



Natural Resources Canada's Induced Seismicity Research

*Honn Kao
Geological Survey of Canada*

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Natural Resources
Canada

Ressources naturelles
Canada

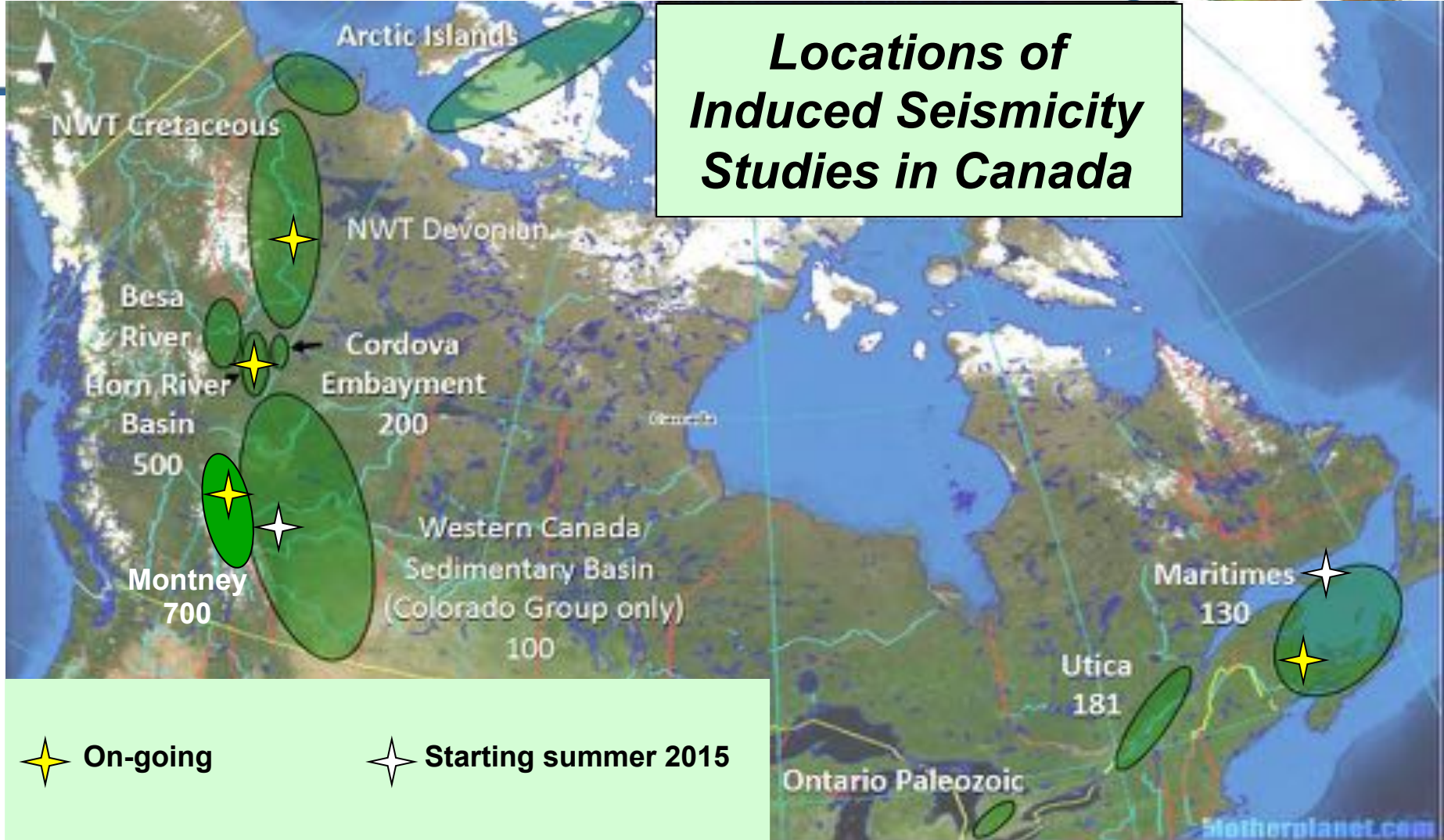
Canada

Project Goals and Outlines



- Initiated in 2012 with both internal and external funding sources
- 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 major shale gas production areas
- Detailed studies of background seismicity to establish pre-development reference lines
- Focused case studies to examine pre-/post-development variations

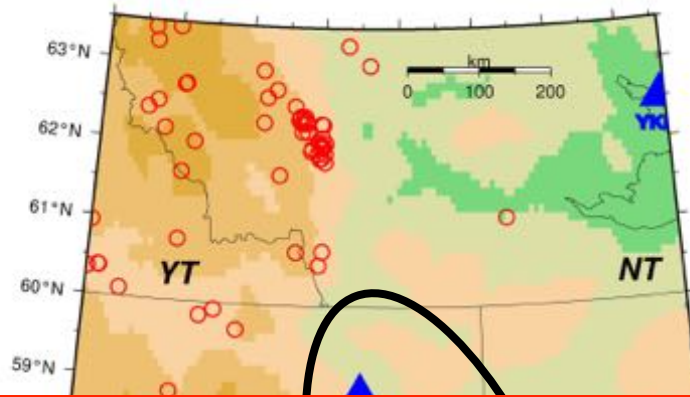
Locations of Induced Seismicity Studies in Canada



