Investigation of Induced Seismicity Related to the Development of Shale Gas in Northeast British Columbia and Northwest Territories, Canada

Honn Kao

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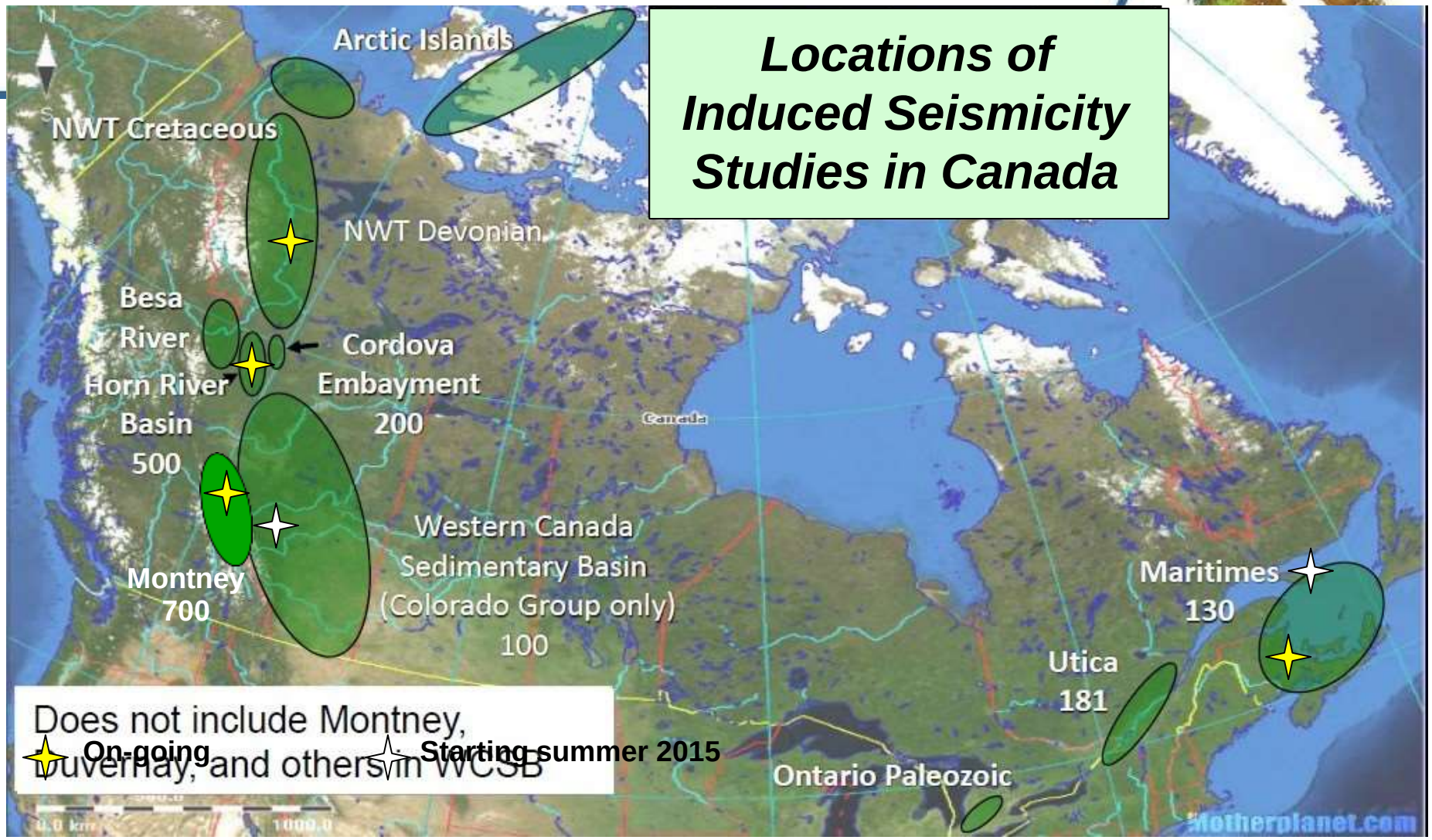
Canada

Outline

- NRCan’s Induced Seismicity Research
- Northeast BC Seismic Array
- Case Study: Horn River Basin, BC
- Case Study: Norman Wells, NWT
- Implications to Shale Gas Development
- Conclusions

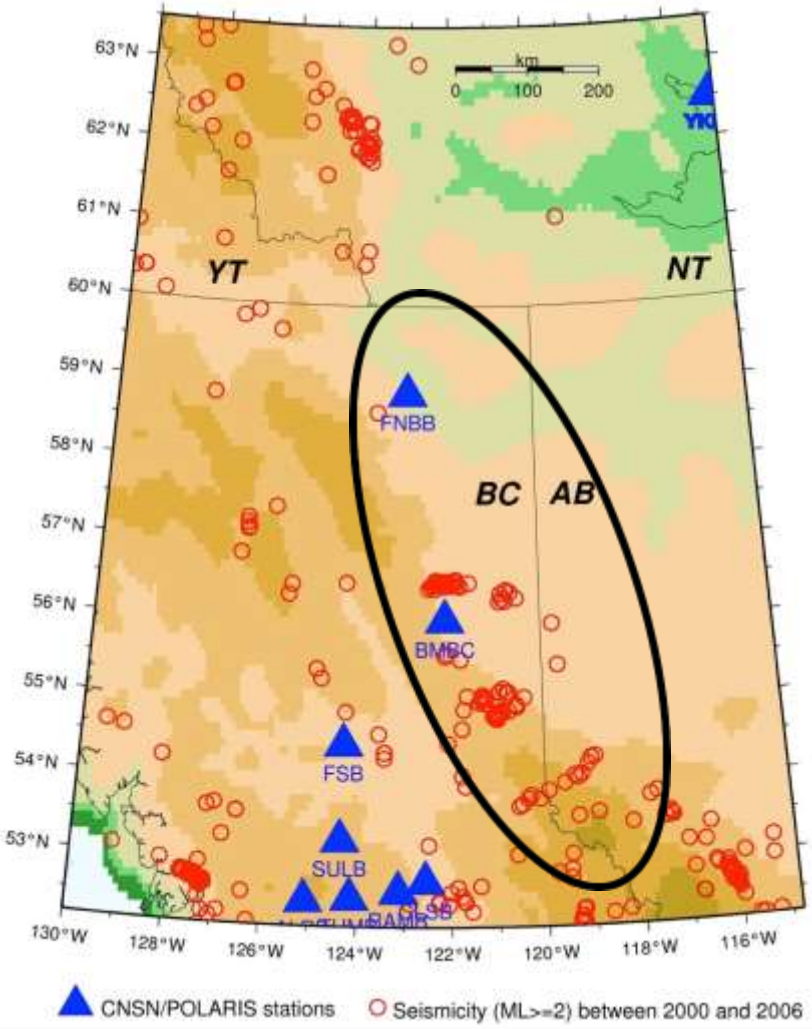
Project Goals and Outlines of NRCan's Induced Seismicity Research

- Initiated in 2012 with both internal and external sources of funding (ecoEII, Geoscience BC and CAPP)
- A coordinated effort involving both public and private sectors to address critical knowledge gaps in induced seismicity related to unconventional shale gas development
- Improved earthquake monitoring for areas with shale gas development potentials
- Detailed studies of background seismicity to establish pre-development reference lines
- Focused case studies to examine pre-/post-development variations

