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Geothermal Energy Potential of Northwest Territories, Canada

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ABSTRACT

We examined the geothermal energy resources of the Northwest Territories (NWT), with particular focus on remote communities with higher geothermal resource potential. The broad area of eastern NWT underlain by the Canadian Shield has low heat flow and geothermal gradients limiting resources largely to heat pump systems, or potentially Enhanced Geothermal Systems. Some notable exceptions are geothermal potential of abandoned mines where large water filled mine tunnels allow high volume production and heat extraction. Of particular interest is the Con Mine site near the capital Yellowknife that is closed and undergoing remediation. Current land use plans are to revert the surface portion of the mine site to industrial development, creating the potential to extract heat form flooded mine tunnels to provide low cost heating solutions for new building construction. Sedimentary basins of the western NWT have inherently low thermal conductivity and act as thermal blankets trapping radiogenic heat. These regions also have higher heat generation than much of Canada. Drilling by the petroleum industry has defined regions of high temperature geothermal resources at depths associated with known aquifer units, suggesting potential for sufficient fluid production rates to produce net power at surface along with associated direct heat use. Potential issues with scaling associated with brines from these levels could cause some technical challenges however. Further research on potential hot sedimentary aquifers could help focus potential exploration targets for geothermal systems. An underlying challenge for future geothermal development in the NWT is the variable degree of permafrost thickness, ranging from discontinuous in the southern portion of the territory to several hundreds of meters in the north. Geothermal well design will have to account for permafrost to ensure production of hot fluids to surface does not induce melting.

1. INTRODUCTION

Northern Canada faces unique challenges in providing reliable sources of power and heat to numerous remote communities that are isolated from electrical grids, and in some cases have only seasonal winter ice-road access, or are only assessable by aircraft. Thermal and power needs are typically meet by hydrocarbons (typically diesel) delivered by truck, barge, and sealift. In the Northwest Territories (NWT) low annual average air temperatures (down to -8 °C) create high energy demand for space heating, more than double the energy used for electricity. That along with large distances required to transport heating fuels leads to average energy consumption in the NWT of 428 GJ/person, double the Canadian average (NWT Energy, 2011). Fuel delivery can be also subject to variable weather conditions, including timing of seasonal freeze-up, as well as ice break-up, that limits shipments of annual fuel supplies to narrow time windows. Given the remoteness of communities, energy production also requires systems that are highly reliable and relatively simple and easy to maintain. Development of local renewable energy resources could address some of the challenges northern communities face, providing them with greater energy security. Wind power has been implemented extensively, along with and solar and biofuel, these sources are hampered by low to no sunlight through the high latitude dark-season, in addition to issues of windmill blade icing during periods of extreme cold. The low average air temperatures of the territory; however, provides a thermal advantage that increases efficiency of geothermal plants compared to warmer climate regions. This thermal advantage, along with the relative simplicity and robustness of geothermal plants, makes geothermal energy a potentially attractive resource for remote communities of Arctic Canada (Majorowicz and Grasby, 2014) Here we assess geothermal potential of Canada's Northwest Territories (NWT).

The NWT represents a vast territory of > 1.3 million km^2 (larger than India) but with a population of only 44,500 in 33 communities. Nearly half the residents (~20,000) reside in the Territorial Capital Yellowknife. Most regions of the NWT have a sub-arctic climate, with short, warm summers and long cold winters. Summer temperatures range from 14 to 24 °C and winter temperatures between -20 and -40 °C. The territory can be divided into four main geological provinces: 1) exposed igneous and metamorphic rocks of the Canadian Shield in the east, 2) undeformed sedimentary basin in the central part, 3) deformed sedimentary rocks along with igneous intrusives of the Mackenzie Mountains in the west, and 4) sediments of the Beaufort-McKenzie Basin along the northern artic coast (Fig. 1). Availability of data to assess geothermal potential is generally sparse, except in regions where there has been historic petroleum or mineral exploration. Previous studies have shown areas of high geothermal potential in Northern Canada. Maps of depths to various temperatures produced Grasby et al. (2009) show high temperature resources at reasonable drilling depths. Estimates of in-place geothermal energy available at depth have also been made for all of Canada (Majorowicz and Grasby, 2010a, Grasby et al., 2012) and specifically for the western and northern Canada (Majorowicz and Grasby 2010b). Thermal springs of the Mackenzie Mountains have been studied by Caron et al. (2008). Previous studies show significant potential of existing geothermal energy resources is large for some parts of MacKenzie Corridor, Beaufort Delta, and the Cordillera region related to regions of moderate to high heat flow (Fig. 2) (Jones et al., 1990; Majorowicz et al., 1988; Majorowicz et al, 1996, Majorowicz and Grasby, 2014).

