

Integrating Geomechanical Analysis and Risk Management for Sustainable Geothermal Energy Extraction at the Alberta No1 Geothermal Project

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Summary

The Alberta No.1 Geothermal Project (ABNo1) in Canada aims to harness deep geothermal energy for power generation, facing challenges related to induced seismicity. The concern for ABNo1 is the fact that induced seismicity in Alberta displays some of the largest magnitudes reported globally, including those of events near Fox Creek and Musreau Lake around 200 km south and southeast of the project site. Therefore, at the beginning of this type of project in Alberta, it is important for companies or regulators to identify problematic or risky faults in advance of the project to avoid induced seismicity (Figure 1). Integrating geomechanical analysis and risk management, this research evaluates the potential for induced seismicity and proposes mitigation strategies, the Traffic Light Protocol (TLP). Geomechanical analysis of target formations informs probabilistic fault stability maps, offering a foundation for future fluid injection projects, including geothermal energy extraction. Additionally, a risk-informed approach recommends implementing the TLP with a red-light threshold of M_L 3.5 for ABNo1. By combining geomechanical assessments with proactive risk mitigation strategies, stakeholders can enhance the safety and sustainability of geothermal energy extraction, contributing to the transition towards renewable energy sources.

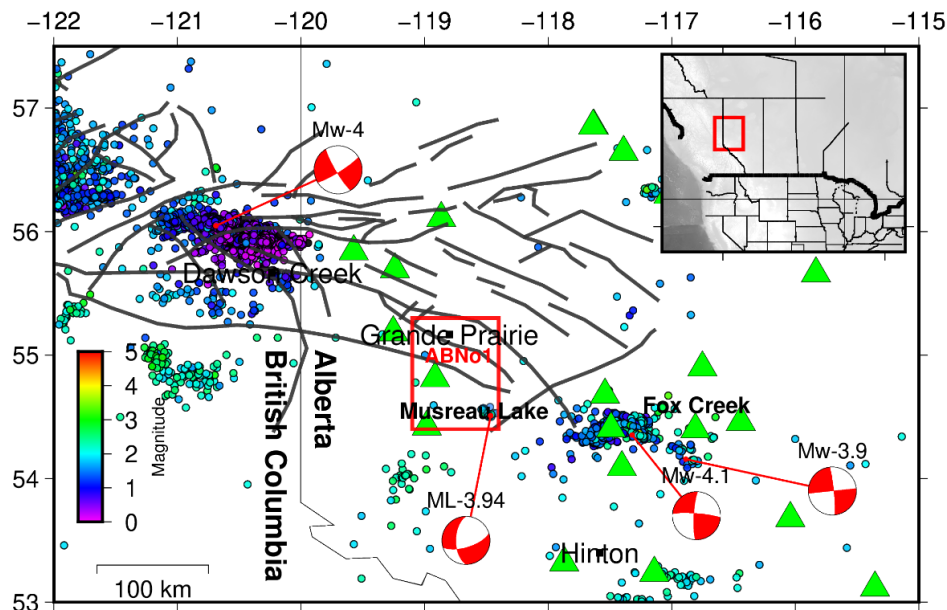


Figure 1: The Alberta No.1 Geothermal Project study area is shown in the red box. Colored circles indicate earthquakes reported in the area. Focal mechanisms are the major induced earthquakes recorded in the area.

Theory / Method / Workflow

The study begins by reviewing the geomechanical properties of the Grande Prairie region, focusing on the Leduc and Granite Wash Formations identified as potential geothermal fluid zones. Through the review of available borehole data and well tests pertaining to geomechanics, a comprehensive geomechanical model of the Leduc and Granite Wash Formations is constructed. This model includes an assessment of intrinsic parameters such as stress tensors, pore pressure, and pre-existing fault orientations and dip, while also addressing associated uncertainties. The analysis identifies a predominant strike-slip regime (with $A_{\phi} \approx 1.2$ to 1.5) and a S_{Hmax} orientation of $45^{\circ} \pm 15$ as the primary stress state in the area. However, due to the lack of direct data from the target formations, uncertainties persist in determining subsurface properties. To account for these uncertainties, a probabilistic approach is adopted. This entails a thorough analysis of the uncertainties associated with each input variable, including stress magnitudes, fault dip directions, and friction coefficients, through Monte Carlo simulations conducted for each fault segment. Using the Mohr-Coulomb Fault theory, this assessment aims to evaluate the probability of fault slippage induced by the elevation of formation pressure resulting from fluid injection activities (Yaghoubi *et al.*, 2022).

