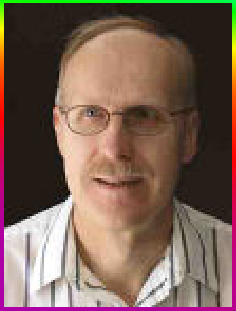
The University of North Dakota

A Remarkable Effort to Test the Concept of Electrical Power Generation from Co-Produced Oil Field Geothermal Waters


Will Gosnold **Mike Mann** **Hossein Salehfar** **Zhengwen Zeng** **Gopal Bandyopadyuy**

Geothermal Energy Utilization Associated with Oil & Gas Development

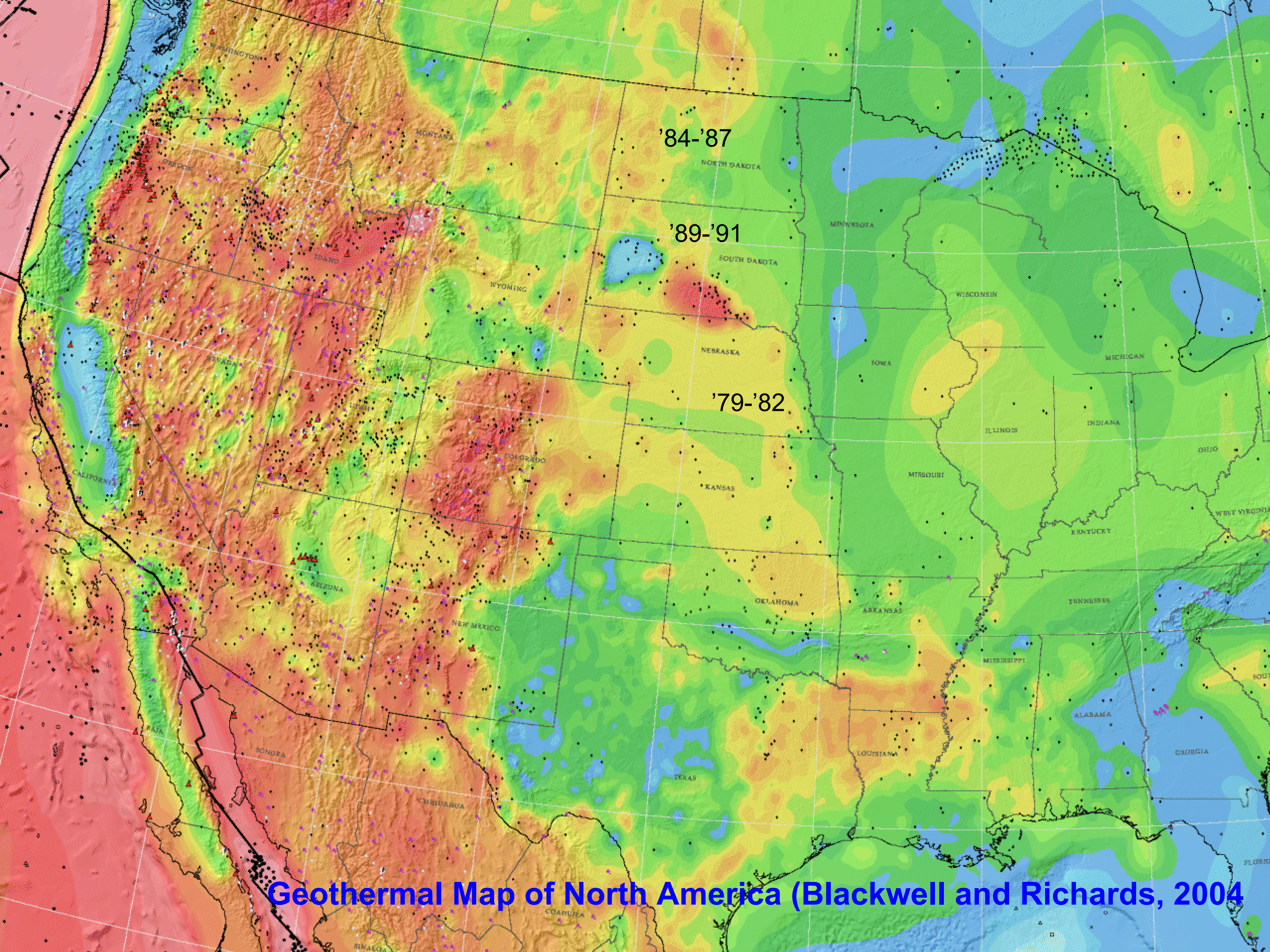
June 17-18, 2008

Southern Methodist University

Dallas, TX

Outline

- **Mid continent Geothermal Resources**
- **Impact of ORC**
- **DOE FOA**
- **Our Project**
- **Outcomes**



Geothermal Map of North America (Blackwell and Richards, 2004

150 °C to 90 °C ND and SD basins

- USGS Circular 893: The principal water producing formations, the Dakota Group and the Madison aquifer contain 2,050 EJ.
- Analysis of all potential aquifers in South Dakota and North Dakota indicates that the total accessible resource base in the two basins is approximately 33,700 EJ.
- The MIT report used the Circular 893 numbers and estimated the US resource base as 100,000 EJ.

Binary Turbine Development

- The key requirement is ΔT
- ORC systems can use temperatures below the boiling point of water
- Sedimentary basins in cold climates
- The 150 °C to 90 °C resource can provide electrical power!

- **NSF EPSCOR**
- <u>**E**xperimental **P**rogram to **S**timulate **C**ompetitive **R**esearch</u>

- **Call for Proposals: Sustainable Alternative Energy**

- **Two Stage Program**

1. **Assess Geology, Geophysics, Engineering, and Economics**
2. **Demonstration Project**

FINANCIAL ASSISTANCE

FUNDING OPPORTUNITY ANNOUNCEMENT

U.S. Department of Energy

Geothermal Technologies Program

Electric Power Generation Using Geothermal Fluid Coproduced from Oil and/or Gas Wells

Funding Opportunity Number: DE-PS36-07GO97033

Announcement Type: Initial

CFDA Number: 81.087

Issue Date: 06/13/2007

Application Due Date: 07/31/2007, 11:59 PM Eastern Time

F. Application Requirements

Applicants must include clear and complete sections detailing 14 Technical, 10 Non-Technical, and Technology Transfer considerations.

- **Technical Considerations** section for projects funded through this funding opportunity must provide clear and concise information including but not limited to:

1. Statement of Project Objectives;
2. Geologic/geothermal reservoir data for the proposed project;
3. Map showing proposed location and layout of wells, above-ground piping, and associated equipment for the project;
4. Operational performance data from any previously tested units;

Technical Considerations (continued)

5. Make, model, and projected net power production of the proposed power plant;
6. Proposed power cycle including but not limited to process schematic2 with stream state points at inlet and outlet of major components;
7. Handling and disposal of power plant working fluid;
8. Plans for water treatment and cleaning of scaled or fouled surfaces; and
9. Nature of cooling water supply (if used).

Technical Considerations (continued)

Actual characteristics of each well or separator that is proposed as a source of geothermal fluid, including:

10. Temperature;
11. Flow rate;
12. Quantitative analysis of produced fluids, including chemical analyses of water cuts and oil /natural gas;
13. Formation and depth from which the fluid is produced;
14. Modifications to the wellhead and/or surface systems, if necessary

(existing production and injection wells must be able to be re-entered without conducting well maintenance operations at the time of application submittal);

Non-Technical Considerations
including but not limited to:

1. Arrangements between leaseholders, developers, owners, operators, and/or others, including proof that all surface and/or subsurface rights including rights to utilize the geothermal resource and the oil and/or gas wells have been secured by the appropriate parties;
2. Proof of ability to provide the non-Federal share of project costs;
3. Status of regulatory and environmental permitting required for the project;
4. Arrangements for distribution/use of power including Power Purchase Agreement (PPA), if applicable;

Non-Technical Considerations (continued)

5. Pro forma applicable to a fully commercial project (not including federal cost share, equipment discounts, etc.) including taxes, royalties, lease payments, renewable energy credits, production tax credits, etc.;
6. Cost/benefit analysis including project benefits and impacts, and avoided cost of electricity;
7. Bill of Materials (BOM) with identification of long-lead items;
8. Deliverables;
9. Key personnel;
10. Project schedule, milestones, stage gates, go/no go decisions, etc.

Technology Transfer Considerations
including but not limited to:

- Plan for information dissemination and technology transfer (including but not limited to papers, web casts, site visits, press releases) to industry and others.

- The program required specific details that were extremely challenging to meet within the time period given.
- Our steps:
  - Commitment of the UND team
  - Contact NDGS
  - Contact UTC
  - Contact WEPC – Basin Electric

- ***University of North Dakota School of Engineering and Mines***
- **William Gosnold**, PhD, Professor of Geophysics and Chair of the Department of Geology and Geological Engineering Project PI.
- **Michael Mann**, PhD, Professor of and Chair of the Department of Chemical Engineering. Design the fluid handling system between the separator and the ORC system. Work with Dr. Zeng on all matters concerning the chemistry of the production and disposal fluids and the processing of any produced salts.
- **Hossein Salehfar**, PhD, Professor of Electrical Engineering. Design the electrical power and work with WEPC engineers to link the ORC system with the power grid.
- **Zheng-Wen Zeng**, PhD, Assistant Professor of Petroleum Engineering in the Department of Geology and Geological Engineering. Fluid handling systems and design of technology for future tech transfer to other systems.
- **Gopal Bandyopadyuy**, PhD, Chemical Engineering Research Associate. On-site engineer for all activities.

