North Dakota Geological Survey
100K Series: Dksn - g - Orr

Deep Geothermal Resources: Estimated Temperatures on Top of the Red River Formation

Dickinson 100K Sheet, North Dakota

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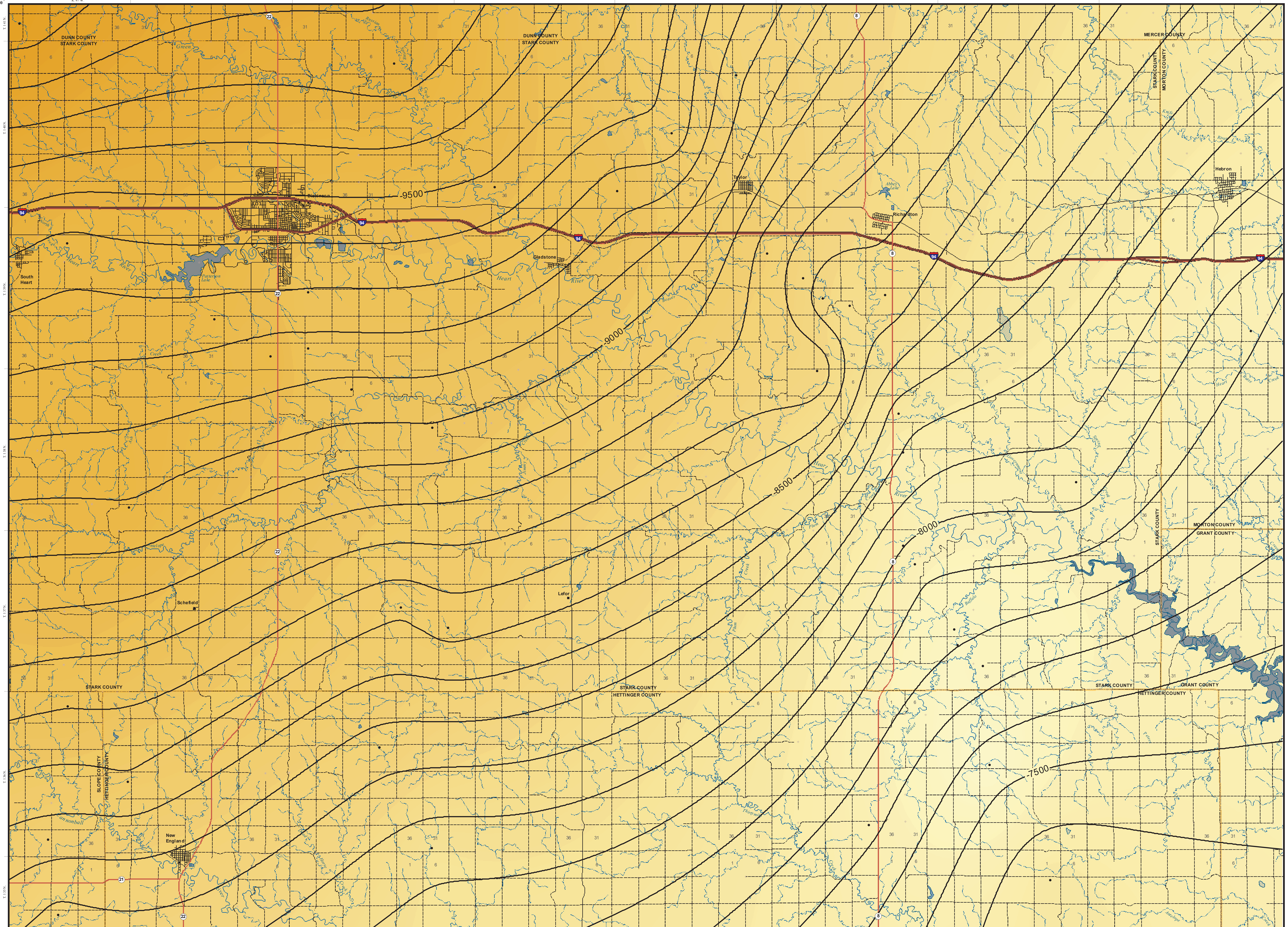
12°
1981 Magnetic North
Declination at Center of Sheet



