

Natural Resources Canada's Induced Seismicity Research Project: An Update

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ABSTRACT The development of unconventional oil and gas in North America has caused a significant increase of seismicity in areas of intense hydraulic fracturing and wastewater injection operations. These induced earthquakes have attracted considerable attention due to their potential seismic hazards. In 2012, Natural Resources Canada (NRCan) initiated the Induced Seismicity Research (ISR) Activity as part of the Shale Gas Research Project (Environmental Geoscience Program) to investigate the possible relationship between hydraulic fracturing (HF) of shale gas and the changing pattern of local seismicity. In 2015 the activity was expanded to include studies of all injection-related seismic events.

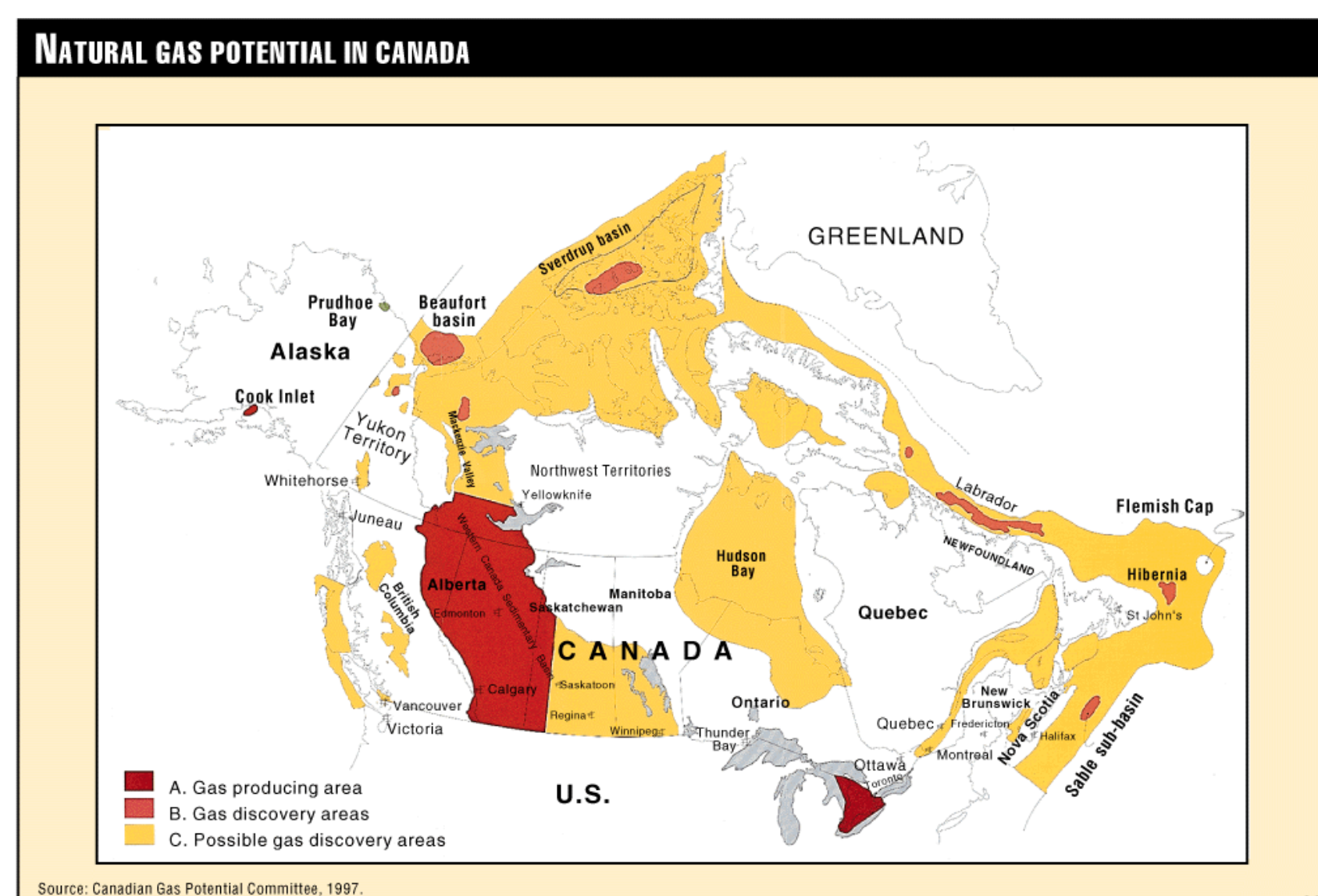
The primary objective of NRCan's ISR Project is to identify and fill critical knowledge gaps on the seismogenesis of induced earthquakes. Another important goal of ISR is to enhance regulatory performance by providing observation-based science and advice.

