geoconvention
Calgary • Canada • May 11-13 2026

Fault Connectivity and Pressure Diffusion in Hydraulic Fracturing: Insights into Induced Seismicity and Mitigation Strategies in the Montney Reservoir

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Summary

The injection of pressurized fluid into deep reservoirs during hydraulic fracturing, can result in slip on stimulated faults and the generation of seismic energy. Following on from a previous study in 2022, we further considered this process by looking at how faults may connect to an active well and how pressurised fluid diffuses along this pathway resulting in induced seismicity.

The analysis had two main objectives:

- The characterization, and modelling of the geometry of inferred, reservoir-scale, geological structures and the nature of their connectivity from two adjacent drill pads. This included a novel way of matching the inferred fault geometry using optimising software controlling the stochastic fault modelling software, FracMan.
- Coupled hydro-mechanical numerical simulation of the pressure diffusion process to validate the underlying conceptual model and test a number of potential mitigation strategies.

This study utilised two primary datasets:

- 2022 Data Set–Open Hole Configuration: This dataset includes seven wells with open hole completions, recording 558 induced seismic events with magnitudes between -0.64 and 3.1. The spatial distribution of events reveals a strongly aligned pattern of seismic lineaments with a broadly NE-SW trend.
- 2024 Data Set–Cased Hole Configuration: This dataset includes wells with plug and perf completions drilled approximately 2.5 km to the southeast, recording significant induced seismicity with a maximum magnitude of 3.1. The spatial distribution of events reveals a

strongly aligned pattern of seismic lineaments with a broadly NE-SW trend, very similar the 2022 dataset.

The study provides an analysis of the available datasets, including the spatial distribution of induced seismic events, the length distribution of interpreted induced seismic lineaments, and the distance of events from active wells. The analysis shows that the structural pattern of the Montney reservoir is consistent between the two pads, with a similar pattern of structures being stimulated at this multi-pad scale. In particular, the size distribution of sub-seismic structures were consistent across all of the available data sets including interpreted regional scale seismic structures.

The study utilized DFN models to simulate hydraulic fracture-induced seismicity, using a simple conceptual geomechanical model that result in NE-SW seismogenic structures and NW-SE aseismogenic structures. The DFN models were optimized using the PEST software to find the best match between observed and simulated seismic events. The analysis revealed that longer hydraulic fractures (open hole completions) result in a larger stimulated volume and increased seismic potential compared to shorter fractures (plug and perf completions). This appears to be driven in part by the longer fractures having an increased probability of intersecting other structures and therefore a greater likelihood of pressure diffusion reaching adversely orientated structures, resulting in slip.

Coupled numerical simulations using the 3DEC version 7.0 (Itasca 2025) software were conducted to validate the conceptual geomechanical model and explore potential mitigation strategies. The simulations confirmed that seismic events predominantly occur on NE-SW oriented structures. However, pressure was also observed diffusing along NW-SE structures without the generation of any seismicity. This validated one of the underlying concepts of the stochastic DFN simulations, helping to demonstrate this as a significant mechanism in how induced seismicity is triggered.

Several mitigation strategies were tested within the 3DEC models:

- Lower Injection Rate: Reducing the injection rate to 75% of the base case showed no significant impact on seismicity.
- Slower Ramp Up: Gradually increasing the injection rate, significantly reduced the number of seismic events.
- Hydraulic Fracture Length: Longer fractures resulted in slightly more seismic events.
- Increased Fluid Viscosity: Higher viscosity fluids reduced the number of larger seismic events, focusing seismicity closer to the well.

