Geothermal Resource Assessment of the Michigan and Illinois Basins: How Deep is Too Deep?

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ABSTRACT

There is general acceptance in the geothermal community that sedimentary basins east of the Mississippi River are too cold to sustain large scale geothermal power production. The question, then, becomes, "How deep is too deep when considering feasible thermal formation waters?" The Michigan and Illinois basins have been evaluated to determine if any formation waters of sufficient temperature exist, where they may be found, and how much energy in place exists for potential power prospecting.

Introduction

Tester et.al. (2006) asserted that geothermal power production can be achievable with formation waters as low as 90°C. With the current state-of-the art technology and depending on local conditions that affect the change in temperature (ΔT), this is certainly possible even with lower temperatures such as those found in Chena Hot Springs (Aneke et al., 2011). Deep sedimentary basins west of the Mississippi River have a large surface area with substantially thermal formation waters, but these conditions are lacking in basins east of the Mississippi River. Are temperatures of at least 90°C found in the Illinois and Michigan basins? How deep are these formations? How much energy is in place? Can we economically provide power from them?

Methods

Bottom-hole temperatures (spatial extent of data shown in Figures 1 and 2) were obtained from the National Geothermal Data System (NGDS) and were imported into a 'file geodatabase' with ArcGIS. These datasets include 6,184 wells within the Illinois basin and 11,833 wells within the Michigan basin. No temperature corrections were included with the datasets, thus corrections were done using the Harrison method (Harrison et al., 2006).

The available heat equation, as used by Brook et al. (1978), is:

$$Q = \rho\, Cp\, V\, \Delta T$$

In this equation, the heat in place (Q) is equal to the density of the rock (ρ) times the heat capacity of the rock (Cp), the volume of the rock in question (V), and the change in temperature (ΔT). To determine the heat capacity and density of rocks common to sedimentary basins, we looked up the values for shale, sandstone, limestone, and dolomite in, "Physical Properties of Rocks and Minerals," by Touloukian et al. (1981). The values we considered are listed in Table 1.

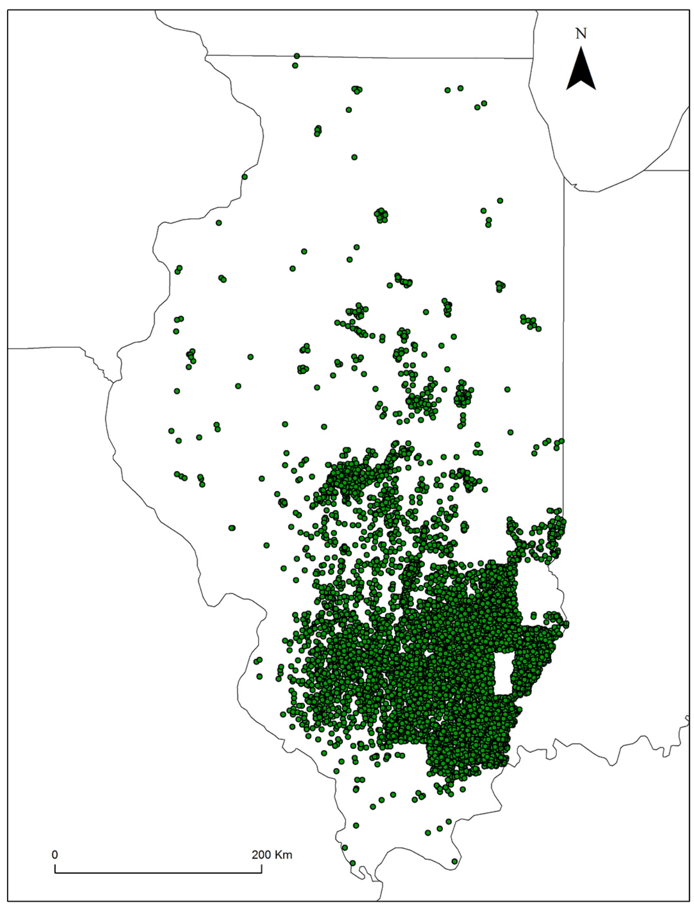

Figure 1. Spatial extent of bottom-hole temperatures in the Illinois basin.

