# Induced and natural seismicity in the Western Canada Sedimentary Basin from 2000 to 2024

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## Summary

The forthcoming Geological Atlas of the Western Canada Sedimentary Basin (WCSB) will include, for the first time, a chapter focused on natural and induced earthquakes. Seismicity in the basin is largely concentrated within a ~300km wide corridor east of the deformation front of the Canadian Cordillera. The northern half of the WCSB is characterized predominantly by natural earthquakes in the Mackenzie and Richardson Mountains, which 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 have experienced induced seismic activity related to unconventional resource development during the last 15 years. This north-south dichotomy 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, recent trends of seismic moment release are broadly similar in both southern and northern halves of the WCSB, despite relative seismic quiescence in the south from 2001 – 2014. 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 could increase the potential for anthropogenic triggering of seismic activity.

## Introduction

For this study, we have compiled a seismicity catalog covering a 25-year time period, from 2000/01/01 to 2024/12/31. Seismicity is mapped in Figure 1, where 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, seismicity is 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 near the west coast is primarily driven by plate-boundary interactions (e.g., Hyndman & Rogers, 2010). Within the WCSB, the largest earthquake is a M5.7 event that occurred on 2006/03/10, 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.

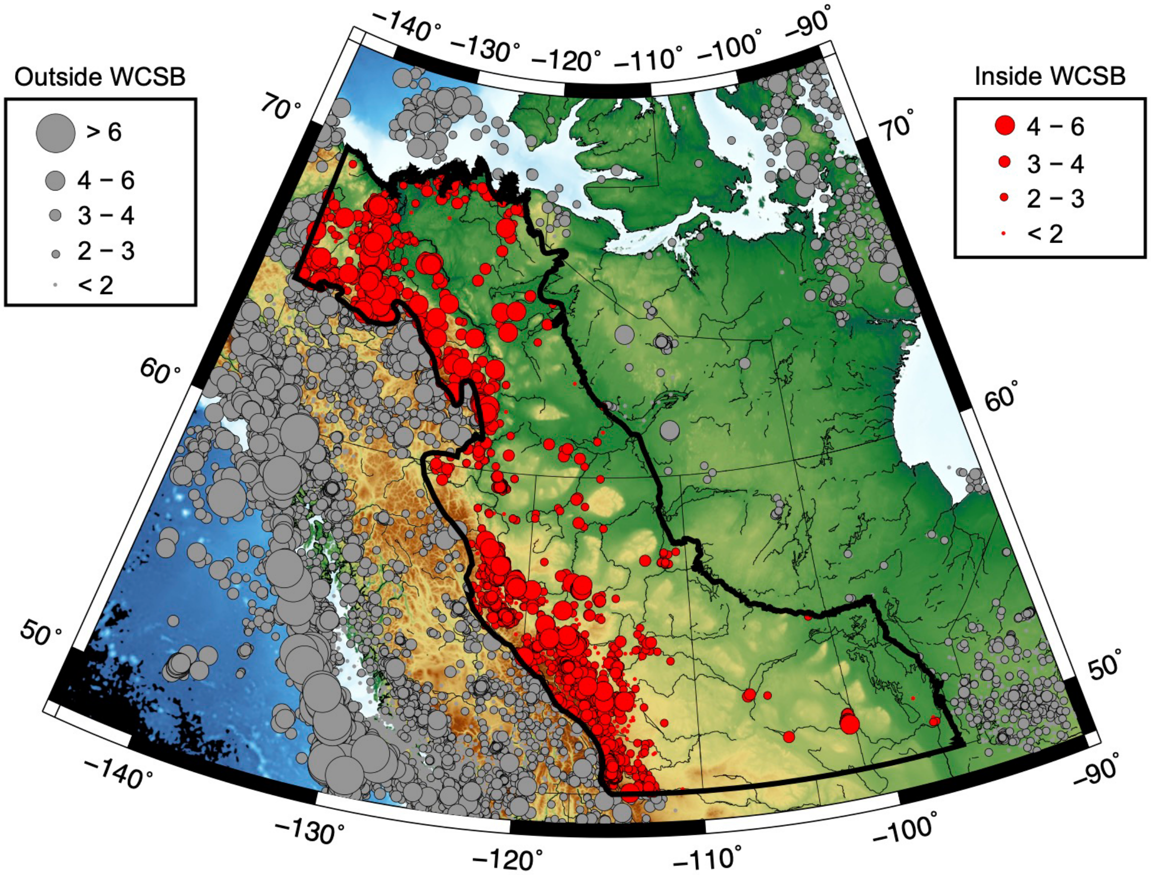


**Fig. 1.** Seismicity of western Canada for the 25-year period from 2000/01/01 to 2024/12/31. Black polygon outlines the Western Canada Sedimentary Basin (WCSB). Earthquake symbols (circles) are sized according to magnitude and coloured to indicate whether inside (red) or outside (gray) the WCSB. The most seismically active region follows the western margin of the North American plate. Most seismic activity within the WCSB occurs along a 300-km wide band east of the Canadian Cordillera, in the western part of the basin. Seismicity data are compiled from various sources (see Figure 2).

## Data Compilation

Our seismicity catalog is derived from three public sources (Figure 2): the Earthquakes Canada online catalog maintained by Natural Resources Canada (NRCan), the Alberta Earthquakes Dashboard maintained by the Alberta Energy Regulator (AER), and the northeast BC seismicity map maintained by the BC Energy Regulator (BCER). Duplicate events (all located within Alberta and BC) were removed from our compiled catalog. In the case of duplicate events, hypocentral parameters and magnitudes provided by the provincial regulator were retained.