While the probability of injection-induced seismicity may be low, the risk of induced earthquakes must consider potential consequences, particularly around the ABNo1 site, inhabited by 82,000 people. Implementing comprehensive risk mitigation measures like the Traffic Light Protocol is crucial for safety. This prompts questions about the maximum earthquake magnitude thresholds, considering significant consequences beyond.

We apply the risk-based framework approach, to quantify the potential damage, nuisance, and LPR impacts caused by injection-induced seismicity and determine the red-light magnitude thresholds. Three key risk metrics are assessed: LPR, damage risk, and nuisance risk. LPR assesses the chance of fatal building collapse during induced seismic events, crucial for community safety. Nuisance risk involves discomfort from ground shaking, impacting society and the economy. Reducing nuisances secures public support for geothermal or injection projects, while damage risk correlates with economic losses, safeguarding infrastructure and property values (Yaghoubi *et al.*, 2023).

Our analysis to determine the red-light threshold incorporated various datasets to capture the complexity of the problem. These datasets included spatial distributions of population, earthquake ground motion prediction equations (GMPEs), information on the location, depth, size, and frequency of induced seismic events, site amplification factors, nuisance and fragility functions, and geological characteristics. Each of these parameters contributes to the quantification of risks associated with injection-induced seismicity despite being characterized by inherent uncertainties. To account for the uncertainties and variability in input parameters, we conducted a Monte Carlo simulation with 3,000 trials. A comprehensive assessment of potential risks can be achieved by considering various factors including relevant parameters along with their associated uncertainty levels (Yaghoubi *et al.*, 2023).

Results and Conclusions

The probabilistic analysis indicates a low probability of fault slip in response to fluid injection, suggesting a relatively low risk of induced seismicity at the ABNo1 project area (Figure 1). This is consistent with the low rate of injection-induced seismicity in the study region. Despite extensive hydraulic fracturing operations in the region, Grande Prairie has experienced minimal induced seismic activity, contrasting with seismically active areas like Fox Creek and Musreau Lake. The

study attributes this difference to variations in pore pressure gradients and fault characteristics between formations (Yaghoubi *et al.*, 2022).

Even if the probability of injection-induced seismicity evaluated becomes low, it does not necessarily translate to low risk, especially considering the potential consequences of an induced earthquake occurring around the project site. First, geomechanics analyses are based on the "mapped faults" in the region; there may be unrecognized critically stressed faults prone to injection-triggered slip. Second, the probabilistic fault slip analysis neglected to account for the gradual impact of thermally induced stresses, poroelastic effects, and changes in properties that might arise during long-term injection and production activity; these will contribute to stress changes and will affect the probability of triggering of earthquakes over time. In addition, earthquake impacts are dominated by the largest event in a sequence: low-probability events cause disproportionately large consequences. To address the associated risk of unexpected large earthquakes and their consequences, we must assess the likelihood and potential consequences of seismic events and implement appropriate mitigation measures, such as establishing a TLP (Yaghoubi *et al.*, 2022).

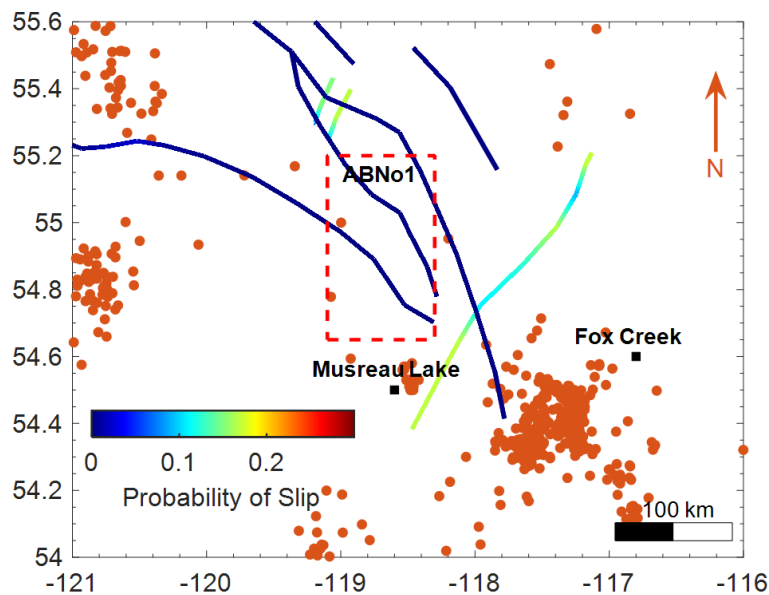


Figure 2: Fault slip intensity map in the vicinity of the project area color-coded according to the probability of slip (Yaghoubi *et al.*, 2022).

