



Unconventional Resource Development and Induced Seismicity in Western Canada



David W. Eaton, Department of Geoscience



"Most experts judge the risk of hydraulic fracturing causing earthquakes to be low."

CCA Expert Panel Report, 2014

"Earthquake activity has sharply increased since 2009 in the central and eastern United States ... linked to industrial operations that dispose of wastewater..."

USGS Newsroom 23 April 2015

Investigation of Observed Seismicity in the Horn River Basin

BC Oil and Gas Commission - August 2012



ENVIRONMENTAL IMPACTS OF SHALE GAS EXTRACTION IN CANADA

The Expert Panel on Harnessing Science and Technology to Understand the Environmental Impacts of Shale Gas Extraction

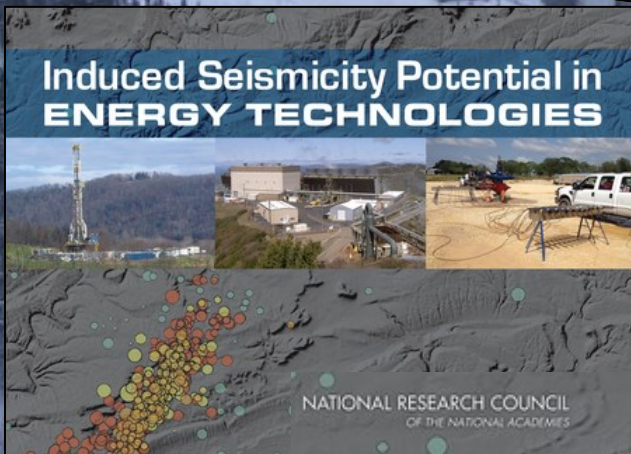
LE DÉVELOPPEMENT DU GAZ DE SCHISTE AU QUÉBEC

Ressources naturelles
et Faune

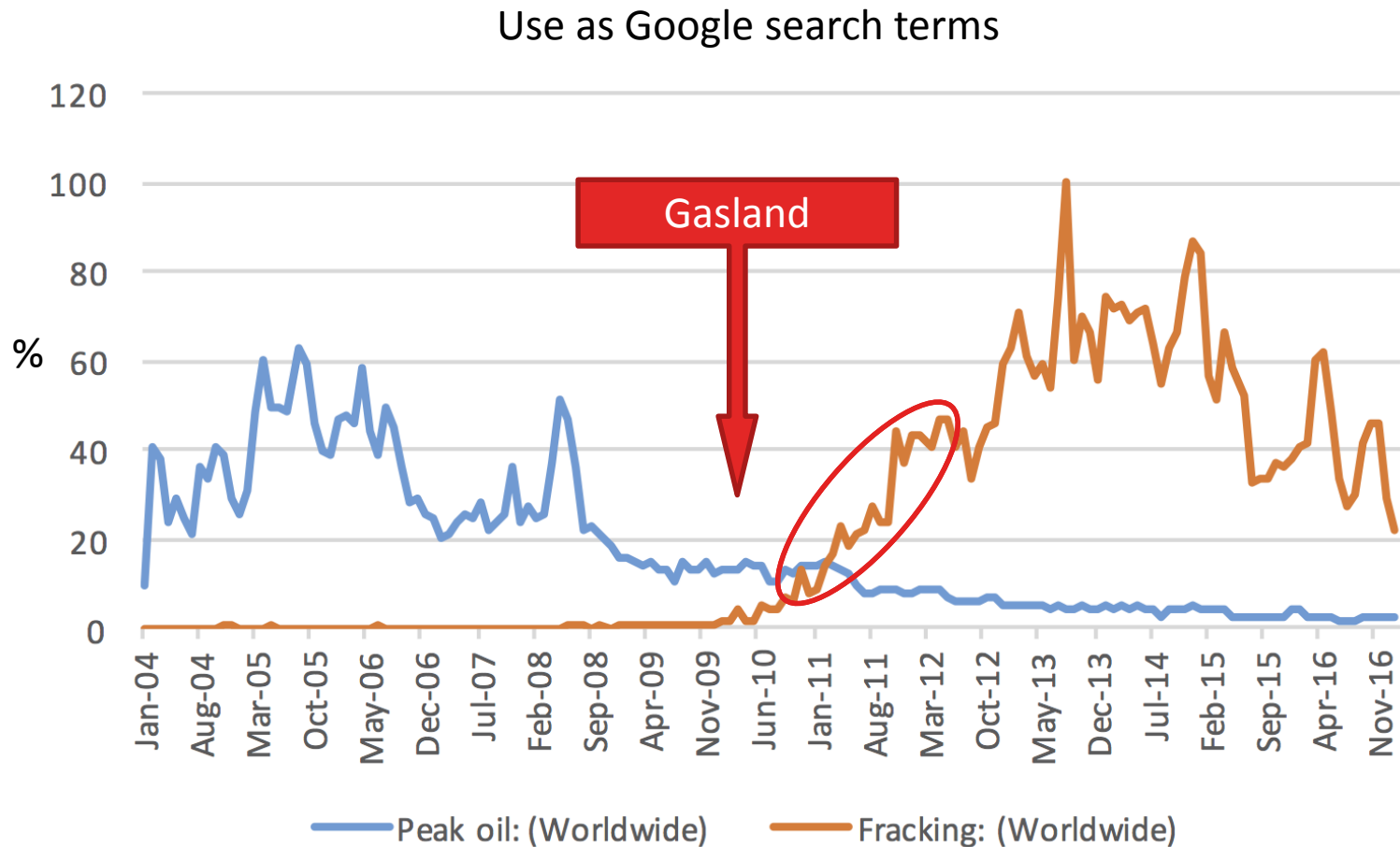
Québec

'Man-made' earthquakes: Is fracking adding to seismic activity in US?
Two new reports, released this week, show links between higher seismic activity in typically dormant areas and the injection of wastewater from hydraulic fracturing operations underground.

YAHOO! NEWS

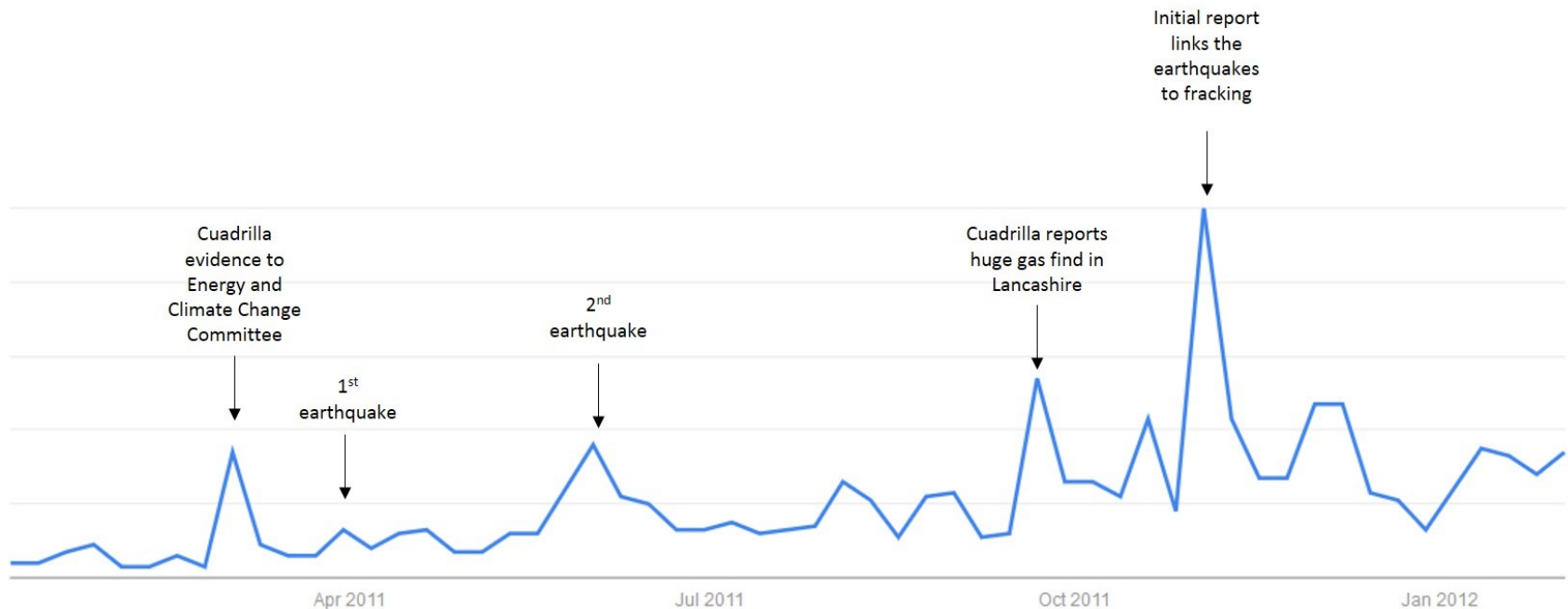


Google Trends: Peak Oil vs. Fracking



Public reaction to induced earthquakes

Use of “fracking” as a Google search term (UK)