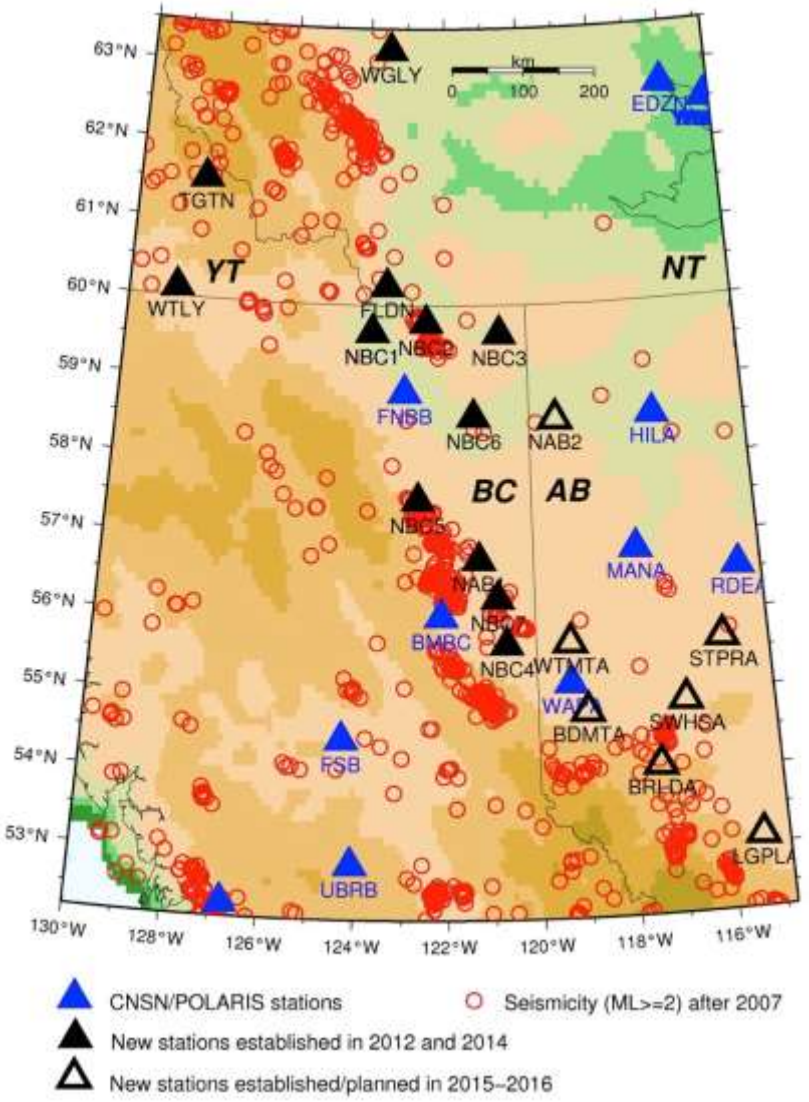

Locations of Induced Seismicity Studies in Canada
Arctic Islands
NWT Cretaceous
NWT Devonian
Besa River
Horn River Basin
500
Cordova Embayment
200
Western Canada Sedimentary Basin (Colorado Group only)
100
Montney
700
Maritimes
130
Utica
181
Ontario Paleozoic
Does not include Montney, Duvernay, and others in WCSB
On-going
Starting summer 2015
Motherplanet.com

Northeast BC and Western AB

Seismic stations before 2012



Seismic stations now and future

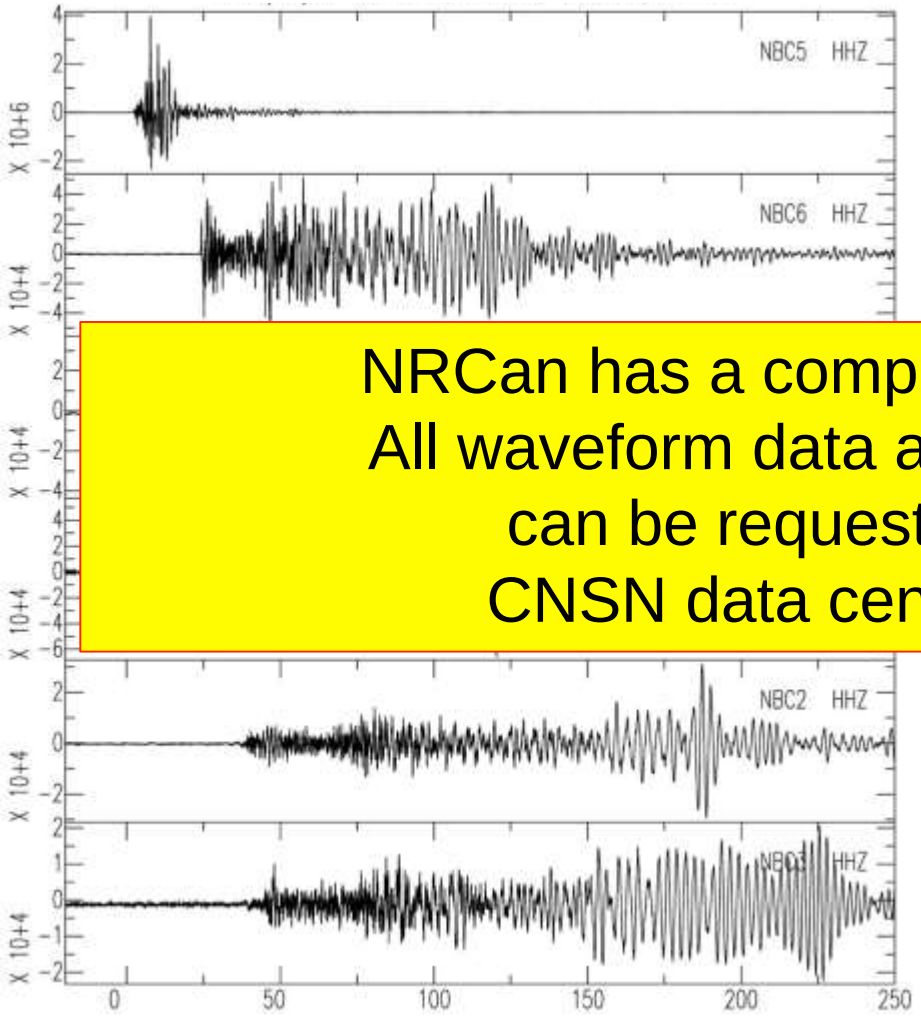


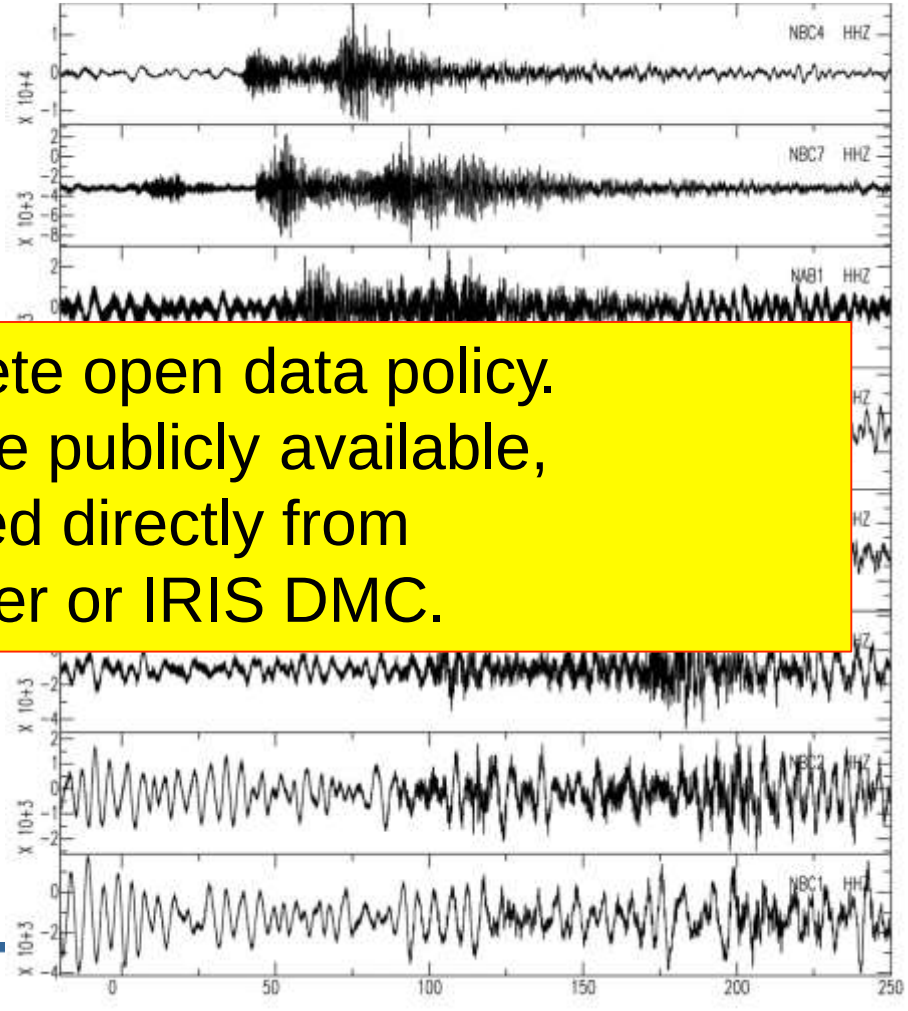
Northeast BC Seismic Array:

Waveforms of the Largest HF-Induced Earthquakes

2014/08/04, Between Fort Nelson and Fort St. John, BC, M_L 4.44

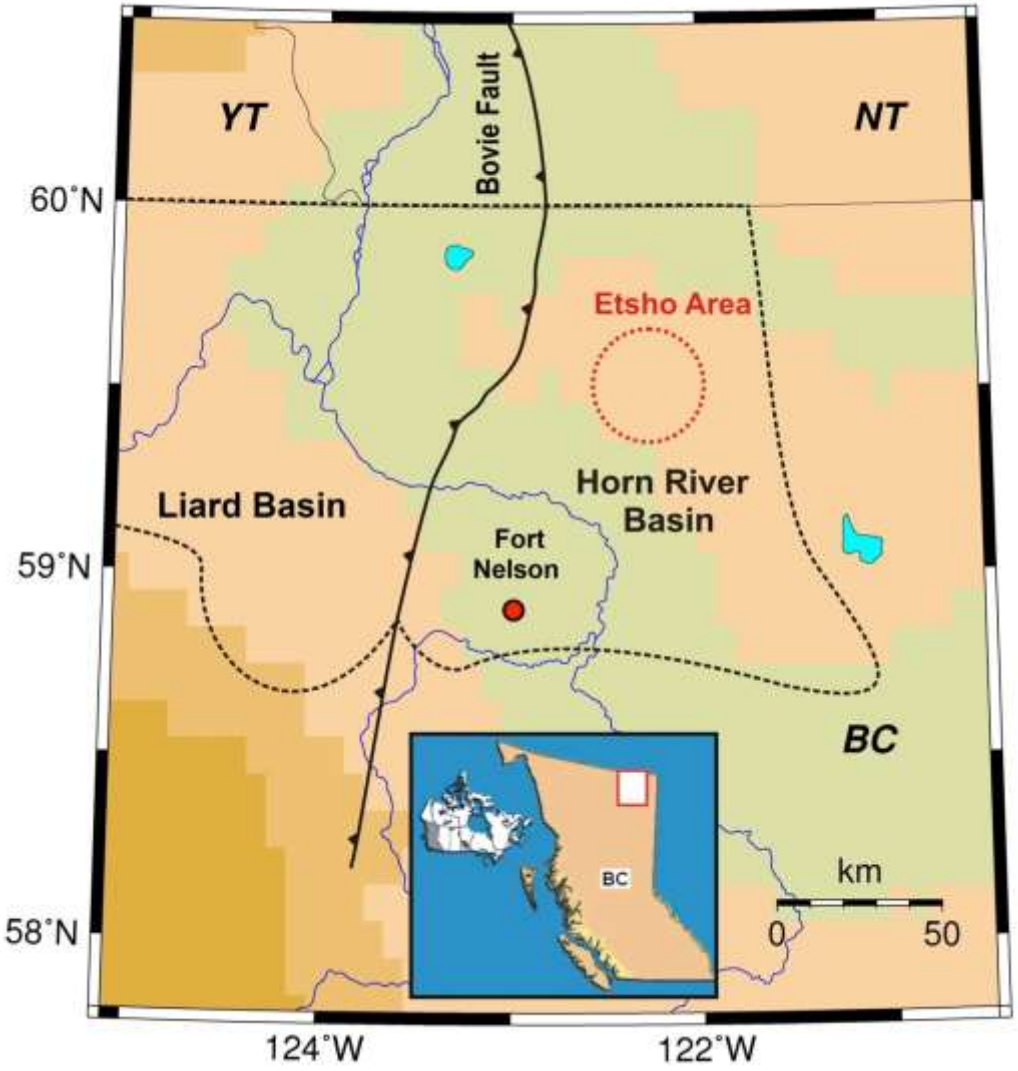
2015/01/23, Crooked Lake, AB, M_L 4.36



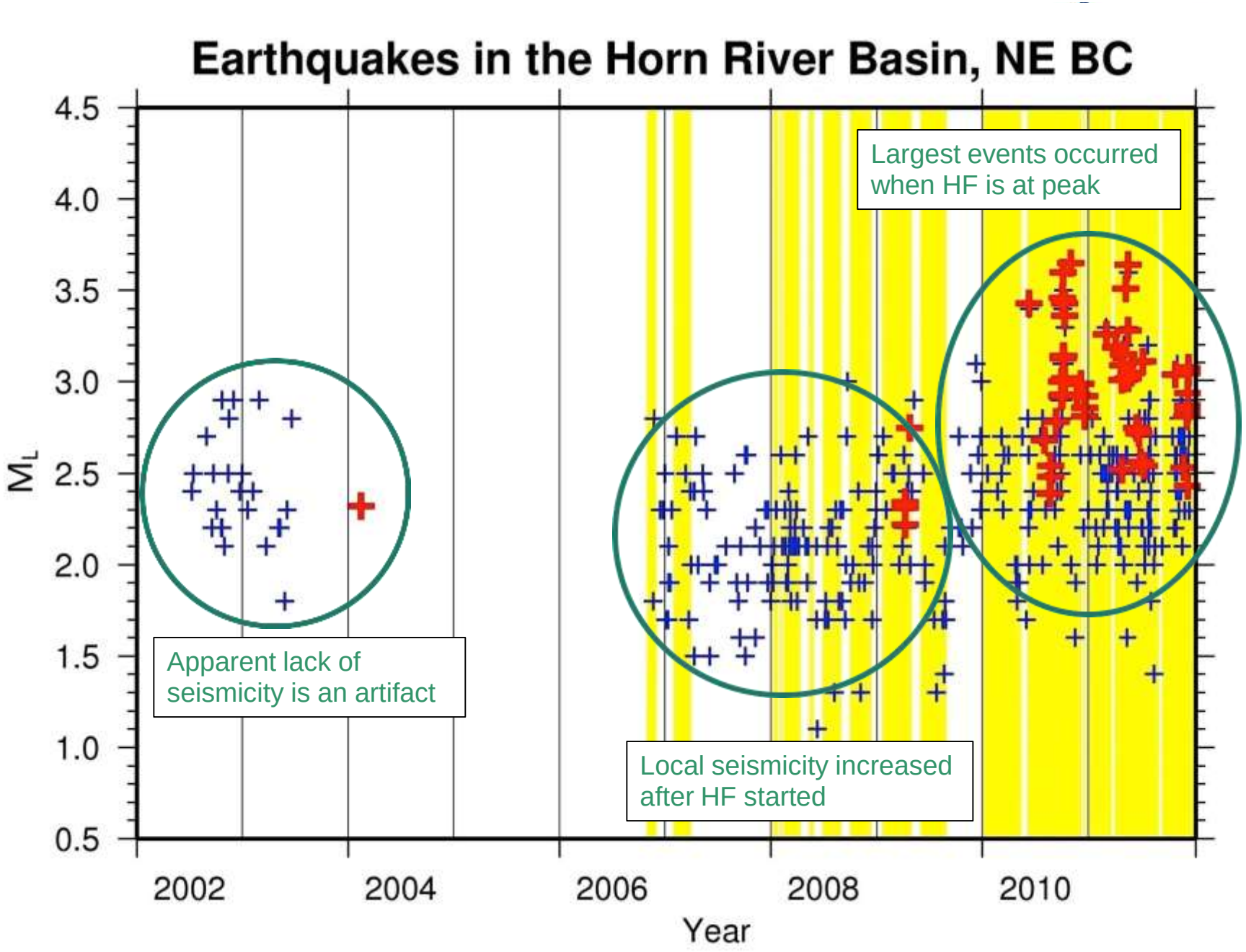


NRCan has a complete open data policy.
All waveform data are publicly available,
can be requested directly from
CNSN data center or IRIS DMC.

Case Study: Horn River Basin, BC



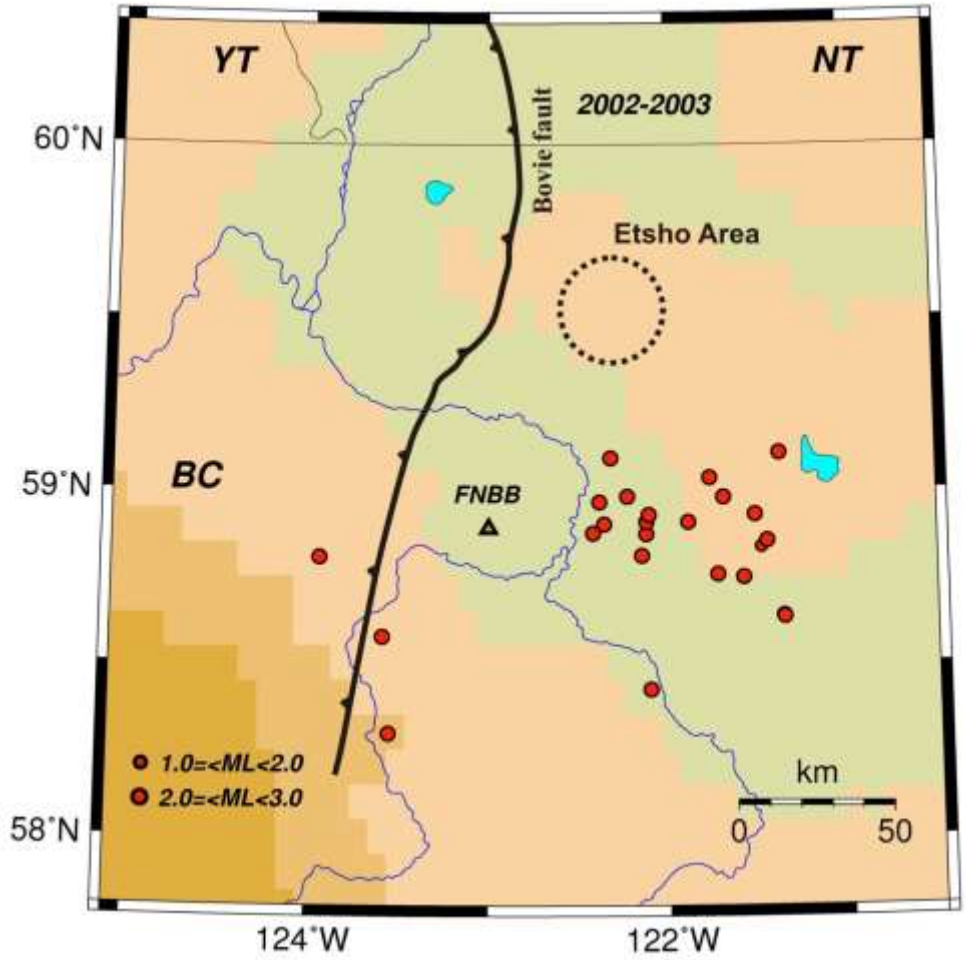
- A major shale gas production area in British Columbia
- Hydraulic fracturing started in as early as late-2006
- Most HF operations in the Etsho area
- Peak shale gas production in 2010 and 2011
- Historically, this area had few earthquakes.