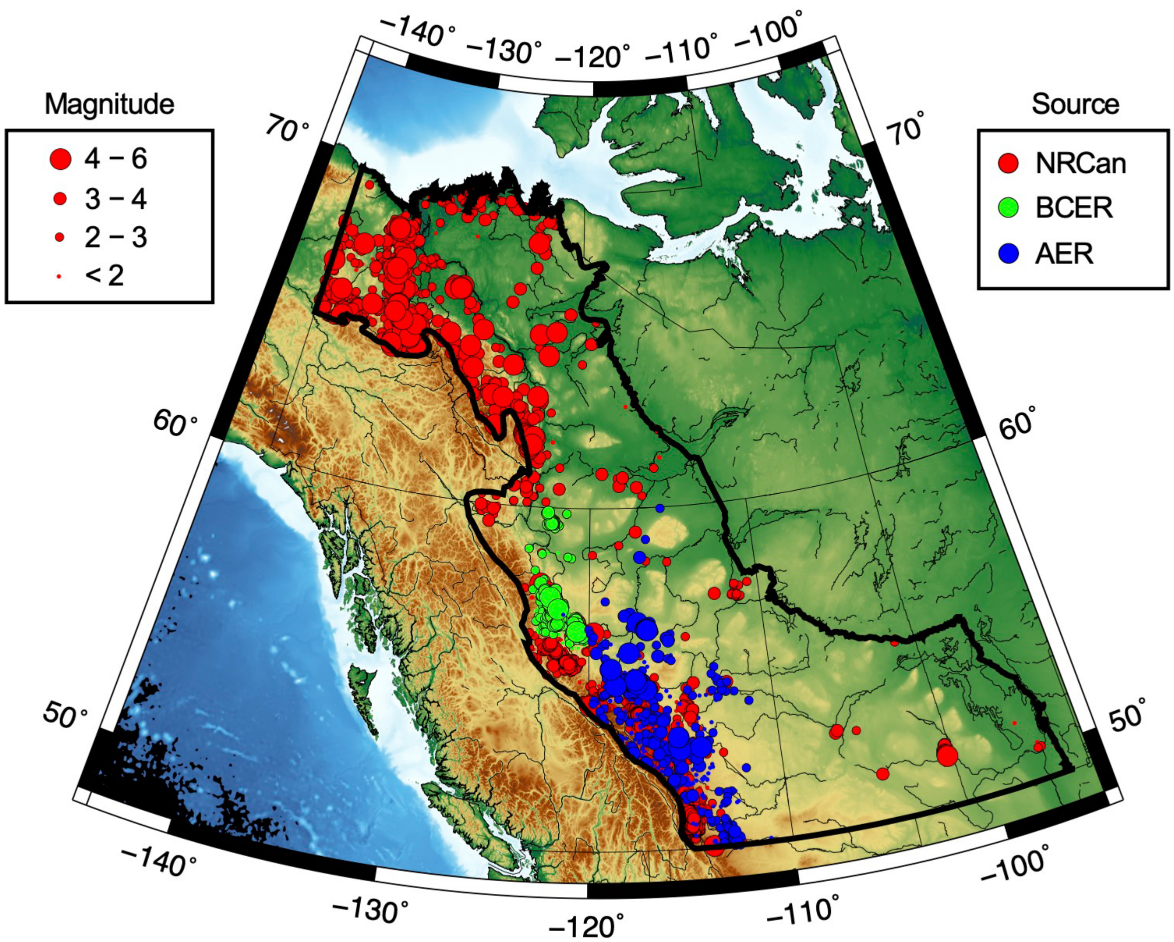


**Fig. 2.** Seismicity within the Western Canada Sedimentary Basin (WCSB; black outline) for the 25-year period from 2000/01/01 to 2024/12/31, coloured according to the data source. NRCan denotes the Earthquakes Canada catalog (https://www.earthquakescanada.nrcan.gc.ca/index-en.php) maintained by Natural Resources Canada. BCER denotes a seismicity dataset containing events greater than magnitude 1.5, maintained by the BC Energy Regulator (https://www.bc-er.ca/data-reports/data-narratives/northeast-b-c-seismicity-map/). AER denotes seismicity data accessed through the Alberta Earthquake Dashboard (https://ags.aer.ca/publications/all-publications/iam-005), maintained by the Alberta Geological Survey, part of the Alberta Energy Regulator (AER). All data from these public sources were downloaded on 2025/01/21.

To varying degrees, the original data sources used to compile our catalog (Figure 2) provide event classifications that are used here after some adjustment. Three categories of events are shown and described in Figure 3: natural earthquakes, mining-related events (including quarry blasts), and known or suspected induced events. The BCER dataset did not include event types, so these were determined independently for this study (Figure 3).

In the northern part of the WCSB (north of 60°N), almost all seismicity is associated with natural earthquakes in the Mackenzie and Richardson Mountains of the Northwest and Yukon Territories. By contrast, in the southern part of the WCSB (south of 60°N), the seismicity is mixed and includes natural earthquakes in addition to extensive induced seismicity and mining-related events. For example, an isolated cluster of events near 111°W longitude consists of induced and mining-related seismicity associated with Potash mining near Esterhazy, Saskatchewan (Gendzwill et al., 1982). Several mining-related events have been detected near 56.7°N, 111.4°W close to Fort McMurray, Alberta.

