GRC *Transactions*, Vol. 39, 2015

Geostatistical Analysis of Bottom-Hole Temperatures in the Denver and Williston Basins: North America

Anna Crowell

Harold Hamm School of Geology and Geological Engineering, University of North Dakota

Keywords

Geostatistics, GIS, Williston Basin, Denver Basin, Bottom-Hole Temperatures

ABSTRACT

Bottom-hole temperatures (BHTs) obtained from oil and gas wells have never been completely reliable due to the formation temperature disturbance caused by the influence of the drilling mud on the formation rock during drilling. A correction method must be applied before any BHT data can be used. The source and method of the correction, however, has been a topic of dissention since the early 70s, when BHTs began to be used for estimates of temperature at depth to determine such things as hydrocarbon maturity, thermal history, and geothermal energy assessment.

Several correction methods are currently used: the Harrison (Harrison et.al., 1983), Kehle (Kehle et.al., 1970), and Förster (Förster et.al., 1996) are among the most prevalent. None of these methods yield a correction that represents a statistically accurate distribution of BHTs, although the Harrison and Kehle have been found to be a much better approximation (Crowell and Gosnold, 2013). All of these methods were developed using a top-down approach, where an equilibrium temperature profile has been obtained and

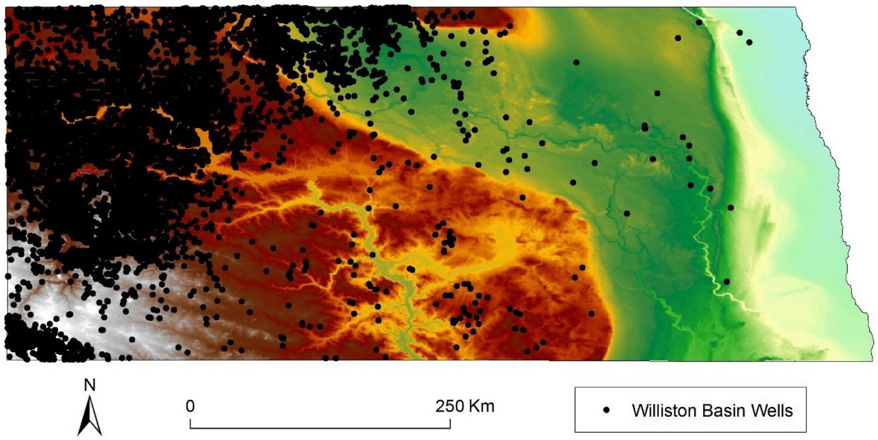

Figure 1. Spatial Representation of the 10,766 wells with bottom-hole temperature data in the Williston Basin.

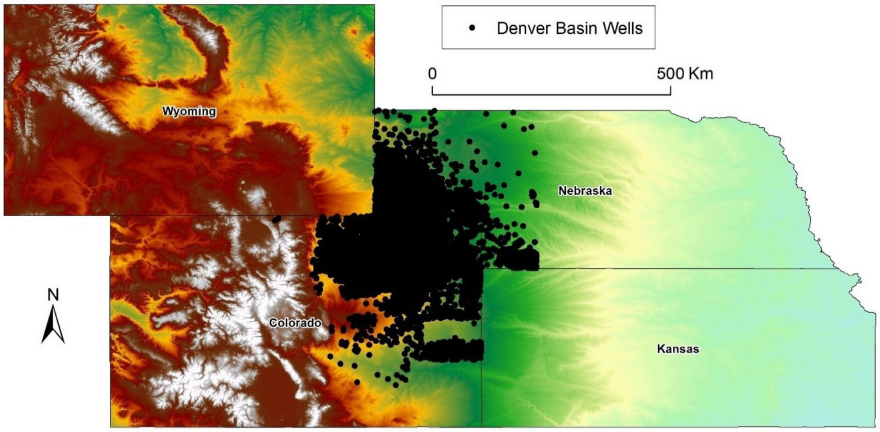

Figure 2. Spatial representation of the 49,222 wells with bottom-hole temperature data in the Denver Basin.

a correction equation was developed to attempt to shift the best fit line of the data points to the best fit line of the data obtained at equilibrium.