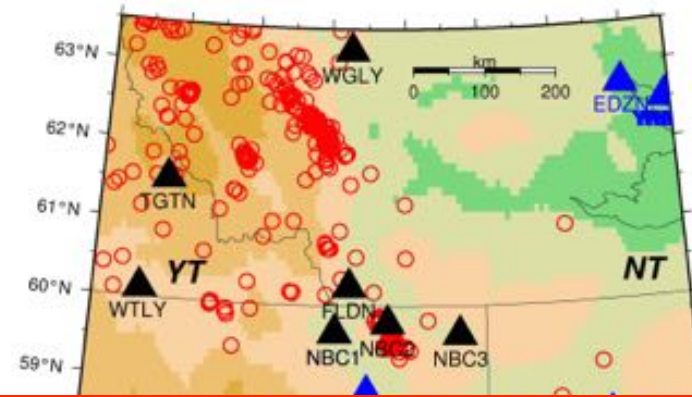
Northeast BC and Western AB



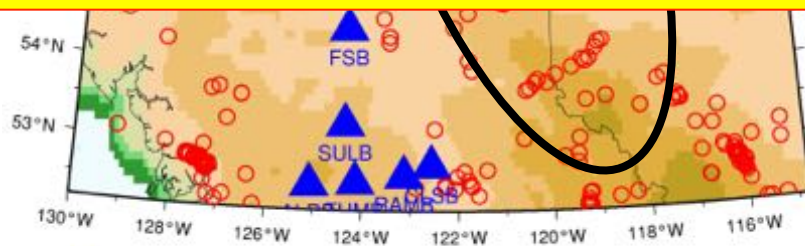
Seismic stations before 2012



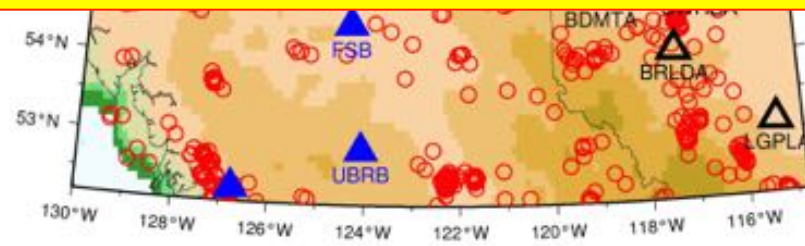
Seismic stations now and future



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

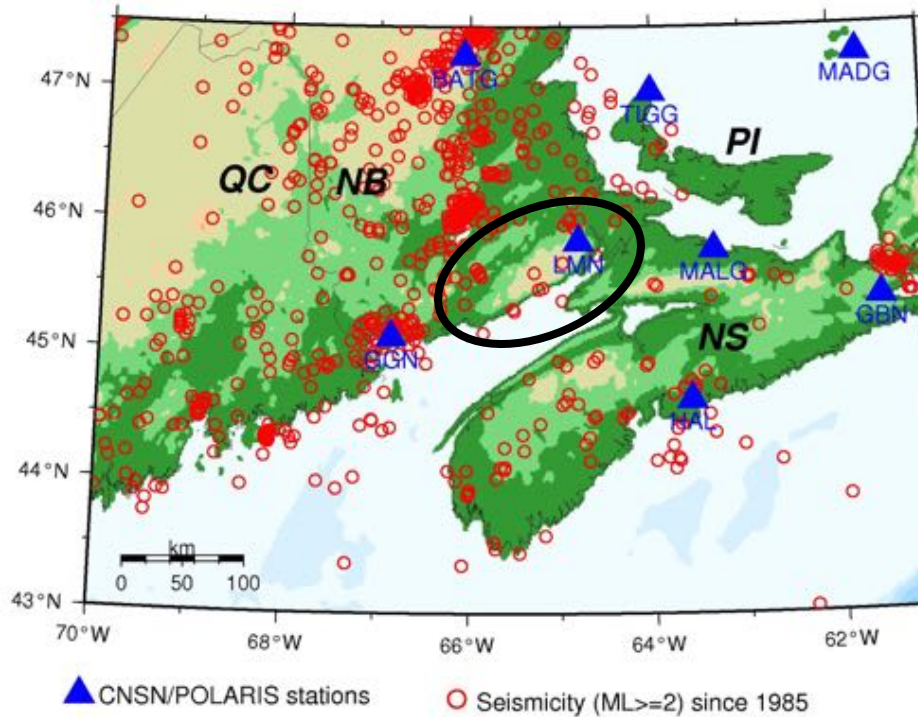


▲ CNSN/POLARIS stations ○ Seismicity (ML \geq 2) between 2000 and 2006

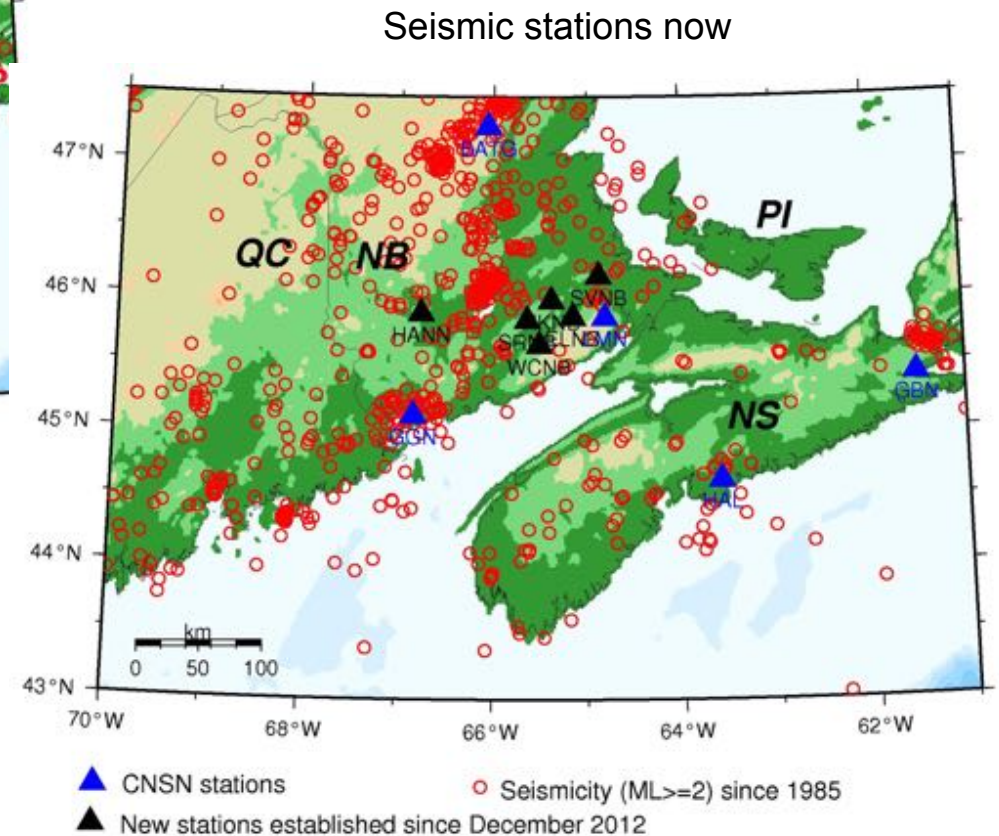


▲ CNSN/POLARIS stations ○ Seismicity (ML \geq 2) after 2007
▲ New stations established in 2012 and 2014
△ New stations established/planned in 2015-2016

