AER/AGS Open File Report 2019-09

The Scientific Induced Seismicity Monitoring Network (SCISMN)

AER/AGS Open File Report 2019-09

The Scientific Induced Seismicity Monitoring Network (SCISMN)

R.J. Schultz[1,2], J. Yusifbayov[1] and T.C. Shipman[1]

[1] Alberta Energy Regulator
Alberta Geological Survey

[2] Stanford University

April 2020

ISBN 978-1-4601-4499-2

Schultz, R.J., Yusifbayov, J. and Shipman, T.C. (2020): The Scientific Induced Seismicity Monitoring Network (SCISMN); Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Open File Report 2019-09, 10 p.

Author addresses:
R.J. Schultz
Department of Geophysics
Stanford University
Mitchell Earth Sciences Building
397 Panama Mall
Stanford, CA 94305
United States
Tel: 650.723.2300
Email: rjs10@stanford.edu

Published April 2020 by:
Alberta Energy Regulator
Alberta Geological Survey
4th Floor, Twin Atria Building
4999 – 98th Avenue
Edmonton, AB T6B 2X3
Canada

Tel: 780.638.4491
Fax: 780.422.1459
Email: AGS-Info@aer.ca
Website: www.ags.aer.ca

Contents

Figures

Acknowledgements

The authors would like to thank Matt Grobe for his tremendous input and aid in making this document better.

Abstract

Earthquakes induced by oil and gas development activities have become a growing concern in Alberta in recent years. Industry can be required to collect and submit earthquake waveform data to the Alberta Energy Regulator. In this report we describe the process, naming convention, and location built to act as a repository to enable the required sharing and storage of submitted seismic information. The Scientific Induced Seismicity Monitoring Network (SCISMN, pronounced as "seism") was developed to support a data reporting requirement as part of compliance assurance and to improve access to data that enable scientific understanding of induced earthquakes. Industry waveform data required to be submitted under a traffic light protocol may be collated under SCISMN within the Incorporated Research Institutions for Seismology (IRIS) data repository. Waveform data submitted in this manner are stored, managed, and disseminated (after a one-year embargo period) through IRIS and can be accessed under the temporary network code **2K** (https://doi.org/10.7914/SN/2K_2014).

We also summarize two of the currently active traffic light protocols within the province and provide an overview of the waveform data that has already been submitted into SCISMN and made available through IRIS pursuant to these protocols. We recommend a station naming practice for seismological vendors to observe when submitting data to SCISMN in order to avoid future station name conflicts as SCISMN grows. Overall, SCISMN provides a robust and transparent sharing mechanism for induced seismicity data.

1 Regional Seismic Monitoring in Alberta

The Alberta Geological Survey (AGS) collects seismometer waveform data through their Regional Alberta Observatory for Earthquake Studies Network (RAVEN; Schultz and Stern, 2015). Data from RAVEN is available publicly, through the Incorporated Research Institutions for Seismology (IRIS). Numerous networks supplement AGS waveform data, such as the Canadian National Seismic Network (CNSN), the Canadian Rockies and Alberta Network (CRANE; Gu et al., 2011), the TransAlta Dam Network (TD), the Alberta Telemetered Seismic Network (ATSN; Eaton, 2014) the Montana Regional Seismic Network (MRSN; D'Alessandro and Stickney, 2012), and others. The spatial distribution of these network stations is displayed in Figure 1.

These networks have been utilized as a regional backbone to catalogue earthquakes that have been ongoing in the province (Stern et al., 2013). Characterizing the ongoing seismicity in the province, both natural and induced, has been one of the mandates of the AGS. These networks have been instrumental in first recognizing cases of induced seismicity occurring within Alberta (Schultz et al., 2014, 2015; Atkinson et al., 2016). Much of the station deployments in the province have been aimed at better understanding this phenomenon. In fact, networks such as RAVEN have been utilized in compliance assurance for monitoring induced events in the Fox Creek area (Alberta Energy Regulator, 2015; Shipman et al., 2018).

