Fault activation by hydraulic fracturing in overpressured shale formations

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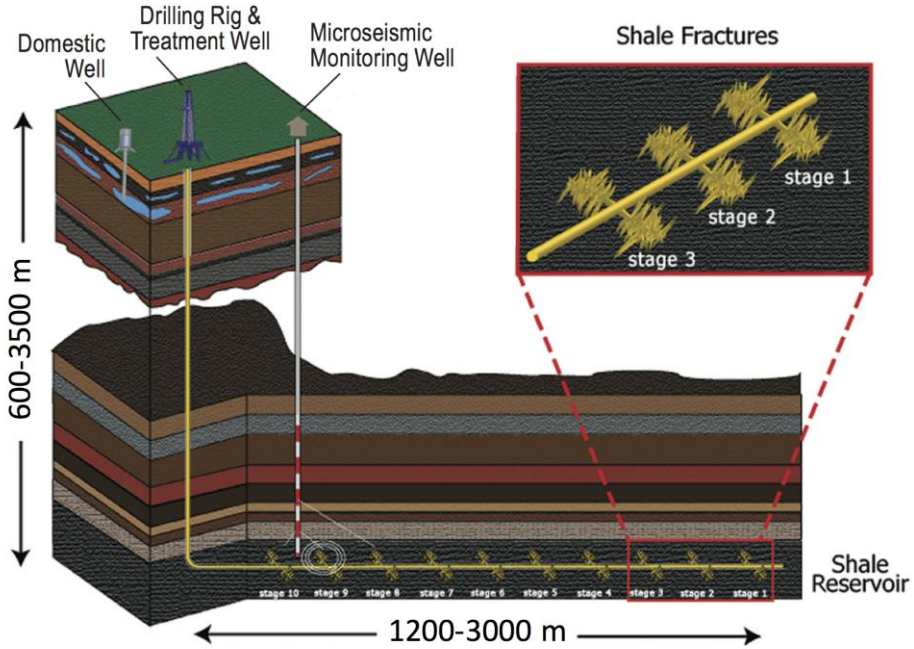
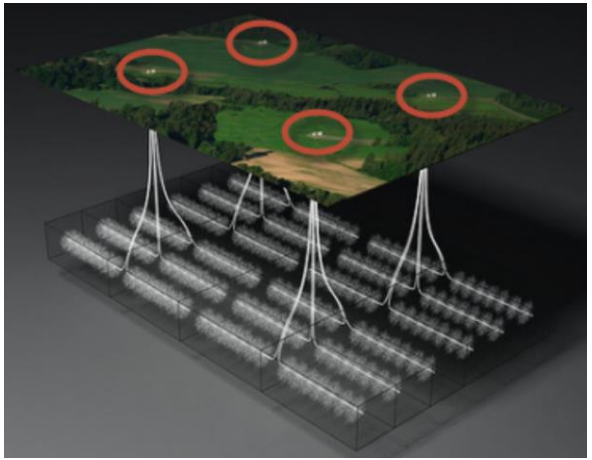
Schatzalp 2nd Induced Seismicity Workshop 14-17 March 2017

Horizontal drilling and multi-stage hydraulic fracturing



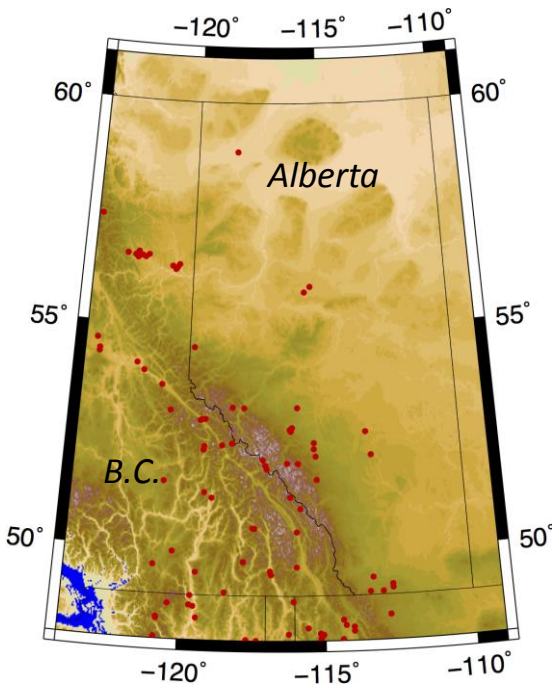


http://crudeoiltrader.blogspot.ca/2012/09/pad-drilling-and-rig-mobility-lead-to.html

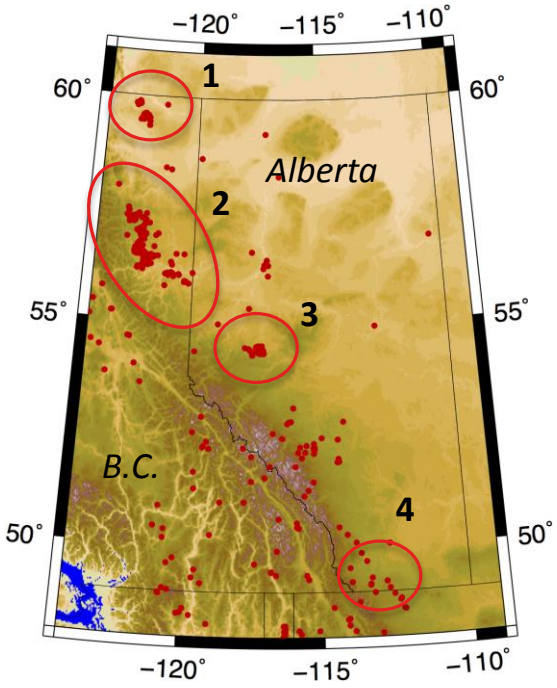
Adapted from Induced Seismicity Potential in Energy Technologies, U.S. National Academy of Sciences, 2012

Western Canada Sedimentary Basin seismicity

2001-2008 (*N* = 97)



2009-2016 (*N* = 429)

