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# Subsurface Fluid Flow and Stress Analysis to Understand Seismicity in the Peace River Region, Alberta

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## Summary

This study investigates the relationship between industrial activities and seismicity in the Peace River region of Alberta, focusing on subsurface fluid flow and its impact on stress fields. Through numerical modeling, we aim to explore how decades of industrial activities have influenced pore pressure and stress distribution within geological formations. By integrating scenario-based analyses, this research provides insights into the potential mechanisms of long-term industrial activities and stress fields underlying observed seismicity.

## Introduction

Industrial activities such as oil production and associated saltwater disposal (SWD) can alter subsurface stress states, potentially inducing seismicity (e.g. Zoback, 2007). Induced seismicity may pose economic, environmental and/or public concern risks to local communities and infrastructure (Ellsworth, 2013; Lei et al., 2019; Stroebe et al., 2021). Understanding whether seismic events in industrial regions are natural or anthropogenic is crucial for developing regulatory frameworks and mitigating risks (e.g. Salvage et al., 2024; Verdon et al., 2019).

In the Peace River region, long-term SWD and steam-assisted heavy oil recovery operations have been conducted at various geological depths (Schultz et al., 2023). The region's seismic activity has recently come under high scrutiny, following the ML 5.6 earthquake on November 30, 2022—one of the largest earthquakes recorded in Alberta's history. The Alberta Energy Regulator (AER Alberta Energy Regulator, 2022) determined the main shock to be natural, citing the absence of nearby hydraulic fracturing, stable deep fluid injection rates in the preceding year, and the estimated hypocenter depth of 6 km, which is deeper than the targeted industrial formations (~2 km).

However, studies by Schultz et al. (2023) and Vasyura-Bathke et al. (2023) argue that the main shock and subsequent seismic sequences may be induced by industrial activities. Both studies report high temporal correlations between seismicity and SWD operations. Yet, one outstanding question is the mechanics behind the 10-year time lag between the onset of industrial activities and the occurrence of the main shock.

## Modeling of Pore Pressure Propagation

This study employs numerical modeling to investigate the spatial and temporal evolution of pore pressure within formations impacted by industrial activities in the Peace River region. A 3D finite element model was developed using data from the Geological Atlas of the Western Canada Sedimentary Basin (Mossop, G.D. and Shetsen, I., comp., 1994), Eaton et al. (1999), Weides et al. (2014), and the 3D representation of the subsurface by Alberta Geological Survey (2021). Known faults were explicitly mapped and incorporated, while potential unmapped faults in unexplored areas were considered to account for uncertainties in geological structures. This modeling approach focuses on how pore pressure propagates through faults and its implications for effective stress.

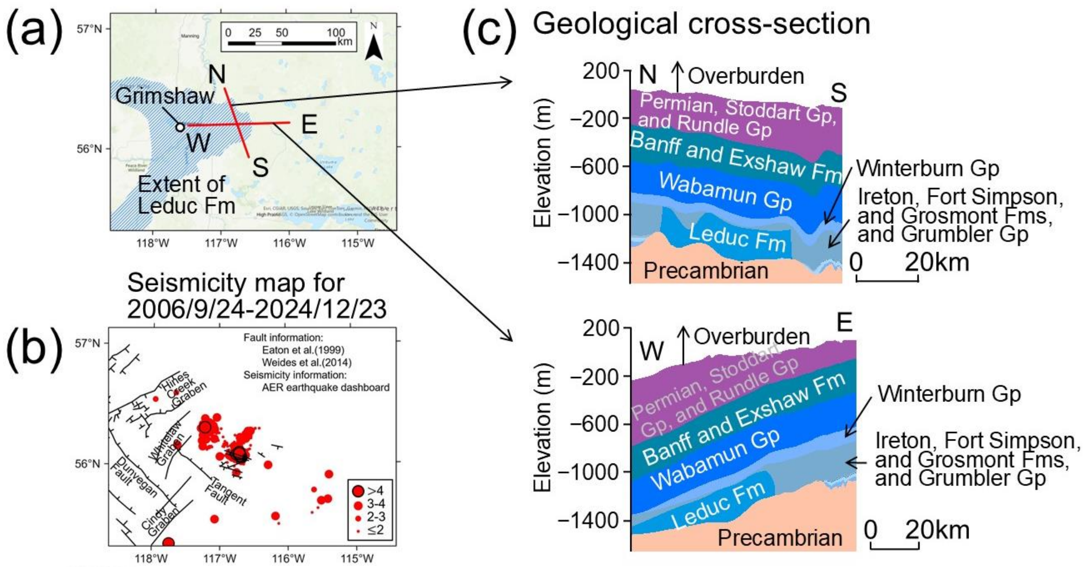


Figure 1: (a) Map of study area with an extent of Leduc Formation. (b) Map of seismicity with known faults. Seismicity data source is AER earthquake dashboard; Faults from Eaton et al. (1999) and Weides et al. (2014). (c) Geological cross-section based on the 3D representation of the subsurface by Alberta Geological Survey (2021).

## Scenario Analysis

Scenario-based analyses were conducted to evaluate the impact of various geological and industrial configurations on subsurface stress states. These scenarios include:

1. Baseline Scenario: A scenario that does not include any faulting is used as a reference for comparing the effects of faults on the stress field.
2. Injection Wells Excluded: The contribution of specific injection wells on a stress field is evaluated by comparing it with a scenario where the target well is excluded.
3. Unexplored Fault Scenarios: Hypothetical scenarios consider the presence of potential unmapped faults in unexplored regions and their influence on stress and pore pressure propagation.

These scenarios were compared to identify critical factors contributing to seismic risk, focusing on how changes in pore pressure influence the Coulomb Failure Criterion (CFC) and fault stability.

## Future Work

While the results of this study offer preliminary insights, the study remains a conceptual model because of the various limitations. Future work aims to refine the modeling framework by integrating advanced coupling methods, including thermo-poroelasticity and two-phase flow. Incorporating long-term pore pressure monitoring data will be crucial for calibrating and validating the model, though the availability of such data remains uncertain. Additionally, expanding the model to consider hydraulic and mechanical influences from distant wells will enhance understanding of regional-scale impacts. By addressing these aspects, we aim to deepen insights into subsurface fluid flow, stress changes, and their connection to seismicity, ultimately supporting the development of effective seismic risk management strategies in industrial regions.

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