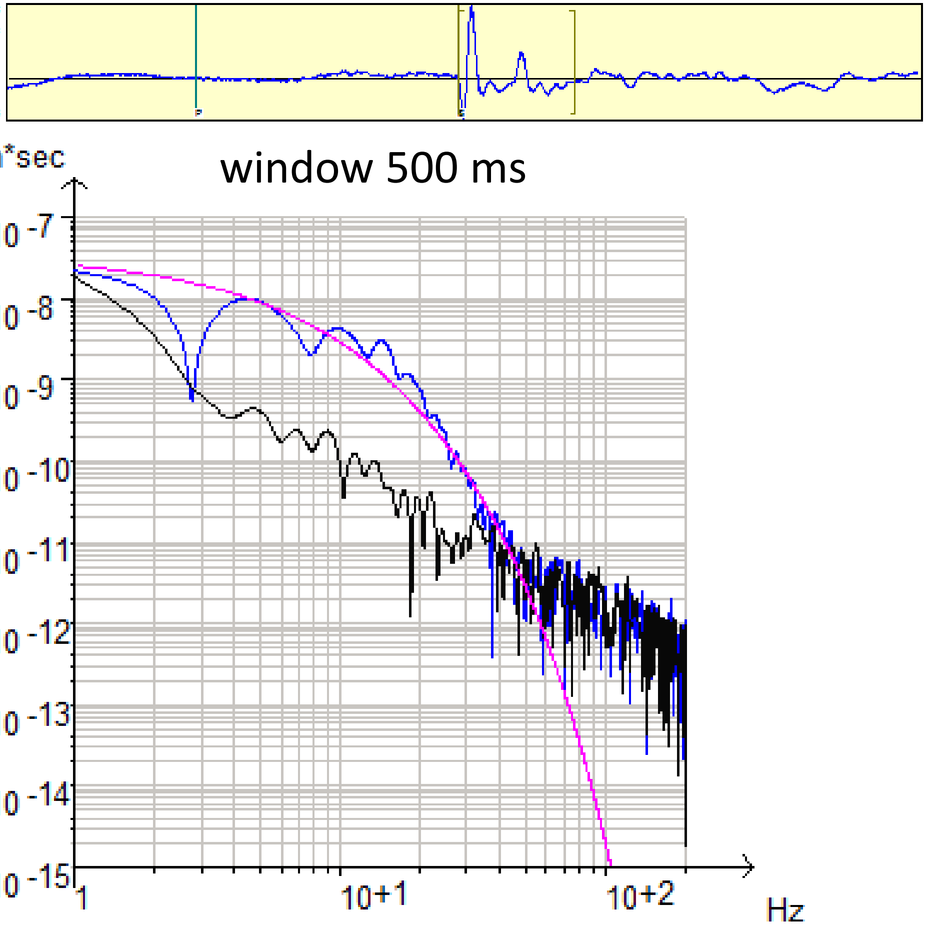


displacement amplitude (m·s)

window 430 ms

frequency (Hz)