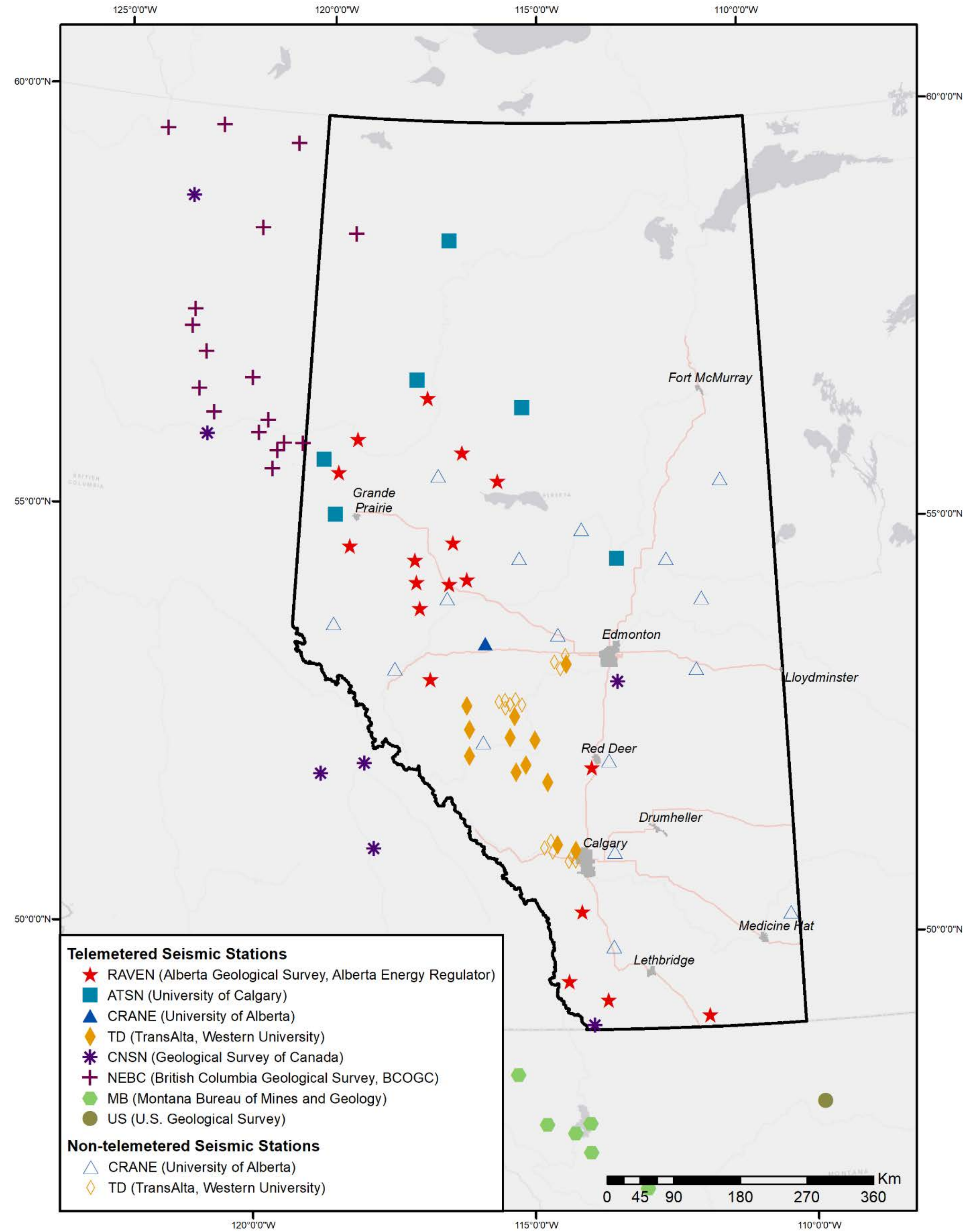

Figure 1. Map of seismic stations (and network affiliations) in Alberta.

2 The Scientific Induced Seismicity Monitoring Network (SCISMN)

A traffic light protocol is a risk management system with multiple seismic magnitude threshold levels built on a site-specific basis for the effective management of and response to induced seismicity (Alberta Energy Regulator, 2015). Compliance assurance within a traffic light protocol is one of the key controls for the effective management of induced earthquakes. Despite the significant increases in regional station density in Alberta, regional networks are limited in their ability to discern induced events because of reporting inaccuracies. For example, regional networks in areas with lower magnitude level yellow-light thresholds in a traffic light protocol may be unable to confidently verify compliance due to inadequate regional detection thresholds and location resolutions. In addition, differences in waveform data accessibility between operators, the AER/AGS, and Natural Resources Canada have created disparate reports of earthquake magnitudes.

As part of the initial solution to these problems, the first Albertan traffic light protocol (Alberta Energy Regulator, 2015) required that operators independently monitor induced earthquakes near their operations. Operators were required to submit waveform data if a red-light event occurs. Two gaps were recognized: 1) a mechanism was needed to collect and disseminate submitted data, and 2) more data is required to develop appropriate site-specific regulatory responses to the induced seismicity hazard. The creation of the Scientific Induced Seismicity Monitoring Network (SCISMN, pronounced as ‘seism’) is a proposed solution to address these issues.