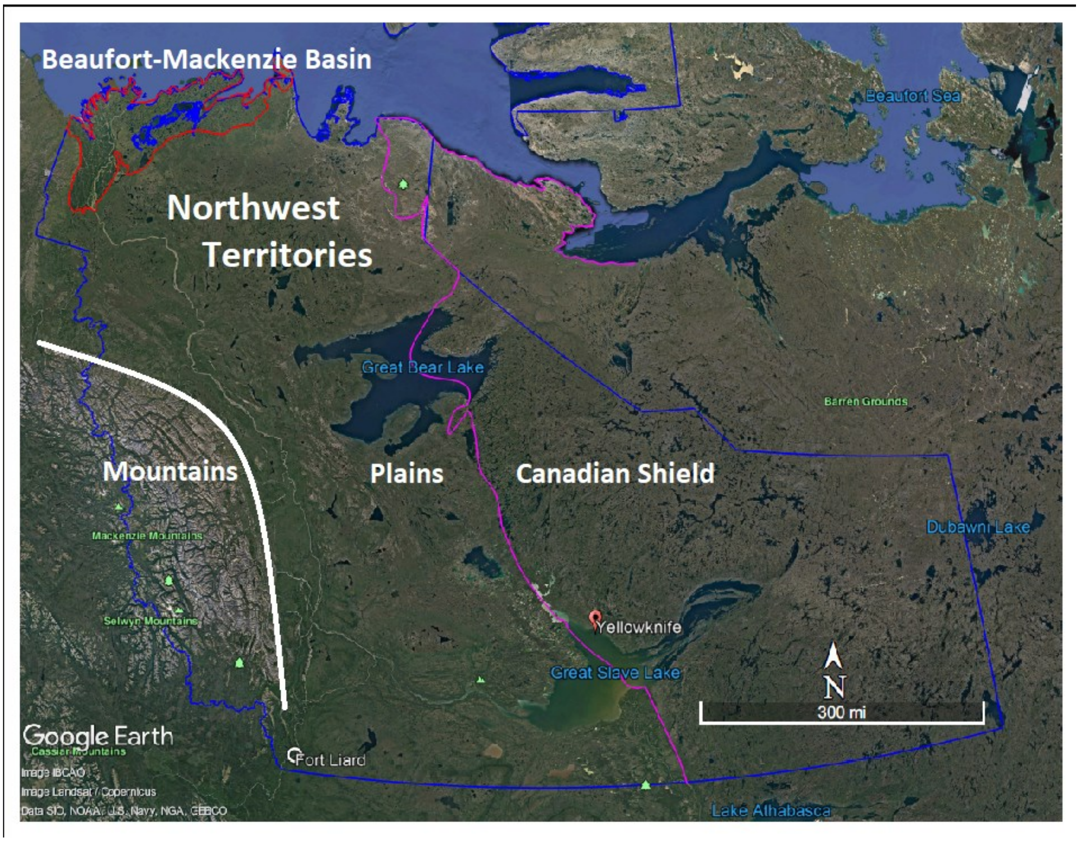

Figure 1: Satellite imaging showing extent of the Northwest Territories along with the major geological provinces of the Candian Shield, Beaufort-Makenzie Basin, the Plains of the Mackenzie Corridor, and in the west the Mackenzie Mountains.