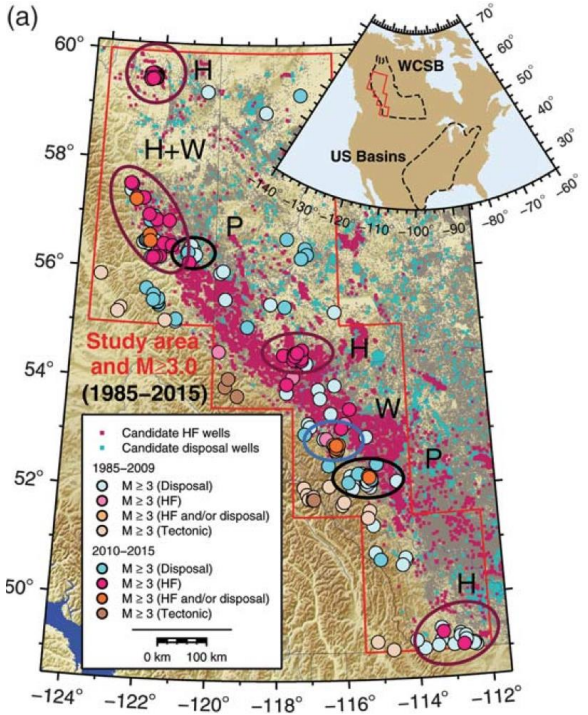


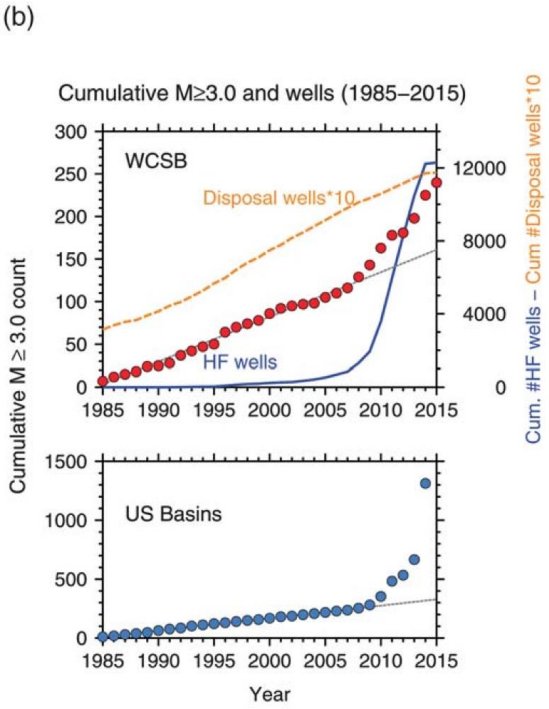
Seismicity clusters with inferred link to hydraulic fracturing

1. Horn River basin (BC Oil and Gas Commission, 2012)
2. Montney (BC Oil and Gas Commission, 2013)
3. Duvernay (Schultz et al., GRL, 2015)
4. Alberta Bakken (Schultz et al., BSSA, 2014)

Source: inducedseismicity.ca/catalogues/ $M_L \geq 2.5$ (probable quarry blasts removed)

Is hydraulic-fracturing (HF) induced seismicity more prevalent in Canada than in the U.S. midcontinent?





Summary of Seismicity Associated with Wells in the Western Canada Sedimentary Basin

	Disposal	HF	Tectonic M ≥3
Number of candidate wells (1985–2015)	1236	12,289	—
Number of wells associated with **M** ≥3	17	39	—
Association % for wells (**M** ≥3)	~1%	~0.3%	—
Number of **M** ≥3 (1985–2009)	126*	13*	14
Number of **M** ≥3 (2010–2015)	33*	65*	7
Association % for **M** ≥3 (2010–2015)	31%	62%	7%

Atkinson et al., SRL (2016)

Comparison with Ohio

Ohio

1400 HF wells: 6 cases of induced seismicity = 0.4%
200 disposal wells: 3 cases of induced seismicity = 1.5%

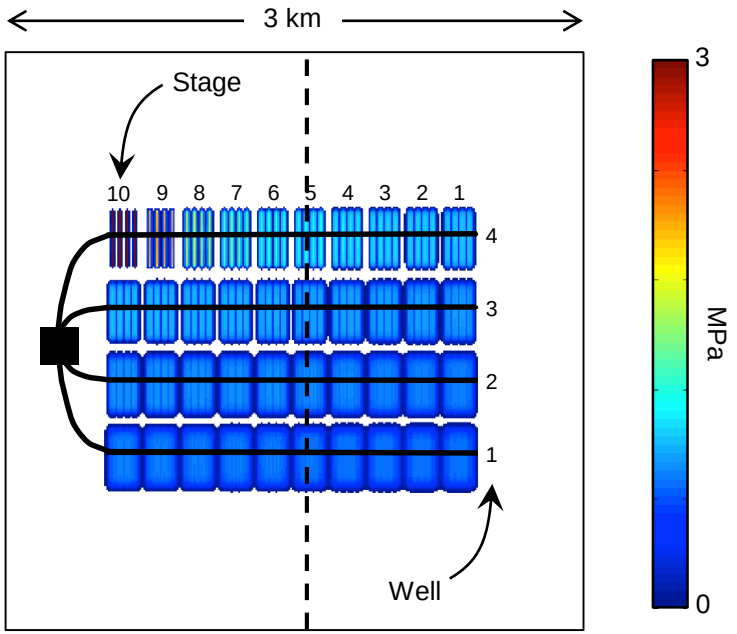
Skoumal et al., JGR (2015)

Western Canada

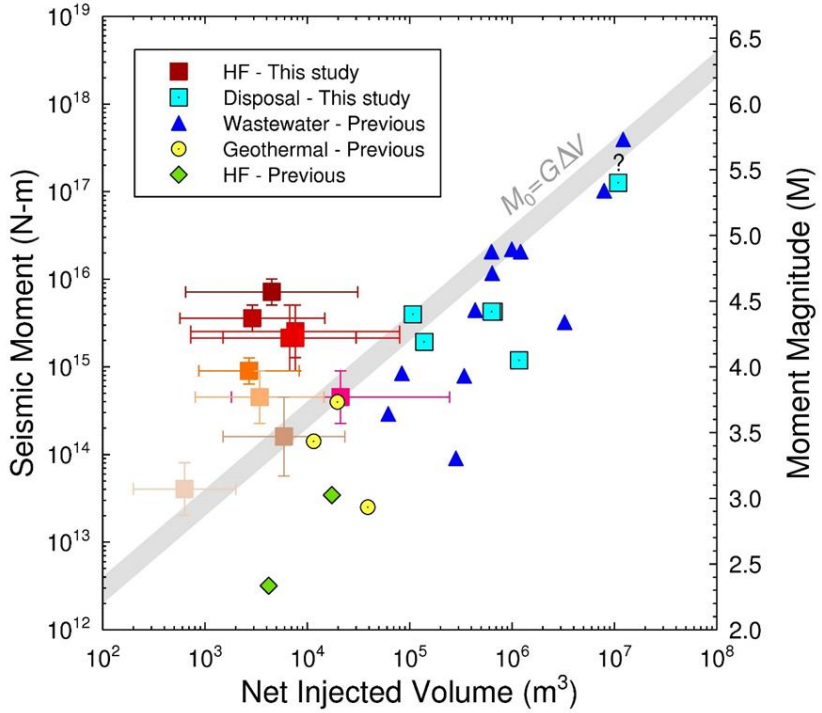
12,300 HF wells: 39 cases of induced seismicity = 0.3%
1240 disposal wells: 17 cases of induced seismicity = 1.4%

Atkinson et al., SRL (2016)

