Revisiting the Geothermal Potential of the Dehcho Region in NWT, Canada – Right Sizing Geothermal Development

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Keywords

Direct use, downhole heat exchanger, arctic, Western Canadian Sedimentary Basin, Northwest Territories, Canada, low temperature, Indigenous, remote communities.

ABSTRACT

The Dehcho Region is located in Canada's Northwest Territories (NWT). The region consists of ten small communities of under 1000 people (2022 total population of 7,174). This represents 16% of the population of NWT, but it should be noted that almost 50% (2022: 21,720) of the population live in the capital City of Yellowknife. Presently, the electricity needs of the Dehcho region communities are supplied by diesel generators. The thermal needs of the communities are provided by heating oil fired furnaces and hydronic systems (in larger buildings), and combustion of wood in individual residences. The southern NWT region was identified several decades ago as having a high potential for geothermal energy, due to the high bottom-hole temperatures discovered during exploration drilling for gas and oil. To increase energy stability and sustainability, as well as reducing the carbon emissions of the Dehcho region, geothermal energy is being evaluated for both heat and power generation. The first detailed evaluation carried out by Terrapin Geothermics was in the community of Nahanni Butte, NWT. The examination of geothermal energy potential at Nahanni Butte encouraged the Dehcho First Nation to begin investigations into the geothermal energy potential of the entire Dehcho Region.

In the winter of 2023, multiple hydrocarbon wells in NWT were abandoned at the direction of the Office of the Regulator of Oil and Gas Operations (OROGO). As part of the closure and abandonment, six wells in the Cameron Hills region were chosen to carry out geothermal temperature logging to ascertain and authenticate the geothermal gradient of the region and the true bottom hole temperatures of the wells. In addition, gamma and density logs were run to verify and confirm the stratigraphic correlations made while drilling the well, these will be used for regional correlations. Compilation, review, and analysis of this newly acquired data will be put into a regional context and be used for geothermal development and energy sustainability decisions in the Dehcho Region. Historical temperature gradients obtained during the original development of the Cameron Hills field averaged 36°C/km. Based on the temperature logging done in 2023 the

average temperature gradient (of the six wells tested) is 41°C/km. Based on this increased gradient, the temperature at the base of the sedimentary sequence is up to 9°C higher than previously predicted. While this is promising for geothermal energy, the depth of the sedimentary basin in the Cameron Hills is only 1,500m, so power generation will likely have to take the form of EGS development in the underlying crystalline basement rocks.

While the Dehcho Region of the NWT has potential for higher temperature geothermal systems, the technology implemented needs to be "right sized" by considering the community's needs and future development plans to find the best application of renewal energy solutions. This may include geothermal technology, or hybrid systems such as waste heat recovery from existing diesel generation, and lower cost thermal systems providing base-load heating on a multidecadal time frame. Each community within the Dehcho will require an individualized plan for energy sustainability based on these findings. This work is funded under the Crown-Indigenous Relations and Northern Affairs Canada's (CIRNAC) Northern Research program, managed by Gonezu Energy Inc, based in Fort Providence, NWT.

1. Introduction

The Dehcho Region of the Northwest Territories, Canada is in the southwestern portion of the territory and boarders Alberta and British Columbia to the south and the Yukon Territory to, the west (Figure 1). The region is home to 7,174 people in 10 communities based on the 2022 Northwest Territories Bureau of Statistics (Figure 2) (Statistics 2022). This accounts for almost 16% of the Northwest Territories total population. Table 1 shows a summary of the Dehcho communities and their respective populations. Of the ten communities in the region only two (Hay River and Enterprise) are presently tied into the Territories existing hydroelectric grid (Figure 3). There are plans to expand the existing hydroelectric plant as well as the grid to include two additional Dehcho communities and the Territories capital city of Yellowknife (2022). The communities that are not tied into the grid primarily rely on diesel generators for electricity. Community heat needs are met by diesel fired furnaces and hydronic systems, while residential buildings use combustion of wood for supplemental heat. To reduce the carbon emissions of the region, the Dehcho First Nation has initiated the investigation of geothermal energy as an alternative source of heat and power for the Dehcho Region.

Figure 1: The Dehcho Region of the Northwest Territories, Canada is in the southwestern portion of the territory to the southwest of the capital Yellowknife. The region boarders Alberta and British Columbia to the south and the Yukon Territory to the west.

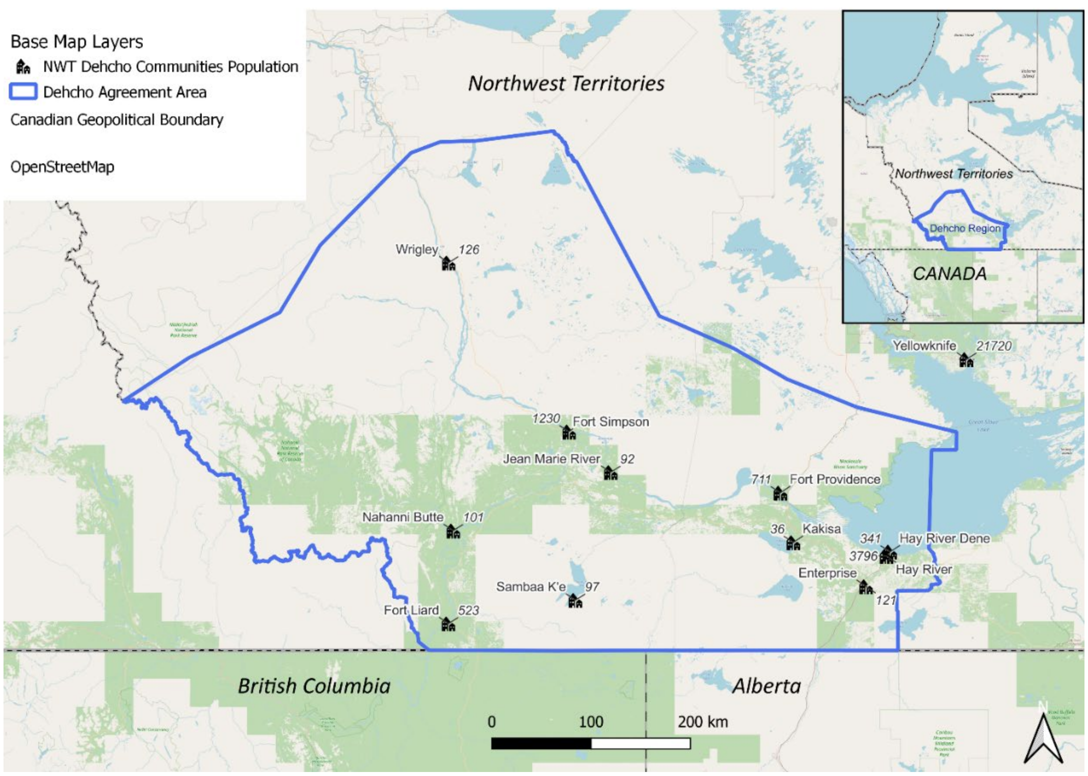

Figure 2: The communities of the Dehcho Region, NWT and their respective populations (Statistics 2022).

