Preliminary Results and New Insights from a Deep Temperature Log in the Western Canada Sedimentary Basin

Katherine Huang[1], Yannick Champollion[2], Catherine Hickson[1]

[1]Alberta No. 1, [2]HydroGeo+

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ABSTRACT

The Alberta No. 1 conventional geothermal project is located in the province of Alberta, south of the city of Grande Prairie. The company recently conducted a detailed temperature log on a SECURE ENERGY idle disposal well within the project area. The goal was to determine the regional thermal gradient and temperatures within the project's target formations and compare results from previous studies that used oil and gas data to estimate temperature. The log yielded a temperature profile from surface to over 4000 m depth and recorded a Bottomhole Temperature (BHT) of 117.9 °C. The calculated thermal gradients are 32.5 °C/km in the upper portion of the well (500.0 m to 2822.0 m) and 21.9 °C/km in the lower portion of the well (2822.0 m to 4043.4 m. The abrupt change in gradient appears to represent the transition between sandstone and shale sequences to more carbonate-dominated sequences within mid-Jurassic formations. The results of the temperature log provide new insights on thermal gradient changes in the Western Canada Sedimentary Basin and interpretations of BHT data.

1. Introduction

The Alberta No. 1 project is a conventional geothermal project aiming to generate 10 MWe electricity and 985 TJ/year of heat. To achieve this, the project is targeting to produce thermal brine of at least 120 °C at 300 l/s total from five purpose-drilled production and injection wells. The project is located within the County of Grande Prairie and Municipal District of Greenview, south of the City of Grande Prairie (Figure 1). The red box in Figure 1 outlines the project area where Alberta No. 1 plans to drill. The location was chosen due to proximity of the Norbord Oriented Strand Board (Norbord) facility and a planned light industrial park near the Hamlet of Grovedale (Figure 2). Norbord and the park are anticipated to be industrial heat offtakers from the direct use (heating and cooling) portion of the project.

An initial analysis of the geothermal resource involved filtering Bottomhole Temperature (BHT) data to estimate temperatures within target formations and calculate an average thermal gradient in the project area which indicated favourable results (Huang et al., 2020; 2021). However, temperature data from oil and gas exploration, such as BHT measurements, are known to have biases and measurement/reporting errors and as such are best used as a preliminary assessment of geothermal resources (Gray et al., 2012). Alberta No. 1 therefore conducted a detailed temperature log on an idle disposal well to determine the regional thermal gradient and temperatures within the project's target formations. Here we discuss the results of the temperature log and their implications on the project and compare results from the previous analysis.