Farahbod et al. (2014, 2015)

Seismic Baseline for NE BC

Pre-HF Background Seismicity (2002-2003)

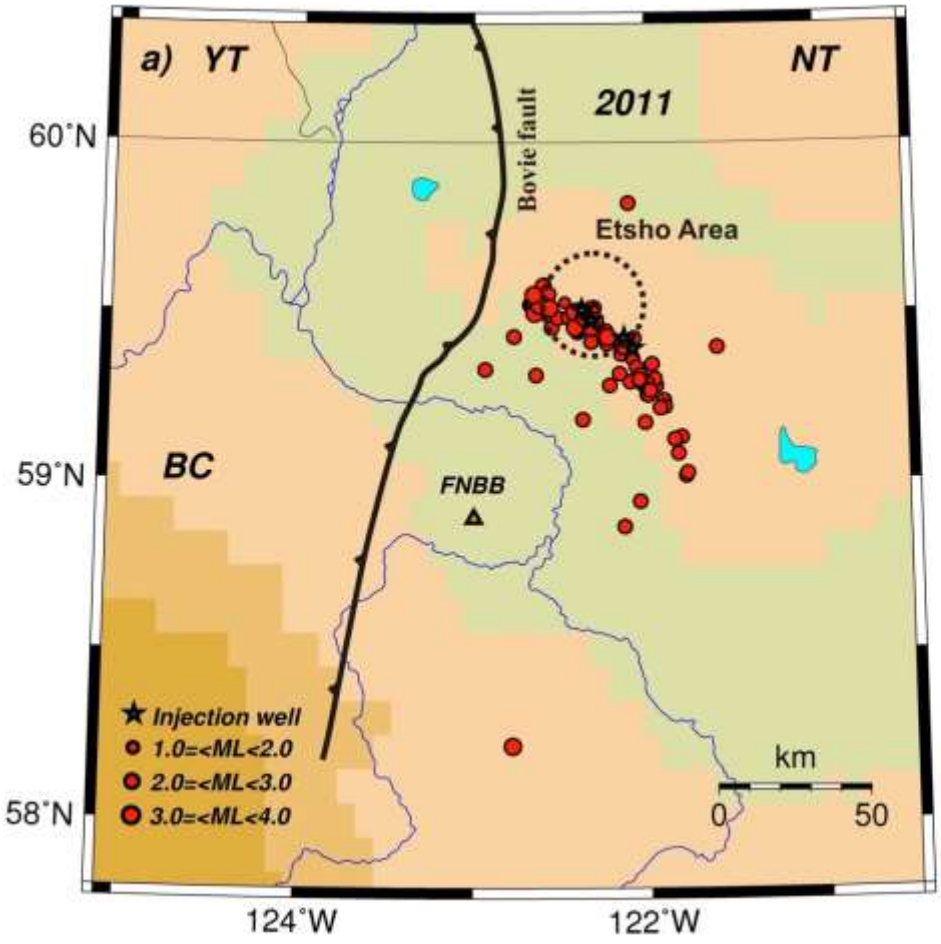


- 4 years before HF
- 24 earthquakes located
- M_L between 1.8 and 2.9, most are smaller than 2.5 (detection threshold of CNSN)
- Most occurred in the southern HRB, none was in the shale gas production area (Etsho)

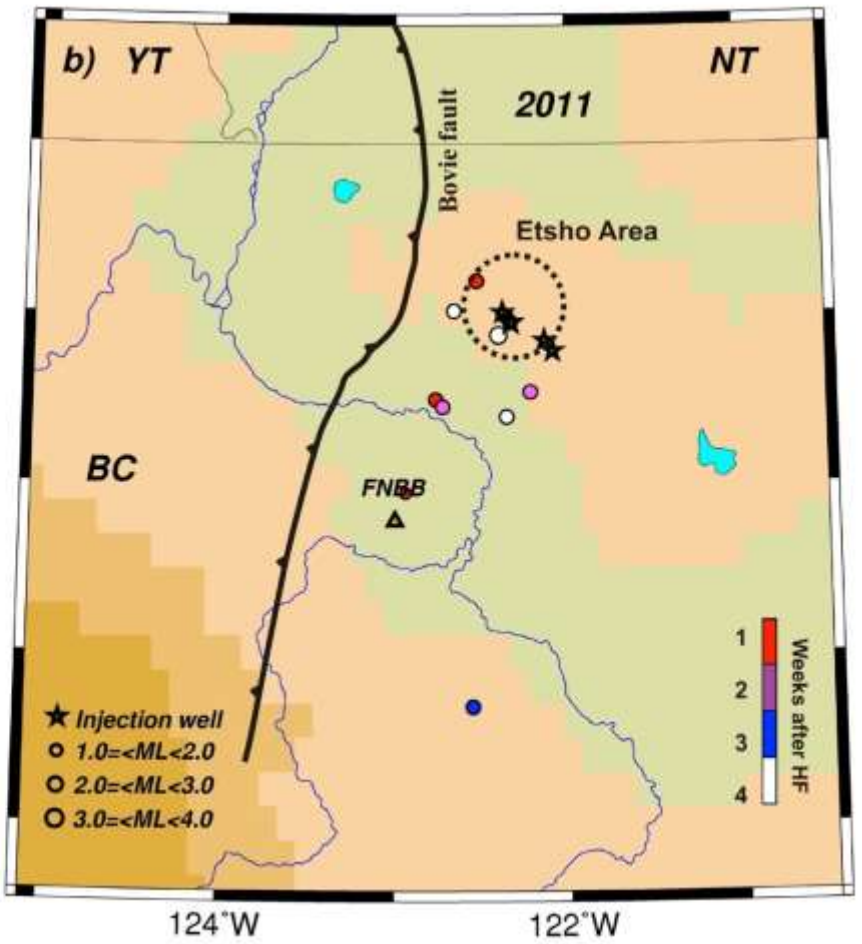
Farahbod et al. (2014)