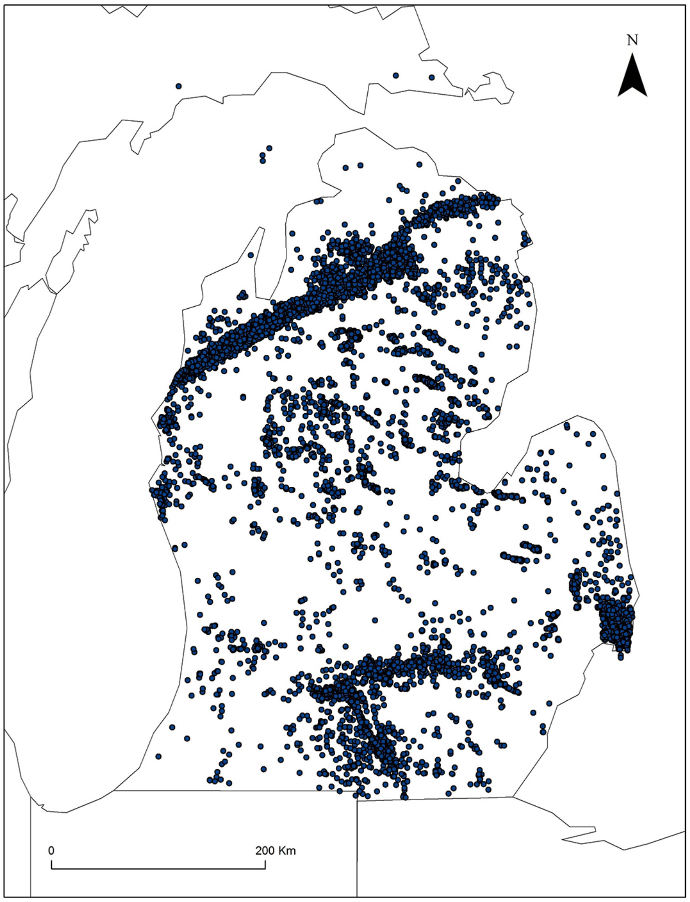

Figure 2. Spatial extent of bottom-hole temperatures in the Michigan basin.

Table 1. Heat capacity and density of dominant rock types (Touloukian et al., 1981).

Rock Type	Density (kg/km^3)	Heat Capacity (J/kg°C)
Shale	2.35E×^{12}	1046.03
Sandstone	2.30E×^{12}	920.48
Limestone	2.60E×^{12}	830
Dolomite	2.90E×^{12}	920

Most of the records did not have formation data associated with them, so we parsed wells out based on 500 meter intervals and analyzed those wells that were 1000m to 4500m in depth. Each of these units were interpolated using the Inverse Distance Weighting (IDW) Method (Figures 3 and 4) and classified manually into 10 degree intervals, with the first break at 90°C, and going up to 150°C. This classification scheme was chosen to be comparable to work done by Crowell and Gosnold in the Denver and Williston Basins (Crowell et al., 2011; Crowell and Gosnold, 2012). We reclassified the interpolation rasters into 90°C+, 100°C+, 110°C+, and 120°C+ temperature intervals and converted the reclassified rasters into polygons, which we dissolved on reclassified values. Using the feature measurement tool in ArcGIS, we obtained polygon areas in square kilometers (km^2). The surface areas from the 90°C+, 100°C+, 110°C+, and 120°C+ intervals were multiplied with the