fc =140 Hz, Q = 90, Mw = 0.8
distance to source: ~1000 m

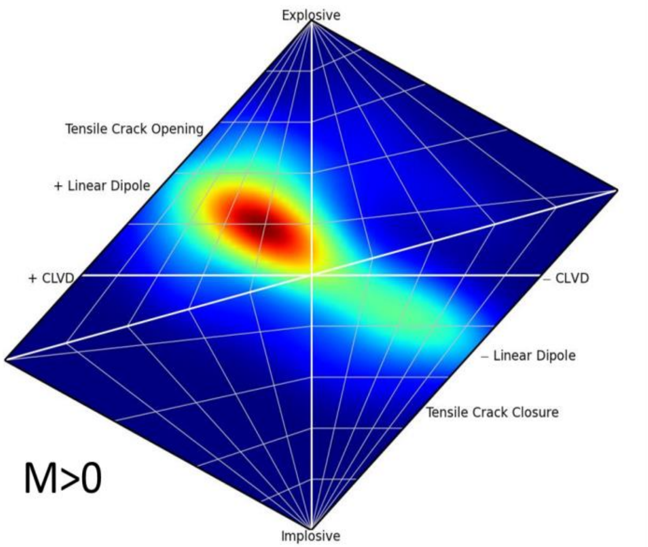


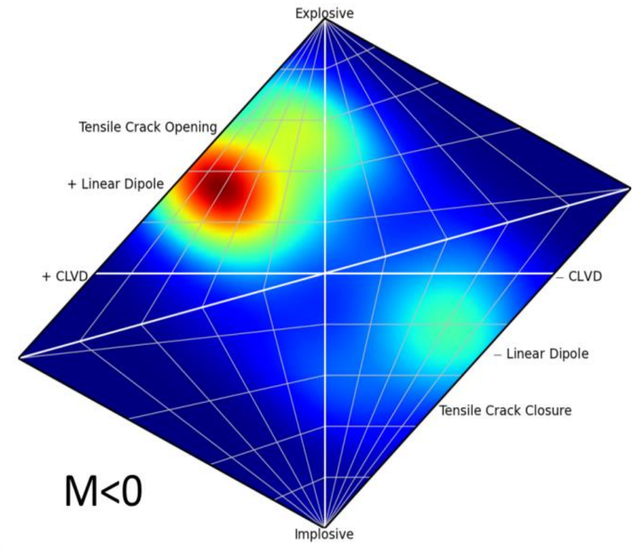
window 500 ms

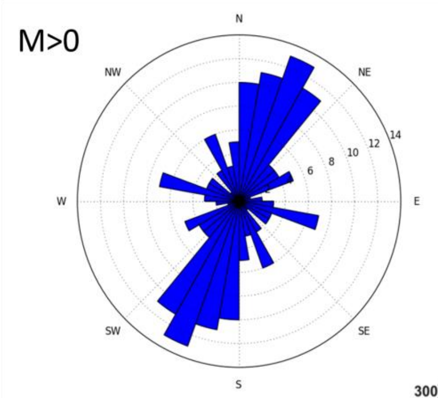
frequency (Hz)

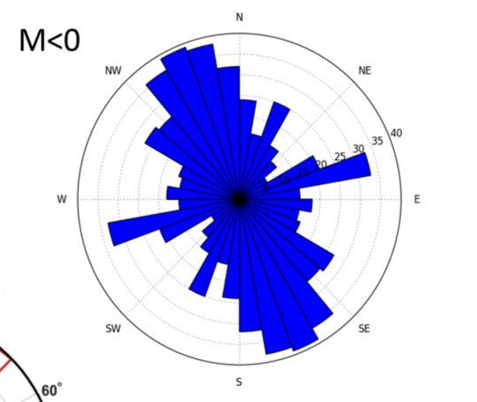
fc =10 Hz, Q = 30, Mw = 1.7
distance to source: ~4200 m