Regional Seismicity During Peak HF Period

Events when HF was conducted



Events when no HF was conducted

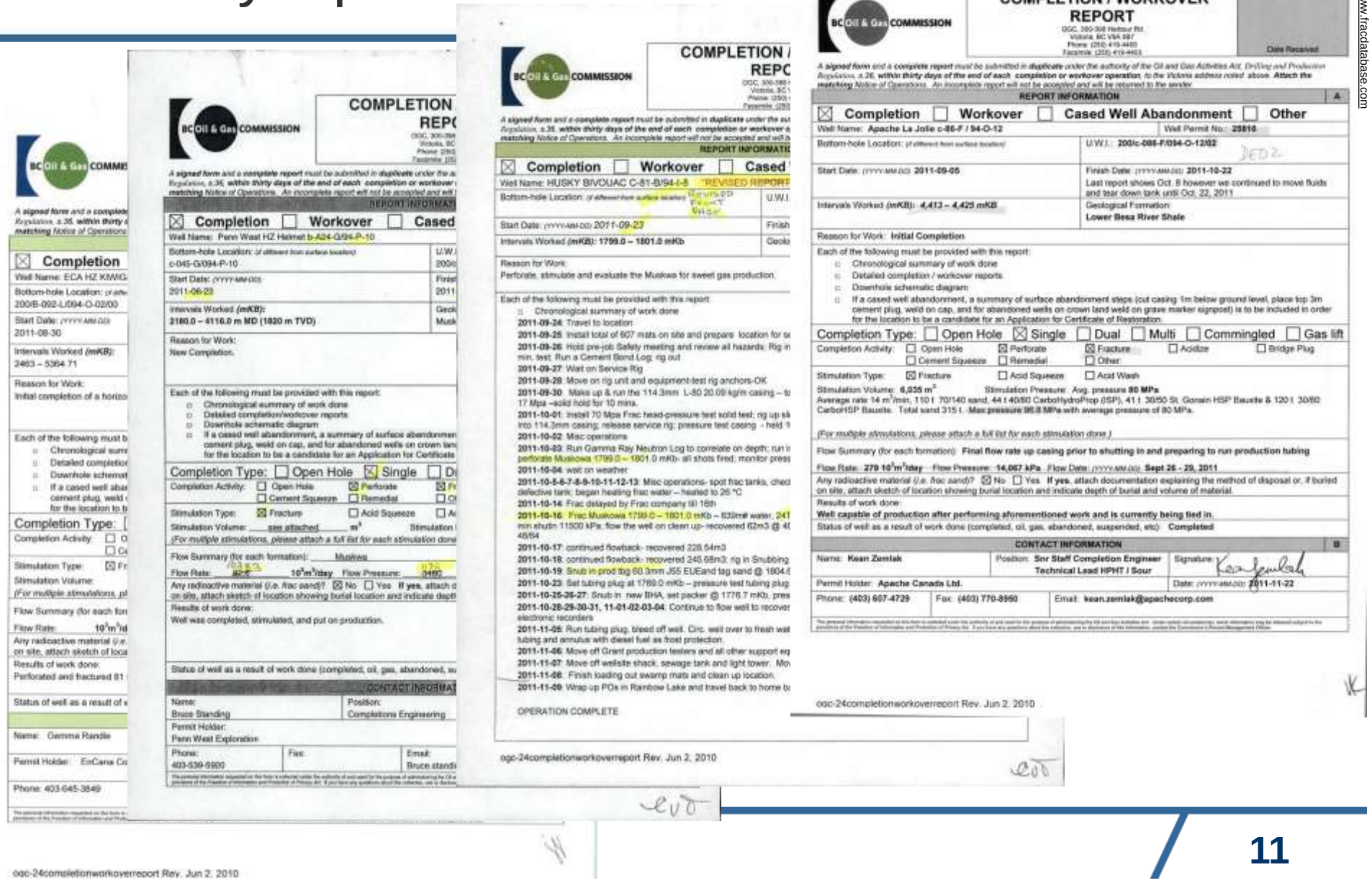


HF days: 84.9% Seismicity: 90.8%

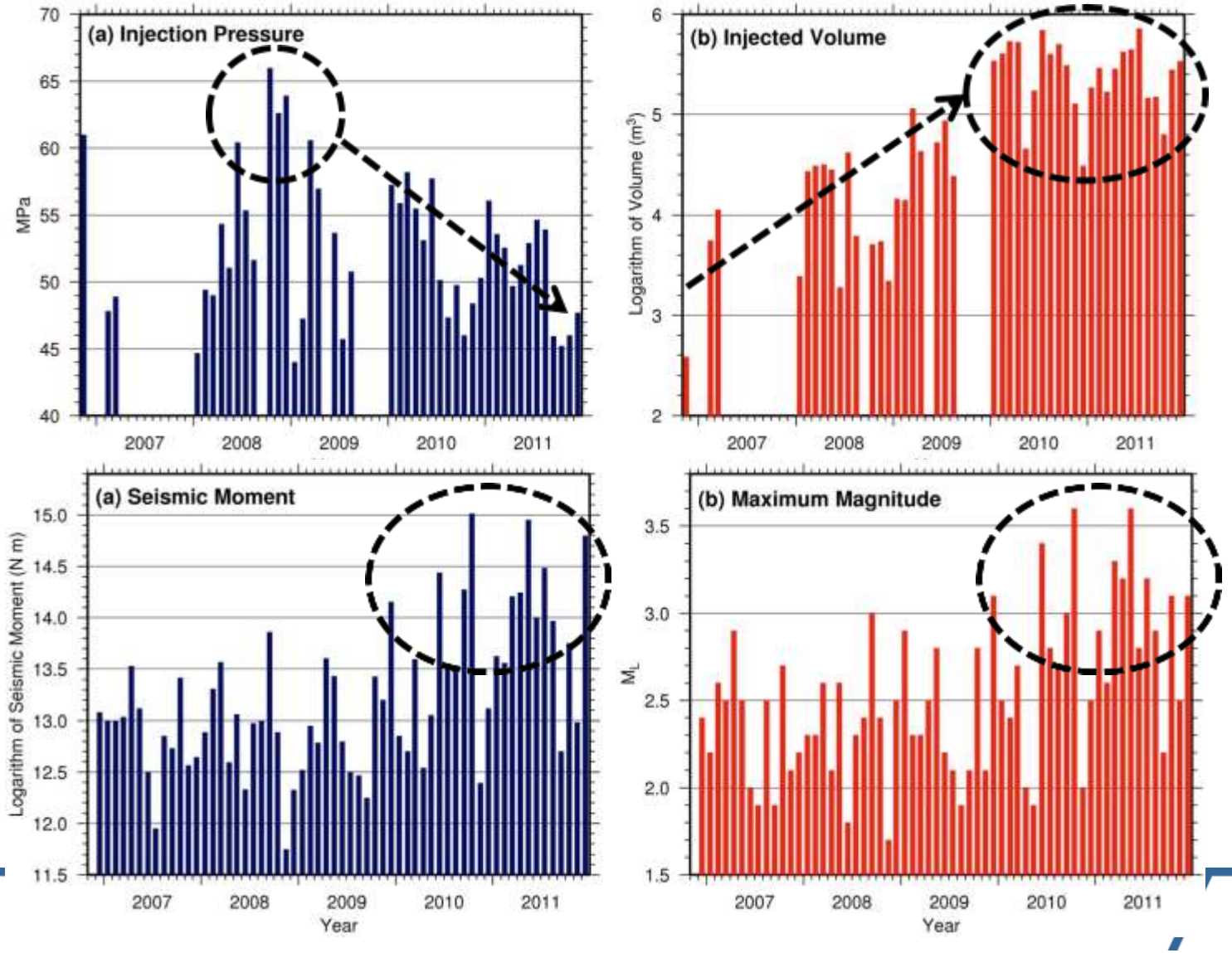
Non-HF days: 15.1% Seismicity: 9.2%

Farahbod et al. (2014)