SCISMN was developed to receive, store, and disseminate industry passive seismic monitoring data collected and submitted as part of regulatory requirements. As part of subsurface orders issued by the Alberta Energy Regulator (AER) (Alberta Energy Regulator, 2015, 2019a, c), operators of hydraulic fracturing operations in regions identified as being susceptible to induced seismicity can be required to submit passive seismic monitoring data to the AER for review and analysis. Depending on the subsurface order, AER may require the operator to submit collected passive seismic monitoring data after a seismic event of a certain threshold magnitude has been detected (Alberta Energy Regulator, 2015), or stipulate that the data must be submitted in real-time (Alberta Energy Regulator, 2019a, c).

Additionally, the Alberta Energy Regulator may request data from any non-telemetered stations or stations that are no longer operational and are or were used in the regions susceptible to induced seismicity. Operators provide data from these stations directly to the AGS, who will then upload the data to the SCISMN portion of the IRIS data repository. Upon upload, data from these stations are held to the same standards (see Section 2.1) as the data from the real-time stations.

Public dissemination of these data, through the IRIS data management centre, supports transparent and credible regulation. Allowing many experts to view these waveform datasets provides an additional benefit: it permits the development of seismological products like refined catalogues (Atkinson et al., 2016; Schultz et al., 2017, 2018), ground motion databases (Assatourians and Atkinson, 2019), ground motion prediction equations, shake maps (Schultz and Nanometrics Inc., 2019), hazard quantification (Ghofrani et al., 2019), focal mechanism solutions (Wang et al., 2016, 2017), geological susceptibilities (Pawley et al., 2018; Galloway et al., 2018), operational controls (Schultz et al., 2018), traffic light performance (Shipman et al., 2018), and high-resolution comparisons to stimulation programs (Eaton et al., 2018; Eyre et al., 2019). All of these products enrich our understanding of induced earthquakes in the province, enabling better support for the regulatory process.

2.1 Station Naming Convention

Here, we cover an important aspect of organizing SCISMN: station naming conventions. With many possible seismogenic regions or plays, operators, and seismological vendors working independently comes the eventuality of conflicting station names when collating all of their data. To circumvent this, we define criteria for naming stations. First, for legacy issues, we recommend that stations that were already named keep their initial name (unless a conflict arises with another existing station). However, when vendors name new stations they should refer to this convention. Within the header information of the Standard for the Exchange of Earthquake Data (SEED) is the station identifier code (FDSN, 2012), which we refer to as the station name. Under current IRIS conventions, station names may have up to five characters. Here, we will recommend that vendors use all five. All other SEED headers should follow IRIS conventions (FDSN, 2012).

The first character in the station name will designate the region or play, for example, ‘D’ for Duvernay or ‘B’ for Brazeau. The second character in the station name will designate the operator who hired the vendor (if a vendor is independently setting up a subscription array, then they would be considered the operator). This character will be based on the first letter in the company’s name. If the first letter is already in use by another company, then the second is used instead (or third, fourth, etc.). The third character in the station name will designate the vendor providing the seismological monitoring service. This character will be based on the first letter in the company’s name. If the first letter is already in use by another vendor, then the second is used instead. The last remaining two characters in the station name should be used as numbers to designate the first, second, third stations installed (e.g., XXX01, XXX02, XXX03). This numerical restriction will provide 100 unique combinations for a single play, operator, and vendor combination. If more than 100 stations are installed, then using letters for the last two characters will also be permitted.

For an example of a station to be named, we consider a hypothetical case. Alberta Fracking Company hires Schultz and Shipman Earthquakes to install and monitor four stations in the Duvernay East Shale Basin. However, a competing vendor, Seismological Services, has already been operating in the basin and submitting data to SCISMN for years. Based on this information, the stations’ names would follow this approach:

1) D is the first character, after the Duvernay Formation.
2) A is the second character, after the A in AFC for Alberta Fracking Company.
3) S would be the third character, after Schultz and Shipman Earthquakes.
    a) S is already taken though, so C is the next choice.
4) The last remaining characters are numerical, based on installation order: DAC01, DAC02, DAC03, and DAC04.

3 Examples of Areas where Seismic Data was Collected for SCISMN

The following sub-sections detail two areas where regulatory protocols require collection of data, and a timeline of induced earthquakes in those seismogenic regions. Overall, this section provides an example for those interested in what data are available through SCISMN, and the prior work conducted on these datasets. This section demonstrates the benefit that collecting and sharing this information delivers to stakeholders.