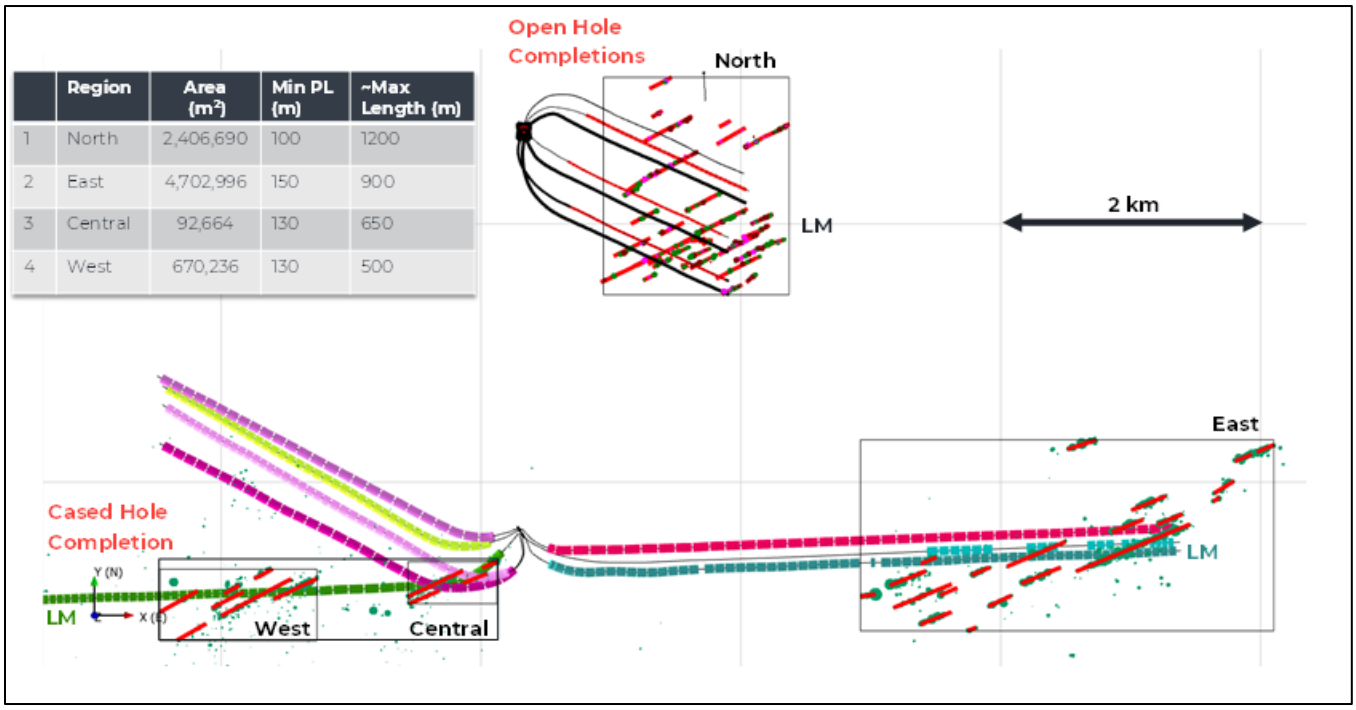
Key conclusions of the study are:

- The structural pattern of reservoir scale structures within the Montney reservoir studied is consistent across the two different pads, despite being several kilometres apart.
- The combination of the PEST-FracMan software provided an effective way to use stochastic structure modelling to simulate induced seismicity and to subsequently select the most geometric likely case from a large catalogue of equi-probable cases.
- Longer hydraulic fractures did increase the seismic potential.
- Slower ramp-up rates and higher viscosity fluids were seen to provide potentially effective mitigation strategies to reduce induced seismicity.

This study provided valuable insights into the relationship between hydraulic fracturing and induced seismicity, offering practical engineering solutions to mitigate seismic risks in hydraulic fracturing operations.

Acknowledgements

We would like to acknowledge financial support from BC Ogris and also support and encouragement from the BC Energy Regulator.



	Region	Area (m²)	Min PL (m)	~Max Length (m)
1	North	2,406,690	100	1200
2	East	4,702,996	150	900
3	Central	92,664	130	650
4	West	670,236	130	500

Figure 1: Interpreted Seismic Lineaments from the 2022 and 2024 Data Sets, also showing the Sub-regions used to Analyse the Data, along with Properties of the Sub-areas Summarised in the Inset Table