Project Partners

- ***North Dakota Geological Survey***
  - Lorraine Manz, PhD, North Dakota Geological Survey. Principal contact and administrator for the North Dakota geothermal regulatory program.
- ***Encore Acquisition Company***
  - Robert Sutherland, P.E., Management oversight for the oil field and all agreements and interactions among the four parties.
- ***West Plains Electric Cooperative, Basin Electric***
  - David C. Schelkoph, C.E.O., West Plains Electric Cooperative Inc. Management oversight for the link with the local electrical power grid and power purchase arrangements.
- ***UTC***
  - Halley Dickey, ORC power module

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- ***Ormat, Inc***
  - Carl Nett, ORC power module (induction generator), the condenser, and ancillary services to install the system.

Objective 1

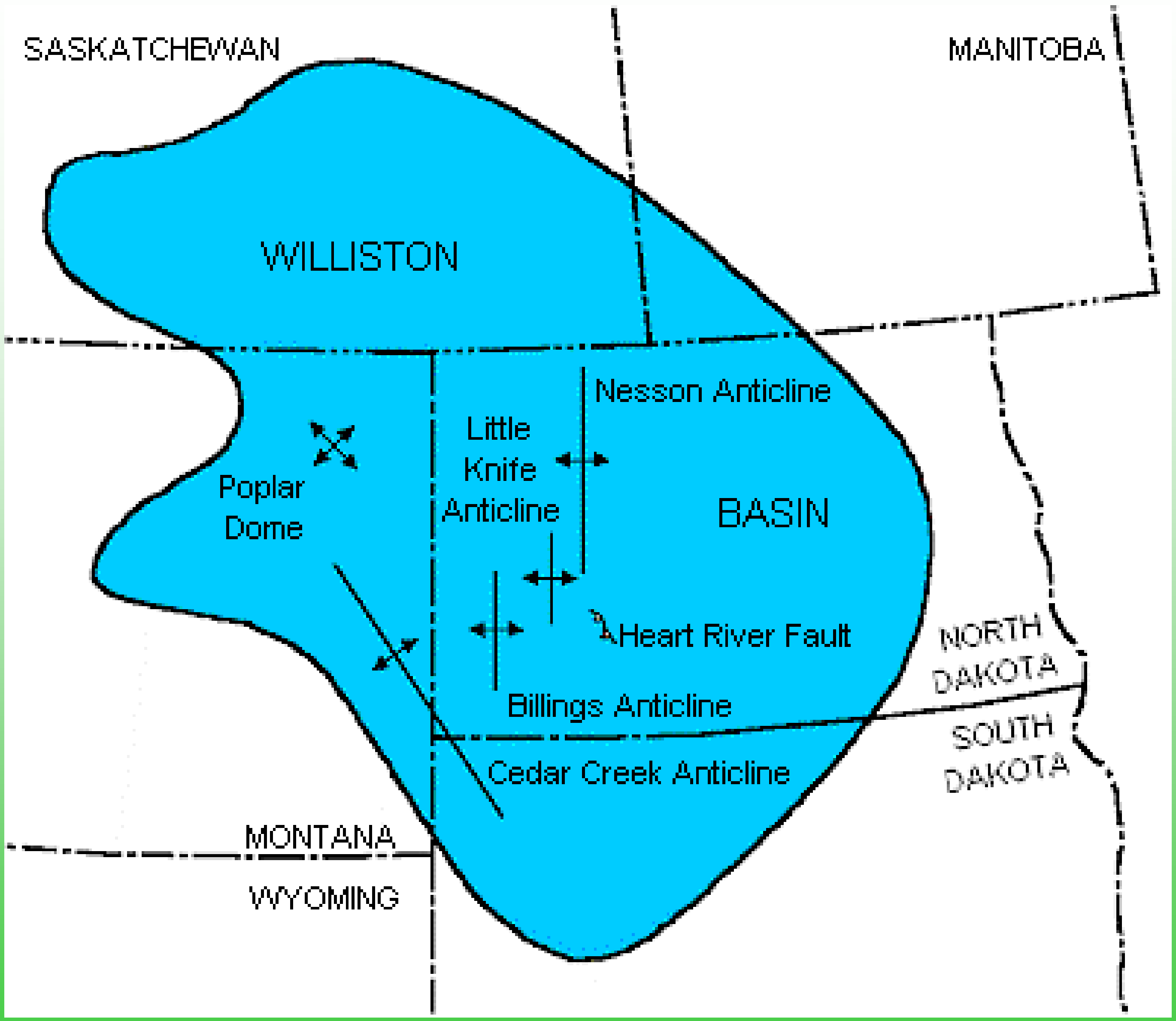
- ***Demonstrate the feasibility of adapting organic Rankine cycle (ORC) technology to generate electricity at economical rates using geothermal waters that are coproduced with oil and gas.***

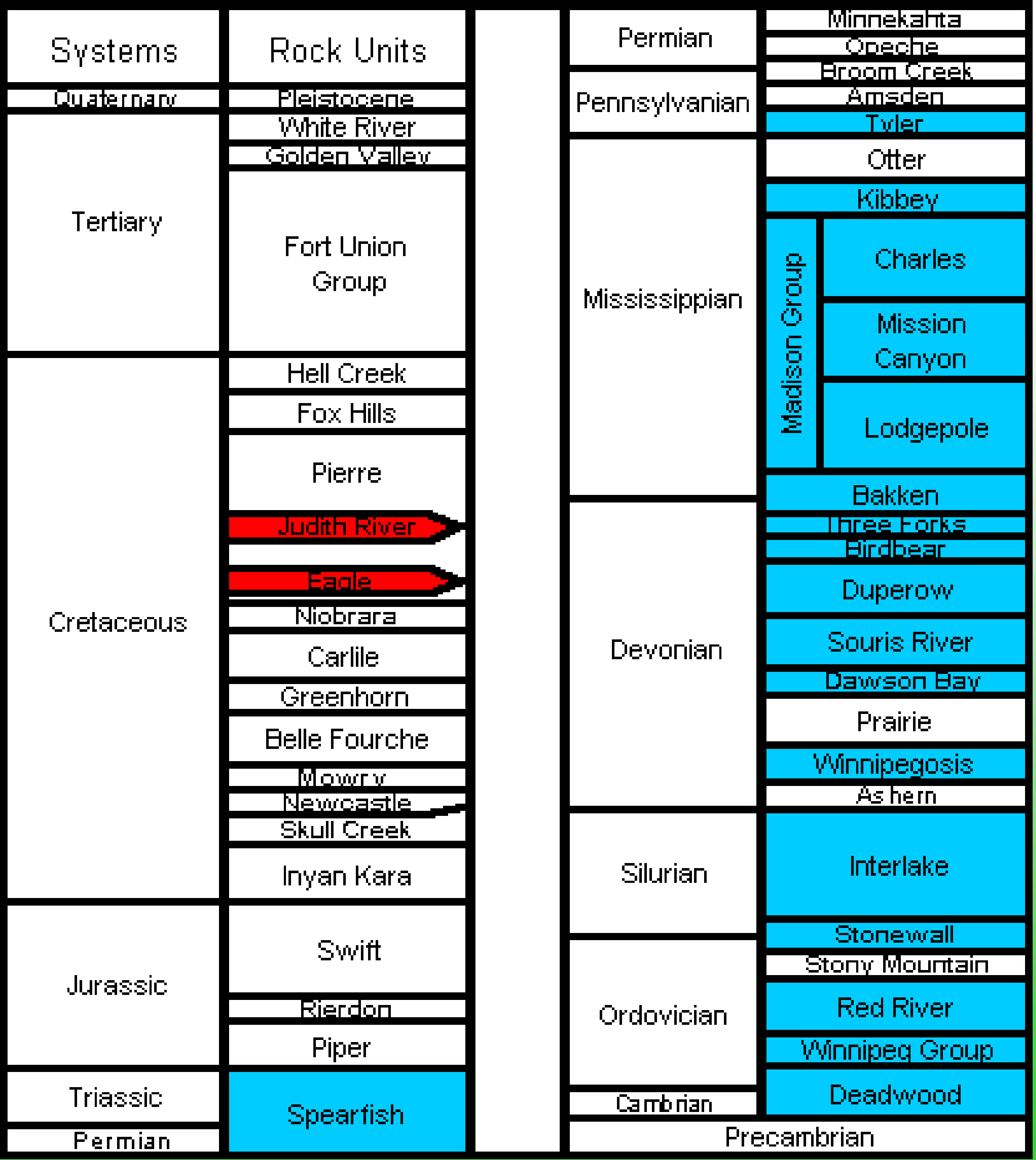
Objective 2

- ***Demonstrate that the widely abundant low-to-intermediate temperature (90 ºC to 150 ºC) geothermal waters existing within sedimentary basins constitute a sustainable, environmentally sound, domestic energy resource that could provide a significant portion of the nation's electrical power.***

Objective 3

- ***Establish a Center of Excellence in ORC-geothermal power to grow the human resource base for large scale development of geothermal energy.***


SASKATCHEWAN
MANITOBA
WILLISTON
BASIN
Nesson Anticline
Little Knife Anticline
Poplar Dome
Heart River Fault
Billings Anticline
Cedar Creek Anticline
NORTH DAKOTA
SOUTH DAKOTA
MONTANA
WYOMING

