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

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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
Montney 700

Locations of Induced Seismicity Studies in Canada

Does not include Montney, Duvernay, and others in WCSB

On-going
Starting summer 2015

Maritimes 130
Utica 181
Ontario Paleozoic
Western Canada Sedimentary Basin (Colorado Group only) 200
Horn River Basin 500
Besa River

NWT Cretaceous
NWT Devonian
Arctic Islands
Northeast BC and Western AB

Seismic stations before 2012

- CNSN/POLARIS stations
- Seismicity (ML≥2) between 2000 and 2006

Seismic stations now and future

- CNSN/POLARIS stations
- Seismicity (ML≥2) after 2007
- New stations established in 2012 and 2014
- New stations established/planned in 2015–2016
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.
Earthquakes in the Horn River Basin, NE BC

- Apparent lack of seismicity is an artifact
- Largest events occurred when HF is at peak
- Local seismicity increased after HF started

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 Operations and Seismicity

(a) Injection Pressure
(b) Injected Volume
(a) Seismic Moment
(b) Maximum Magnitude
Injected Volume vs. Seismicity

- For injected volumes of ~150K m$^3$/month
- For injected volumes of ~20K m$^3$/month

Farahbod et al. (2015)
Case Study: Norman Wells, NWT

Background Seismicity 2000-2006

- Background seismicity, NRCan earthquake catalogue 2000–2006

Background Seismicity 2007-2013

- Background seismicity, NRCan earthquake catalogue 2007–2013
- CNSN stations
Norman Wells Local Array

Cairns et al. (2014)
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 = $2.5 \times 10^{16}$ N m
- Average monthly moment release = $5.04 \times 10^{15}$ N m.
- Equivalent to one Mw 4.4 earthquake each month
During and Post-HF Periods

**During HF (2015/2/08 – 2015/3/24)**

- New stations installed by NRCAN in 2013/09
- Seismicity located by NRCAN local array between 2014/02/08 and 2014/03/24
- Seismicity reported in NRCAN catalog
- Hydraulic fracturing sites 2014/02/08 – 2014/03/14


- New stations installed by NRCAN in 2013/09
- Seismicity located by NRCAN local array between 2014/03/25 and 2014/04/30
- Seismicity reported in NRCAN catalog
- Hydraulic fracturing sites 2014/02/08 – 2014/03/14
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 = $2.5 \times 10^{16}$ N m
- Average monthly moment release = $5.04 \times 10^{15}$ 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 = $2.1 \times 10^{15}$ N m
- Average monthly moment release = $7.51 \times 10^{14}$ 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 m³, 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
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Thank You