The Geothermal Atlas of Alberta

Nevenka Nakevska, Arif Rabbani, Alex Onojeghuo, Hugo Geng, Matthias Grobe, Dan Palombi

Alberta Geological Survey / Alberta Energy Regulator, Edmonton, Canada; Contact: ***nevenka.nakevska@aer.ca***

Overview

Background

- Geothermal energy in the Alberta portion of the Western Canada Sedimentary Basin (WCSB) remains largely untapped despite its potential (Figure 1).
- Geothermal gradient in the Alberta Basin ranges from 23 to 50 °C/km, with an average value of 33.2 °C/km.
- The highest temperatures are found in the deepest parts of the basin, reaching values above 180°C at depths of >6 km.

Objectives

- Develop a methodology for formation-scale geothermal favourability mapping.
- Evaluate geothermal resource potential at the formation scale.
- Build the Geothermal Atlas of Alberta.
- Apply the formation-scale geothermal favourability mapping methodology to three Devonian geological units: the Granite Wash, Leduc and combined Swan Hills and Slave Point formations.

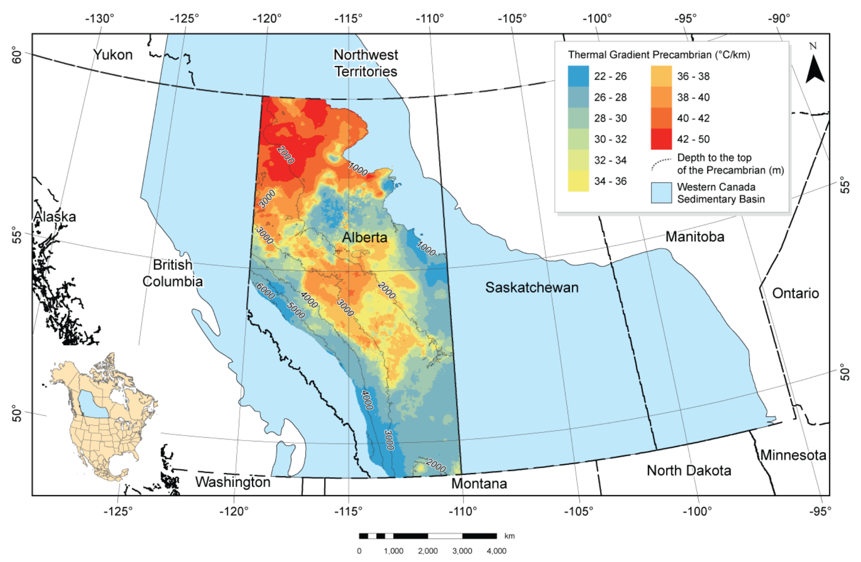

Figure 1. Geothermal gradient distribution in the Alberta portion of the WCSB. Modified from Wright et al. (1994) and Brinsky et al. (2021).

Geothermal Favourability Mapping Methodology

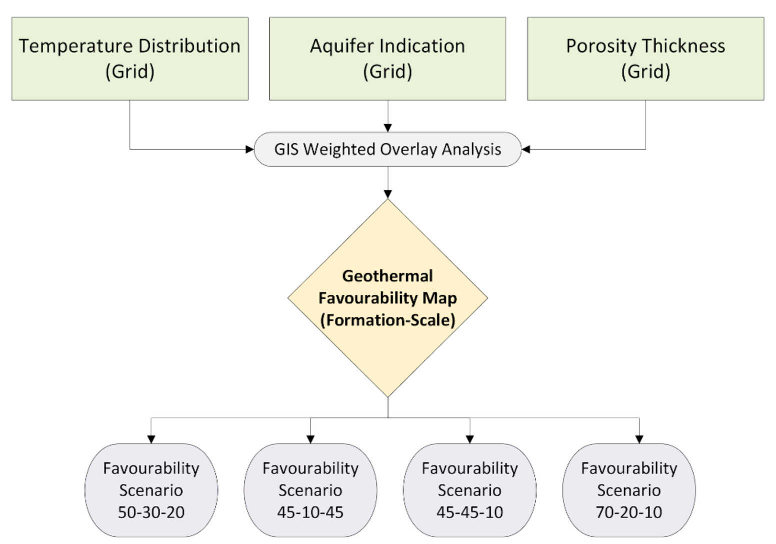

Figure 2. Workflow for geothermal favourability analysis.

