Using GIS to Estimate Geothermal Energy Reserves in Sedimentary Basins; Williston Basin, North Dakota

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Abstract: We estimated the useable thermal energy of selected oil-producing formations that have temperatures in a range from 90° C to more than 150 °C in the Williston Basin. We determined the total solid rock volume of ten reservoirs, which we grouped by system from Pennsylvanian to Cambrian, and estimated the reservoir size of each of the following temperature ranges; 90°-100° C, 100°-110° C, 110°-120° C, 120°-130° C, 130°-140° C, 140°-150° C, and 150° C up. We assumed a heat exchanger exit temperature of 50° C, meaning that the water lost 40°-100° C in the process. The recovery factor was obtained from Sorey et al (1982), who determined that a recovery factor of 0.001 of the total thermal energy, per year, was appropriate for a sedimentary basin the size of the Williston Basin.

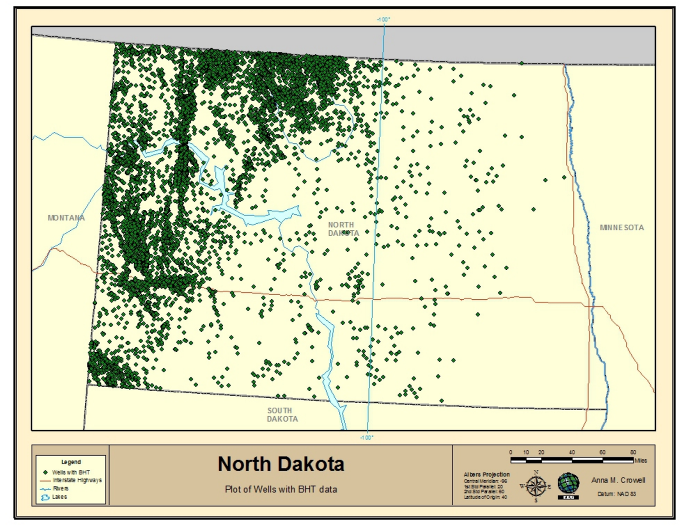


Figure 1 – ArcGIS plot of all wells in North Dakota with bottom-hole temperature data.

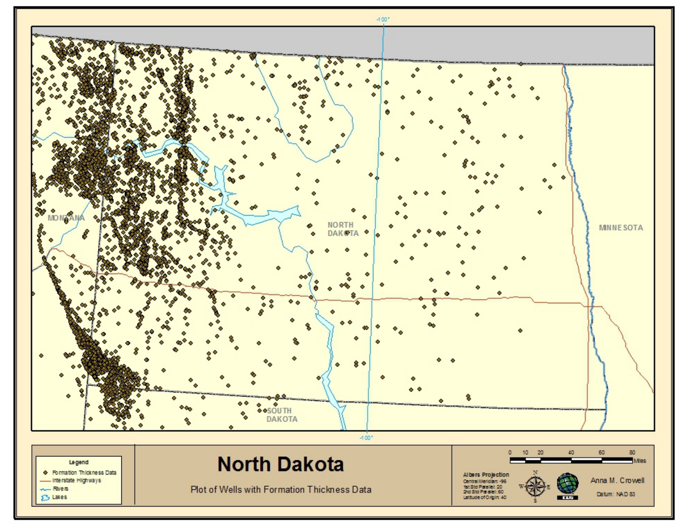


Figure 2 – ArcGIS plot of all wells in North Dakota with formation thickness data.

Introduction: The Williston Basin is a large intracratonic basin that underlies parts of North Dakota, South Dakota, Montana, Saskatchewan, and Manitoba. Initial subsidence began in the Ordovician and the basin consequently has an abnormally complete rock record (Heck 2002). The basin covers approximately 133,644 square kilometers, and contains, "sedimentary rocks of every geologic period from the Cambrian through the Tertiary," (Carlson and Anderson, 1965). The stratigraphy reflects the sequence subdivision created by Sloss (1963), who noted that there are six major unconformities found in the cratonic interior of North America and that each reflects a period of regression maxima.