<https://drillordrop.com/2016/04/01/fracking-campaigners-mark-earthquake-anniversary-with-wake-up-call-protest/>

Induced seismicity:

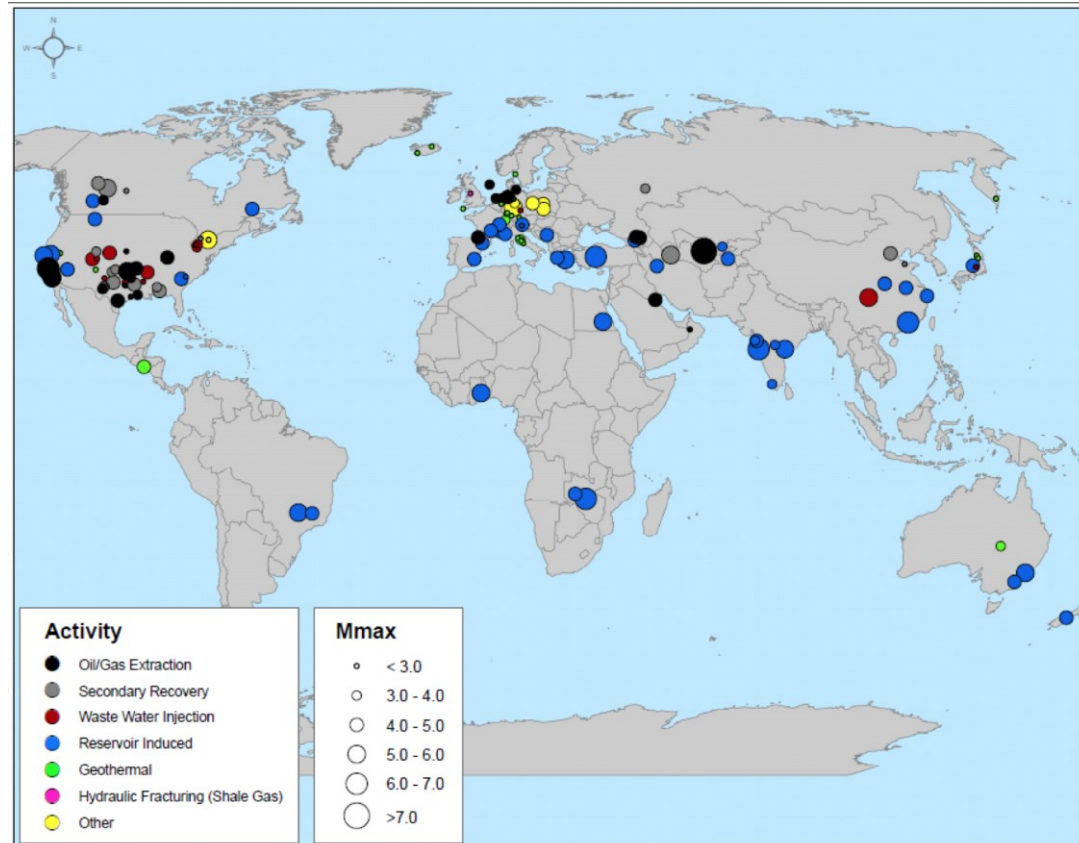
Earthquakes attributed to human activity.

Energy Technologies:

- Impoundment of large reservoirs behind dams
- Geothermal development
- **Injection or withdrawal of fluids from the subsurface**

Other examples:

- Mining
- Underground nuclear tests



NRC, 2012

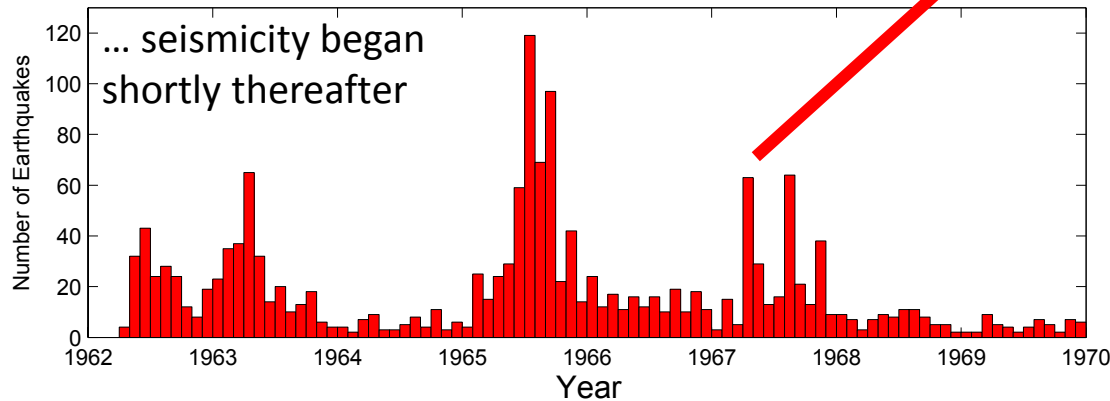
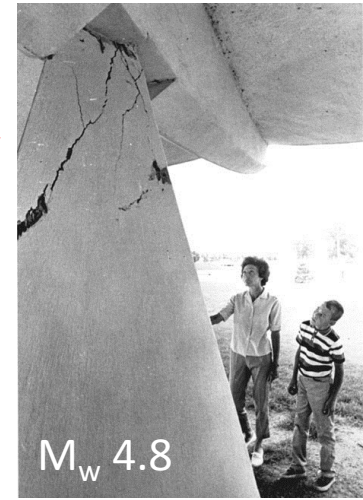
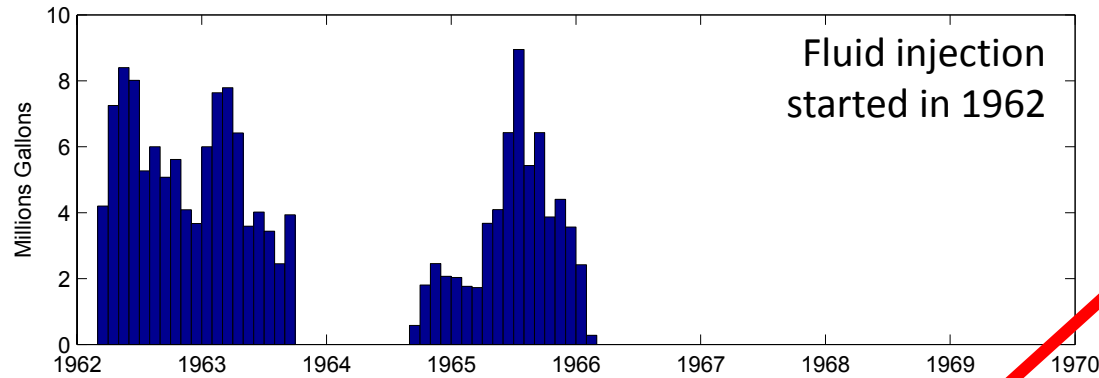
At time of publication of this report in 2012, only one earthquake was believed to be induced by hydraulic fracturing (Preese Hall, UK)

Investigation of Observed Seismicity in the Horn River Basin

BC Oil and Gas Commission - August 2012

- 38 earthquakes induced by hydraulic fracturing (2009 – 2011), in magnitude range 2.2 to 3.8

Rocky Mountain Arsenal (Denver earthquakes)