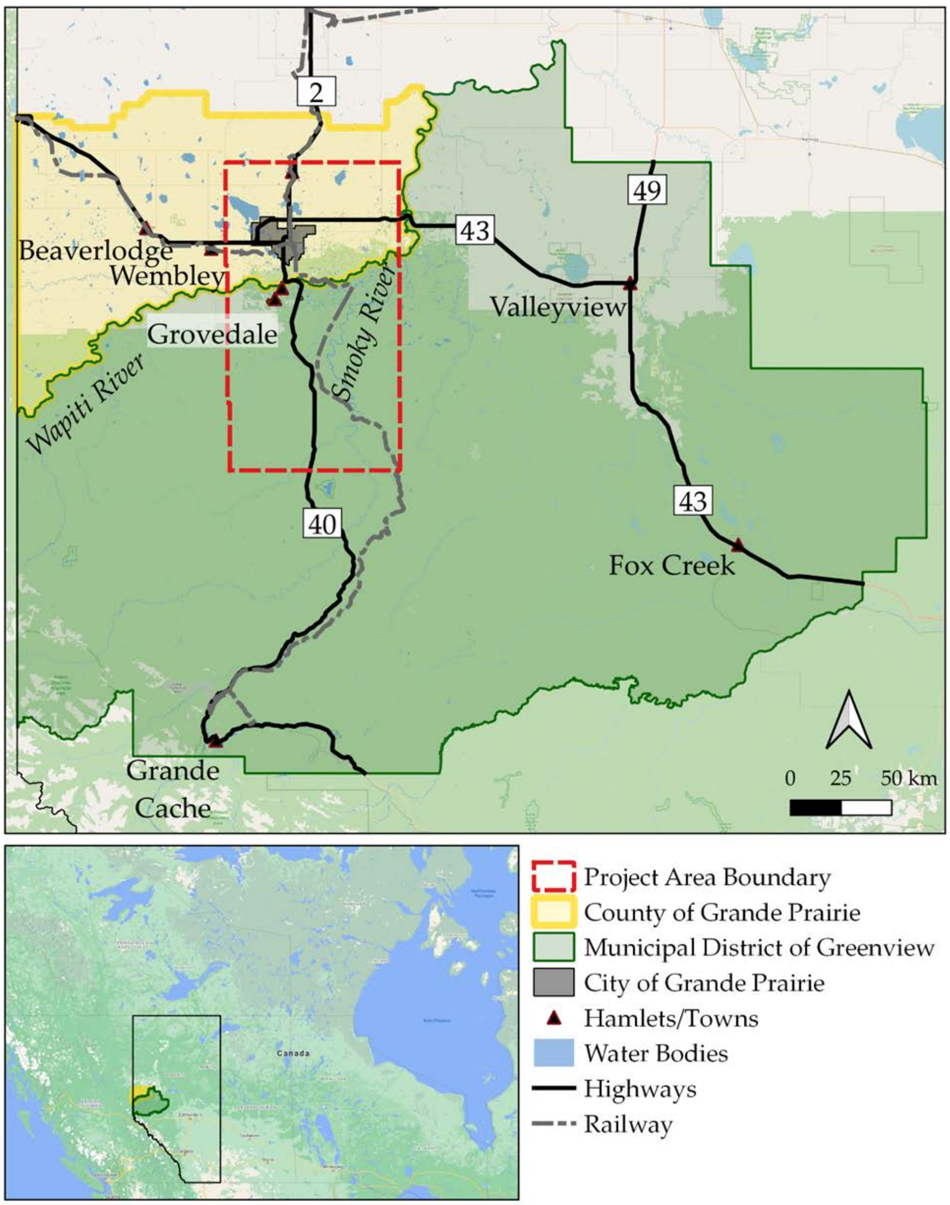

Figure 1: The Alberta No. 1 project is located within the Municipal District of Greenview and County of Grande Prairie.