Sussex Basin, New Brunswick



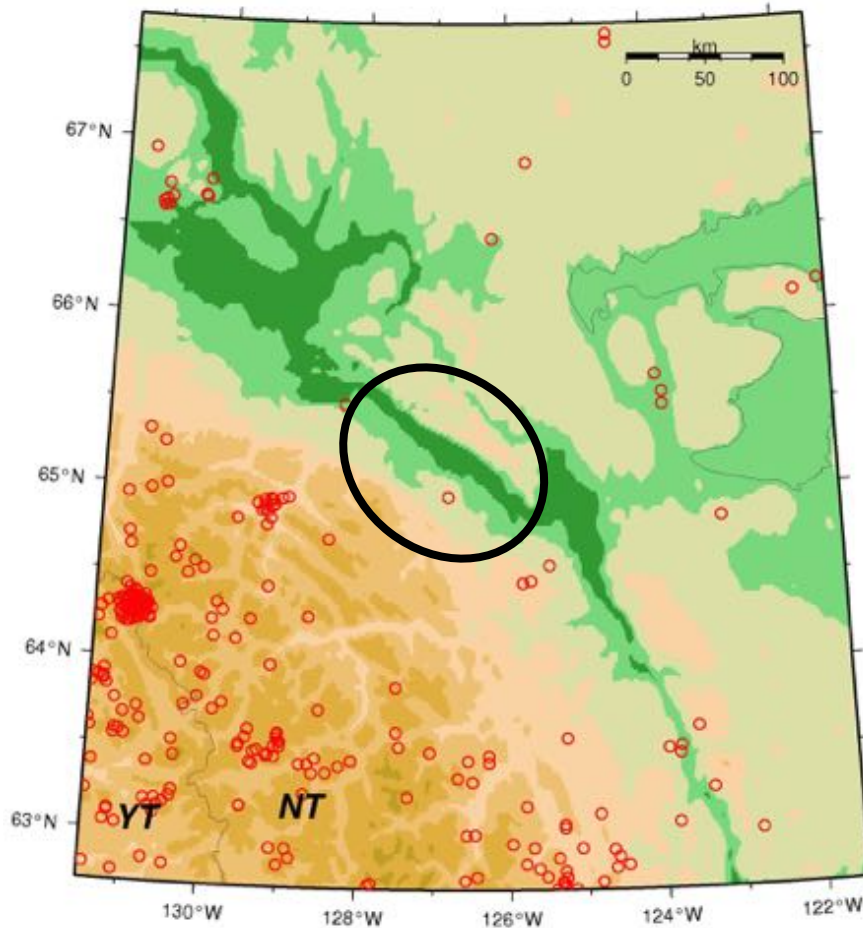
Seismic stations before 2012



Norman Wells, Northwest Territories

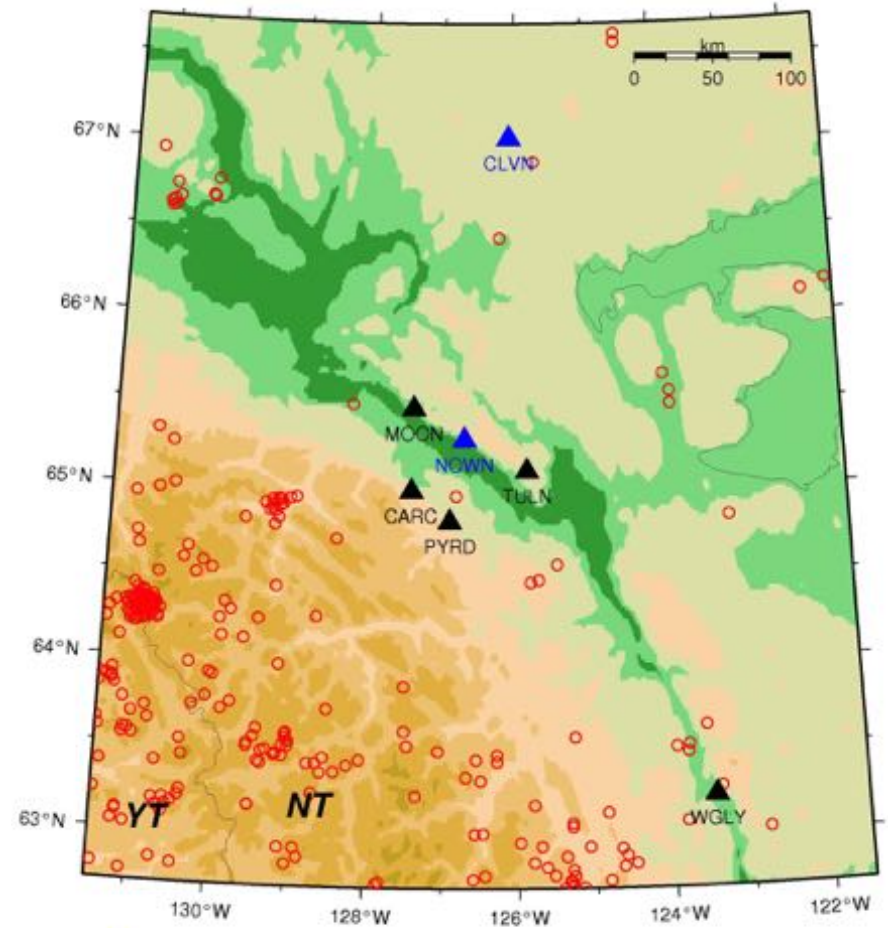


Seismic stations before 2012



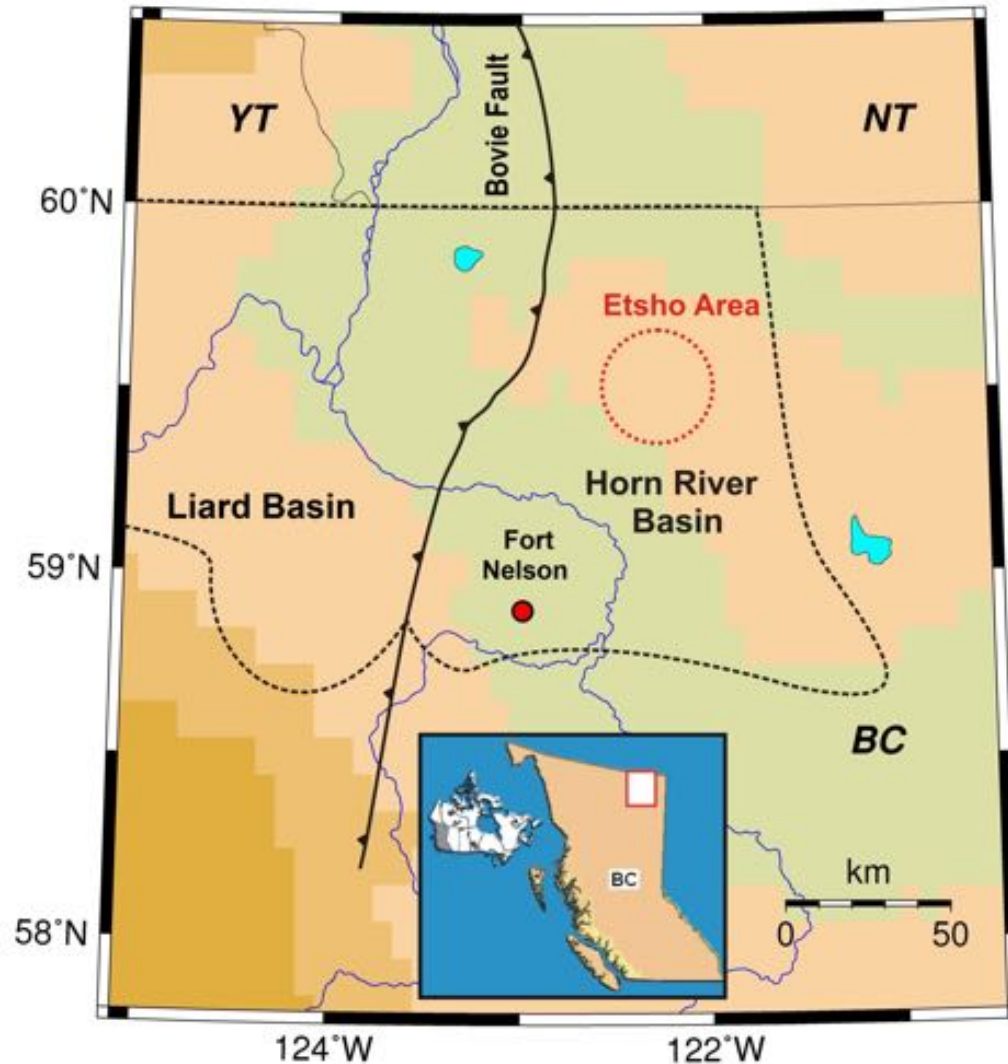
▲ CNSN/POLARIS stations ○ Seismicity (ML>=2) since 2000

