Induced Seismicity Monitoring Project (ISMP)

May 1, 2024 – May 1, 2025 Annual Report

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Contents

Executive Summary

The BC Seismic Research Consortium (BC SRC) was originally established by Geoscience BC, the Canadian Association of Petroleum Producers (CAPP), and the BC Energy Regulator (BCER) (formerly the BC Oil and Gas Commission) and works closely with Natural Resources Canada (NRCan) to monitor seismicity in Northeastern British Columbia (NEBC). It followed a recommendation from the BCER in response to concerns regarding induced seismicity associated with hydraulic fracturing in the Horn River Basin.

The BC SRC is responsible for maintaining the PQ, 1E, and XL seismic networks. In addition, the BC SRC has access to stations from the CN network operated by NRCan. The BC SRC has in the past used data from the EO, RV, and S3 networks, which were operated by the University of Calgary, the Alberta Energy Regulator, and Symroc (under an NRCan contract), respectively.

The BC SRC is made up of representatives from each of the current consortium partners: Geoscience BC, CAPP, BCER, and the BC Oil and Gas Research and Innovation Society (BC OGRIS). Funding for the BC SRC is shared between Geoscience BC and the BC OGRIS. NRCan provides technical and operational support for seismic monitoring, based at the Pacific Geoscience Centre in Sidney, British Columbia.

This report summarises the actions and research taken by the BC SRC for the period May 1, 2024, to May 1, 2025.

Key Statistics

Statistic	Value
Total events detected	6,005
Events in the KSMMA	4,279
Events in the NMSMMA	1,644
Events with $M_L > 2.0$	215
Events with $M_L > 3.0$	10
Events with $M_L > 4.0$	1
Largest magnitude	M_L 4.44
Damage reports	None reported to BCER

Update on Seismic Monitoring in NEBC

A map view of seismic stations monitored by the Consortium is shown in Figure 1, and station data availability is shown in Figure 2. A total of 30 stations contributed phase arrivals for event locations during the reporting period (May 1, 2024, to May 1, 2025).

During the reporting period, two station relocations were completed:

- NBC7 (PQ network): Relocated on July 31, 2024
- MG08 (XL network): Relocated on August 1, 2024

An earthquake catalogue for the reporting period has been developed and included with this report as Appendix A. Seismic event details are also available at the BCER GeoPortal, with information

such as date, time (UTC), latitude, longitude, depth, and local magnitude. The seismic stations used to locate events in this catalogue are listed in Appendix B.

Seismicity from May 1, 2024, to May 1, 2025

From May 1, 2024, to May 1, 2025, there were 6,005 events detected. In the KSMMA, there were 4,279 events, while in the NMSMMA, there were 1,644 events. A map view of the seismicity in the KSMMA is shown in Figure 3 and seismicity for the NMSMMA is shown in Figure 4.

There were 215 events with M_L greater than 2.0, 10 events with M_L greater than 3.0, and 1 event with M_L greater than 4.0. The largest event occurred on February 12, 2025, with a magnitude of M_L 4.44, located in the NMSMMA region.

Figures 5 and 6 show the magnitude frequency distribution, also known as the Gutenberg-Richter relationship, of seismicity in the KSMMA and NMSMMA areas, respectively. The magnitude of completeness, above which the catalogue is considered to be complete, was M_L 1.0 for the KSMMA and M_L 1.1 for the NMSMMA, calculated using the Maximum Curvature (MAXC) method (Wiemer & Wyss, 2000).

Changes to Routine Seismic Monitoring in Northeast BC

The routine seismic monitoring for NEBC has had several years to mature and develop and is now reaching a relatively stable state of routine operation. The seismic monitoring workflow remained stable throughout the reporting period with no major changes to detection algorithms or processing procedures.

The real-time system provides notifications to interested parties within minutes of a seismic event occurring. The real-time system uses a similar workflow to the automatic portion of the catalogue development, with EQTransformer (Mousavi et al., 2020) providing the earthquake phase arrival time estimates, and NonLinLoc (Lomax et al., 2000) calculating the earthquake origin parameters.

Research Communication

Members of the BC SRC are associated with the following presentations during the reporting period (May 1, 2024, to May 1, 2025):

Conference Presentations

1. Dokht, R.M.H., & Kao, H. (2024, December 9–13). Spatiotemporal variability of hydraulic fracturing-induced seismicity in the South Montney Play: A seismogenic index-based approach. *AGU Annual Meeting 2024* (Abstract S51C-3253), Washington, DC, United States.
2. Kao, H., Babaie Mahani, A., & Smith, B. (2024, June 17–19). Discrepancy in the magnitude values of earthquakes in the Western Canada Sedimentary Basin. *GeoConvention 2024*, Calgary, AB.