Healy et al., Science, 1968

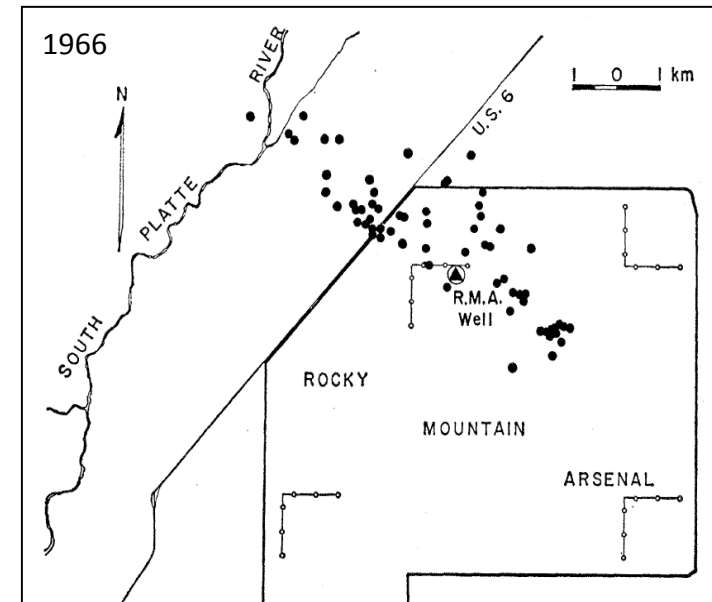
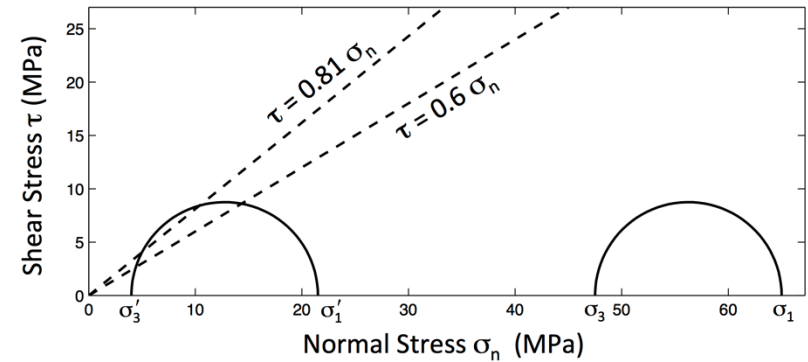
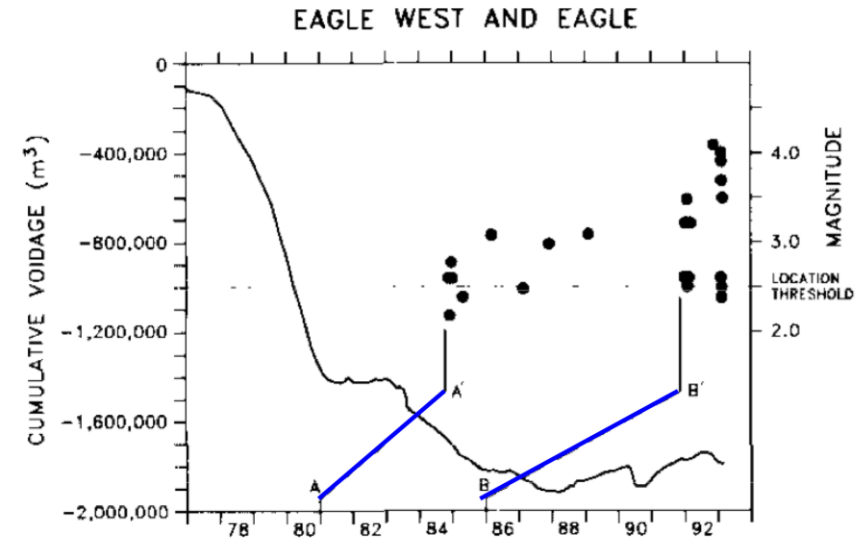
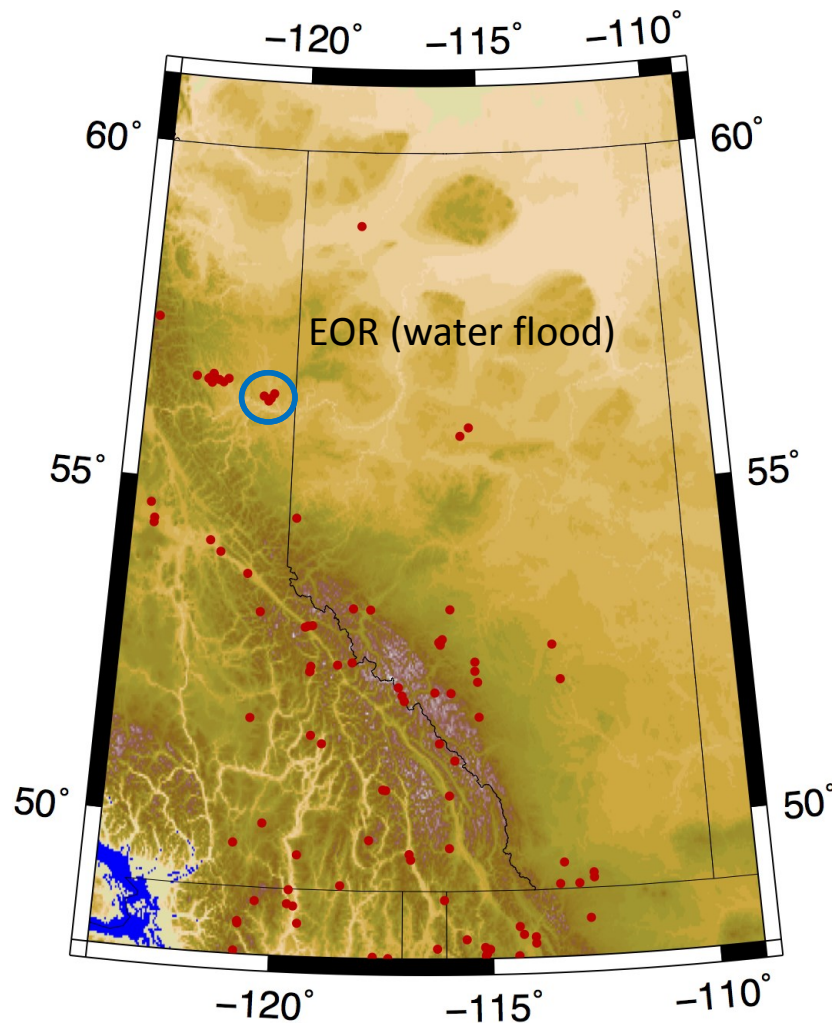


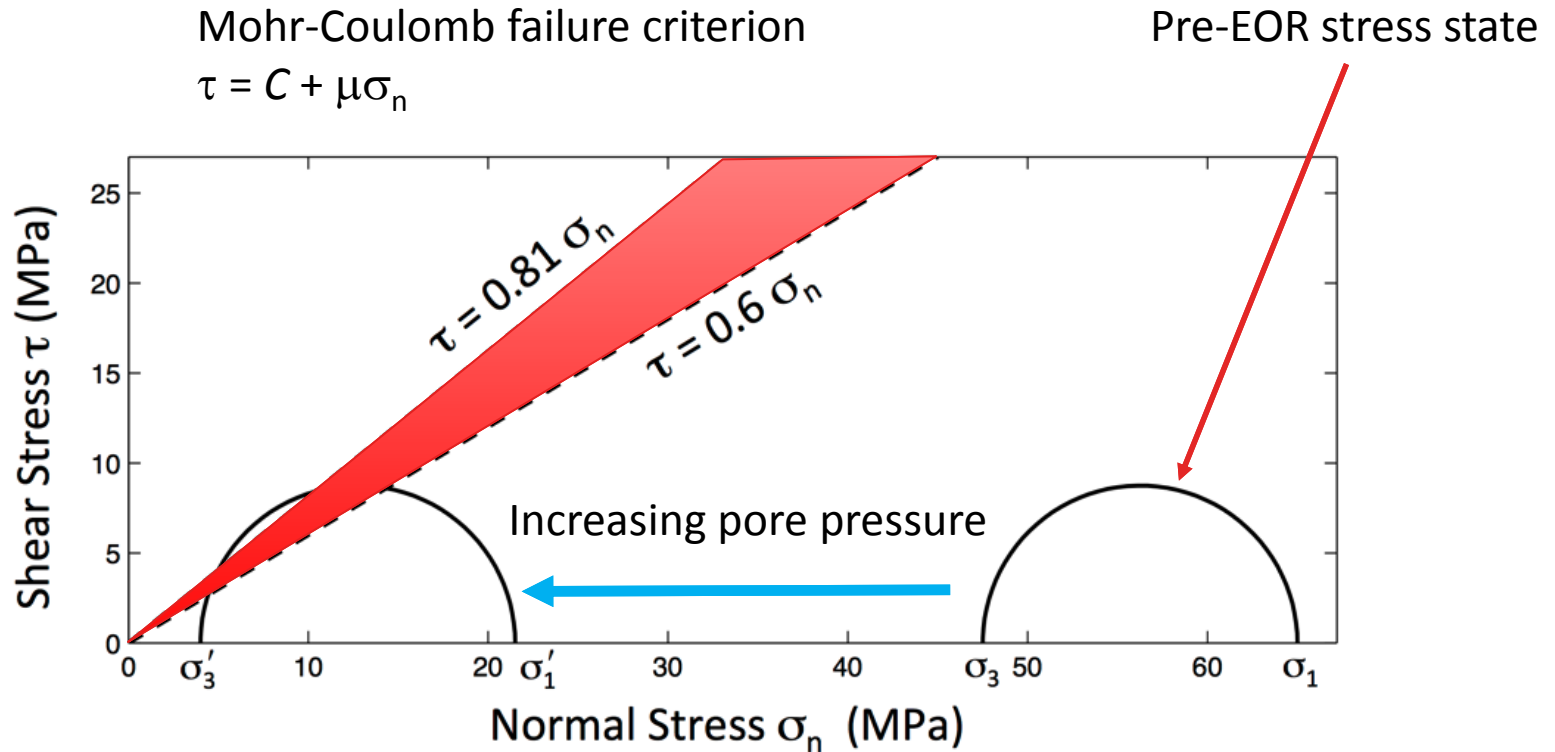
Photo courtesy A. McGarr

2001-2008 ($N = 97$)