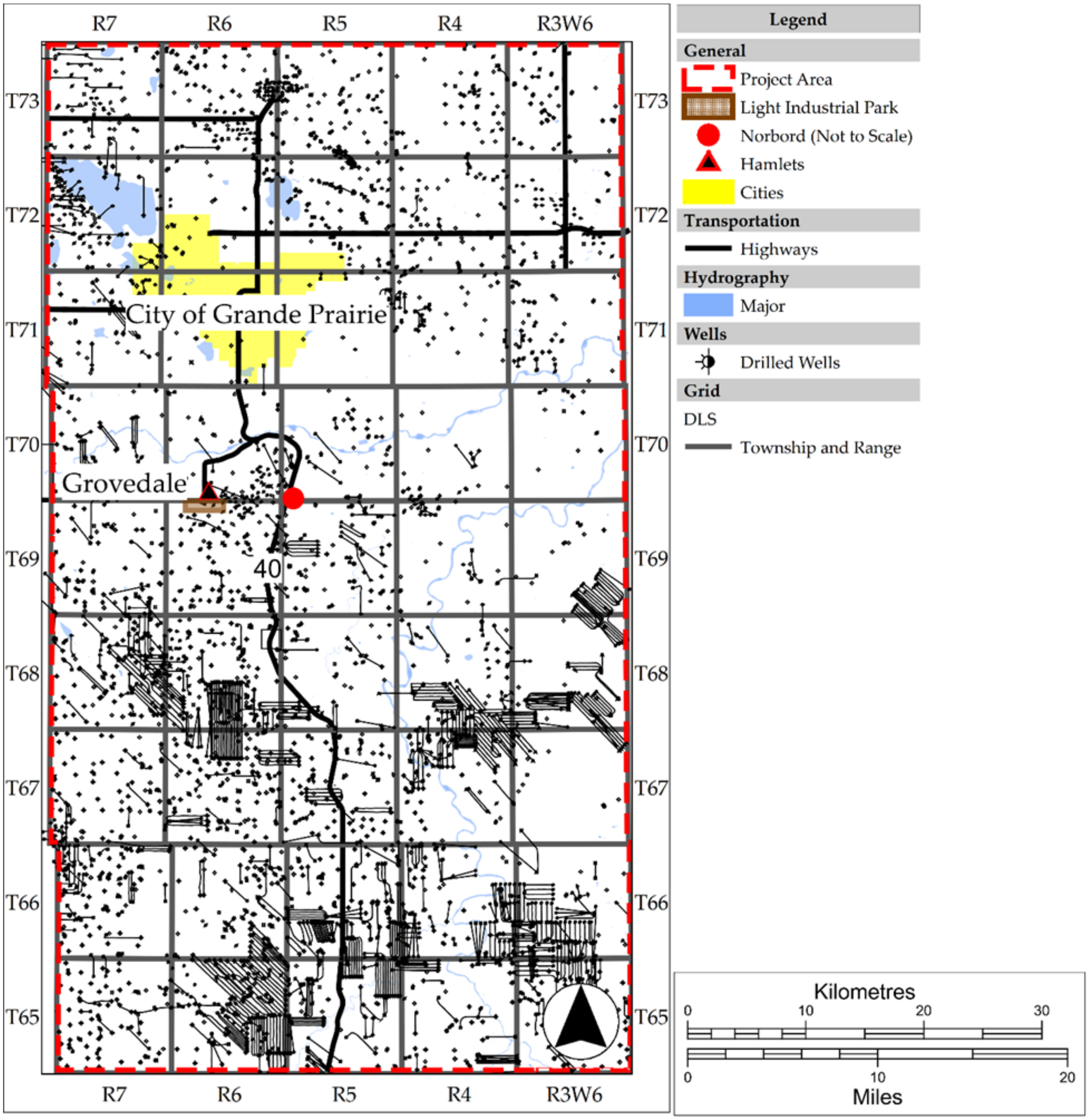

Figure 2: The wells previously drilled are shown within the project area where Alberta No. 1 plans to drill production and injection wells. The area encompasses a planned light industrial park near the Hamlet of Grovedale and the Norbord Oriented Strand Board facility.

2. Geological Background

The Western Canada Sedimentary Basin (WCSB) is composed of a wedge undeformed Phanerozoic strata overlying Precambrian crystalline basement and covers most of Alberta. The wedge is thickest in the southwest portion along the Foothills and tapers off to the northeast where the basement is exposed (Mossop and Shetsen, 1994). The Phaerozoic strata can be divided into upper and lower successions. The lower succession was formed from deposition of sea clastics and carbonates on a passive margin from Early Cambrian to Jurassic. The upper succession was formed from deposition of siliclastics from mountain erosion into a foreland basin in mid- to late-Jurassic to Paleocene (Mossop and Shetsen, 1994). In general, the upper sandstone- and shale-dominant units have lower thermal conductivity values than the lower carbonate-dominant units, which directly affects thermal gradient and heat flow (Blackwell and Richards, 2004).

Target formations for the Alberta No. 1 project are Devonian-aged limestone units that have been hydrothermally altered to dolomite, as well as interbedded sandstone units. Specifically, the target formations span from the top of the Winterburn Group to the base of the Granite Wash Formation, which overlies the Precambrian Basement (Figure 3).