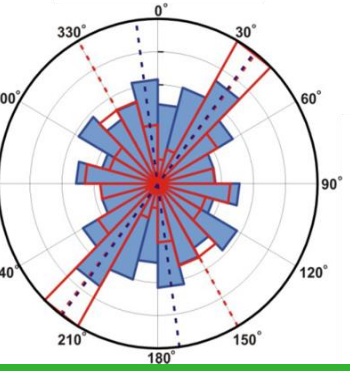
Failure Types



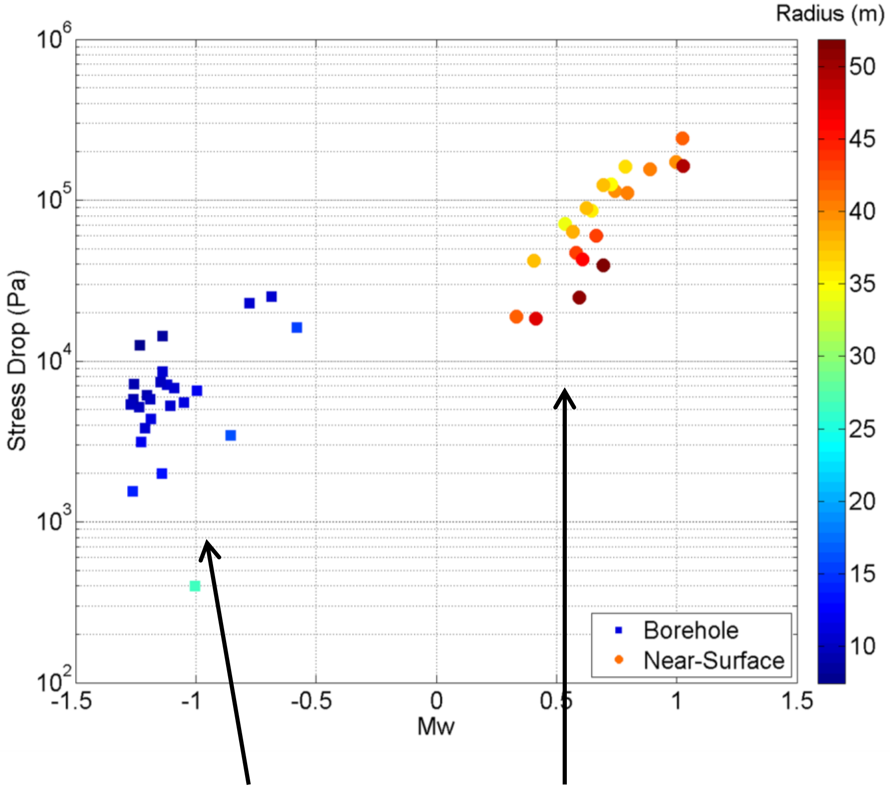






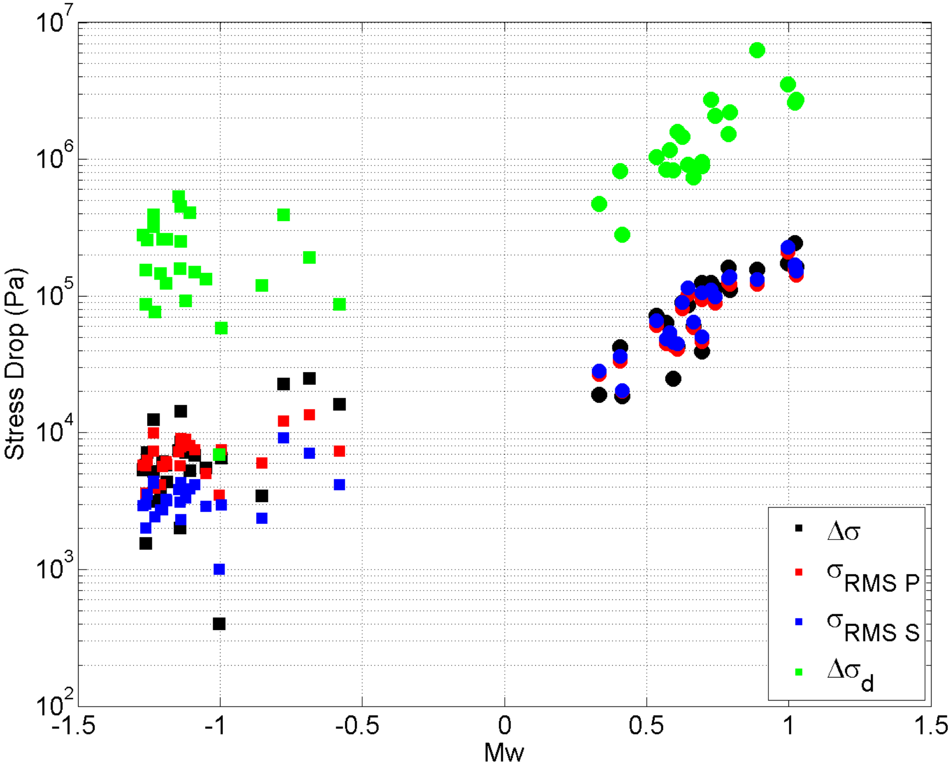


Stress Release Estimates