In addition, formation data are not always included with the bottom-hole temperature data. This makes resource assessment based on formation difficult, if not impossible. We therefore hypothesize that by using two geostatistical methods, Moran's I and Getis-Ord, we will be able to evaluate if a better correlation exists between a depth-interval well parsing versus a geochronological unit well parsing, and if a correlation exists, is it strong enough to indicate that a correction factor is possible.

Methods

We used geostatistical methods to examine the BHT datasets for the Williston basin (Figure 1) in North Dakota, and the Denver basin (Figure 2) in Colorado and Nebraska. The first geostatistical method we used was a spatial autocorrelation method called Global Moran's I. Global Moran's I is a geostatistical method that examines the frequency distribution of a dataset and compares it to an expected or random dataset. A Z-value is generated that can then be used to determine if the data is clustered (correlated) or random (non-correlated). We also wanted to determine the degree of clustering with a dataset if it is spatially correlated. We used the Getis-Ord Hot Spot analysis, which determines a Z-value and returns whether the data sets are random (non-correlated), low clustering (weakly correlated) or high clustered (strongly correlated). The datasets were then split up into 500 meter depth interval units as well as geo-chronological units, and analyzed the using both geostatistical methods. Once Z-values were calculated, we were able to determine if the data were spatially auto-correlated based on BHT, and therefore correctable. We were also be able to tell if parsing out wells using the depth interval method, or by the geochronological unit method, was statistically best for resource assessment.

Figure 3. Moran's I analysis for the Denver Basin. Non-correlated units are denoted in red.

Denver Basin

Interval	Z-score	Distribution	p-value	# wells	Interval	Z-score	Distribution	p-value	# wells
500-1000m	21.42	Clustered	0	1,414	Upper Cretaceous	46.05	Clustered	0	12,739
1000-1500m	30.93	Clustered	0	8,772	Lower Cretaceous	113.85	Clustered	0	33,148
1500-2000m	67.62	Clustered	0	17,924	Jurassic	0.77	Random	0.44	480
2000-2500m	115.6	Clustered	0	19,524	Permian	2.22	Clustered	0.026	331
2500-3000m	8.68	Clustered	0	1,542	Pennsylvanian	7.76	Clustered	0	1,478
					Mississippian	31.5	Clustered	0	845
					Ordovician	0.207	Random	0.836	132
					Cambrian	4.34	Clustered	0.00004	54
All Wells	182.12	Clustered	0	49,222					

Figure 4. Results of the Getis-Ord analysis for the Denver Basin. Non-correlated units are shown in red, while weakly correlated units are shown in yellow.

Denver Basin

Interval	Z-score	Distribution	p-value	# wells	Interval	Z-score	Distribution	p-value	# wells
500-1000m	0.99	Random	0.32	1414	Upper Cretaceous	67.25	High Cluster	0	12739
1000-1500m	8.73	High Cluster	0	8772	Lower Cretaceous	68.56	High Cluster	0	33148
1500-2000m	13.69	High Cluster	0	17924	Jurassic	-0.01	Random	0	480
2000-2500m	8.88	High Cluster	0	19524	Permian	0.79	Random	0.43	331
2500-3000m	64.32	High Cluster	0	1542	Pennsylvanian	-6.84	Low Cluster	0	1478
					Mississippian	-10.58	Low Cluster	0	845
					Ordovician	-0.57	Random	0.57	132
					Cambrian	-2.92	Low Cluster	0.0035	54
All Wells	158	High Cluster	0	49222					

Results

Denver Basin

The Moran's I (Figure 3) analysis indicates that BHTs are correlated stronger by depth interval unit than by geochronological unit, since the z-values indicate clustering within the dataset for every interval, whereas only five of the eight geochronological units were spatially correlated. The Getis-Ord Analysis (Figure 4) indicates that four of the five depth intervals were highly clustered, indicating a high spatial correlation. The geochronological units were only highly clustered (high spatial correlation) in two instances, and either random or low clustering (non-correlated or low-correlation) for the other six units.

Williston Basin

The results of the Moran's I analysis for the Williston Basin (Figure 5) were not nearly as polarized as the results for the Denver Basin. All eight depth interval units were clustered showing spatial autocorrelation, and eight of the nine geochronological units were clustered. The results of the Getis-Ord analysis for the Williston Basin are shown in Figure 6. Six of the eight depth interval units were highly clustered, one was weakly clustered, and one was random. Of the nine geochronological units, six were highly clustered and three were random.