Maximum magnitude and injected volume

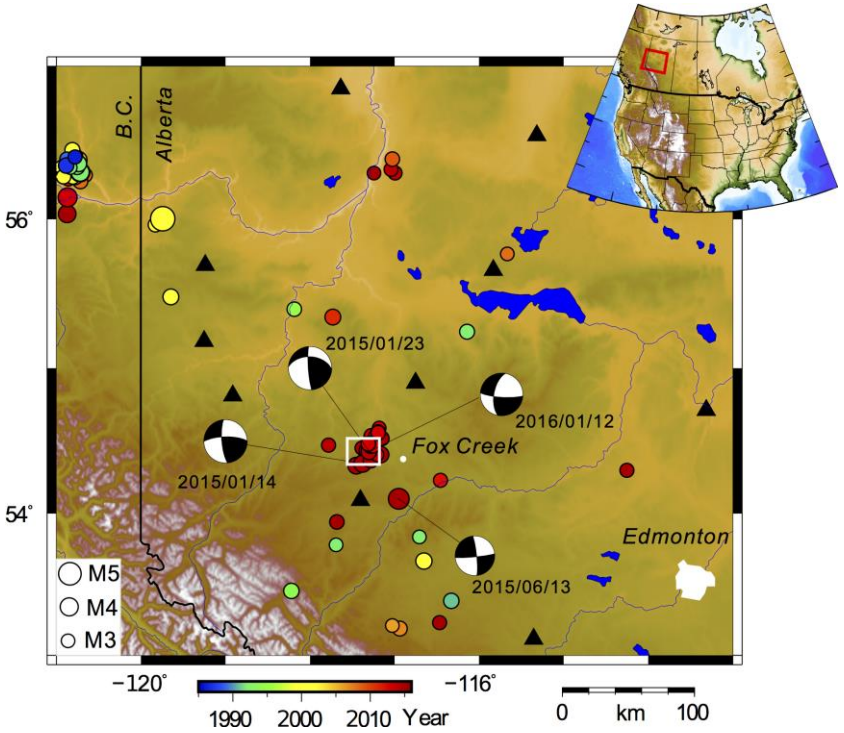


Pore pressure model for well pad

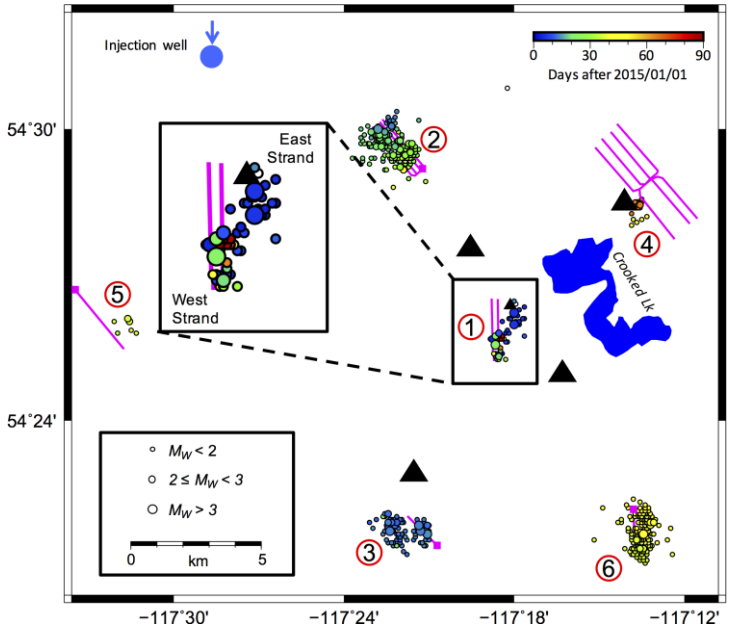


Atkinson et al., SRL (2016)

Case study: Fox Creek, Alberta



Duvernay shale

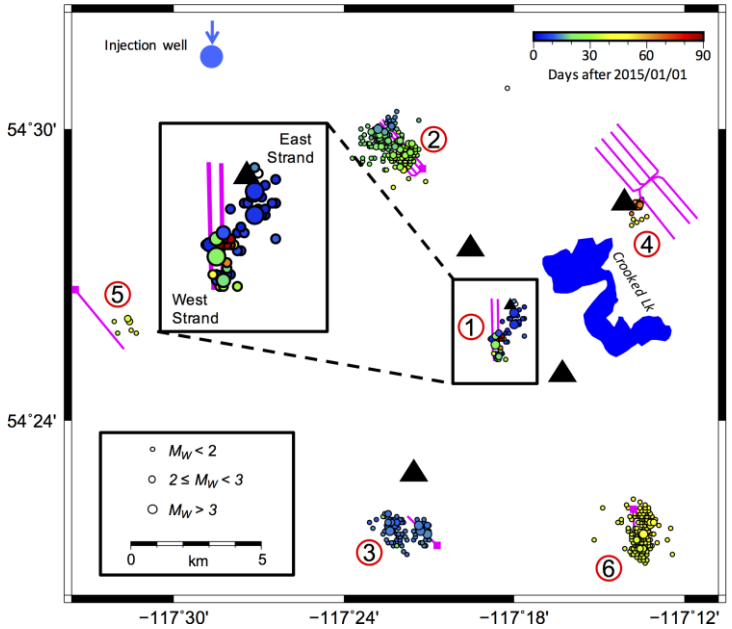


Bao and Eaton, Science (2016)

Case study: Fox Creek, Alberta

Duvernay shale

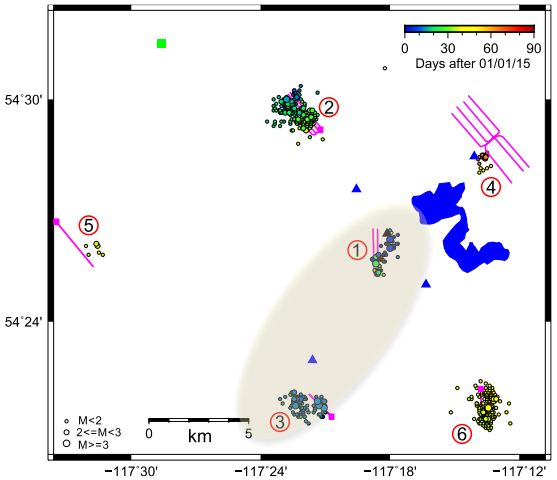
- Winter 2015 Duvernay completions at 6 pads
- Template matching + double-difference relocations
- Seismicity strongly clustered near HF operations
- Cluster 1 suggests two fault strands