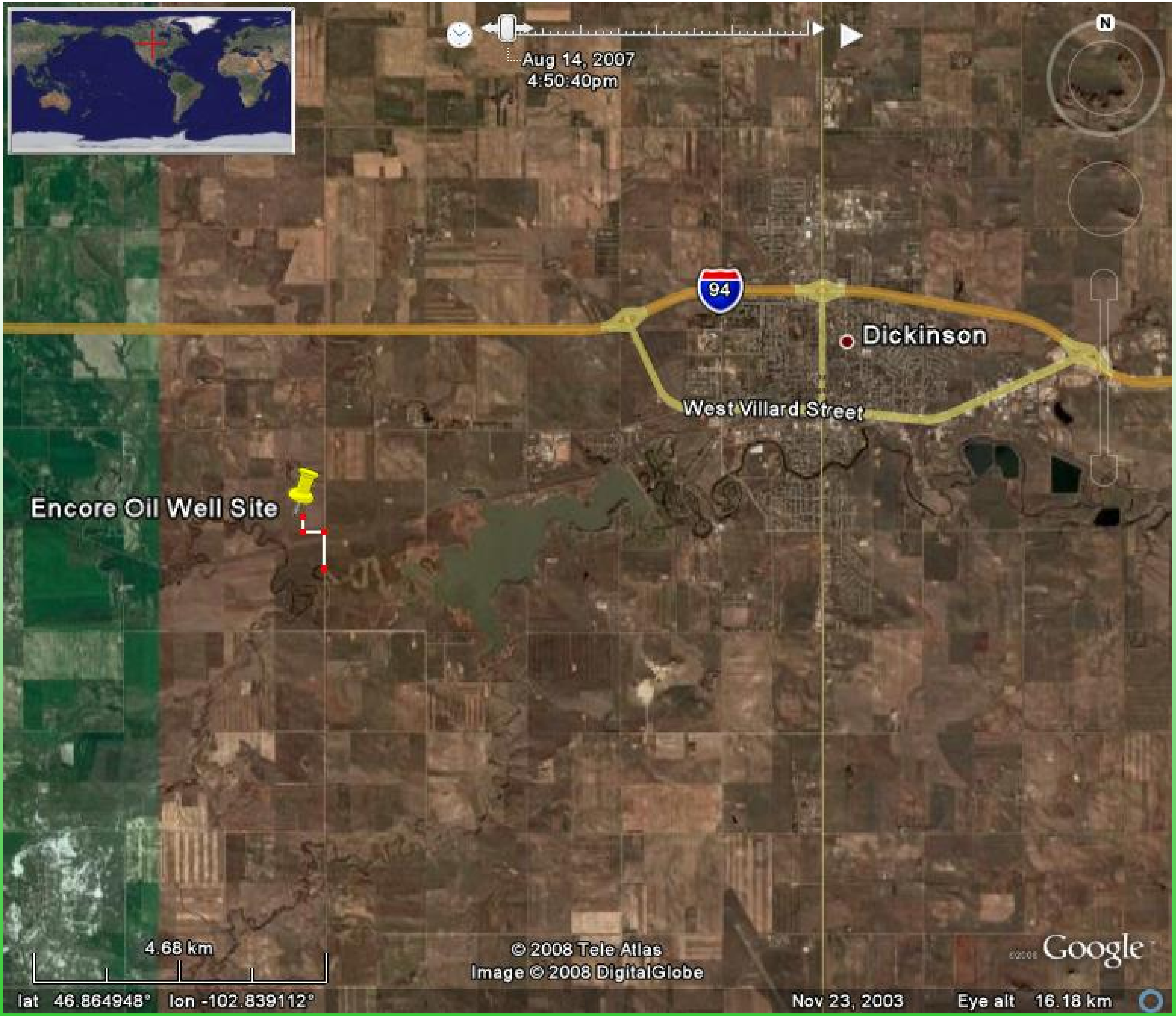


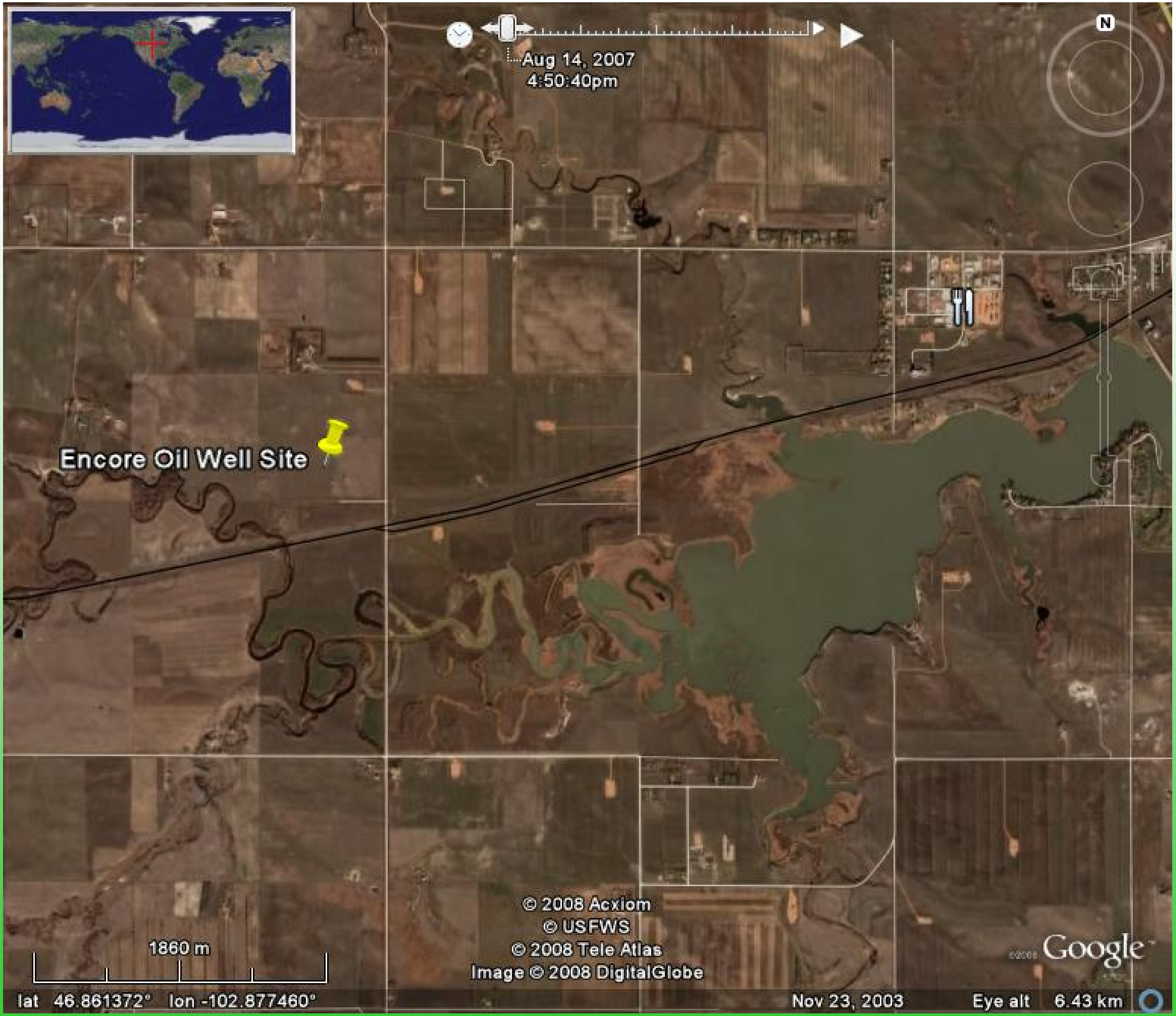
The production and reinjection unit is a reef system within the Lodgepole Fm (Miss).

Fm depth is between 2787 m (9142') to 3023 m (9918') below ground surface.

Formation temperature is 118 ºC (244 ºF) and produced water temperature at the surface is above 100 C.

The selected well currently produces approximately 11,500 bbl per day (400 gpm) of water.


Aug 14, 2007
4:50:40pm
N
94
Dickinson
West Villard Street
Encore Oil Well Site
4.68 km
© 2008 Tele Atlas
Image © 2008 DigitalGlobe
Google
lat 46.864948° lon -102.839112°
Nov 23, 2003
Eye alt 16.18 km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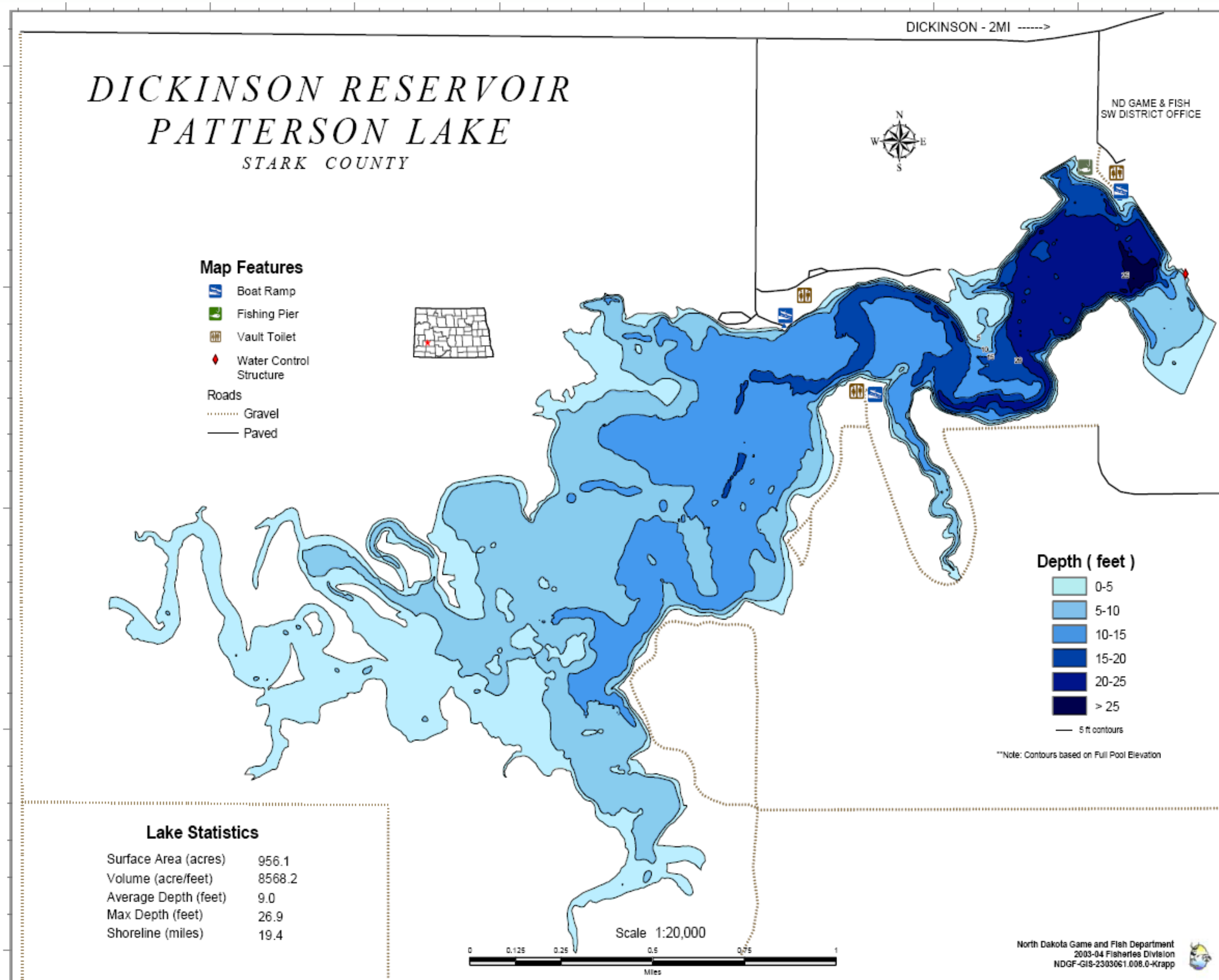
Encore Oil Well Site
© 2008 Acxiom
© USFWS
© 2008 Tele Atlas
Image © 2008 DigitalGlobe
1860 m
Google
lat 46.861372° lon -102.877460°
Nov 23, 2003
Eye alt 6.43 km


