Ancient and recent temperature evaluation using geochemical data and geostatistics in Perth Basin, Western Australia

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Abstract

In this study, I applied geochemical and statistical calculations for evaluation of temperature changes in the Perth Basin, Western Australia. The geochemical calculation includes deriving ancient temperatures from Rock-Eval pyrolysis Tmax and/or vitrinite reflectance and comparing them to recent well temperatures taken from well reports. The results show that Permian rock temperature change from ancient to recent, range from -207° to +6.2°C. The analyzed data were first treated statistically with exploratory methods to discover any pattern of distribution. The methods used were a scatterplot, a histogram and a bubble plot. The scatterplot revealed no correlation between delta temperature and depth. The histogram showed the delta temperatures have an asymmetrical distribution and the bubble plot conveyed the wide range of delta temperatures across the study area. In addition, two Kriging interpolation methods were employed to predict delta temperature distribution across the region; Ordinary Kriging interpolation and Kriging with External Drift. Finally, the cross-validation error Root Mean Square Error of Prediction (RMSEP) between the two methods was calculated and compared. RMSEP results for the Ordinary Kriging was 42.53365 and the Kriging with External Drift was 44.77281.

Introduction

Perth Basin is a sedimentary basin on- and offshore of southern Western Australia (Fig. 1). It has seen mediocre petroleum production from the 1950s-1980's and in recent years has been revitalized as a highly prospective basin for oil and gas, and recently, geothermal energy (Government of Western Australia, 2014). An essential element for a productive petroleum system is mature hydrocarbons. Hydrocarbons are born with the help of intense heat from overburden pressure or geologic events, such volcanism or faulting (North, 1985). It is therefore important to understand the thermal regime of an area of interest not only for petroleum energy but also, and perhaps more importantly, for renewable geothermal energy. This study hopes to compare ancient subsurface temperatures to recent subsurface temperatures of Perth Basin and determine any effect depth has on the temperatures because temperature should increase with depth because of the geothermal gradient (Forrest et al., 2007). This change in temperature (delta temperatures) can be used to better understand areas that are more suitable for energy exploration because they are either cooling or heating.

The temperature data sets used in this study are twofold. The recent temperatures are straightforward as they are simply taken from well reports and literature (Geoscience Australia; Holgate and Gerner, 2010; Jackson et al., 1982). The calculation of ancient temperatures are more involved as they are derived from geochemical rock sample analysis of vitrinite reflectance, Tmax(Ro), and maximum temperature recorded from the analysis of Rock-Eval pyrolysis, Tmax(REpryo).

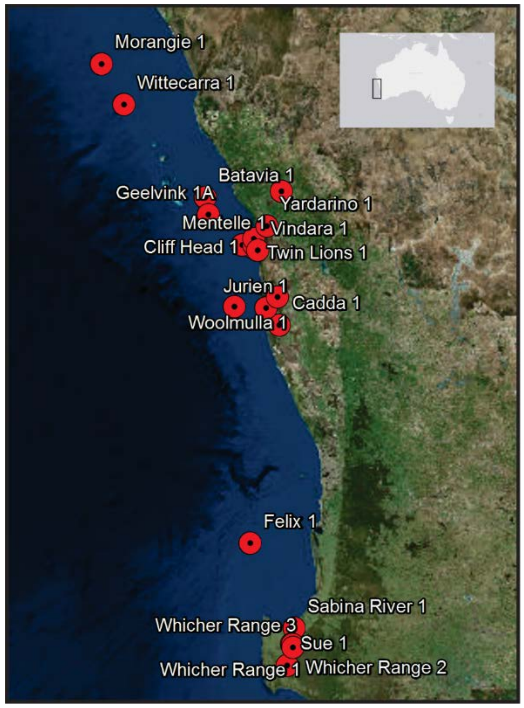

Figure 1. Index map of the study area with studied wells in Perth Basins, Western Australia. Inset of Australia shows larger map location.

Methods

Data

Well data was primarily taken from the website of Geoscience Australia Petroleum Well Database provided for free by the Australian Government. However, some wells that were not available from Geoscience Australia were found from publications. The initial search was based on 350+ petroleum wells offshore Western Australia's Perth Basin. Of these 350+ wells only 21 have the necessary information for a temperature comparison. The two different temperature values are both from the Permian age interval (299-253 million years ago). This age was chosen because that is the age of an ancient rifting event and also because it is a last prevalent age before basement has been reached (Jorgensen et al., 2011).