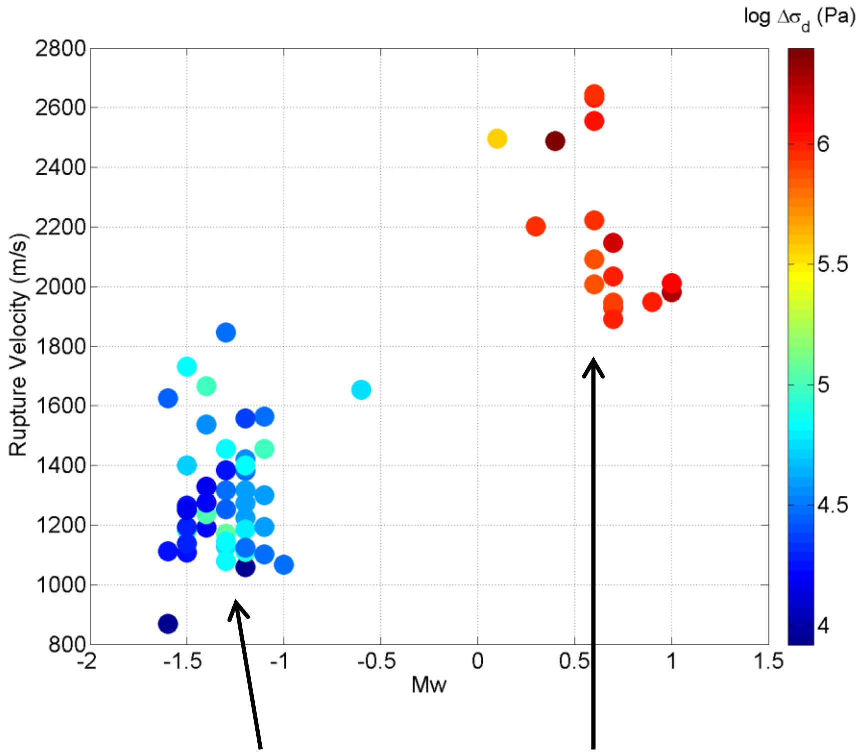


<M0 cluster
borehole
data

>M0 cluster
near-surface
data



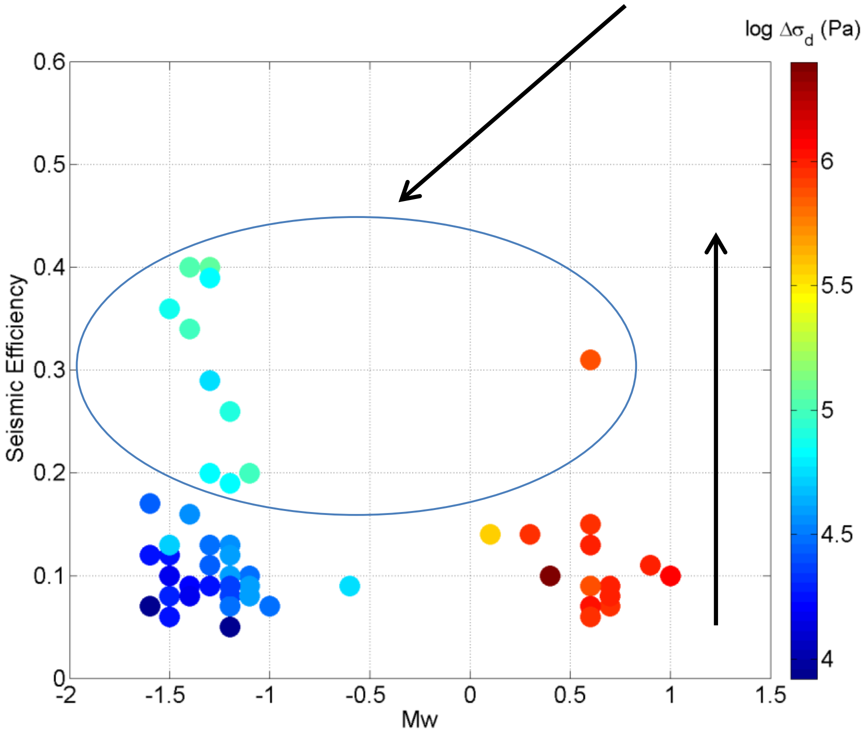