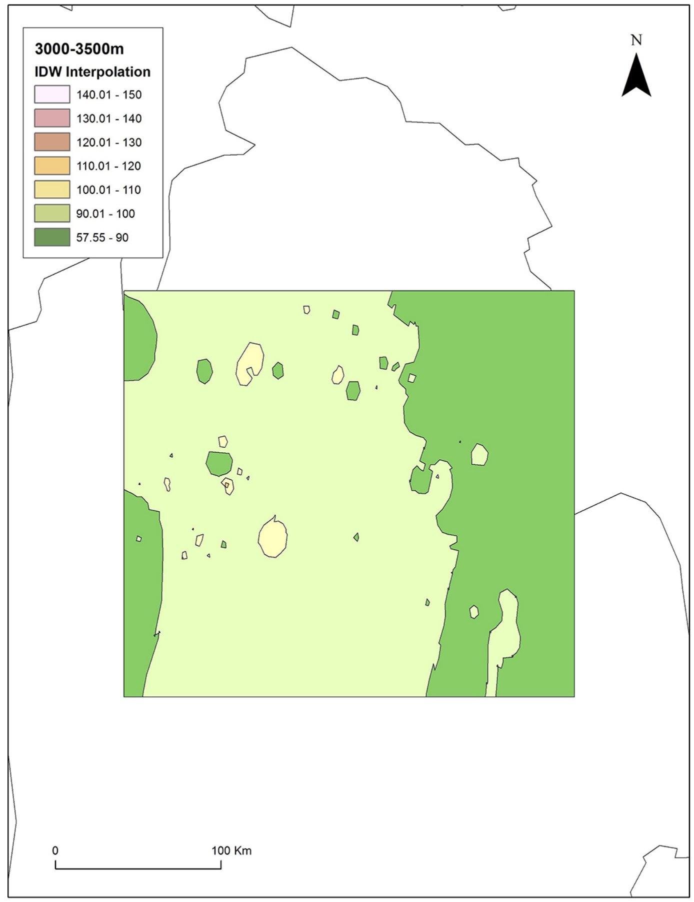

Figure 3. BHT interpolation for the 3000-3500 meter interval.

0.5 kilometer (km) thicknesses, and volumes calculated. The last parameter needed for the heat in place equation was the change in temperature. Michigan is a northern tier state, so it is reasonable to assume that with air cooling, a ΔT of 40°C can be used.

Results

The Illinois basin only has one temperature recorded over 90°C out of the 6,184 wells. The temperatures, therefore, do not fit within the scope of this study and the basin was discarded as a candidate for large-scale geothermal power production.

The Michigan basin has temperatures over 90°C below a depth of 3000 meters. A total of 172 wells were analyzed in the 3000-4000 meter depth interval. The 3000-3500 meter interval has a minimum temperature of 57.5°C, a maximum temperature of 115.3°C, and a mean temperature of 92.6°C with a standard deviation of ±7°C. The 3500-4000 meter interval has a minimum temperature of 90.3°C, a maximum temperature of 117.4°C, and a mean temperature of 109.9°C with a standard deviation of 10.1°C. The available energy in place for each depth interval is listed in Tables 2 and 3. The recovery factor of 0.001 was determined by Sorey et al., (1982) when they looked at well spacing, well draw-down, and how much water and energy could be extracted without depleting the resource over a thirty-year period. It is important to remember that the recovery rate as defined by Sorey et al. (1982) is not a guarantee of energy extraction, but is more accurately described as a ***sustainable*** extraction rate.