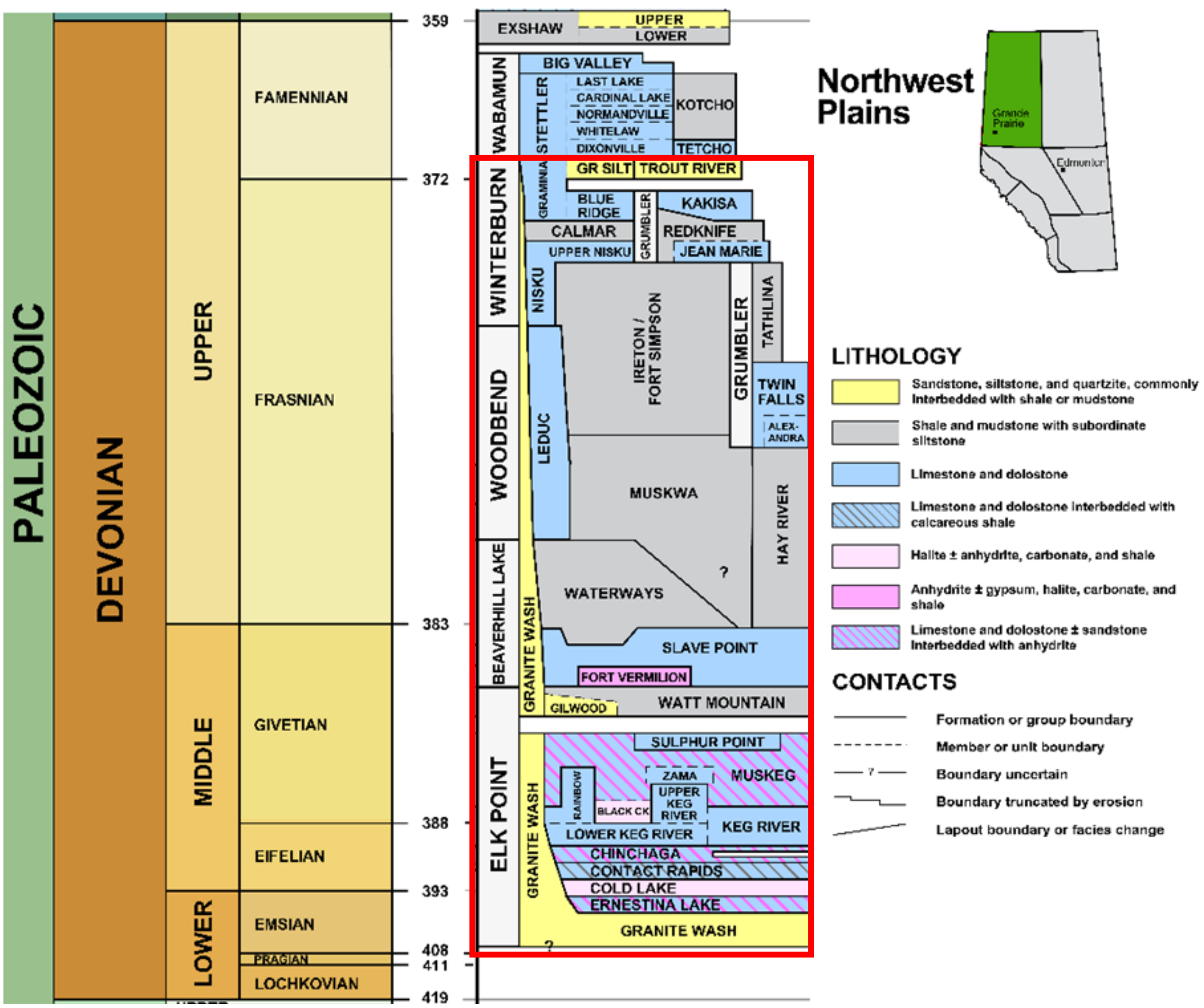

Figure 3: General stratigraphy of Devonian units in the Northwest Plains of Alberta. The Alberta No. 1 project area is not underlain by all the units depicted but is targeting the formations from the Winterburn Group to the Granite Wash Formation, outlined in red (adapted from Alberta Geological Survey, 2019).

3. Previous Alberta No. 1 Study

Huang et al. (2020) assessed BHT measurements to estimate temperatures within the target formations for nine areas in Alberta, including a very similar study area to the Alberta No. 1 project area. BHT data were filtered for errors and biases and uncorrected to provide a lower estimate of temperature. An average thermal gradient of 25.8 °C/km and gradient change with depth of -0.7 °C/km was reported. The study suggests that thermal gradient does not change significantly with depth, and therefore a linear gradient was applied. The results of the recently conducted temperature log contradict this interpretation, which is discussed in Results and Discussion.

4. Methodology

4.1 Temperature Log

To record an accurate temperature log, a well must have time to re-heat after drilling, as drilling fluids are known to cool the wellbore. A SECURE ENERGY perforated and cased deep disposal well within the Alberta No. 1 project area had been idle for over 2 years, making it a suitable well to conduct a temperature log. The well was originally drilled past 4100 m depth, but a packer and plug have since been placed, making the total depth 4043.4 m (note: all depths are reported as depth from KB). The logging took place in February 2021 and recorded temperature and depth from surface to total depth going downhole, going up hole, and at the surface and bottom of the well. Details of the logging are described in Champollion et al. (2021).

4.2 Data Interpretation

Downhole and up hole data were both plotted versus depth and revealed a recording issue for the downhole data; therefore, the up hole measurements, which appear to have no issues, were used for the analysis. From the temperature versus depth plots, it is visually apparent that a gradient inflection point occurs at approximately 2800 m depth. To determine the exact depth of the inflection, as well as assess noise within the data, we calculated moving average gradients for 10 m, 20 m, 50 m, 100 m, and 1000 m intervals using Equation 1.

$$TG_{Avg} = \frac{T_D - T_{D-x}}{x} \times 1000 \tag{1}$$

where TG_{Avg} is the moving average thermal gradient (°C/km), T_D is temperature at depth (°C), D is depth below KB (m), and x is the interval (m).

The moving averages for all intervals were plotted versus depth, making the approximate depth of the inflection point evident. The exact depth was taken at the peak from the 10 m interval minus 5 m. The moving average plots also revealed significant noise from surface to approximately 300 m depth, which was interpreted to be due to warming of the ground and atmosphere during the past century. Taking extra precaution to avoid any effects of climate change, we removed data from surface to 500.0 m.

The inflection point was then plotted on a temperature versus depth profile. Next, we calculated the upper thermal gradient from 500.0 m to the inflection point, and from the inflection point to total depth.

4.3 Lithology Log

Formation tops were exported from the well ticket in geoSCOUT. Rock descriptions for the depth interval 1845.0 m to 4534.0 m were included in the database. We summarized the descriptions for each formation and categorized them into seven lithologies. We then correlated the temperature-depth profile to the lithology log.

5. Results and Discussion

5.1 Moving Average Thermal Gradient Plots

Figure 4 displays the moving average thermal gradient plot for 10 m, 20 m, 50 m, 100 m, and 1000 m intervals and the selected gradient inflection point. The larger intervals (50 m, 100 m, 1000 m) help to discern noise from actual temperature variations controlled by lithology. The shorter intervals (10 m, 20 m) can be used to pinpoint exact depths of temperature variations. Considerable noise in the data can be observed in the upper 300 m of the log. The peak around 2800 m depth was interpreted to be the gradient inflection point.

The same plot for the depth range 2500 m to 3500 m is shown in Figure 5. Larger intervals for the moving averages have longer lags and therefore will peak at depths lower than the actual temperature change. The 10 m moving average peaks at 2827.0 m depth, so the gradient inflection point was calculated to be 2822.0 m.