3.1 Subsurface Order No. 2 Area (Fox Creek)

Since December 2013, earthquakes in the Fox Creek area have been induced as a result of hydraulic fracturing operations in the Duvernay Formation (Schultz et al., 2017, 2018). A 4.4 M_L event induced by hydraulic fracturing on 23 January 2015 was the first to be felt in Fox Creek (Schultz and Nanometrics Inc., 2019). This felt event prompted the creation of a traffic light protocol in the Fox Creek area via a Subsurface Order (Alberta Energy Regulator, 2015). Under this protocol, operators targeting the Duvernay Formation in this area are required to monitor and report all events within 5 km of their hydraulic fracturing pad down to the yellow-light threshold of 2.0 M_L. If the red-light threshold (4.0 M_L) is exceeded, the operators are required to immediately cease operations at the affected well and return the well to a safe state. The AER can then request that the operator share their seismic monitoring data.

To date, there have been two red-light cases invoked within the Subsurface Order No. 2 area. The first occurred on 13 June 2015, was reported at 4.4 M_L, and was induced by operations on a nearby eight well pad (Figure 2). In this case, the operator hired a seismological vendor who had installed a dense array of seismometers within a 3 km radius of their pad – eight of which were shared. Segments of data timed with earthquakes are available from 29 April 2015 to 5 July 2015. These data were subject to studies that were able to increase the catalogue of events ten-fold (Schultz et al., 2017) and delineate the focal mechanism as strike-slip (Wang et al., 2016). Due to the red-light data sharing requirements under Subsurface Order No. 2, seismic data from this red-light event is available at IRIS under SCISMN.

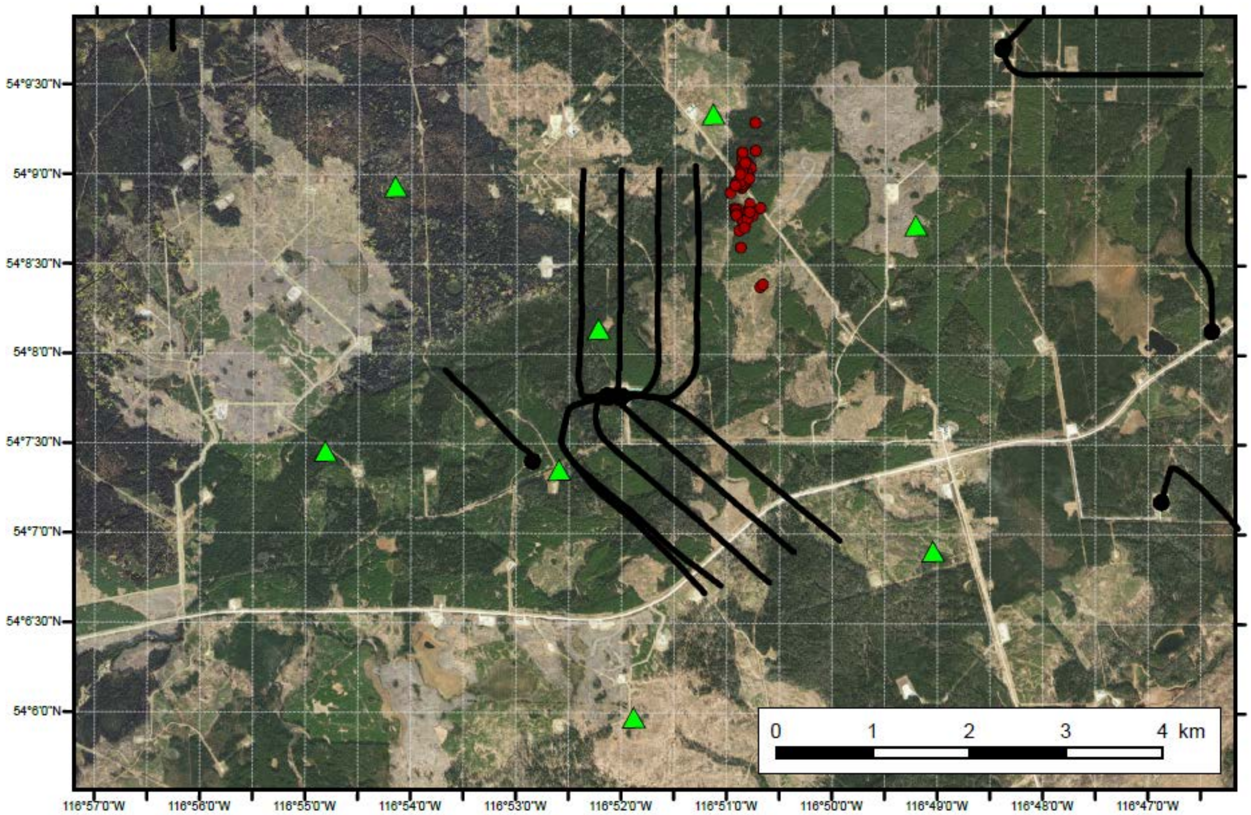

Figure 2. Station availability from the first red-light invoked under Subsurface Order No. 2. Locations of catalogued earthquakes (circles), stations (triangles), and nearby Duvernay wells (tadpoles) are shown alongside local satellite imagery for spatial context.

