2024 Brings Record M≥3.0 Earthquakes to British Columbia's Peace River Region

Allan Chapman
Chapman GeoResearch
Victoria BC
Email: chapgeo.research@gmail.com
11-January-2025

Abstract

Induced earthquakes have become common in British Columbia's Peace River region (the Montney Trend) since hydraulic fracturing began 20 years ago. A record number of magnitude ≥3.0 earthquakes occurred in 2024. These earthquakes are likely all, or almost all, human-caused, with hydraulic fracturing being the primary cause and waste fluid disposal into deep wells being a secondary culprit. Associated factors include: the volumes of frack fluid injected per well and the mass of proppant injected per well, both of which have increased steadily year-over-year, to record highs in 2024; cumulative effects associated with injection of large volumes of frack fluids and disposal fluids over time, and the movement of those fluids through highly permeable faults and fractures over long distances; and increased rates of drilling and hydraulic fracturing in the highly seismogenic North Peace area. Given the anticipated large increase in drilling and hydraulic fracturing to feed BC's nascent LNG operations, the record-setting rate of M≥3.0 earthquakes is concerning, pointing to the need for enhanced protections for at-risk populations.

Citation:

Chapman, A. R. (2025).2024 Brings Record M≥3.0 Earthquakes to British Columbia's Peace River Region. Chapman GeoResearch, Victoria, BC. 11-Jan-2025, 6pp.

Introduction

Induced earthquakes have become ubiquitous in regions of unconventional petroleum development (Atkinson, et. al., 2016; Schultz et. al, 2020). The Peace River region of British Columbia is no exception. Multi-stage hydraulic fracturing (HF, or fracking) began in northeast British Columbia (NEBC) in July 2005, almost twenty years ago. Since then, many thousands of wells have been drilled and fracked in the Montney Trend, the unconventional tight gas and natural gas liquids play that underlies most of BC's Peace River region. From the onset of hydraulic fracturing in NEBC, seismicity monitoring quickly showed that hydraulic fracturing was inducing earthquakes. Since about 2008, thousands of earthquakes have resulted from hydraulic fracturing, most small, but some sufficiently large to result in public safety and infrastructure risk (**Figure 1**) (Ghofrani and Atkinson, 2020; Atkinson et. al., 2020). Induced earthquakes have developed into a significant public safety concern across BC's Peace River region, where there are both concentrated urban and dispersed rural populations (Chapman, 2021). For 2024, the year just ended, there occurred the largest number of M≥3.0 earthquakes ever recorded in a single year in the Montney Trend. It is a concerning harbinger of the future for BC's Peace River region.

Magnitude ≥3.0 Earthquakes

Earthquake monitoring across NEBC has been conducted by the Geological Survey of Canada (GSC) with historic and real-time earthquake information published in the GSC's Earthquakes Canada catalogue, using data from the Canadian National Seismographic Network and affiliated regional networks. The GSC has, historically, been the de facto standard for earthquake

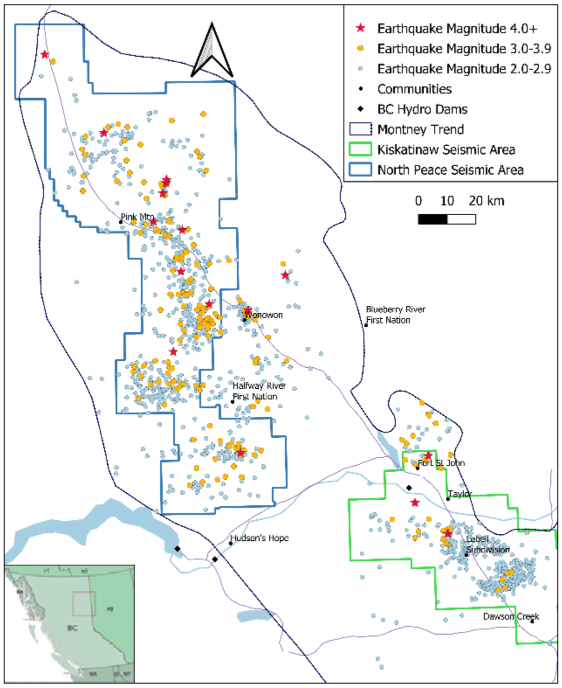

Figure 1. Induced earthquakes (2005-2024) in British Columbia's Montney Trend, showing Magnitude 2+, 3+ and 4+ earthquakes, key communities, and the Kiskatinaw Seismic Area and the North Peace Seismic Area.