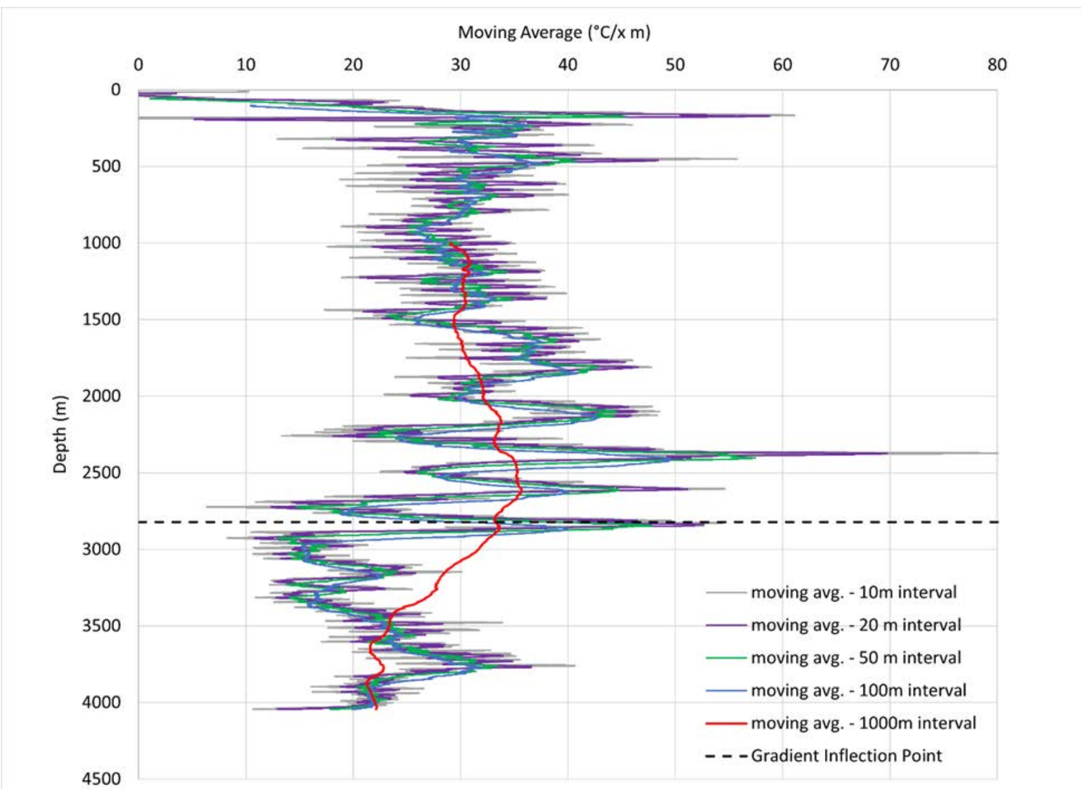

Figure 4: Moving averages thermal gradients for 10 m, 20 m, 50 m, 100 m, and 1000 m intervals from surface to total depth. The approximate location of the gradient inflection point is apparent around 2800 m depth.

