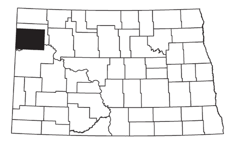
North Dakota Geological Survey
100K Series: Wlst - g - Kik - b



Deep Geothermal Resources: Estimated Temperatures at the Base of the Inyan Kara Formation

Williston 100K Sheet, North Dakota

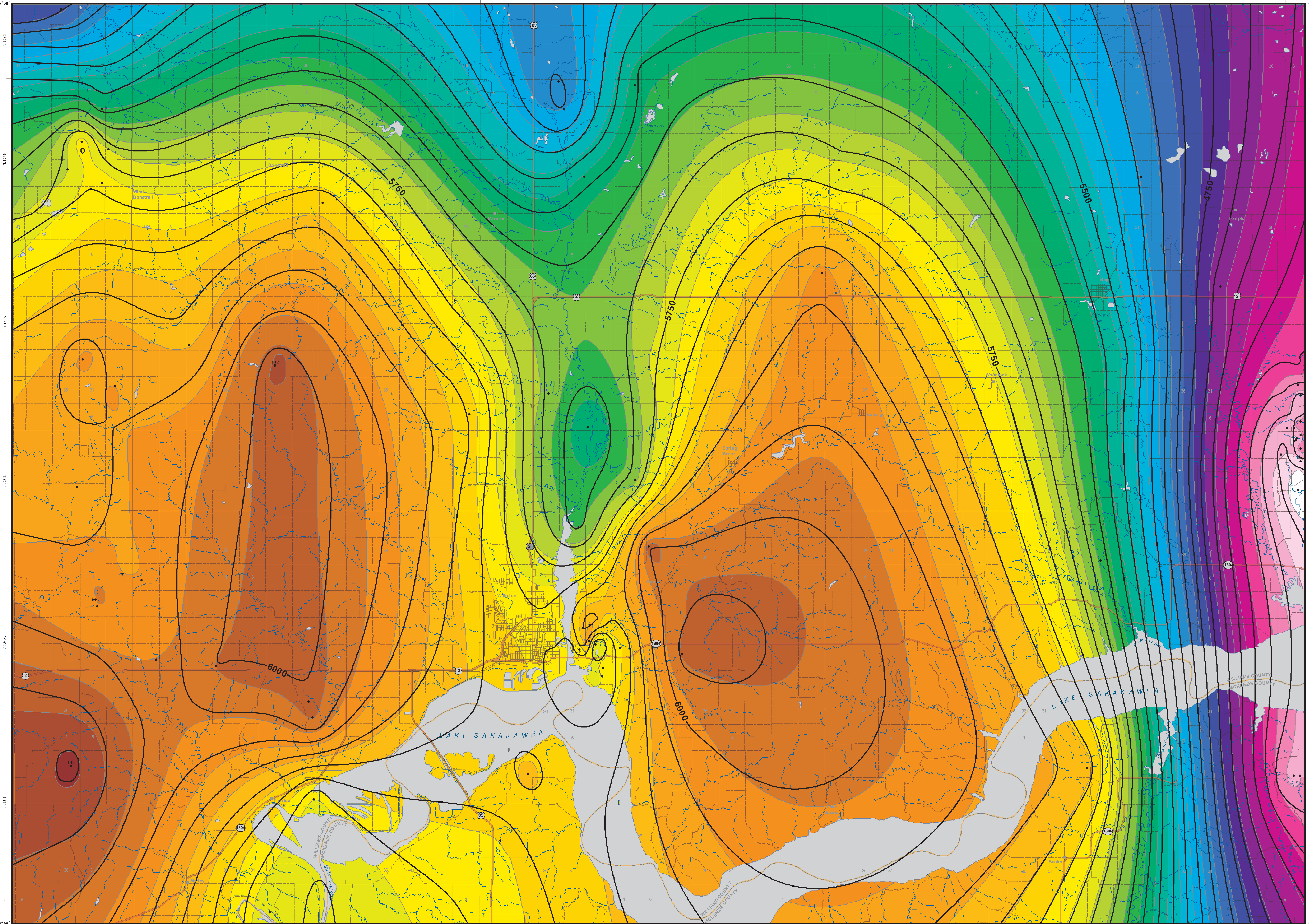
Plentywood	Crosby	Kenmare
Culbertson		Stanley
Sidney	Watford City	Parshall

Adjoining 100K Maps

13°30'

1983 Magnetic North
Declination at Center of Sheet

Edward C. Murphy, State Geologist
Lynn D. Helms, Director Dept. of Mineral Resources



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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 energy (< 100° F) is extracted from the shallow subsurface (~8-400 feet) for use in domestic and commercial heating and cooling systems. Historically, deeper, hotter resources in these regions have not been developed because they were not economical. However, as the nation explores ways to reduce its dependency on foreign energy sources and also begins to look more closely at renewable energy, accessing deep geothermal energy resources, particularly via existing oil and gas wells, is attracting a great deal of interest (http://www.smu.edu/geothermal/).

