

Building the Geothermal Atlas of Alberta to Explore Geothermal Resource Potential

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Summary

Geothermal energy in the Alberta portion of the Western Canada Sedimentary Basin (WCSB) remains largely untapped despite its potential. The basin, known for its vast hydrocarbon resources, also features subsurface geological conditions conducive to hosting geothermal energy resources. Recent efforts by the Alberta Geological Survey (AGS) focus on identifying and characterizing geothermal reservoirs at the formation scale. The study includes creating new geothermal favourability maps for several geological units using updated data and geostatistical modelling techniques. A key outcome of this work is the development of a comprehensive Geothermal Atlas of Alberta, which features relevant geoscience data and information, including geothermal favourability maps and estimates of heat-in-place and power generation capacity. The Geothermal Atlas of Alberta was created and is shared using Esri's ArcGIS online software. Using data-driven mapping approaches, the platform interacts with a rich repository of geological data and offers users interactive access to geothermal energy related spatial data. It facilitates the identification of potential areas for geothermal exploration, assists in selecting the most favourable subsurface targets and provides tools for cartographic visualization and data analysis.

Background

Sedimentary basins are promising for geothermal energy development due to their widespread availability, combined with significant thermal energy content (albeit mostly low enthalpy), presence of fluids, high natural transmissivity at moderate depths, and proximity to users (Birdsell et al., 2024). However, electricity generation is relatively new in low-enthalpy sedimentary basins compared to more extensively studied high-enthalpy systems that employ binary cycle energy conversion technologies, e.g., Organic Rankine cycle or Kalina cycle (Agemar et al., 2014). The Molasse Basin in southern Germany and the WCSB are being actively explored for this purpose (Agemar et al., 2014; Banks and Harris, 2018; Moeck et al., 2020; Rabbani et al., 2022).

The WCSB, a foreland basin bordered by the Rocky Mountains to the west and the Precambrian Canadian Shield to the north and east, has undergone significant geological evolution. This geological history resulted in diverse lithologies and notable variations in geothermal gradients, influencing the basin's geothermal potential (Bachu and Burwash, 1994). These gradients, alongside regional heat flow values, are critical in understanding the geothermal characteristics and resource potential within different parts of the WCSB (Harris, 2023). The geothermal potential in the basin has been continuously explored, with studies indicating promising prospects in various formations (e.g., Jessop, 2008; Majorowicz and Grasby, 2010). Majorowicz and Grasby (2021) evaluated the WCSB for geothermal energy potential in a more recent regional assessment, focusing on electrical power generation and district heating. In the Alberta portion of the WCSB, Ardakani and Schmitt (2016) identified five significant aquifers in the Athabasca region suitable for low-enthalpy geothermal energy development. Banks and Harris (2018) studied

geothermal reservoirs in northwestern and west-central Alberta for commercial exploitation. Weides and Majorowicz (2014) conducted 3D structural geological modelling in northwestern Alberta, focusing on several formations. Additionally, Weides et al. (2013) and Hofmann et al. (2014) contributed significantly to understanding Paleozoic formations and enhanced geothermal systems in central Alberta. Collectively, these studies highlight Alberta's rich geothermal energy potential.

While several regional studies have explored the geothermal potential of the WCSB, a more comprehensive, formation-scale assessment focusing on key reservoirs and aquifers in the Alberta Basin is still outstanding. Over the last three years, the Alberta Geological Survey (AGS), a branch of the Alberta Energy Regulator (AER), has been crafting an integrated approach to delineate geothermal resources, focusing on the identification of deep aquifers (> 1000 m) with geothermal potential.

Workflow

Our methodology utilizes a combination of core analyses, well logs, and drillstem test data to identify aquifers that can support geothermal energy extraction. We leverage various datasets while adopting a technique similar to that of Palmer-Wilson et al. (2018). This involves a geographic information system (GIS) overlay analysis using regional temperature data (Brinsky et al., 2022) and geological parameters to supplement data layers for temperature, porosity, and aquifer indication. These layers were then reclassified and weighted according to their importance to generate formation-scale favourability maps for individual geological units of interest for geothermal exploration and development, such as the Leduc Formation, the combined Swan Hills and Slave Point formations, the Granite Wash, the Gilwood Member, and the Basal Cambrian Sandstone. This systematic, multicriteria GIS process categorizes geothermal potential into four distinct classes (i.e., low, medium, high, very high).