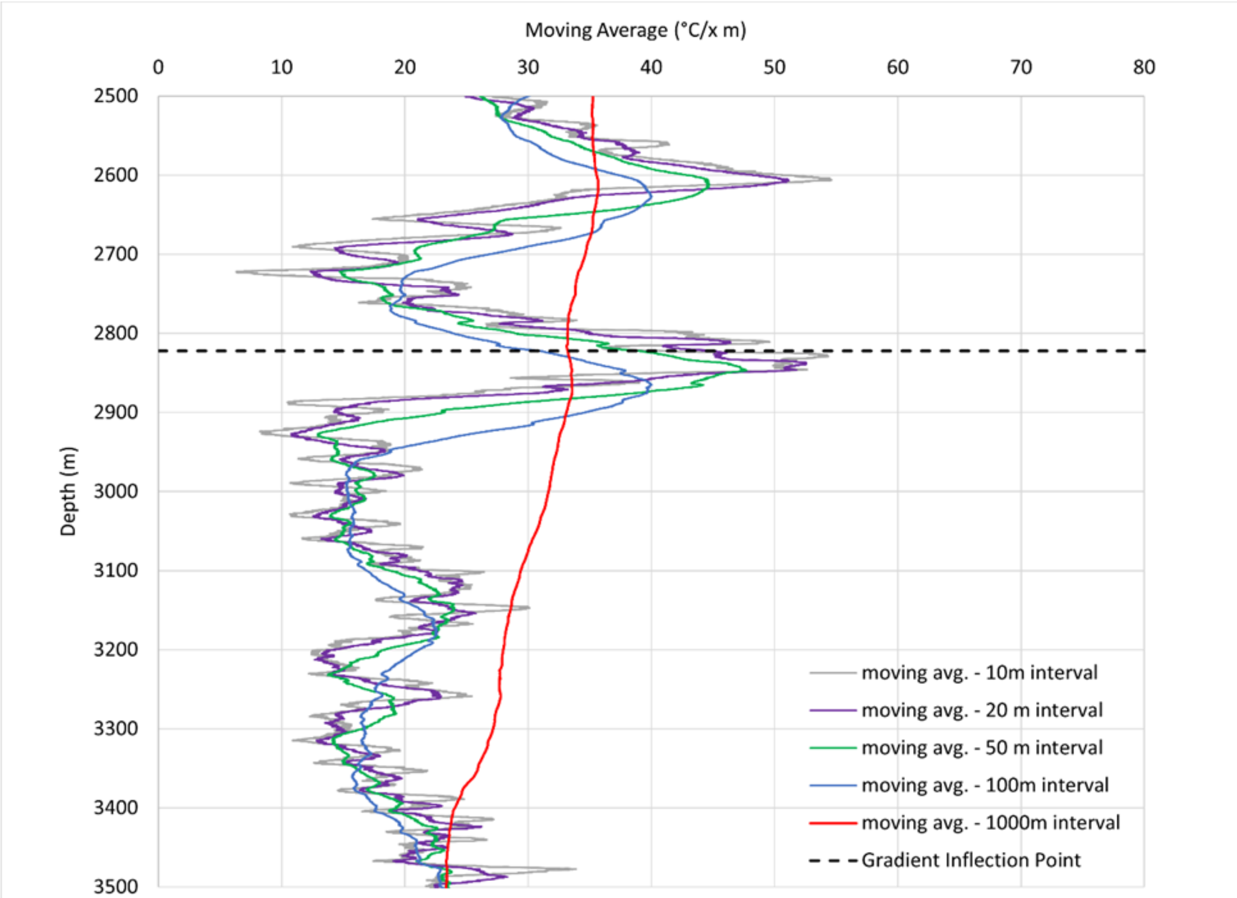

Figure 5: Moving thermal gradient averages at the depth interval where the gradient decreases. The depth was determined to be 2822.0 m.

5.2 Temperature-Depth Profile and Lithology

The log recorded a temperature of 117.9 °C at total depth (4043.4 m) in the Nisku Formation, which calculates an average thermal gradient from surface to depth of 29.0 °C/km. The upper gradient (from 500.0 m to 2822.0 m) is 32.1 °C/km. A temperature of 91.1 °C was recorded at the gradient inflection point at 2822.0 m. The lower gradient (from 2822.0 m to 4043.4 m) is 21.9 °C/km. The log also exhibits small-scale variations at all depths, likely related to changes in lithology, mineralogy, porosity, and permeability. The temperature depth-profile and lithology log are shown in Figure 6. The data for the upper 500 m was not used to calculate the gradient, but kept in the profile to show the temperature variability near the surface.

The gradient inflection point occurs within the Jurassic formations at the approximate boundary of the distinct sedimentary successions of the WCSB. The lower succession of carbonate sequences was deposited from Early Cambrian to Jurassic, while the upper succession of siliciclastic rocks was deposited from mid- to late-Jurassic to Paleocene.