DICKINSON RESERVOIR
PATTERSON LAKE
STARK COUNTY
DICKINSON - 2MI ------>
ND GAME & FISH
SW DISTRICT OFFICE
N
S
E
W
Map Features
Boat Ramp
Fishing Pier
Vault Toilet
Water Control Structure
Roads
Gravel
Paved
Depth (feet)
0-5
5-10
10-15
15-20
20-25
> 25
5 ft contours
**Note: Contours based on Full Pool Elevation
Lake Statistics
Surface Area (acres) 956.1
Volume (acre/feet) 8568.2
Average Depth (feet) 9.0
Max Depth (feet) 26.9
Shoreline (miles) 19.4
Scale 1:20,000
0
0.125
0.25
0.5
0.75
1
Miles
North Dakota Game and Fish Department
2003-04 Fisheries Division

Some Engineering Aspects

- Water chemistry
- Cooling cycle of the heat exchanger
- Fluid disposal
- A prototype water-cooled Ormat Energy Converter (OEC) estimated at 330 kW gross and 280 kW net.

Water Chemistry for Knopik #1-11 (NDGS 13715)

Cations	#1 (mg/L)	#2(mg/L)	#3(mg/L)	#4(mg/L)	#5(mg/L)	#6(mg/L)
Na	92500.0	101800.0	104200.0	104800.0	105200.0	82600.0
Ca	5262.6	9209.6	9773.4	9021.6	9397.5	13156.5
Mg	1785.8	4881.1	5119.2	3452.4	5833.4	5119.2
Fe	0.6	1.3	1.1	1.1	1.3	1.2
K	600.0	860.0	870.0	930.0	1060.0	2150.0
Ba	1.6	8.9	9.2	9.0	9.8	7.7
Cr	0.1	0.2	0.2	0.2	0.2	0.2
Anions						
Chloride	158089.0	189919.0	192041.0	189919.0	193102.0	164455.0
Carbonate	1995.4	0.0	0.0	0.6	0.0	0.0
Bicarb.	3600.2	280.7	396.6	414.9	372.2	384.4
Sulfate	411.8	197.0	159.1	70.8	220.9	64.5
Nitrate	0.0	0.0	0.0	0.0	0.0	0.0
TDS	264247.1	307137.7	312569.8	308619.1	315197.4	267938.7

Cooling cycle of the heat exchanger

- During the winter months, the low ambient temperature of the air would be used to condense the turbine outlet vapor using banks of high finned tubes.
- During the summer months, plate heat exchangers would be used to transfer the heat to cooling water drawn from a bank of shallow tube wells sunk in the bed of the Heart River that flows about 1/2 mile south of the project site.

- Disposal of the geothermal fluids in three existing disposal wells in the Eland-Lodgepole field.
  - NDGS 13731 (1/2 miles)
  - NDGS 13819 (1/2 mile)
  - NDGS 13764 (1.5 miles)
- Fluid injection into Lodgepole formation.
- The combined injectivity of these three wells is 21,000 bbl/day and our requirement is 11,500 bbl/ day.

Objective 2

- ***Demonstrate that the widely abundant low-to-intermediate temperature (90 ºC to 150 ºC) geothermal waters existing within sedimentary basins constitute a sustainable, environmentally sound, domestic energy resource that could provide a significant portion of the nation's electrical power.***

Williston Basin

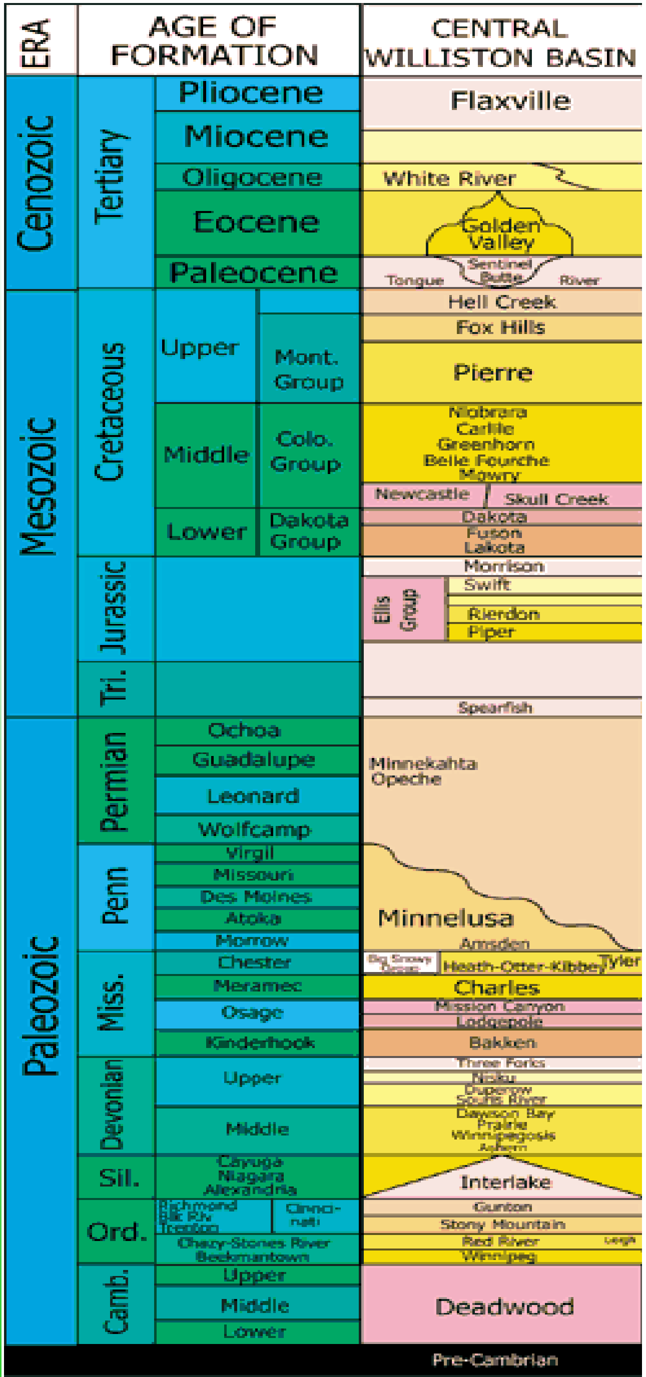
- 41 hydrocarbon producing formations, 39 produce oil and 2 produce nitrogen and methane.
- Total oil 1,602,055,219
- Total water 2,927,574,334

