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Regional-Scale Geothermal Exploration Using Heterogeneous Industrial Temperature Data; a Case Study from the Western Canadian Sedimentary Basin

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ABSTRACT

A number of potential geothermal targets have been previously identified in the Alberta Basin (Canada). These targets were identified mainly based on temperature data collected by the oil and gas industry, which are known to be inherently biased by drilling activities and contain large measurement errors. Utilizing the vast number of measurements available from the oil and gas industry we have determined which measurements are statistically reliable in order to re-evaluate the previous temperature estimates for these anomalies, and provide a regionally accurate temperature model. Over 70% of the available measurements were removed from the temperature database based on this method, resulting in a regionally consistent database with average standard deviations of 3°C across all measurement locations.

Three previously identified thermal anomalies in Alberta are re-evaluated using this new temperature database. These are: 1) a hot anomaly near the towns of Hinton and Edson, possibly related to the nearby Miette hot springs (Jones et al., 1982), 2) another anomaly near the town of Swan Hills to the east, and 3) an anomaly near the town of Rainbow Lake in the northwest corner of the province (Majorowicz et al., 2014).

1. INTRODUCTION

Geothermal exploration in hot sedimentary aquifers requires a different approach from the classical high enthalpy exploration model. One such approach is to map geothermal parameters such as temperature to narrow down regions which contain potential geothermal targets. The Alberta Basin in Canada contains a large amount of borehole data collected by the oil and gas industry, including temperature data measured using a number of different methods (e.g. temperatures recorded during drill stem tests).

Temperature data from the oil and gas industry have been used for many geothermal projects worldwide (e.g. Crowell and Gosnold, 2011), and it has long been recognized that temperature measurements made by the oil and gas industry are not always directly useable for geothermal exploration (e.g. Jessop, 1990; Middleton, 1979; 1982). First, we have compiled the available temperature measurements in the Alberta Basin. Then the data were manually pre-culled for values affected by the errors described by Lengyel (2013). However, the large number of data points makes it impractical to manually cull the entire database. Therefore, we have designed a statistical method for the remaining data points to identify the remaining erroneous values and to reduce noise in the data. Here we present the results of this robust culling method in order to depict an accurate picture of the temperature field within the Alberta Basin, specifically focusing on three known hot temperature anomalies near the towns of Hinton and Edson, Swan Hills, and Rainbow Lake.

2. AVAILABLE TEMPERATURE DATA

Previous results in northern Alberta and Saskatchewan (Gray et al. 2012 and Lengyel, 2013) have shown that maximum temperature thermometers can cause a significant bias in the temperature data. This bias affects most significantly shallow data where the temperature at the bottom of the well is colder than at the surface. Therefore in order to both focus on depths where there is realistic geothermal potential, and to remove a majority of the data adversely affected by the maximum temperature thermometer, this study removed all data at depths shallower than 1000m below the surface. The remaining 389,179 measurements from Alberta were used to build a new temperature database.

Commonly used measurements available from the oil and gas industry are bottom hole temperature (BHT) data, which are measurements made at the bottom of a well shortly after a drilling campaign has finished. These data are known to be highly affected by drilling activities (e.g., Bullard, 1947), and are systematically colder than the equilibrium temperature (i.e., the temperature of the subsurface prior to drilling). A correction for this cooling effect can be made using the Horner correction (Lachenbruch and Brewer, 1959) if a set of consecutive measurements are made at the same depth and mud circulation and shut in times are known. For this study all BHT data have been removed except for the few (<2%) data points which could be corrected with the Horner correction.

Two other sources of temperature data were used for this study; drill stem test (DST) and well pressure survey (WPS) data. Both of these data types contain errors from different sources as explained by Lengyel (2013). These errors were manually addressed where possible. In total there were 269,650 temperature measurements available after removing the BHT data, and approximately 31% of these data were manually culled, leaving 186,179 measurements after manual culling.