HF Completion Reports Filed by Operators



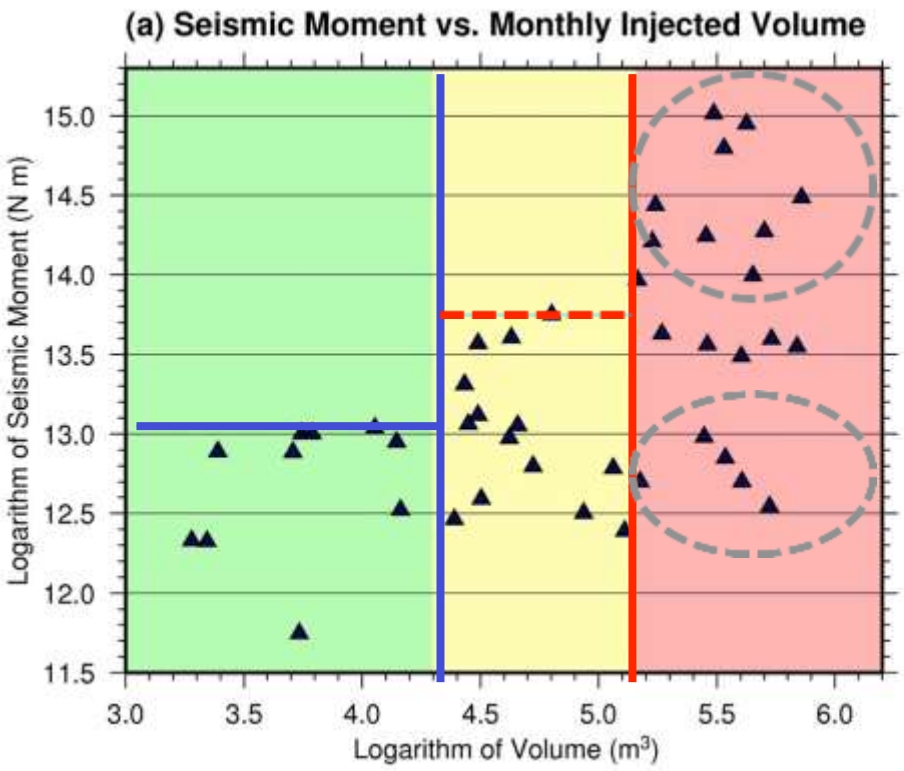
HF Operations and Seismicity

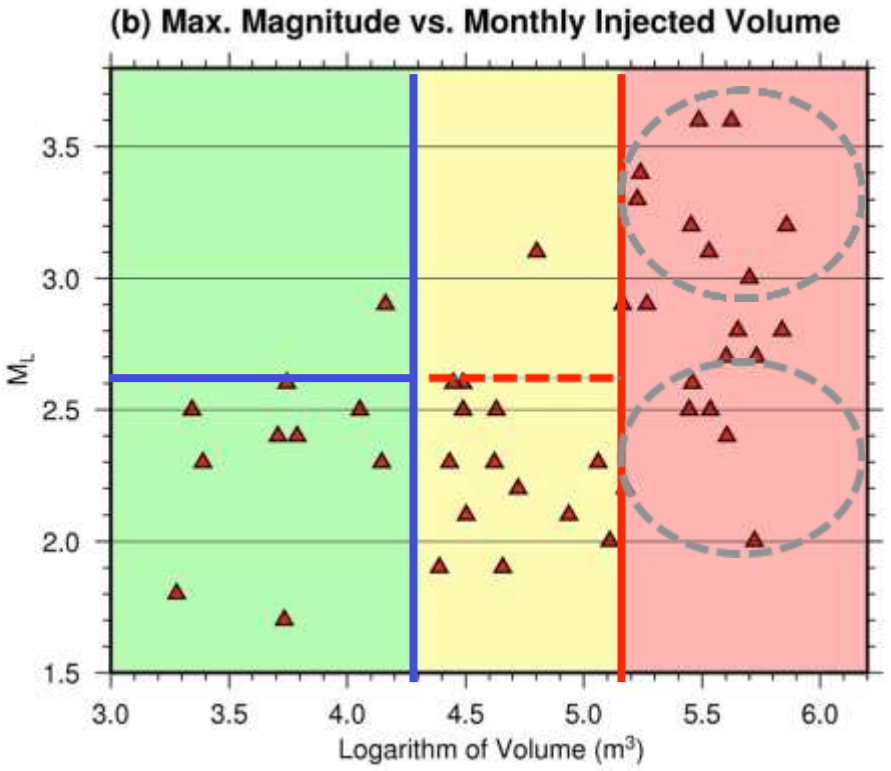


Injected Volume vs. Seismicity

~150K m^3/month

~150K m^3/month

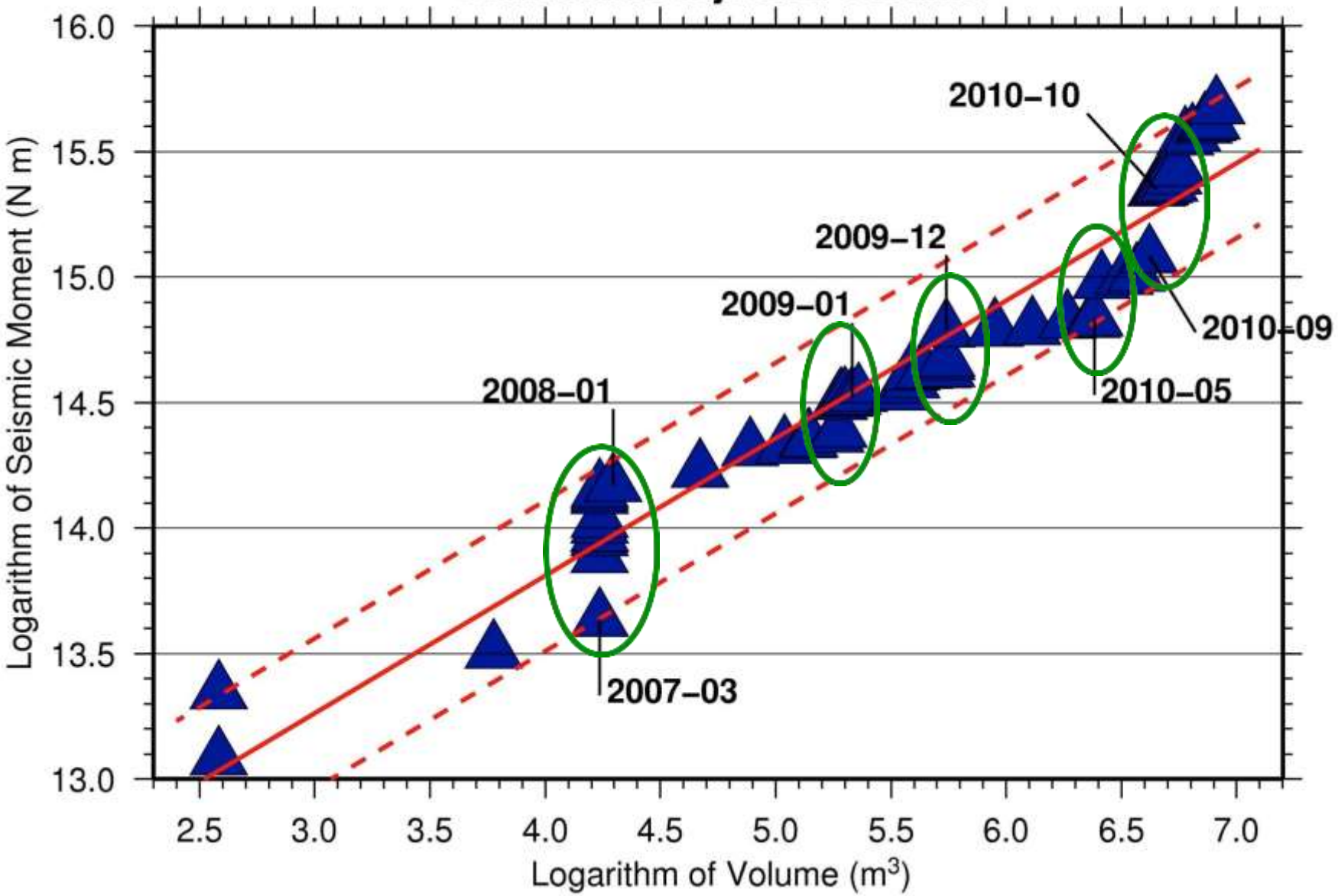




~20K m^3/month

~20K m^3/month

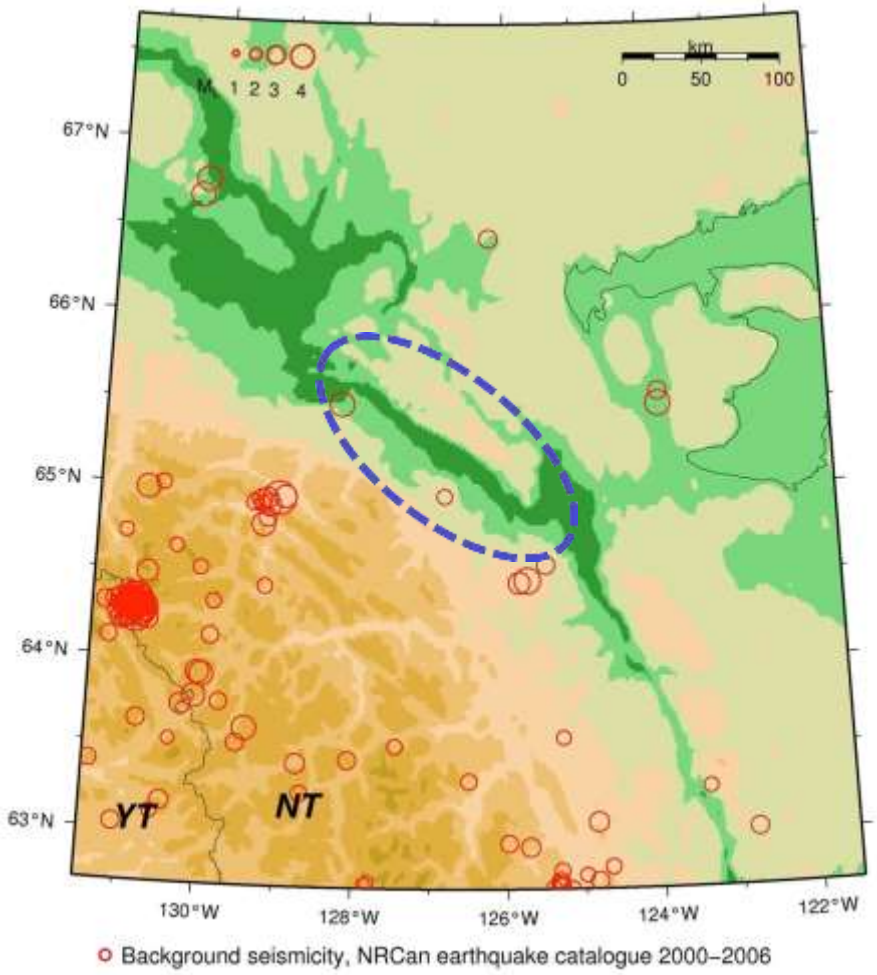
Farahbod et al. (2015)



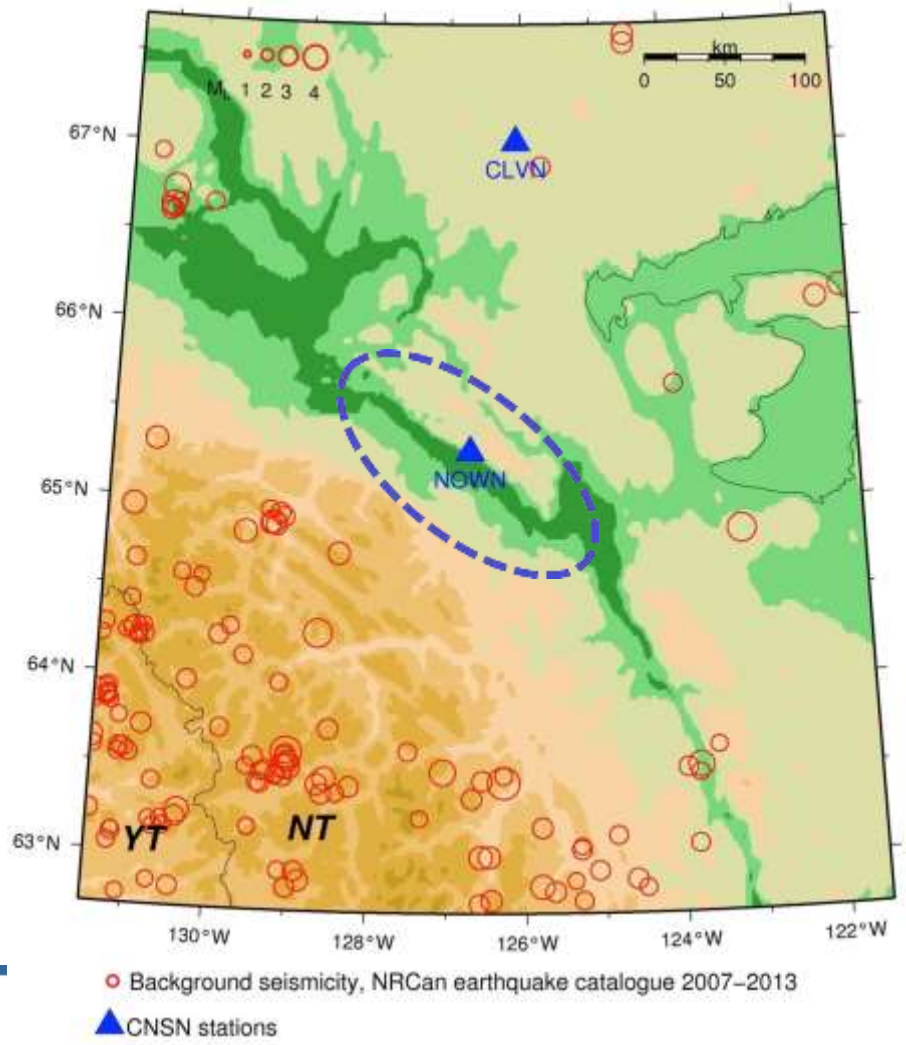
Farahbod et al. (2015)