NRCan's ISR Project has three major tasks: 1) improve real-time earthquake-monitoring capability in major shale gas basins where current seismic coverage is sparse; 2) establish the baseline (pre-development) regional seismicity pattern for places where unconventional oil and gas is deemed likely to be developed in the near future.; and 3) conduct targeted studies on significant induced events to understand the relationship between their seismogenesis and man-made operations.

Working closely with provincial and territorial governments, new real-time broadband seismograph stations have been installed in British Columbia (BC), Alberta (AB), New Brunswick (NB), Northwest Territories (NT), Quebec (QC), and Yukon Territory (YT). Studies of seismicity before, during, and after HF operations have been completed for the Horn River Basin in northeast BC, the Moncton and Sussex areas in southern NB, and the Norman Wells area of the central MacKenzie Valley, NT. Similar studies, with the addition of an InSAR component, are planned for the Montney play of BC and the Fox Creek area of AB.

Detailed studies into recent $M > 4$ events in BC and AB are currently underway (including the $M_w 4.6$ Montney earthquake of August 17, 2015) examining source processes and ground motions to better understand the causes of induced seismicity and potential hazards.

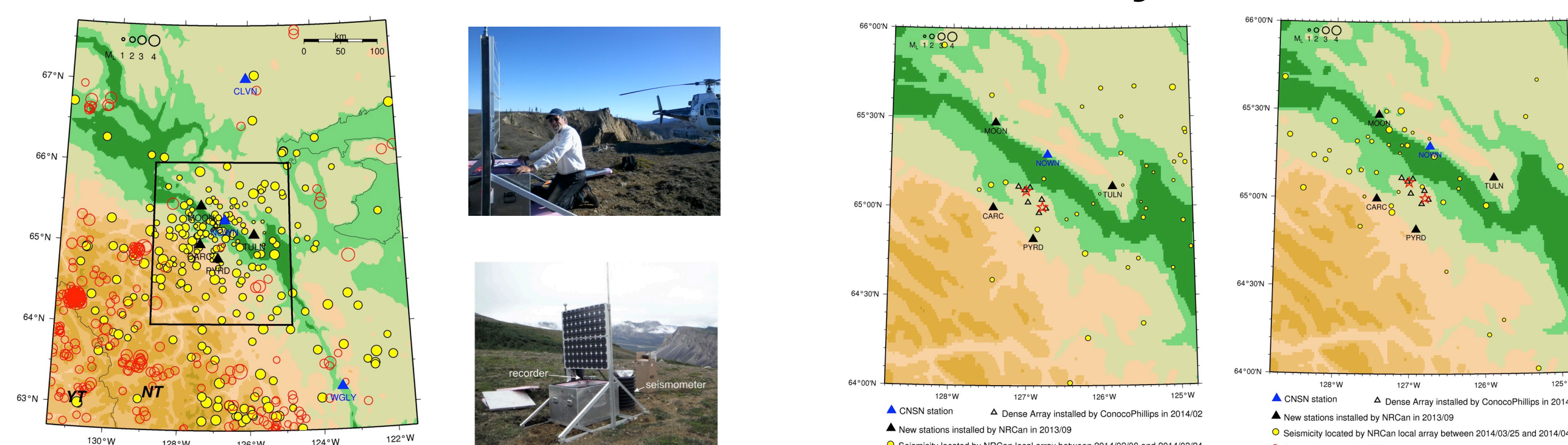
Unconventional Oil and Gas in Canada



Key Targeted Areas

1. West Canadian Sedimentary Basin, including British Columbia, Alberta, Saskatchewan, Yukon, and Northwest Territories.
2. Maritimes Basin, including New Brunswick and Nova Scotia.
3. St. Lawrence Platform, Quebec.