monitoring and mapping in Canada (Visser et. al., 2017). Earthquakes of M≥3.0 are generally felt on the ground surface, and so are a useful threshold through which to examine long-term trends in earthquake frequency (earthquakes of smaller magnitude can also be felt in some circumstances, depending on proximity to the epicentre and amplification of ground shaking from near-surface soil conditions).

Before 2008, earthquakes of M≥3.0 were rare in the Montney Trend. With the onset of hydraulic fracturing, however, the frequency of M≥3.0 earthquakes increased substantially (Chapman, 2021). During 2008-2019 there were around 5-10 per year (2020 was anomalously low, with only one M≥3.0 earthquake). The frequency of M≥3.0 earthquakes then increased to 17-24 per year for 2021-2023, with a record of 34 M≥3.0 earthquakes in 2024 (**Figure 2**). There are several factors linked to the increased earthquake frequency, but we can conclude that it is not solely attributable to an increase in drilling rates. The rate of M≥3.0 earthquakes increased from an average of 1.7 per 100 hydraulic fractured wells in 2012-2020, to an average rate of 5.5 in 2021-2024, and then to 7.3 M≥3.0 earthquakes per 100 hydraulic fractured wells in 2024 (**Figure 3**).

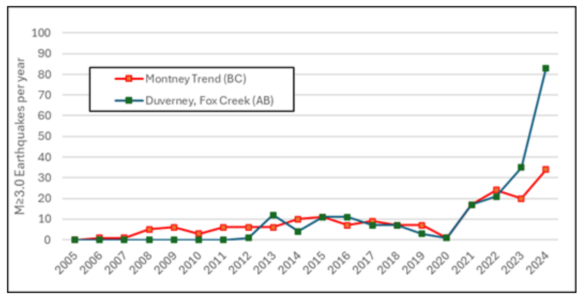

Figure 2. Magnitude 3.0 or larger earthquakes in the BC Montney Trend and the Duvernay Play near Fox Creek, Alberta, 2005-2024.

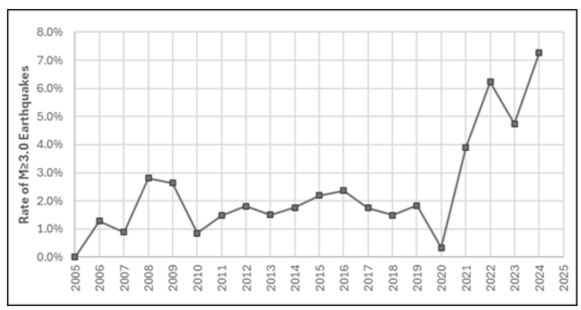

Figure 3. The annual rate of M≥3.0 earthquakes as a percent of hydraulically fractured wells in the BC Montney Trend (2005-2024).

This significant increase in the frequency of M≥3.0 earthquakes is not limited to the Montney Trend in British Columbia. The Duvernay unconventional petroleum area near Fox Creek, Alberta, has also experienced a very substantial increase in M≥3.0 earthquakes, beginning in 2021, with a record 83 earthquakes in 2024, a 10X increase from its 2012-2020 average (refer to **Figure 2**).

The BC Energy Regulator (BCER) and the Alberta Geological Survey (AGS) have separate earthquake monitoring systems, each relying in part on industry-collected data, and utilizing different analytical methods from the GSC. The distance calibration functions used by the BCER and the AGS underestimate local magnitude values relative to the methods used by the GSC (Babaie Mahani et. al., 2024). The BCER and AGS catalogues (accessed 10-Jan-2025) both also show the record number of M≥3.0 earthquakes in 2024. For the M≥3.0 earthquakes in 2024 found in the GSC catalogue, the GSC mean magnitude is M=3.37 and the BCER mean magnitude is M=2.92. The differences between the GSC and BCER catalogues are more pronounced for earthquakes in the North Peace Seismic Area (M=0.51) than in the Kiskatinaw Seismic Zone (M=0.09), leading to questions as to whether the BCER's modified distance calibrations and analytical methods have introduced bias in estimating and reporting magnitude. The discrepancies amongst the various earthquake catalogues are problematic.

