Remote Dynamic Triggering of Earthquakes in Three Canadian Shale Gas Basins, Northeastern British Columbia and Alberta, Northwest Territories and New Brunswick: Progress Report

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Wang, B., Harrington, R., Liu, Y. and Kao, H. (2017): Remote dynamic triggering of earthquakes in three Canadian shale gas basins, northeastern British Columbia and Alberta, Northwest Territories and New Brunswick: progress report; *in* Geoscience BC Summary of Activities 2016, Geoscience BC, Report 2017-1, p. 21–24.

Introduction

The Earth's crust is full of faults, and several studies indicate that the brittle crust is in a critically stressed state with failures on the verge of happening (Zoback and Zoback, 2002; Hill, 2008). Local faults can be activated by the transient stress from the seismic waves of distant mainshocks with hypocentre distances ranging from hundreds to thousands of kilometres, this is called dynamic triggering (Hill et al., 1993; Gomberg et al., 2001; Prejean et al., 2004; Hill and Prejean, 2007). The organized study of dynamic triggering could help to interpret the mechanism of earthquake nucleation and fault activation. Meanwhile, testing the minimum transient stress necessary to trigger an earthquake could help to investigate the stress state of local faults (Brodsky and Prejean, 2005; van der Elst et al., 2013; Aiken and Peng, 2014; Wang et al., 2015).

In this project, a search for dynamic triggering in three shale basins in Canada will be undertaken to see if these three regions, which represent different types of tectonic regimes, are susceptible to triggering. At the same time, the current stress state of local faults will also be investigated. If triggering happens, the specific triggering response properties for each of the different basins will be examined, as well as the factors that could be causing dynamic triggering. For the three shale basins (Figure 1), one basin is situated in northeastern British Columbia and western Alberta (BCAB), one basin is situated in the Northwest Territories (NWT) and one basin is situated in New Brunswick (NB). These three areas have all seen an increase in the number of seismic stations installed; studies show that they have experienced relatively high seismicity rates recently, which may be related to the fluid injection from unconventional oil/gas production (Rivard et al., 2014; Schultz et al., 2014, 2015; Eaton and Mahani, 2015; Farahbod et al., 2015; Lamontagne et al., 2015; Atkinson et al., 2016). For example, the number of earthquakes catalogued by Natural Resources Canada (NRCan) in BCAB was 24 in 2002 compared with a total of 168 in 2014 (Natural Resources Canada, 2016). Figure 2 shows the newly installed seismic stations and catalogued earthquakes (2013–2015) in the three areas of this study.

Keywords: *British Columbia, dynamic triggering, shale basins, induced seismicity*

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Method

The multi-station matched method (MMF) detects similar signals by cross-correlating the waveforms of known events, referred to as templates, with continuous waveform data at multiple stations to detect the small and uncatalogued earthquakes. Templates will be built using earthquake data from the NRCan catalogue (Natural Resources Canada, 2016).

Statistical Measure of the Level of Triggering

After detecting and counting earthquakes from the continuous waveforms, the β statistical value will be used as the quantitative measure of the level of dynamic triggering. The β statistical value represents differences between the number of events in a specific time window and the expected number of events in that time window (Matthews and Reasenberg, 1988). The following equation will be used to calculate the β statistical value (Aron and Hardebeck, 2009):

$$\beta(N_a, N, T_a, T) = \frac{N_a - N(T_a / T)}{\sqrt{N(T_a / T)(1 - T_a / T)}}$$

where T_a is the length of time window after the mainshock and T is the total length of time window, variable Na is the number of events after the mainshock and N is the total number of events. Here the total time window has been set

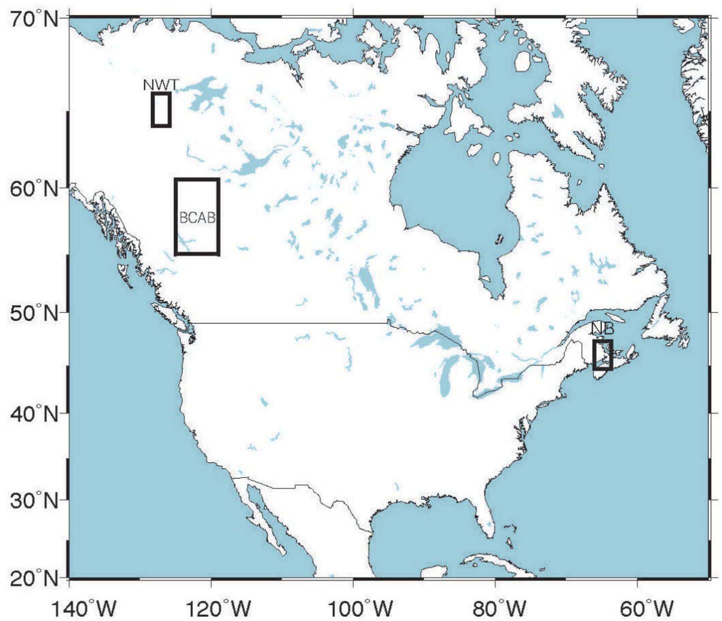

Figure 1. Black boxes show the locations of the three shale basins in Canada. Abbreviations: BCAB, British Columbia and Alberta; NB, New Brunswick; NWT, Northwest Territories.

to be even, meaning $T_a = 1/2 \times T$. The maximum time windows used in the MMF detection for each of the three basins are 10, 5 and 5 days. The β statistical value varies slightly as a function of time window length.