ISR for Norman Wells in Central McKenzie Valley, NT



- A local array was established in 2013 to better monitor the background seismicity (baseline study).
- Many small events were identified and located (yellow dots) that were not reported in the national earthquake database. (Cairns et al., 2014)
- Two small scale HF were completed in this area during Feb and March 2014.
- Earthquake occurrence rate and the seismic moment release show no clear variation for pre-, during, and post-HF periods.

ISR for northeast BC

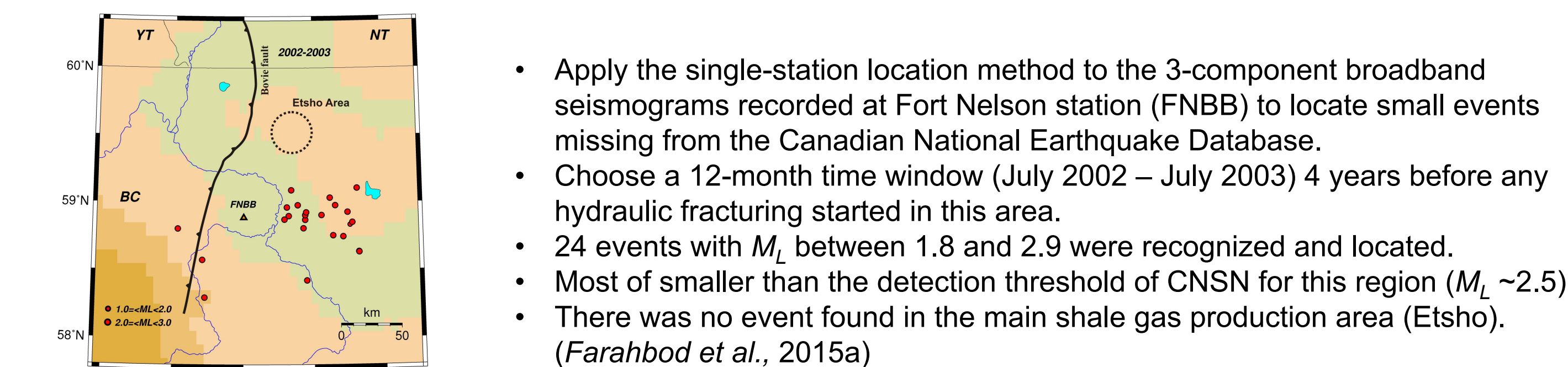
1. Densification of Regional Seismograph Network



The Canadian National Seismograph Network (CNSN) had only two stations in NE BC before 2012.