## Discussion

Figure 4 shows magnitude versus time for natural and induced seismic events within the WCSB. Over the 25-year period of this study, natural seismicity has occurred at an approximately uniform rate. By contrast, the seismicity rate for induced events increases dramatically starting at the end of 2013.

As expected, differences in seismicity rate also exist between the northern and southern parts of the WCSB, as shown in Figure 5. The northern part of the basin, which is characterized by a predominance of natural earthquakes, exhibits a relatively uniform rate of seismic events ($M \geq 2.5$), whereas in the southern part of the basin there are significant variations in the rate with time. We interpret these variations in seismicity rate to be largely controlled by induced seismic activity, as shown in Figure 4.

Figure 6 provides another perspective on seismicity, based on cumulative seismic moment release. We remark that magnitude data provided in the original data sources and compiled into our catalog consists of various representations of local magnitude. Here, we have used a simple conversion from local magnitude to seismic moment from Hanks and Kanamori (1979). In a regional study in western Canada (Ristau et al., 2005), this simple conversion was found to be reliable for local magnitudes greater than M3.6. As shown in Figure 6, the moment-release rate is dominated by rare larger events. Following a natural earthquake near Dawson Creek BC on 14 April 2001, the southern part of the WCSB was nearly quiescent for over a decade. Starting in late 2013, the moment release rate increased in the south, and for the past several years it has been about the same as in the northern part of the WCSB.

