The University of North Dakota

Geothermal in the Oil Field

August 18-19, 2010

Casper, WY

Why Using Binary Power Generation in the Oil Field Makes Cents

Will Gosnold[1], Robert Klenner[1], Mark McDonald[1], Preston Wahl[1]
Kirtipal Barse[2], Joel Johnson[3]

1- UND Geology and Geological Engineering, 2- UND Chemical Engineering,
3 – Berrendo Geothermal

Outline

- ND Geothermal Projects
  - How they came to be
  - Status of current projects
- UND Geothermal Laboratory
  - Thermal conductivity
  - Basin analysis
- Impact on Oil Fields

Geothermal Energy in Sedimentary Basins in the North Central US

- **North Dakota & Montana 31,800 EJ**
- **Eastern Colorado 2,640 EJ**
- **South Dakota 5,950 EJ**
- **Nebraska 3,720 EJ**
- **Kansas 4,980 EJ**
- **Williston Basin (aquifers only) USGS Circular 893 2,050 EJ**

Technology Advances

- Commercialization of binary power systems that can produce electrical power from low-temperature thermal fluids

Pratt & Whitney
Model 200
Chena Hot Springs

Project Development

- Concept of binary power plants and low temperature resources
- Assemble science and engineering team
- Support from NDIC – NDGS
- Oil field operator
- Electrical Grid Connect
- Investment partners
- Proposal to DOE
  - Initial economic feasibility study
  - Team building and collaboration

The University of North Dakota

PREEC

Geothermal Energy Team

Will Gosnold
Geol & Geol Engr.

Richard LeFever
Geol & Geol Engr.

Mike Mann
Chemical Engr.

Hossein Salehfar
Electrical Engr.

Zhengwen Zeng
Geol & Geol Engr.

Rob Klenner
MS Geol

Preston Wahl
Soph GGE

James (Josh) Crowell
MS Student Geol

Kirtipal Barse
PhD Student ChE

Ana Crowell
MS Student Geol

Samir Dahal
PhD Elec Eng

The University of North Dakota

PREEC

Geothermal Energy Business Team

Joel Johnson
CEO Berrendo Energy

Joshua Fershee, J.D.
Asst. Professor
UND Law School

Megan Talley
Bus. Intern
UND Center for Innovation

Jordan Schuetzle, J. D.
UND Center for Innovation

NDIC Oil & Gas Division Home Page - Mozilla Firefox

File Edit View History Bookmarks Yahoo! Tools Help

nd.gov https://www.dmr.nd.gov/oilgas/

Most Visited Getting Started Latest Headlines Customize Links Free Hotmail Windows Marketplace Windows Media Windows

Search Web Mail Shopping Personals My Yahoo! News Games Travel Finance Answers Sports

NDIC Oil & Gas Division Home Page

North Dakota nd.gov Official Portal for North Dakota State Government

Services
- Rules & Regulations
- Forms
- Hearing Dockets
- Active Drilling Rigs
- Daily Activity Reports
- Confidential Well List
- General Statistics
- Seismic
- Well Search
- Report a Spill/Incident
- GIS Map Server
- Publications
- Surface-Mineral Owner
- Basic Services
- Premium Services
- Electronic Filing
- Related Links
- FAQ / Web Help

Contact Us
- Employee Directory
- E-Mail Addresses

NORTH DAKOTA
OIL AND GAS DIVISION

Welcome to the North Dakota Industrial Commission, Department of Mineral Resources, Oil and Gas Division, home page.

Proposed Rule Changes!

See the proposed rule changes or the full notice

Bakken and Three Forks Information!