3. Eaton, D., Kao, H., Canales, M., & Shipman, T. (2025, April 27–May 2). The big picture in western Canada: Induced seismicity from geo-energy applications is approaching the natural moment release rate of tectonically active northern regions. *EGU General Assembly 2025*, Vienna, Austria (EGU25-20644). https://doi.org/10.5194/egusphere-egu25-20644

Technical Reports and Papers

The following reports or papers are associated with BC SRC research during the reporting period (May 1, 2024, to May 1, 2025):

Peer-Reviewed Publications

1. Babaie Mahani, A., Kao, H., & Smith, B. (2024). Investigation of the discrepancy in the earthquake magnitude values reported by different agencies in the Western Canada Sedimentary Basin. *Journal of Seismology*, 28, 753–764. https://doi.org/10.1007/s10950-024-10225-4
2. Esfahani, F., Babaie Mahani, A., & Kao, H. (2024). Analysis of the influential factors controlling the occurrence of injection-induced earthquakes in Northeast British Columbia, Canada, using machine-learning-based algorithms. *Journal of Seismology*, 28, 1489–1504. https://doi.org/10.1007/s10950-024-10248-x
3. Tan, F., Kao, H., Yi, K.M., Nissen, E., Goerzen, C., Hutchinson, J., Gao, D., & Farahbod, A.M. (2024). Next generation seismic source detection by computer vision: Untangling the complexity of the 2016 Kaikōura earthquake sequence. *Journal of Geophysical Research: Solid Earth*, 129(5), e2024JB028735. https://doi.org/10.1029/2024JB028735
4. Kuponiyi, A.P., Kao, H., Dosso, S.E., & Ardakani, O.H. (2024). Three-dimensional geometry of sedimentary basins and Moho beneath Western Canada from ambient seismic noise tomography. *Canadian Journal of Earth Sciences*, 61(12), 1234–1250.
5. Wang, B., Kao, H., Yu, H., Li, G., Dokht, R.M.H., & Visser, R. (2024). Unveiling key factors governing seismogenic potential and seismogenic productivity of hydraulic fracturing pads: Insights from machine learning in the Southern Montney Play. *Earth and Planetary Science Letters*, 626, 118511. https://doi.org/10.1016/j.epsl.2023.118511

Work In Progress

The seismic monitoring process has generally stabilized. However, improvements to the process may still be made. The performance of automatic seismic analysis programs is continuously improving, and further testing and verification must be made as these programs are investigated and adopted.

Ongoing research and development efforts include:

- Continued evaluation and improvement of machine learning algorithms for phase picking
- Development of automated station health monitoring tools
- Assessment of catalogue quality and completeness
- Exploration of enhanced velocity models for improved location accuracy

Conclusions

Through continued development of the seismic monitoring process and maintenance of the seismic network, the seismic monitoring capabilities for NEBC remain robust. A total of 6,005 events were detected for this reporting period, with magnitudes ranging from M_L -1.0 to M_L 4.44.

Several research themes have been investigated by members of the BC SRC over the past year. Based on the publications from this reporting period, these themes include:

- Magnitude discrepancy analysis between reporting agencies in the Western Canada Sedimentary Basin
- Machine learning applications for understanding factors controlling injection-induced seismicity
- Computer vision techniques for seismic source detection
- Ambient seismic noise tomography for mapping sedimentary basin and Moho geometry beneath Western Canada

The routine monitoring catalogue for the past year has been included as Appendix A.

References

Lomax, A., Virieux, J., Volant, P., and Berge-Thierry, C. (2000). Probabilistic earthquake location in 3D and layered models. In *Advances in Seismic Event Location* (pp. 101-134). Springer, Dordrecht.

Mousavi, S.M., Ellsworth, W.L., Zhu, W., Chuang, L.Y., and Beroza, G.C. (2020). Earthquake transformer - an attentive deep-learning model for simultaneous earthquake detection and phase picking. *Nature Communications*, 11(1), 3952.

Wiemer, S., and Wyss, M. (2000). Minimum magnitude of completeness in earthquake catalogs: Examples from Alaska, the Western United States, and Japan. *Bulletin of the Seismological Society of America*, 90(4), 859-869.