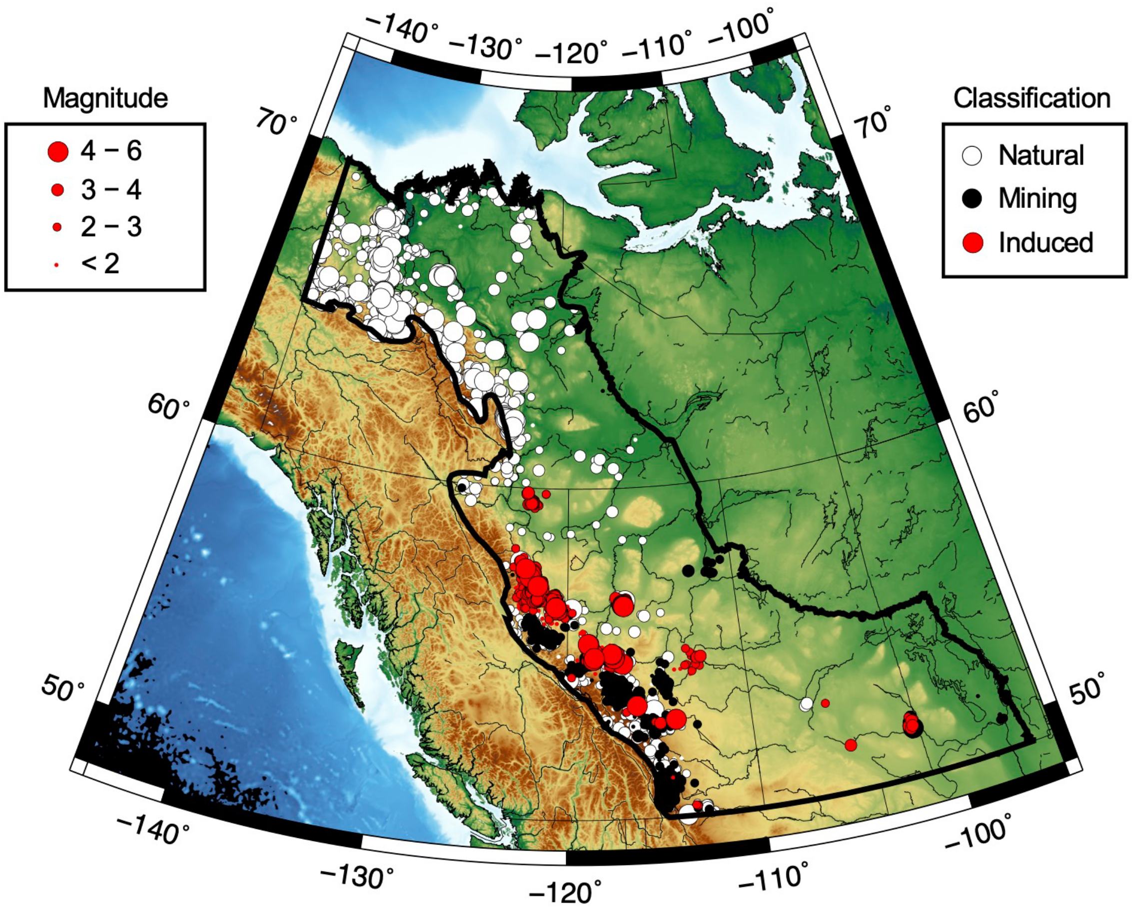


**Fig. 3.** Natural, mining-related and induced seismicity within the Western Canada Sedimentary Basin (WCSB; black outline) for the 25-year period from 2000/01/01 to 2024/12/31, coloured according to event classification. The online NRCan catalog is classified into the following categories: earthquakes, induced events, blasts, mining-related events and landslides. In our compiled catalog, blasts and mining-related events are combined into a single category, and landslides are omitted. The AER dataset is classified into the following categories: known induced, suspected induced, suspected earthquake and under assessment. Here, known and suspected induced events are combined into a single category of induced events, and suspected earthquakes are treated as earthquakes. Events that are under assessment are retained in the compilation but are not shown in the map above. The BCER dataset does not specify categories of events. Here, all events that lie within or immediately adjacent to the Kiskatinaw Seismic Monitoring and Mitigation Area (KSMMA) and the North Peace Ground Motion Monitoring Area, as well as events within the Horn River Basin, are classified as induced.