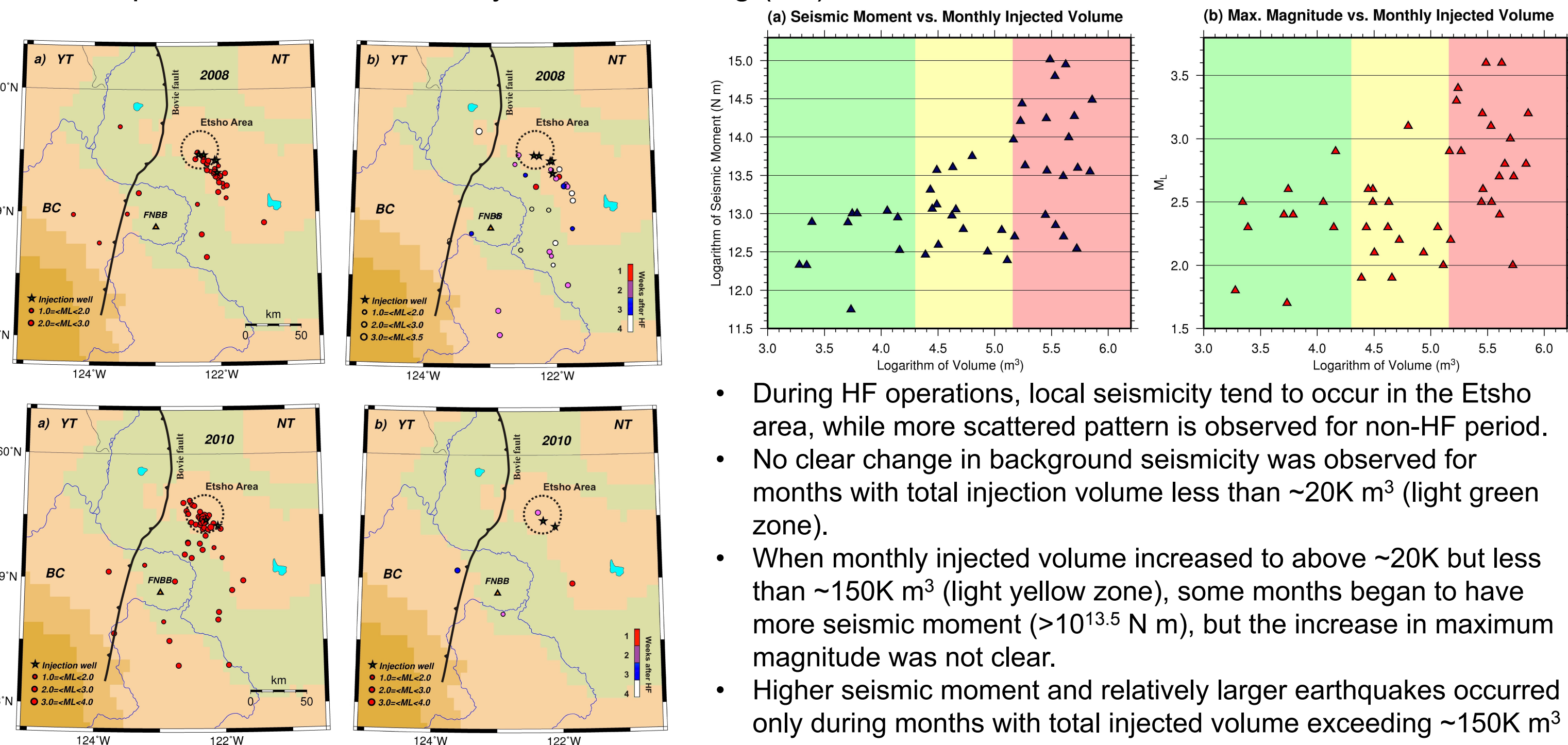
- Network performance analysis was done and published (Mahani et al., 2016)

1. Establishing the baseline of background seismicity for the Horn River Basin, BC



- Apply the single-station location method to the 3-component broadband seismograms recorded at Fort Nelson station (FNBB) to locate small events missing from the Canadian National Earthquake Database.
- Choose a 12-month time window (July 2002 – July 2003) 4 years before any hydraulic fracturing started in this area.
- 24 events with M_L between 1.8 and 2.9 were recognized and located.
- Most of smaller than the detection threshold of CNSN for this region ($M_L \sim 2.5$).
- There was no event found in the main shale gas production area (Etsho).

2. Earthquake occurrences and hydraulic fracturing (HF)

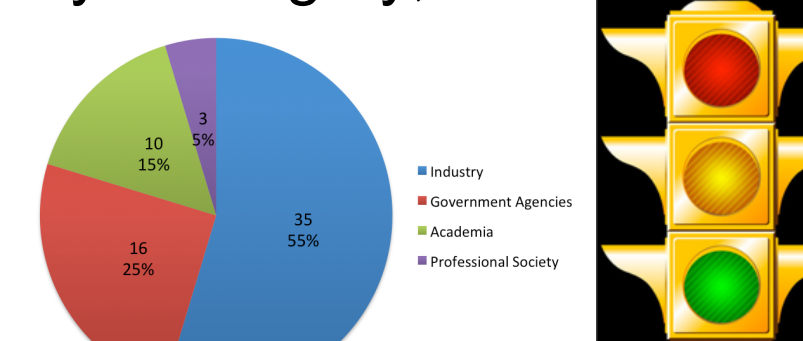


- During HF operations, local seismicity tend to occur in the Etsho area, while more scattered pattern is observed for non-HF period.
- No clear change in background seismicity was observed for months with total injection volume less than $\sim 20K m^3$ (light green zone).
- When monthly injected volume increased to above $\sim 20K$ but less than $\sim 150K m^3$ (light yellow zone), some months began to have more seismic moment ($> 10^{13.5} N m$), but the increase in maximum magnitude was not clear.
- Higher seismic moment and relatively larger earthquakes occurred only during months with total injected volume exceeding $\sim 150K m^3$ (light red zone).