We adopt a risk-informed approach to estimating red-light thresholds for induced seismicity around the ABNo1 project site. Utilizing detailed methodology and analysis, the study evaluates spatial variations in nuisance, damage, and local personal risk (LPR) associated with injection-induced seismicity. Figure 3a displays the risk curve at the geothermal ABNo1 project site, with red-light thresholds for different risk metrics. An M_L of 3.55 represents the red-light threshold for nuisance risks, indicating the level of ground shaking causing disturbance. The LPR threshold is M_L 4, posing a risk of building collapse death. The damage risk threshold is M_L 4.1, indicating potential economic consequences like building damage and repair costs. Figure 3b shows the integrated TLP map combining iso-LPR, iso-nuisance, and iso-damage maps. At the ABNo1 site,

the examination of the three risks and their combination reveals a red-light threshold ranging from 3.5 to 3.66 (Yaghoubi *et al.*, 2023).

The combined findings of these studies contribute to the field of geothermal energy development by providing a comprehensive assessment of the potential for induced seismicity at the ABNo1 geothermal project site and proposing a novel, integrated TLP approach for managing these risks. Employing an iso-risk approach, the study determines red-light thresholds tailored to specific risk tolerances across the study area. The methodologies and insights from these studies offer valuable guidance for the development of effective risk management strategies in the ABNo1 project, emphasizing the importance of comprehensive and conservative approaches to ensure the safety and well-being of residents in the vicinity of such projects.

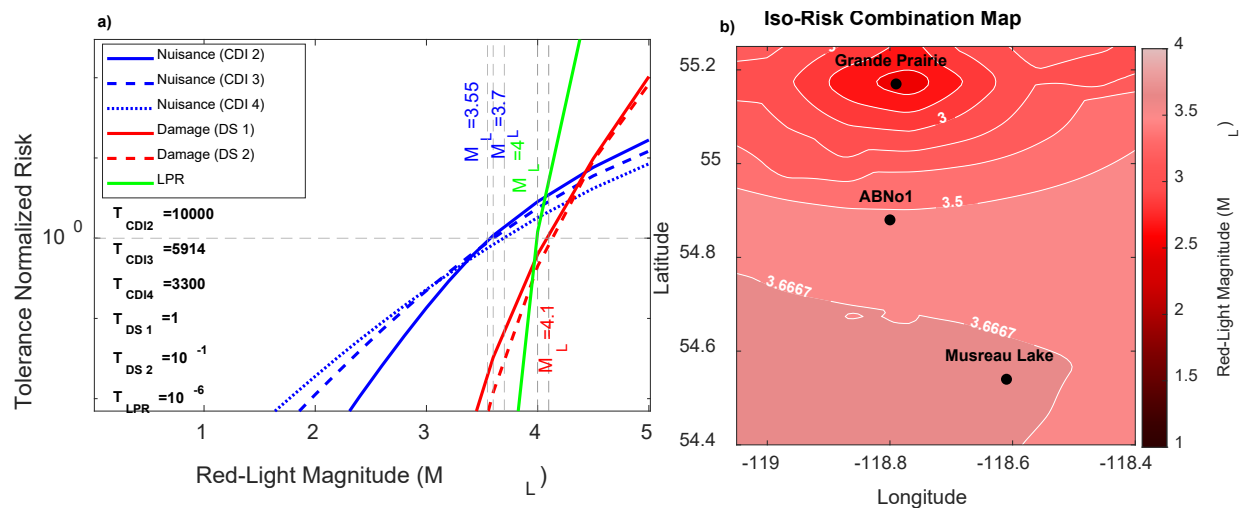


Figure 3: Red-light thresholds for ABNo1 geothermal site. All risk curves are standardized based on their tolerances. The $M_L=3.55$ and $M_L=3.7$ represents the nuisance red-light magnitude, $M_L=4$ indicates the LPR threshold, and $M_L=4.1$ depicts the damage risk threshold.

References

- Yaghoubi, A., Hickson, C.J., Leonenko, Y. and Dusseault, M.B., 2022. Probabilistic assessment of induced seismicity at the Alberta No. 1 geothermal project site. *Canadian Journal of Earth Sciences*.
- Yaghoubi, A., Schultz, R., Hickson, C.J., Wigston, A. and Dusseault, M.B., 2023. Induced Seismicity Traffic Light Protocol at the Alberta No. 1 Geothermal Project Site. Unpublished Work