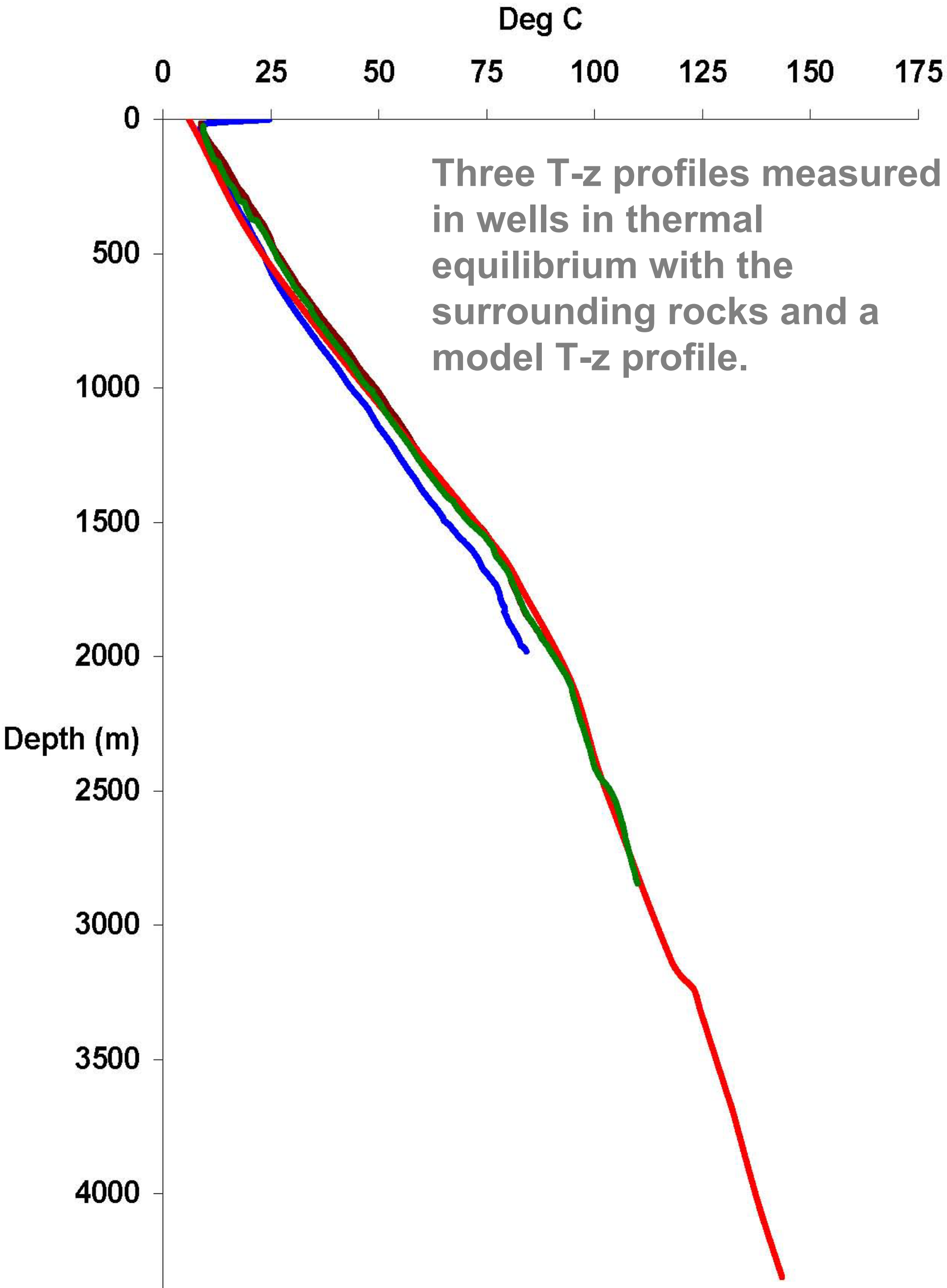
Thermostratigraphy is the application of Fourier's law of heat conduction to calculate temperature at depth

$$Q = \frac{dT}{dZ} K$$

Determine Q from equilibrium T-z and K.
Assume Q is constant, K and dz are known

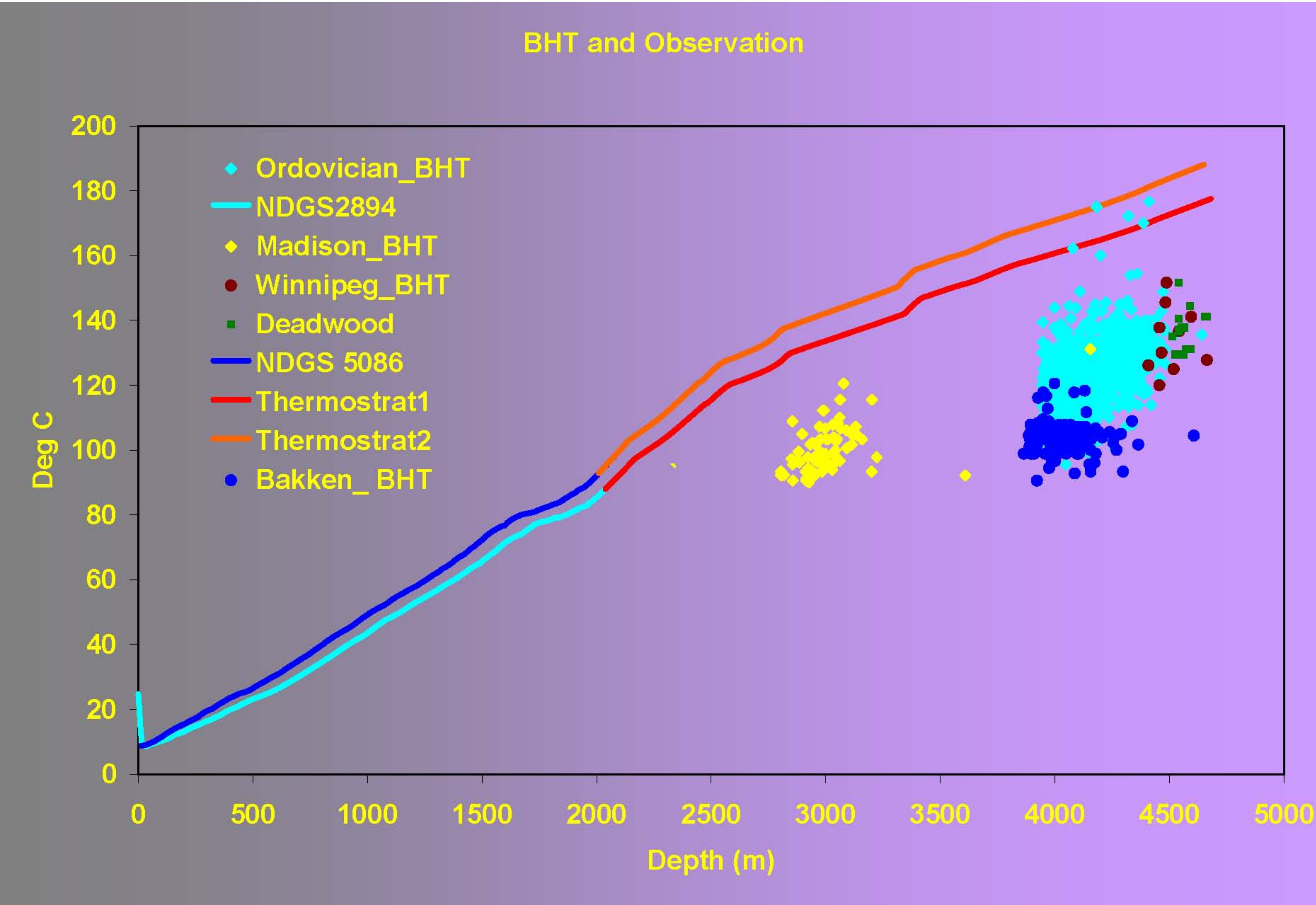
$$T(z) = T_0 + \sum_{i=1}^{n} \frac{Z_i}{K_i} Q$$





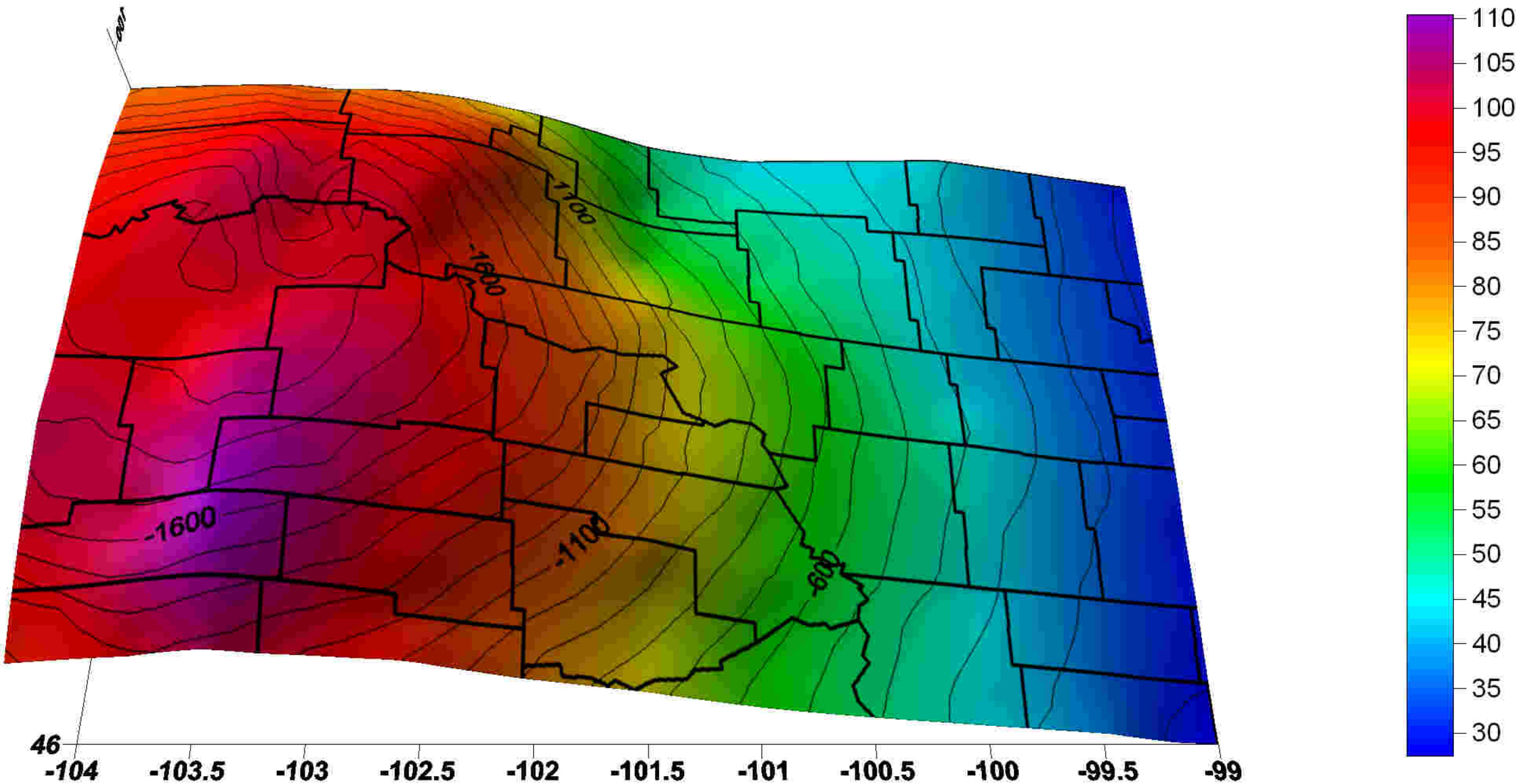
Three T-z profiles measured in wells in thermal equilibrium with the surrounding rocks and a model T-z profile.

