Detailing the relationship between hydraulic fracturing parameters and induced seismicity using small-magnitude earthquakes

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The extensive development over the last decade of low-permeability tight shale formations in the Western Canada Sedimentary Basin (WCSB) using hydraulic fracturing (HF) techniques for oil and gas exploration has been associated with an increasing number of M3+ earthquakes (e.g., M4.5 on 30 November 2018 near Dawson Creek, and a Mw 4.6 on 17 August 2016 near Fort St. John). Avoiding economic losses due to operational shutdowns and mitigating damage caused by ground shaking requires developing quantitative relationships between operational parameters and the rate of fault activation in areas of low historical seismicity rates such as the WCSB.

Here we present the first results of a detailed study of the relationship between earthquake occurrence and operational parameters using dense seismic array and the British Columbia Oil and Gas Commission operational database to quantitatively assess the relative influence of operational parameters and geological conditions on earthquake generation. We first enhance a local, automatically generated seismic catalog of > 8000 events in the Kiskatinaw (Montney Formation) in the time period between July 2017 - December 2020 area using a multi-station matched-filter approach. We then use a machine learning picker as an independent detection algorithm for the same time period and retain events with the best initial locations detected by both the matched-filter and machine-learning approaches. The combined approach leads to > 30,000 additional earthquakes, which we relocate using a double-difference technique, lowering the magnitude of completeness Mc from ~1.3 to ~0.2.

As shown by several previous studies, while most earthquakes show a clear spatio-temporal correlation with HF operations, the majority of HF operations are not associated with felt earthquakes (e.g., M3+). To investigate the correlation between individual HF stage stimulation and earthquake occurrence, we correlate operational and geological characteristics with > 13000 HF stages. Geological data consists of the target formation for injection, which consists of either the Lower or Upper Montney Formations for the majority of stages. We then use a gradient-boosted decision tree machine learning algorithm combined with an approach to explain the model predictions to assess whether a specific stage is seismogenic. The decision-tree-algorithm allows us to estimate the importance of each injection parameter for the generation of seismicity. First results show that the target formation is the most influential parameter, where the Lower
Montney Formation is more prone to higher rates of seismicity. In addition, the total pumped fluid volume and the maximum treating pressure are the important injection parameters that are positively correlated with seismicity. In contrast, the average injection rate and breakdown pressure may be relatively less influential. We will present the results for specific stages and discuss the importance of their injection parameters in relation to seismicity. Our results could help to determine why only some HF wells are seismogenic.