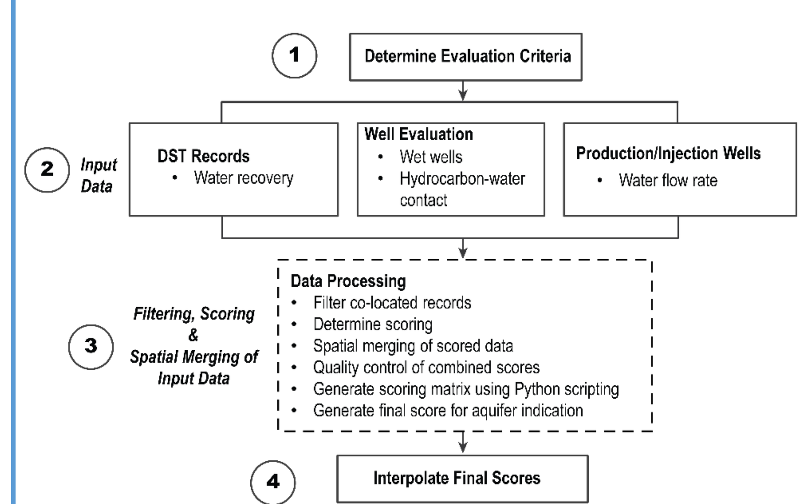

Figure 3. Workflow for creating the aquifer indication layer.

- Created three spatial data layers (grids): temperature, aquifer indication, and porosity thickness (PHI*H) (Figure 2).
- Obtained gridded subsurface temperature data for selected geological units from Alberta's 3D temperature model (Brinsky et al., 2021).
- Evaluated drillstem test water recovery, hydrocarbon-water contact, and water production data to generate aquifer indication grids (Figure 3).
- Estimated pore volume from well logs using petrophysical porosity cutoffs and calibration with core data to generate porosity thickness grids (Figure 4).
- Evaluated data to define favourable ranges for temperature, aquifer indication, and porosity-thickness and assigned scores to each range.
- Classified spatial data into four favourability classes and integrated layers using GIS weighted overlay analysis (Figure 5).
- Conducted sensitivity analysis for weighting scenarios and produced geothermal favourability maps for selected geological unit (Figures 7-10).

Results

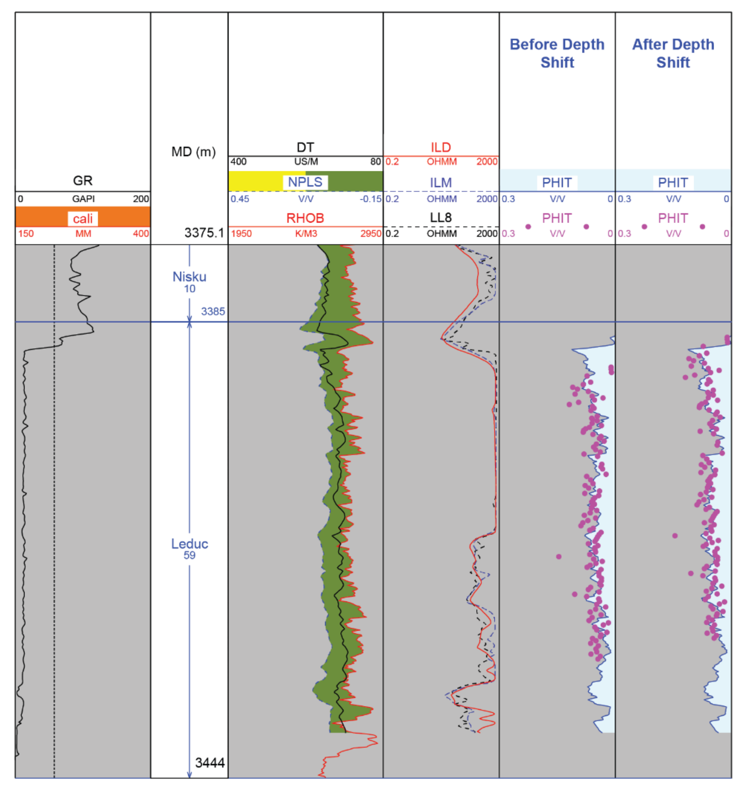

Figure 4. Example of core-log depth correlation in the Leduc Formation.