These M≥3.0 earthquakes in BC's Montney Trend are likely all, or almost all, human-caused, with hydraulic fracturing being the primary cause and waste fluid disposal into deep wells being a strong secondary culprit. Of the frack fluid injected into a well during hydraulic fracturing operations, a portion flows back to the ground surface after the well is completed. Under BC law, flowback fluid is considered a hazardous waste and is either recycled and reused for further frack operations or is disposed of by oil and gas operators by injection into deep wells. Investigations have suggested that 10-15 percent of earthquakes induced by petroleum activity result from waste fluid injection into deep wells (Ghofrani and Atkinson, 2020). Because hydraulic fracturing and wastewater disposal operations are occurring at the same time in the same geographic space, it is difficult to disentangle their relative earthquake effects, and so they are usually lumped together.

Factors

There are several factors that are likely associated with the substantial increase in the frequency of M≥3.0 earthquakes beginning in 2021 in the Montney Trend, with the record in 2024:

- In-well factors that are part of hydraulic fracturing operations are important considerations, such as increases in injected frack fluid volumes per well over time and increases in the mass of proppant injected per well over time. The volume of injected hydraulic fracture fluid per well in the Montney Trend has risen consistently year-over-year, to an average of 24,000 m^3 per well in 2024, and the mass of injected proppant has also increased year-over-year to an average of 5,000 tonnes per well in 2024 (**Figure 4**). These 2024 rates are an increase of 3X from 2012.

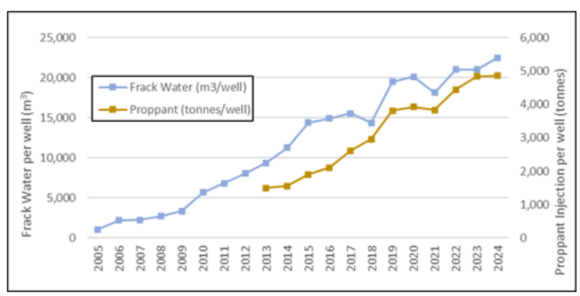

Figure 4. Changes in frack fluid and proppant injection rates per well in the BC Montey Trend, 2005-2024.

- There is a cumulative effect associated with antecedent fluid injection from hydraulic fracturing and wastewater disposal. Portions of the Montney Trend are highly faulted and fractured, with some of these faults and fractures creating high permeability pathways through which injected fluids can migrate over months and years to locations distant from the location of initial injection. This potentially alters the seismogenic characteristics of zones to where fluids have migrated, making them more susceptible to future earthquakes (Schultz et. al., 2020). The total volume of injected hydraulic fracture fluid per year in the Montney has increased steadily year-over-year (**Figure 5**). During the 2005-2024 period, a total of 98 million m^3 of hydraulic fracture fluid was injected into the subsurface in BC's Montney Trend.

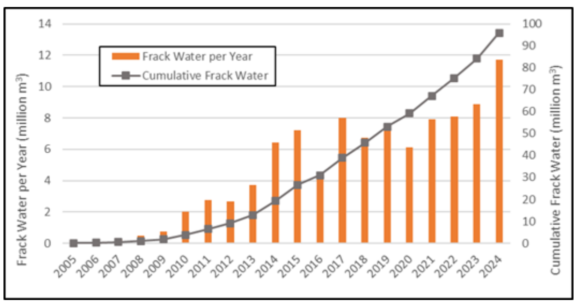

Figure 5. Annual frack fluid injection volumes, and cumulative frack fluid injection in the BC Montney Trend, 2005-2024.

This large fluid volume has largely remained underground, by the initial hydraulic fracturing operation, by the reuse of frack flowback fluid for further hydraulic fracturing, or by the injection of frack flowback wastewater into disposal wells. A total of 39 million m^3 of frack flowback fluid has ben injected into disposal wells in the Montney Trend during 2005-2024 (**Figure 6**). The cumulative effect from antecedent fluid injection has not been well studied but was discussed in Chapman (2021).