Seismic stations now



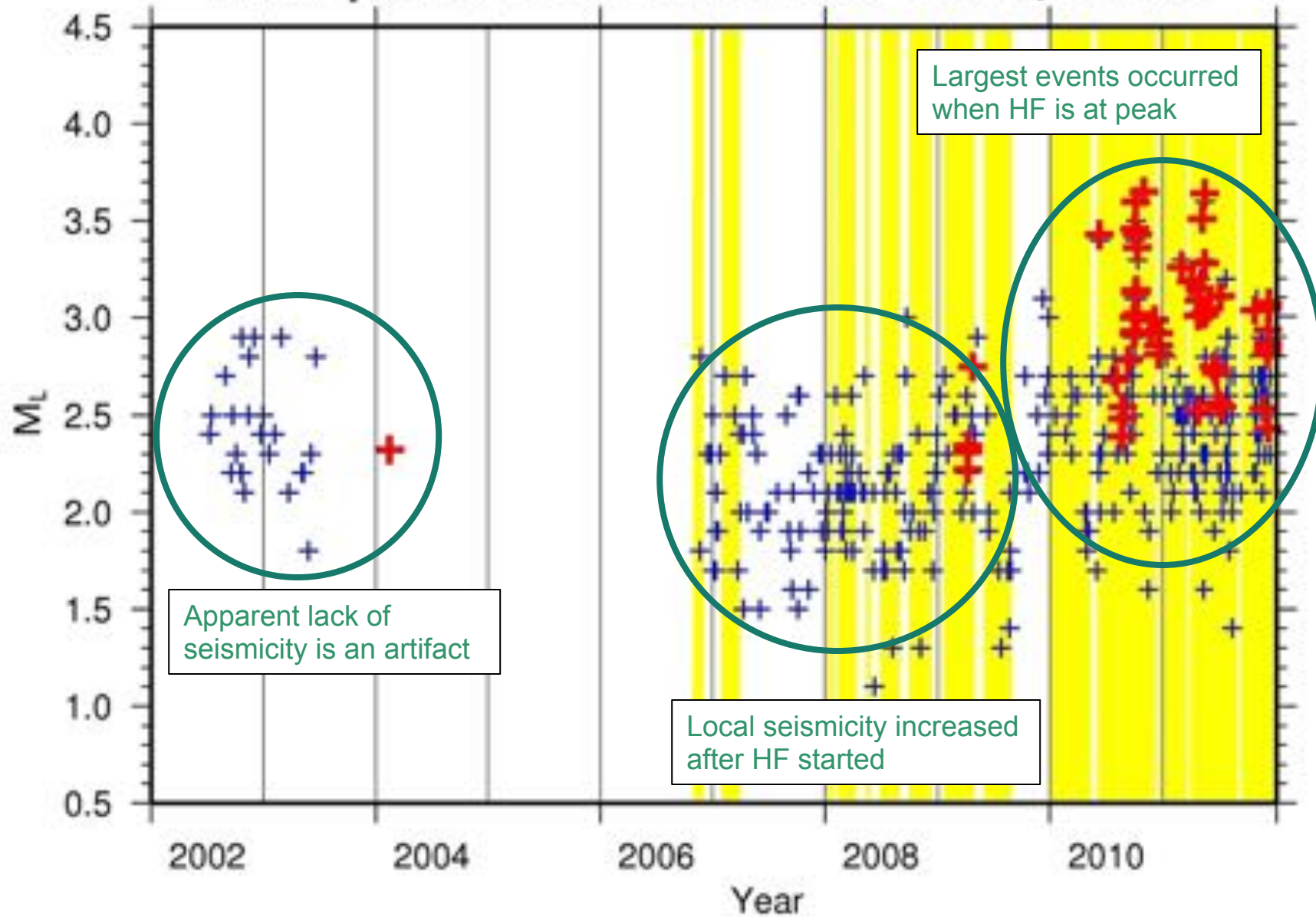
▲ CNSN stations ○ Seismicity (ML>=2) since 2000
▲ New stations established since December 2012

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.

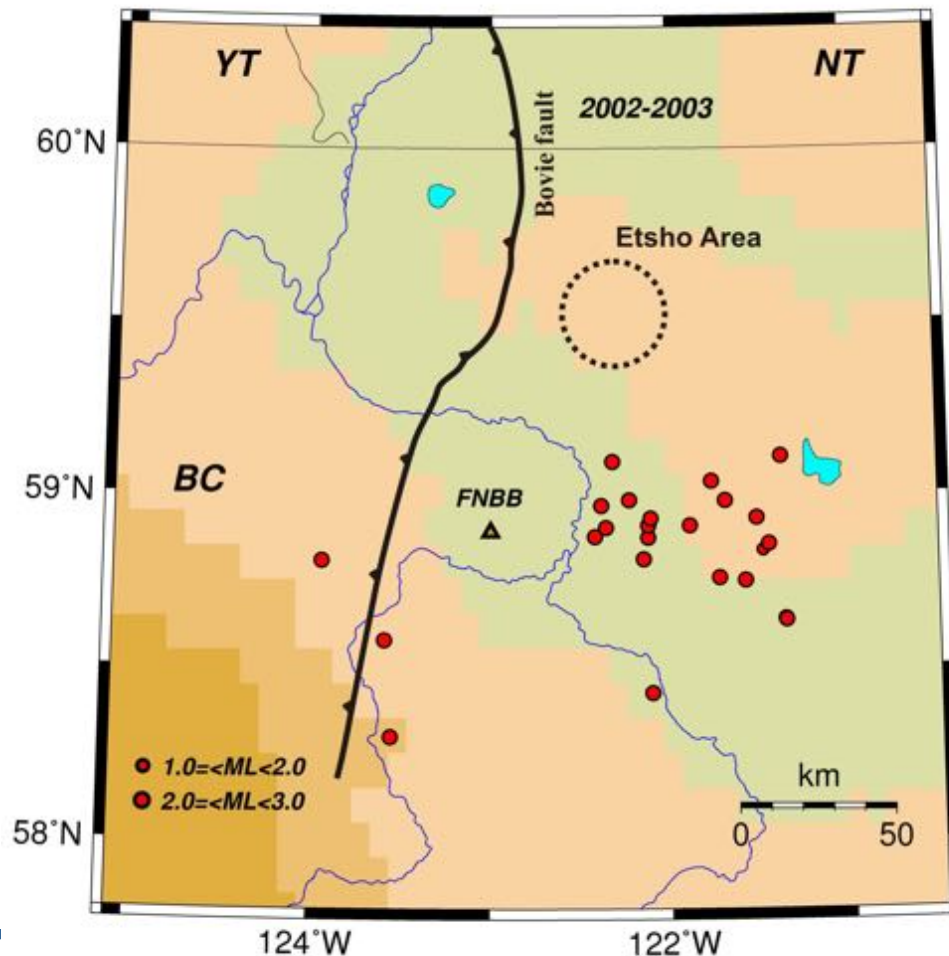
Earthquakes in the Horn River Basin, NE BC