Table 1: Population of the communities in the Dehcho Region, the territory capital city of Yellowknife and their percentage of the territory's population (Statistics 2022).

Community	Population 2022	% of Total NWT Population
Enterprise	121	0.27
Fort Liard	523	1.15
Fort Providence	711	1.56
Fort Simpson	1230	2.70
Hay River Dene Reserve	341	0.75
Hay River	3796	8.32
Jean Marie River	92	0.20
Kakisa	36	0.08
Nahanni Butte	101	0.22
Sambaa K'e	97	0.21
Wrigley	126	0.28
Total Study Area	**7174**	**15.73**
Yellowknife (NWT Capital City)	21720	47.63
Total Including Yellowknife	**28894**	**63.36**

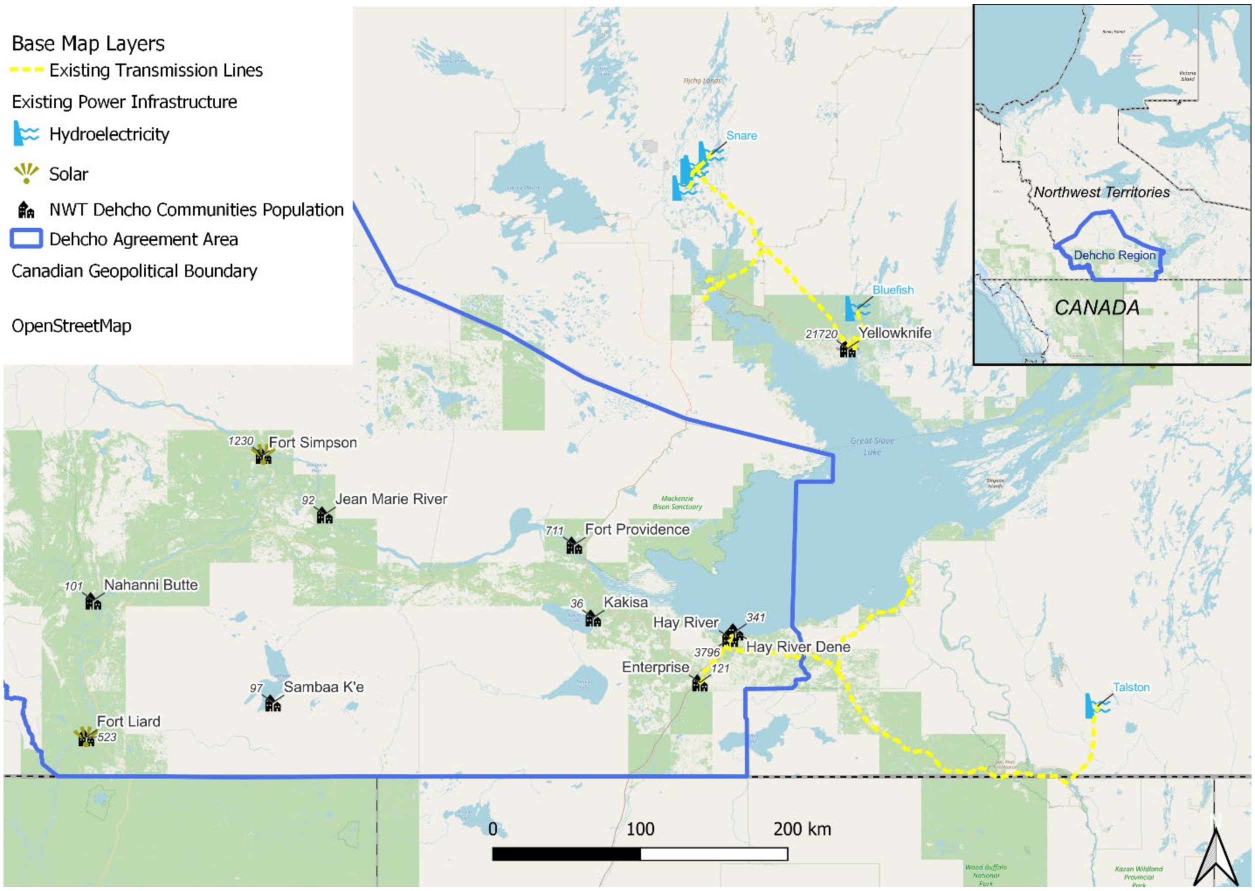

Figure 3: The existing hydroelectric plants and associated transmission lines in the Northwest Territories. Only two of the ten communities (Hay River and Enterprise) in the Dehcho Region are connected to the existing grid. There are plans to expand the Taltson hydroelectric facility and its grid to include Kakisa, Fort Providence and connect it to Yellowknife.

Between the 1960s and the early 2000labels, the Dehcho area was developed for oil and gas, with over 450 wells drilled for hydrocarbon resource assessment and extraction (Figure 4) (OROGO 2022). The majority of the data from these wells is publicly available and managed by the Office of the Regulator of Oil and Gas Operations (OROGO). This data set has been used to develop geothermal energy assessments in the past. Most recently, EBA Engineering Consultants Ltd. (now Tetra Tech) completed a geothermal favorability map of the Northwest Territories in 2010 at the request of the government of the Northwest Territories (Klump et al. 2010). This map captured the higher-than-average geothermal favorability present throughout much of the Dehcho Region (Figure 5).