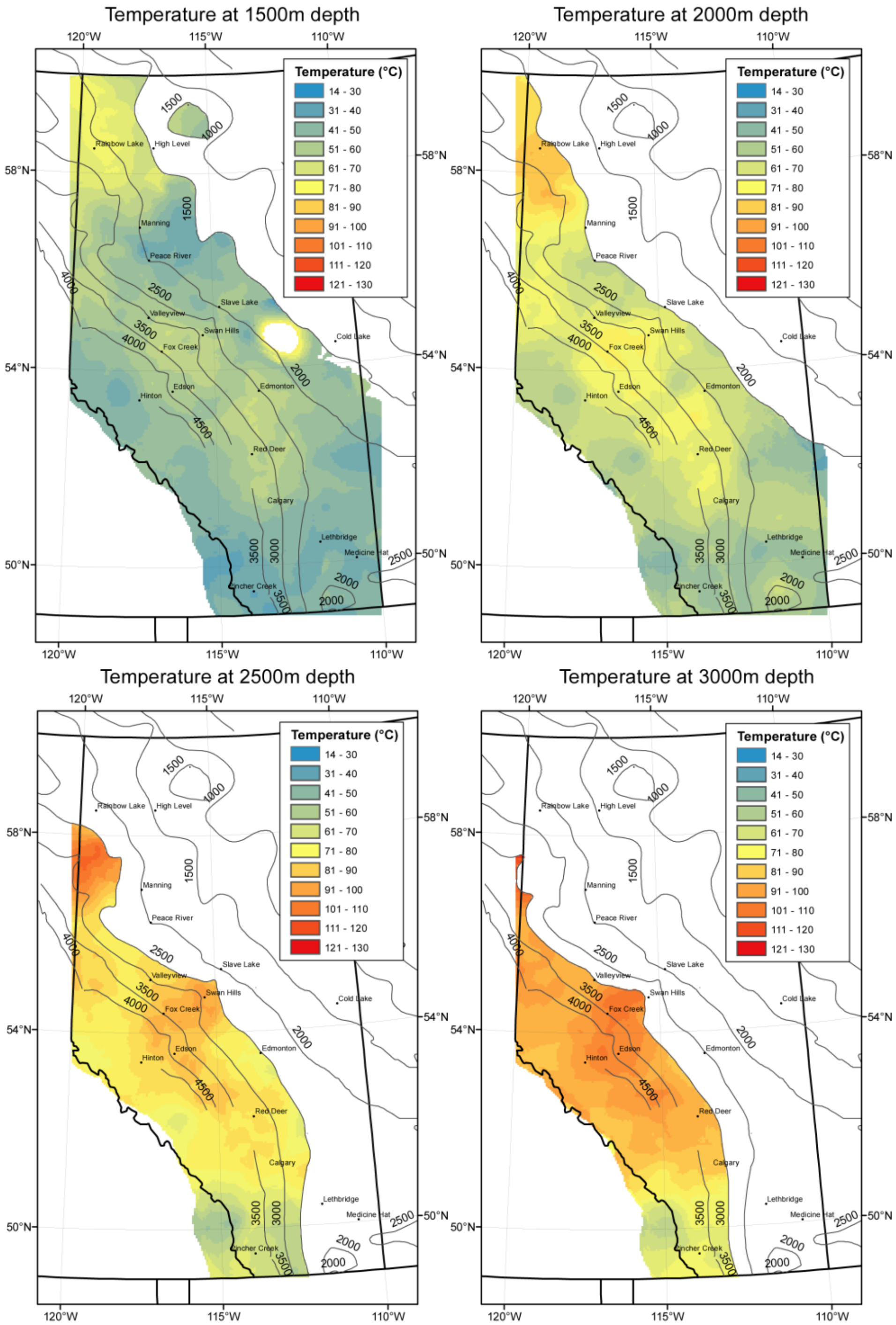

Figure 1: Maps of temperature at four different depths (1500, 2000, 2500, and 3000m). The contour lines represent the depth to the Precambrian basement. The temperatures are not extrapolated into the basement since there is relatively little well control below the basin rocks. In the top left map (1500m depth) the hole in the data grid represents the lack of nearby data.