Next Steps

Since project initiation at the beginning of 2016, coding, waveform processing and the building of candidate templates from waveform selections have been completed, and the code is running for the detections. After determining seismicity rates in the windows surrounding each mainshock, the β statistic value will be calculated to quantify if statistically significant triggering has occurred or not. Where triggering occurs, calculations of triggered earthquake focal mechanisms may help explain how pre-existing receiver faults become critically stressed, and what physical factors are directly correlated with dynamic triggering. Cases of observed triggering may imply that the seismic response to

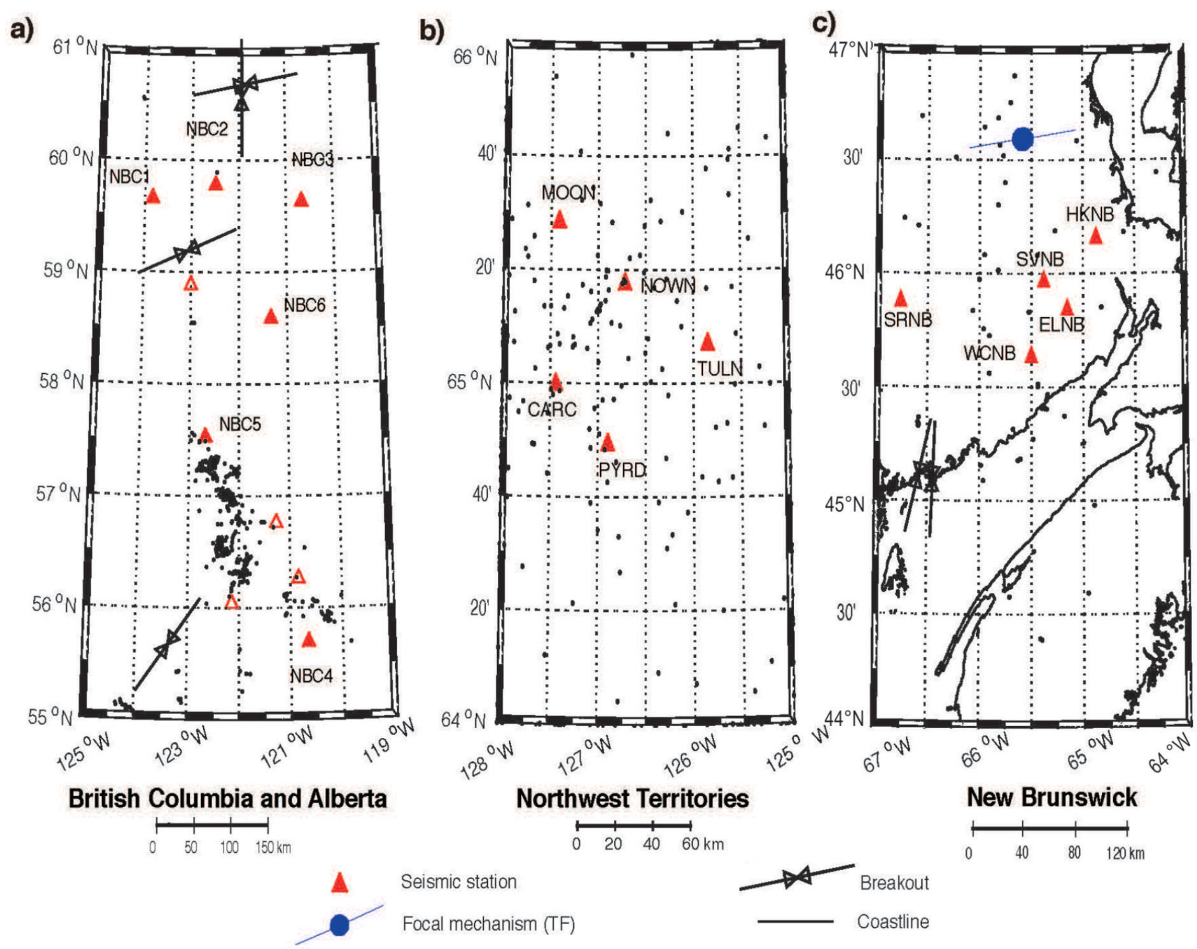

Figure 2. Locations of the newly installed Natural Resources Canada seismic stations in each of the study areas: **a)** British Columbia and Alberta, **b)** Northwest Territories and **c)** New Brunswick. Seismic stations used in the analysis shown as filled red triangles, remaining stations shown as unfilled red triangles and catalogued earthquakes (2013–2015) shown as black dots (Natural Resources Canada, 2016). Abbreviation: TF, thrust fault.

injection activity could be intense. Alternatively, if triggering occurs but the seismic response to injection activity is limited, it could imply that hydraulic communication with basement faults is key to inducing earthquakes. This project will be finished at the beginning of 2017.

Acknowledgments

This project is funded by two Natural Sciences and Engineering Research Council of Canada Discovery grants to R. Harrington and Y. Liu at McGill University, as well as partial funding from the McGill University FRQNT – New University Researchers Start Up Program. Support was given to B. Wang through the Geoscience BC scholarship fund.

The authors would also like to thank H. Yu for providing guidance on this project.

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