The second red-light case occurred on 12 January 2016, was reported at 4.8 M_L, and was induced by the single southern well on a three-well pad (Figure 3). A year prior, the northern two wells on this pad were responsible for the 23 January 2015 4.1 M_L felt event. For the monitoring requirement, this operator hired a seismological vendor who had installed a semi-local/regional network of seismometers – four of which were shared as part of the red-light requirement. These four stations are roughly within an 8 km radius around the hydraulic fracturing pad. Continuous waveform data from these stations are available from 1 January 2016 through 19 January 2016. These data were subject to numerous studies that were able to increase the catalogue to 90 conventionally recorded events (Schultz et al., 2017) and delineate the focal mechanism as strike-slip within a transtensional fault system (Wang et al., 2017). These results were later reconfirmed with even higher-resolution microseismic data (Eyre et al., 2019) and 3D reflection seismic data (Chopra et al., 2017). Due to the red-light data sharing requirements under Subsurface Order No. 2, seismic data from this red-light event are available at IRIS under SCISMN.

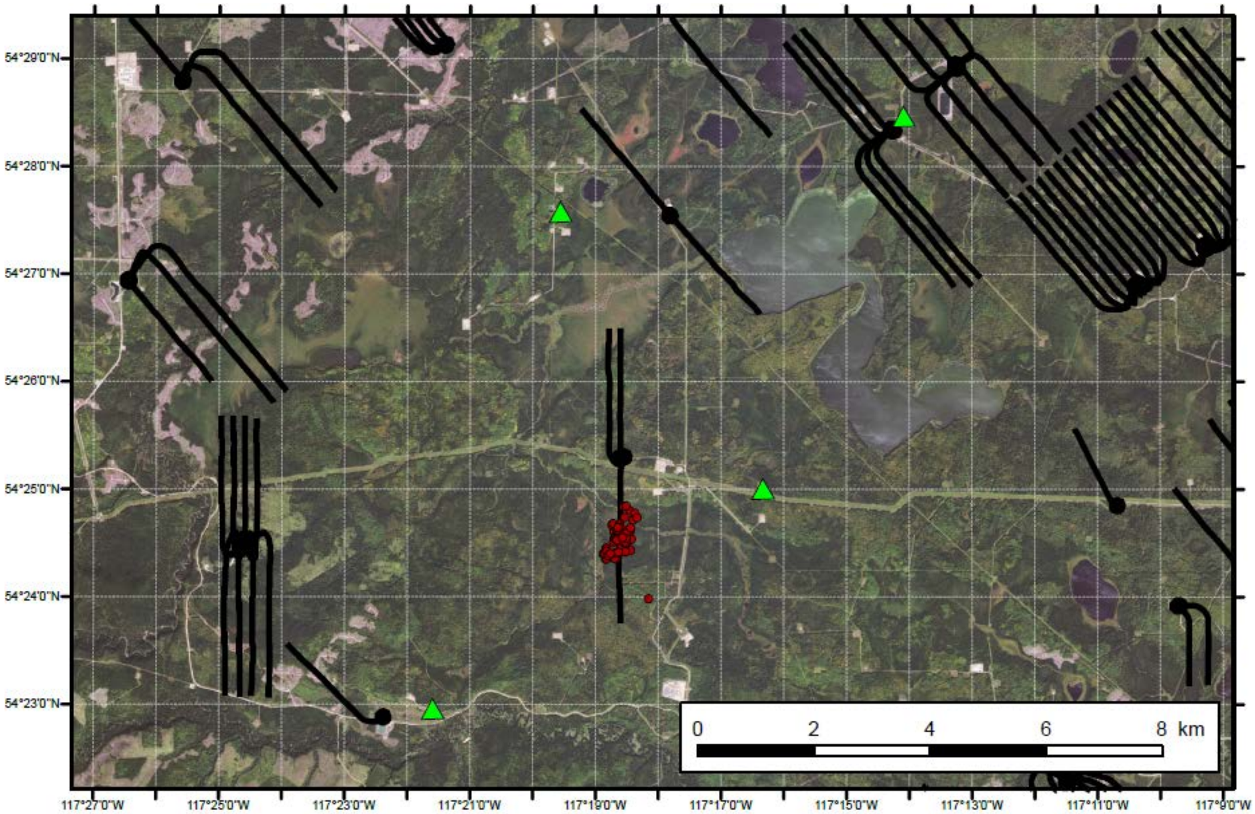

Figure 3. Station availability from the second red-light invoked under Subsurface Order No. 2. Locations of catalogued earthquakes (circles), stations (triangles), and nearby Duvernay wells (tadpoles) are shown alongside local satellite imagery for spatial context.