While the EBA map (Klump et al. 2010) gives an estimate of the areas with geothermal potential, it does not capture the feasibility of developing a geothermal resource. In order to have a geothermal resource, three elements are required: heat, porosity, and permeability. In a conventional geothermal system, the porosity and permeability that are present in the rocks are used to produce geothermal fluids to the surface. In North America, conventional geothermal systems are most abundant in sedimentary rocks. In an enhanced (or engineered) geothermal system (EGS), porosity and permeability are artificially created in the rock, most commonly by pumping down cold ground water over periods of weeks to months.

EGS systems are most frequently created in crystalline rock, similar to the Precambrian basement in the NWT (Hickson et al. 2022). The geothermal map developed by EBA illustrates the heat potential but does not capture the presence (or lack thereof) of a geothermal reservoir, or the technology that would be required to extract the geothermal resource. This current work expands on the previous geothermal evaluations done in the Dehcho Region, but incorporates the thickness of the sedimentary sequence, porosity and permeability present in the sedimentary rocks and the depth to the crystalline Precambrian basement.

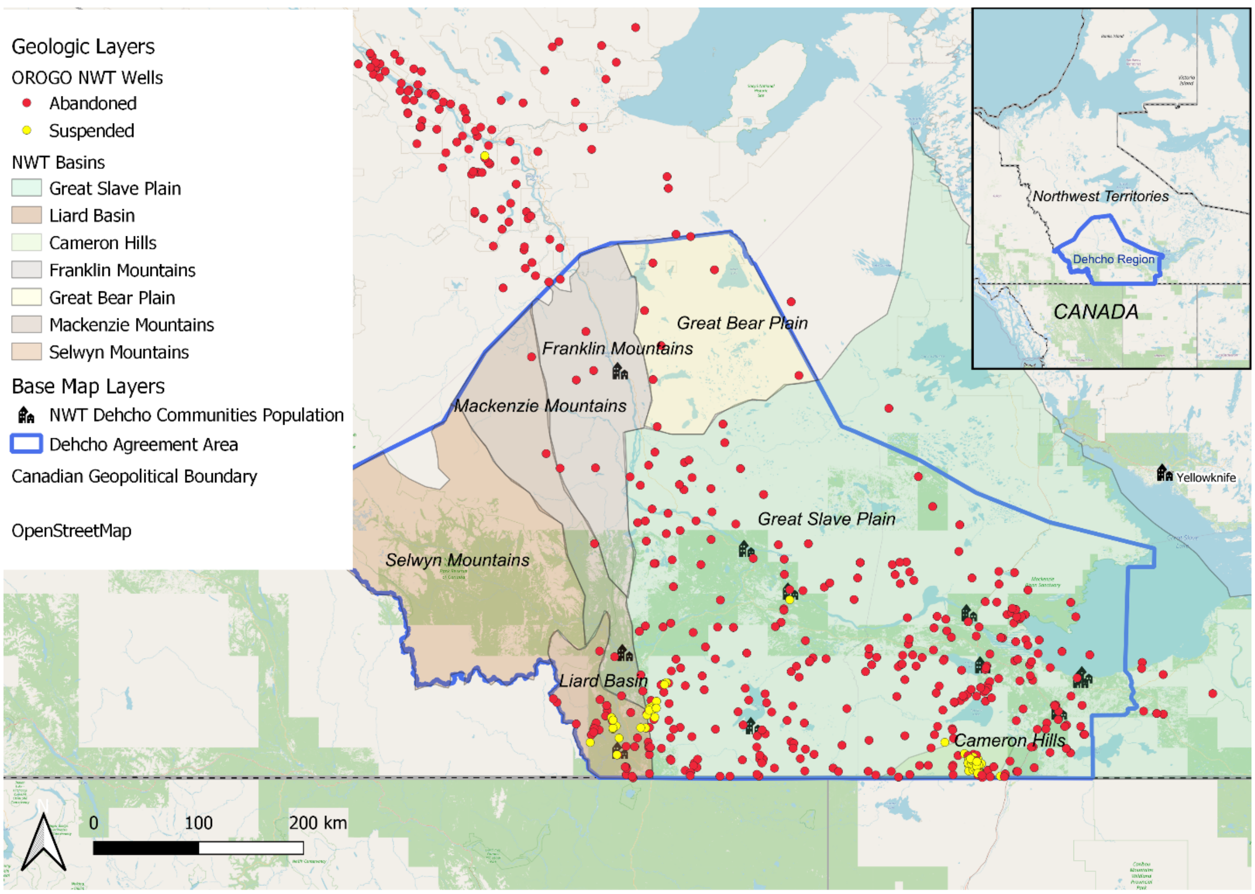

Figure 4: Over 450 hydrocarbon wells have been drilled in the Dehcho Region across seven geologic basins. Red wells are abandoned and Yellow wells are suspended as of 2022 (OROGO 2022).