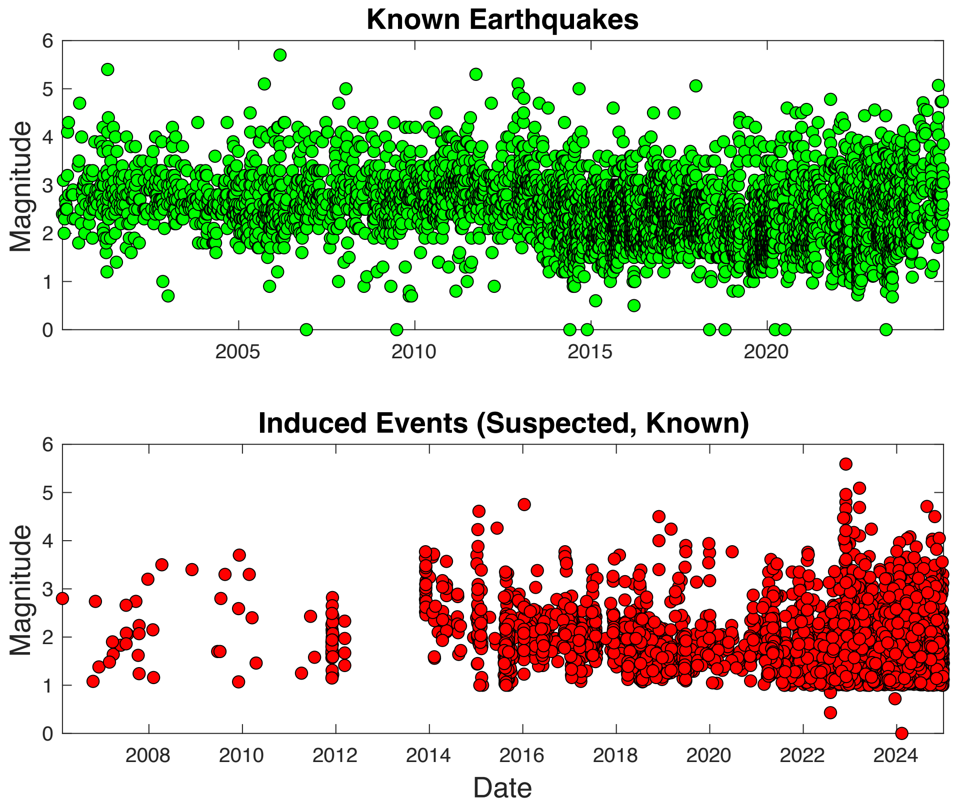


**Fig. 4.** Magnitude versus time for events within the WCSB that are classified as earthquakes (shown in Figure 3 as natural events) and induced (both suspected and known). The distribution of earthquakes is relatively uniform throughout the 25-year study period, with minor variability that likely reflects changes in the monitoring network over time. Induced events exhibit a dramatic increase in the rate of seismicity beginning approximately at the end of 2013.

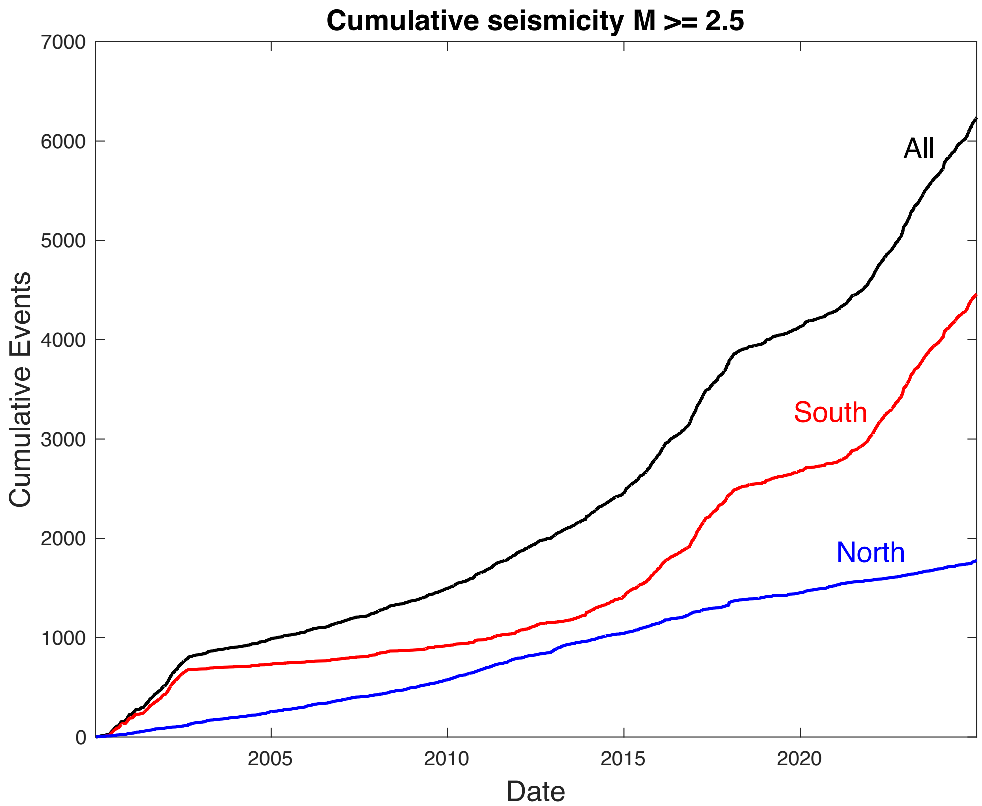


**Fig. 5.** Cumulative events of all types, with magnitude ≥ 2.5, for all of the WCSB (black curve), south of 60°N (red curve) and north of 60°N (blue curve). In the northern part of the basin, where events are predominantly natural earthquakes (Figure 3), the seismicity rate remains nearly constant. By contrast, the southern part of the basin is marked by strong variability in seismicity rate.