3.2 Subsurface Order No. 7 (Red Deer)

Two seismic events (19 March 2018 and 4 March 2019) in the Red Deer region were large enough (3.1 M_L and 4.2 M_L) to be felt by nearby residents who were between 4 and 10 km away. The observation of these events in a typically seismically quiescent region was suspicious, considering the contemporaneous development of hydraulic fracturing operations targeting the Duvernay Formation in the East Shale Basin. Because deployments of stations in the province have been skewed to more seismically active areas (Schultz and Stern, 2015), assessing the induced status of this cluster was significantly aided by industry supplemented data (Figure 4). Through the use of this supplemental data, it was found that earthquakes in this region were strongly related to hydraulic fracturing operations (Schultz and Wang, 2020).

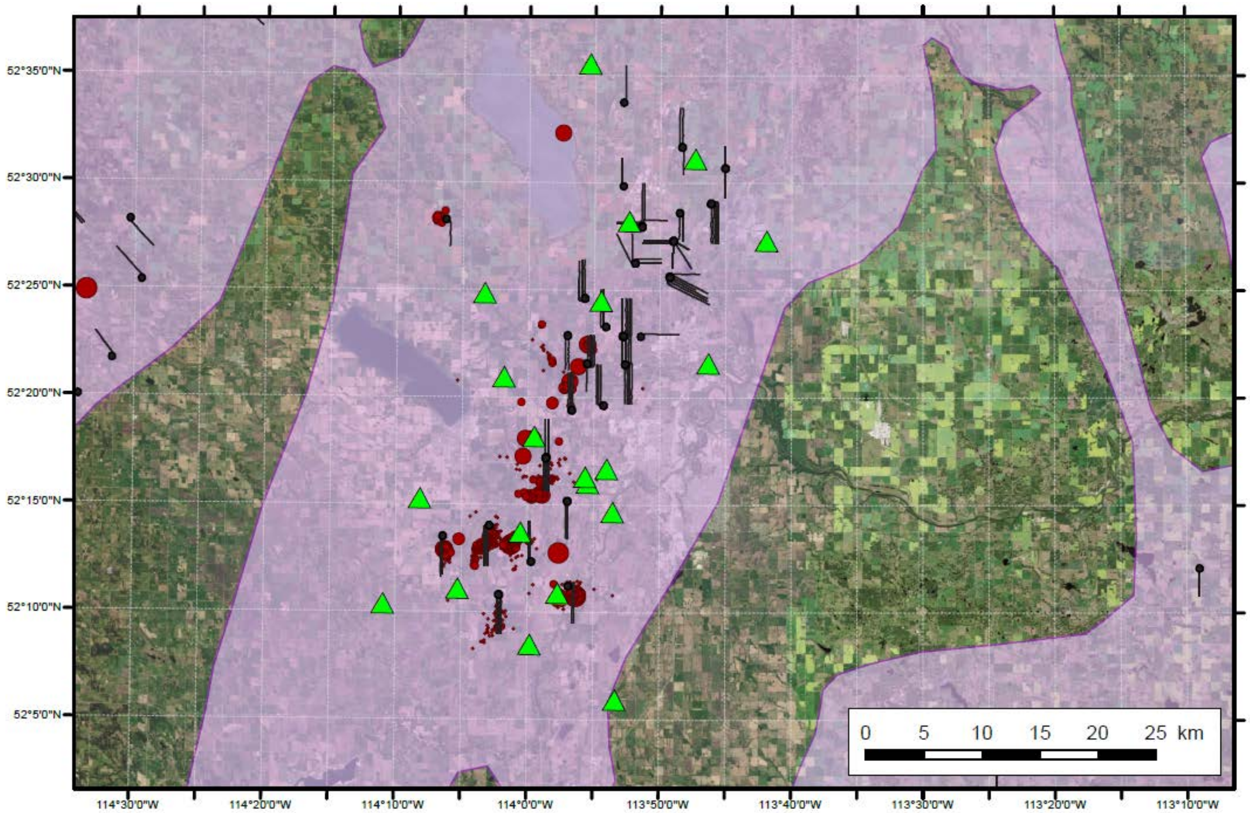

Figure 4. Station availability from the first red-light invoked under Bulletin 2019-07 (Alberta Energy Regulator, 2019b). Locations of catalogued earthquakes (circles), stations (triangles), Duvernay Formation (purple area), and wells causing the earthquakes (tadpoles) are shown alongside local satellite imagery for spatial context.