Figures

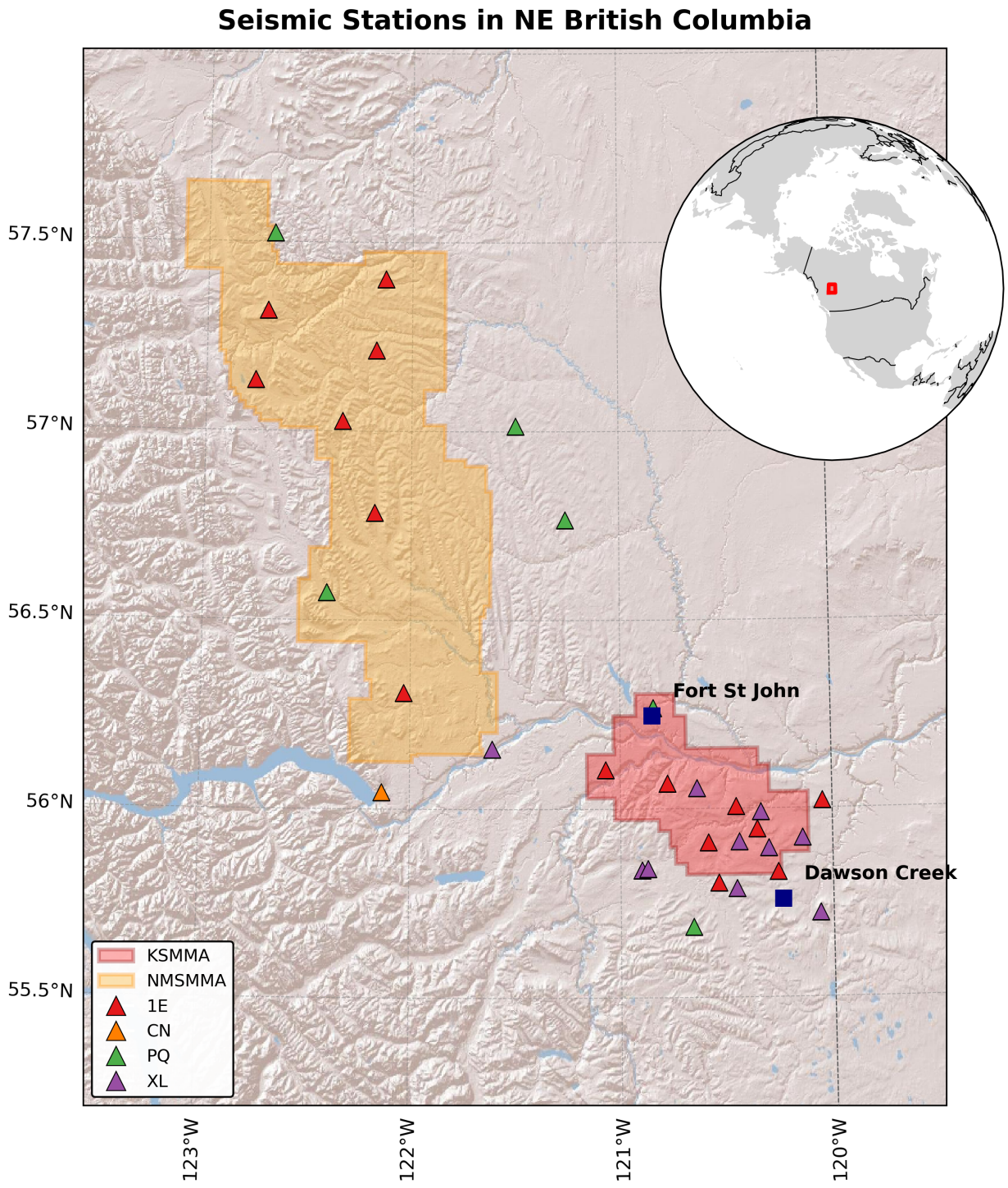

Figure 1: Seismic stations in NE BC and surrounding area coloured by network code. The KSMMA and NMSMMA monitoring boundaries are shown.