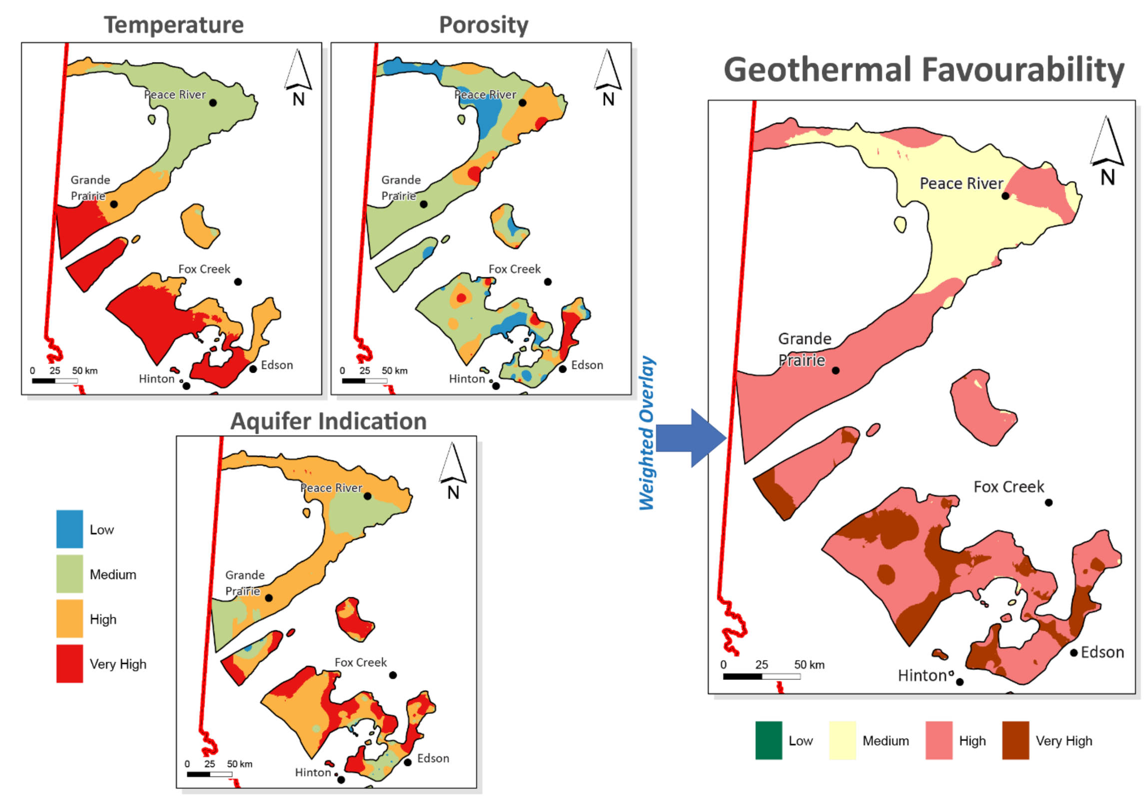

Figure 5. Geothermal favourability map of the Leduc Formation in west-central Alberta, weighted 50% temperature, 30% aquifer indication, and 20% porosity thickness.