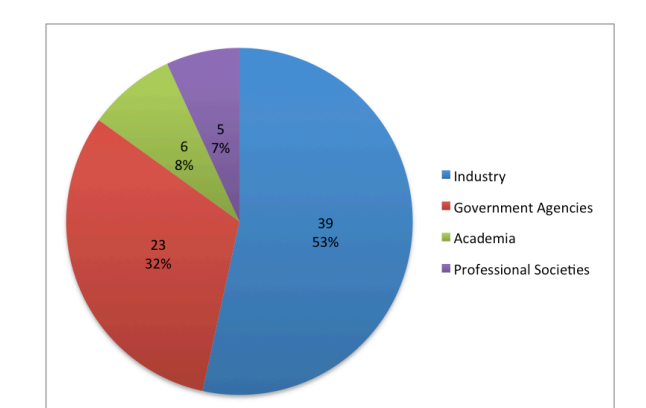
(Farahbod et al., 2015b)

Technical Meetings on Regulatory Performances for Induced Seismicity

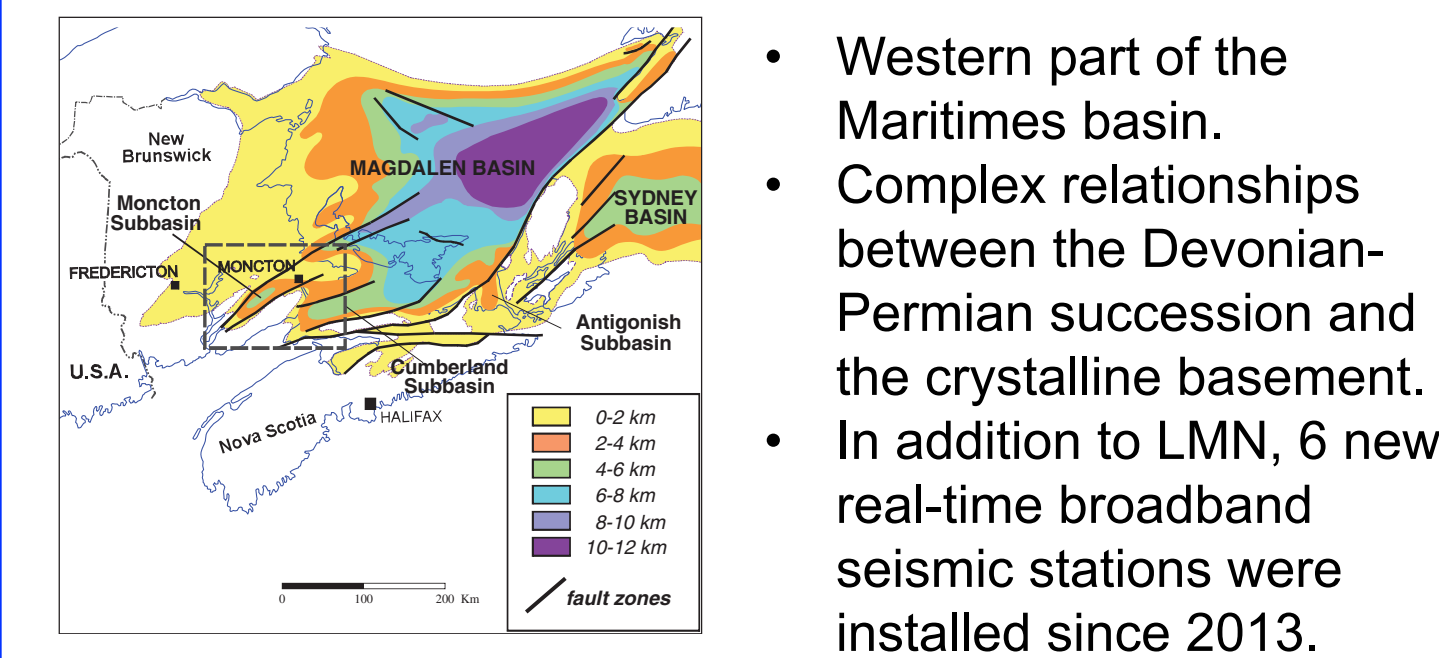
- Oct. 6, 2015, at the Downtown Campus of the University of Calgary; "Traffic Light Protocol (TLP) for Induced Seismicity"; 64 participants; Meeting conclusion and recommendations are published as a GSC Open-File Report (Kao et al., 2016).