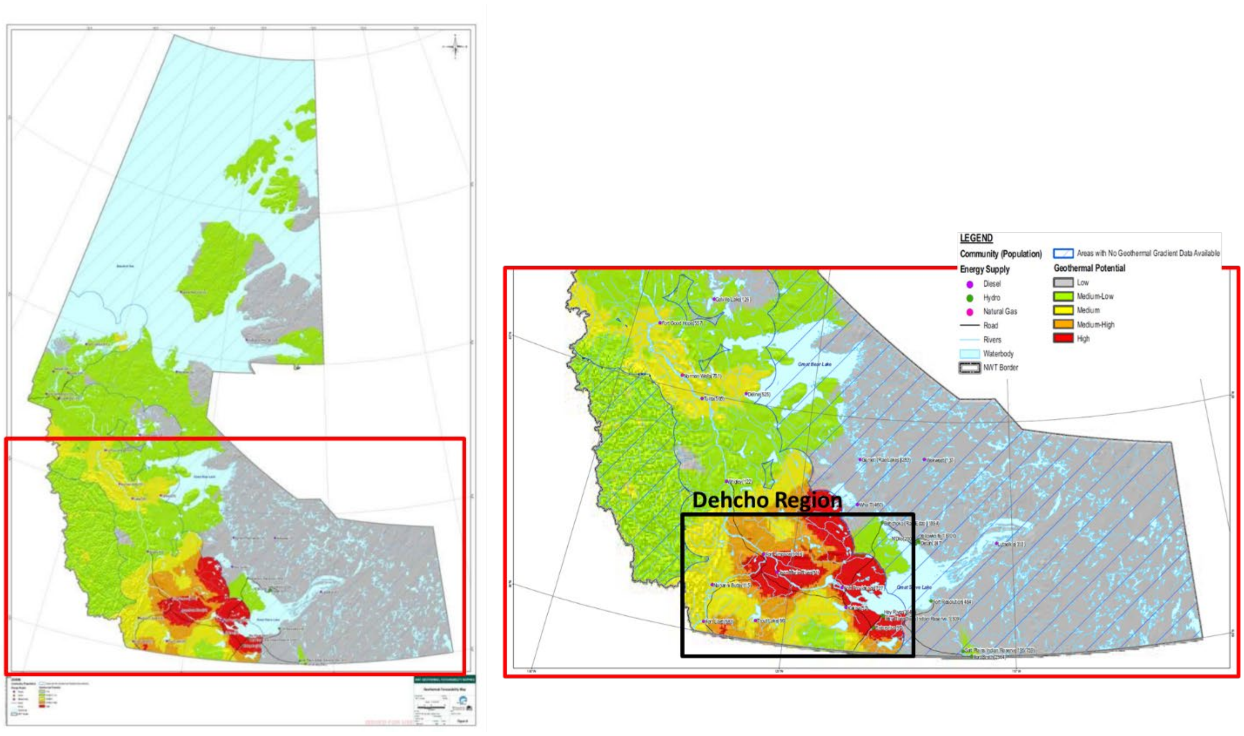

Figure 5: Government of the Northwest Territories Geothermal Favorability Map from 2010, showing a higher geothermal favoribility present in the Dehcho Region (Klump et al. 2010). It should be noted that this map represents geothermal potential, but is incorrectly labeled a "favourability" map, see text for additional details.

2. 2023 Temperature Logging Results at Cameron Hills, NWT

The Cameron Hills project was initiated in November 2022, when it was recognized, that a significant opportunity existed to update the geothermal energy potential map for the Dehcho Region by obtaining modern, updated downhole logging information collected during the abandonment of wells in the Dehcho Region. In early 2023 multiple hydrocarbon wells in NWT were abandoned at the direction of the Office of the Regulator of Oil and Gas Operations (OROGO). Of these wells scheduled to be abandoned were 44 wells in the Cameron Hills hydrocarbon field. The Cameron Hills field is a Horst and Graben play with the past production coming from the Keg River, Sulphur Point and Slave Point formations (Figure 6). The majority of wells (and past production) occur within the horst trap structure. Most wells were drilled slightly into the Precambrian basement, which occurs at ~1500m TVD.

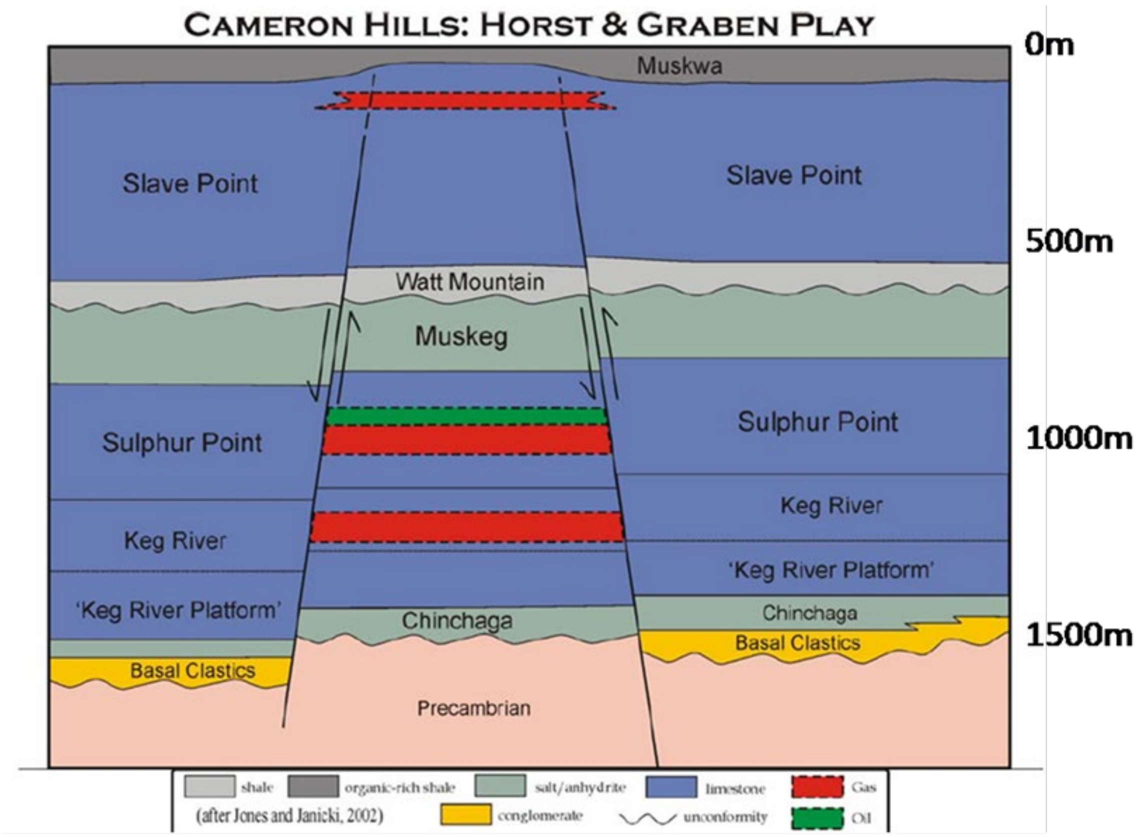

Figure 6: Schematic geological structure and stratigraphy of Cameron Hills oil and gas play (Rocheleau et al. 2014). Production occurred between 1985 and 2006 with hydrocarbons shipped to Alberta via pipeline.

The wells of the Cameron Hills field are in receivership and do not have a current owner or operator. ELM Inc., based in Calgary, AB, was contracted by the receiver to abandon these wells. OROGO and the receiver agreed that including additional thermal gradient measurements was a technically and scientifically appropriate undertaking. ELM was instructed to conduct the measurements using funding provided by CIRNAC and administered by Gonezu. Terrapin developed the logging protocol, completed the QA and QC of the data and provided an analysis of the date under contract to Gonezu.