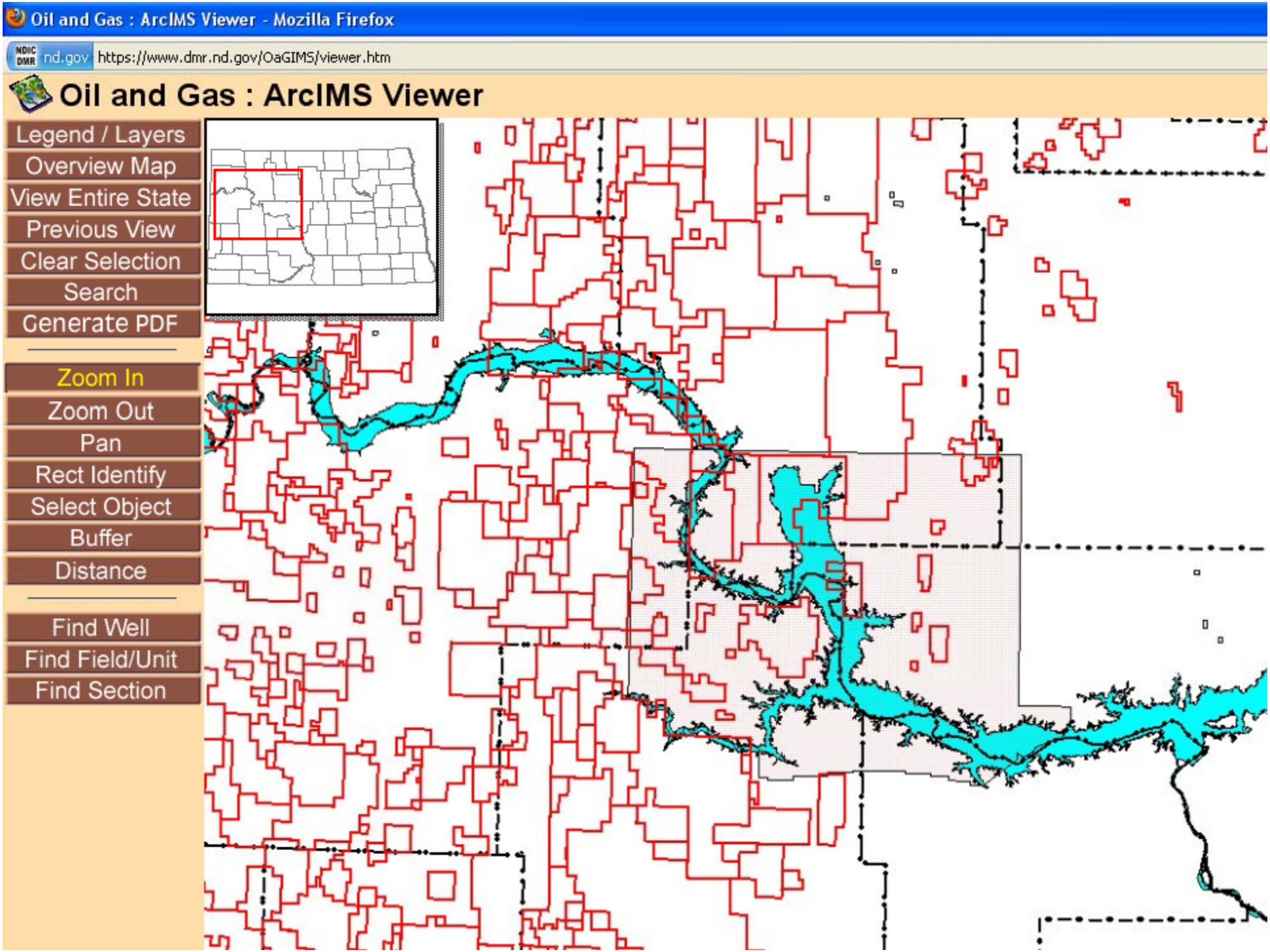
The ND Petroleum Council proudly announces its new Royalty Owner Information Center!

The Oil and Gas Division regulates the drilling and production of oil and gas in North Dakota. Our mission is to encourage and promote the development, production, and utilization of oil and gas in the state in such a manner as will prevent waste, maximize economic recovery, and fully protect the correlative rights of all owners to the end that the landowners, the royalty owners, the producers, and the general public realize the greatest possible good from these vital natural resources.

Phone: (701) 328-8020
Fax: (701) 328-8022
Mail:
NDIC Oil and Gas Division
600 East Boulevard Ave Dept 405
Bismarck, ND 58505-0840
General Shipping:
NDIC Oil and Gas Division
1016 East Calgary Ave
Bismarck, ND 58503-5512
Core and Samples Shipping:
ND Geological Survey Core Library
Campus Road and Cornell
Grand Forks, ND 58202

Done

start Surfer - Ordovi... 2 Adobe Acro... 2 Windows E... 6 Microsoft O... 2 Microsoft O... 2 Novell Grou... NDIC Oil & Gas ... Oil and Gas : A... 1:38 PM


Oil and Gas : ArcIMS Viewer - Mozilla Firefox
nd.gov
https://www.dmr.nd.gov/OaGIMS/viewer.htm
Oil and Gas : ArcIMS Viewer
Legend / Layers
Overview Map
View Entire State
Previous View
Clear Selection
Search
Generate PDF
Zoom In
Zoom Out
Pan
Rect Identify
Select Object
Buffer
Distance
Find Well
Find Field/Unit
Find Section