- Not all geographic parts of the Montney Trend are equally seismogenic. The BCER's well completions data indicate that the seismogenic North Peace area had more hydraulic fracturing wells in 2021-2024 than in the 5 years prior. But, the 2021-2024 well count was still less than that of 2014 and 2015, which experienced substantially lower earthquake rates.

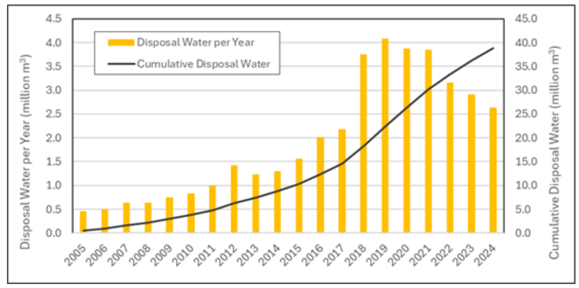

Figure 6. Annual waste water disposal injection volumes, and cumulative disposal injection in the BC Montney Trend, 2005-2024.

- The Montney formation contains multiple layers, which are targeted separately with horizontal well bores. There are differences in seismogenicity among the layers. If the horizontal wellbores hydraulically fractured in 2021-2024 were more concentrated in the more seismogenic layers, more earthquakes would be anticipated. This hypothesis has not been examined for this paper.

The Future?

The Montney Trend is intended to be the critical source of methane for BC's nascent Liquefied Natural Gas (LNG) industry, with LNG Canada's operation at Kitimat expected to come online in 2025, initiating what is anticipated to be a doubling of the rate of drilling and hydraulic fracturing over the next few years (Hughes, 2024). Significant increases in the frequency of induced earthquakes appear to be the future for BC's Peace River region. Following the probabilistic framework of van der Elst et. al. (2016), increases in the frequency of large magnitude, potentially damaging earthquakes should not be unexpected. BC's current regulations have not succeeded in preventing the substantial increase in M≥3.0 earthquakes discussed in this paper. As well, the regulations have not demonstrated an ability to *a priori* determine where M≥3.0 earthquakes will occur. This highlights the need for regulatory improvements, focused on enhanced protection of at-risk populations in the Peace River region. This should include the implementation of a substantive and defensible regulated Traffic Light Protocol earthquake mitigation system across the entirety of BC's petroleum development lands (e.g., Schultz et al., 2021) and should include the creation of "no fracking and no injection" zones around areas of concentrated population (e.g., Atkinson, 2020). As well, numerous research foci are suggested, including: quantifying the implications of the increased earthquake rates in relation to the likelihood of large magnitude earthquakes (e.g., M≥5.0); research into the relationships between these moderate and large magnitude induced earthquakes and the specific industrial activities that are causative; investigation and mapping of seismogenic faults with potential to produce large magnitude earthquakes (e.g., M≥5.0); and research into seismic risk assessment focussed on at-risk communities across the Peace River region.

British Columbia's experiment in unconventional petroleum development and hydraulic fracturing may have untethered the seismic demons. Can they be controlled?

Acknowledgements

The author thanks Dr. Gail Atkinson for suggestions on induced earthquakes in Alberta.

The author is a former senior geoscientist with the BC Oil and Gas Commission (now the BC Energy Regulator), and was the recipient of the C. J. Westerman Award for Geoscience in 2014, for "professional affairs that exhibit high levels of dedication and integrity to the geoscience profession", from Engineers and Geoscientists BC.

Data and code availability

The data used to produce the results and figures of this study are available online for download at GitHub (https://github.com/allanroychapman/Montney_EQ3). The earthquake data analyzed for this report were extracted from Geological Survey of Canada's Earthquakes Canada catalogue (GSC, 2025) and the BC Energy Regulator's catalogue (BCER, 2025c) on 06Jan2025. Data on hydraulically fractured wells for 2005-2011 were extracted from the BC Energy Regulator's Wells database (BCER, 2025a); and data on hydraulically fractured wells for 2012-2024 were extracted from the BC Energy Regulator's FracFocus database (BCER, 2025b). All geospatial analysis was done with QGIS. Analysis was completed primarily using code contained within Microsoft Excel.