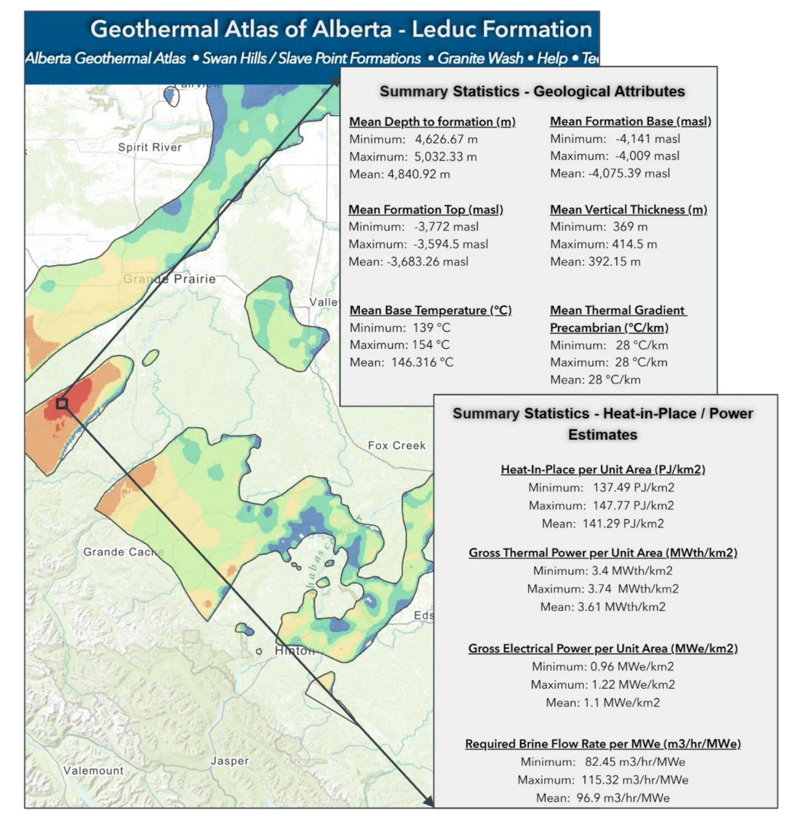

Figure 6. Geothermal Atlas application displaying user-selected area in the Leduc Formation with geological and geothermal summaries.

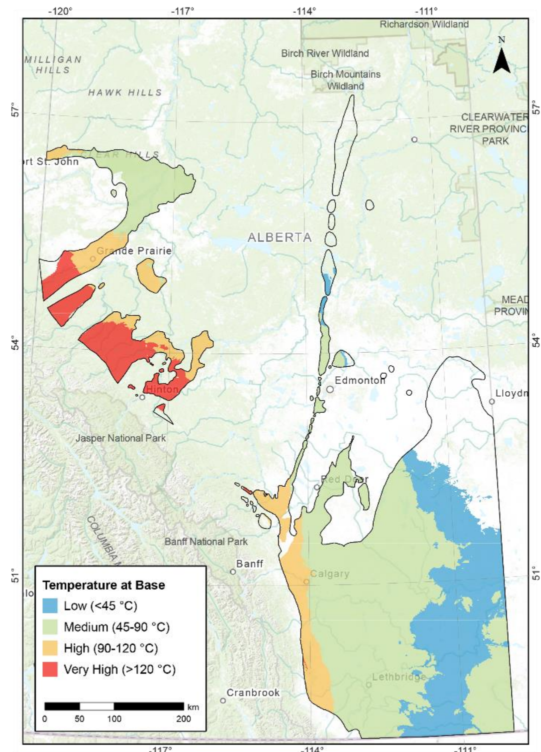

Figure 7. Subsurface temperature distribution at the base of the Leduc Formation derived from Alberta's 3D temperature model.

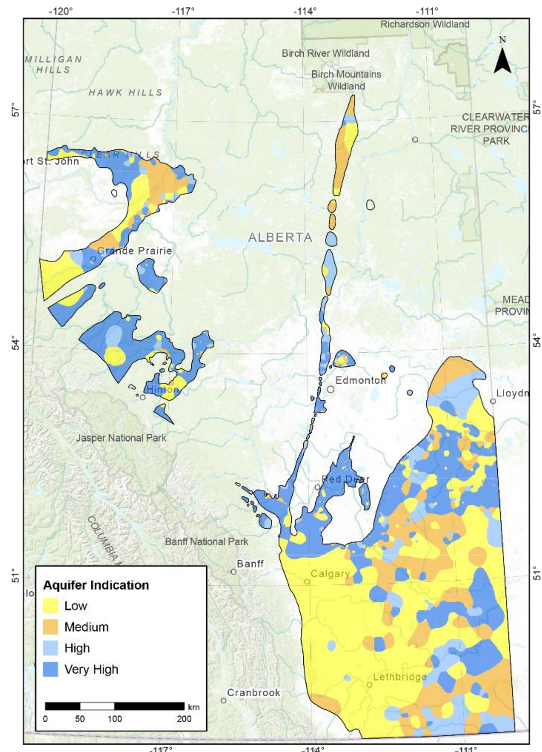

Figure 8. Spatial distribution of aquifer characteristics in the Leduc Formation based on drillstem tests, water production, and hydrocarbon-water contact data.