During the abandonment procedure 6 of the 44 wells were logged for temperature, cement bond, gamma ray, neutron, and density (Figure 7). Two of the wells (A-73 and I-74) had to have packers pulled, zones cemented, and fluid circulated prior to testing. These wells were temperature logged following circulation and again 24 hours after circulation. The other four wells were temperature logged prior to any other abandonment activity. The logging procedure consisted of a slow logging run (<30 m/min) from surface casing to the uppermost abandonment plug. The logging tool then sat at the abandonment plug for 30 minutes. The well was then logged at the same speed on the way up. The data from these logging runs was then provided as las files for analysis.

The logging data for the six wells was plotted and compared with the historical temperatures taken during drilling, as shown in Figure 8 and Table 2. The historical temperature gradients range from 30 °C/km to 39 °C/km, while the gradients calculated from the 2023 logs range from 36 °C/km to

48 °C/km. Figure 8 shows that the average gradient from the six wells obtained during the 2023 temperature logging program is roughly 5 °C/km higher than historically calculated from drilling data (35.99 °C/km historical gradient versus 41.05 °C/km 2023 temperature log). This higher gradient results in the temperature at the top of the crystalline Precambrian basement being approximately 9 °C higher than expected. These results have positive implications for the geothermal potential and shows that past estimates of the Cameron Hills gradient, and potentially the entire Dehcho Region's geothermal gradient are likely low. These updated results must be considered when estimating the geothermal gradients for the Dehcho Region communities.

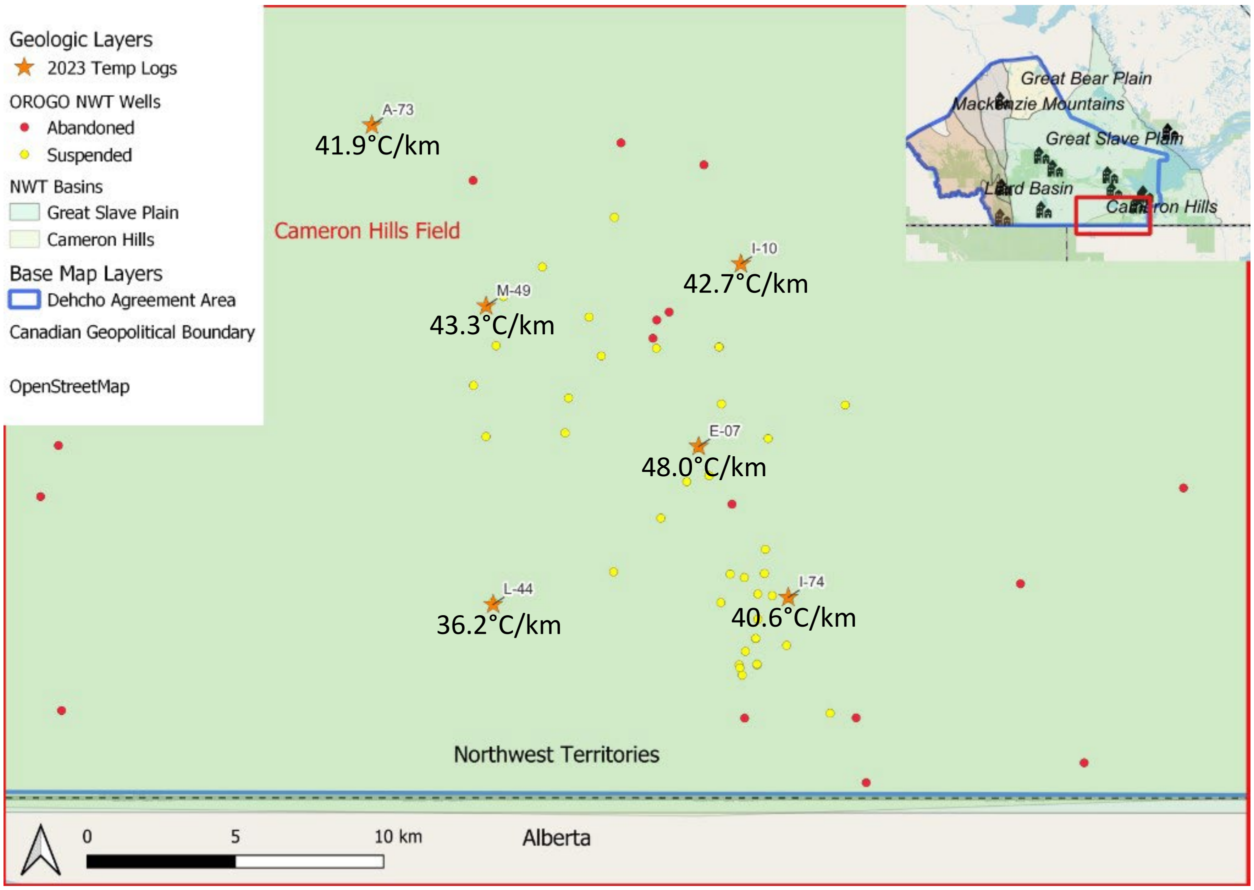

Figure 7: Six wells in the Cameron Hills field were logged prior to abandonment in early 2023 as shown by orange stars. The gradient for each well was calculated based on the deepest logged temperature and the average daytime surface temperature for the area. The estimated gradient for each well is shown in black below the well location, they range from 36°C/km to 48°C/km.

Table 2: The results of the 2023 temperature logging program for six wells in Cameron Hills and the historical temperature data, test type and test date. Note that well L-44 historical temperature was obtained from the static gradient and is closest to the temperature measured during the 2023 logging.