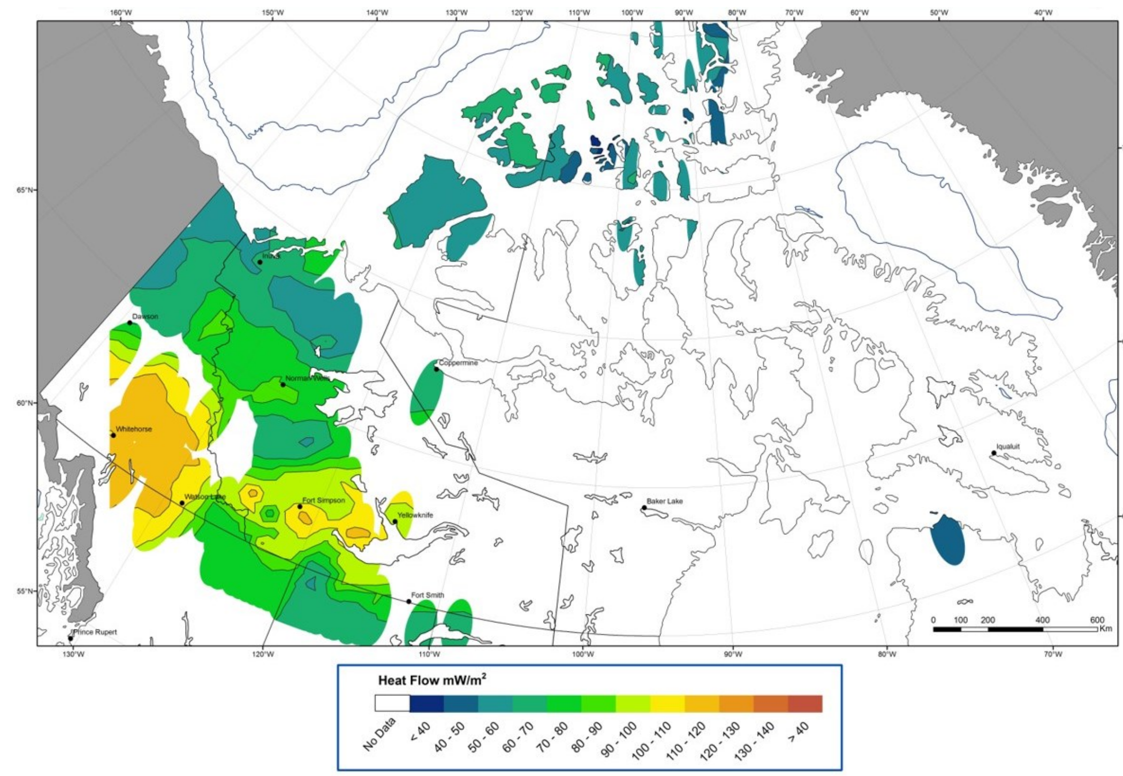

Figure 2: Map showing contours of heat flow for northern Canada, including the Northwest Territories, showing high heat flow in areas of the southern NWT and moderate values in the Beaufort Delta area (after Majorowicz and Grasby, 2014).

2. METHODS

We examined previous data, including assessment of geothermal gradients by Majorowicz and Grasby (2010; 2014) as well as Chen et al., 2008). Most geothermal data for the NWT are derived from petroleum exploration wells. Bottom hole temperatures (BHT) measured by logging tools after completion of drilling were assessed to determine geothermal gradients. Due to thermal disturbances related to drilling they were corrected using the "Horner" method (Dowdle and Cobb, 1975). Drill stem test (DSTs) data measured during production test were also examined as they represent closer to true formation temperatures. The majority of DST temperatures fall along the same trend as corrected BHTs, showing that these two data sources have consistent depth-temperature relationships and are reliable data for regional assessments. These data were also augmented with precise temperature logs collected in portions of the study area (Jessop et al., 2005). The precise data logs were used to constrain temperatures in the upper few hundred metres along with the base of permafrost.

3. NWT RESOURCE POTENTIAL

3.1 Canadian Shield

The Canadian Shield region has large gaps in available geothermal data. Available data for the Canadian Shield in the NWT indicates low heat generation and geothermal gradients, as would be expected for continental cratons dominated by rocks > 3900 Ma (Majorowicz and Grasby 2010a; Grasby et al., 2012). The most detailed temperature logs for the shield area were collected from deep wells at the now abandoned Con Mine site, near Yellowknife. While low gradients that large flooded mine tunnels have been investigated for direct heating potential for parts of city of Yellowknife (Ghomshei, 2007). This direct heating usage within the city was voted against by citizens, in a decision that was thought to be partly due to the economic model presented in addition to technical/cost challenges of fluid transport to the city. However, more recent plans to develop an industrial park in the reclaimed mine site presents new opportunities to assess direct heat use, including establishing building codes for new construction to optimize the on sight energy resource. Assessment of well logs at the Con Mine, with temperature logging down to ~ 1 km, indicates low geothermal gradients of ~17.6 °C/km (Fig. 3). However, deep levels of the mine have temperatures in excess of 30 °C and has an estimated renewable heat resource of 10 to 20 MWt (Ghomshei, 2007). There are other numerous mine sites across the shield portion of the NWT however good quality depth/temperature gradients are currently lacking to assess geothermal potential at these sites. If reasonable gradients exist there is potential to reduce energy costs associated with remote mining operations.