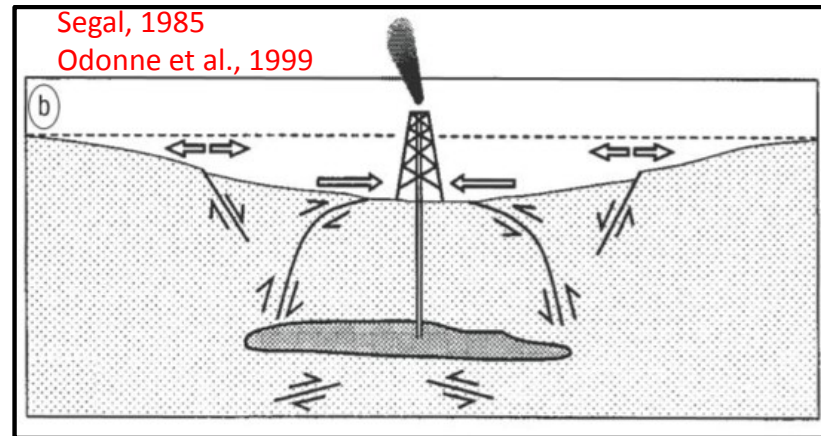
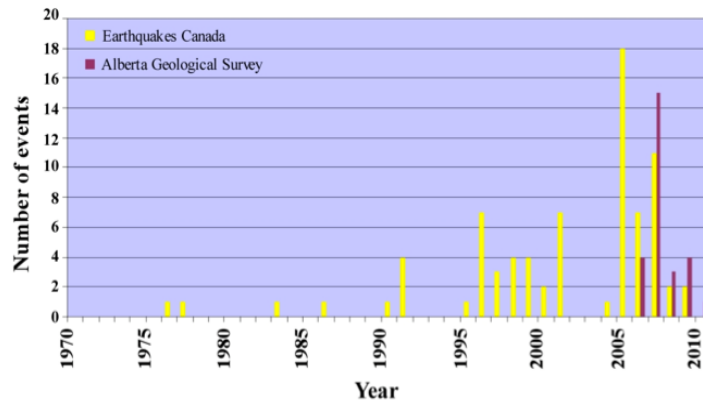
Horner et al., Can. J. Expl. Geophys., 1994

Effect of pore pressure increase

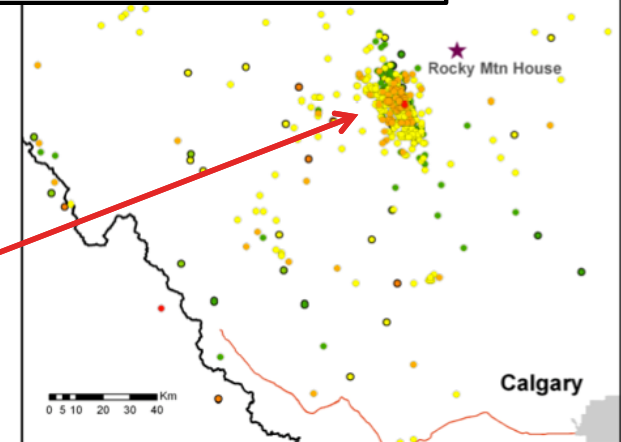
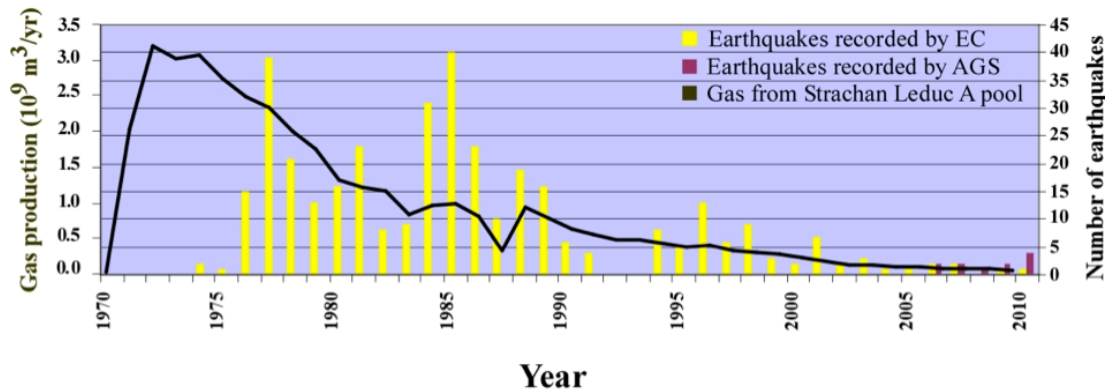


Other induced seismicity (pre 2009)