In the Red Deer area, induced earthquakes were initially managed via a regulatory bulletin (Alberta Energy Regulator, 2019b), which has now been replaced by a subsurface order (Alberta Energy Regulator, 2019c). Currently, operators are required to monitor and report all events within a 5 km radius of their operations, down to the yellow-light threshold of 1.0 M_L. The red-light threshold within this region is set at 3.0 M_L and requires the immediate suspension of hydraulic fracturing operations at the subject well. Supplemental industry data was collected as part of the regulatory process to develop this initial traffic light protocol. This includes the supplementary data utilized in the aforementioned study (Schultz and Wang, 2020). The operator in the Duvernay East Shale Basin hired a seismological vendor to install and manage a semi-local/regional network of broadband seismometers. This includes twenty-one stations within a ~1300 km^2 area west of Red Deer (Figure 4). Due to the sharing requirements under Subsurface Order No. 7, seismic data from in this area are available through the IRIS data management centre.

4 Summary

This report describes the Scientific Induced Seismicity Monitoring Network (SCISMN) – a data repository to collate all of industry's induced seismicity data submitted as part of regulatory protocols. In this report we summarized the state of seismological monitoring in Alberta and the rationale for building this new network. We highlighted a station naming convention to organize the network. Finally, we presented some examples of data stored within SCISMN and summarized some studies that utilized this data. All data within SCISMN is publicly available at the IRIS data management centre, after a one-year embargo period, under the temporary network code **2K** (http://ds.iris.edu/mda/2K/). Data within this network will be updated routinely, as new seismic data are collected pursuant to existing, new, or amended traffic light protocols.

5 References

Alberta Energy Regulator (2015): Subsurface Order No. 2: Monitoring and reporting of seismicity in the vicinity of hydraulic fracturing operations in the Duvernay zone, Fox Creek, Alberta; AER Bulletin 2015-07, 3 p., URL <https://aer.ca/documents/orders/subsurface-orders/SO2.pdf>.

Alberta Energy Regulator (2019a): Subsurface Order No. 6: Monitoring and reporting of seismicity in the vicinity of Brazeau, Alberta; AER Subsurface Order, 5 p., URL <https://www.aer.ca/documents/orders/subsurface-orders/SO6.pdf>.

Alberta Energy Regulator (2019b): Recommendations around hydraulic fracturing in the Red Deer area; AER Bulletin 2019-07, 2 p., URL <https://www.aer.ca/documents/bulletins/Bulletin-2019-07.pdf>.

Alberta Energy Regulator (2019c): Subsurface Order No. 7: New monitoring, setback, and response requirements to manage the risk of induced seismicity in the Red Deer Region; AER Subsurface Order, 4 p., URL <https://www.aer.ca/documents/orders/subsurface-orders/SO7.pdf>.

Assatourians, K. and Atkinson, G. M. (2019): Processed ground-motion records from induced earthquakes for use in engineering applications; Canadian Journal of Civil Engineering, doi: 10.1139/cjce-2018-0222.

Atkinson, G. M., Eaton, D. W., Ghofrani, H., Walker, D., Cheadle, B., Schultz, R., Scherbakov, R., Tiampo, K., Gu., Y.J., Harrington, R.M., Liu, Y., van der Baan, M. and Kao, H. (2016): Hydraulic fracturing and seismicity in the Western Canada Sedimentary Basin; Seismological Research Letters, v. 87(3), p. 631–647, doi: 10.1785/0220150263.

Chopra, S., Sharma, R. K., Ray, A. K., Nemati, H., Morin, R., Schulte, B. and D'Amico, D. (2017): Seismic reservoir characterization of Duvernay shale with quantitative interpretation and induced seismicity considerations—a case study; Interpretation, v. 5(2), p. T185–T197, doi: 10.1190/INT-2016-0130.1.

D'Alessandro, A. and Stickney, M. (2012): Montana seismic network performance: An evaluation through the SNES method; Bulletin of the Seismological Society of America, v. 102(1), p. 73–87, doi: 10.1785/0120100234.

Eaton, D. (2014): Alberta Telemetered Seismograph Network (ATSN): Real-time monitoring of seismicity in northern Alberta; CSEG Recorder.

Eaton, D. W., Igonin, N., Poulin, A., Weir, R., Zhang, H., Pellegrino, S. and Rodriguez, G. (2018): Induced seismicity characterization during hydraulic-fracture monitoring with a shallow-wellbore geophone array and broadband sensors; Seismological Research Letters, v. 89(5), p. 1641–1651, doi: 10.1785/0220180055.

Eyre, T. S., Eaton, D. W., Zecevic, M., D'Amico, D. and Kolos, D. (2019): Microseismicity reveals fault activation before Mw 4.1 hydraulic-fracturing induced earthquake; Geophysical Journal International, p. 534–546, doi: 10.1093/gji/ggz168.