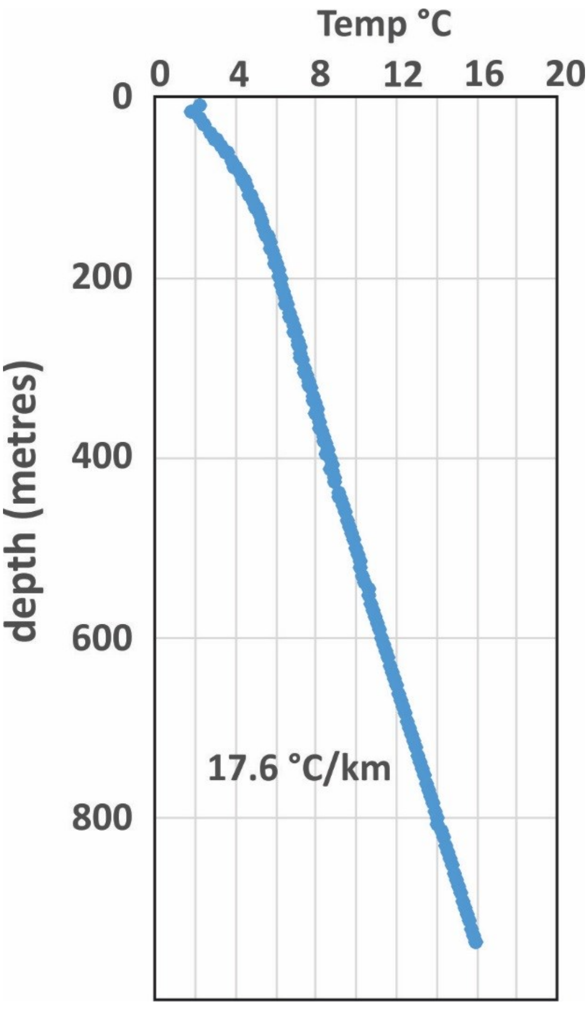

Figure 3: Plot of depth temperature data derived from high precision temperature logging in the Con Mine area, showing a low thermal gradient in the Canadian Shield region.

3.2 Mackenzie Mountains

There are no communities within the Mackenzie Mountains although there are mine sites with significant power and heat needs. The Mackenzie Mountains (Gordey and Anderson, 1993) includes 4 major components: 1) Late Precambrian to Middle Devonian platform-basin assemblage, 2) Devonian-Mississippian turbidite basin assemblage, 3) Mississippian to Triassic clastic shelf assemblage, and 4) regional Jurassic-Cretaceous deformation associated with granitic intrusions of the Mid-Cretaceous Selwyn Plutonic Suite (related to collision of an island arc with western North America) (Gabrielse et al., 1965). Compressive and right lateral strike-slip adjustments in the Mackenzie Mountains continued throughout the Tertiary (~40 Ma) and to the present (e.g. the 1985 Nahanni Earthquake) (Hyndman et al., 2005; Gendzwill, 1994). The Mackenzie Mountains are presently experiencing shortening, at an average of 4 mm/yr (Hyndman et al., 2005). Heat flow and heat generation in the Mackenzie Mountain region is known to be high where assessed (Lewis et al., 2003; Jessop et al., 1984; Majorowicz and Jessop, 1981; Majorowicz 1996), with estimates of 105 ± 22 mW/m^2. Lewis et al. (2003) suggest high crustal heat generation is primarily responsible for the thermal anomalies in this region. The main manifestation of thermal anomalies are the spring systems within the mountain belt. However, most thermal springs occur within the mountain belts where there is a lack of heat flow measurements (Caron et al., 2008), making it difficult to assess if the springs are related to geothermal anomalies, as compared to structural anomalies that allow deep fluid circulation in areas of low heat flow (e.g., Grasby and Hutcheon, 2001). The nearest previously determined geothermal gradients near spring outlets is 23 °C/km (Hyndman et al., 2005) suggesting that thermal gradients are not overly high. It is possible that Plutons have locally higher heat generation and thus higher thermal gradients (Caron et al., 2008), however this has not been assessed.