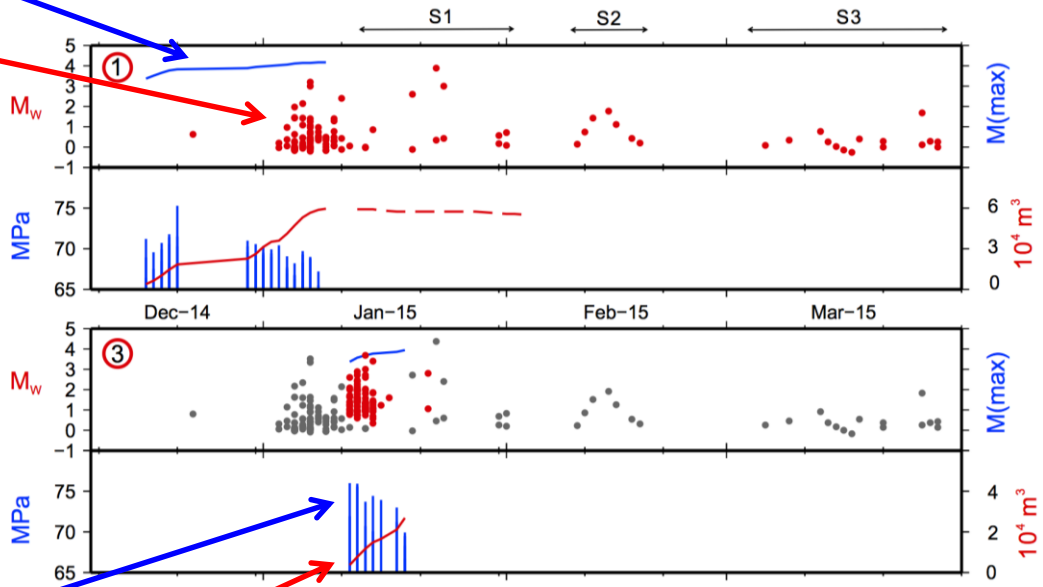
Bao and Eaton, Science (2016)

Case study: Fox Creek, Alberta

Predicted maximum magnitude
Event magnitudes



Comparison with injection data

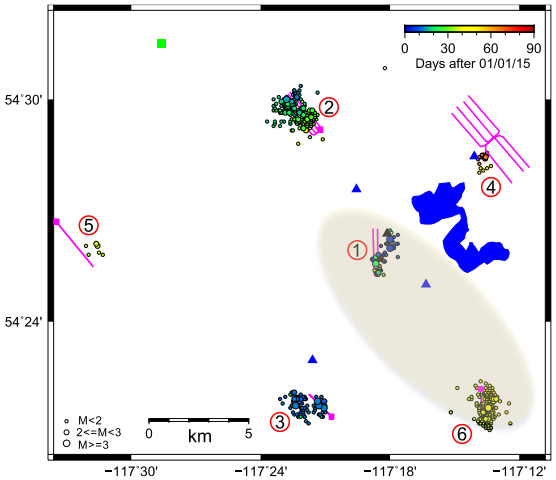


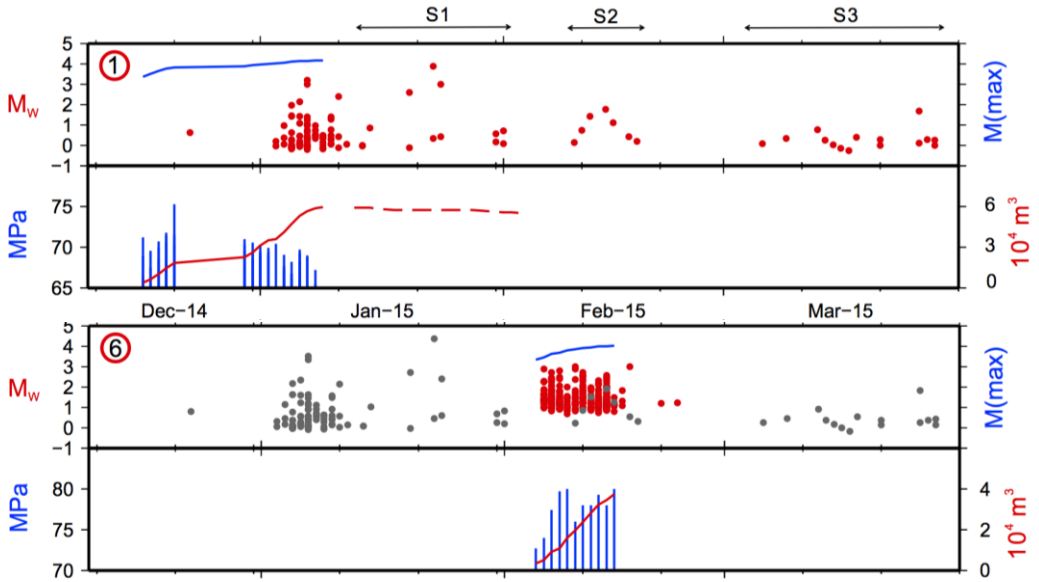
Injection pressure
Cumulative injected volume

Bao and Eaton, Science (2016)

Case study: Fox Creek, Alberta

Comparison with injection data

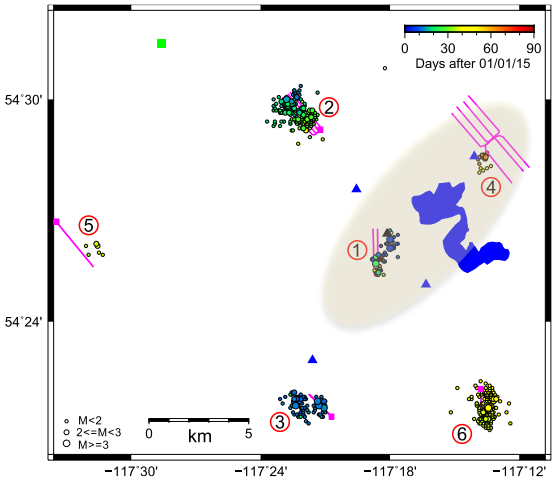


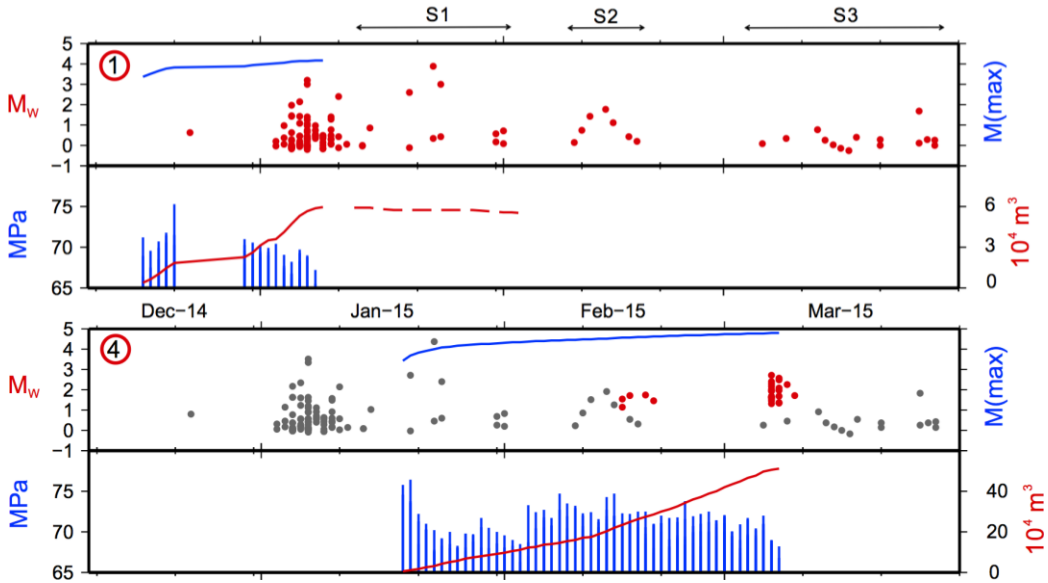


Bao and Eaton, Science (2016)