Following geothermal favourability mapping, we utilized the USGS volumetric method to estimate the total thermal energy of key aquifers. This method considers temperature, reservoir volume, and rock/fluid properties (Williams et al., 2008). A stochastic Monte Carlo sampling approach is used to manage uncertainties for input parameters, providing an early-stage exploration estimate of potential resources. The spatial resolution (smallest areal size) used is the Legal Subdivision (LSD) of approximately 400 by 400 m. Additionally, a well-based approach was employed to capture changes in reservoir parameters. Subsequently, we calculated the potential for gross thermal and electrical power generation using methods that factor in exergy, electrical efficiency, and brine flow rates. For specific units, we also incorporated flow rate based methods, using data from drillstem tests (DST) and injection/production reports, to estimate gross thermal and electrical power. This comprehensive cross-validation approach allows for a detailed assessment of the basin's geothermal energy generation potential.

The final data and information products created as part of the geothermal favourability mapping and resource quantification analysis are then hosted in a purpose-built, web-based, interactive GIS application, the Geothermal Atlas of Alberta, designed to provide users easy access to a comprehensive collection of geoscience data and knowledge relevant for geothermal resource characterization, quantification, and development in Alberta.

Results

Our study has successfully developed formation-scale geothermal favourability maps for target geological units such as Leduc, Swan Hills / Slave Point, Granite Wash, and Gilwood. Using GIS multi-criteria methodology, this novel approach classifies regions into four geothermal favourability levels, from low to very high. Figure 1 illustrates the geothermal favourability mapping results for the Leduc Formation in west-central Alberta, displaying data layers for temperature, porosity-thickness, and aquifer indication. These layers are crucial in informing the geothermal favourability map, highlighting areas with significant geothermal potential within the formation. This visual representation aids in understanding the subsurface characteristics to identify promising areas for geothermal exploration and development.

The Geothermal Atlas interface includes a main landing page with provincial-focused geological and geothermal data layers, related information and formation-specific pages. The map layers are categorized into specific themes that host thematic information. For example, the 'Geothermal Favourability Maps' theme hosts the favourability mapping input parameter layers and different favourability maps based on specific weight criteria. Other themes include Base Map Layers, Geology and Structure, Resource Quantification, Hydrogeology and Geochemistry, and Other Relevant Information. Figure 2 is a detailed view of the geothermal resource quantification layer for the Leduc Formation with a summary statistics table showing the results of the heat-in-place and power generation capacity calculations for a user-specified area.

Novel Information

While previous studies on Alberta's geothermal potential primarily focused on qualitative and quantitative assessments, often on specific locations of interest or relying on geothermal gradients, our approach delivers a more comprehensive, multi-criteria evaluation at the formation-scale. We utilize core analyses, well logs, and drillstem tests for a detailed assessment of porosity, aquifer presence, and temperature. This methodology, adapted from practices in other regions, aims to produce formation-scale favourability maps and can be applied to diverse geological formations in Alberta. The forthcoming interactive Geothermal Atlas of Alberta is intended to serve as a centralized public resource, hosting relevant data and findings, and support effective strategies for developing geothermal energy in the province.

