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The relevance of small-magnitude earthquakes in detailing the spatiotemporal correlation between hydraulic fracturing related injection and seismicity

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Over the last decade, low-permeability tight shale formations in the Western Canada Sedimentary Basin (WCSB) have been extensively developed using hydraulic fracturing (HF) techniques for oil- and gas exploration. In the meantime, an increasing number of M3+ earthquakes (e.g., M_L 4.5 11/30/2018 near Dawson Creek, and an M_w 4.6 08/17/2016 near Ft. St. John) has been associated with HF operations. By increasing the seismicity in areas of low historical seismicity, the relationship between operational parameters and the rate of fault activation needs to be fully understood to avoid economic losses due to operation shutdowns or damages caused by ground shaking.

As earthquakes follow a well-known power-law magnitude-frequency relation, standard earthquake catalogs are typically dominated by microearthquakes in quantity. However, they usually still miss a large number of earthquakes due to insufficient station coverage and/or limited duration of observation. The latter could also lead to an inadequate time window for detecting larger earthquakes, which results in uncertainties of the power-law relation parameters for a particular area.

Here, we enhance a local seismic catalog derived from a dense seismic network in the Kiskatinaw (Montney Formation) area in British Columbia, Canada, using a multi-station matched filter technique. The existing automated STA/LTA catalog > 8000 earthquakes contains earthquakes from July 2017 - July 2020 with manually revised phase arrivals from up to 25 broad-band stations, ranging between M_L -0.6 to 4.5. Using all the ~8000 events from the initial catalog as templates, we detected > 40,000 additional earthquakes, lowering the magnitude of completeness M_c from ~1.3 to ~0.2. We observe a b-value of approximately 1, and the majority of events occurred between 1.0 - 3.0 km depth, where injection depths range from 1.5 - 2.5 km.

In addition to the previously observed clustering of earthquakes around specific HF wells, we also observe ~8000 earthquakes with no apparent spatial (up to 5 km) or temporal (within two weeks of the reported HF stimulation) connection to HF operations. We estimate the contribution of the uncorrelated events to background seismicity rates. Furthermore, we detect earthquakes with templates related to HF operations, with spatial, but lacking temporal correlation to HF

stimulation. Spatially correlated earthquakes with a no temporal correlation could highlight either areas with delayed induced seismicity (if following well stimulation) or areas with previous background seismicity (if preceding it). We will also show the correlation between background seismicity rates and cumulative injection rates and volumes of all wells within the study area.