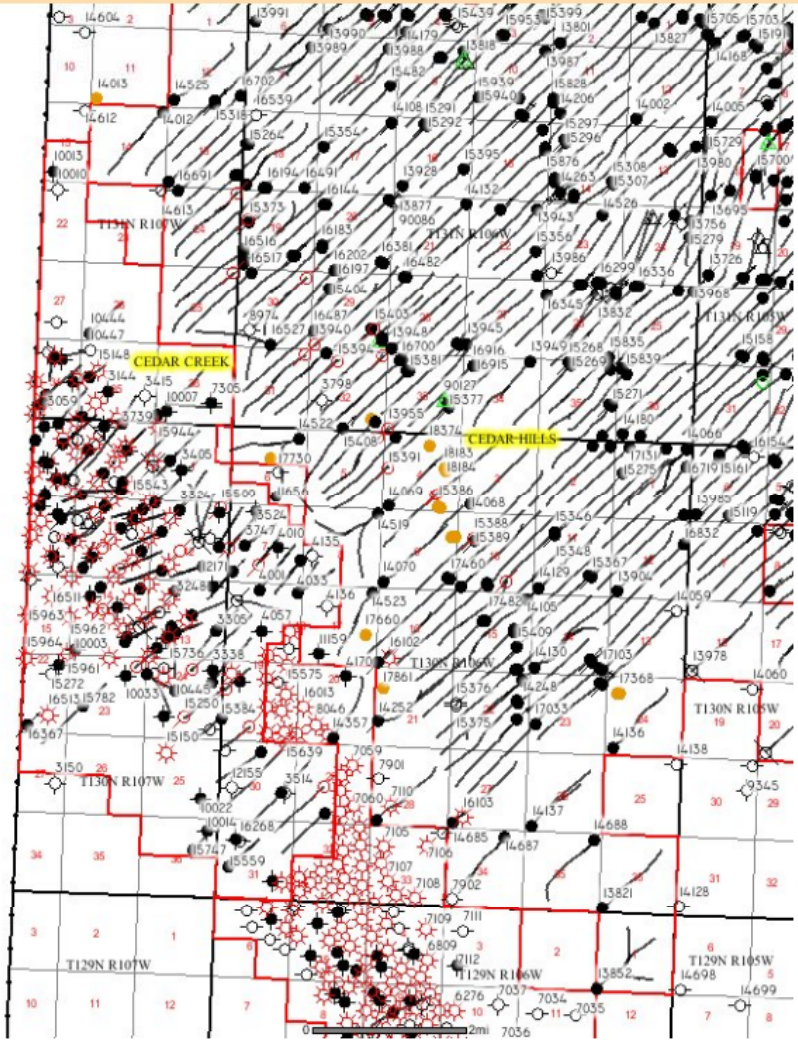
Oil and Gas : ArcIMS Viewer - Mozilla Firefox

https://www.dmr.nd.gov/OaGIMS/viewer.htm

Oil and Gas : ArcIMS Viewer

Download Shape Files

- Legend / Layers
- Overview Map
- View Entire State
- Previous View
- Clear Selection
- Search
- Generate PDF
- Zoom In
- Zoom Out
- Pan
- Rect Identify
- Select Object
- Buffer
- Distance
- Find Well
- Find Field/Unit
- Find Section



ND OIL & GAS LAYERS

- Oil and Gas
  - Wells
  - Rig Location
  - Directional Surveys
  - Directional Legs
  - Horizontal Surveys
  - Horizontal Legs
  - Cases Docketed
  - Oil Fields
  - Unit Boundaries
  - Inspector Areas
  - Drilling / Spacing
  - Seismic
  - Gas Plants
- Other
- Imagery
  - Topo/DRG 250k
  - Topo/DRG 100k
  - NAIP 2005

Refresh Map

Auto Refresh

Help:

- A closed group, click to open.
- An open group, click to close.
- A map layer.
- A hidden group/layer, click to make visible.
- A visible group/layer, click to hide.
- A visible layer, but not at this scale.
- A partially visible group, click to make visible.
- An inactive layer, click to make active.
- The active layer.

Get a listing of all Fields / Units by name starting with the letter below:

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

Enter a partial or full Name to search for.

Search

Seach for name in

- Field
- Unit

Find

Map Data Last Updated : 10/26/2009

Done

start | Surfer - [Plo... | 3 Adobe A... | 2 Window... | 6 Microsof... | 2 Microsof... | 5 Novell Gr... | Unit Monthly... | Oil and Gas ... | performanc... | 2:17 PM

Electric Power Generation from Low Temperature Geothermal Fluids

- Project funding
  - DOE $1,733,864
  - Berrendo Geothermal, LLC $1,500,000
  - UND $233,864
- Industry and Public Partners
  - Continental Resources, Inc.
  - Berrendo Geothermal, Inc
  - North Dakota Industrial Commission

Electric Power Generation from Co-Produced Fluids

- Project funding
  - DOE $1,733,864
  - Berrendo Geothermal, LLC $1,500,000
  - UND $233,864
- Industry and Public Partners
  - Denbury, Inc
  - Berrendo Geothermal, Inc
  - North Dakota Industrial Commission

Energy Conversion systems
ORC Vendors

- Ormat – ORC – turbine with air or water cooling
- Pratt & Whitney - ORC – turbine with air or water cooling
- Electratherm – ORC – screw expander with water cooling
- Calnetix – ORC – turbine with air or water cooling
- Turbine Air Systems – ORC – turbine with air or water cooling

Other Energy Conversion Systems

- Deluge – Natural energy engine
- Recurrent Engineering – Kalina cycle – turbine with air or water cooling

Feasibility Study

- **Project Description**
- *Scope Statement (Matt)*
- *Objectives (Matt)*
- *Project Requirements (Joel)*
  - Energy Production Criteria
  - Host Oil Company Criteria
  - Power Purchase Criteria
  - Financial Criteria

Feasibility Study

- **Site Description**
- *Geothermal Supply (Will)*
- *Oil field Operations (Matt)*
- **Regulatory and Permitting**
- *Geothermal Energy Rights (Joel)*
- *Electrical Interconnection (Hossein)*
- Other Permits (Mark)

Feasibility Study

- **Technology Evaluation**
- *Basis for Evaluation (Matt/Joel)*
  - Physical Parameters
  - Operational Parameters
  - National Electric Code Area Classification

Feasibility Study

- ***Technology Descriptions of Organic Rankine Cycle Providers (Matt)***
- Pratt & Whitney Power Systems
- Ormat Technologies Inc.
- ElectraTherm / Roughrider Power LLC

- ***Technology Descriptions of Kalina Cycle Providers (Matt)***
- Recurrent Engineering

- ***Technology Descriptions of Thermal Hydraulic Providers (Matt)***
- Deluge Inc.