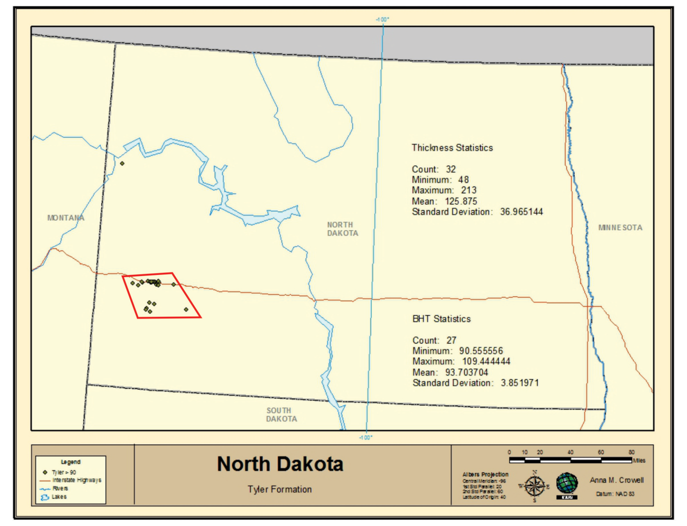
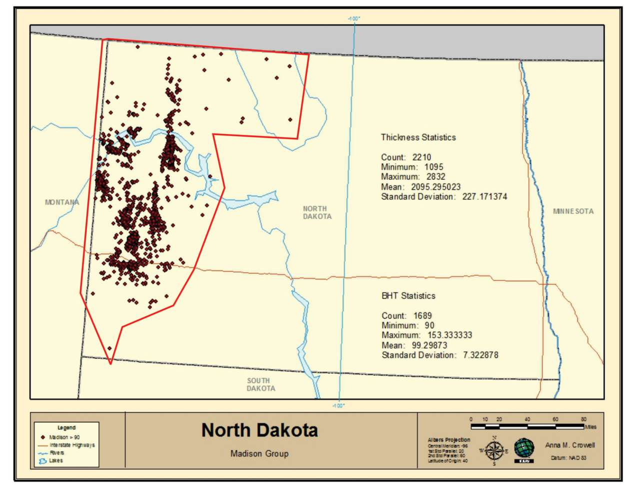


Figure 3 – In the Pennsylvanian, the Tyler formation reservoir has an area of 3.692 x 10^9 m^2, an average thickness of 125.875 m, and a total rock volume of 4.647 x 10^{11} m^3. The average temperature of this reservoir is 93.704° C. The total thermal energy of this reservoir is 1.07 x 10^{17} J at 90°-100° C, 5.59 x 10^{16} J at 100°-110° C, and 4.01 x 10^{16} J at 110°-120° C.

Methods: We used GIS techniques to determine the surface area of each formation that had water with the appropriate temperature for each range, and then calculated the volume of each reservoir with formation thickness data. The range of useable temperature was taken from the MIT Report: The Future of Geothermal Energy (2006), where it is stated that the minimum temperature required for a binary power plant is 90° C. We used the recovery factor of a large sedimentary basin from Sorey et al (1982), which is 0.001.

We calculated the useable energy in each reservoir from $Q = \rho C p V \Delta T$, where Q is the available heat, ρ is the density of water, Cp is the heat capacity of water, V is the volume of the reservoir, and ΔT is the change of water temperate as it enters and exits the heat exchanger. The following assumptions were made: the density of water at 100 degrees Celsius is 965.3 kg/m^3, the heat capacity of water is 4181.3 Joules / (kg * K), and the temperature of the water as it exits the exchanger was decreased to 50° C.

Figure 4 -- The Mississippian formation reservoirs have an area of 5.057 x 10^{10} m^2, an average thickness of 2479.895 m, and an approximate rock volume for the total reservoir of 1.010 x 10^{14} m^3. The average BHT was 99.289° C. The total thermal energy of this reservoir is 1.58 x 10^{19} J at 90°-100° C, 1.98 x 10^{19} J at 100°-110° C, 2.10 x 10^{19} J at 110°-120° C, 2.31 x 10^{19} J at 120°-130° C, and 1.14 x 10^{19} J at 130°-140° C.