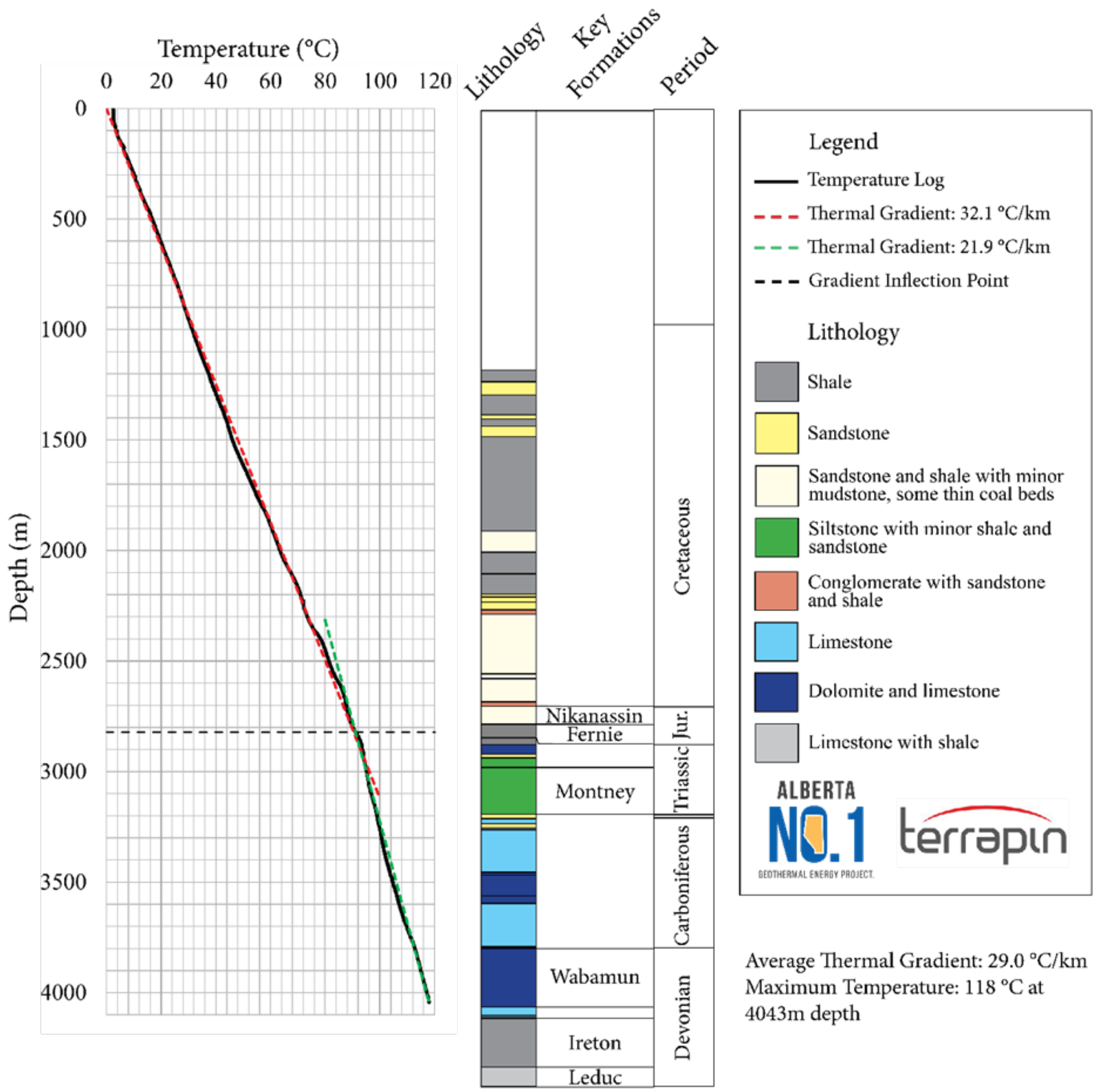

Figure 6: Temperature-depth profile and lithology log of the well that the temperature log was run. A sharp decrease in thermal gradient is correlated with a change in lithology from siliclastics to carbonates.

Specifically, the inflection point occurs in the shale-dominant Fernie Formation. The Fernie Formation is overlain by the sandstone- and shale-dominant Nikanassin Formation, which is then overlain by thick, Cretaceous sandstone and shale sequences. Underlying the Fernie Formation are thin dolomite and limestone, and thick siltstone sequences of Triassic and Permian ages. Lithology then transitions with depth to thick, Devonian limestone and dolostone units. The higher thermal gradient correlates well with the sandstone and shale units, which are generally characterized by lower thermal conductivity values than carbonate units, which are correlated with the lower thermal gradient.

The Nisku Formation, where 117.9 °C was recorded, is part of the Winterburn Group and is one of the uppermost target formations. It is unknown if thermal gradient changes within the lower Devonian limestone (with shale) units. However, assuming that the thermal gradient will remain positive, increasingly higher temperatures are expected within these underlying target formations. Therefore, the required temperature of 120 °C for the project should exist within most of the target formations just below the Nisku Formation. The results also validate the existence of temperatures sufficient for direct use applications much shallower in the region.

5.3 A Relook at Previous Studies

The BHT data assessed by Huang et al. (2020) ranged from 90 °C to 125 °C around 4000 m depth. The temperature recorded by the log falls within the upper range, which suggests that the filtered, uncorrected BHT data may be accurate in estimating temperature at depth. However, given the large range in temperatures, the usefulness of this for assessing the geothermal resource is limited.

The plot showing the average thermal gradient of 25.8 °C/km and gradient change with depth of -0.7 °C/km is shown in Figure 7. Huang et al. (2020) interpreted from the results that thermal gradient is linear with depth, and therefore the Harrison correction, which utilizes a 2nd order polynomial fit to account for a lower thermal gradient within the lower sequences, is not appropriate for the data (Harrison et al., 1983). The results of the temperature log contradict this, as the thermal gradient distinctly decreases as lithology changes. The interpretation from Huang et al. (2020) may be attributed to the scatter in the data. Although the upper and lower thermal gradients are distinct in the temperature log, they would be difficult to discern among noise and scattered data. There are several implications to this new insight. First, the Harrison correction may be a suitable correction method for BHT measurements in the project area, and possibly throughout the WCSB. Second, if a correction method is not used, a linear gradient is not suitable for predicting temperature at depth; filtered BHT measurements may instead predict a range of temperatures at specific depths.

3. Conclusions

A detailed temperature log conducted in an idle disposal well confirmed that temperatures within Alberta No. 1’s target formations meet the requirements to produce electricity and heat. The results also provide new insights on previous studies which used Bottomhole Temperature measurements to estimate thermal gradient and temperature at depth.