The Dakota Group contains the shallowest of four major geothermal aquifers that occur in the Williston Basin. It lies unconformably above the Jurassic-age Swift Formation. The map shows calculated temperatures (°F) for the base of the Inyan Kara Formation, the oldest of the four rock units that comprise the Dakota Group (fig. 1).

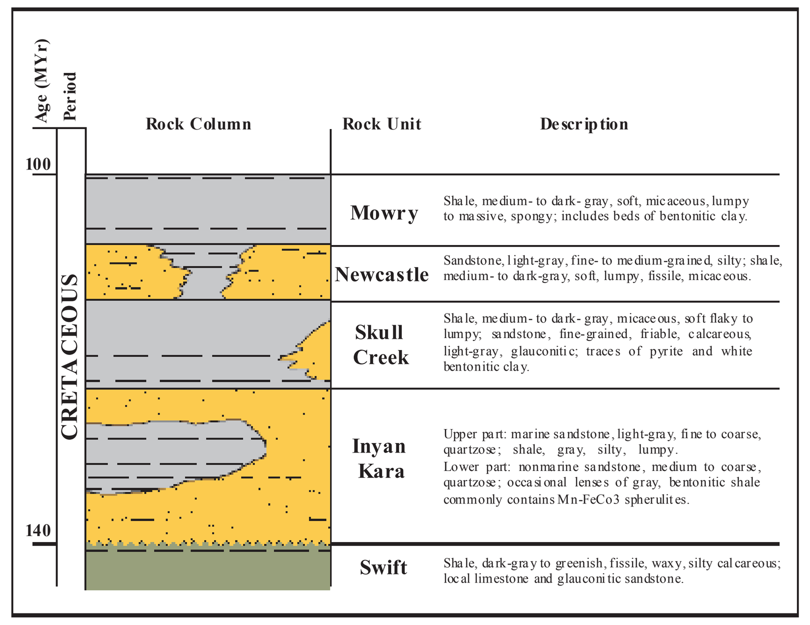

Figure 1. Generalized stratigraphy of the Dakota Group.

There are no reliable data sets for North Dakota that either list, or enable determination by extrapolation, subsurface temperatures for Cretaceous 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. Any method used to accurately calculate subsurface temperatures must therefore 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, K and Q 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 Inyan Kara are shown in Table 1.

Formation	Thermal Conductivity (W/M K)
Late Cretaceous, Paleogene and Neogene clays, silts and sands	1.7
Pierre	1.2
Greenhorn	1.2
Mowry, Newcastle, Skull Creek	1.2
Inyan Kara	1.6

Table 1: Thermal conductivity estimates from Gosnold (1984)

Regional heat flow (Q= 62 mW/m^2) was averaged from statewide data.

Rock units and thicknesses were obtained from oil well log tops (July 2006 update). Temperatures were only calculated for wells where all relevant log tops were given since omissions (particularly for the Pierre Formation) do not necessarily imply that units are absent.

Metadata used in the compilation of this map is available on CD.

References
Gosnold, W.D. Jr., 1984, Geothermal Resource Assessment for North Dakota. Final Report: U.S. Department of Energy Bulletin No. 84-04-MMRRI-04.

Temperature/°F

193	185	177	169
192	184	176	168
191	183	175	167
190	182	174	166
189	181	173	165
188	180	172	164
187	179	171	
186	178	170	

Geologic Symbols

Depth (in feet from surface) To Base of Inyan Kara Formation

193 Data Points. Selected points show temperature in °F

Scale 1:100,000

0 1 2 3 4 Miles

Mercator Projection — 1927 North American Datum

Standard parallel 48° 00' — Central meridian 103° 30'

Shaded Relief - Vertical Exaggeration 9x

Other Features

Water

River/Stream - Perennial

Stream - Intermittent

County Boundary

Federal Highway

State Highway

Paved Road

Unpaved Road

Note: This map was expanded beyond the normal Williston 100k Sheet to include an additional width of two miles to the Montana border.

Cartographic Compilation: Elroy L. Kadrmas