3. STATISTICAL CULLING

Due to the large number of available temperature data, it was impossible to thoroughly cull the entire database by manually reviewing all questionable measurements as was done in Saskatchewan, Canada (Lengyel, 2013). Therefore, with the assumption that the majority of systematic biases were removed by the initial manual culling stage, we developed a statistical method to remove random noise.

The method developed for the statistical culling is a type of jackknife resampling which iteratively tightens culling thresholds in order to first remove outliers, and then remove data points too far away from the regional mean. The result is a temperature database where the standard deviation calculated with 3D universal kriging at each data point is less than 5°C. The final temperature database displayed in the following figures includes 126,998 temperature measurements from across the Alberta Basin, representing 47% of the initial database prior to manual culling.

4. RESULTS

The resulting temperature database represents a consistent set of temperature measurements throughout the Alberta Basin, and therefore it represents accurately long wavelength temperature variations throughout the basin. However, short wavelength changes are removed. This is an accurate representation of the regional temperature field, as in the Alberta Basin the regional scale heat transfer is characterized by conduction, and convection is only important at the local scale (Bachu, 1988). Therefore the current temperature database is accurate at the regional scale, but it may not properly represent features at the local scale.

The temperature maps in the figures are generated by using 3D universal kriging of the final temperature database, where temperature is linearly dependent on depth. The semivariogram model used for kriging is an exponential model with a range of 100km in the horizontal direction, 1km in the vertical direction, a sill of 22°C, and a nugget of 2°C (modeled and interpolated using the gstat software package in R; Pebesma, 2004).

Figure 1 shows four depth slices of the data, ranging from depths of 1.5km to 3km. The contour lines on each of these maps indicate the depth the Precambrian basement rocks, and the temperatures are cropped where the depth slice intersects the Precambrian basement rocks since little to no temperature data is available below the basin. Figure 1 illustrates that the topography of the Precambrian surface strongly influences the locations of anomalous temperatures. For example, at a depth of 2.5km the highest temperatures are spatially coincident with regional lows in the basement surface.

4.1 Rainbow Lake Anomaly

Figure 1 shows that at shallow depths (1.5km) the most apparent temperature anomaly is in the northwest corner of Alberta near Rainbow Lake. This anomaly has been noted previously by Majorowicz et al. (2014) and contains the highest temperatures measured in Alberta at shallow depths (e.g., the 2km depth slice shows temperatures over 90°C).

Figure 2 shows the unfiltered data on the left (including the colder BHT data), and a map of the filtered data at a depth of 2.25km on the right. The unfiltered data shows a large spread in temperature, highlighting the necessity for removing the erroneous data. The map on the right side of Figure 2 shows the spread of data available at 2.25km (+/- 125m), as well as indicating that temperatures as high as 110°C can be expected at a depth of 2.25km.