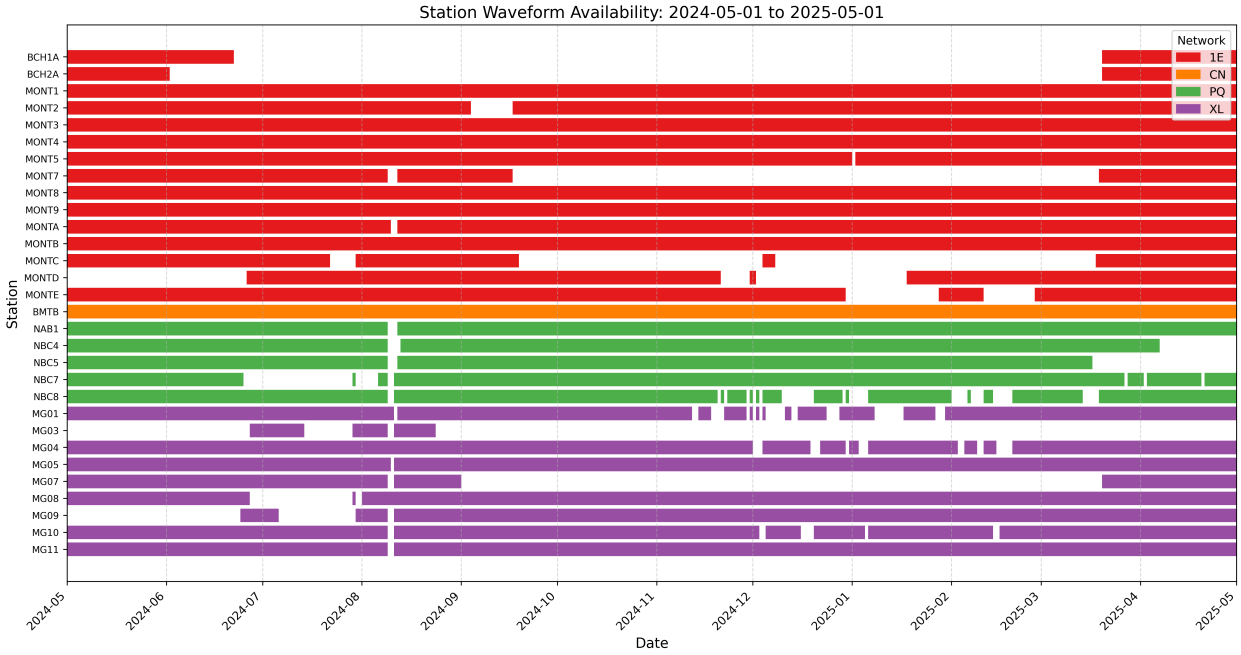

Figure 2: Gantt chart of station data availability based on waveform archive records from EarthScope. Stations are grouped by network and sorted alphabetically. Data gaps are generally attributed to power supply or network connection issues. A synchronized outage affecting multiple stations in August 2024 was caused by transmission issues, which were subsequently resolved. Notable extended outages during the reporting period affected BCH1A, BCH2A, MONT7, MONTC, MONTD, and MG07. A successful maintenance trip in spring 2025 restored data transmission from BCH1A, BCH2A, MONT7, MONTC, and MG07, and performed preventative maintenance on several other stations.