Case Study: Norman Wells, NWT

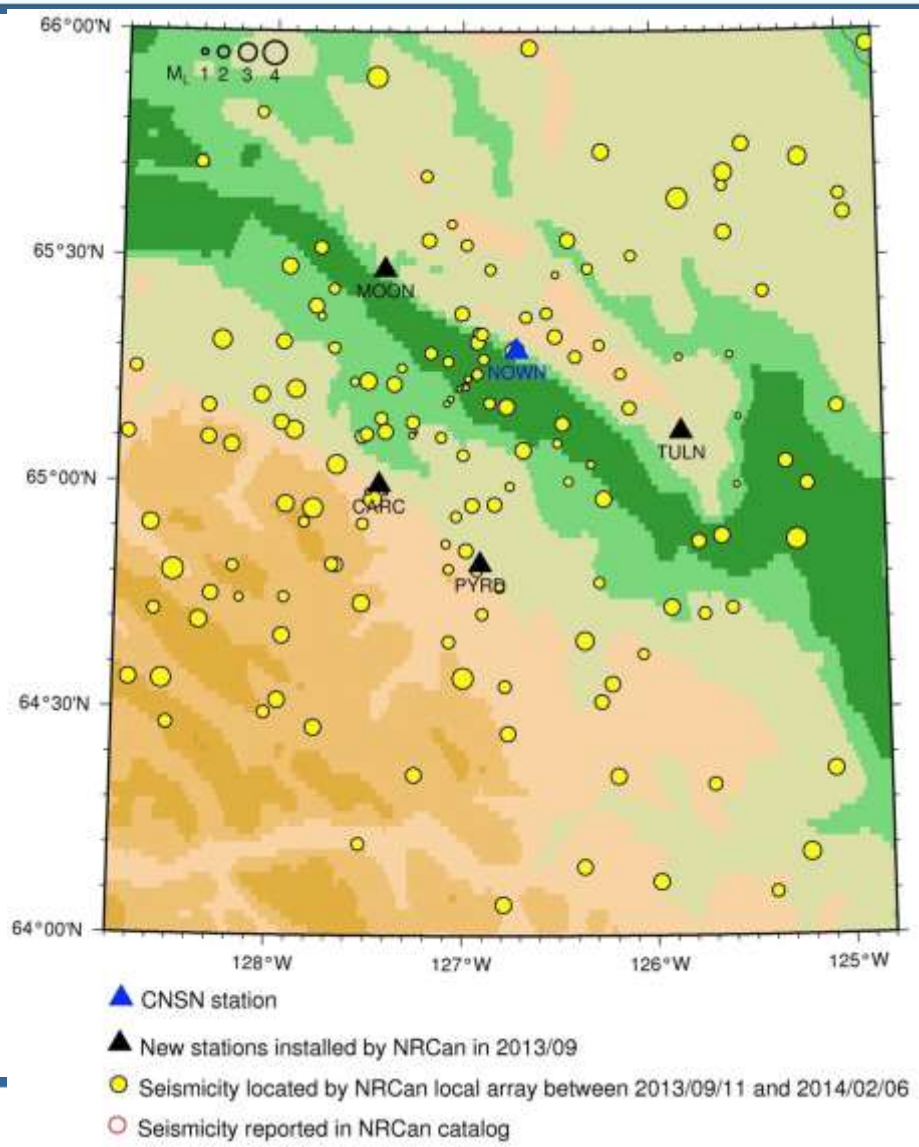
Background Seismicity 2000-2006

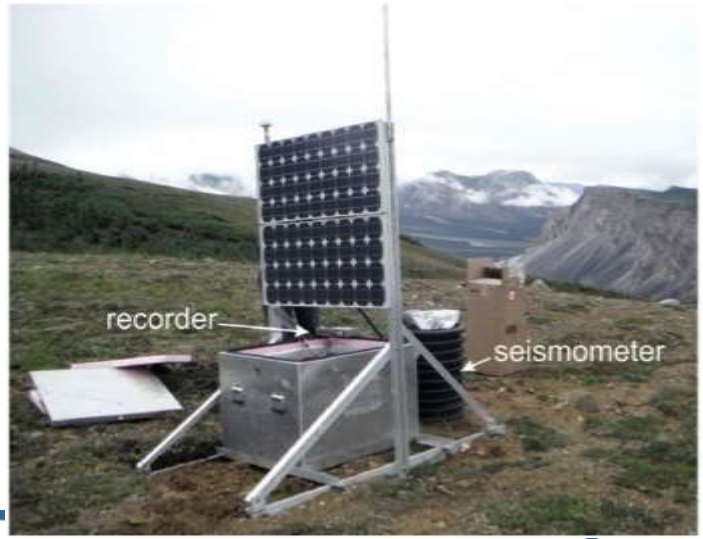


Background Seismicity 2007-2013



Norman Wells Local Array

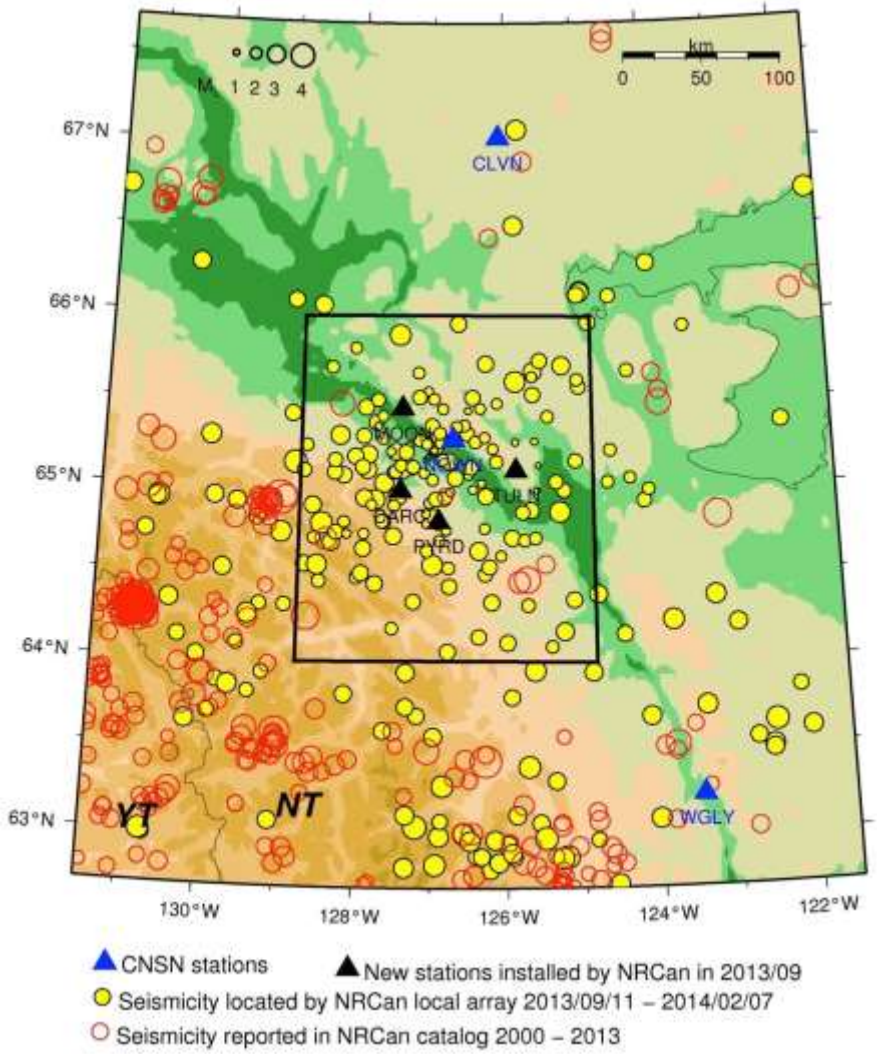




Cairns et al. (2014)