UWI	Short Name	Historical Test Date	Historical Test Type	Historical Max Temperature (°C)	Historical Temperature Depth (mTVD)	Historical Calculated Gradient (°C/km)	2023 Temperature Log Test Date	2023 Max Temp (°C)	2023 Temp Depth (mTVD)	2023 Calculated Gradient (°C/km)	Precambrian Top (mTVD)
300/A-73 60-20N 117-30W	A-73	1990-02-22	Sonic Log	**47.00**	1579	**29.91**	2023-02-14	**52.9**	1306	**41.90**	1559.00
300/E-07 60-10N 117-30W	E-07	2006-03-23	DST	**53.60**	1354	**38.98**	2023-01-14	**58.16**	1251	**48.00**	
300/I-10 60-10N 117-30W	I-10	1986-02-19	DST	**52.00**	1517.7	**33.57**	2023-01-27	**55.9**	1382.7	**42.70**	1518.70
300/I-74 60-10N 117-15W	I-74	2000-01-26	Static Gradient	**54.66**	1417.9	**37.86**	2023-01-23	**53.8**	1296.9	**40.60**	1623.30
300/L-44 60-10N 117-30W	L-44	1990-01-17	DST	**56.80**	1524.4	**36.46**	2023-01-17	**46.8**	1361.4	**36.20**	1607.20
300/M-49 60-10N 117-30W	M-49	2003-03-02	DST	**51.30**	1415.8	**35.55**	2023-01-21	**56.1**	1334.8	**43.30**	
Average				**52.56**		**35.39**		**53.94**		**42.12**	**1577.05**

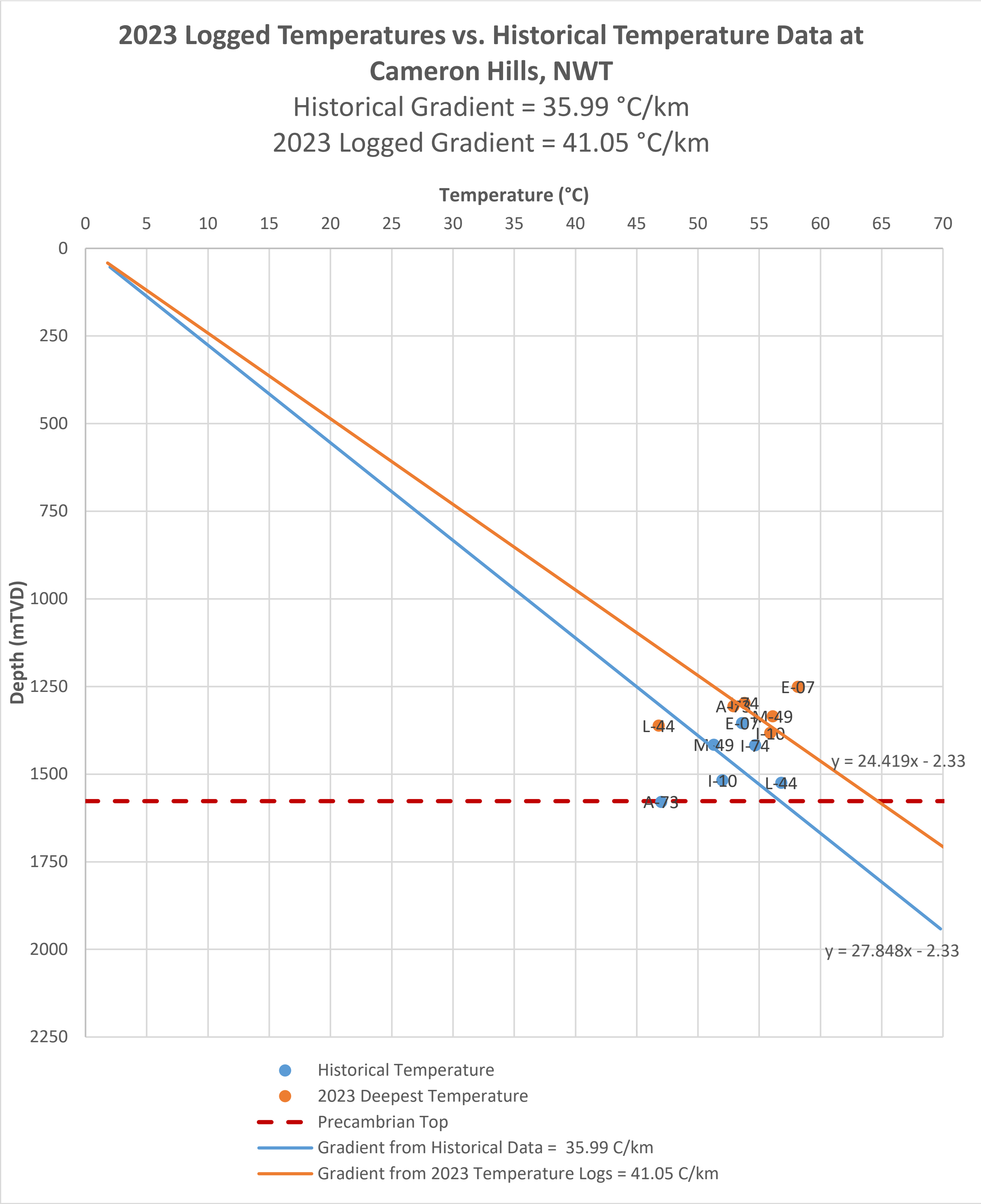

Figure 8: The historical temperatures for six wells in the Cameron Hills field taken during drilling versus the deepest temperature recorded from the 2023 temperature logs taken on the same six wells. The figure shows the gradient measured with the 2023 temperature logs to be approximately 5°C/km higher than the historical temperatures. The top of the granitic Precambrian basin is shown in purple, the rock formations above this are all sedimentary.

3. Community Specific Gradient Evaluation

As part of this work a community specific geothermal gradient, stratigraphic column and reservoir potential will be calculated from existing well data. OROGO captures most data acquired during the drilling of hydrocarbon wells and makes it available to the public. This dataset provides most of the information used to calculate the geothermal gradient at each of the Dehcho communities. To estimate these gradients, the raw highest measured temperature and associated depth were taken at the wells nearest each community. These temperatures were typically from drill stem tests (DST) and occasionally from well logs. Past work on DST's has shown that they are less reliable than other downhole tests, and typically read a temperature lower than the actual temperature. This is due to the influence of drilling fluids in the rock surrounding the wellbore (Förster et al. 1997). An example of this phenomenon is shown with the downhole temperature logging results completed in 2023 at Cameron Hills, as compared with the historical temperature data (Figure 8).

The raw temperature for each well nearest to the community was plotted versus the depth, and a best fit line placed through the data. This line represents the site specific geothermal gradient for the community. The average surface temperature was used as the x-intercept for the linear best fit line. Figure 9 shows an example of the geothermal gradient calculated from historical drilling data at Kakisa, one of the Dehcho Region communities. The results of the gradient for each community are shown in Table 3 and Figure 10. Because most of these temperatures were measured by DST's during drilling, it is likely that these gradients are lower than the natural geothermal gradients for the communities. Despite the calculated gradients likely measuring low, the gradients for this area are still significantly higher than the gradients present to the south in the rest of the Western Canada Sedimentary Basin, which measure around 33°C (Weides et al. 2014).