- ***Condenser Cooling Considerations (Matt)***
- Single-Unit versus Multi-Unit Cooler-Condensers
- Forced-Air versus Evaporative Cooling
- Binary Power Plant Supplier Selection (Joel/Matt)

Feasibility Study

- **Economic Analysis**
- *Economic Model (Andy/Joel)*
  - Goals
  - Description of Economic Model
  - Inputs, Parameters, and Assumptions
  - Renewable Incentives Available
  - Contingencies and Sensitivity Analyses
  - Results

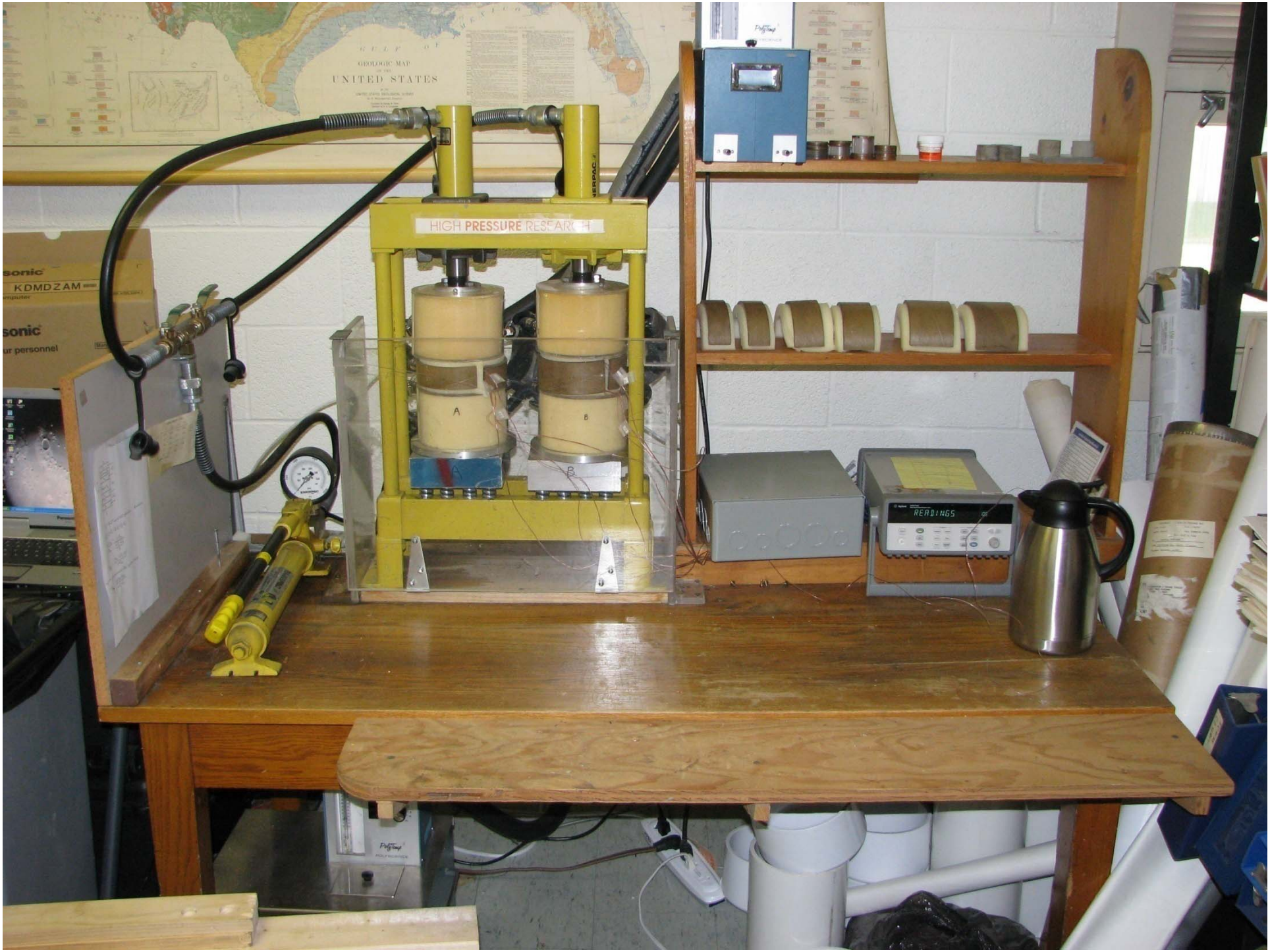
Feasibility Study

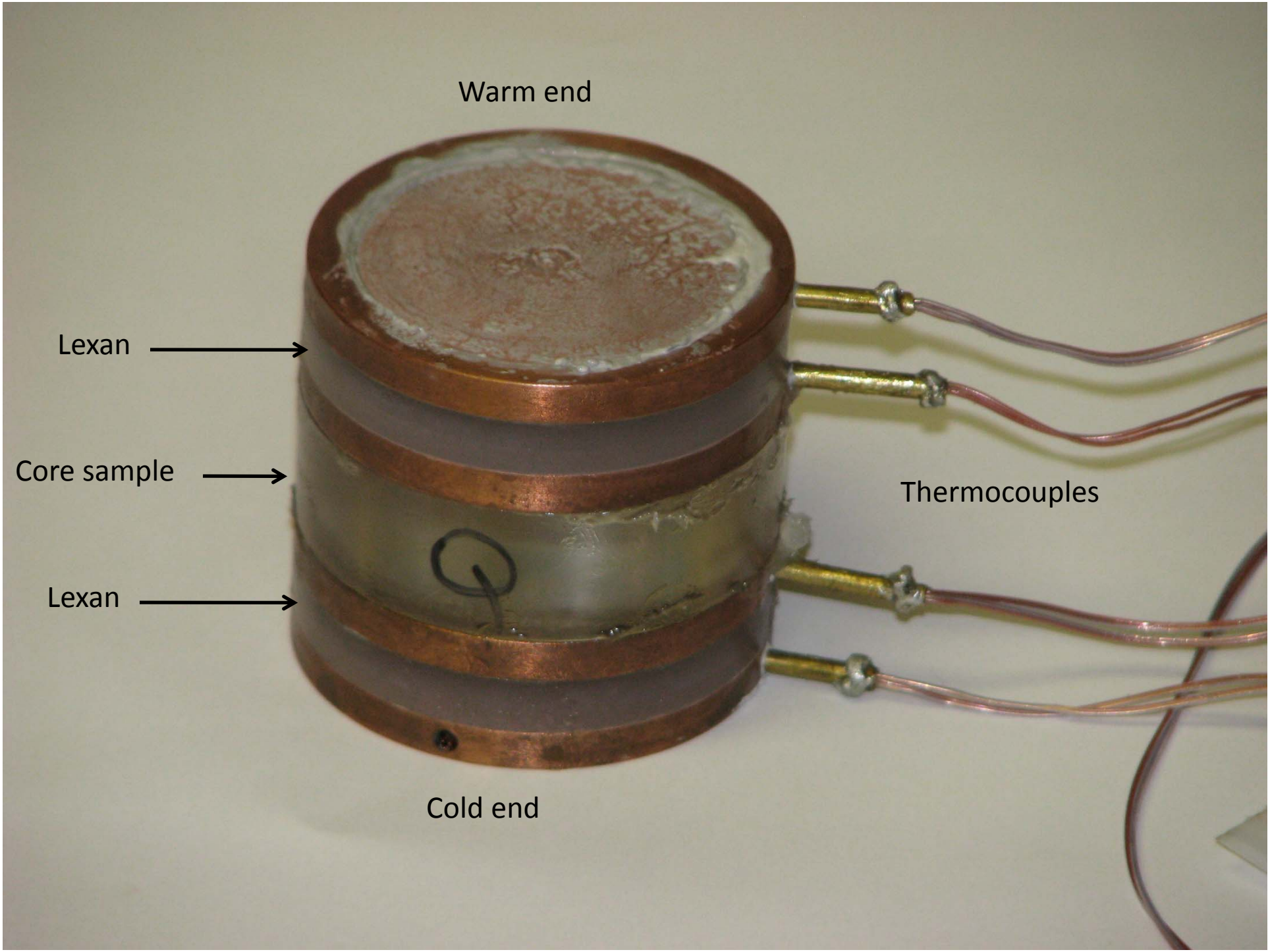
- **Assessment of Low-Temperature Geothermal Opportunities**
- *Quantity and Quality of Comparable Geothermal Resources (UND)*
  - Williston Basin
  - Other Locations
- *Other Factors to be Considered (Matt/Joel)*
  - Transmission Constraints
  - Power Pricing
  - Host Oil Company Concerns
  - Go/No Go Decision (Joel/Matt)

UND Geothermal Laboratory

- 2 Portable Electronic Divided Bars
- 2 Conventional Divided Bars
- 2 GeLi gamma ray spectrometers
- High resolution manual temperature logging system