Seismic Baseline for NE BC



Pre-HF Background Seismicity (2002-2003)



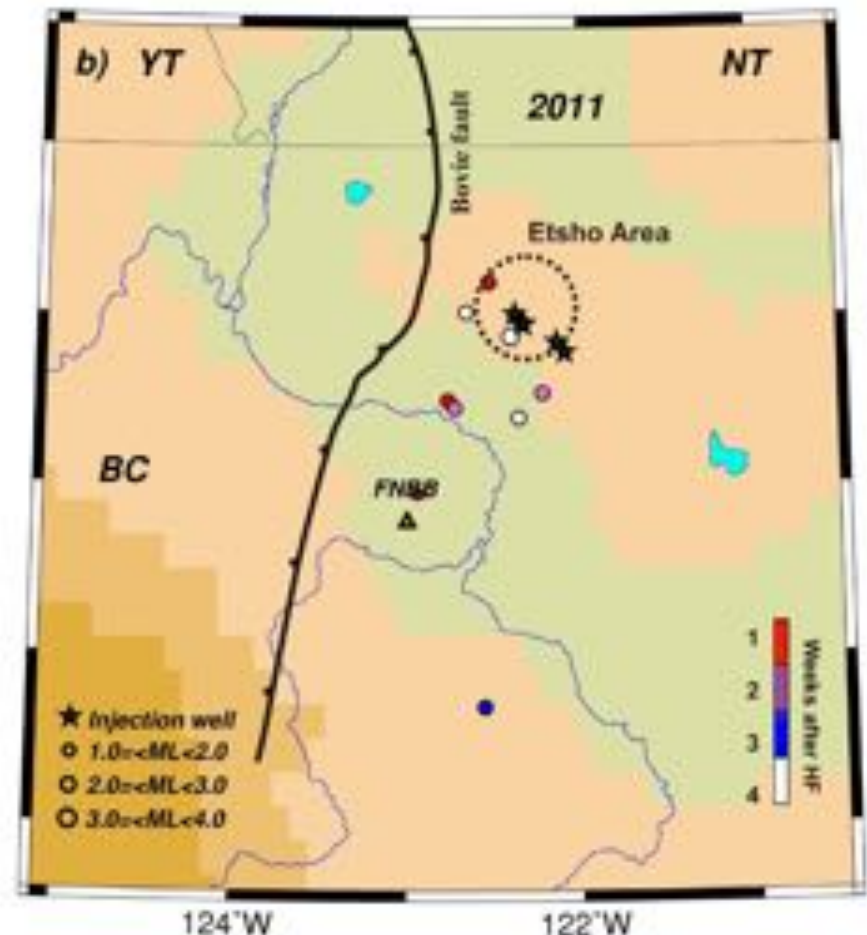
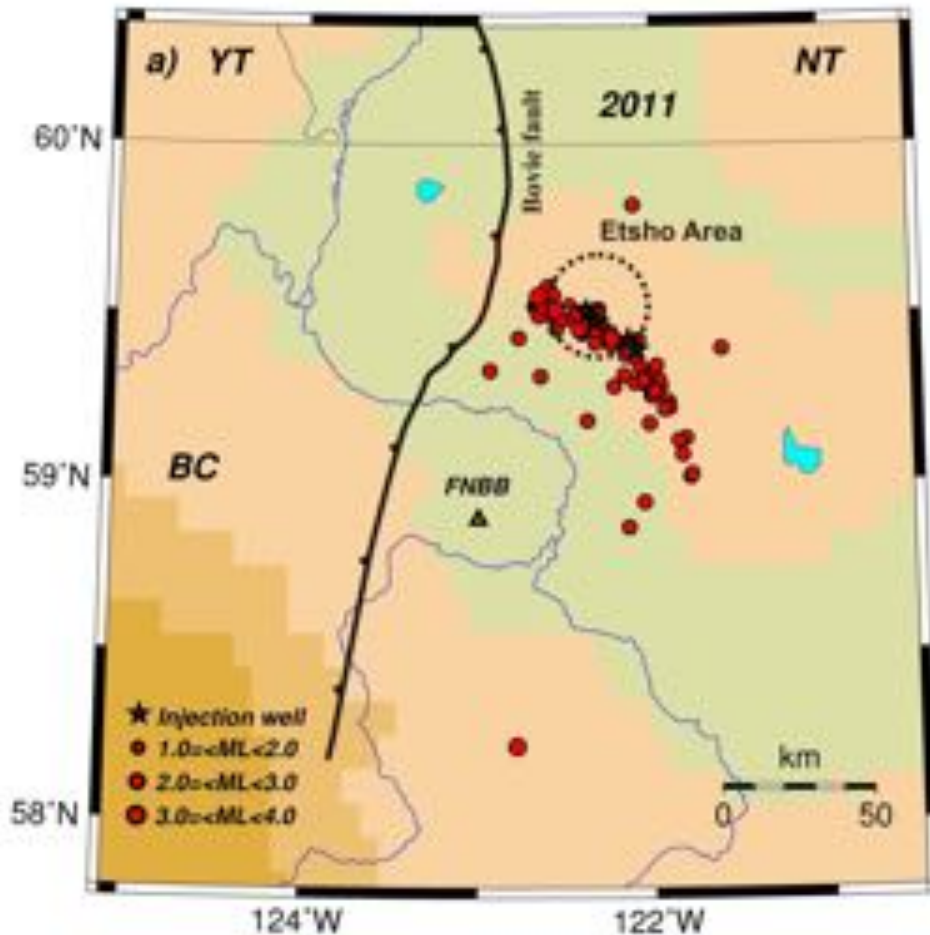
- 4 years before HF
- 24 earthquakes located
- M_L between 1.8 and 2.9, most are smaller than 2.5 (detection threshold of CNSN)
- Most occurred in the southern HRB, none was in the shale gas production area (Etsho)

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%

HF Completion Reports Filed by Operators



BC Oil & Gas COMMISSION

COMPLETION REPORT
OGC, 300-398
Victoria, BC
Phone: (250) 352-1100
Facsimile: (250) 352-1101

A signed form and a complete report must be submitted in duplicate under the authority of the Oil and Gas Activities Act, Drilling and Production Regulation, s.36, within thirty days of the end of each completion or workover operation, to the Victoria address noted above. Attach the matching Notice of Operations. An incomplete report will not be accepted and will be returned to the sender.

