geoconvention
Calgary • Canada • May 15-17 2023

Natural and induced seismicity in the Western Canada Sedimentary Basin

David W. Eaton[1], Honn Kao[2], Mauricio Canales[3] and Todd Shipman[4]
[1] Department of Geoscience, University of Calgary
[2] Pacific Geoscience Centre, Natural Resources Canada
[3] Alberta Geological Survey
[3] Alberta Energy Regulator

Summary

Seismicity in the Western Canada Sedimentary Basin (WCSB) is largely concentrated within a ~300km wide corridor east of the deformation front of the Canadian Cordillera. To encompass the full northern extent of the basins of western Canada, the area of interest for the 2027 WCSB Atlas has been enlarged to encompass the Mackenzie corridor and Richardson Mountains. The northern half of this area is characterized by natural earthquakes that are strongly influenced by plate-boundary interactions along the west coast of North America. To the south, seismicity in northeastern BC and western Alberta includes areas that are prone to induced (human-caused) seismic activity related to unconventional resource development during the last decade. This north-south partitioning of seismicity is reflected in Canada's national seismic hazard maps, which consider only natural seismic hazards and highlight areas of relatively elevated seismic hazard in the Mackenzie and Richardson Mountains. Nevertheless, trends of seismic moment release since the year 2000 are broadly similar in both southern and northern halves of the WCSB with cumulative rates of ~3 to 6 x 10^{16} N-m/yr despite relative seismic quiescence in the south from 2001 – 2014. Recently developed short-term seismic hazard maps for Alberta show localized areas of elevated seismic hazard that track temporarily and spatially varying levels of industry activity. The advent of large-scale carbon capture and storage (CCS) and geothermal projects raise the potential for other anthropogenic triggering mechanisms.

Seismicity of Western Canada

Figure 1 shows M ≥ 2 seismicity of western Canada for the time period from 2000/01/01 to 2022/11/16. Events that fall within the Western Canada Sedimentary Basin (WCSB), as defined for the 2027 WCSB Atlas, are shown in red. Outside of the WCSB, there are 31,874 events shown in gray. The largest earthquake plotted on the map was a M7.8 event on 2012/10/28, located 80 km south of the Village of Queen Charlotte, BC. The seismicity in this region is primarily driven by plate-boundary interactions (e.g., Hyndman & Rogers, 2010). Within the WCSB, there are 7,312 shown in Fig. 1, with the largest earthquake being a M5.7 event within the Mackenzie Mountains. This M5.7 event occurred on 2006/03/10 and was located 117 km west of Norman Wells. The seismicity within the WCSB includes both natural and induced events (Zhang et al., 2016). Natural seismicity in the WCSB is likely driven by far-field processes linked to plate-boundary stresses, whereas induced seismicity (seismic events attributed to human activities;

Eaton, 2018) are associated with unconventional oil and gas development, quarry blasts at coal mines and (to a lesser extent) potash mining.

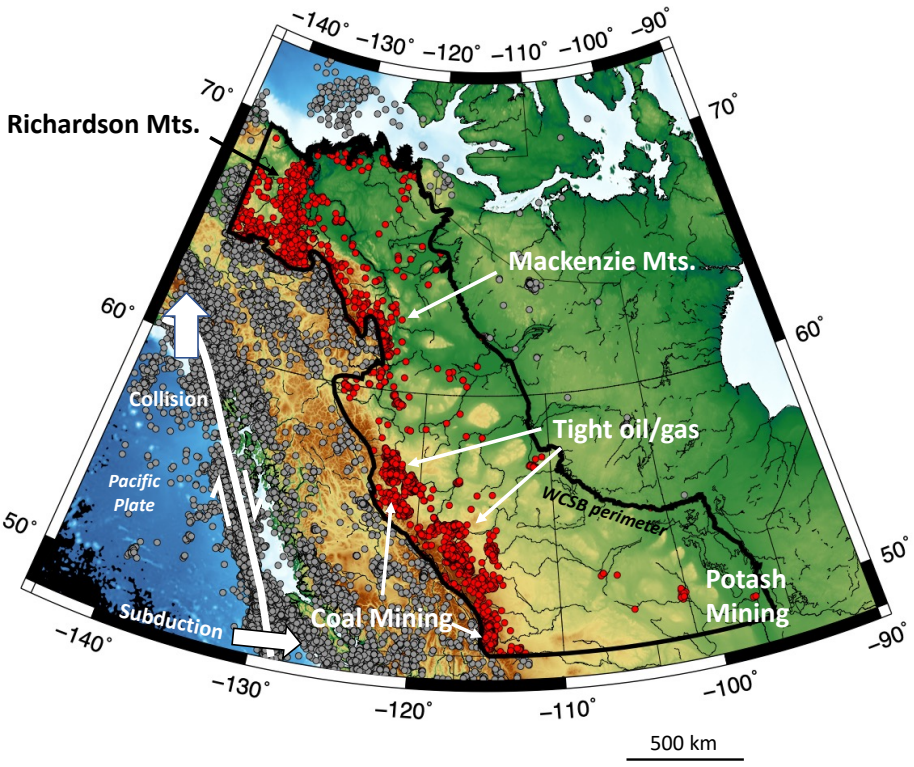

Figure 1. Seismicity map of western Canada for the period 2000/01/01 to 2022/11/16 (source: NRCan online catalog), showing simplified plate boundary processes. Events that lie within the perimeter of the Western Canada Sedimentary Basin (WCSB) are plotted in red. Generalized locations associated with induced seismicity linked to tight oil and gas, coal mining and potash mining are labelled.