Portable Electronic Divided Bar

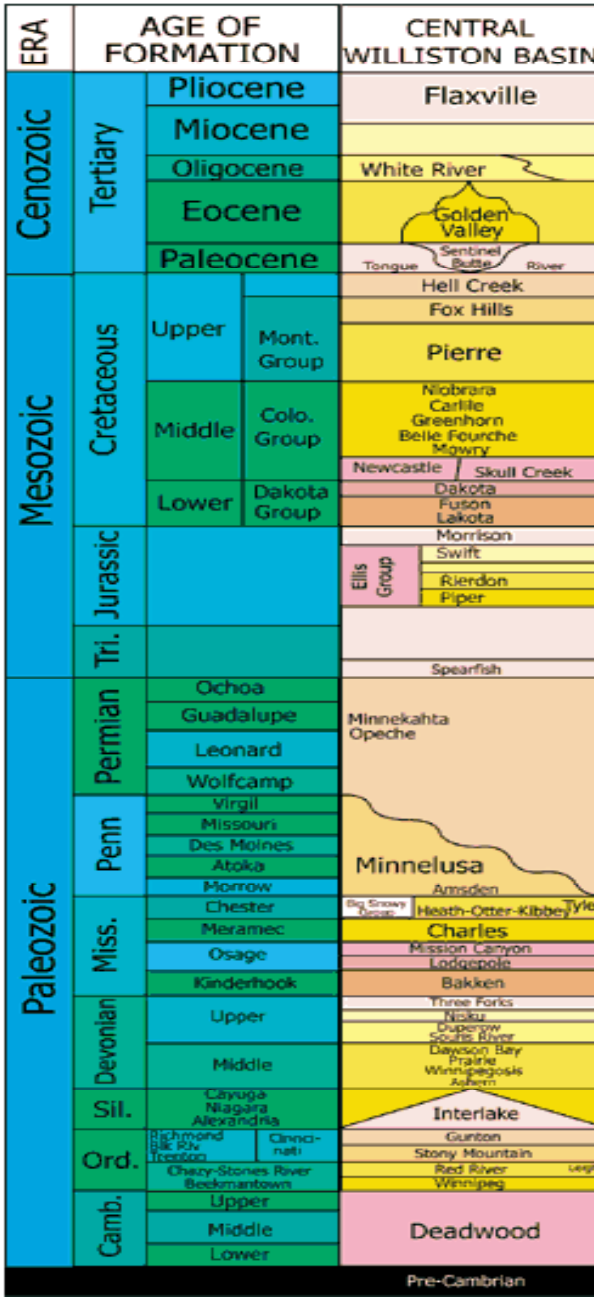

GEOLOGIC MAP
UNITED STATES
HIGH PRESSURE RESEARCH
A
B
READINGS

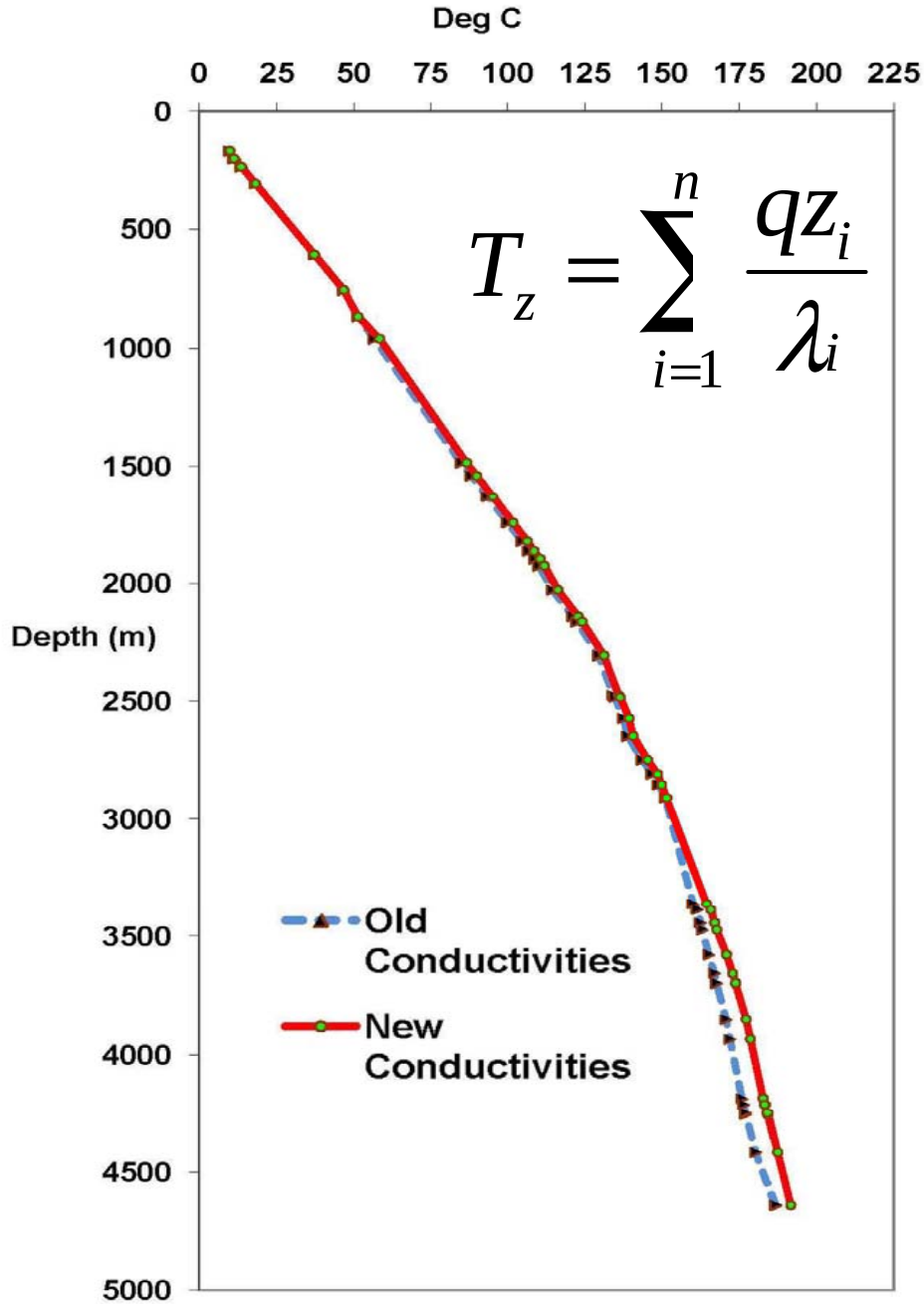

Warm end
Lexan
Core sample
Lexan
Thermocouples
Cold end

FRAGILE

Formation	System	Rock Type	Cond. W/m/K	N	Pub. Lit.
Pierre	Cretaceous	Sh	0.89 ± .26	22	1.10
Madison	Mississippian	Ls	2.43 ± .78	41	3.50
Duperow	Devonian	Ls	3.10 ± .30	18	3.50
Souris River	Devonian	Ls	2.37 ± .63	10	3.50