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References

- Agemar, T., Weber, J., and Schulz, R., 2014. Deep geothermal energy production in Germany. *Energies* 7, 4397–4416.
- Bachu, S. and Burwash, R., 1994. Geothermal regime in the Western Canada Sedimentary Basin. In *Geological Atlas of the Western Canada Sedimentary Basin*. Edited by G. Mossop and I. Shetsen. Canadian Society of Petroleum Geologists and Alberta Research Council, Special Report 4, 447–454.
- Banks, J. and Harris, N.B., 2018. Geothermal potential of foreland basins: A case study from the Western Canadian Sedimentary Basin. *Geothermics* 76, 74–92.
- Birdsell, D. T., Adams, B.M., Deb, P., Ogland-Hand, J.D., Bielicki, J.M., Fleming, M.R., and Saar, M.O., 2024. Analytical solutions to evaluate the geothermal energy generation potential from sedimentary-basin reservoirs. *Geothermics*, 116, 102843.
- Brinsky, J., Singh, A., Hauck, T.E., Grobe, M., and Palombi, D., 2022. Temperature mapping of select Devonian strata in Alberta. Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Open File Report 2021-05, 28 p.
- Harris, N.B., 2023. Critical problems in the development of basin-hosted geothermal resources—considerations from the Western Canada Sedimentary Basin. *PROCEEDINGS, 48th Workshop on Geothermal Reservoir Engineering*.
- Hofmann, H., Weides, S., Babadagli, T., Zimmermann, G., Moeck, I., Majorowicz, J., and Unsworth, M., 2014. Potential for enhanced geothermal systems in Alberta, Canada. *Energy*, 69, 578– 591.
- Jessop, A.M., 2008. Review of National Geothermal Energy Program Phase 1 – Geothermal Potential of Sedimentary Basins. Geological Survey of Canada, Open File Report 5690.
- Majorowicz, J.A. and Grasby, S.E., 2010. High potential regions for enhanced geothermal systems in Canada. *Natural Resources Research* 19, 177–188.
- Majorowicz, J. and Grasby, S. E., 2021. Deep geothermal heating potential for the communities of the Western Canadian Sedimentary Basin. *Energies*, 14(3), 706.
- Moeck, I., Dussel, M., Weber, J., Schintgen, T., and Wolfgramm, M., 2019. Geothermal play typing in Germany, case study Molasse Basin: A modern concept to categorise geothermal resources related to crustal permeability. *Netherlands Journal of Geosciences*, 98, E14.
- Palmer-Wilson, K., Banks, J., Walsh, W., and Robertson, B., 2018. Sedimentary basin geothermal favourability mapping and power generation assessments. *Renewable Energy*, 127, 1087–1100.
- Rabbani, A., Banks, J., Brinsky, J., and Palombi, D., 2022. Multivariate and geochemical analyses of brines in Devonian strata of the Western Canada Sedimentary Basin for geothermal energy development. *Geothermics*, 105, 102498.
- Weides, S., Moeck, I., Majorowicz, J., Palombi, D., and Grobe, M., 2013. Geothermal exploration of Paleozoic formations in Central Alberta. *Canadian Journal of Earth Sciences*, 50(5), 519 –534.
- Weides S. and Majorowicz, J. A., 2014. Implications of spatial variability in heat flow for geothermal resource evaluation in large foreland basins: the case of the Western Canada Sedimentary Basin. *Energies* 7, 2573–2594.
- Williams, C.F., Reed, M.J., and Mariner, R.H., 2008. A review of methods applied by the US Geological Survey in the assessment of identified geothermal resources. US Geological Survey Open-File Report 2008-1296, 27 p.

