Source Properties of Earthquakes around Hydraulic-Fracturing Sites near Dawson Creek, Northeastern British Columbia

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Introduction

Tectonic earthquakes occur due to failure of critically stressed faults. The source of stress perturbation could be natural or anthropogenic. Anthropogenic sources of stress perturbation include solid-matrix stress transfer and pore-pressure enhancement that could result from enhanced hydrocarbon recovery and wastewater injection. In the last few decades, several studies have shown a clear correlation between reservoir stimulation and seismicity (e.g., Schultz et al., 2015; Atkinson et al., 2016). The fluid-injection operations increase fault loading rate to levels above tectonic loading rate. This mechanism reduces recurrence intervals and produces earthquakes with moment magnitude up to $\mathbf{M_w}$ 5+ (e.g., 2016 $\mathbf{M_w}$ 5.8 Pawnee, Oklahoma earthquake; United States Geological Survey, 2016). The recent increase in seismicity related to anthropogenic activities in northeastern British Columbia (BC) and western Alberta (e.g., Atkinson et al., 2016) necessitates a better understanding of the fault-rupture processes for adequate seismic-risk assessment. The source properties, such as stress drop and fault-plane solution of earthquakes, provide insight into crustal-stress conditions and delineate ‘blind’ faults and possible amplitude of induced ground motion.

This project involves monitoring seismicity near hydraulic-fracturing sites in northeastern BC through a data-acquisition campaign employing nine temporary broadband and two permanent Canadian National Seismograph Network (CNSN) stations (Figure 1). The continuous waveform data are scanned to detect earthquakes, including events that are below the detection threshold of the current permanent seismic stations of CNSN around the study area. Fault-plane solution and stress drop of the events are determined from further analysis of the data to delineate seismotectonic structures and infer crustal stresses and their orientation(s), relative fault maturity and ground-motion potential.

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Methods

Fault-Plane Solution

Fault-plane solutions are determined by fitting a suite of synthetic waveforms, precalculated for ~35 000 possible moment-tensor solutions using a 1-D velocity model, to observed data. To infer the moment-tensor solutions, a bootstrap-based full moment-tensor probabilistic-inversion scheme (Grond), with capability to infer moment-tensor solution of small earthquakes recorded by a sparse seismic network, is used to determine fault-plane solutions (Dahm et al., 2018). Synthetic waveforms, precalculated using Qseis code (Wang, 1999), are fit to recorded waveforms to determine the best fault-plane solution.

Stress Drop

Stress drop (i.e., the difference between initial and final stress on a fault following an earthquake) is calculated by analyzing observed data in the frequency domain. An earthquake waveform is a convolution of source term, instrument term and path term (i.e., velocity structure between source and instrument locations). To isolate the source term, the instrument and path terms must first be removed. The spectral ratio of co-located events with magnitude difference ≥1 is computed to determine their relative source term; proximity of event pairs are quantified by their cross-correlation values. The spectral-ratio approach is used to infer parameters such as corner frequency (a measure of the source duration) and seismic moment (a measure of energy), hence stress drop. The spectral ratios are fit to determine corner frequency of the larger event, as well as the smaller event if resolvable, and their relative seismic moment using the expression

$$\Omega(f) = \frac{\Omega_0^m}{\Omega_0^e}\left[\frac{\left(1+\left({}^{f}/_{f_c^e}\right)^{\gamma n}\right)}{\left(1+\left({}^{f}/_{f_c^m}\right)^{\gamma n}\right)}\right]^{1/\gamma}$$

where the *m* and *e* superscripts refer to the main event and empirical Green’s Function (eGF) event, respectively, and

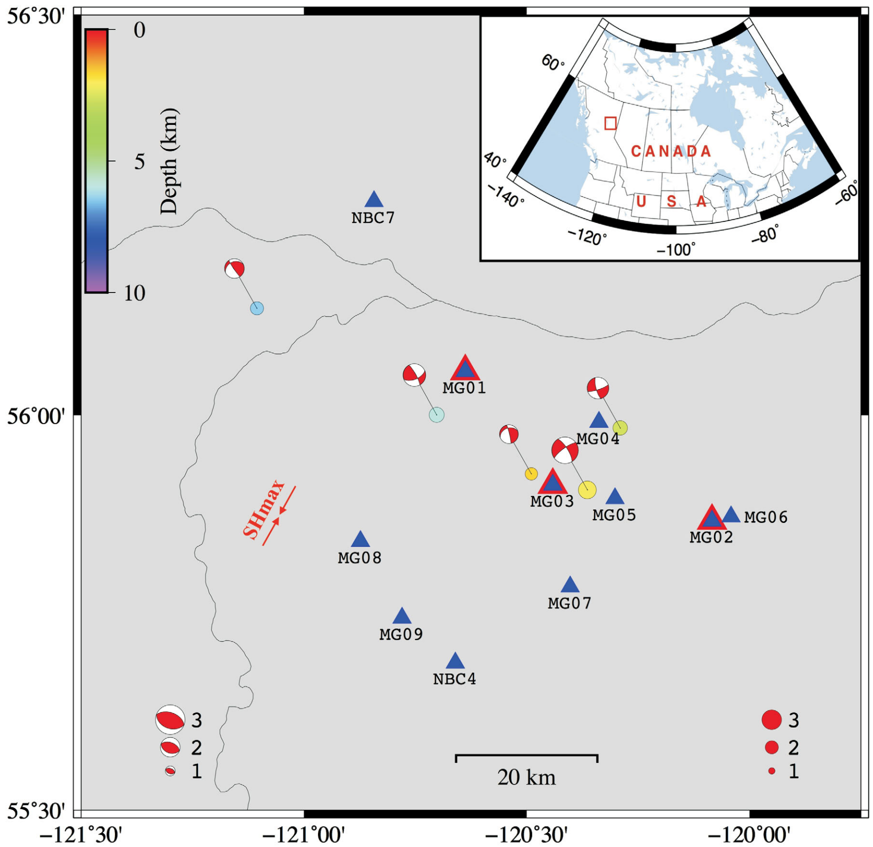

Figure 1. Study area in northeastern British Columbia. Coloured circles are scaled by local magnitude and represent events reported in the Natural Resources Canada catalog. 'Beach-balls' represent the fault-plane solution of each event. Blue triangles indicate nine temporary broadband stations (MG01 to MG09) and two permanent CNSN stations (NBC4 and NBC7). Triangles with red border indicate co-located broadband and strong-motion stations. Red arrows indicate approximate orientation of regional maximum compressional stress inferred from P-axes trend.

Ω_0 is the long-period spectra amplitude, f is frequency, f_c is corner frequency, n is the spectra falloff rate and γ is a factor that controls the shape of the corner (Boatwright, 1978; Hartzell, 1978).

Results and Next Steps

Preliminary fault-plane solutions highlight failure on faults oriented roughly northwest-southeast from northeast-southwest regional maximum horizontal compression (Figure 1), possibly exerted by the subduction of the Pacific Plate beneath the North American Plate.

The next steps involve refinement of the velocity model using a tomography technique. The refined velocity model would further constrain the moment-tensor solutions. The python script for the spectral-ratio analysis is almost completed and testing will begin in the coming months. This project will be completed by mid-2019 as part of the lead author's graduate research and published in the lead author's thesis.

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