Pre-HF Seismic Reference Line

CNSN Catalog + Events Recorded by NWLA

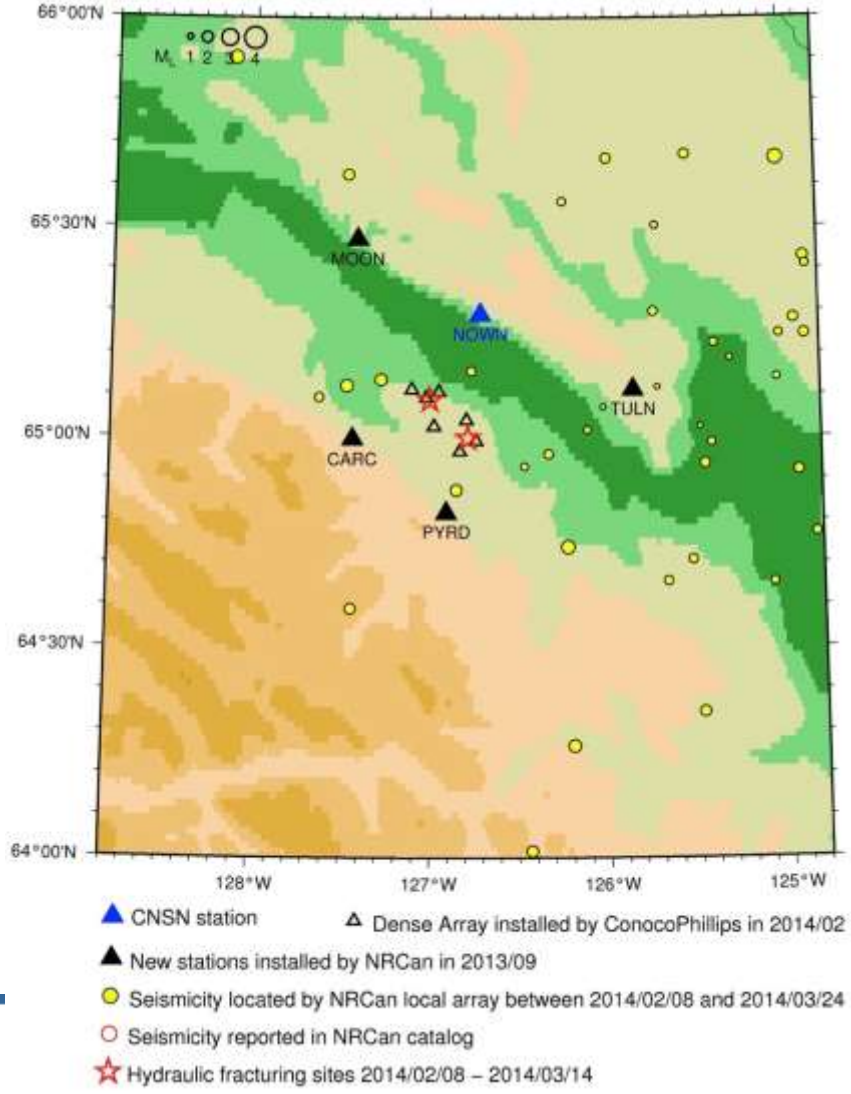


For the Norman Wells area:

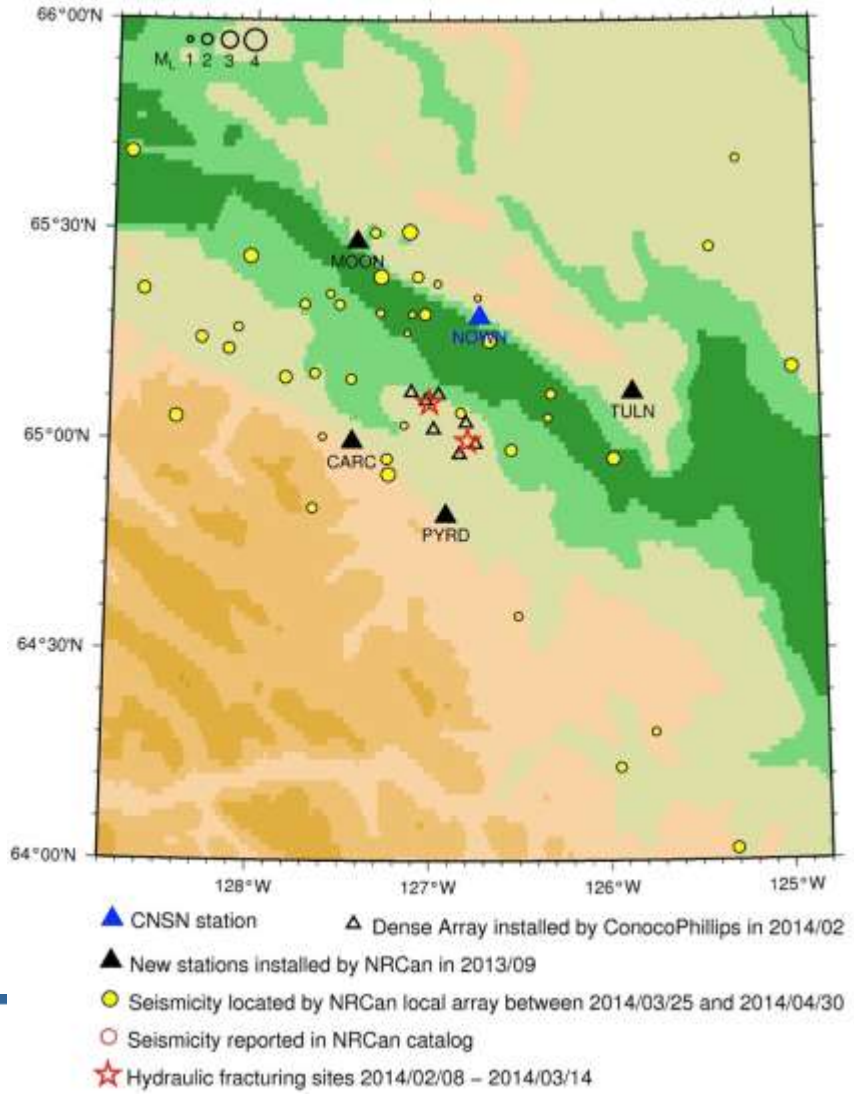
- 156 events between 2013/9/11 and 2014/2/7
- On average, ~30 events per month
- Max. M_L = 3.6
- Min. M_L = 0.4
- Total seismic moment = 2.5 x 10^{16} N m
- Average monthly moment release = 5.04 x 10^{15} N m.
- Equivalent to one Mw 4.4 earthquake each month

During and Post-HF Periods

During HF (2015/2/08 – 2015/3/24)



Post-HF (2015/3/25 – 2015/4/30)



Comparison of pre- and post-HF Seismic Patterns in Norman Wells

Pre-HF Period:

- 156 events between 2013/9/11 and 2014/2/7
- On average, ~30 events per month
- Max. M_L = 3.6
- Min. M_L = 0.4
- Total seismic moment = 2.5 x 10^{16} N m
- Average monthly moment release = 5.04 x 10^{15} N m.
- Equivalent to one Mw 4.4 earthquake each month

During and Post-HF Period:

- 81 events between 2014/2/8 and 2014/4/30
- On average, ~29 events per month
- Max. M_L = 2.8
- Min. M_L = 1.0
- Total seismic moment = 2.1 x 10^{15} N m
- Average monthly moment release = 7.51 x 10^{14} N m.
- Equivalent to one Mw 3.8 earthquake each month
- Injected Volume: 6.3K m^3 (Feb 2014)
  7.7K m^3 (Mar 2014)

There was no clear increase in the frequency and magnitude of local seismicity due to HF in the Norman Wells region!

Implication to Shale Gas Production: Sustainable Development

1. We must know the overall background seismic level before development (i.e., each region's baseline).
2. For each region, we need to determine the tolerance level of the geological system against HF (i.e., up to increased frequency of local earthquakes but not increased maximum magnitude).
    - empirical approach (this study), or
    - theoretical modeling
3. Based on each region's acceptable risk level (which depends on population density and community consensus), regulators can set the level of development and production that is sustainable in the long run (i.e., theoretical max. magnitude and/or injected volume).

Conclusions

- To confidently recognize any variation in regional/local seismicity that are possibly related to shale gas development, it is critical to establish a reliable reference line for the pre-HF era.
- Taking the HRB as a whole, injected volume appears to be a more important factor than the injection pressure.
- The initial effect of an increased injected volume is an increase in earthquake frequency but not magnitude.
- Relatively large seismic moment release ($>10^{14}$ N m) occurred only when the monthly injected volume exceeded ~150,000 m^3, but large monthly injected volume != large monthly seismic moment.
- Variable time lags, from days to up to 4 months, are observed between intense HF and the occurrence of a significant local earthquake.
- Preliminary result in Norman Wells is consistent with the HRB result.
- We emphasize the concept of sustainable development.

External Collaborators

BC Oil and Gas Commission

Alberta Energy Regulator

Northwest Territories Geoscience Office

New Brunswick Department of Energy and Mines

Ministère des Ressources Naturelles du Québec

Geoscience BC

Energy Institute of New Brunswick

Canadian Association of Petroleum Producers

University of Calgary, University of Alberta

University of Western Ontario, McGill University

Thank You