REPORT INFORMATION

Completion Workover Cased

Well Name: ECA HZ KAMIG

Well Permit No.: 24816

Well Status: C

Well Type: C

Well Depth: 20

Well Interval: 21

Well Completion: C

Well Workover: C

Well Cased: C

Well Abandoned: C

Well Other: C

Well Completion Date: 2010

Well Workover Date: 2010

Well Cased Date: 2010

Well Abandoned Date: 2010

Well Other Date: 2010

The general information requested on this form is collected under the authority of and used for the purpose of administering the Oil and Gas Activities Act, Drilling and Production Regulation, s.36. If you have any questions about this collection, see the disclosure.

BC Oil & Gas COMMISSION

COMPLETION / WORKOVER REPORT
OGC, 300-398 Harbour Rd.
Victoria, BC V8A 0B7
Phone: (250) 419-4400
Facsimile: (250) 419-4403

Date Received: _____

A signed form and a complete report must be submitted in duplicate under the authority of the Oil and Gas Activities Act, Drilling and Production Regulation, s.36, within thirty days of the end of each completion or workover operation, to the Victoria address noted above. Attach the matching Notice of Operations. An incomplete report will not be accepted and will be returned to the sender.

REPORT INFORMATION

Completion Workover Cased Well Abandonment Other

Well Name: *Amorha 1 & 2, 3 & 4, 5, 6, 7, 8, 9, 10*

Well Permit No.: *24816*

Well Status: *C*

Well Type: *C*

Well Depth: *20*

Well Interval: *21*

Well Completion: *C*

Well Workover: *C*

Well Cased: *C*

Well Abandoned: *C*

Well Other: *C*

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Well Workover Date: *2010*

Well Cased Date: *2010*

Well Abandoned Date: *2010*

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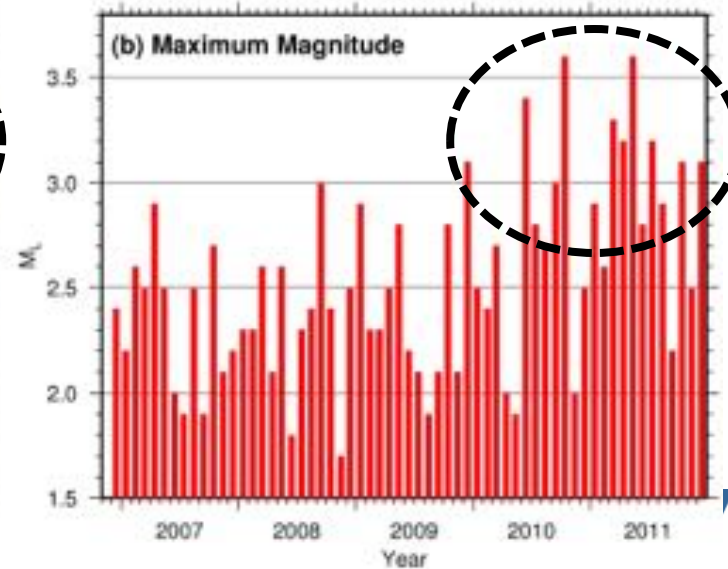
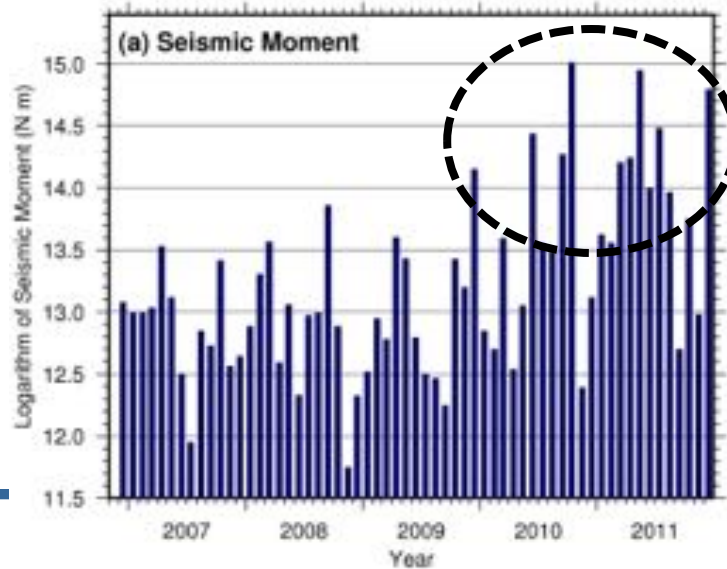
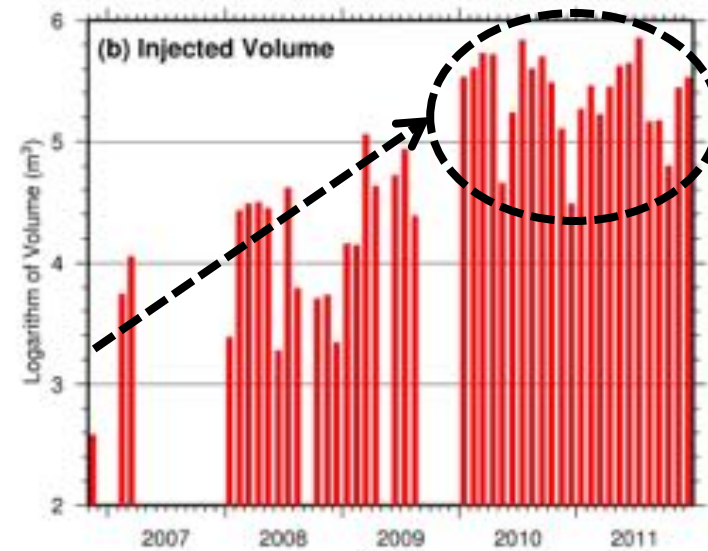
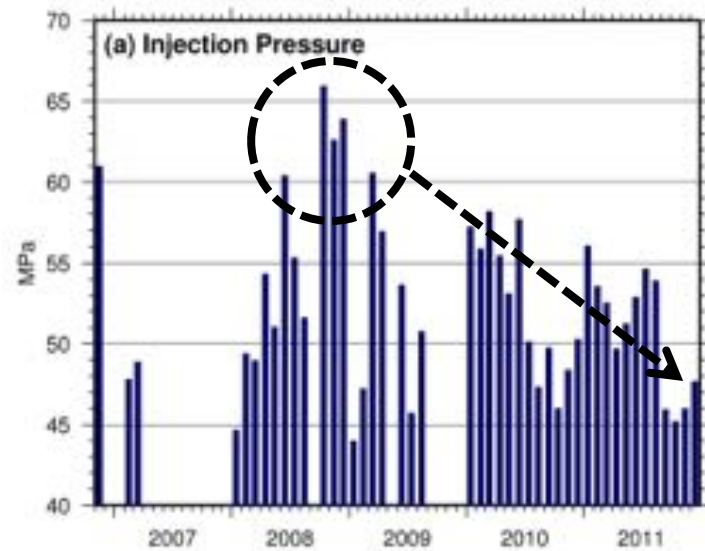
Well Abandoned Date: *2010*