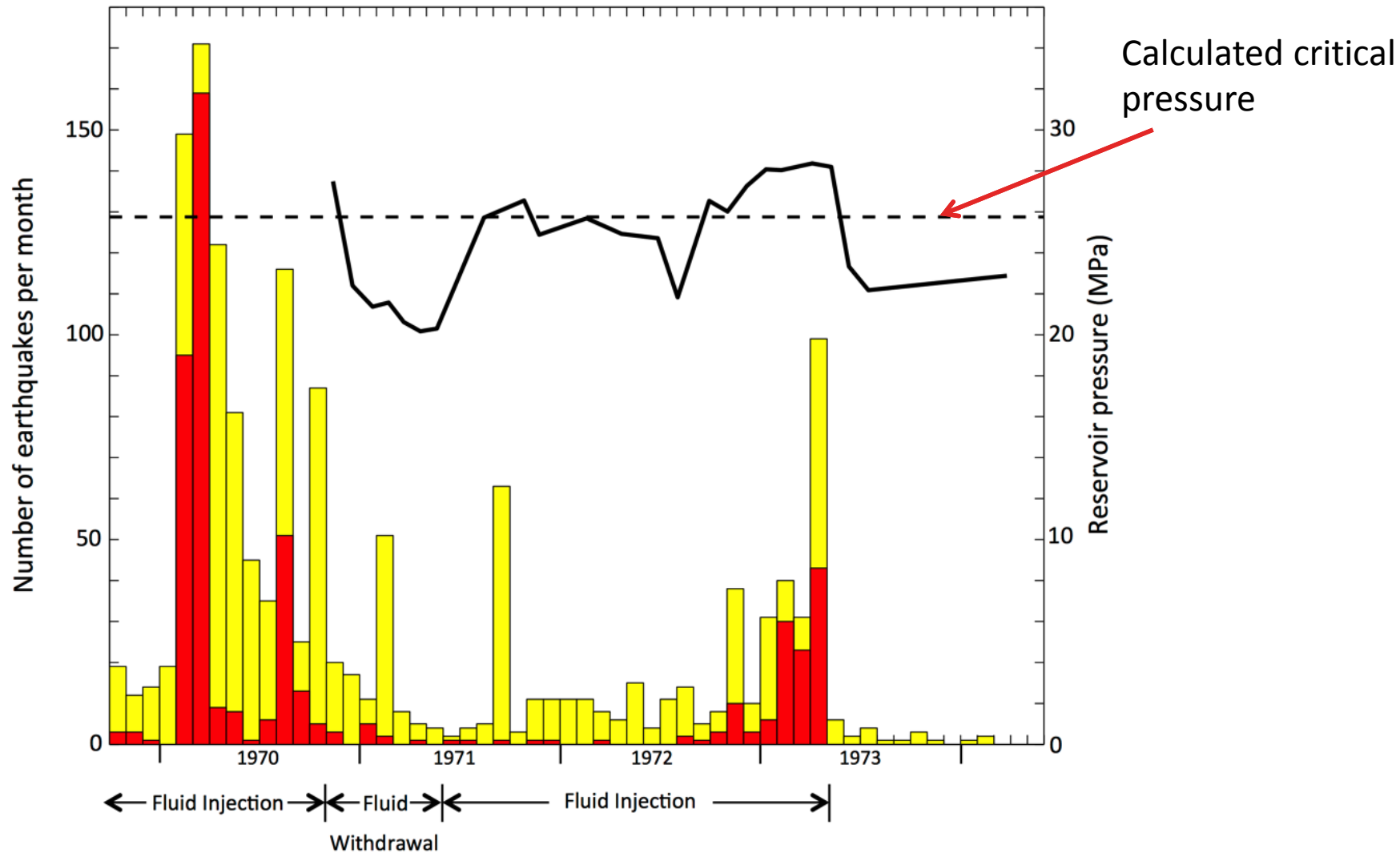
Brazeau River Cluster



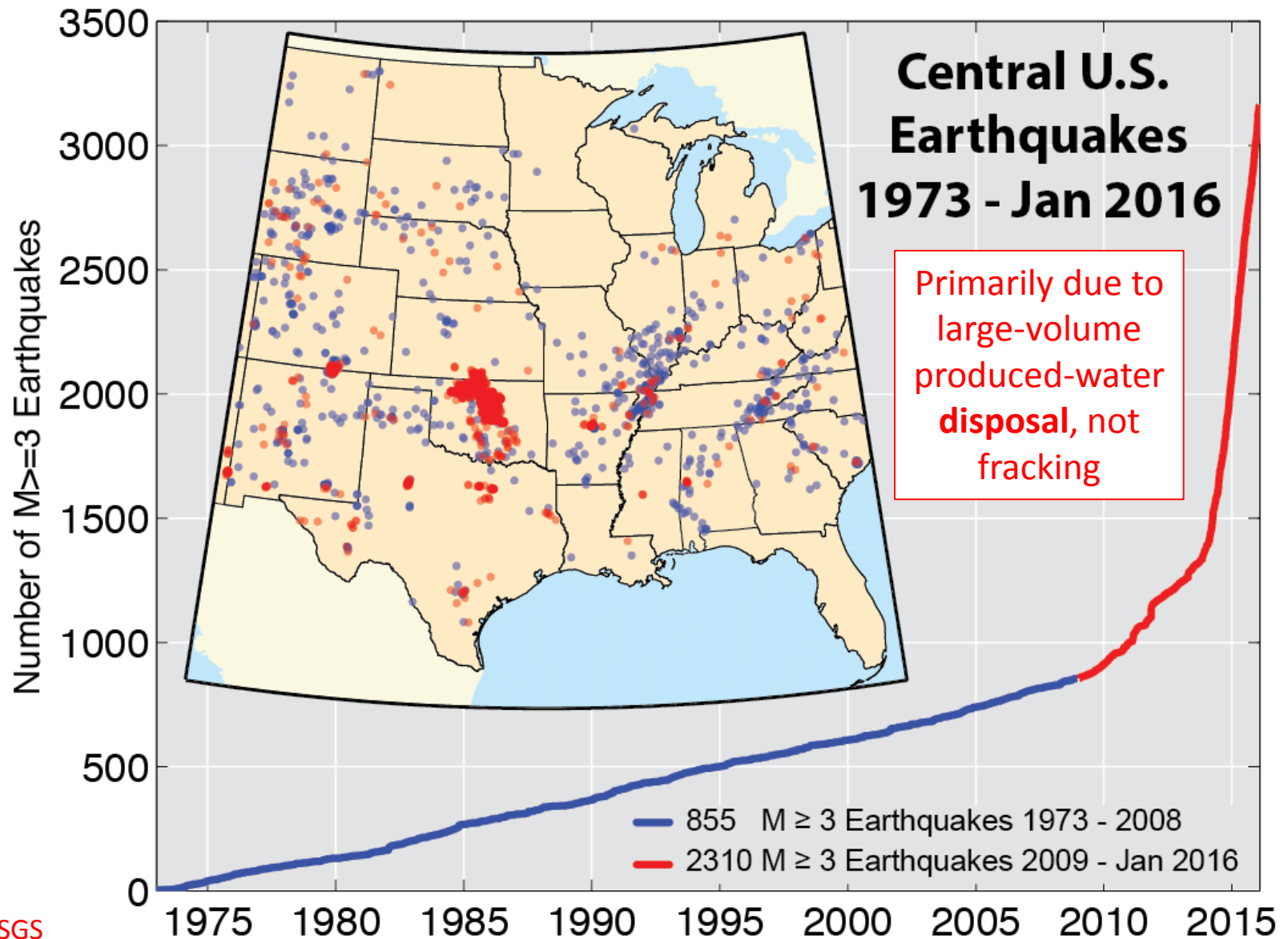
Rocky Mountain House Cluster



Stern et al., 2013



Seismicity of the US midcontinent



Recent induced earthquakes in Oklahoma

M_w 5.8



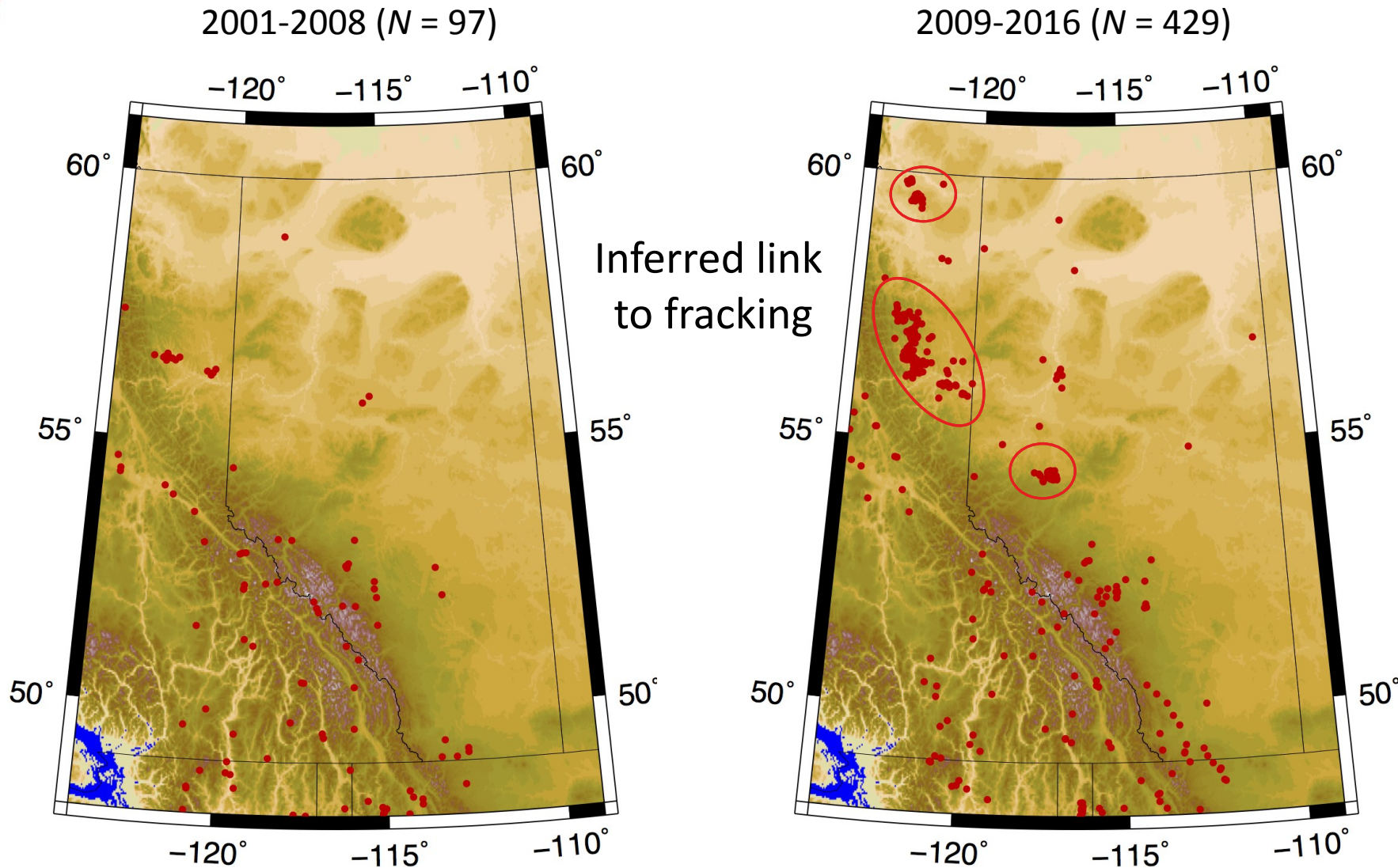
September 3, 2016 (Pawnee)