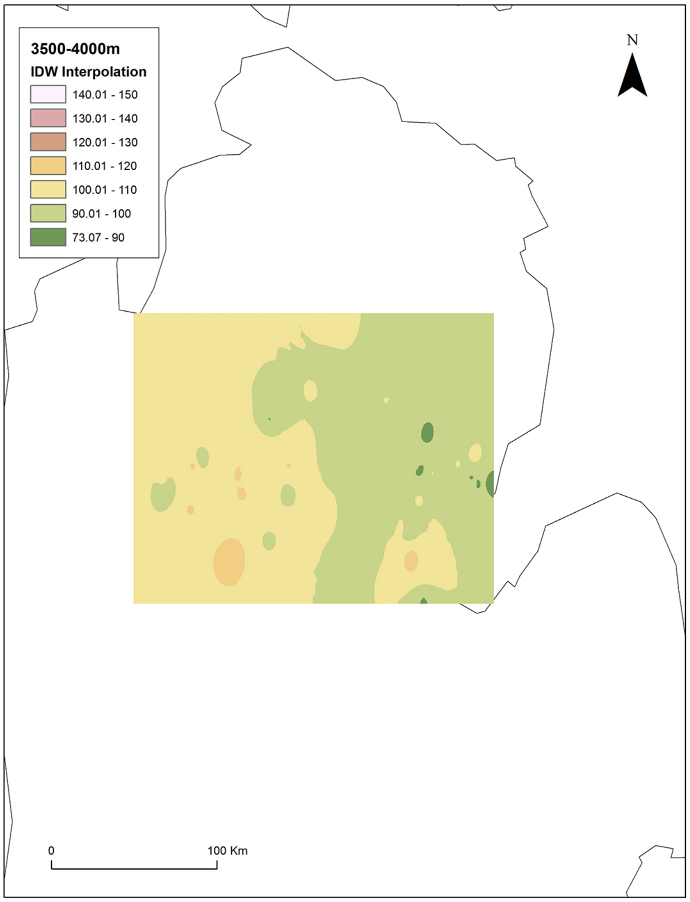

Figure 4. BHT interpolation for the 3500-4000 meter interval.

Table 2. Parameters and available heat in place for the 3000-3500 meter depth interval in the Michigan basin.

Temp. Interval	Area (km²)	Volume (km³)	Average Temp. (°C)	ΔT	Q (J)	Recoverable (J)	MWt
90°C +	41,323.39	20,661.70	92.6	52.6	$23{,}000\times10^{17}$	$23{,}000\times10^{14}$	$64{,}000\times10^{4}$
100°C +	770.09	385.05	92.6	52.6	430×10^{17}	430×10^{14}	$1{,}200\times10^{4}$
110°C +	4.46	2.23	92.6	52.6	2.5×10^{17}	2.5×10^{14}	6.9×10^{4}

Table 3. Parameters and available heat in place for the 3500-4000 meter depth interval in the Michigan basin.

Temp. Interval	Area (km²)	Volume (km³)	Avg Temp. (°C)	ΔT	Q (J)	Recoverable (J)	MWt
90°C +	18,090.85	9,045.43	109.9	69.9	130×10^{19}	130×10^{16}	37×10^{7}
100°C +	19,239.72	9,619.86	109.9	69.9	140×10^{19}	140×10^{16}	39×10^{7}
110°C +	605.46	302.73	109.9	69.9	4.5×10^{19}	4.5×10^{16}	1.3×10^{7}

Table 4. Final estimate of energy in place, after recovery factor and taking power plant efficiency into account, along with estimated number of homes powered.

Temp. Range (°C)	Recoverable (J)	In MWt	After Efficiency (12%) (MWt)	# Homes Powered
90°C	370×10^{16}	110×10^{7}	123×10^{6}	61,716,000,000
100°C	150×10^{16}	42×10^{7}	50×10^{6}	25,020,000,000
110°C	4.5×10^{16}	1.3×10^{7}	1.5×10^{6}	750,600,000

Conclusions

Although no temperatures suitable for large-scale power production have been found in the Illinois basin, future work for other geothermal uses, such as district heating and direct use, may be worthwhile. The calculation of heat flow points and projection to isotherms would be especially valuable to determine how deep formations of interest would be.

The Michigan basin has limited potential for large-scale power production. The 90° C isotherm only begins to appear at a depth of 3000 meters, which is infeasible for economic power production with current technology. The energy summary, along with the estimate after passing the fluid through a binary Organic Rankin Cycle with an efficiency of 12% and the number of homes possibly powered can be found in Table 4.

Even though the appropriate isotherm is too deep to produce economically with current technology, and taking into account that the available energy in place is approximately 1/5th that of a large, deep, hot basin such as the Denver-Julesberg (Crowell and Gosnold, 2013), an estimated 61 trillion homes can potentially be powered if technology evolves to that level. An estimate by the US Census bureau states that the number of homes in the United States as of 2010 is 80 million (U.S. Census Bureau, 2010). If only a fraction of the energy can be produced, we can still greatly offset fossil fuel usage.

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