Vitrinite is a type of organic material found in coal and hydrocarbons. When immersed in oil and studied under a reflecting microscope, the amount of light reflected can be measured and reported as a percentage, vitrinite reflectance, Ro. Maturity is a measure of how much organic sediments have turned into hydrocarbons from thermal alteration. Therefore, Ro is an index of the maturity of sediments (North, 1985). Hence, diagenetic Tmax (Ro) can be obtained from Ro by the following equation from Barker and Pawlewicz, 1986:

$$\ln(Ro) = 0.0078 * T - 1.2$$

Tmax can also be obtained from Rock-Eval analysis of ground rock samples. When hydrocarbons undergo pyrolysis, the kerogen (an oil precursor) crack at a maximum temperature which is related to the initial hydrocarbon diagenesis. Jarvie et al. (2005) produced a conversion formula to calculate %Ro from Tmax(REpyro) data.

$$\text{calculated Ro} = 0.0180 \times \text{Tmax(Pyro RE)} - 7.16$$

Results and Discussion

Once the Permian delta temperatures for the Perth Basin were calculated, some statistical analysis were run to better understand the results. These took place with the statistical software R. First, exploratory methods were done. Second, ordinary Kriging interpolation, as well as Kriging with external drift based on depth was then computed. Finally, the comparison of these two Kriging results were compared based on the Root Mean Square Error of Prediction cross-validation method, RMSEP. RMSEP is the prediction error of the measured vs predicated delta temperatures.

The expectation is that ancient temperatures would be hotter than recent temperatures; there shouldn't be any positive temperature changes because the heat would have equilibrated or lessened over time. Distribution should be normal. In addition, temperatures should increase with depth because of the geothermal gradient (Forrest et al., 2007).

However, based on preliminary data analysis from a histogram, bubble and scatterplot, there is no correlation between delta temperatures and depth, and more interesting is that delta temperatures have an asymmetrical distribution. Figure 2 is a simple scatter plot of subsurface depth and delta temperatures. There is no correlation between the two. Figure 3 is a histogram of the delta temperatures and it is apparent that the dataset is asymmetrical, not normally distributed. Figure 4 is a bubble plot of delta temperature distribution of the Perth Basin. Again, is it apparent there is a wide range of values of temperature change ranging from -207°C to 6.2°C. Also of note, is that there is a positive value very close to a very negative delta temperature.

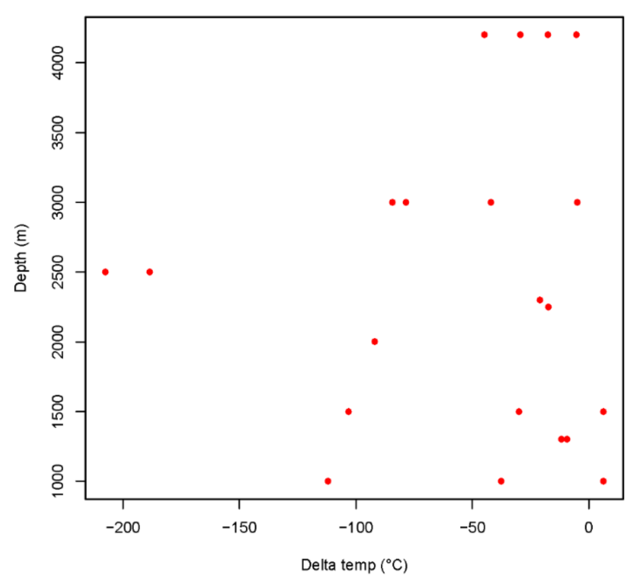

Figure 2. Scatterplot of delta temperatures vs. depth.

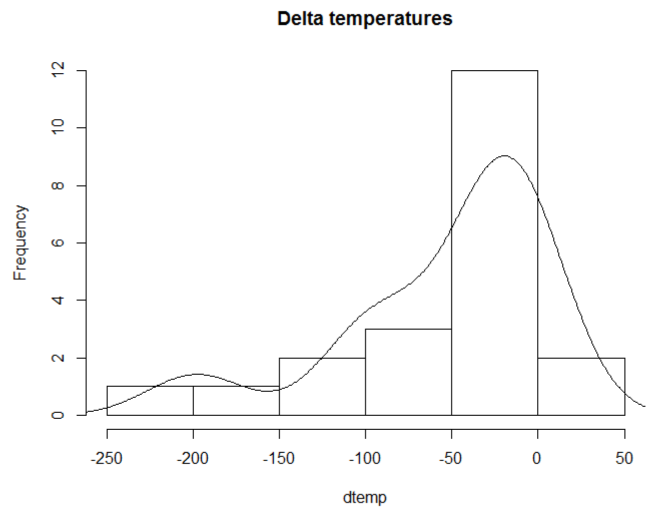

Figure 3. Histogram of delta temperatures indicating an asymmetrical distribution.