Competing interests

The author has no competing interests

References

Atkinson, G. M., Eaton, D. W., Ghofrani, H., Walker, D., Cheadle, B., Schultz, R., Shcherbakov, R., Tiampo, K., Gu, J., Harrington, R. M., Liu, Y., van der Baan, M., & Kao, H. (2016). Hydraulic Fracturing and Seismicity in the Western Canada Sedimentary Basin. Seismological Research Letters, 87, 631-647. https://doi.org/10.1785/0220150263

Atkinson, G. M. (2020). The Intensity of Ground Motions from Induced Earthquakes with Implications for Damage Potential. Bulletin of the Seismological Society of America, 110, 2366-2377. https://doi.org/10.1785/0120190166

Barbaie Mahani, A., H. Kao and B. Smith (2024). Investigation of the discrepancy in the earthquake magnitude values reported by different agencies in the Western Canada Sedimentary basin. J Seismology, 28, 753-764. https://doi.org/10.1007/s10950-024-10225-4

BCER (2025a). Wells Database. https://www.bc-er.ca/data-reports/data-centre/?category&format&sort&q=wells

BCER (2025b). FracFocus Database. https://reports.bc-er.ca/ogc/f?p=200:2:1057249272671::NO:::

BCER (2025c). Earthquake Database. https://geoweb-ags.bc-er.ca/portal/apps/webappviewer/index.html?id=a1ecce14d6ae4c92a5295c62a3ee618b

Chapman, A. (2021). Hydraulic Fracturing, Cumulative Development and Earthquakes in the Peace River Region of British Columbia, Canada. Journal of Geoscience and Environment Protection, 9, 55-82. https://doi.org/10.4236/gep.2021.95006

GSC (Geological Survey of Canada) (2025). National Earthquake Database. https://www.earthquakescanada.nrcan.gc.ca/stndon/NEDB-BNDS/bulletin-en.php

Ghofrani, H., & Atkinson, G. M. (2020). Activation Rate of Seismicity for Hydraulic Fracture Wells in the Western Canada Sedimentary Basin. Bulletin of the Seismological Society of America, 110, 2252-2271. https://doi.org/10.1785/0120200002

Hughes, D. (2024). Drilling into the Montney: How LNG Expansion Will Accelerate Drilling, Fracking and Environmental Impacts in Northeast B.C. and Adjacent Alberta. David Suzuki Foundation. ISBN: 978-1-988424-97-2. https://davidsuzuki.org/science-learning-centre-article/drilling-into-the-montney-report/

Schultz, R., Beroza, G., & Ellsworth, W. (2021). A Risk-Based Approach for Managing Hydraulic Fracturing-Induced Seismicity. Science, 372, 504-507. https://doi.org/10.1126/science.abg5451

Schultz, R., Skoumal, R. J., Brudzinski, M. R., Eaton, D., Baptie, B., & Ellsworth, W. (2020). Hydraulic Fracturing-Induced Seismicity. Reviews of Geophysics, 58, e2019- RG000695. https://doi.org/10.1029/2019RG000695

Schultz, R., Wang, R., Gu, Y. J., Haug, K., & Atkinson, G. (2017). A seismological overview of the induced earthquakes in the Duvernay Play near Fox Creek, Alberta. *Journal of Geophysical Research: Solid Earth*, 122, 492–505. https://doi.org/10.1002/2016JB013570

van der Elst, N. J., Page, M. T., Weiser, D. A., Goebel, T. H. W., & Hosseini, S. M. (2016). Induced Earthquake Magnitudes Are as Large as (Statistically) Expected. Journal of Geophysical Research: Solid Earth, 121, 4575-4590. https://doi.org/10.1002/2016JB012818

Visser, R., Smith, B., Kao, H., Barbaie Mahani, A., Hutchinson, J., & McKay, J. E. (2017). A Comprehensive Earthquake Catalogue for Northeastern British Columbia and Western Alberta, 2014-2016. Geological Survey of Canada, Open File 8335, 1. https://doi.org/10.4095/306292