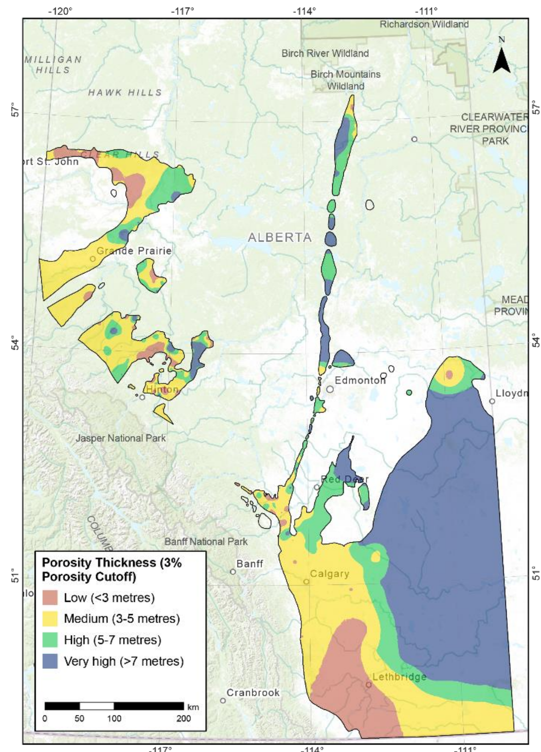

Figure 9. Porosity-thickness (PHI*H) distribution in the Leduc Formation estimated from well-log data.

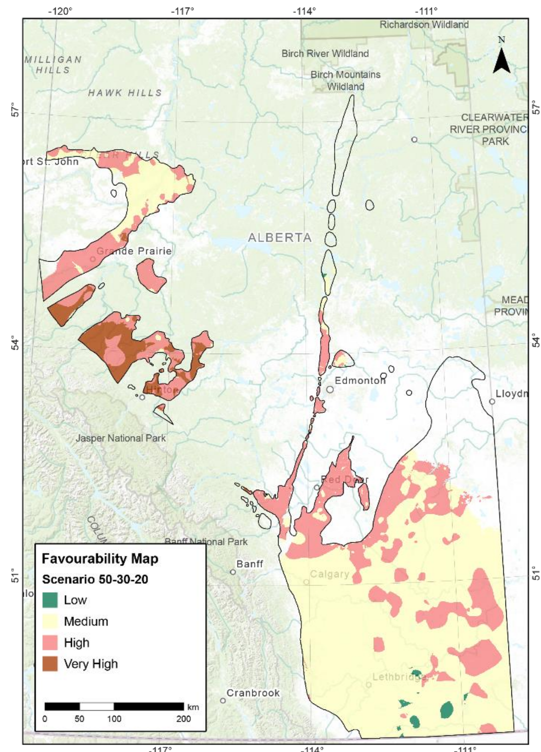

Figure 10. Formation-scale geothermal favourability map of the Leduc Formation integrating temperature, aquifer indication, and porosity-thickness grids.

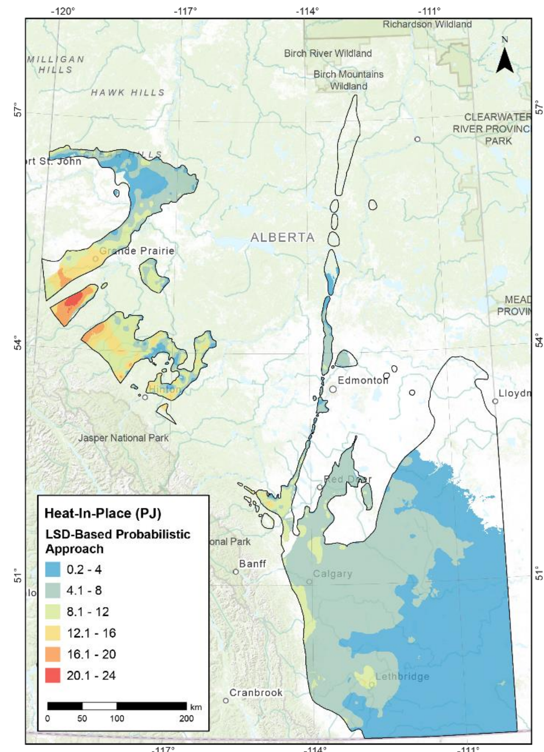

Figure 11. Estimated heat-in-place for the Leduc Formation calculated using the USGS volumetric method.

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Resource Quantification Methodologies

- Applied USGS volumetric heat-in-place resource estimation method (Williams et al., 2008) to estimate gross thermal energy (PJ), thermal power potential (MWth), and electrical power potential (MWe).