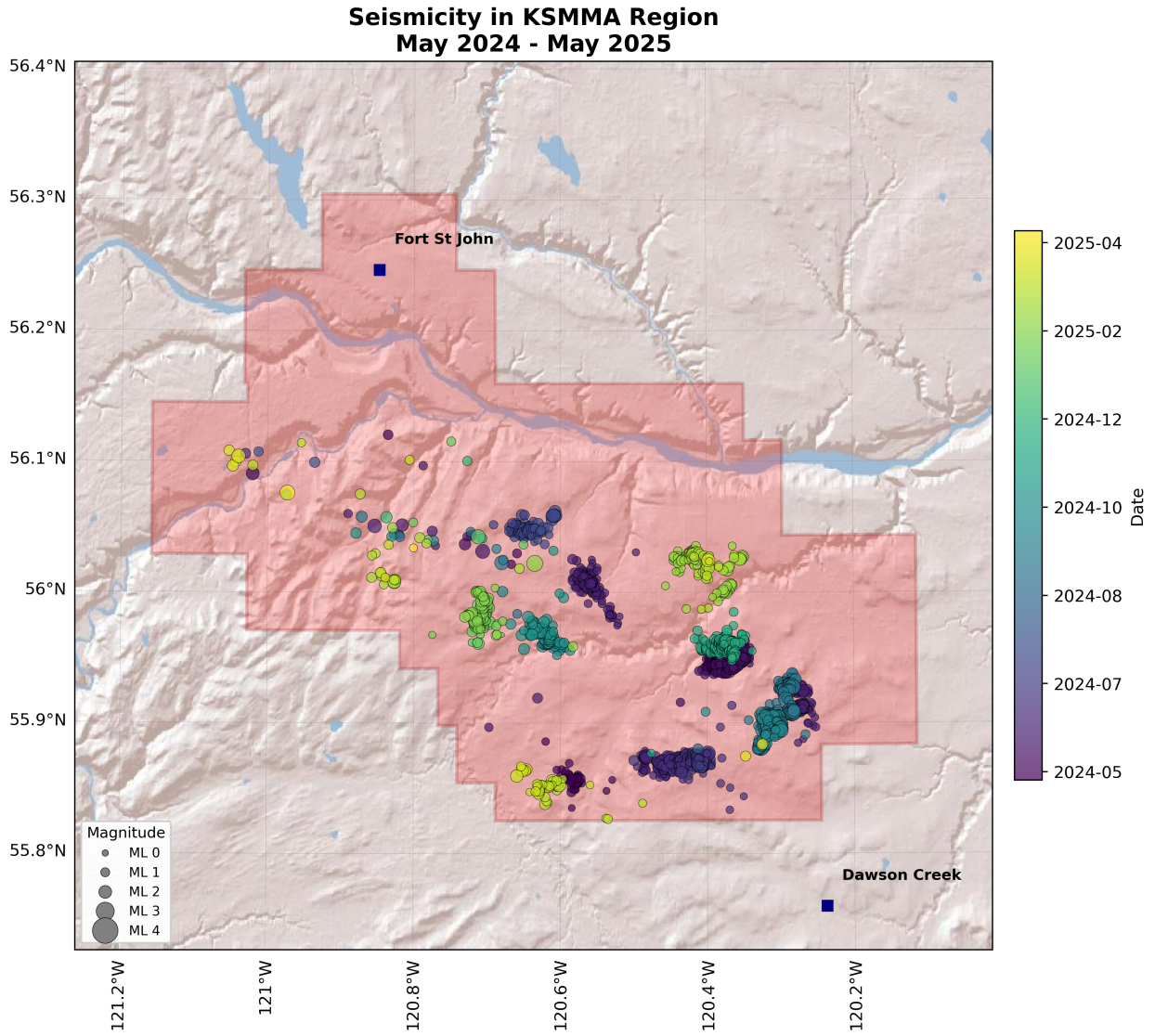

Figure 3: Map view plot of seismicity in the KSMMA. Events are sized by magnitude and coloured by date. The largest event during the reporting period was M_L 2.86, which occurred on September 30, 2024, at 19:49:16 UTC.