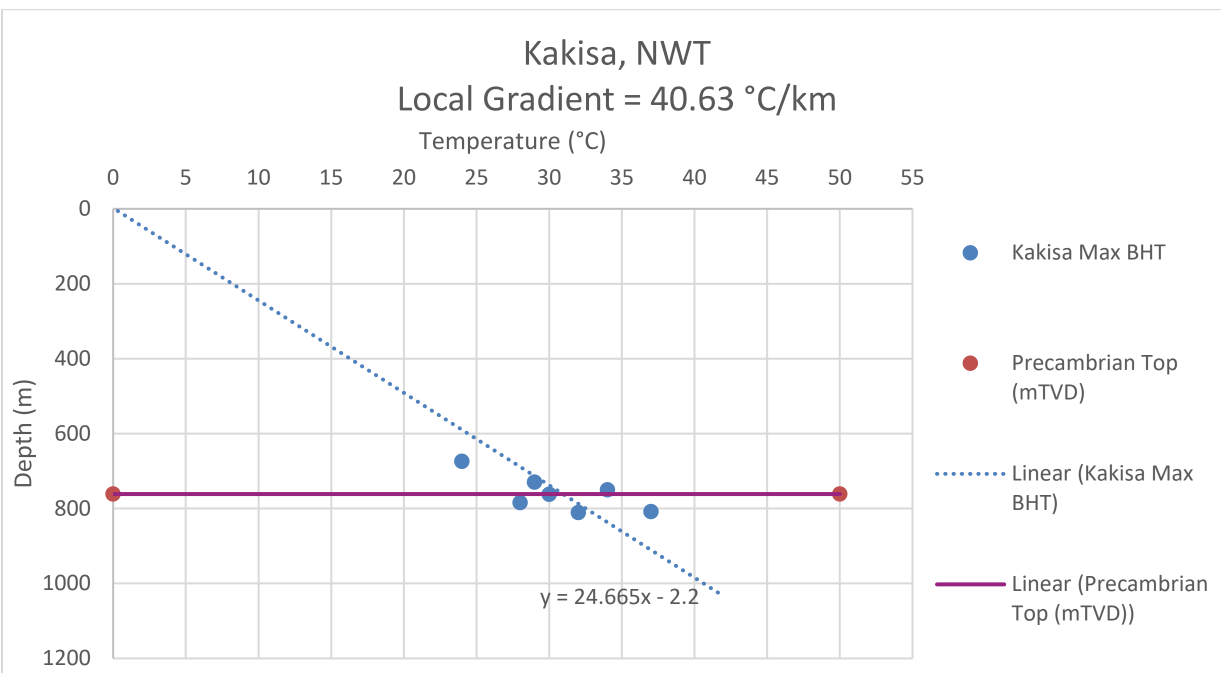

Figure 9: The calculated geothermal gradient for Kakisa, NWT based on the raw bottom hole temperatures of the wells nearest the community.

Table 3: The geothermal gradient calculated for each Dehcho community from raw bottom hole temperature data. The depth to the Precambrian basement from wells was then used to estimate the temperature at the top of the crystalline Precambrian basement.

Community	Population (2022)	Geothermal Gradient (°C/km)	Depth to Precambrian (mTVD)	Temperature at Precambrian Top (°C)
Kakisa	36	40.63	761.25	30.93
Hay River	3796	57.28	614.60	35.20
Enterprise	121	55.39	720.43	39.90
Fort Providence	711	52.07	589.15	30.68
Nahanni Butte	101	51.51	1200.00	61.81
Fort Liard	523	40.71	5000.00	203.55
Jean Marie River	92	55.81	683.70	38.16
Sambaa Ke	97	41.16	1771.03	72.90
Wrigley	126	24.32	1718.90	41.80
Fort Simpson	1230	44.96	755.90	33.99
Cameron Hills 2023 Data	0	41.05	1577.05	64.74
Cameron Hills Historical Data	0	34.99	1577.05	55.18

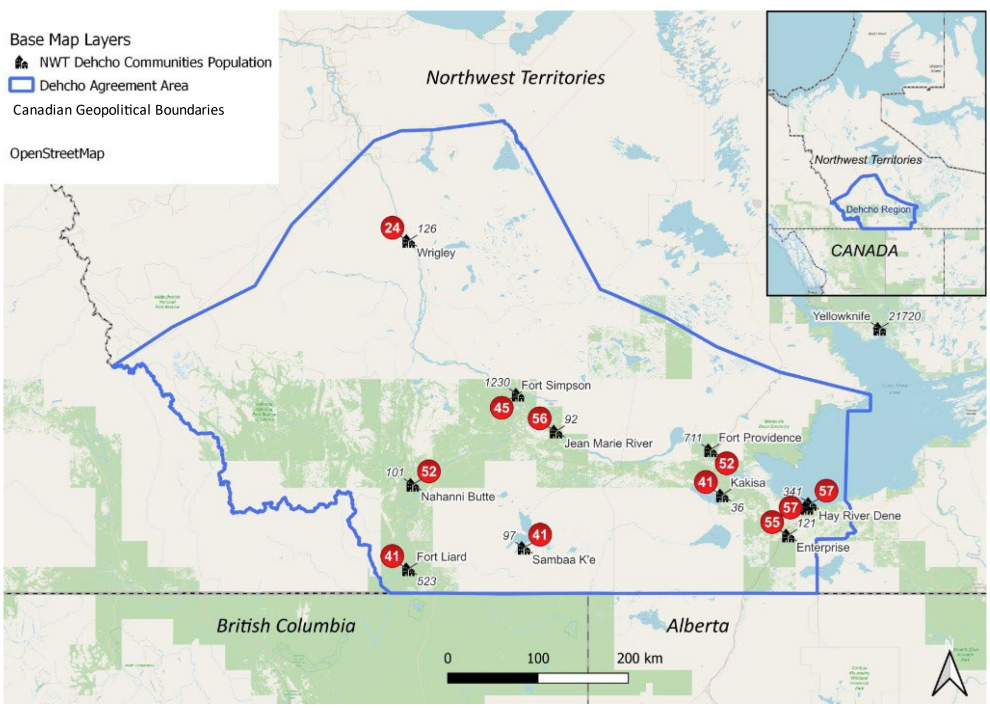

Figure 10: The geothermal gradient for each Dehcho community calculated using raw bottom hole temperatures from the nearest wells and average surface temperatures for the communities.