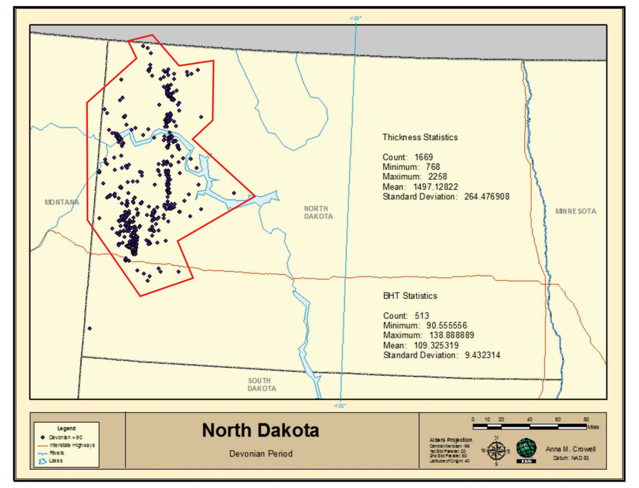
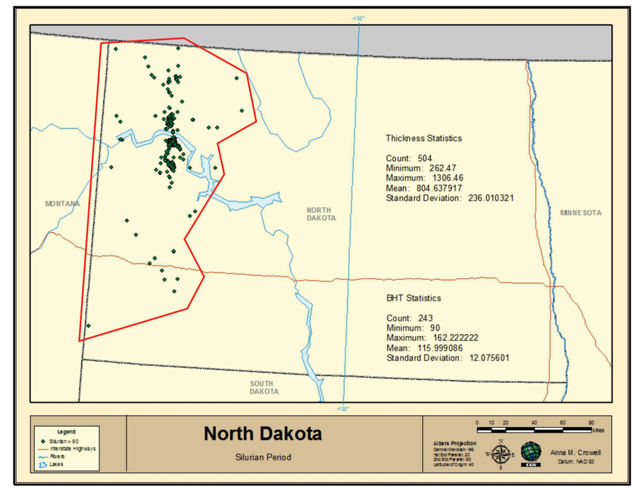


Figure 5 -- The Devonian formation reservoirs have an area of 5.819 x 10^{10} m^2, an average thickness of 1497.128 m and a total rock volume of 5.688 x 10^{13} m^3. The average BHT is 109.325° C. The total thermal energy of this reservoir is 5.78 x 10^{18} J at 90°-100° C, 1.44 x 10^{19} J at 100°-110° C, 1.07 x 10^{19} J at 110°-120° C, 9.99 x 10^{18} J at 120°-130° C, 6.43 x 10^{18} J at 130°-140° C, 6.10 x 10^{18} J at 140°-150° C, and 6.37 x 10^{18} J at 150° C and up.

Figure 6 -- In the Silurian, the Interlake formation reservoir has an area of 4.195 x 10^{10} m^2, an average thickness of 808.638 m, and a rock volume of 3.375 x 10^{13} m^3. The average BHT is 115.999° C. The total thermal energy of this reservoir is 2.79 x 10^{18} J at 90°-100° C, 5.67 x 10^{18} J at 100°-110° C, 3.49 x 10^{18} J at 110°-120° C, 4.97 x 10^{18} J at 120°-130° C, 3.18 x 10^{18} J at 130°-140° C, 3.03 x 10^{18} J at 140°-150° C, and 8.23 x 10^{17} J at 150° C and up.



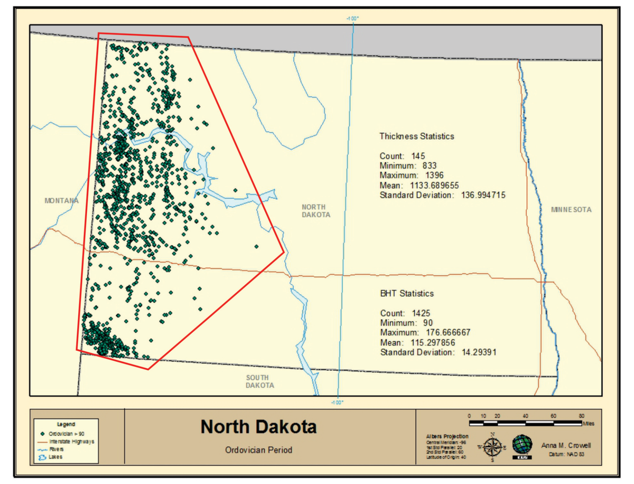
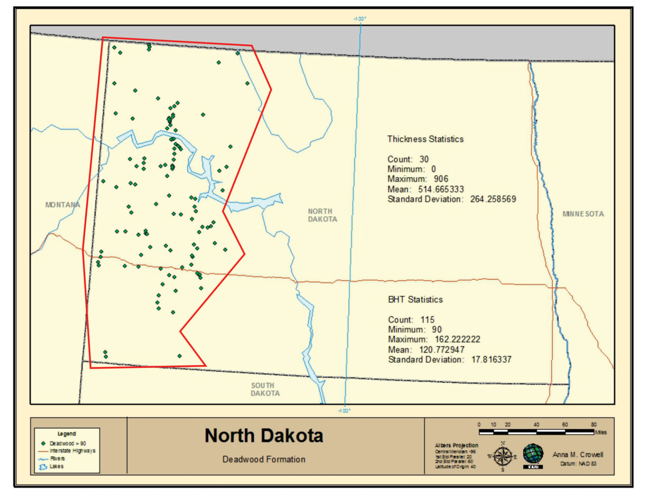