Case study: Fox Creek, Alberta

Comparison with injection data

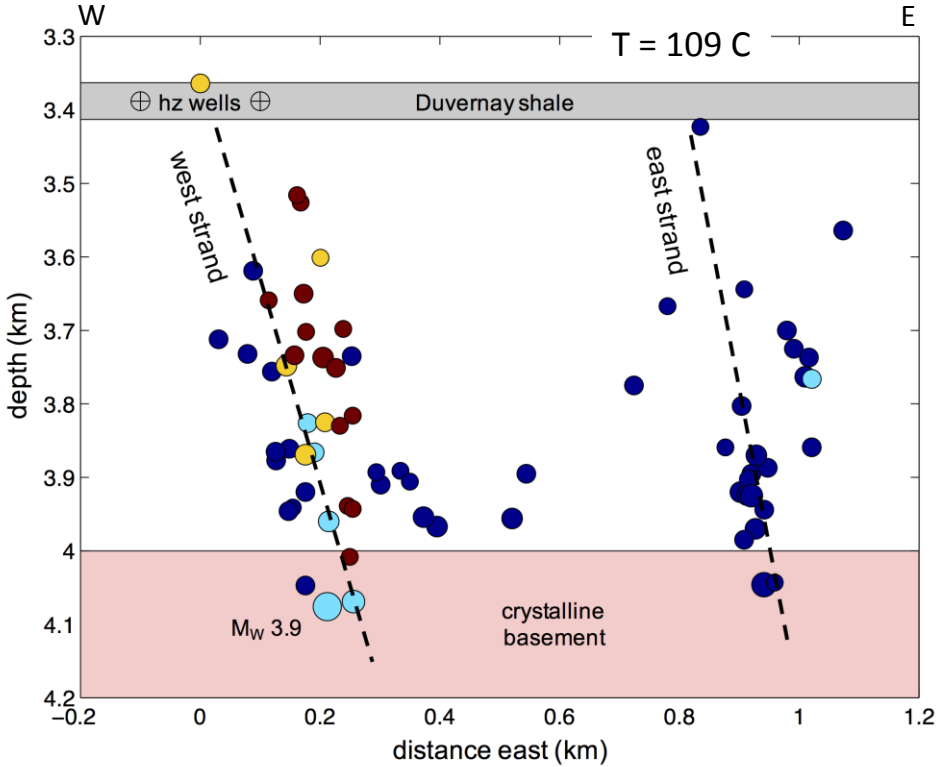




Bao and Eaton, Science (2016)

Fault activation

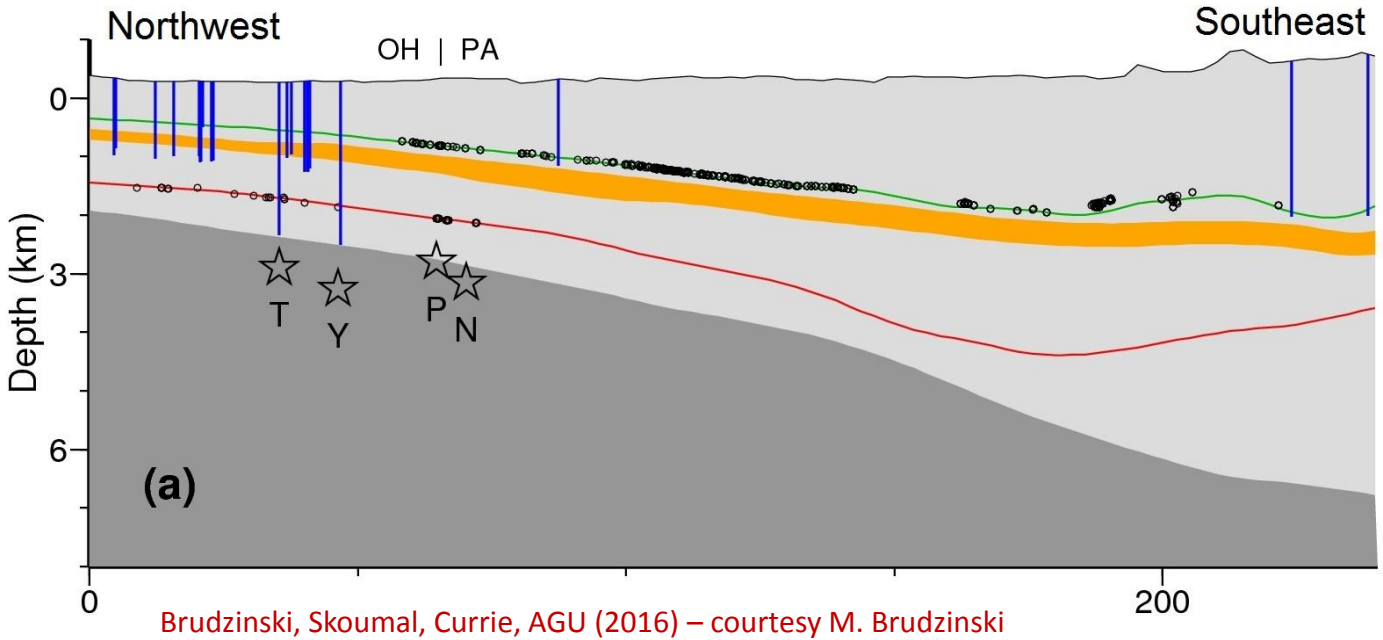
- ~ optimally oriented fault strands extending into crystalline basement
- More persistent west strand projects to location between two zipper-frac'd horizontal wells
- Transient response of east strand is best explained by stress, not pore pressure



Bao and Eaton, Science (2016)