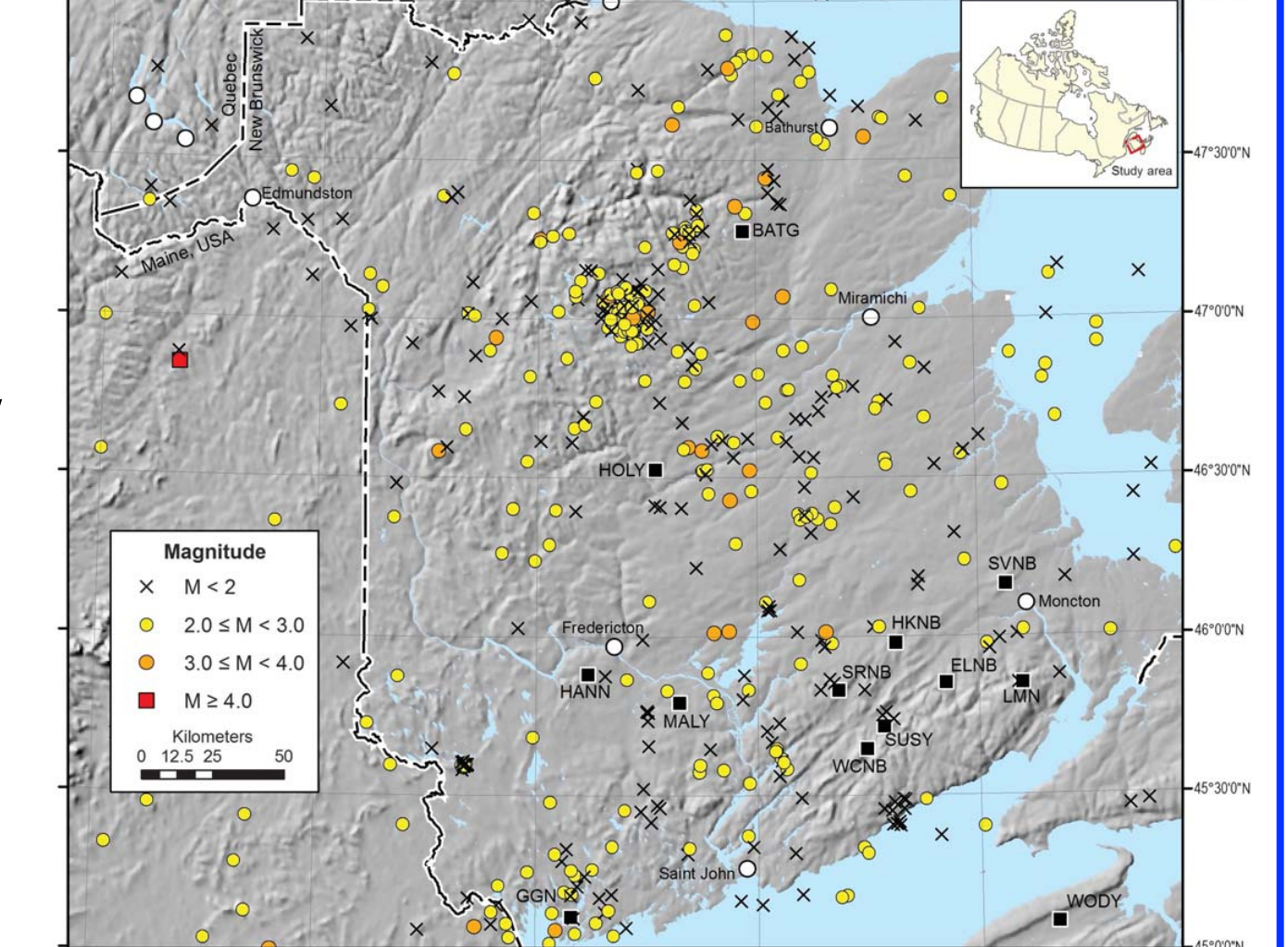
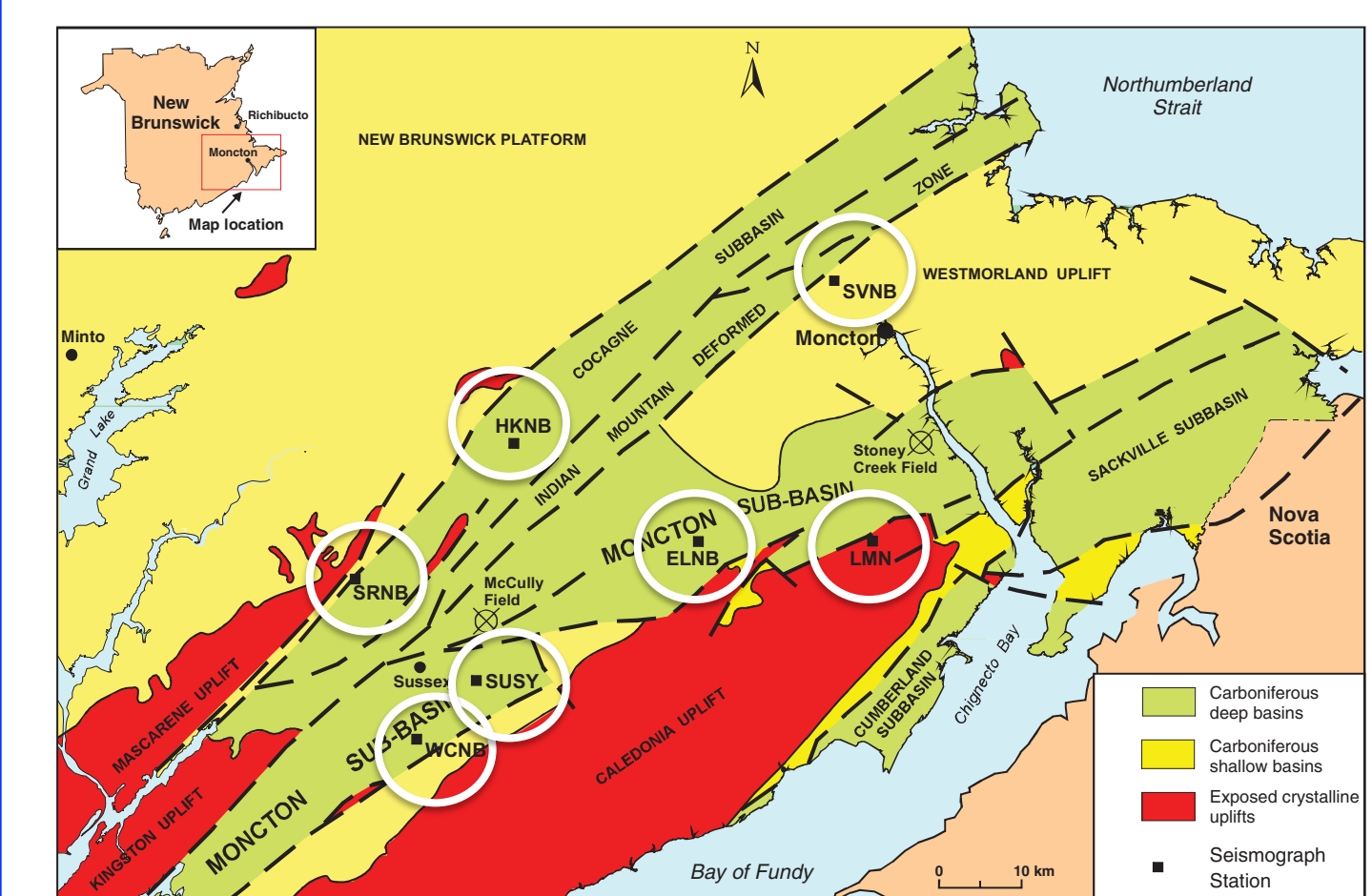
- Jan. 29, 2016, at the GSC-Pacific Sidney office; "New Regulation Proposal for Induced Seismicity and Data Sharing Framework"; 73 participants; Will have a follow-up meeting in Spring 2017.