Figure 5. Results of the Moran's I analysis for the Williston Basin. Non-correlated units are denoted in red.

Williston Basin

Interval	Z-score	Distribution	p-value	# wells	Interval	Z-score	Distribution	p-value	# wells
500-1000m	8.97	Clustered	0	253	Cretaceous	8.89	Clustered	0	261
1000-1500m	40.3	Clustered	0	905	Jurassic	7.05	Clustered	0	50
1500-2000m	24.93	Clustered	0	990	Pennsylvanian	5.18	Clustered	0	216
2000-2500m	48.63	Clustered	0	846	Mississippian	134	Clustered	0	7,285
2500-3000m	23.6	Clustered	0	2,773	Devonian	21.24	Clustered	0	914
3000-3500m	23.86	Clustered	0	3,532	Silurian	32.34	Clustered	0	372
3500-4000m	10.86	Clustered	0	705	Ordovician	4.49	Clustered	0.00000	1,487
4000-4500m	2.32	Clustered	0.0199	707	CambroOrd	7.62	Clustered	0	100
					Precambrian	1.3	Random	0.195	51
All Wells	130	Clustered	0	10,766					

Figure 6. Results of the Getis-Ord analysis for the Williston Basin. Non-correlated units are shown in red, while weakly correlated units are shown in yellow.

Williston Basin

Interval	Z-score	Distribution	p-value	# wells	Interval	Z-score	Distribution	p-value	# wells
500-1000m	4.77	High Cluster	0.00000	253	Cretaceous	2.2	High Cluster	0.02758	261
1000-1500m	3.2898	High Cluster	0.00100	905	Jurassic	1.36	Random	0.173	50
1500-2000m	-0.489	Random	0	990	Pennsylvanian	0.573	Random	0.567	216
2000-2500m	-10.12	Low Cluster	0	846	Mississippian	50.8	High Cluster	0	7285
2500-3000m	9.96	High Cluster	0	2773	Devonian	16.66	High Cluster	0	914
3000-3500m	17.88	High Cluster	0	3532	Silurian	8.039	High Cluster	0	372
3500-4000m	8.747	High Cluster	0	705	Ordovician	2.12	High Cluster	0.03385	1487
4000-4500m	3.788	High Cluster	0.00015	707	CambroOrd	6.39	High Cluster	0	100
					Precambrian	1.5	Random	0.13221	51
All Wells	65.78	High Cluster	0						

Discussion

The geostatistical analyses for both basins, completed by using depth interval units, yields better spatial autocorrelation results than intervals defined by geochronological units; therefore, it is still possible to do a layer-by-layer geothermal resource assessment using data that is missing formation information. Since the bottom-hole temperatures are statistically clustered in relation to depth, the temperatures appear to be correctable with the commonly-used depth-variable correction methods, such as the Harrison and Kehle.

Conclusions

Both the Moran's I and the Getis-Ord analyses showed a clustered distribution of bottom-hole temperatures for the Williston and Denver basins, indicating that a systematic correction based on depth is possible. Further work must be done to determine the parameters needed in order to create the best possible correction equation.

We have debated whether grouping bottom-hole temperatures by formation, or by 500 meter depth intervals is the statistically best method for geothermal resource assessments. With the results of this analysis we can state, with confidence, that the depth interval unit method is the most statistically accurate grouping of bottom-hole temperatures.

References

Crowell, A., and W. Gosnold, 2013. "GIS-Based Resource Assessment of the Denver Basin: Colorado and Nebraska." Geothermal Resources Council *Transactions*, v. 37, p. 941-944.

Esri, Inc., 2013. "ArcGIS 10.2 Helpfiles." Environmental Systems Research Institute, Redmond, CA. www.esri.com. Accessed 4-20-2015.

Förster, A., Merriam, D.F., and Davis, J.C., 1996. "Statistical analysis of some bottom-hole temperature (BHT) correction factors for the Cherokee Basin, southeastern Kansas: Tulsa." Geol. Soc. Trans., p. 3-9.

Harrison W.E., K.V. Luza, M.L Prater, and P.K. Chueng, 1983. "Geothermal resource assessment of Oklahoma." Oklahoma Geological Survey, Special Publication 83-1.

Kehle, R. O., R. J. Schoeppel, and R. K. Deford, 1970. "The AAPG Geothermal Survey of North America." Geothermics, vol. 2, no. PART 1, p. 358-367.