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Geothermal energy is a renewable resource capable of producing an uninterrupted supply of electrical power and heat. In stable sedimentary basins, low-temperature geothermal energy (< 40°C, < 100°F) is extracted from the shallow subsurface (~8-600 feet, 2.5-200 m) for use in domestic and commercial heating and cooling systems. Historically, deeper, hotter resources in these regions have not been developed because they typically lack one or more of the essential requirements that make high-temperature geothermal resources technically and economically viable.

Conventional methods of generating electricity using geothermal energy rely on hot (> 100°C, > 212°F) relatively shallow (< 10,000 feet, < 3000 m), easily developed hydrothermal resources. Generally associated with active plate boundaries and/or volcanism, these high-grade hydrothermal systems are characterized by high thermal gradients, and highly fractured, porous reservoir rocks through which natural waters or steam can freely circulate. Large-scale, cost-effective electric power generation usually requires fluid temperatures above 150°C (300°F) but smaller systems based on standard binary-cycle technology are capable of producing electricity using geothermal fluids at temperatures as low as 100°C (212°F).

Natural sources of high-grade hydrothermal energy are geographically limited. In the U.S. they are restricted to the western states and currently represent less than 1% of the nation's electrical power generating capacity. Yet the amount of heat at depths less than 30,000 feet (10,000 m) below the surface of the continental U.S. is substantial. By replicating natural hydrothermal conditions it is possible, in some regions, to turn this heat into an economically viable resource. In 2005 an 18-member MIT-led interdisciplinary panel conducted a comprehensive technical and economic assessment of geothermal energy as a viable source of energy for the U.S. (U.S. Department of Energy, 2006). The study estimated that, based on current technology, geothermal energy could be producing more than 100GW of affordable electricity by 2050, equivalent to roughly10% of the present-day capacity of the U.S.

Enhanced (or engineered) geothermal systems (EGS) are engineered reservoirs designed to produce energy as heat or electricity from geothermal resources that are otherwise not economical due to lack of water and/or permeability (U.S. Department of Energy, 2008). EGS technology uses adaptations of techniques developed in the oil and gas, and mining industries to fracture hot, low-porosity rocks in the deep subsurface and extract the heat with water via a system of injection and production wells.

With infrastructures already in place and the abundance of horizontally drilled and/or artificially stimulated wells, oil and gas fields are prime candidates for the application of EGS technology. Of particular interest are those wells regarded as marginal or unproductive because they produce too much water. Geothermal waters that are coproduced with oil and gas are an expensive waste product that must be disposed of either in evaporation ponds or by re-injection into the subsurface. If sufficiently hot (> 100°-150°C, > 212°-300°F) and available in sufficient quantity, however, these waters may be capable of generating cost-effective electricity (McKenna and others, 2005).

The Ordovician-age Red River Formation is the deepest of four major geothermal aquifers that occur in the Williston Basin. The map shows calculated temperatures (°C) for the top of the Red River Formation in the vicinity of Dickinson in southwestern North Dakota.

There are no data sets for North Dakota that list accurate temperatures for Paleozoic rocks. Bottom hole temperatures from oil well logs are unreliable and to assume that a simple linear relationship exists between temperature and depth would be incorrect. Although grossly linear, the geothermal gradient in the upper lithosphere is significantly affected by thermal variables (heat flow and thermal conductivity) in the earth's crust and any method used to accurately calculate subsurface temperatures must take these factors into account. Provided the subsurface stratigraphy is known, Gosnold (1984) showed that at a given depth (Z) the temperature (T) can be represented by the following equation:

$$T = T_o + \sum_{i=1}^{n} Z_i(Q/K_i)$$

Where:
T_o = Surface temperature (in °C)
Z_i = Thickness of the overlying rock layer (in meters)
K_i = Thermal conductivity of the overlying rock layer
N = Number of overlying rock layers
Q = Regional heat flow