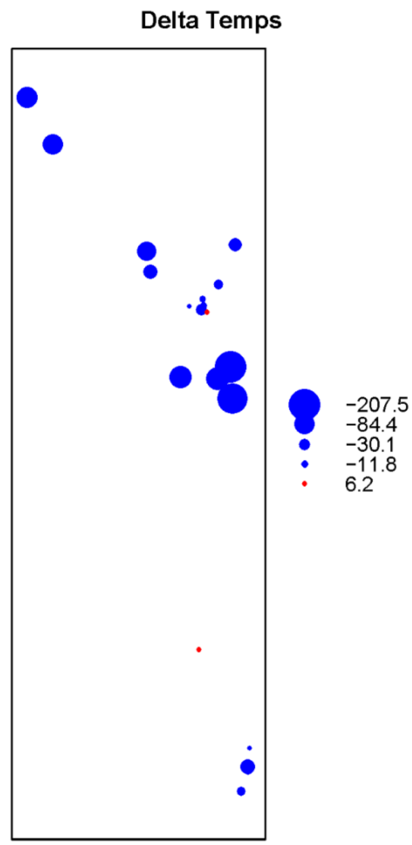

Figure 4. Bubble plot of delta temperatures. Note the range of values and the two positive change in temperature points.

Once the distribution and correlation of data set it known, spatial interpolation is the next stage to understand predictive values of delta temperatures and depth. First, a variogram analyzes the spatial dependence between depth values and delta temperature values. Because the data is so unevenly distributed and there is no correlation, the variogram for each, only model a few data points each (Fig. 5). Using the variogram model the Ordinary Kriging and Kriging with Extern Drift were computed (Fig. 6).

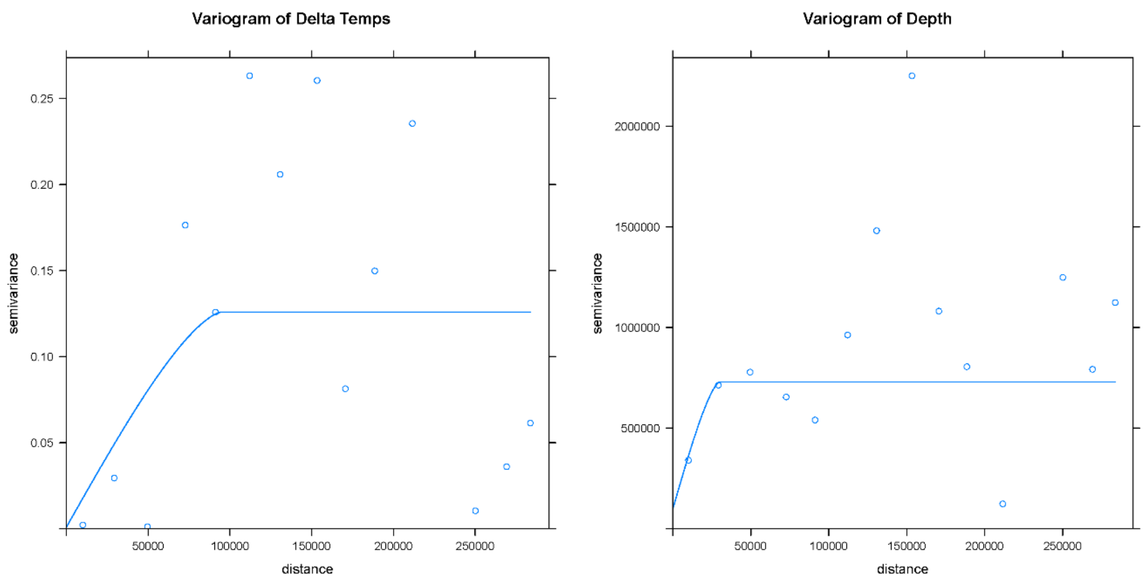

Figure 5. Variogram for delta temperatures and depths.