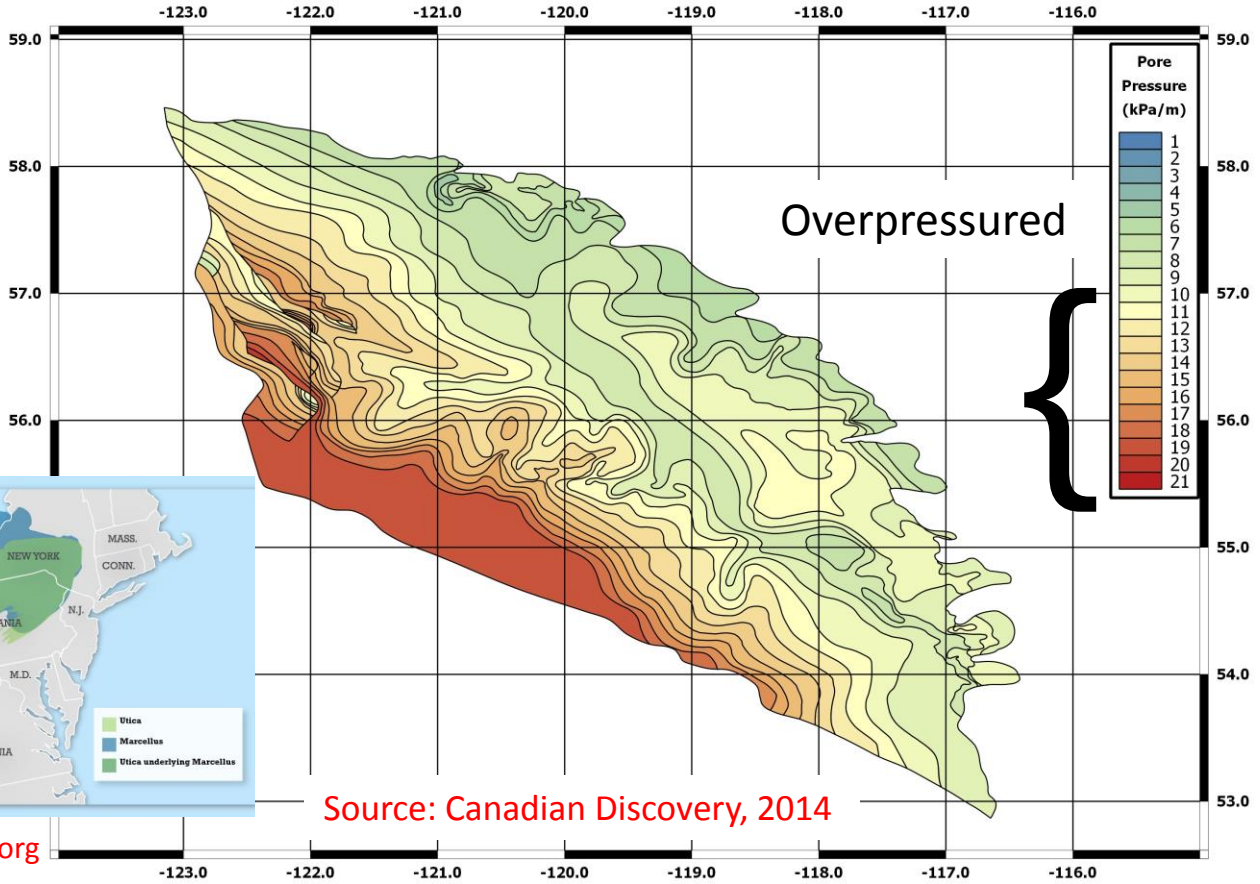
Distance of target formation to basement

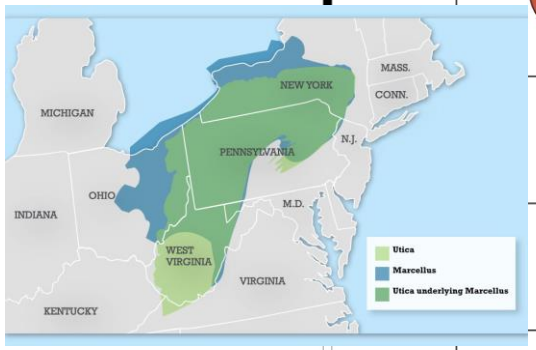
- Proximity of basement appears to raise likelihood of induced seismicity
- In central US, basement primarily hosts faults capable of M>2 seismicity