Quantification Approaches

Well-based Deterministic Method:

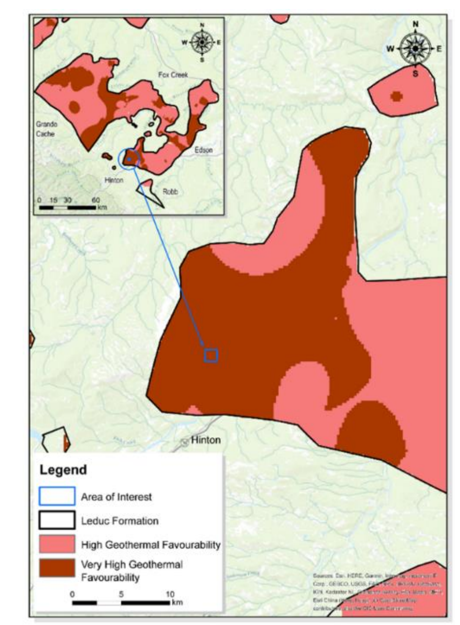
$$\frac{Q_{th}}{area} = \int_{Formation\_Base}^{Formation\_Top} [V_{sh}(\mathrm{h}) \cdot \rho_{sh} C_{sh} + V_{Dol}(\mathrm{h}) \cdot \rho_{Dol} C_{Dol} + V_{Cal}(\mathrm{h}) \cdot \rho_{Cal} C_{Cal} + \emptyset(\mathrm{h}) \cdot \rho_F C_F] \cdot (Temp(\mathrm{h}) - T_0)\mathrm{dh}$$

- Estimates heat-in-place and power potential from well logs by converting the USGS heat-in-place equation to 1D format.
- Executes calculations at each logging depth with inputs from porosity, temperature, and mineralogy logs, capturing variations of reservoir parameters along the well path and integrating these inputs to provide energy and power estimates per unit area.

LSD-based Probabilistic Method:

$$HIP, Q_{th} = [(1-\emptyset)(\rho_R C_R) + \emptyset(\rho_F C_F)] \cdot A_R \cdot H \cdot (T_R - T_0)$$

- Utilizes Monte Carlo simulation to model variability for input parameters.
- Simulations run in Python, performing 1,000 iterations per data entry for different geological locations.
- Input parameters include temperature, porosity, thickness, volumetric heat capacity, recovery factor, and utilization factor.
- Figures 11 and 12 provide an example map showing distribution of heat-in-place and an example resource estimation for the Leduc Formation.



Parameter	Probabilistic (LSD-based)	Deterministic (Well-based)
Heat-in-place (PJ)	117.39 ± 4.37	119.33
Heat-in-place at the wellhead (PJ)	11.74 ± 0.44	11.93
Gross thermal power potential (MW_{th})	3.01 ± 0.61	2.73
Gross power potential (MW_e)	0.93 ± 0.19	0.76
Gross power potential per unit area (MW_e/km^2)	0.64	0.52
Required brine flow rate ($m^3/hr/MW_e$)	94.0	117.22

Figure 12. Geothermal resource estimation for an example area of interest in the Leduc Formation in west-central Alberta.

Summary

Our study developed formation-scale geothermal favourability maps for one siliciclastic and two carbonate Devonian units in the Alberta Basin. We used a GIS multi-criteria methodology (modified after Palmer-Wilson et al., 2018) to delineate regions into four favourability classes based on porosity, aquifer indication, and temperature. This approach, underpins the evaluation of regional geothermal energy potential, estimating gross thermal energy, thermal power, and electrical power for the three geological units. These outputs (Figure 6) are integrated into the Geothermal Atlas of Alberta, a public, web-based GIS platform. Version 1.0 includes the results of geological characterization and geothermal evaluation of the Devonian Leduc Formation, the combined Swan Hills and Slave Point formations, and the Granite Wash, offering geoscience data, favourability maps, and tools for location-specific queries, with plans for future expansion.

References

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.

Palmer-Wilson, K., Banks, J., Walsh, W. and Robertson, B. (2018): Sedimentary basin geothermal favourability mapping and power generation assessments; Renewable Energy, v. 127, p. 1087–1100.

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.

Wright, G.N., McMechan, M.E. and Potter, D.E.G. (1994): Structure and architecture of the Western Canada Sedimentary Basin; *in* Geological Atlas of the Western Canada Sedimentary Basin, G.D. Mossop and I. Shetsen (comp.), Canadian Society of Petroleum Geologists and Alberta Research Council, URL https://ags.aer.ca/atlas-the-western-canada-sedimentary-basin/chapter-3-structure-and-architecture [November 2024].