4. Future Work

Once the geothermal gradient has been calculated for each community, the well logs for the surrounding wells will be analyzed for regional stratigraphy and porosity. A detailed study is already under way by INRS and the NWT Geological Survey (NTGS) that will inform the current study (Rajaobelison et al. 2023). If core was taken for a well, the test results for porosity and permeability will be used in addition to the well log data. A detailed stratigraphic section will be created for each community showing the formations that have the porosity and permeability to host a geothermal resource. An example of this detailed stratigraphic section showing the formations alongside the geothermal gradient and potential geothermal technologies is shown Figure 11 (Rajaobelison et al. 2023).

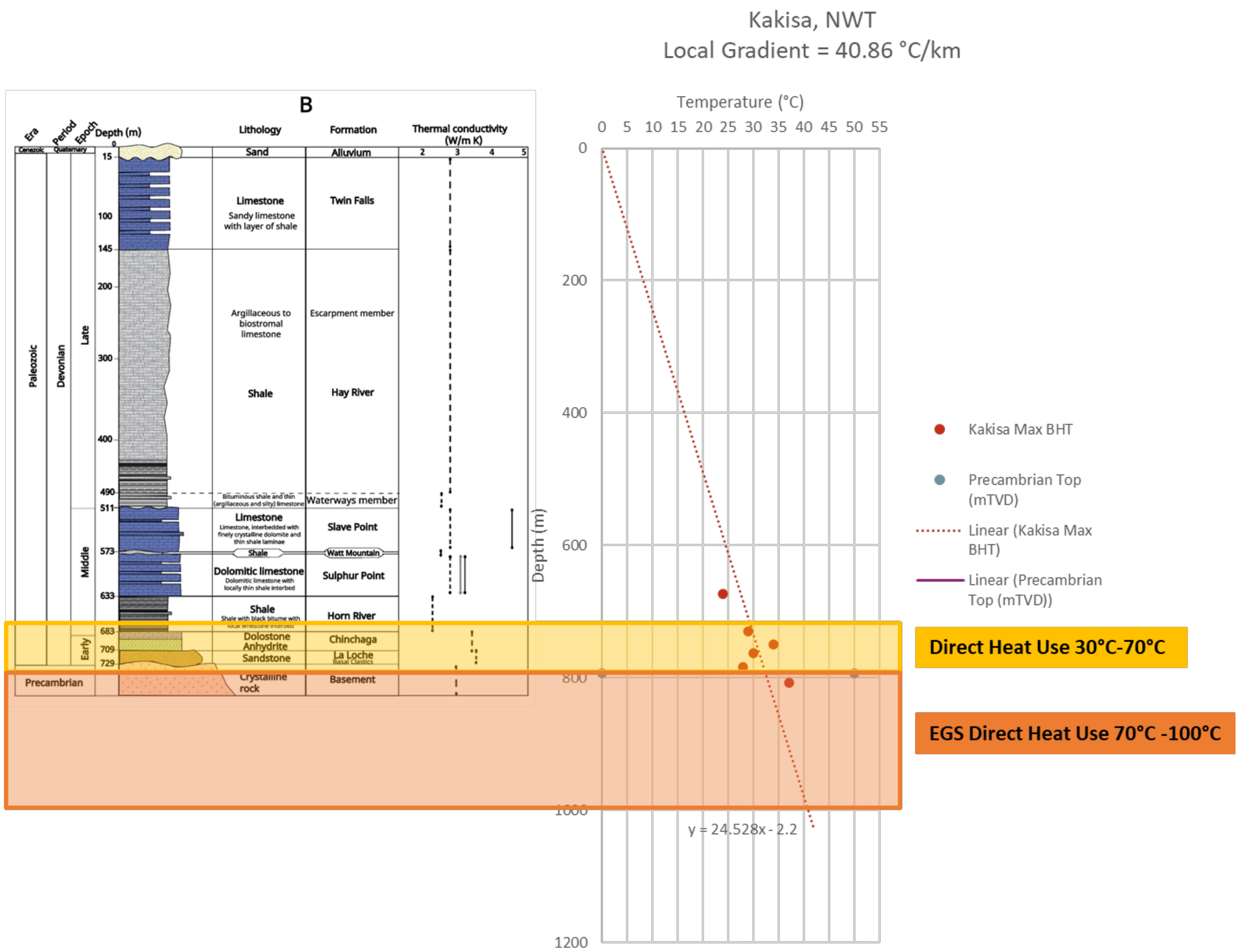

Figure 11: An example of the detailed community stratigraphic column from Kakisa, NWT (Rajaobelison et al. 2023) alongside the geothermal gradient and the potential geothermal technologies available for use.

This evaluation will be completed on a regional basis by Terrapin and more detailed analysis for each community will be carried out by the joint work undertaken by the INRS and NTGS for each of the Dehcho Region communities. With the results of this combined work, the communities will be able to choose the geothermal technology that is the best fit for them based on their population and estimated geothermal resource.

5. Conclusions

The promising geothermal potential of the Dehcho Region has been known for some time. However, a detailed analysis of the geothermal resource for the Dehcho communities has yet to be determined. The initial results of this work show that the geothermal gradient in the area ranges from a low of 24 °C/km in the northwest at Wrigley to a high of 57 °C/km in the southeast at Hay River. The next step will be to determine if there is a geothermal reservoir present in the sedimentary sequence below the communities. This would enable the communities to capture geothermal energy for direct heat use and tailor the design to their specific needs and geology.

Based on the thickness of the sedimentary rocks throughout most of the Dehcho Region being less than 2 km (apart from Fort Liard), temperature within and at the bottom of the sedimentary sequence is too low over most of the region to generate power. For this reason, if power generation is desired by the Dehcho First Nation, it would require the development of an EGS system. In the vicinity of Fort Liard, power generation from rocks within the sedimentary sequence is possible, but the detailed work to determine the suitability of these sedimentary formations has yet to be completed. Both EGS and conventional geothermal systems involve high capital costs and are unlikely to be economic for the communities to undertake themselves. An EGS power system would need to be a regional system that is tied into the existing or expanded hydroelectric grid.

Acknowledgement

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