M_w 5.0

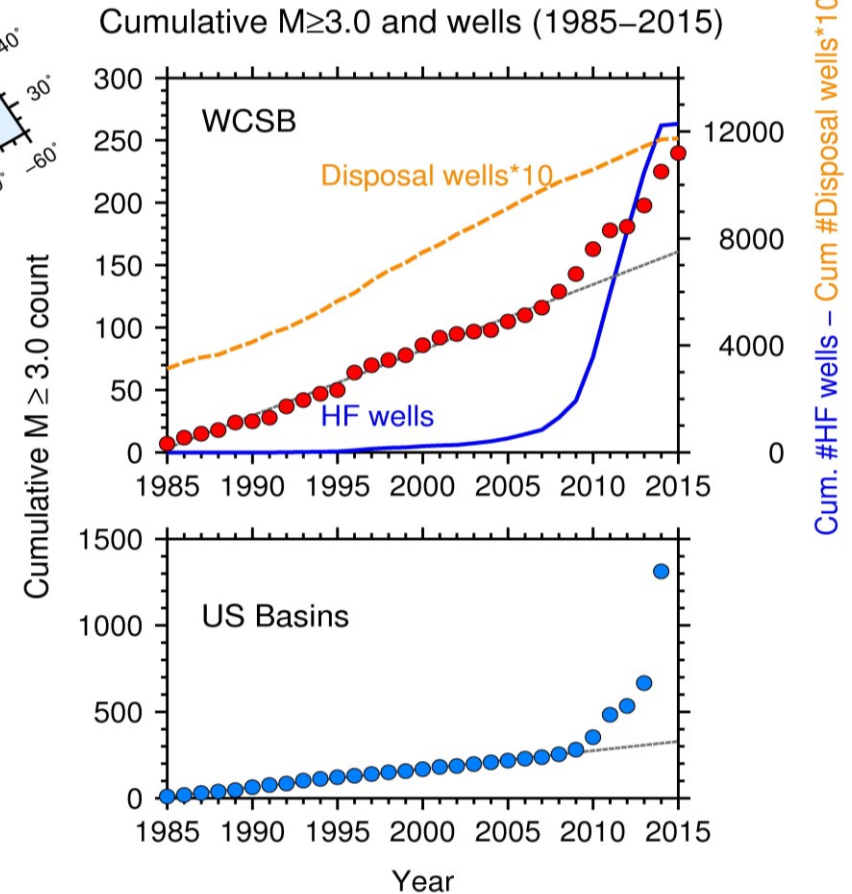
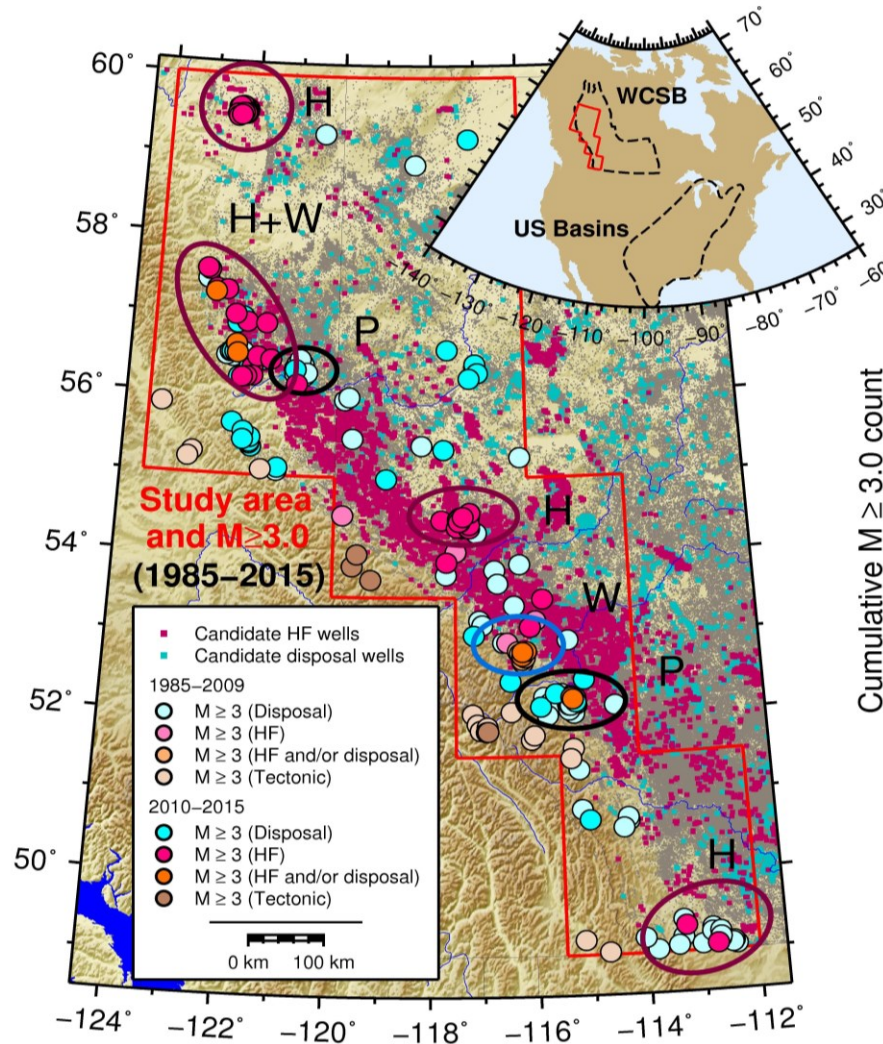


November 7, 2016 (Cushing)

Seismicity of western Canada



Comprehensive study for WCSB



Criteria to recognized induced seismicity

- Are the events the first known earthquakes of this character in the region?
- Is there a clear (temporal) correlation between injection and seismicity?
- Are epicentres located near wells (within 5 km)?
- Do some earthquakes occur at or near injection depths?
- If not, are there known geologic features that may channel flow to the sites of earthquakes?
- Are changes in pressure at bottom of wellbore sufficient to encourage seismicity?
- Are changes in fluid pressure at hypocentral locations sufficient to encourage seismicity?

Seismicity Associated with Wells in the WCSB

	Disposal	HF	Tectonic $M \geq 3$
No. Candidate Wells (1985-2015)	1236	12,289	-
No. of Wells Associated with $M \geq 3$	13	39	-
Association % for wells ($M \geq 3$)	1.0%	0.3%	-
No. $M \geq 3$ (1985-2009)	126*	13*	14
No. $M \geq 3$ (2010-2015)	33*	65*	7
Association % for $M \geq 3$, 2010-2015	31%	62%	7%

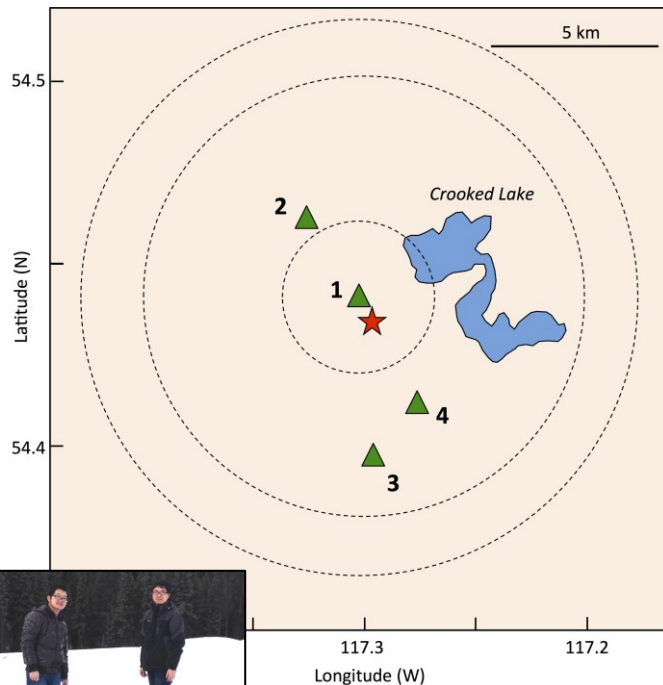
Case Study: Fox Creek, AB

I highly suspect that last night's M 4.4 earthquake near Fox Creek, AB, is an induced seismicity. Can anyone confirm that HF activity was performed in the epicentral region in recent days?
If confirmed, its magnitude of 4.4 should not be taken lightly.

Honn Kao, Ph.D.
Research Scientist, Seismology

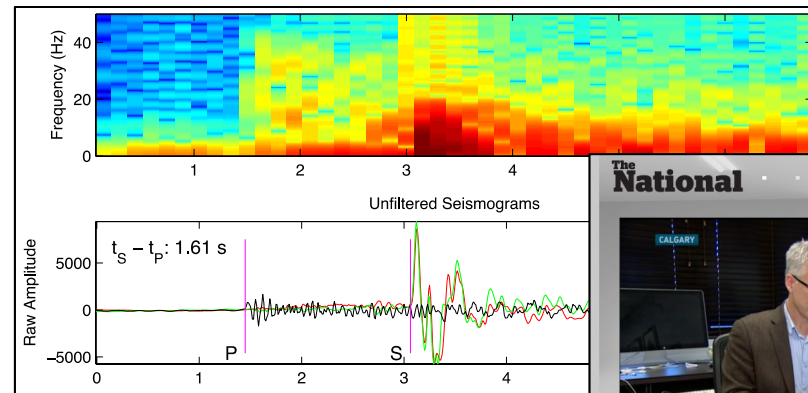
23 January, 2015

Geological Survey of Canada
Pacific Geoscience Centre
9860 West Saanich Road
P.O.Box 6000
Sidney, B.C. V8L 4B2
CANADA