The over 200 documented springs in the Mackenzie Mountains range in temperatures from 0.3 to 63.6 °C (Caron et al., 2008). While a commonly used definition for ‘thermal’ springs is discharge waters with temperatures > 5 °C above average air temperature, this definition is not functional in high latitude regions with subzero average air temperatures (i.e in northern Canada even frozen water could be defined as a thermal spring). Therefore, in the Mackenzie Mountains we only consider springs > 20 °C as thermal (a total of 29 springs). Using silica geothermometry to estimate maximum sub-surface temperatures (up to 108 °C), in addition to the average geothermal gradient, the deepest circulation depth in the mountain belt is 4.7 km. These are considered minimum estimates of the system’s highest temperatures since dilution and re-equilibration of waters would only lower the estimated temperatures and thus depth. These results do point though to effective advective heat flow and high permeability to depth in the region and consequent potential for localized geothermal systems.

3.3 Mackenzie Corridor

The Mackenzie Corridor is a sedimentary basin that forms a northern extension of the Western Canada Sedimentary Basin. The basin lies between deformed sediments of the Mackenzie Mountains to the west and Canadian Shield to the east. The basins comprise a sedimentary wedge that thickens from zero at the eastern erosion edge with the shield; up to 6 km adjacent to the Mackenzie Mountains fold and thrust belt. Data from over 2000 petroleum exploration and development wells provide the primary data source to assess geothermal potential in this region (Fig. 4). Thermal gradients are variable and range upwards to 50 °C/km (Majorowicz and Grasby, 2019; 2014). The southern portion of the Mackenzie Corridor appears to have the highest geothermal temperatures at the shallowest depths due to a combination of relatively high heat flow (some 90 mW/m^2) and a low thermal conductivity thermal blanket (<2 W/m K). There are several communities located within this region, including Fort Liard, Fort Simpson, Jean Marie River, Fort Providence and Hay River, that could potentially benefit from geothermal development. One challenge, however, is that the sedimentary sequence is characterized by thick units of Paleozoic shale, requiring deep drilling (> 3km) to reach more porous and permeable units at depth. While there has been suggested plans to develop local geothermal power for some of these remote communities no projects to date have reached a drilling stage to define potential fluid production rates.

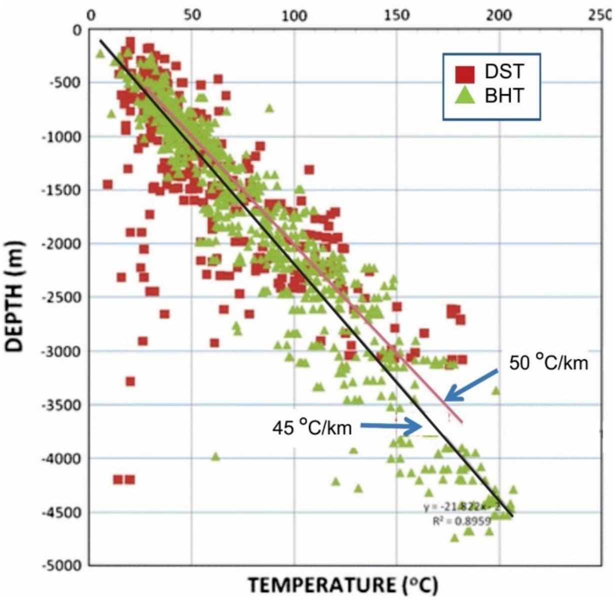

Figure 4: Plot of depth temperature data derived from petroleum wells in the Mackenzie Corridor, showing drill stem test (DST) as well as corrected bottom hole temperatures (BHT) from which are derived average geothermal gradients. The DST measurements have less thermal disturbance and are thought to reflect a more accurate thermal gradient (red line) that is slightly higher that that derived from BHT data (black line) (after Majorowicz and Grasby, 2014).

3.4 Beaufort-Mackenzie Basin

The Beaufort-Mackenzie Basin (BMB) represents a late Cretaceous-Cenozoic post-rift infill of more than 14 km of sediments in a rapidly subsiding deltaic and marine depositional environment in northern Canada (Dixon et al., 1992). The BMB had a complex evolution, that initiated in an open marine setting through most of the Paleozoic followed by a rift-drift system in the Jurassic to Early Cretaceous (Dixon et al., 1994). The Late Cretaceous-Cenozoic history was affected by compression and folding and faulting of the deltaic complexes (Lane and Dietrich, 1995). Permafrost thickness in the BMB varies considerably, from less than 50 m in the western Beaufort Sea to over 740 meter in the central Mackenzie Delta and eastern Beaufort Sea (Issler et al., 2009). Data from over 250 petroleum exploration wells in the BMB, drilled down to 5 km depth, provides information of the basin's thermal structure (Fig. 5). Temperature-depth plots show geothermal gradients ranging from ~25 °C/km in the eastern BMB to 30 °C/km in the western portion of the basin (Chen et al., in prep.). Given this, at any given depth the western BMB is ~20 °C higher than the eastern BMB. Temperatures can also fluctuate locally, particularly in the deeper parts of the basin, related to warmer fluids, driven by mechanical compaction, migrating upwards along permeable fault zones (Chen et al., 2008; Grasby et al., 2009). Overall the geothermal potential in this region is moderate, and development is likely less attractive than local gas fields in addition to large gas hydrate resources in the region (Majorowicz and Hannigan, 2000).