Use the equilibrium temperature not the BHT



The energy resource in Joules is the product of density*volumetric heat capacity*volume*dT $q_r = \rho c_v a d\,(t - t_{ref})$

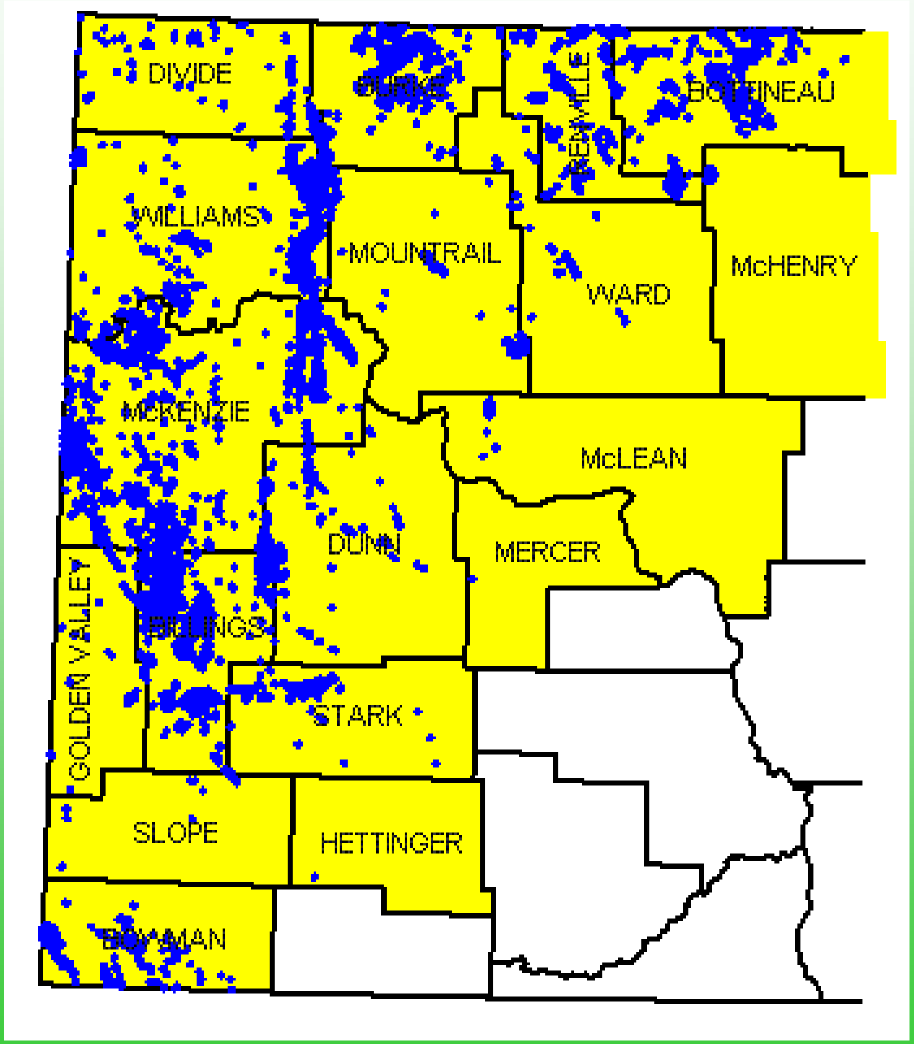
The Madison Fm in western North Dakota contains 1,476 EJ.



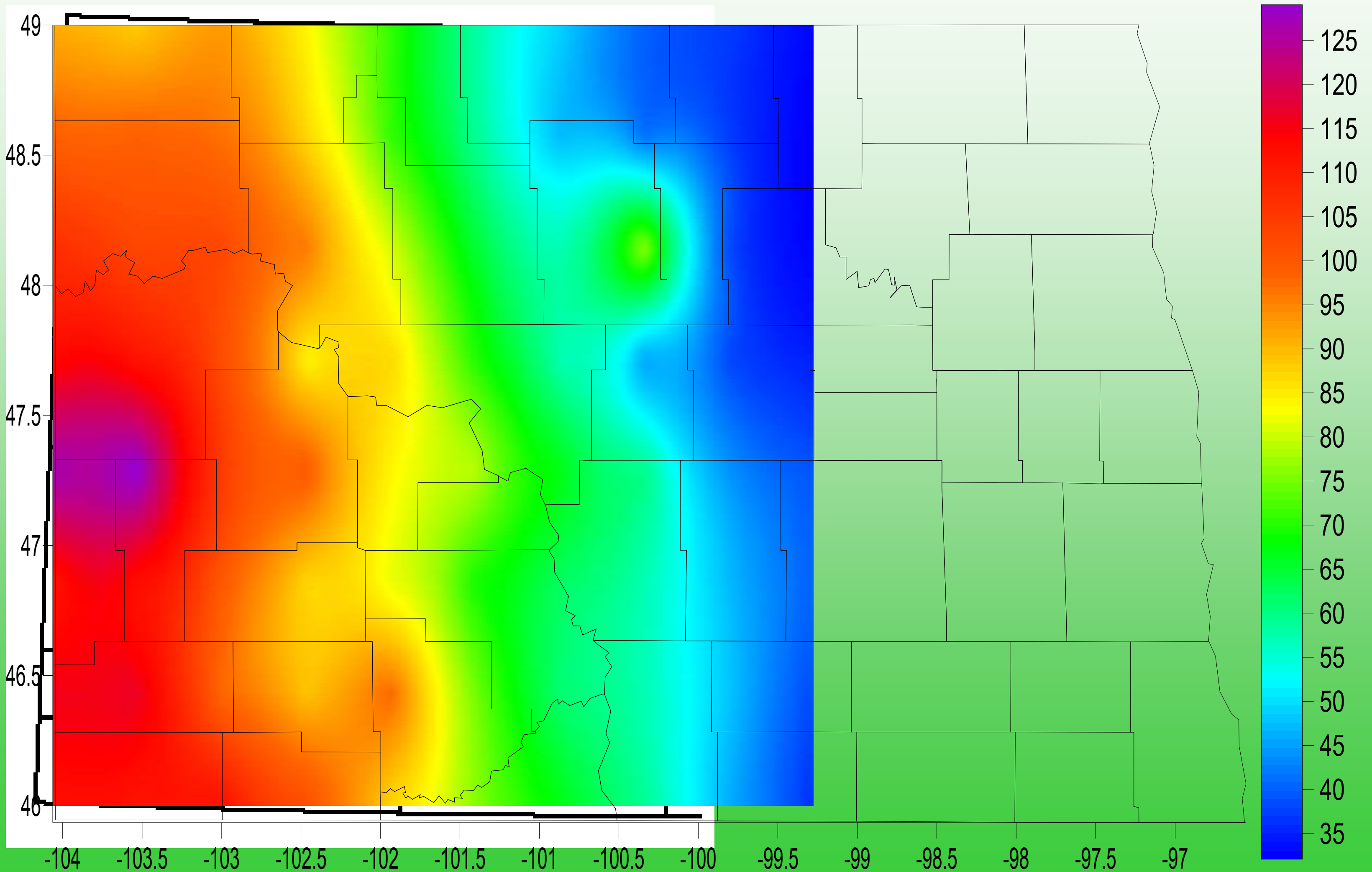
Colors are temperature, contours are depth (m), lines are county boundaries

FORMATION	BARRELS OF OIL	BARRELS OF WATER	MAX. TEMP C
Spearfish	582,601	320,626	120+
Spearfish/Madison/Charles	52,923,055	81,138,008	120+
Tyler	17,279,723	9,616,114	120+
Madison	1,003,859,751	2,266,631,018	132
Bakken (Sanish)	43,079,616	4,876,685	135+
Birdbear (Nisku)	16,532,269	19,875,577	135+
Duperow	48,360,560	51,290,164	135+
Souris River	58,090	61,886	140+
Dawson Bay	3,985,365	1,191,086	145+
Winnipegosis	8,853,724	6,663,034	145+
Interlake	62,397,829	140,808,361	145+
Stonewall	14,699,878	5,134,309	145+
Winnipegosis	8,853,724	6,663,034	145+
Red River	162,448,927	162,167,866	150+
Winnipeg/Deadwood	168,170	256,474	150+
Total	1,602,219,737	2,927,676,055	