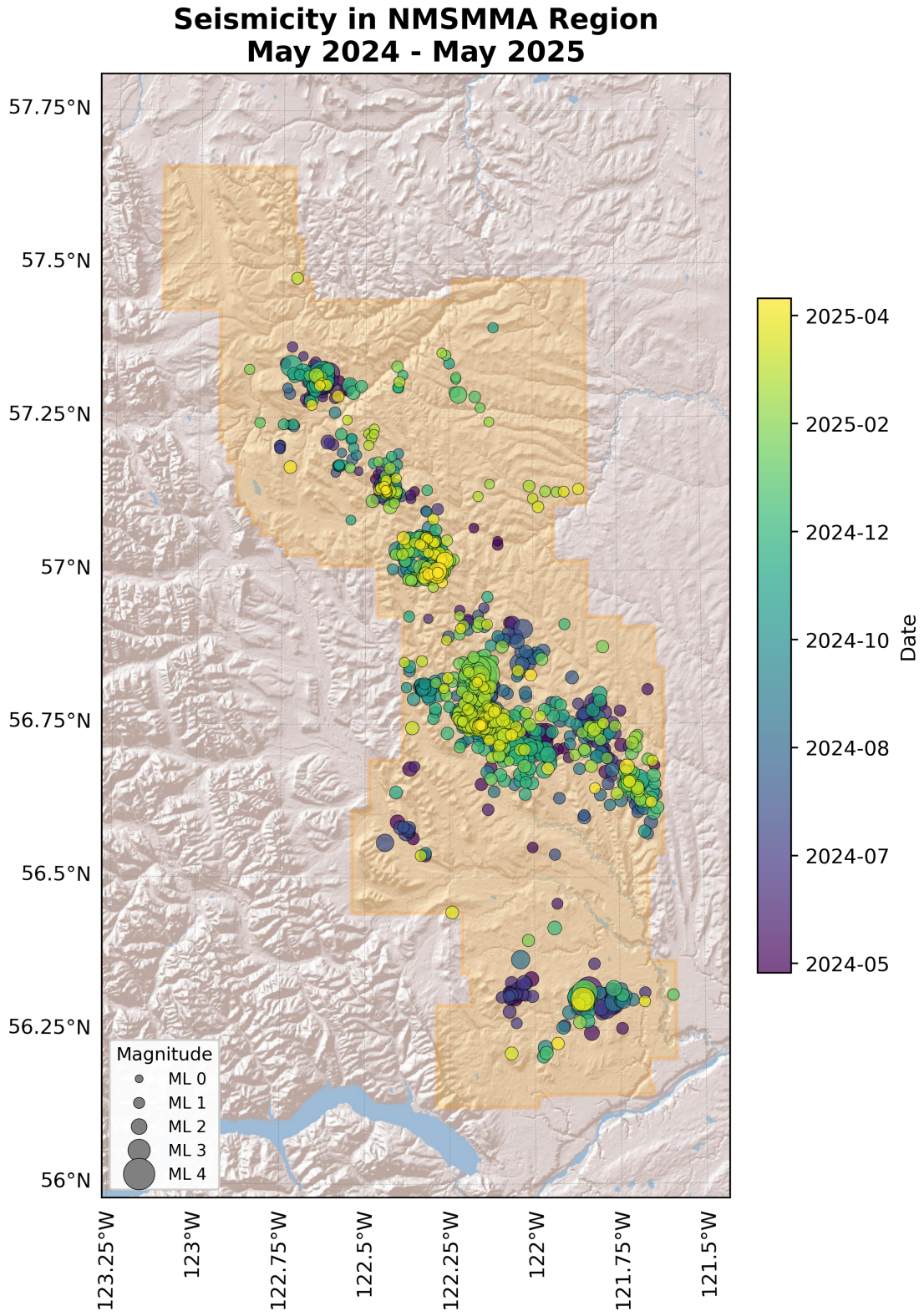

Figure 4: Map view plot of seismicity in the NMSMMA. Events are sized by magnitude and coloured by date. The largest event during the reporting period was M_L 4.44, which occurred on February 12, 2025, at 06:52:25 UTC.