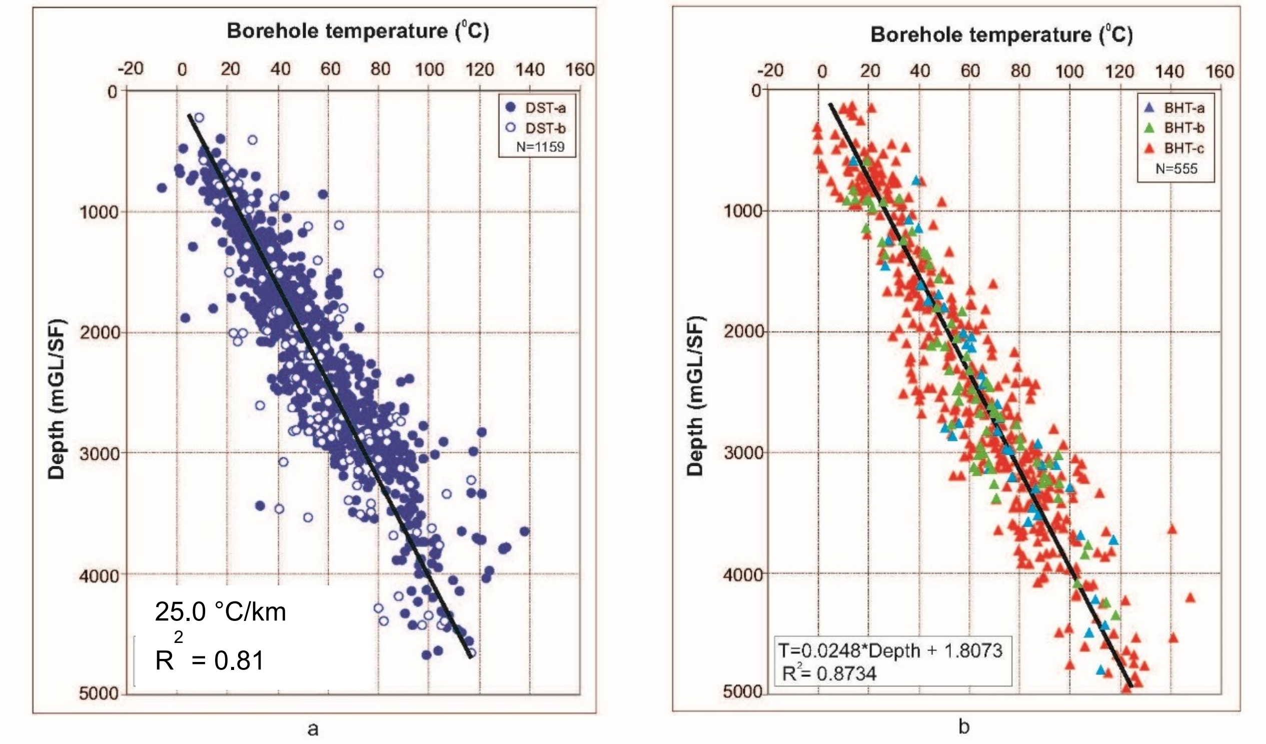

Figure 5: Plot of depth temperature data derived from petroleum wells in the Beaufort Mackenzie Basin for both a) DST data, and b) corrected BHT data. For this region both data sources provide a consistent geothermal gradient.

4. CONCLUSIONS

The Northwest Territories, Canada, is a vast area characterized by dispersed remote and isolated communities, with high per capita energy demand given the low average air temperatures as well as long winter dark period. Provision of energy to meet demand in these areas is both a logistical and financial challenge. Offsetting the current dominant diesel energy systems with local renewable supplies could bring greater energy security to the north. Geothermal energy forms a potential supply for many communities. Our knowledge though is limited to relatively sparse data that was mostly collected for other purposes. While these data support certain regions of the Territory having high geothermal potential, more detailed assessment would likely require a purposefully designed geothermal research effort, including focused data collected.

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