Rupture Characteristics



<M0 cluster
borehole
data

>M0 cluster
near-surface
data

Deeper formation events

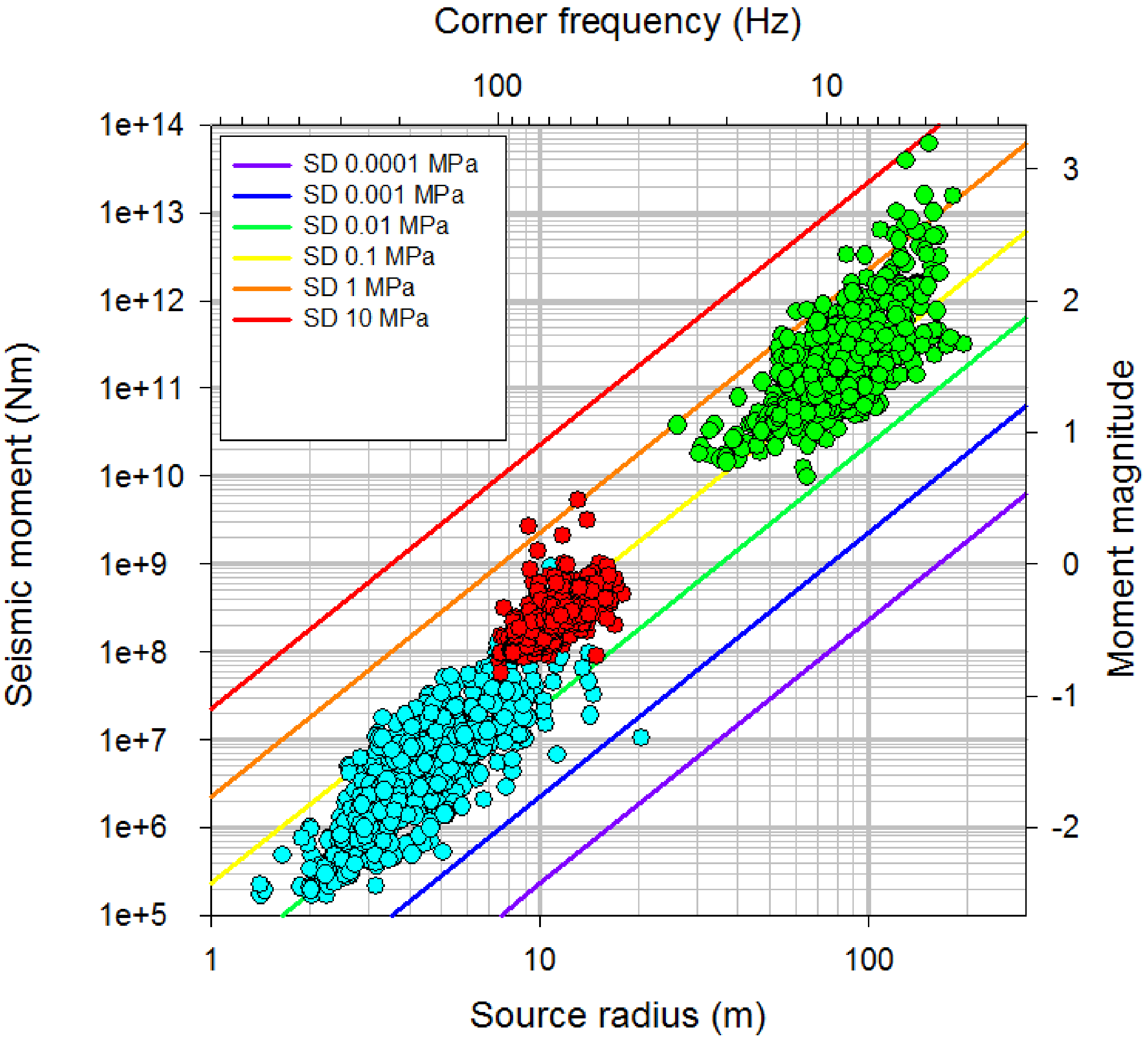


Rupture velocities:

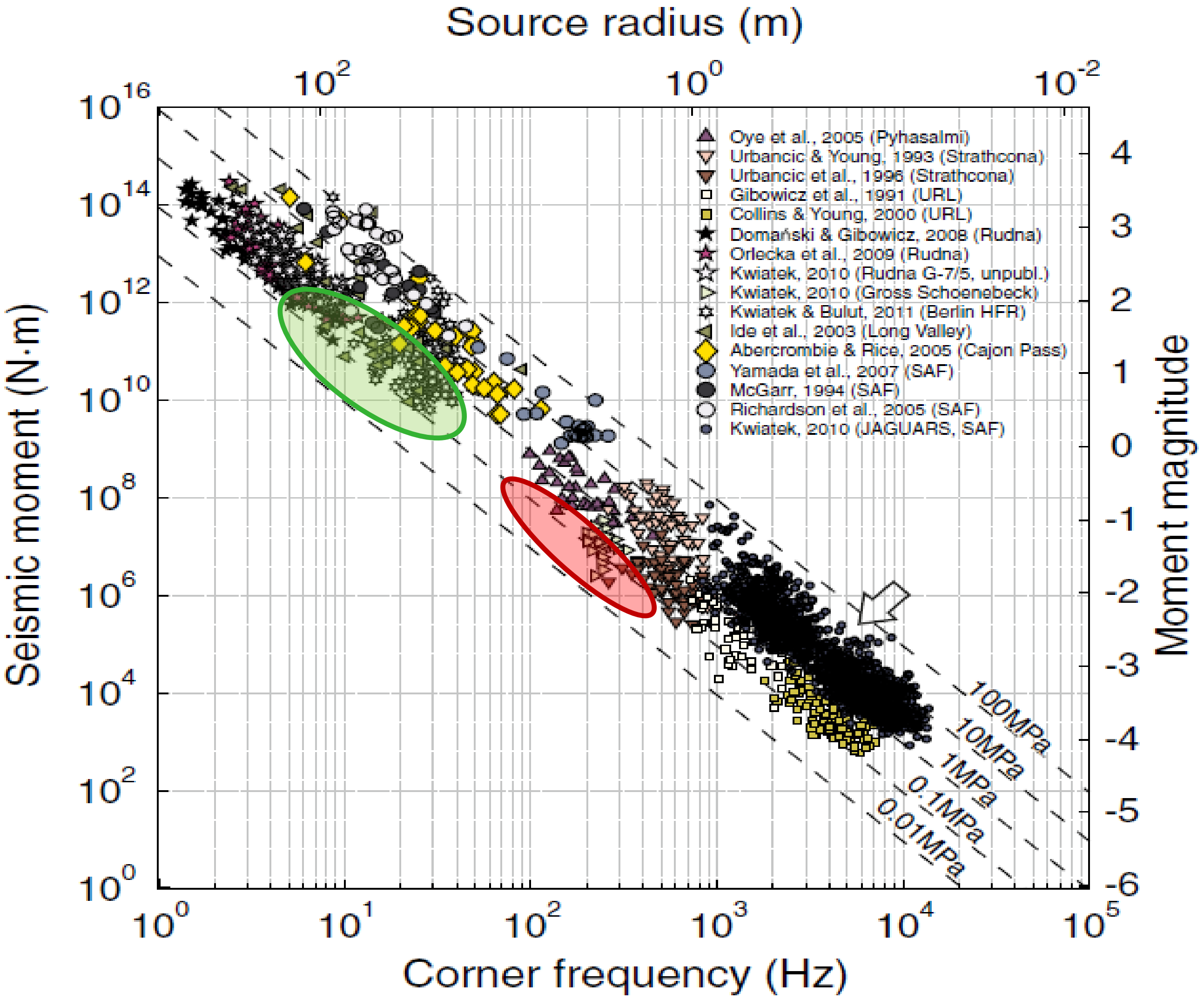
M>0; ~0.5Vs to ~0.8Vs
M<0; ~0.3Vs to ~0.5Vs

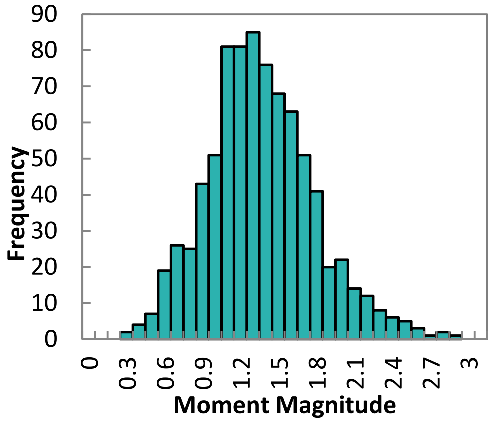
Transition from reservoir to below reservoir events correlate with increasing seismic efficiency – transition from induced to triggered events?

Observed Scaling Behavior



Fracture Scaling





Generally, smaller stress drops are observed for hydraulic fracture stimulations over observed scale sizes

Summary

Hydraulic Fracturing Process

- Generally… Shear-tensile failures with low radiated energy, dynamic stress and seismic efficiency, consistent with slow rupture velocities
  - Increased seismic efficiencies with growth out-of-zone
- Events are overshoot (slip weakening), with fluids lubricating fractures and resulting in a decrease in resisting friction
- Deeper larger events (M>0) tend to have faster rupture velocities and are more efficient in radiating energy
- Stress drop relationships consistent with natural earthquakes

  $\Delta\sigma_d > \Delta\sigma$ and $\Delta\sigma_{RMS;}$ $\Delta\sigma \sim \Delta\sigma_{RMS}$

  For induced seismic events, stress drops scale similarly, however, are generally lower than natural earthquakes
- Suggests the impact of HF events not as pervasive as natural earthquakes

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