Figure 7 -- The Ordovician formation reservoirs have an area of 9.712 x 10^{10} m^2, an average thickness of 1133.690 m, and a total rock volume of 7.241 x 10^{13} m^3. The average BHT is 115.298° C. The total thermal energy of this reservoir is 6.50 x 10^{18} J at 90°-100° C, 1.18 x 10^{19} J at 100°-110° C, 1.73 x 10^{19} J at 110°-120° C, 1.65 x 10^{19} J at 120°-130° C, 1.56 x 10^{19} J at 130°-140° C, 1.06 x 10^{19} J at 140°-150° C, and 9.32 x 10^{18} J at 150° C and up.

Figure 8 -- In the Cambrian, the Deadwood formation reservoir has an area of 5.295 x 10^{10} m^2, an average thickness of 514.665 m, and a total rock volume of 2.725 x 10^{13} m^3. The average BHT was 120.773°. The total thermal energy of this reservoir is 1.18 x 10^{18} J at 90°-100° C, 1.72 x 10^{18} J at 100°-110° C, 4.24 x 10^{18} J at 110°-120° C, 5.41 x 10^{18} J at 120°-130° C, 4.34 x 10^{18} J at 130°-140° C, 3.13 x 10^{18} J at 140°-150° C, and 2.41 x 10^{18} J at 150° C and up.



Conclusions: The total thermal energy of the reservoirs, grouped by temperature range, is; 3.22 x 10^{19} J at 90°-100° C, 5.18 x 10^{19} J at 100°-110° C, 5.69 x 10^{19} J at 110°-120° C, 5.99 x 10^{19} J at 120°-130° C, 4.10 x 10^{19} J at 130°-140° C, 2.29 x 10^{19} J at 140°-150° C, and 1.89 x 10^{19} J at 150° C and up.

We realize that the calculated volumes are not perfectly accurate; however, the numbers provide a reasonable estimate of subsurface and indirectly measurable reservoir volumes. Obtaining formation data from a larger number of well logs would provide a more accurate estimate.

Temp range (°C)	Total Thermal Energy (J)	Recoverable (0.001)	J to kWh	Efficiency @ 6.7% (kWh)	Efficiency @ 24.1% (kWh)
90-100	3.22 x 10^{19}	3.22 x 10^{16}	8.94 x 10^{09}	5.99 x 10^{08}	2.16 x 10^{09}
100-110	5.35 x 10^{19}	5.35 x 10^{16}	1.49 x 10^{10}	9.95 x 10^{08}	3.58 x 10^{09}
110-120	5.69 x 10^{19}	5.69 x 10^{16}	1.58 x 10^{10}	1.06 x 10^{09}	3.81 x 10^{09}
120-130	5.99 x 10^{19}	5.99 x 10^{16}	1.66 x 10^{10}	1.11 x 10^{09}	4.01 x 10^{09}
130-140	4.10 x 10^{19}	4.10 x 10^{16}	1.14 x 10^{10}	7.63 x 10^{08}	2.75 x 10^{09}
140-150	2.29 x 10^{19}	2.29 x 10^{16}	6.36 x 10^{09}	4.26 x 10^{08}	1.53 x 10^{09}
150 +	1.89 x 10^{19}	1.89 x 10^{16}	5.26 x 10^{09}	3.52 x 10^{08}	1.27 x 10^{09}

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