Jan. 25

M_L 2 aftershock



AER Traffic Light System - Duvernay Zone, Fox Creek

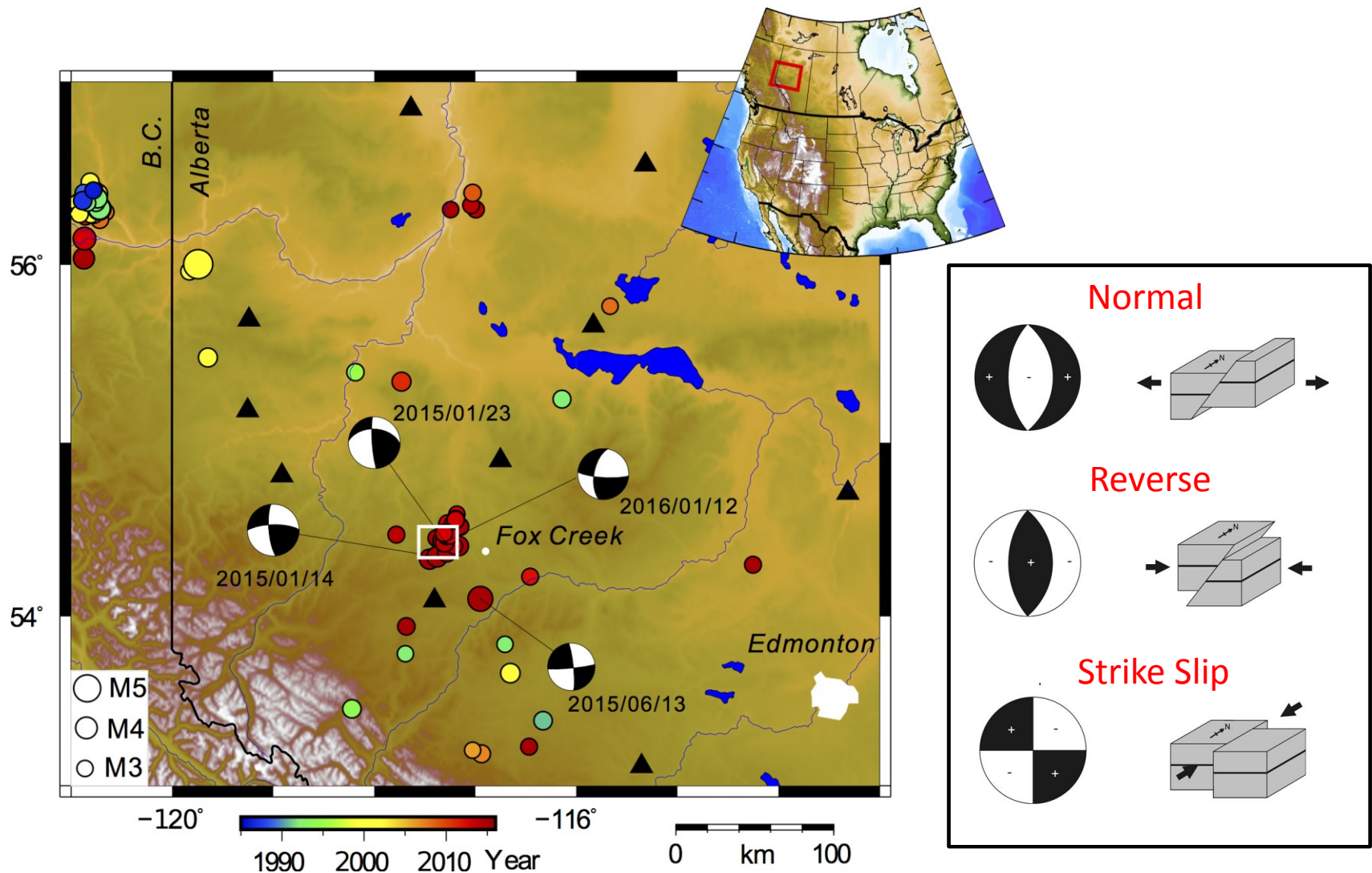


February 2015

Alberta Energy Regulator

- **Assess the potential** for induced seismicity from hydraulic fracturing
- Follow a **traffic light protocol** with staged thresholds.
- **Immediately report** to the AER seismic events of 2.0 ML or greater and invoke their response plan.
- Cease hydraulic fracturing operations if a seismic event of **4.0 ML or greater** is detected in the vicinity of operations.