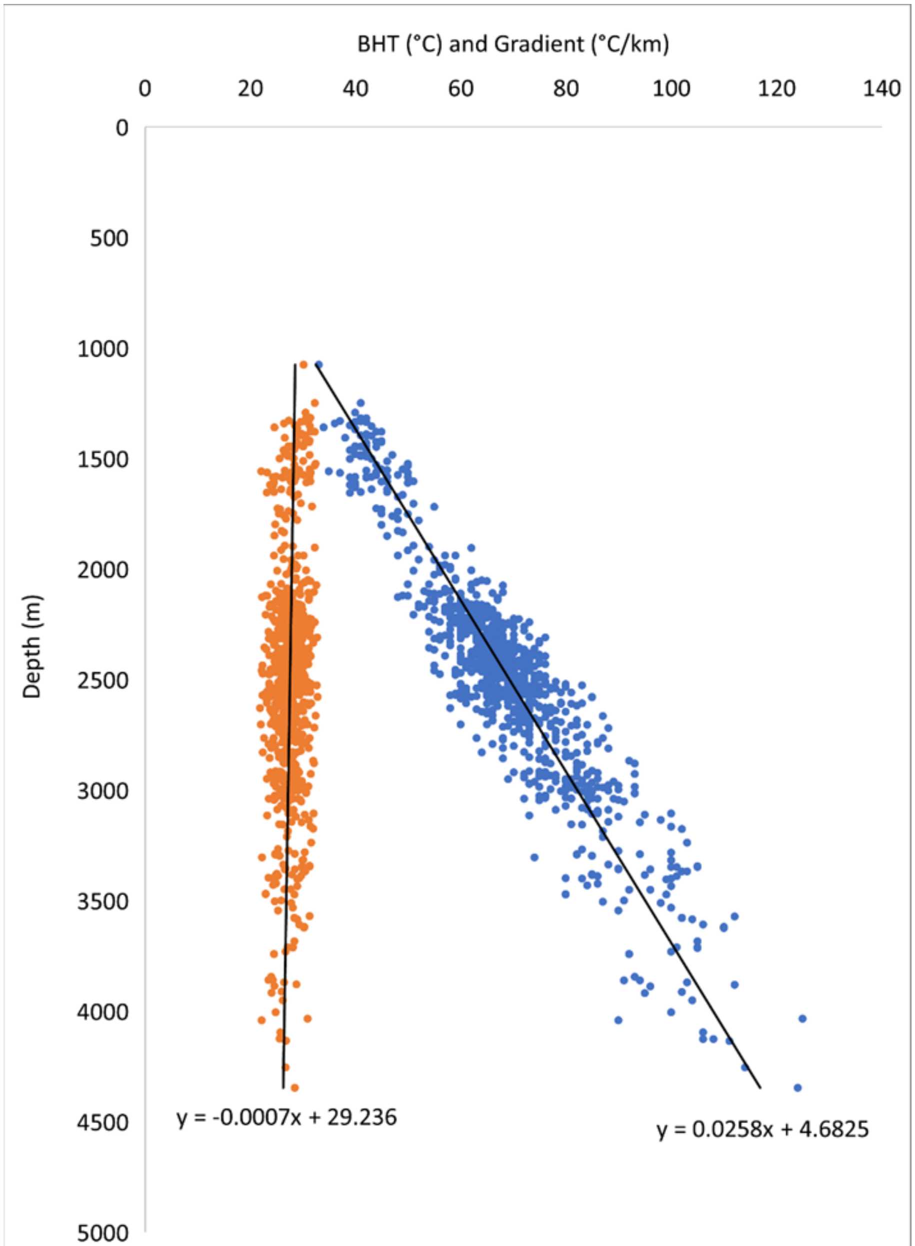

Figure 7: Filtered and uncorrected BHT measurements and calculated gradients from Huang et al. (2020).

The log recorded a temperature of 117.9 °C at 4043.4 m depth. The thermal gradient of the upper portion of the well from 500.0 m to 2822.0 m is 32.1 °C/km. The lower gradient from 2822.0 m to 4043.4 m is 21.9 °C/km. This change in thermal gradient occurs within Jurassic-aged formations and correlates to the boundary between lower, carbonate-dominated and upper, siliclastic-dominated sequences related to the deposition history of the Western Canada Sedimentary Basic. The decrease in gradient at this boundary contradicts the interpretations of the BHT data by Huang et al. (2020) that thermal gradient is linear with depth. However, the results of the temperature log fall within the upper range of BHT measurements (90 °C to 125 °C) around 4000 m depth, which the temperature log confirmed. This suggests that filtered, uncorrected BHT data can provide a wide-range estimate of temperature at depth but could be significantly biased to the lower end of the in-situ temperature range.

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