Brudzinski, Skoumal, Currie, AGU (2016) – courtesy M. Brudzinski

Montney Fairway: Pore Pressure





marcelluscoalition.org

Source: Canadian Discovery, 2014

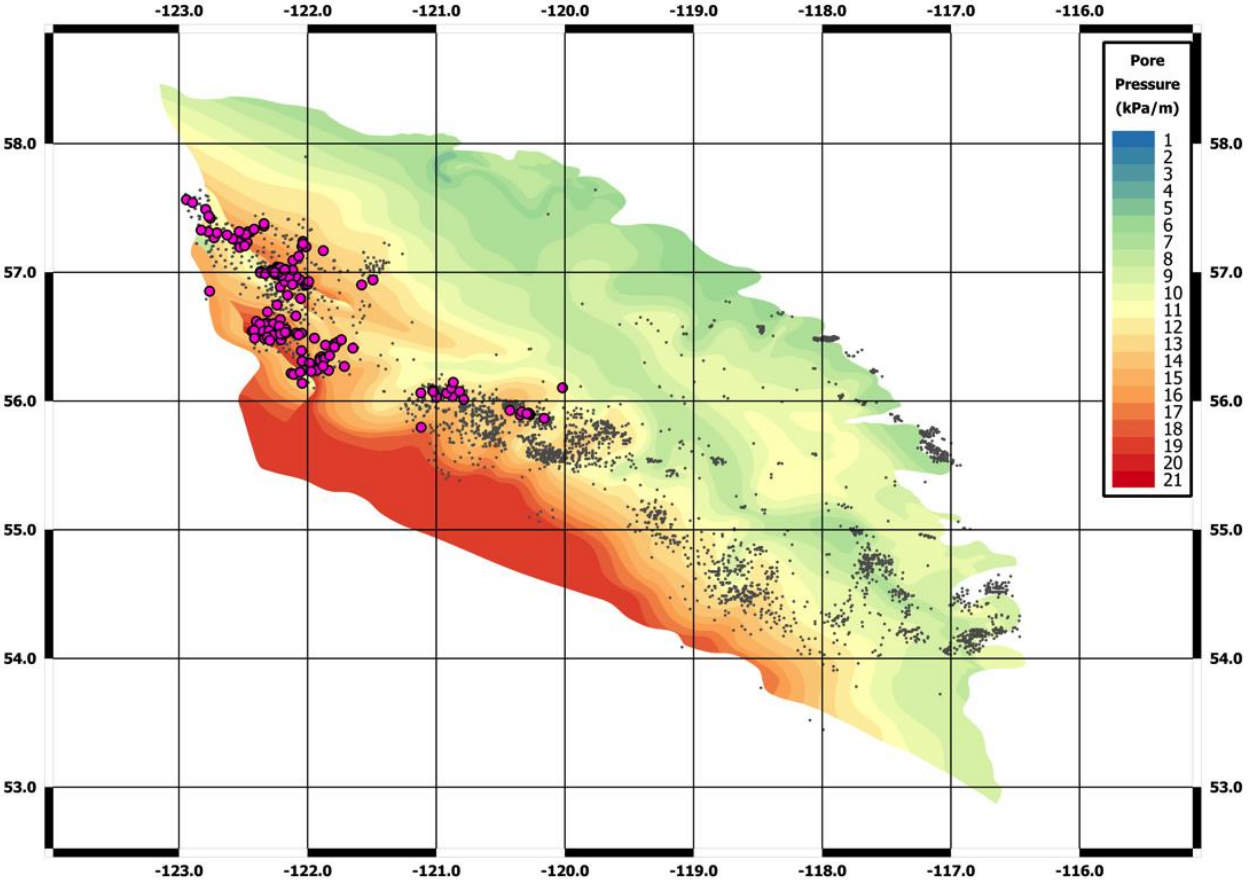
Compaction disequilibrium

Thermogenic processes

Montney Fairway: HFIS

Black dots:
5489
HF wells

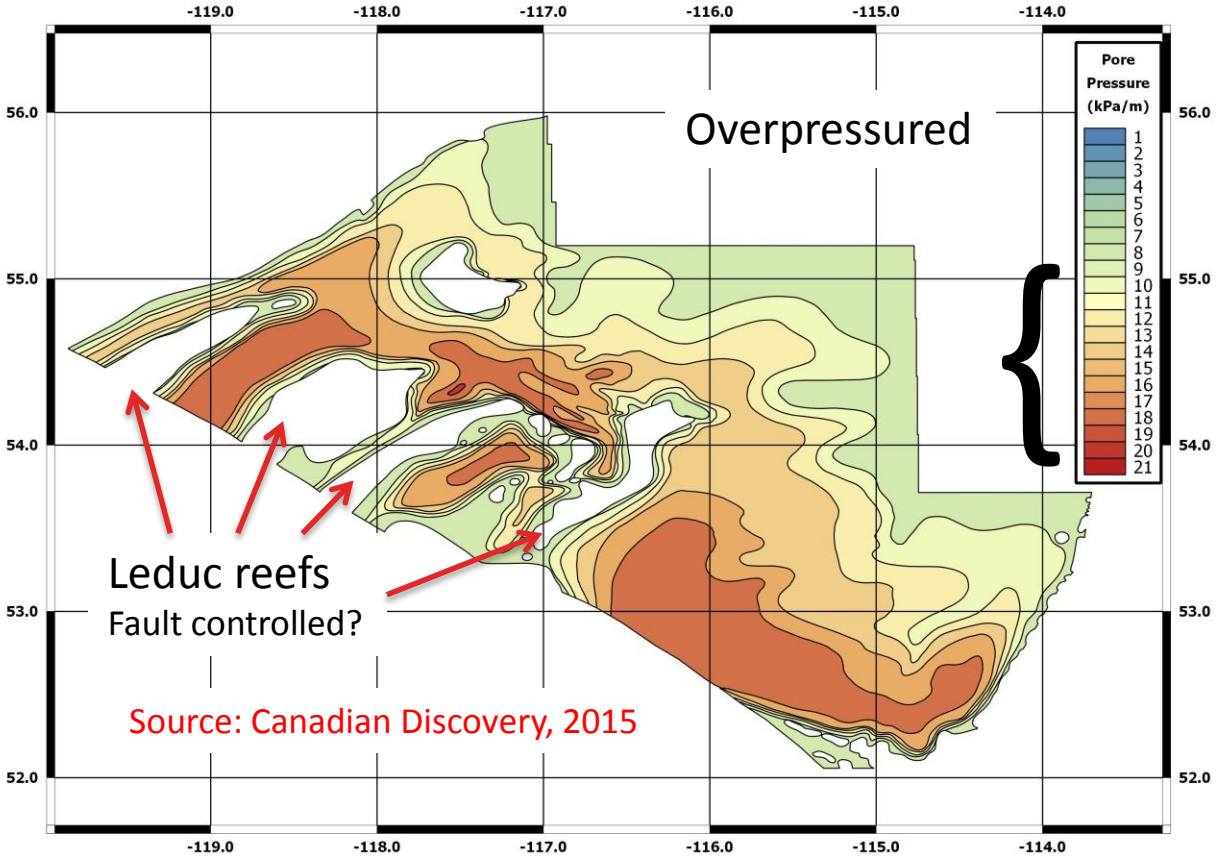
Source:
Geoscout



Magenta circles:
154 post-2009 earthquakes ($M_L \geq 2.5$)