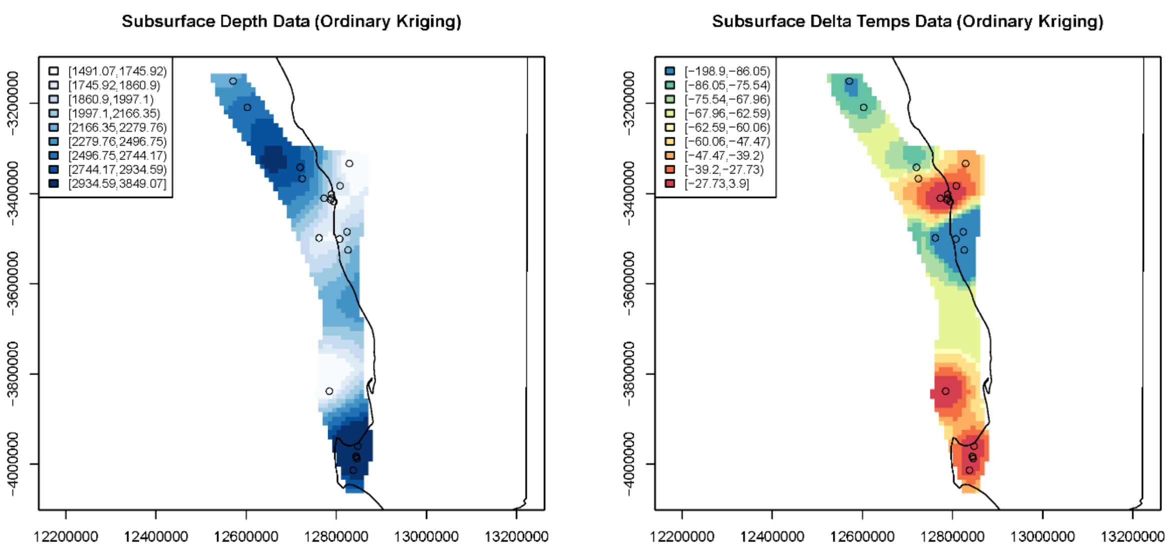

Figure 6a. The ordinary Kriging interpolated surface of depth data (left) and b. The ordinary Kriging interpolated surface of the delta temperatures (right).

After careful visual inspection (Fig. 7), the two interpolation methods don't appear to have changed much by adding in the depth parameter. Indeed, when the cross-validation RMSEP is calculated, the Ordinary Kriging is 42.53365 and the Kriging with External Drift is 44.77281. This means when you predict a value from the Kriging with External Drift, the average error of that prediction is slightly worse than not Ordinary Kriging. Therefore, adding the depth component to the interpolation is not necessary.

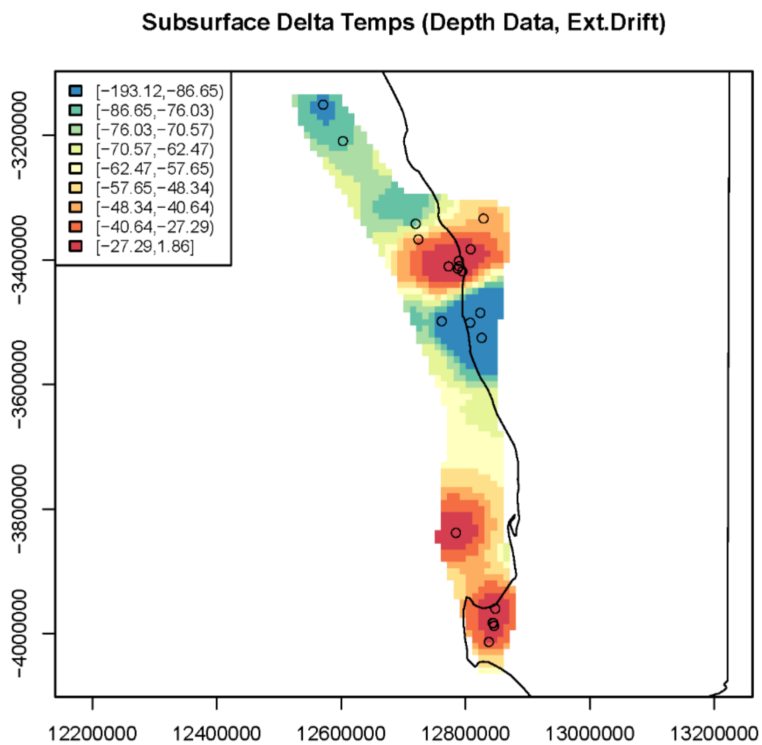

Figure 7. The predicate values of delta temperatures based on Kriging with External Drift.

Conclusion

This study set out to determine the change in temperature from ancient subsurface rocks and recent well samples. By searching through 350+ wells in the Perth Basin Western Australia, twenty-one wells had the two necessary components to make this calculation. Then, a unique method of determining ancient temperatures from geochemical analysis was performed to calculate delta temperatures. Once the delta temperatures were calculated for each well, Kriging interpolation was created to predict delta temperatures across the region. When cross-validation methods were done on the two Kriging methods, it revealed that the depth parameter is not an important variable to consider for delta temperatures. In addition, the distribution of values is such that there must be some underlying geologic processes at work, and not just geothermal gradients that are contributing to the thermal regime in Perth Basin.

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