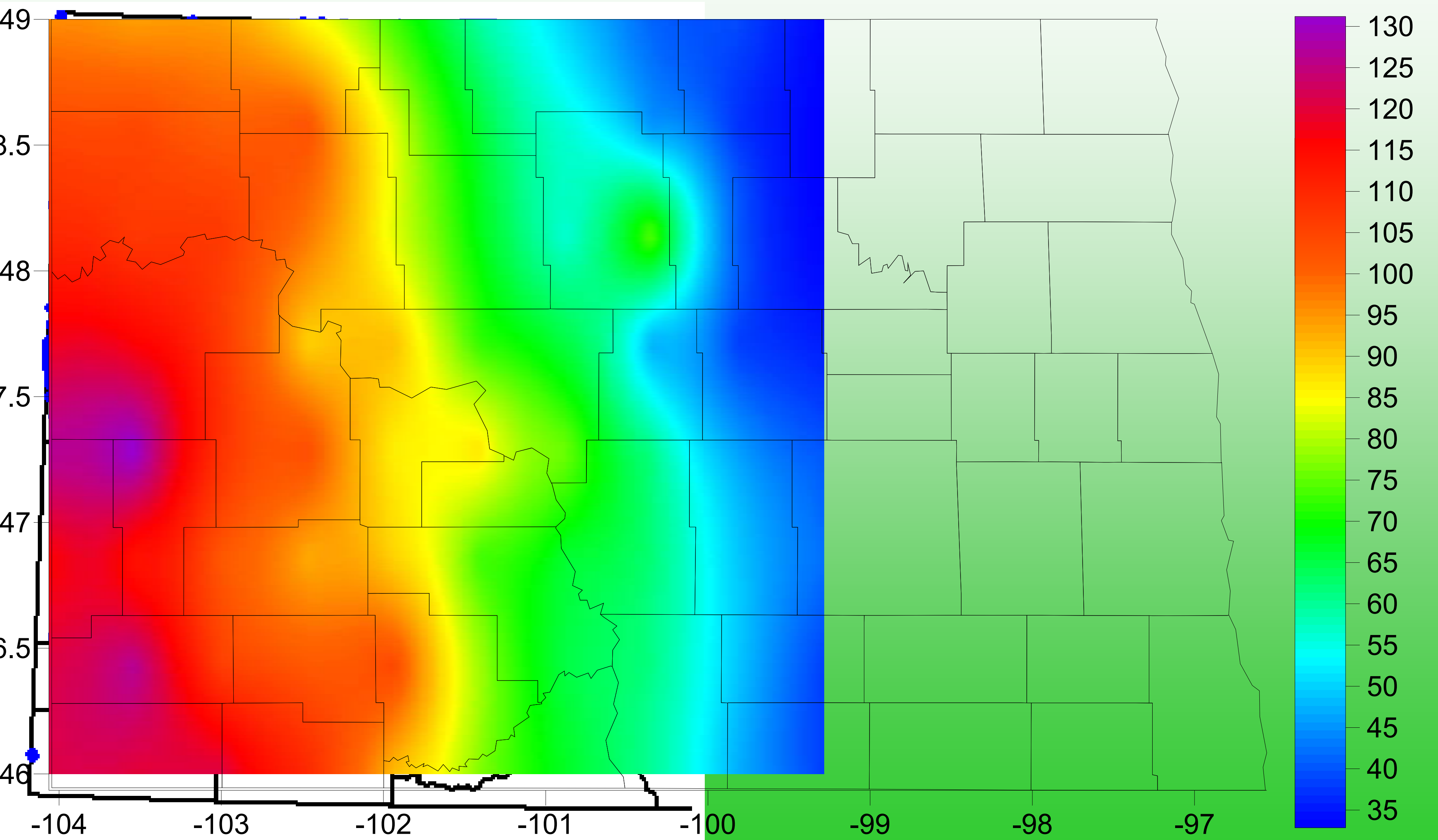
ND oil producing counties



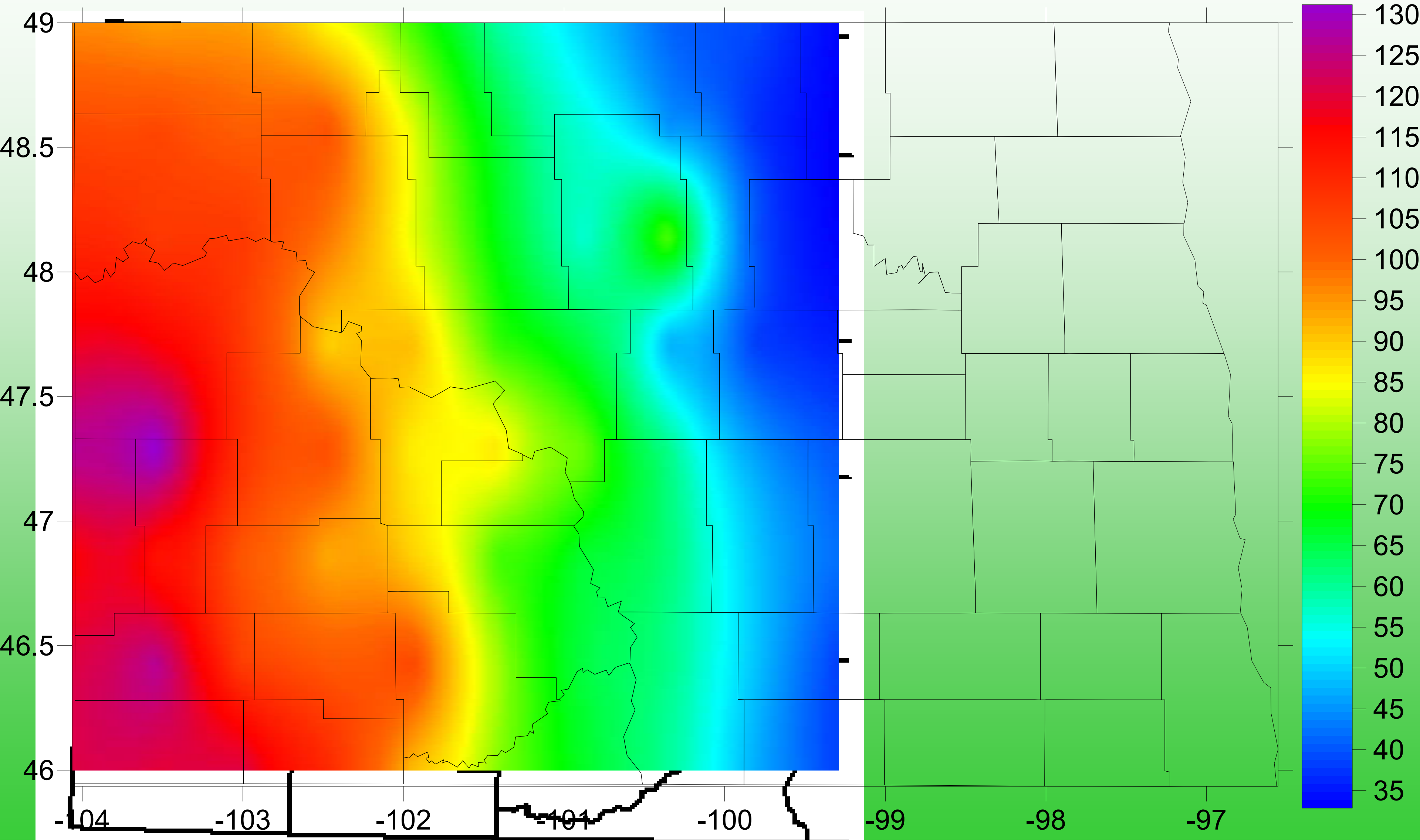
Bakken Fm (Ordovician)



Madison Fm (Miss) Maximum thickness 600 m

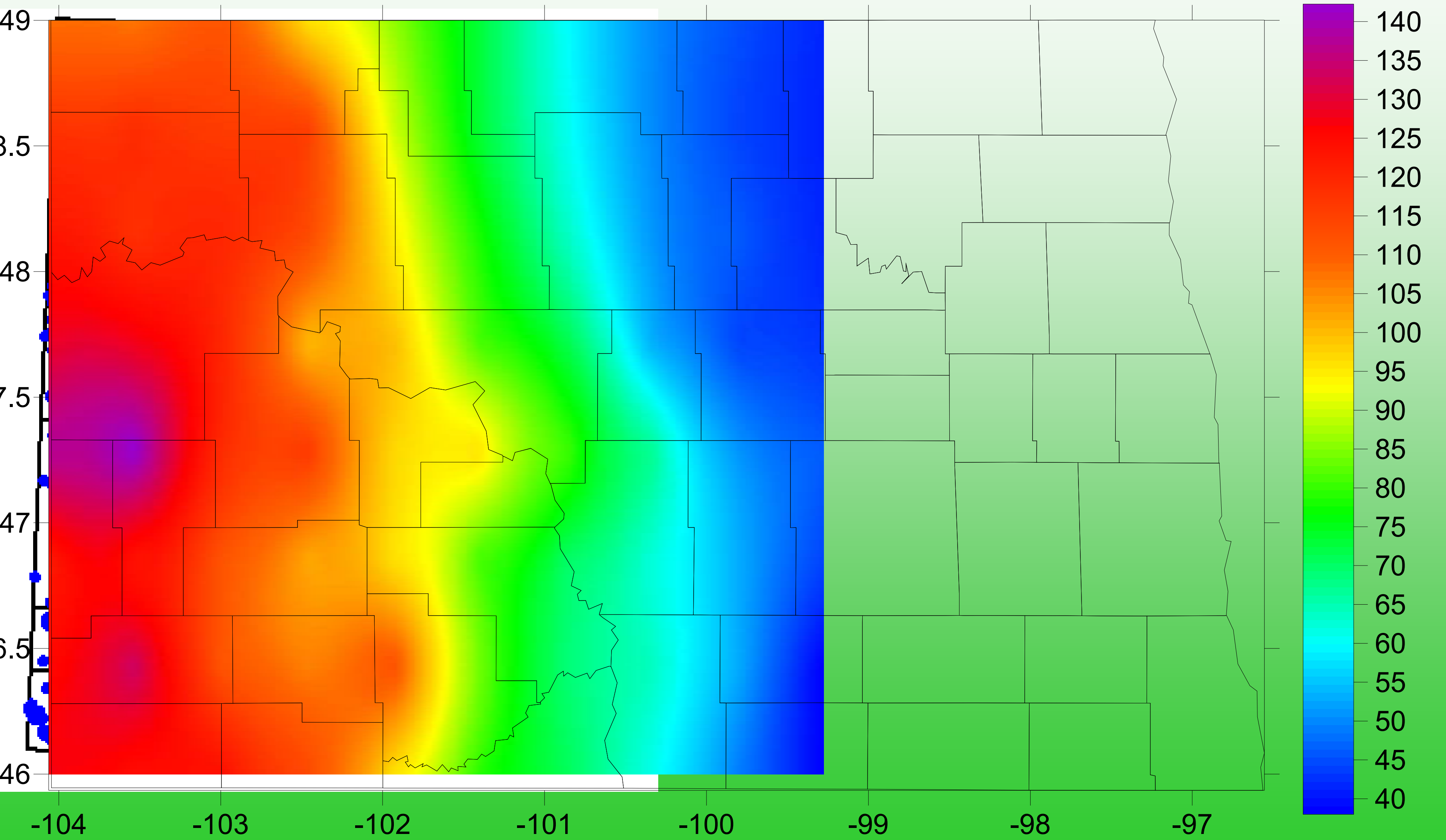


Duperow (Devonian)