Source: NRCan

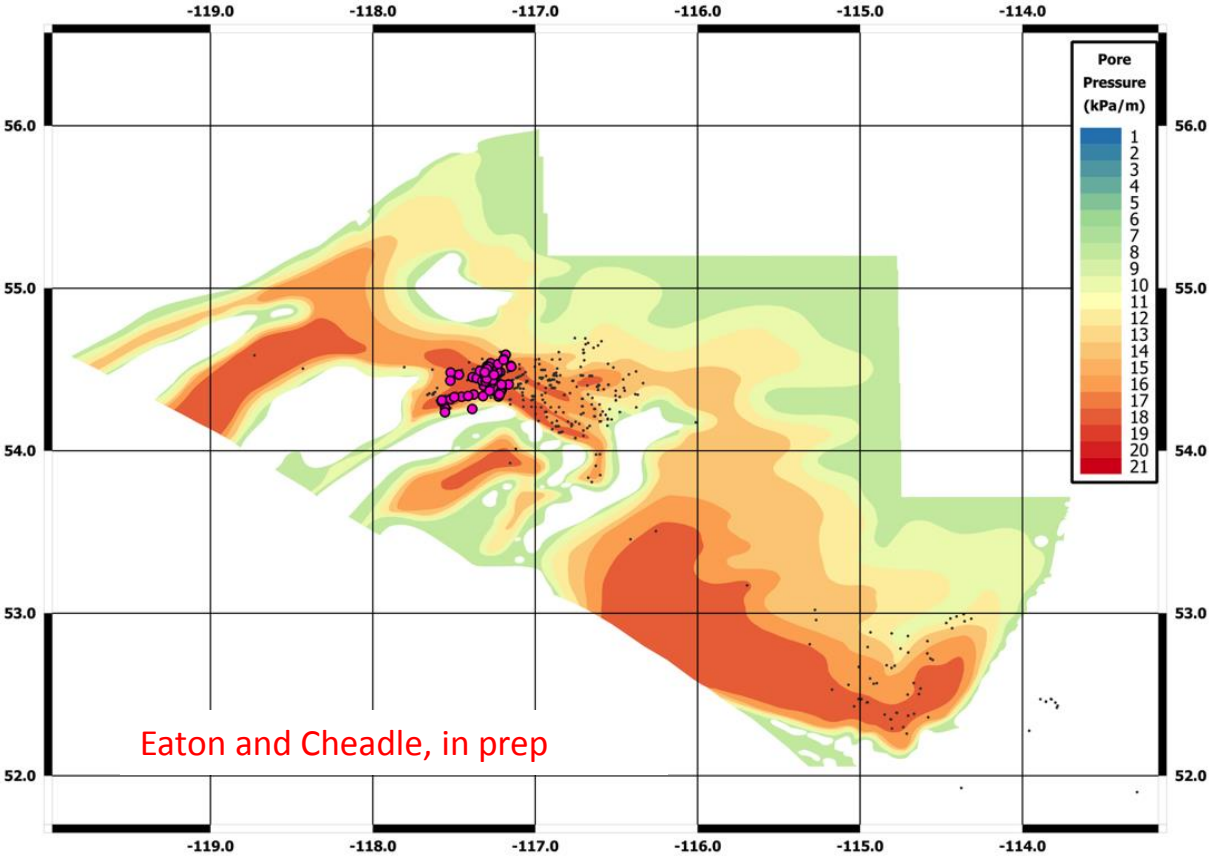
Duvernay Fairway: Pore Pressure



Duvernay Fairway: HFIS

Black dots:
374
HF wells

Source:
Geoscout

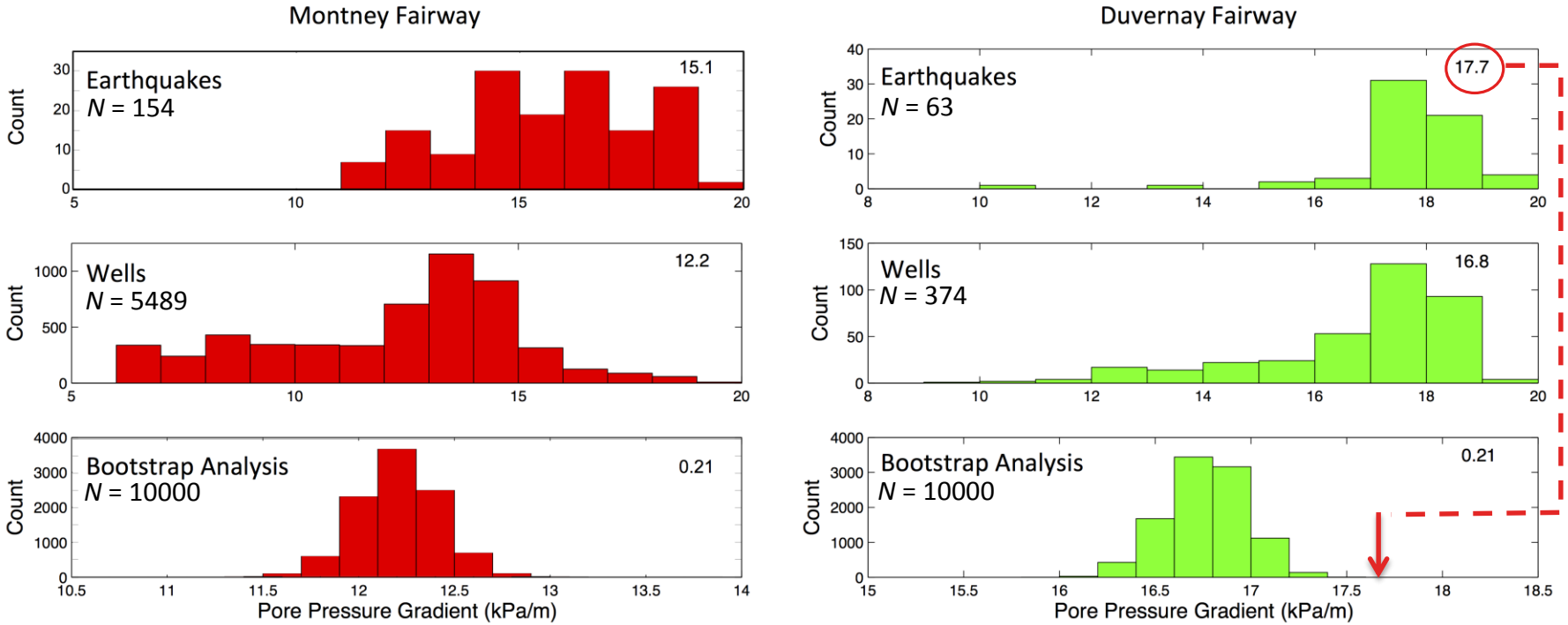


Magenta circles:
63 post-2009 earthquakes ($M_L \geq 2.5$)

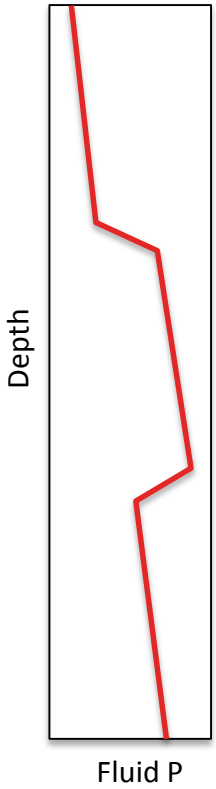
Source: NRCan

Random chance? Unlikely

Bootstrap Analysis



Petroleum system fault-valve model[1]

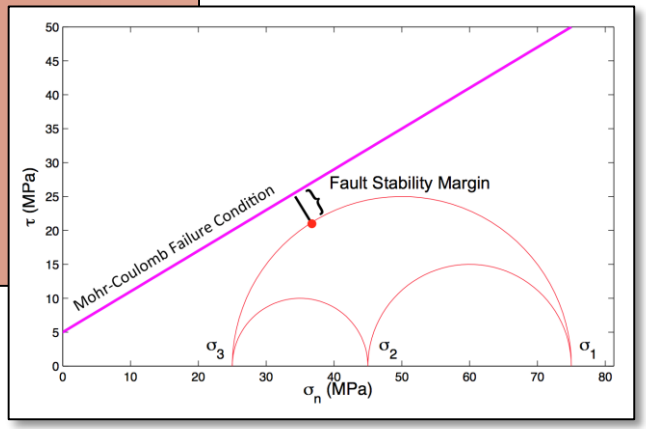


2. State of dynamic equilibrium is achieved as pore-pressure diffuses into adjacent layers

4. Episodic fault slip facilitates hydrocarbon migration

1. Organic-rich shale in oil/gas generation window provides source of elevated pore pressure

3. Pre-existing fault is brought to critically stressed state by elevated pore pressure

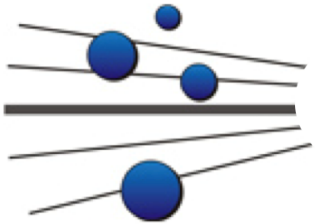


[1] Sibson, Tectonophysics, 1992

Conclusions

1. In western Canada and Ohio (Utica play), HF induced seismicity is associated with ~0.3-0.4% of MFHW completions and ~1.4-1.5% of disposal wells
2. In some cases, maximum magnitude exceeds a predicted limit based on net injected volume (McGarr 2014)
3. Distinct activation signatures of poroelastic stress triggering (transient) and fluid-pressurized faults (more persistent)
4. Spatial correlation of seismicity clusters with shale overpressure; petroleum system fault-valve model?

Acknowledgements



Microseismic Industry Consortium