Well Other Date: *2010*

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www.tracodatabase.com

HF Operations and Seismicity



Injected Volume vs. Seismicity

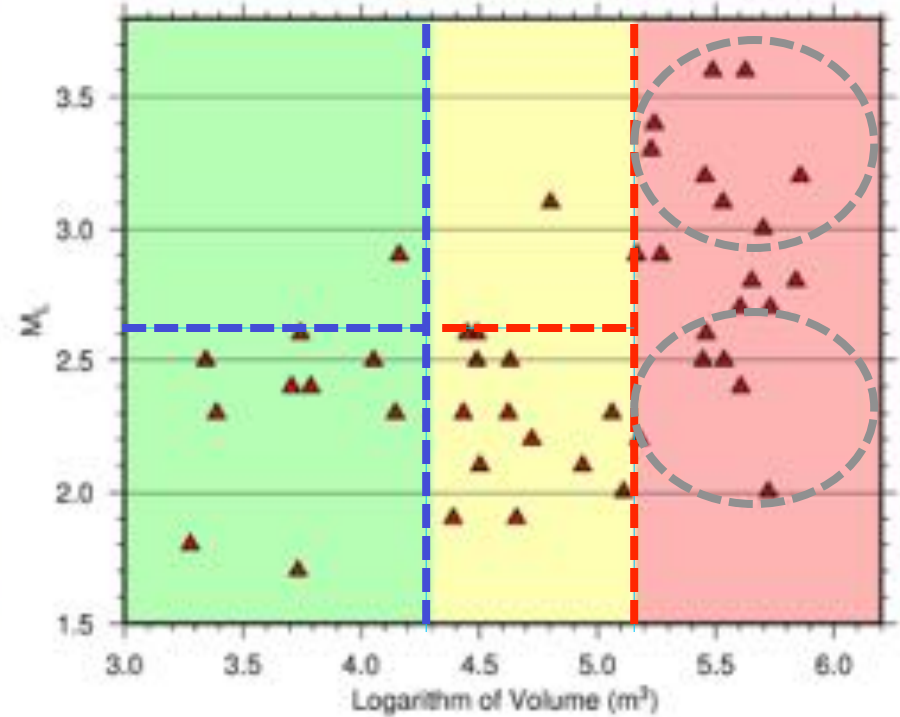
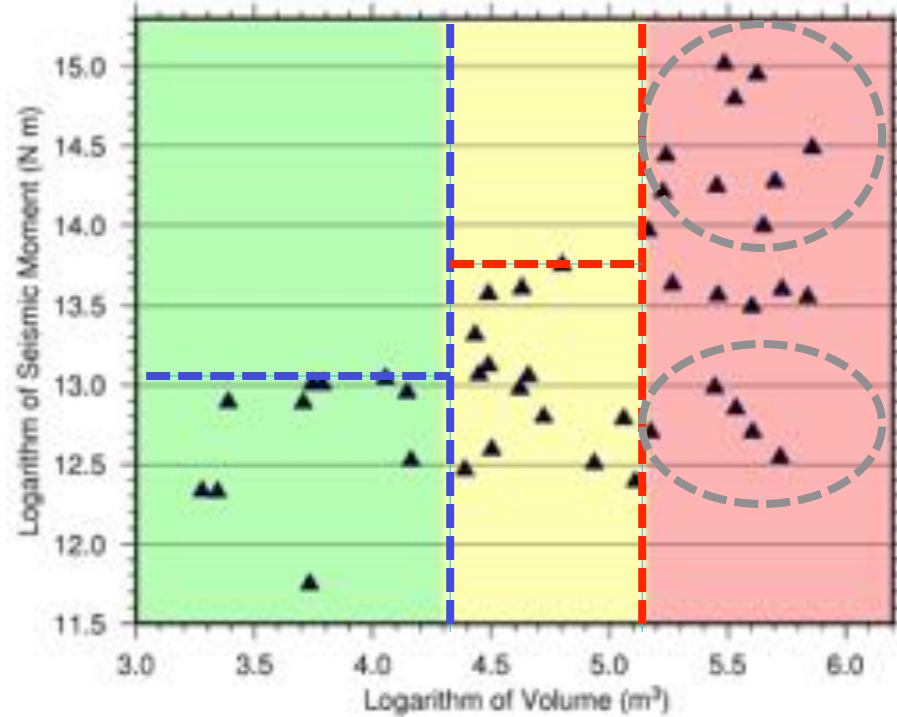