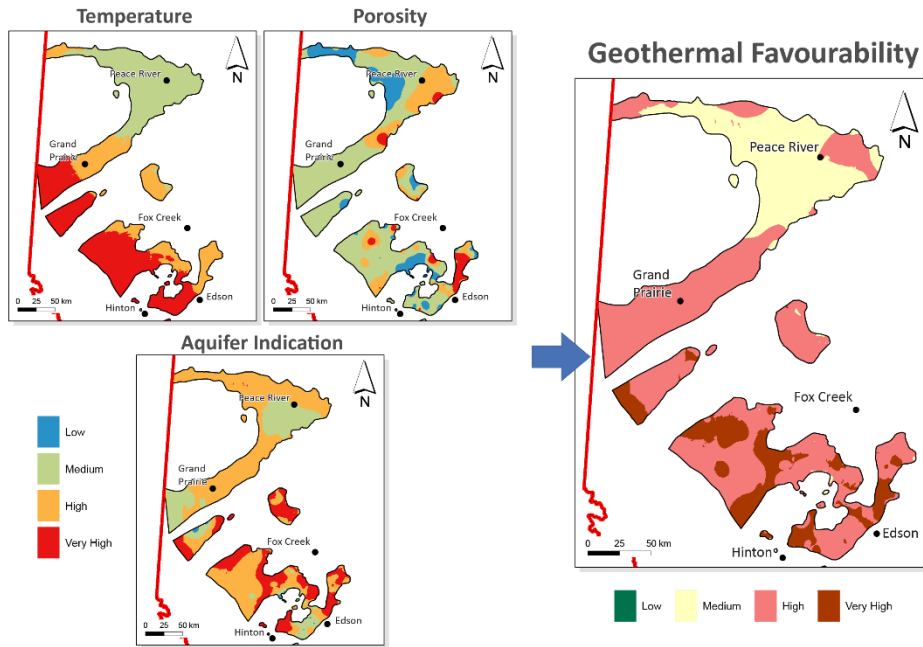


Figure 1. Geothermal favourability mapping of the Leduc Formation in west-central Alberta. Our approach combines spatial analysis and a GIS multi-criteria approach, using temperature, porosity, and aquifer indication data to identify areas with geothermal potential. Individual data layers are shown on the left and the resultant geothermal favourability map is shown on the right.

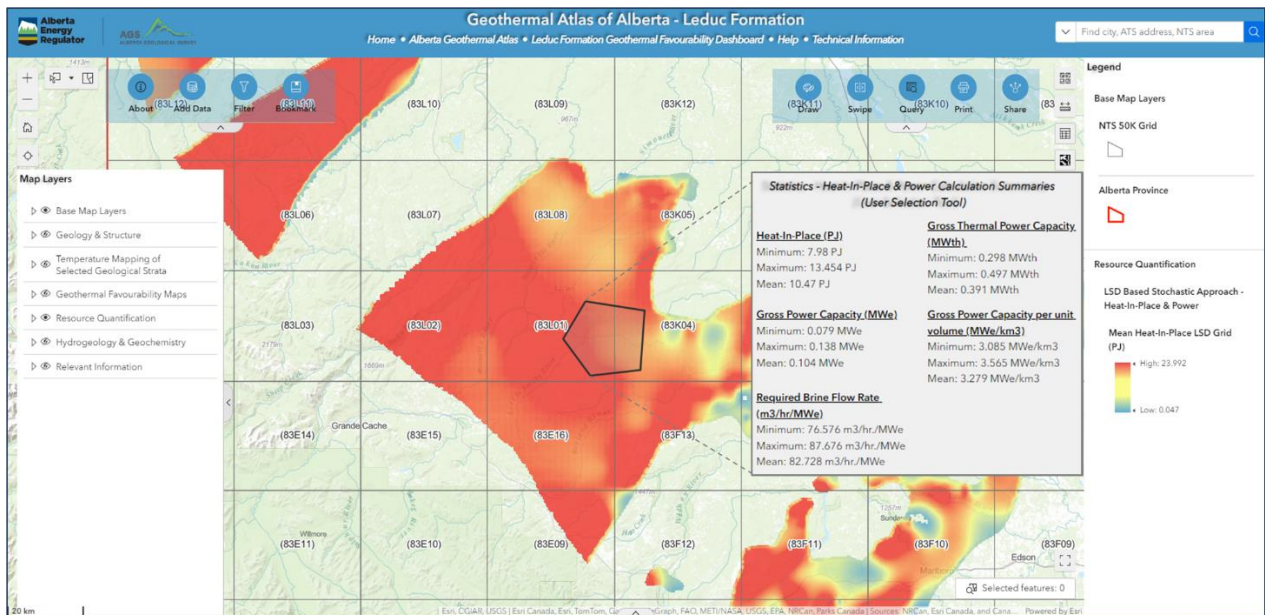


Figure 2. Detailed view of the resource quantification layer for the Leduc Formation in the Geothermal Atlas of Alberta showcasing geothermal resource summary statistics with colour-coded heat-in-place (HIP) values using a volumetric stochastic method for a user-specified area.