Case Study: Fox Creek, AB

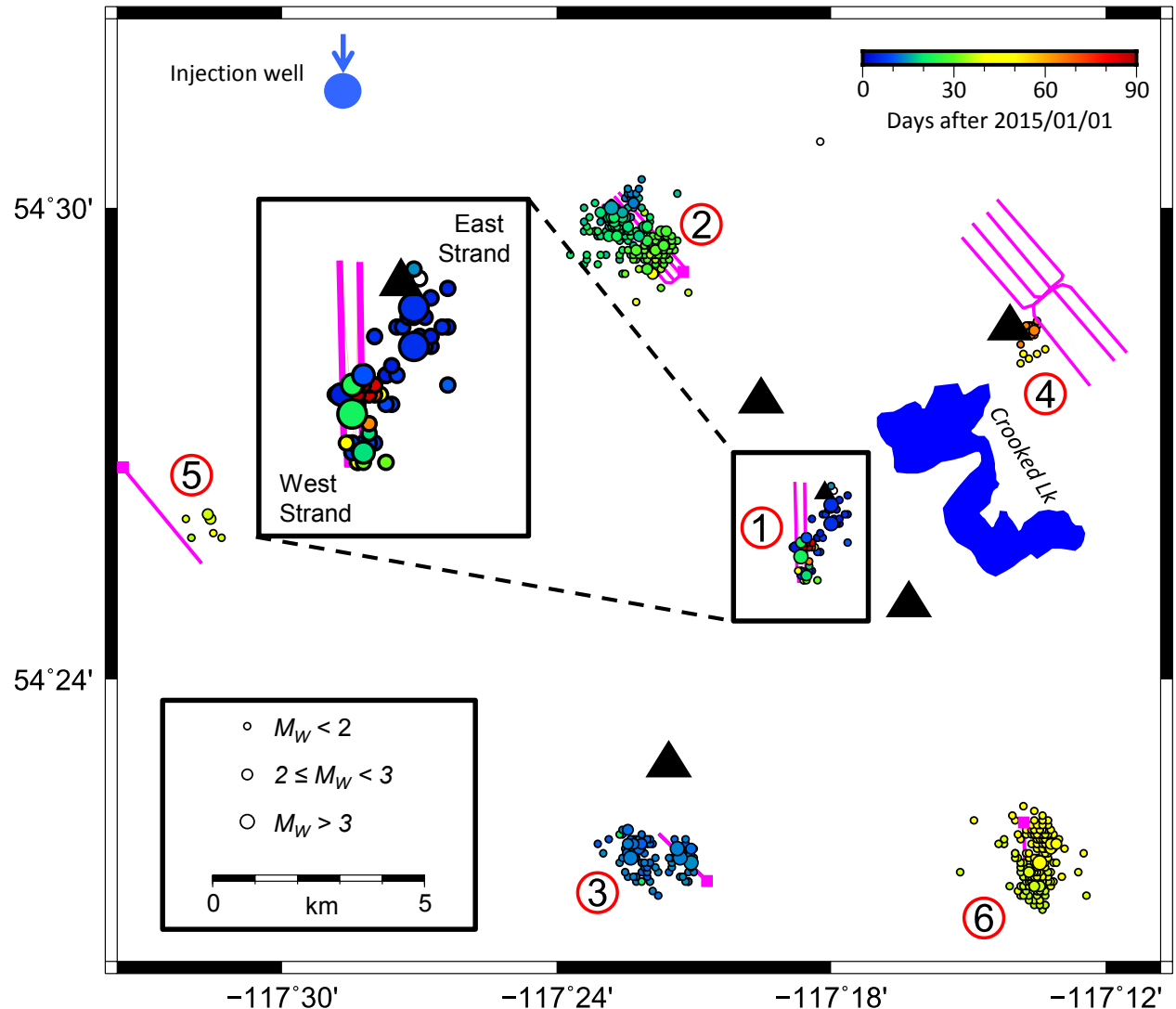


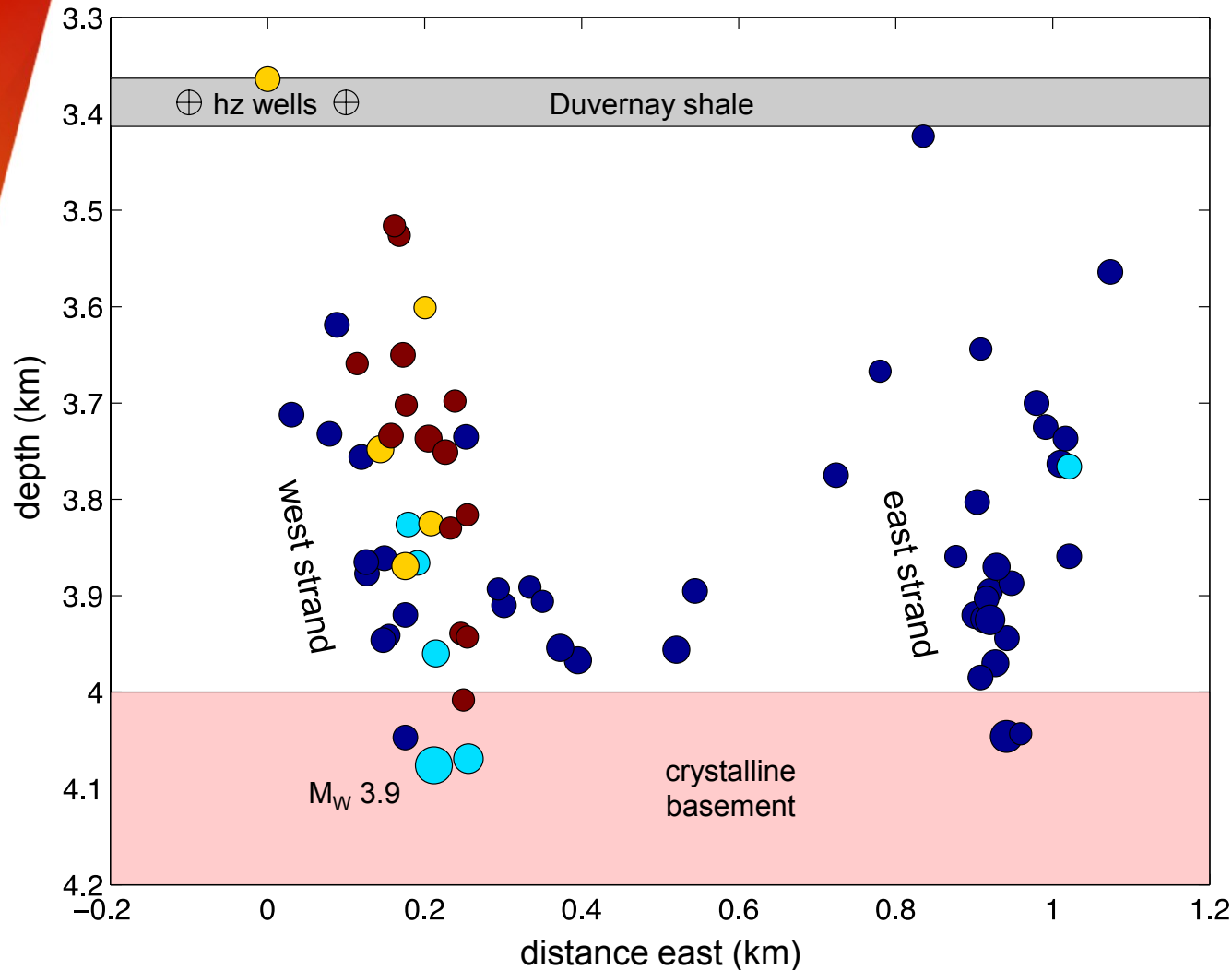
Case Study: Fox Creek, AB

Winter 2015 Duvernay completions at 6 pads

Seismicity strongly clustered near HF operations

Cluster 1 reveals two fault strands



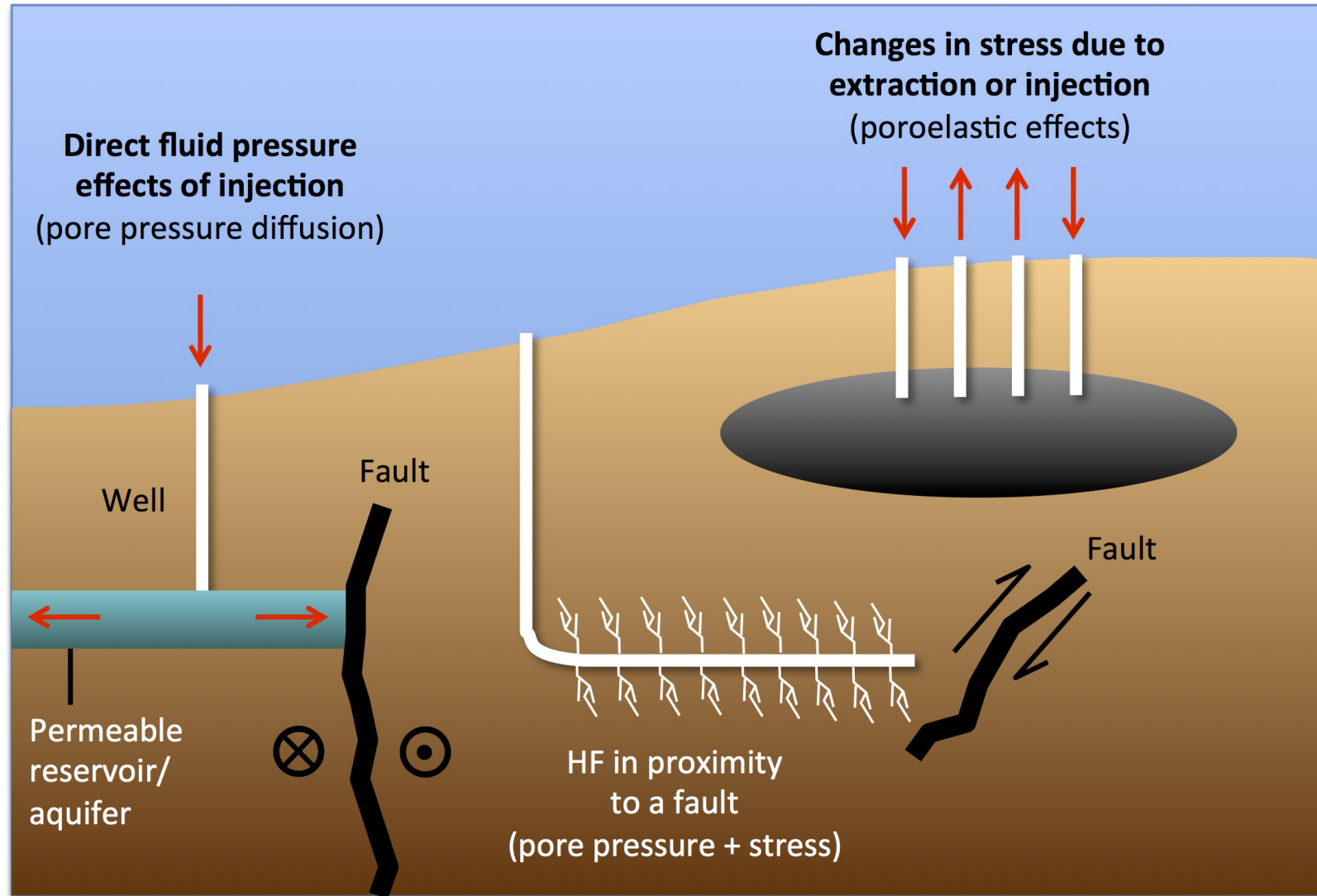


Sub-vertical faults
extending into
crystalline basement

More persistent west
fault strand projects to
location between two
horizontal wells

Transient response of
east strand is best
explained by stress,
not pore pressure

Induced seismicity from fluid injection/extraction



Fundamental Knowledge

- What are the (slip weakening) frictional characteristics of **inactive** faults?
- Why does seismicity (and triggering sensitivity?) persist after completion?

Hazard Assessment

- How can seismogenic (**critically stressed**) faults be identified and mapped?
- How do critically stressed faults affect the local stress field?
- Does **overpressure** correlate with hazard?
- Does maximum magnitude correlate with **net injected volume**?
- Does wellbore **azimuth** matter?

Monitoring

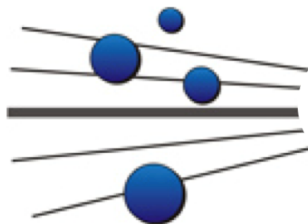
- What is the best magnitude scale to use?
- What are the best traffic-light criteria (e.g. ground motion)?
- What **ground-motion prediction equations** are appropriate for this setting?
- How can induced and natural events be rapidly distinguished?
- Are there any robust, **diagnostic foreshock** patterns that precede a large event?

Hazard Mitigation

- After an event has been triggered, does **flowing back** the well reduce (or increase) hazard?
- Can hazard be reduced by using other types of fracturing fluids or methods?
- Does reducing **treatment pressure** help?

Then there are still the unknown unknowns ...

- Induced earthquakes have attracted significant public attention
- Research on injection-induced seismicity has been active for decades, with recent resurgence
- Injection-induced seismicity in Canada is more strongly linked to hydraulic fracturing than in the U.S., where the primary trigger is large-volume disposal
- Significant strides in understanding and mitigating induced seismicity have been achieved through collaborative research (industry-university-regulators)



Microseismic Industry Consortium



UNIVERSITY OF
CALGARY

Questions?