ISR for Moncton sub-basin, NB



- Western part of the Maritimes basin.
- Complex relationships between the Devonian-Pennsylvanian succession and the crystalline basement.
- In addition to LMN, 6 new real-time broadband seismic stations were installed since 2013.



- HF in McCally gas field in 2009, 2010 and 2014.
- Between September 2009 and September 2013, only one earthquake was detected (20 Oct 2011).
- Between September 2013 and January 2015, four small events (m_b between 0.4 and 1.9) have been located.
- None of these events appear to be related to the local HF operations. (Lamontagne et al., 2015)

Working Progress

1. ISR for the Liard basin located in southeast Yukon Territory and northeast BC



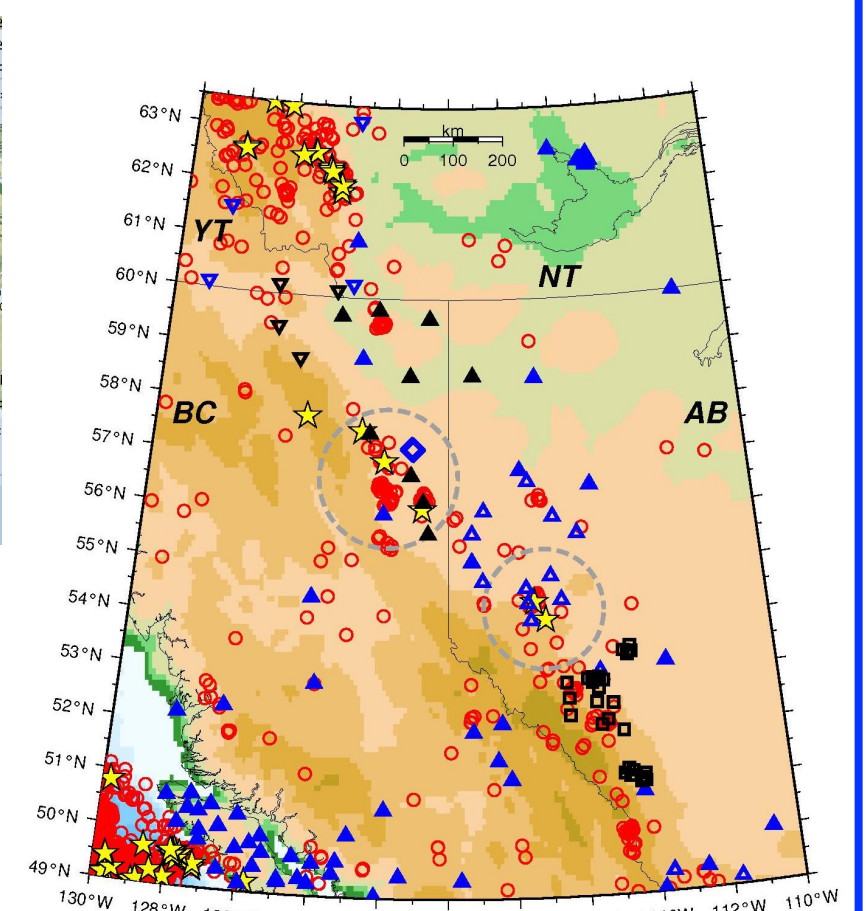
- Funded by both the Yukon government and NRCan to install 5 additional real-time broadband seismograph stations.
- Reconnaissance and preliminary site visit completed in early 2015.
- Purchase of equipment completed in late 2015, installation completed in mid 2016.
- Project goal: establish a reliable baseline of regional seismicity in preparation for possible future development of shale gas.

2. ISR for the Anticosti Island, QC

- Exploration for unconventional oil and gas is currently underway.
- HF operations for extracting tight oil and shale gas are planned in the near future.
- Installation of 3-4 broadband seismic stations completed in late 2015.



Maximum size of HF-related induced earthquakes keep increasing since 2010.



* The largest hydraulic fracturing-induced event occurred on August 17, 2015, in northern Montney, BC.

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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, Yukon Geological Survey, Geoscience BC, Energy Institute of New Brunswick, Canadian Association of Petroleum Producers, University of Calgary, University of Alberta, University of Western Ontario, University of Ottawa, McGill University



Natural Resources Canada

Ressources naturelles Canada