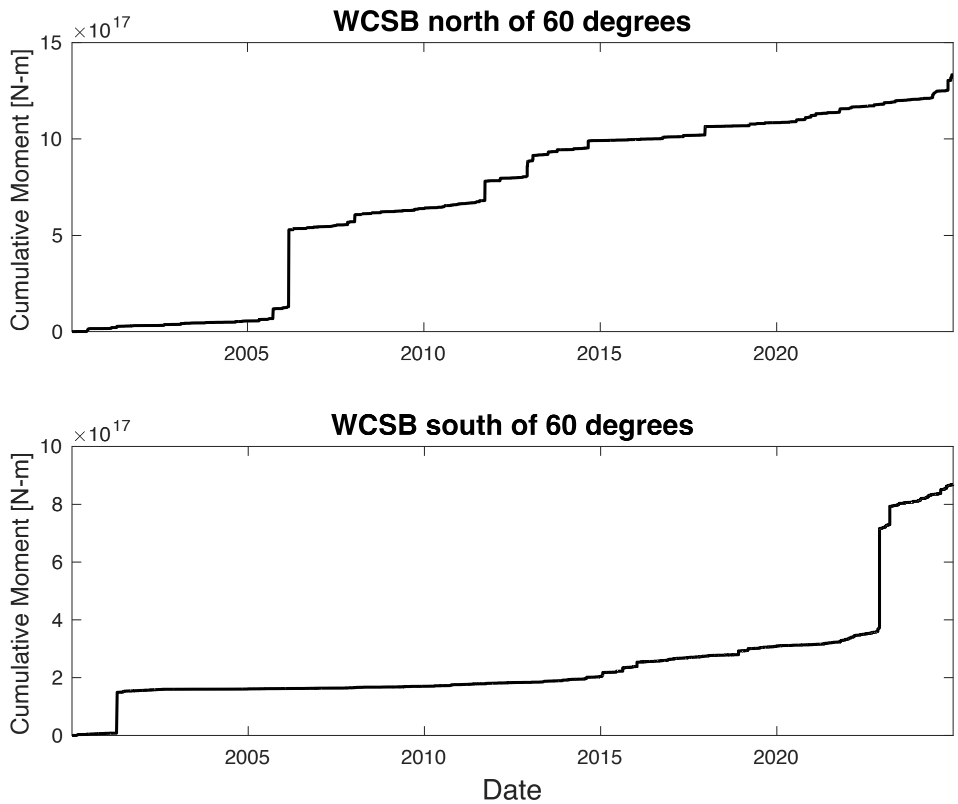


**Fig. 6.** Cumulative seismic moment release within the WCSB over a period of 25 years for the northern and southern parts of the basin. Due to the logarithmic nature of seismic moment, step-like jumps in moment release correspond to larger seismic events. In the north, the largest event (M5.7) was a natural earthquake that occurred in the Mackenzie Mountains on 5 March 2006. The largest events in the southern part of the basin are a M5.4 natural earthquake near Dawson Creek, BC on 14 April 2001 and a M5.59 induced event near Peace River AB on 30 November 2022.

## Conclusions and Future Work

This contribution represents a progress report for our forthcoming chapter in the new Atlas of the Western Canada Sedimentary Basin, which is scheduled for publication in 2027. The longer-term perspective afforded by a 25-year time window, coupled with the holistic view of seismicity across the entirety of the WCSB, provides fresh context and perspective for understanding induced and natural seismicity. To date, we have nearly completed our compilation and merging of data from various public sources, with minor additional data QC still in progress. In the final publication, we plan to include analysis of earthquake source mechanisms, including stress inversion, as well as a discussion of probabilistic seismic hazard analysis and regulatory measures. We will also incorporate recent techniques for robust analysis of seismic activity rate (e.g., van der Elst, 2021; van der Elst and Page, 2023).

## Acknowledgements

Seismicity data were obtained from online earthquake databases maintained by NRCan, BCER and AER as describe in Figure 2. Generic Mapping Tools (GMT) version 5.4.5 (Wessel et al., 2013) was used to produce maps.

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