~150K m³/month

~150K m³/month

(a) Seismic Moment vs. Monthly Injected Volume

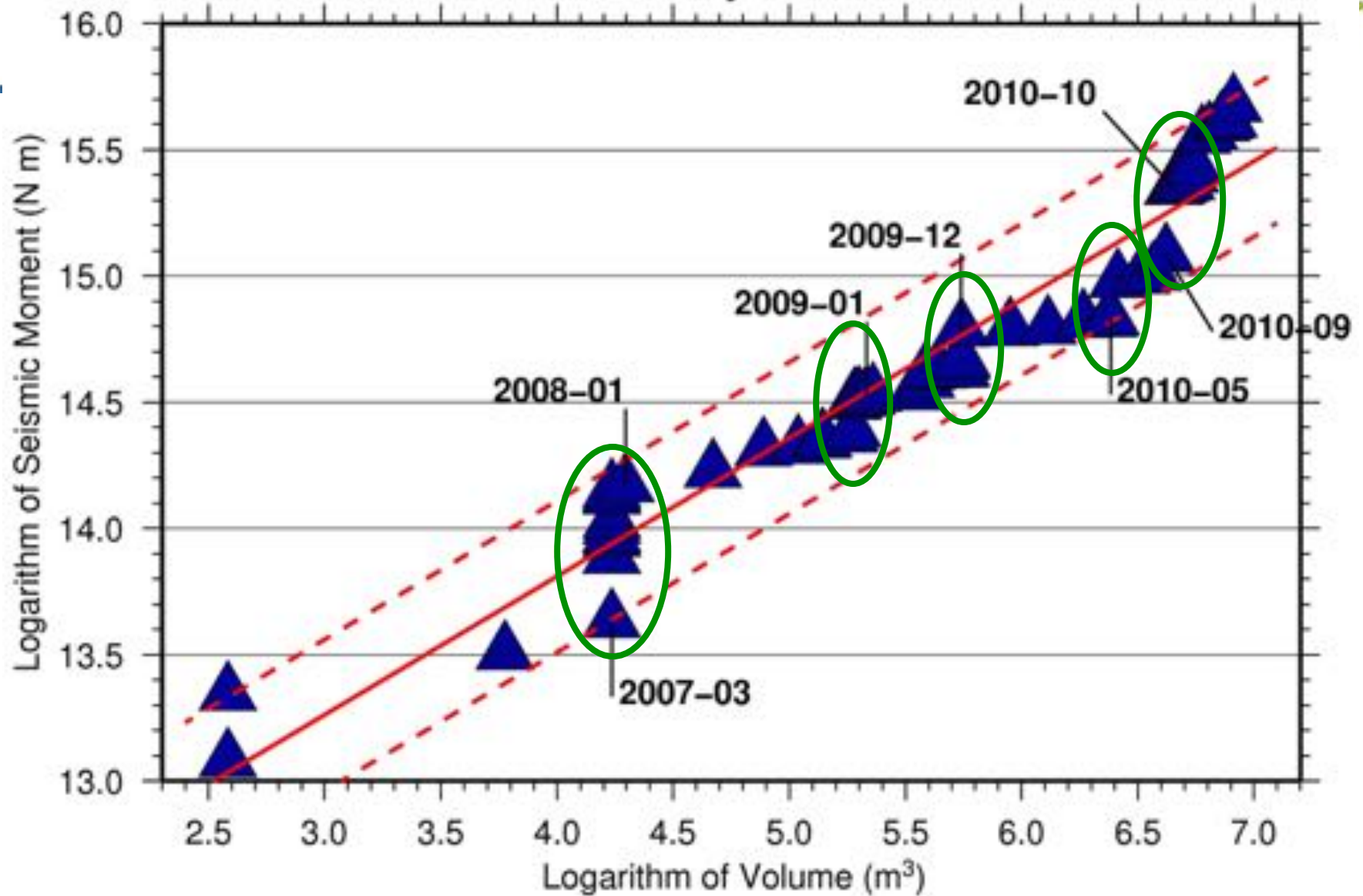
(b) Max. Magnitude vs. Monthly Injected Volume



~20K m³/month

~20K m³/month

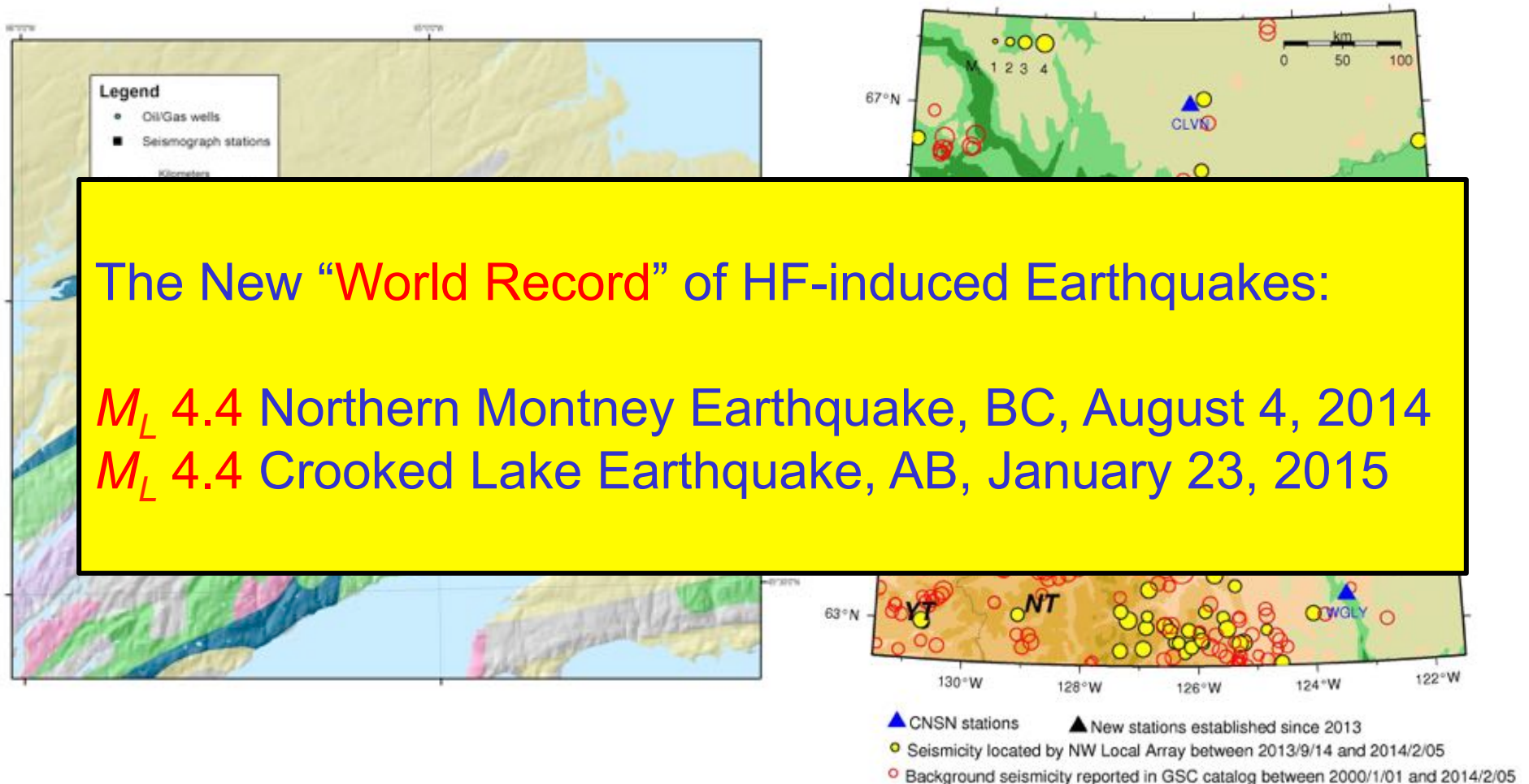
Cumulative Seismic Moment vs. Cumulative Injected Volume



Other Case Studies in NB and NT



Small-scale HF in NB in Aug/Sep 2014 Small-scale HF in NT in Feb/Mar 2014



Conclusions



- NRCan's Induced Seismicity Research now covers major shale gas basins in Canada, including BC, AB, QC, NB and NT.
- To confidently recognize any variation in regional/local seismicity that are possibly related to shale gas development, it is critical to **establish a good reference 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 $\sim 150,000$ m³**, but **large monthly injected volume \neq 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.

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