Figure 2 shows cumulative seismic moment for the events within two regions of the WCSB: north of 60° N and south of 60° N. To the north, seismicity in the WCSB is almost entirely natural in origin and occurs primarily in two zones, the Mackenzie Mountains and Richardson Mountains. Using M ≥ 3 events, the average seismic moment release rate is 6.4 x 10^{16} N-m/yr, as shown by the red line. The seismicity trend is punctuated by step-like jumps associated with larger events, including the 2006/03/10 M5.7 event west of Norman Wells.

The seismicity rate south of 60° exhibits a distinctly different pattern. Following the 2001/04/14 M5.4 event in Alberta, east of Dawson Creek, B.C., this region experienced a decade-long interval of relative seismic quiescence. A marked increase in seismic moment release rate, starting in about 2015, is due to elevated induced seismicity rates associated with unconventional oil and

gas development (Atkinson et al., 2016). For the time period considered here, the average seismic moment release rate in the WCSB south of 60° N is 1.6 x 10^{16} N-m/yr. However, it should be noted that a M5.3 event on 2022/11/30, and subsequent seismicity sequence, falls after the time period considered in this report. Inclusion of this event in subsequent analysis will increase the average moment release rate for this region.

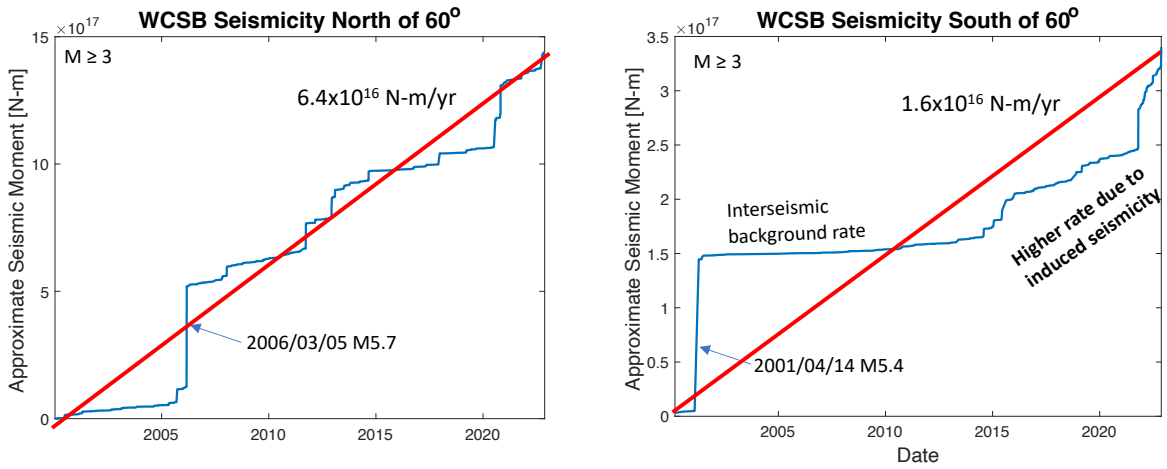

Figure 2. Graphs of seismic moment release versus time for the WCSB north of 60° N (left) and south of 60° N (right). The cumulative seismic moment that is plotted represents an approximation, because magnitudes from the database were used without conversion to moment magnitude.

Conclusions

This progress report for the 2027 WCSB Atlas highlights areas of natural and induced seismicity in the Western Canada Sedimentary Basin (WCSB). North-south partitioning of seismicity is evident, wherein events are dominated by natural seismicity north of 60° N and, in the last decade, events south of 60° N are dominated by induced seismicity. This partitioning is reflected in Canada's national seismic hazard maps, which consider only natural seismic hazards. Induced seismicity is primarily related to unconventional oil and gas development as well as blasting for coal mining. The advent of large-scale carbon capture and storage (CCS) and geothermal projects raise the potential for other anthropogenic triggering mechanisms.

Acknowledgements

Seismicity data used in Figures 1 and 2 are from the NRCan online earthquake database (https://earthquakescanada.nrcan.gc.ca/stndon/NEDB-BNDS/bulletin-en.php). Figure 1 was produced using Generic Mapping Tools (GMT) version 5.4.5 (Wessel et al., 2013).

References

Atkinson, G.M., Eaton, D.W., Ghofrani, H., Walker, D., Cheadle, B., Schultz, R., Shcherbakov, R., Tiampo, K., Gu, J., Harrington, R.M. and Liu, Y. (2016). Hydraulic fracturing and seismicity in the Western Canada Sedimentary Basin. Seismological Research Letters, 87(3), 631-647.

Eaton, D. W. (2018). Passive seismic monitoring of induced seismicity: Fundamental principles and application to energy technologies. Cambridge University Press.

Hyndman, R. D., & Rogers, G. C. (2010). Great earthquakes on Canada's west coast: a review. Canadian Journal of Earth Sciences, 47(5), 801-820.

Wessel, P., W. Smith, H. F., Scharroo, R., Luis, J. and Wobbe, F. (2013). Generic Mapping Tools: Improved Version Released, EOS Trans. AGU, 94(45), 409–410.

Zhang, H., Eaton, D. W., Li, G., Liu, Y., & Harrington, R. M. (2016). Discriminating induced seismicity from natural earthquakes using moment tensors and source spectra. Journal of Geophysical Research: Solid Earth, 121(2), 972-993.