For the data set used to produce this map T_0 and K were assumed to be constants. Mean surface temperature (T_0 = 5.1°C, 41°F) was calculated from monthly station normals (at Bismarck Municipal Airport, Fargo Hector Airport, Grand Forks International Airport, and Williston Sloulin Airport) for the period 1971 to 2000 (http://cdo.ncdc.noaa.gov/climatenormals/clim81/NDnorm.pdf). Thermal conductivities (K) for formations overlying the Red River Formation are shown in Table 1.

System	Thermal Conductivity (W/m K)
Quaternary	1.4
Tertiary	1.2
Cretaceous	1.2
Jurassic	1.3
Triassic	1.3
Permian	2.9
Pennsylvanian	1.7
Mississippian	2.9
Devonian	2.7
Silurian	3.5
Ordovician	2.7

Table 1: Thermal conductivity estimates from Gosnold (2007)

Heat flow (Q) was corrected for the effects of post-glacial warming (Beardsmore and Cull, 2001, W.D. Gosnold, written communs., 2009). Temperatures depicted on this map assume constant regional steady state heat flow of 70 mW/m^2 at depths below 6,500 feet (2,000 m).

Rock units and thicknesses were obtained from oil well log tops (July 2008 update). The map was compiled using approximately 80 data points (wells). Estimated temperatures ranged from 118°C (244°F) to 152°C (306°F) in this map sheet.

References

Beardsmore, G.R., and Cull, J.P., 2001, Crustal Heat Flow: New York, Cambridge University Press, 324 p.

Gosnold,W.D. Jr., 1984, Geothermal resource assessment for North Dakota. Final report: U.S Department of Energy Bulletin No. 84-04-MMRRI-04.

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McKenna, J., Blackwell, D., Moyes, C., and Patterson, P.D., 2005, Geothermal electric power supply possible from Gulf Coast, Midcontinent oil field waters: Oil & Gas Journal, Sept. 5, 2005 p. 34-40.

Tester, J. W., Anderson, B., Batchelor, A., Blackwell, D., DiPippo, R., Drake, E., Garnish, J., Livesay, B., Moore, M.C., Nichols, K., Petty, S., Toksoz, N., Veatch, R., Augustine, C., Baria, R., Murphy, E., Negraru, P., Richards, M., 2006., The future of geothermal energy: Impact of enhanced geothermal systems (EGS) on the United States in the 21st century: Massachusetts Institute of Technology, DOE Contract DE-AC07-05ID14517, Final Report.

U.S. Department of Energy, 2008, Enhanced geothermal Systems: http://www1.eere.energy.gov/geothermal/enhanced_geothermal_systems.html (Version 9/24/2008).

Geologic Symbols

Top of Red River Formation (feet above sea level)

Data Points (wells)

Temperature/°C

152
150
148
146
144

144
142
140
138
136

136
134
132
130
128

128
126
124
122
120
118

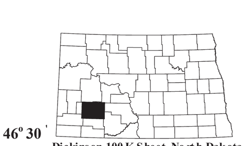
Other Features

Water
Water - Intermittent
River/Stream - Perennial
River/Stream - Intermittent
Section Corners
County Boundary
US Highway
State Highway
Paved Road
Unpaved Road

Scale 1:100,000

0 1 2 3 4
Miles

Mercator Projection
Standard parallel 46° 30'
1927 North American Datum
Central meridian 102° 30'



Dickinson 100 K Sheet, North Dakota

Grassy Butte	Killdeer	Hazen
Belfield		Glen Ullin
Bowman	Mott	Elgin

Adjoining 100 K Maps

Cartographic Compilation: Elroy L. Kadrmas