Dawson Bay	Devonian	Ls	2.70 ± .63	5	3.50
Ashern	Devonian	Ls / Do	3.07 ± .24	6	3.50
Interlake	Silurian	Do / LS	4.21 ± .69	28	3.50
Stonewall	Silurian	Do / Ls	3.93 ± .01	2	3.50
Stony Mt.	Silurian	Do / Ls	4.14 ± .45	4	3.50
Red River	Ordovician	LS / Do	3.38 ± 1.01	47	3.50
Black Island	Ordovician	Do - SS	4.76 ± .64	5	3.50
Deadwood	Cambrian	Do - SS	3.71 ± .89	31	2.40

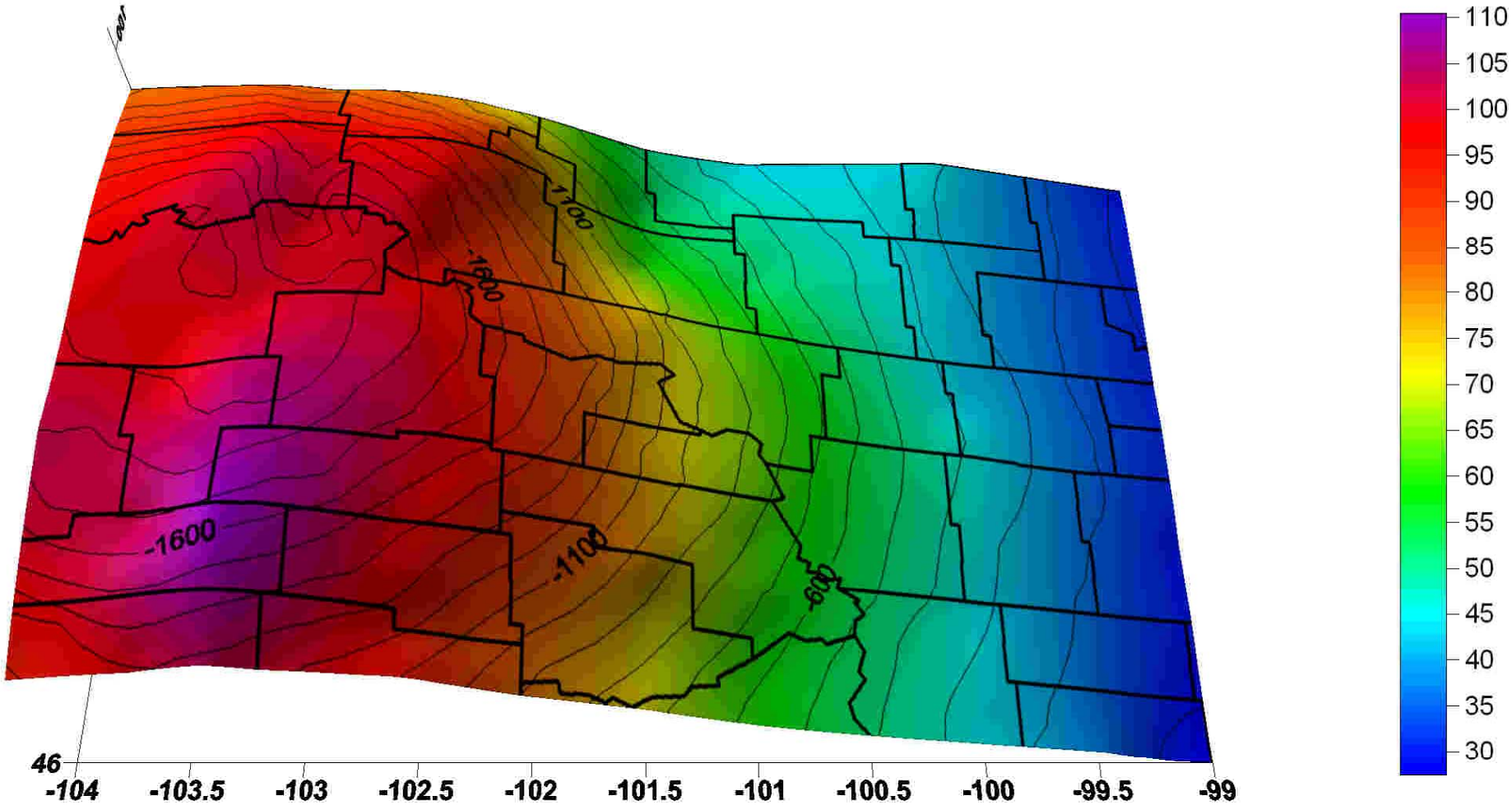
Temperature vs. Depth in Williston Basin