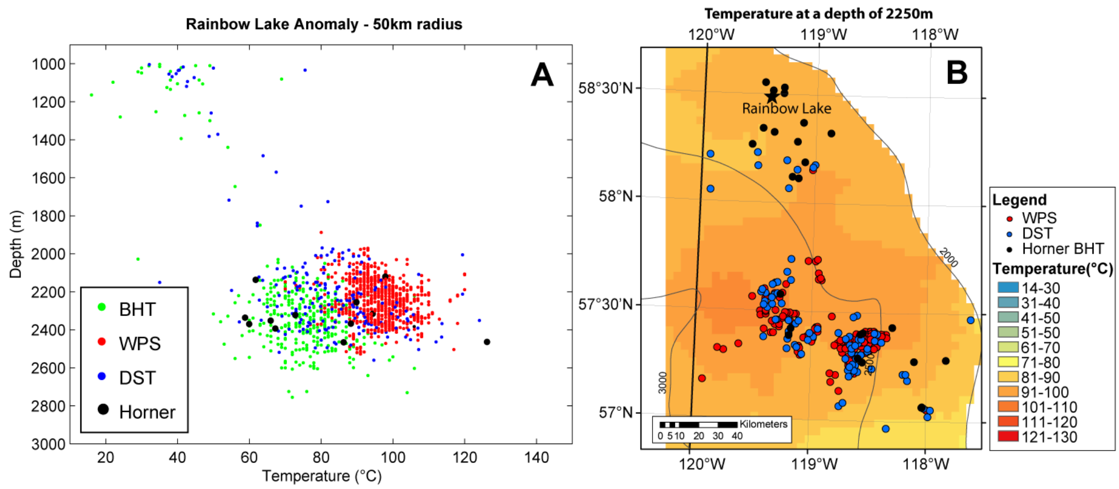

Figure 2: The Rainbow Lake anomaly, A) shows a temperature - depth plot of the data prior to culling, B) shows a map of the results after culling, and depicts the spatial extent of the anomaly at a depth of 2.25km, with statistically robust temperatures as high as 110°C.

4.2 Swan Hills Anomaly

The 2.5km depth slice in Figure 1 shows that another anomaly becomes apparent around Swan Hills. At this location temperatures over 100°C are present at depths as shallow as 2.5 km. The anomaly appears to be correlated in space to a topographic low in the depth to the basement surface.

Figure 3 shows a plot of the Swan Hills anomaly, again showing a wide spread in the unfiltered temperatures in A, but also indicating a cluster of anomalously high WPS temperature measurements (red ellipse) with temperatures slightly above 110°C at a depth of 2.25km. These high temperatures are measured in the relatively small area indicated by the red circle in the map in B. The surrounding data at 2.25 km are closer to 100°C, and also represent a warm anomaly in comparison to much of the rest of the Alberta Basin at this depth.

4.3 Hinton - Edson Anomaly

The Swan Hills anomaly is connected to an anomaly first discovered by Lam et al. (1982), known as the Hinton-Edson anomaly (see the 3km depth slice in Figure 1). This anomaly was originally thought to contain temperatures as high as 175°C at 4.2km depth, although Jones et al., (1984) have shown to expect temperatures closer to 140°C at 4.2km. Further to this, Majorowicz et al., (1984) showed that the geothermal gradient changes at the paleozoic unconformity (approximately 3km depth), from a relatively average gradient near the surface (30.4°C/km) to a higher gradient at depth (35.2°C/km). This explains why there is no obvious anomaly at shallow depths in the Hinton-Edson region (Figure 1), and this anomaly only becomes apparent at depths below the unconformity.