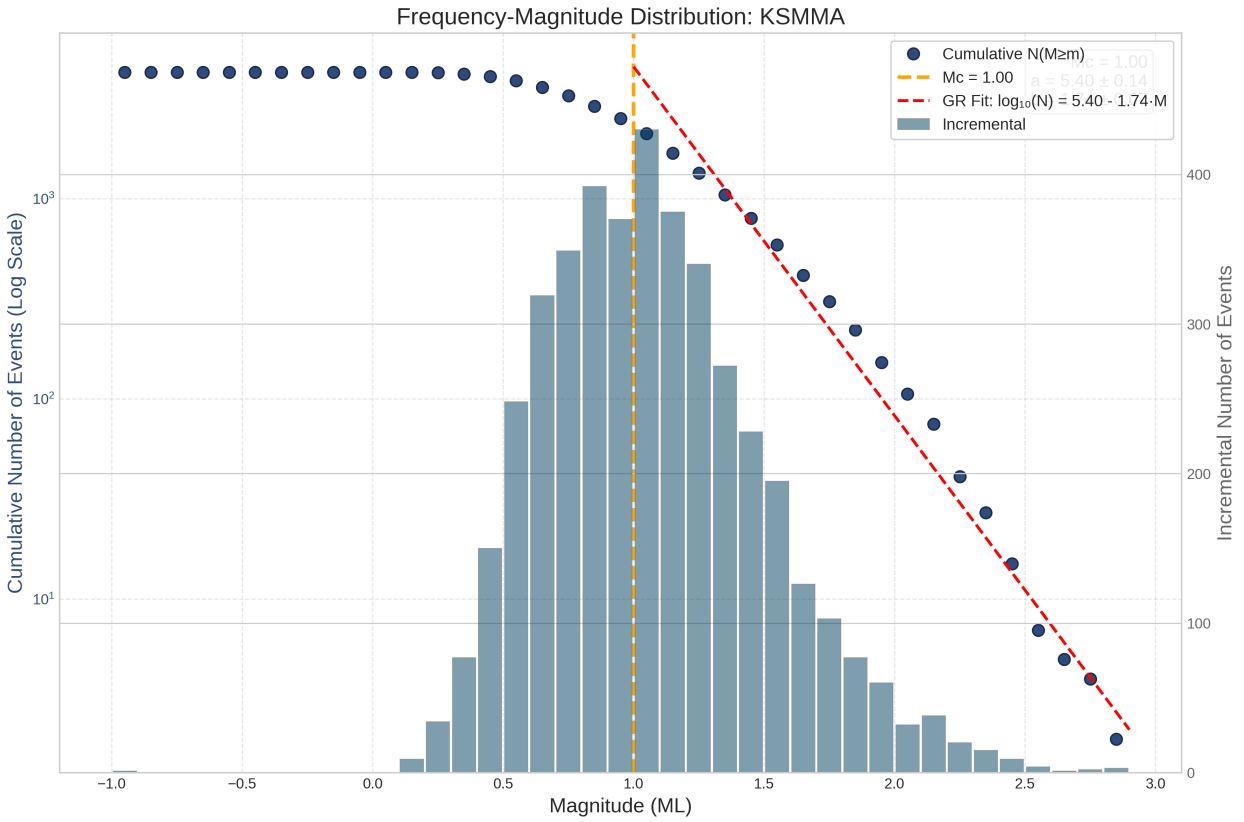

Figure 5: Magnitude frequency distribution for the KSMMA region. The magnitude of completeness (M_c) is indicated by the vertical dashed line.

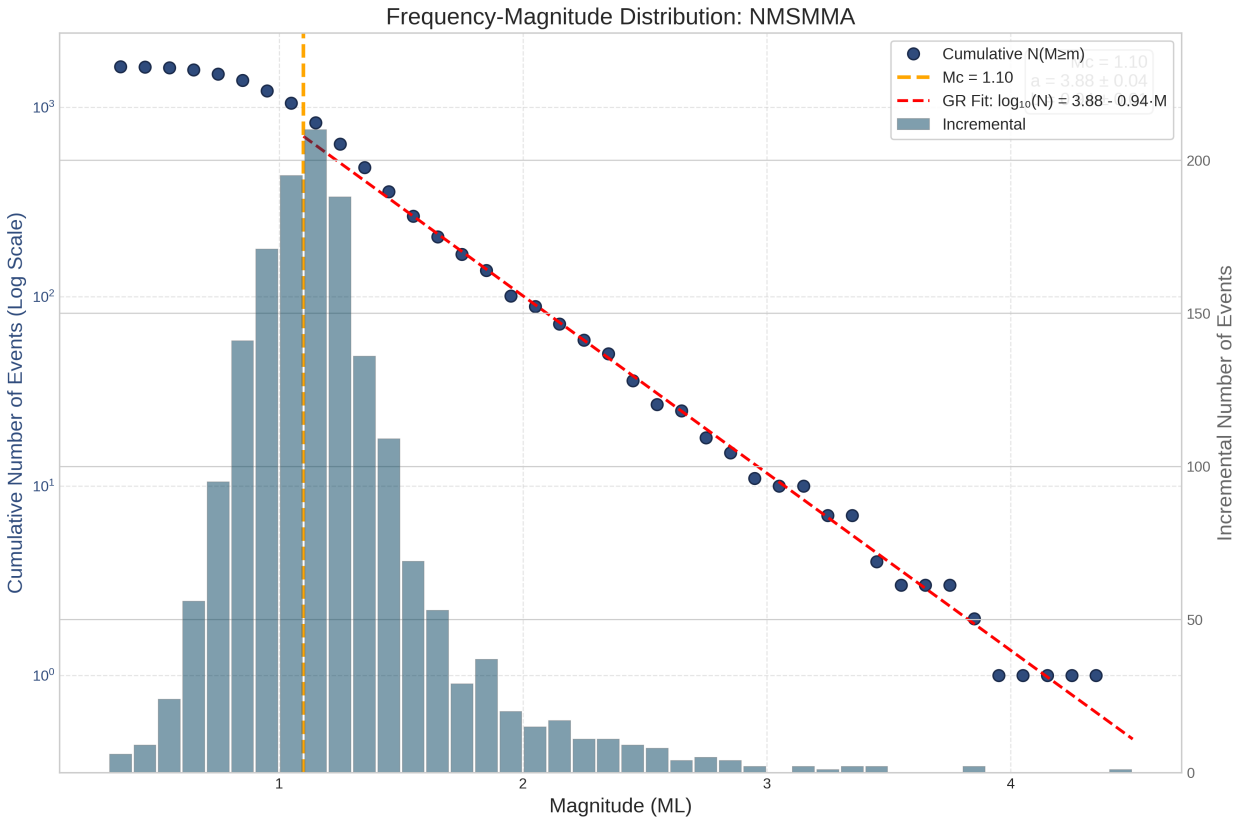

Figure 6: Magnitude frequency distribution for the NMSMMA. The magnitude of completeness (M_c) is indicated by the vertical dashed line.