FDSN, International Federation of Digital Seismograph Networks (2012): SEED Reference Manual; IRIS Incorporated Research Institutions for Seismology, 224 p., URL <http://www.fdsn.org/pdf/SEEDManual_V2.4.pdf>.

Galloway, E., Hauck, T., Corlett, H., Pană, D. and Schultz, R. (2018): Faults and associated karst collapse suggest conduits for fluid flow that influence hydraulic fracturing-induced seismicity, Proceedings of the National Academy of Sciences, v. 115(43), p. E10003–E10012, doi: 10.1073/pnas.1807549115.

Ghofrani, H., Atkinson, G. M., Schultz, R. and Assatourians, K. (2019): Short-term hindcasts of seismic hazard in the Western Canada Sedimentary Basin caused by induced and natural earthquakes; Seismological Research Letters, v. 90(3), p. 1420–1435, doi: 10.1785/0220180285.

Gu, Y.J., Okeler, A., Shen, L. and Contenti, S. (2011): The Canadian Rockies and Alberta Network (CRANE): New constraints on the Rockies and western Canada sedimentary basin; Seismological Research Letters, v. 82(4), p. 575–588, doi: 10.1785/gssrl.82.4.575.

Pawley, S., Schultz, R., Playter, T., Corlett, H., Shipman, T., Lyster, S. and Hauck, T. (2018): The geological susceptibility of induced earthquakes in the Duvernay play; Geophysical Research Letters, v. 45(4), p. 1786–1793, doi: 10.1002/2017GL076100.

Schultz, R. and Nanometrics Inc. (2019): Initial seismic hazard assessment for the induced earthquakes near Fox Creek, Alberta (between January 2013 and January 2016); Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Special Report 104, 115 p.

Schultz, R. and Stern, V. (2015): The Regional Alberta Observatory for Earthquake Studies Network (RAVEN); CSEG Recorder, v. 40(8), p. 34–37.

Schultz, R. and Wang, R. (2020): A newly emerging case of hydraulic fracturing induced seismicity in the Duvernay East Shale Basin; Tectonophysics v. 779, p. 1–9, doi: 10.1016/j.tecto.2020.228393.

Schultz, R., Stern, V. and Gu, Y. J. (2014): An investigation of seismicity clustered near the Cordel Field, west central Alberta, and its relation to a nearby disposal well; Journal of Geophysical Research: Solid Earth, v. 119(4), p. 3410–3423, doi: 10.1002/2013JB010836.

Schultz, R., Mei, S., Pană, D., Stern, V., Gu, Y. J., Kim, A. and Eaton, D. (2015): The Cardston earthquake swarm and hydraulic fracturing of the Exshaw Formation (Alberta Bakken play); Bulletin of the Seismological Society of America, v. 105(6), p. 2871–2884, doi: 10.1785/0120150131.

Schultz, R., Wang, R., Gu, Y. J., Haug, K. and Atkinson, G. (2017): A seismological overview of the induced earthquakes in the Duvernay play near Fox Creek, Alberta; Journal of Geophysical Research: Solid Earth, v. 122(1), p. 492–505, doi: 10.1002/2016JB013570.

Schultz, R., Atkinson, G., Eaton, D. W., Gu, Y. J. and Kao, H. (2018): Hydraulic fracturing volume is associated with induced earthquake productivity in the Duvernay play; Science, v. 359(6373), p. 304–308, doi: 10.1126/science.aao0159.

Shipman, T., MacDonald, R. and Byrnes, T. (2018): Experiences and learnings from induced seismicity regulation in Alberta; Interpretation, v. 6(2), p. SE15–SE21, doi: 10.1190/INT-2017-0164.1.

Stern, V.H., Schultz, R.J., Shen, L., Gu, Y.J. and Eaton, D.W. (2013): Alberta earthquake catalogue, version 1.0: September 2006 through December 2010; Alberta Energy Regulator, AER/AGS Open File Report 2013-15, 36 p.

Wang, R., Gu, Y. J., Schultz, R., Kim, A. and Atkinson, G. (2016): Source analysis of a potential hydraulic-fracturing-induced earthquake near Fox Creek, Alberta; Geophysical Research Letters, v. 43(2), p. 564–573, doi: 10.1002/2015GL066917.

Wang, R., Gu, Y. J., Schultz, R., Zhang, M. and Kim, A. (2017): Source characteristics and geological implications of the January 2016 induced earthquake swarm near Crooked Lake, Alberta; Geophysical Journal International, v. 210(2), p. 979–988, doi: 10.1093/gji/ggx204.