Geothermal Mapping in Alberta - a Statistically Robust Approach

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Introduction

In order to obtain a robust estimate of temperature at depth in the Alberta Basin, temperature data were compiled from oil and gas measurements. These steps were used to remove both systematic and random bias in the data:

Step 1 – the dataset was manually culled based on available metadata and known issues.
Step 2 – A statistical approach was used to ensure the remaining data were regionally consistent.
Step 3 – Modelling of the data to obtain robust temperature – depth estimates.

The result is a regionally consistent model of temperature in the Alberta basin, which can be used to interpret heat transfer mechanisms and geothermal potential.

Step 1: Manual Data Culling

We have compiled four types of temperature estimates from oil and gas well data which are commonly available from the oil and gas industry:

BHT – Bottom Hole Temperatures. Measured shortly after drilling is complete, these are widely available, but highly affected by drilling activities.
DST – doll test temperature. These include temperature measurements, ideally sampling the reservoir fluids and reporting the equilibrium reservoir temperature.
WPS – well pressure survey data (including annual pool pressure survey data). These data are regularly measured long after drilling has finished, and often reflect the equilibrium subsurface temperature.
Horner Corrected BHT data – When multiple BHT measurements are made at the same depth and both the shut in time and mud circulation time are known, corrections can be applied to estimate the equilibrium temperature (e.g. Lachnichrus and Brewer, 1999).

The first step in obtaining a robust dataset was to manually remove datapoints which are incorrect due to digitization error, erroneous points which were estimated instead of measured, etc. A full explanation of the potential errors can be found in Lengyel (2013), and Gray et al. (2012). Figure 1 shows how much data was originally available, and how much was removed in the manual data culling process.

Figure 1 – Bar graph showing how much data was manually culled relative to the amount of data available.

The measurements locations are clustered in oil and gas reservoirs, and there are many outliers which do not match the nearby datapoints. We use an iterative jackknife method to remove the most obvious outliers first, and then tighten the thresholds more and more each iteration to ensure nearby datapoints are consistent with one another. The result is a database where the 3D covariance weighted averages of each datapoint have standard deviations mostly below 5°C (see Figure 5).

Step 2: Statistical Data Culling

The result is a database where the 3D covariance weighted averages of each datapoint have standard deviations mostly below 5°C (see Figure 5).

Figure 2 – Map showing the uneven distribution of temperature data available in Alberta (e.g. Swan Hills area is densely sampled, while the Precambrian basement from the surface). Temperature highs can be noted south of Rainbow Lake, and in the region of Swan Hills, Holts, and Edson. Southern Alberta is generally relatively cold, while northern Alberta is relatively warm at any given depth.

Figure 3 – Temperature along the top of the Precambrian basement. This map shows the increasing temperature with depth of this surface, with a few areas where warmer temperatures are present at shallower depths (southern Swan Hills). Note that the color scale is different from Figure 7.

The heat flow through the basin can be calculated using the temperature difference between the top and bottom of the basin, along with estimates of the total thermal conductivity through the entire basin. The temperature difference we used is from the data shown in Figure 8, as well as assuming the surface temperature is 0°C. The thermal conductivity model was made by using thermal conductivity measurements of Alberta basin rocks by Beach et al. (1987), and assigning values based on lithology to lithology logs available across the basin. Figure 9 shows the integral thermal conductivity through the basin, and Figure 10 shows the calculated heat flow.

The heat flow anomaly in the northwest corner of the province has been identified in other studies (e.g. Majorowicz et al., 2013), and the advantage of this new temperature dataset is the ability to interpret the anomaly in more detail than before.

The next step in this study is to begin to interpret changes in heat flow with depth, which can be associated with a divergence from purely conductive heat transfer such as fluid flow.

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Figure 4 – Histogram showing the standard deviation of the data calculated using 3D co-variance weighted averaging before (left) and after (right) statistical culling.

Figure 5 – Temperature well data before statistical culling.

Figure 6 – Bar graph showing the amount of data culled by statistical culling.

References