Appendix A: Earthquake Catalogue

Earthquake Catalogue May 1, 2024 - May 1, 2025 (provided separately as Excel file)

The earthquake catalogue is provided as a separate Excel file (`earthquake_catalogue.xlsx`) containing the following sheets:

Summary

This sheet contains a text-based summary of key statistics for the overall region, the KSMMA, and the NMSMMA.

Origin

This sheet contains the primary hypocentral parameters for all earthquakes located during the reporting period.

Column	Type	Description
Event_ID	int	Unique identifier for each earthquake
Origin_Time_UTC	datetime	The date and time of the event origin (UTC)
Latitude	float	Latitude in degrees North
Longitude	float	Longitude in degrees East
Depth_km	float	Depth of the event in km
ML	float	Local magnitude of the event
Num_Phases	int	The number of phase arrivals used to locate the event
Horizontal_Error_m	float	The maximum horizontal uncertainty in metres
Minor_Error_m	float	The minimum horizontal uncertainty in metres
Azimuth_deg	float	The azimuth of the major axis of the uncertainty ellipse in degrees
Monitoring_Area	string	The monitoring area (KSMMA, NMSMMA, or Outside)

KSMMA_RedLight_Events

This sheet contains a subset of the Origin data, listing only the events within the KSMMA that exceeded the M_L 3.0 “red light” threshold.

NMSMMA_RedLight_Events

This sheet contains a subset of the Origin data, listing only the events within the NMSMMA that exceeded the M_L 4.0 “red light” threshold.

Appendix B: Seismic Station Inventory

The following table lists the seismic stations used for monitoring in northeastern British Columbia during the May 1, 2024 - May 1, 2025 reporting period. A dash ('-') in the End Date column indicates the station was still active at the end of the reporting period (May 1, 2025).

Network	Station	Start Date	End Date	Latitude (N)	Longitude (E)	Elevation (m)
1E	BCH1A	2019-10-04	-	55.8324	-120.2590	689
1E	BCH2A	2019-10-05	-	55.9461	-120.3561	761
1E	MONT1	2018-10-01	-	55.9102	-120.5865	697
1E	MONT2	2018-10-01	-	56.0197	-120.0470	642
1E	MONT3	2018-10-01	-	56.0058	-120.4539	783
1E	MONT4	2018-10-01	-	57.3184	-122.7057	1110
1E	MONT5	2018-10-16	-	57.0269	-122.3360	1097
1E	MONT7	2018-10-16	-	56.3079	-122.0316	797
1E	MONT8	2019-07-15	-	56.0673	-120.7774	695
1E	MONT9	2019-10-07	-	55.8039	-120.5388	832
1E	MONTA	2019-10-05	-	56.1043	-121.0700	651
1E	MONTB	2022-10-21	-	57.4026	-122.1302	959
1E	MONTC	2022-10-21	-	57.1338	-122.7622	1181
1E	MONTD	2022-10-21	-	56.7848	-122.1778	737
1E	MONTE	2022-10-21	-	57.2139	-122.1745	1024
CN	BMTB	2017-09-18	-	56.0451	-122.1332	1099
PQ	NAB1	2014-08-19	-	56.7663	-121.2587	754
PQ	NBC4	2014-01-01	-	55.6873	-120.6602	815
PQ	NBC5	2014-01-01	-	57.5231	-122.6776	1161
PQ	NBC7	2014-08-10	2024-07-31	56.2678	-120.8426	676
PQ	NBC7	2024-07-31	-	57.0139	-121.4974	822
PQ	NBC8	2016-01-01	-	56.5731	-122.4044	709
XL	MG01	2017-06-19	-	56.0548	-120.6380	721
XL	MG03	2017-06-16	-	55.9122	-120.4414	697
XL	MG04	2017-06-17	-	55.9914	-120.3380	682
XL	MG05	2017-06-15	-	55.8951	-120.3019	795
XL	MG07	2017-08-10	-	55.7884	-120.4547	742
XL	MG08	2017-06-14	2024-08-01	55.8412	-120.8731	722
XL	MG08	2024-08-01	-	55.8381	-120.8997	722
XL	MG09	2021-09-30	-	56.1591	-121.6081	795
XL	MG10	2019-10-01	-	55.7229	-120.0633	798
XL	MG11	2021-10-01	-	55.9222	-120.1423	657

Report Date: May 2025