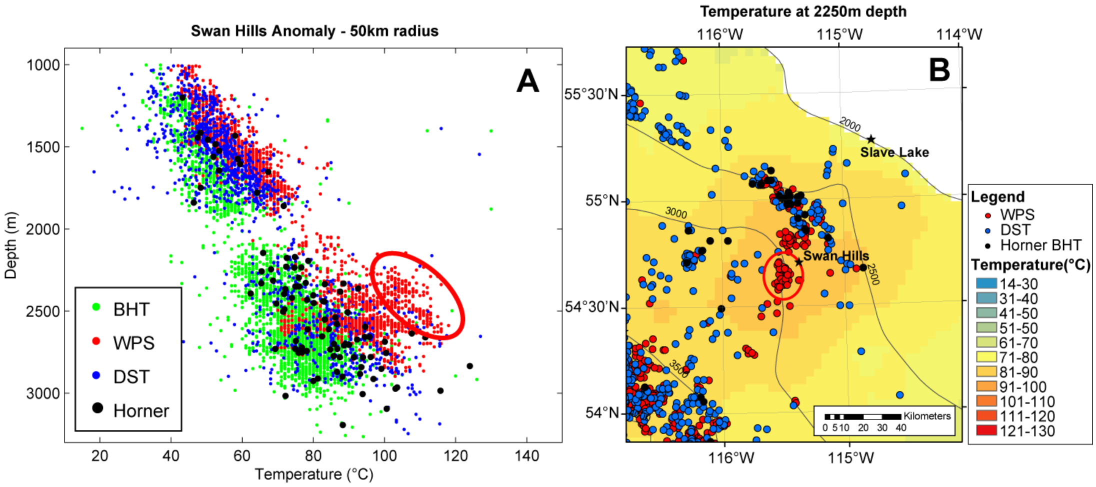

Figure 3: The Swan Hills anomaly, A) shows temperature depth plots prior to culling. The red ellipse highlights a number of WPS measurements indicating higher than average temperatures in a small region. B) shows a map of the results after culling. The recorded temperatures in the red ellipse represent temperatures at a depth of 2250m slightly warmer than 110°C, while surrounding measurements are closer to 100°C at the same depth.

Figure 4A indicates a plot of the available data in the vicinity of the Hinton Edson anomaly (prior to culling), and Figure 4B shows a close up of the anomaly in the final temperature database at a depth of 4.25km.

The temperatures in the final temperature database (Figure 4B) do not indicate temperatures as high as originally anticipated by Lam et al., (1982), however the highest temperatures measured anywhere in the Alberta Basin are reported from this area.

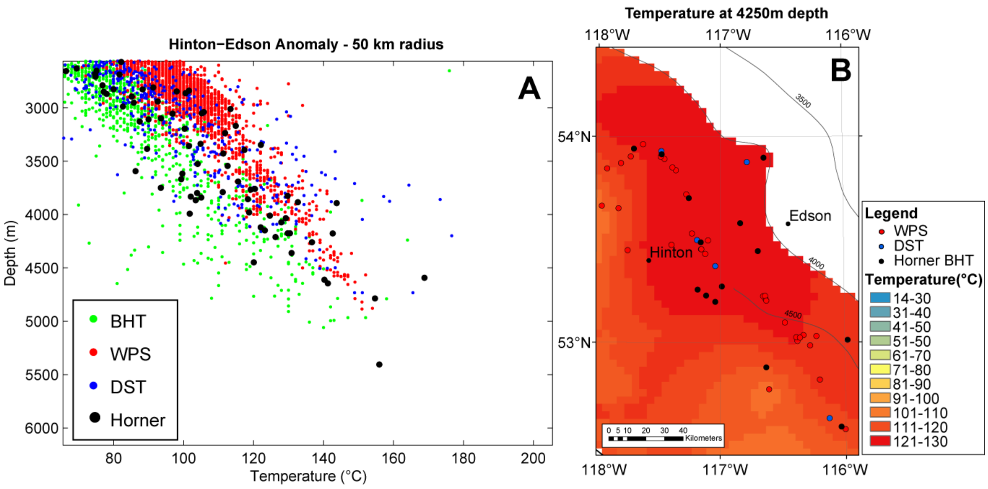

Figure 4: Temperature depth plot of all available measurements within a 50km radius of the Hinton - Edson anomaly pointed out by Lam et al. (1982). A) shows all available data points from within a 50km radius, B) shows a map of the results after culling the database.

5. CONCLUSION

The temperatures of three anomalies located within the Alberta Basin have been re-evaluated using a new regionally consistent temperature database. This new temperature database is compiled from three different sources of temperature data collected by the oil and gas industry, and represents a statistically robust, regionally consistent estimate of temperatures within the Alberta Basin.

The Hinton-Edson anomaly represents the warmest temperatures measured in Alberta, but requires relatively deep drilling to access these temperatures. The Swan Hills anomaly is spatially related to the Hinton-Edson anomaly, but is located at shallower depths and therefore is easier to access. Lastly, the Rainbow Lake anomaly in northwest Alberta has relatively high temperatures at shallow depths, and is also regionally widespread, indicating a significant geothermal potential for a wide variety of applications.

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