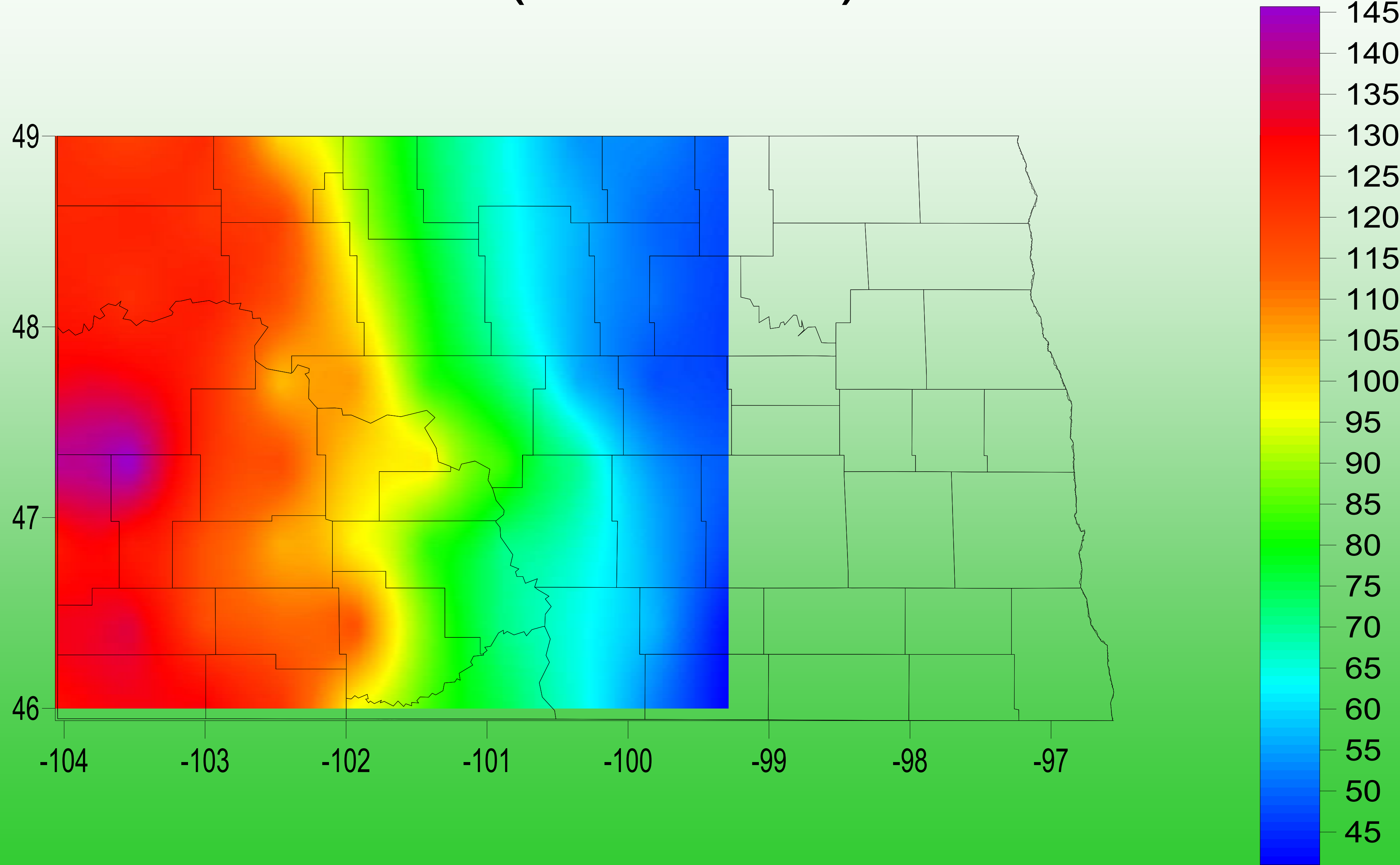


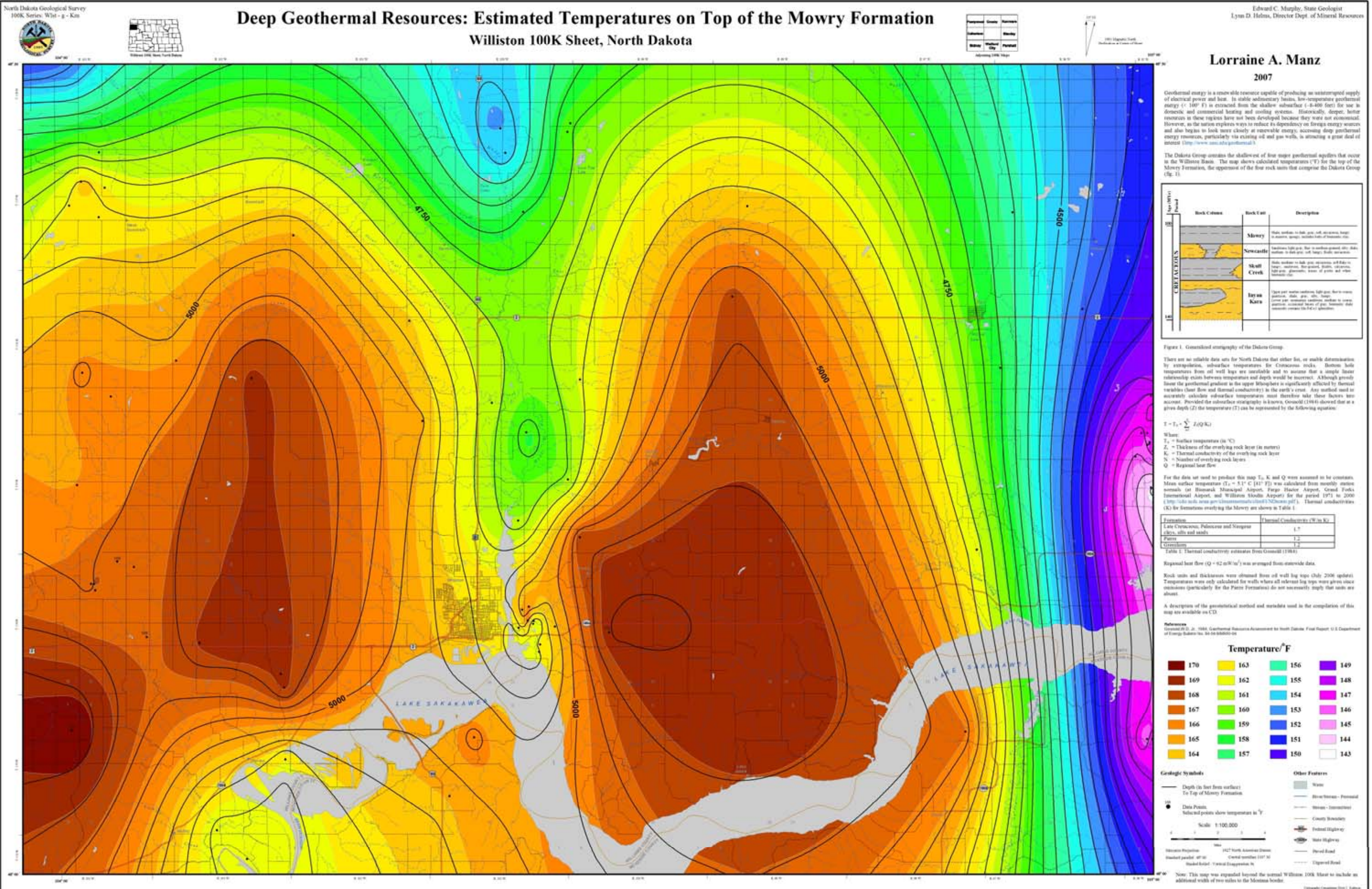
Red River Fm (Ordovician)

Maximum thickness 215 m



Deadwood Fm
(Cambrian)




Deep Geothermal Resources: Estimated Temperatures on Top of the Mowry Formation
Williston 100K Sheet, North Dakota
Lorraine A. Manz
2007
North Dakota Geological Survey
4750
4500
5000
LAKE SAKAKAWEA
Figure 1. Generalized stratigraphy of the Dakota Group.
Rock Column
Rock Unit
Description
CRETACEOUS
Mowry
Newcastle
Skull Creek
Inyan Kara
Table 1: Thermal conductivity estimates from Gosnold (1984)
Temperature/°F
170
169
168
167
166
165
164
163
162
161
160
159
158
157
156
155
154
153
152
151
150
149
148
147
146
145
144
143
Geologic Symbols
Other Features

Outcomes

Center of Excellence Application

- $3 million from State Dept. of Commerce
- $6 million from industry
- Seven objectives – one is development of electrical power from oil field waters

Minnesota Dept. Natural Resources

- EGS to meet requirement for power from renewable sources

Final Points

- Estimates of the energy that could be generated from co-produced U.S. oil field waste waters range from 4,590 to 21,933 MWe depending on the temperature of the resource.
- Development of existing capped and abandoned wells for water production can provide significant, sustainable, and environmentally sound power resource.

The University of North Dakota

North Dakota Morning Commute

“If you consider it a sport to gather your food by drilling through 8 inches of ice and sitting there all day hoping that the food will swim by, you might live in North Dakota.” Jeff Foxworthy