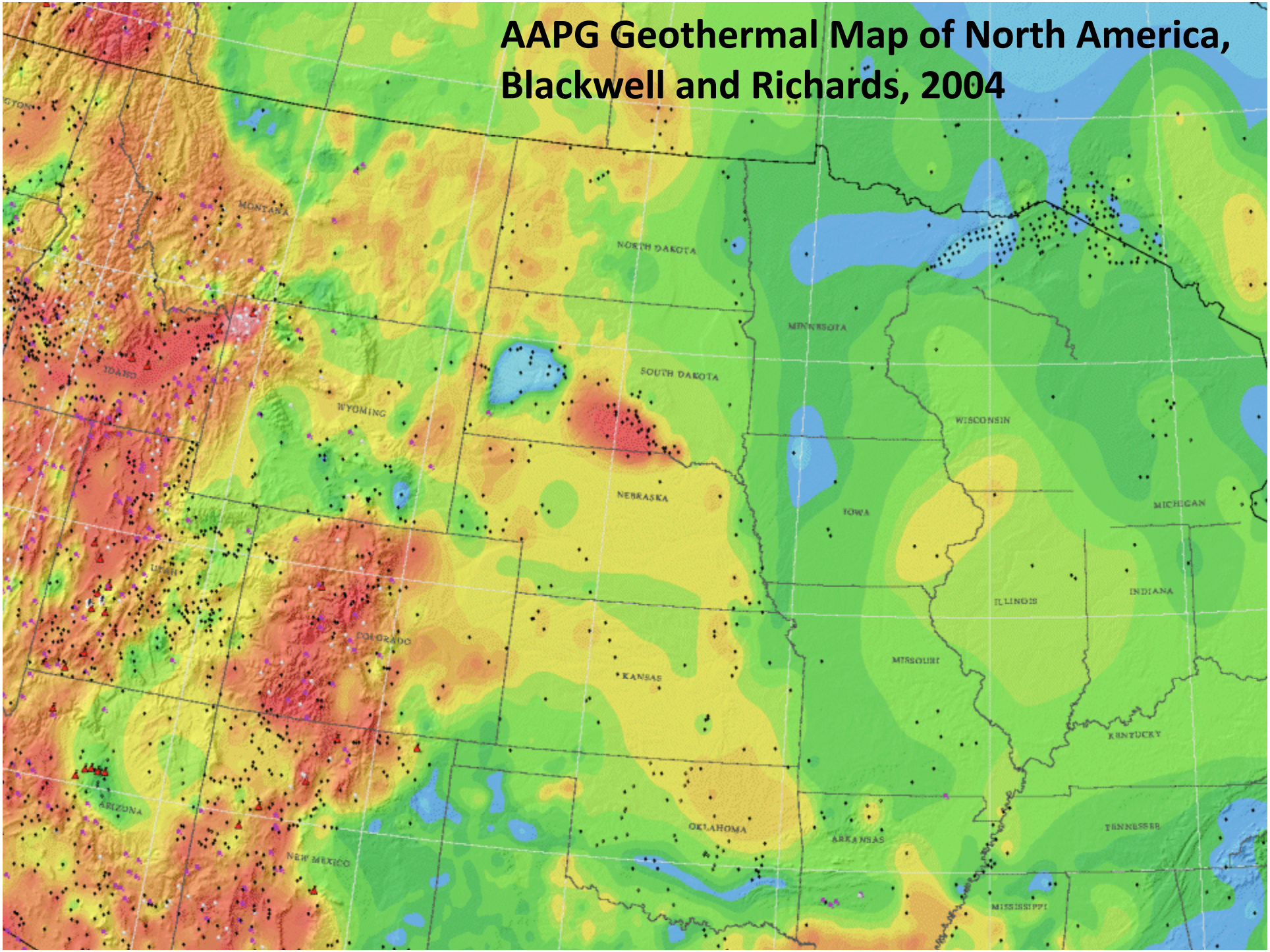


$$T_z = \sum_{i=1}^{n} \frac{q z_i}{\lambda_i}$$

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



AAPG Geothermal Map of North America, Blackwell and Richards, 2004

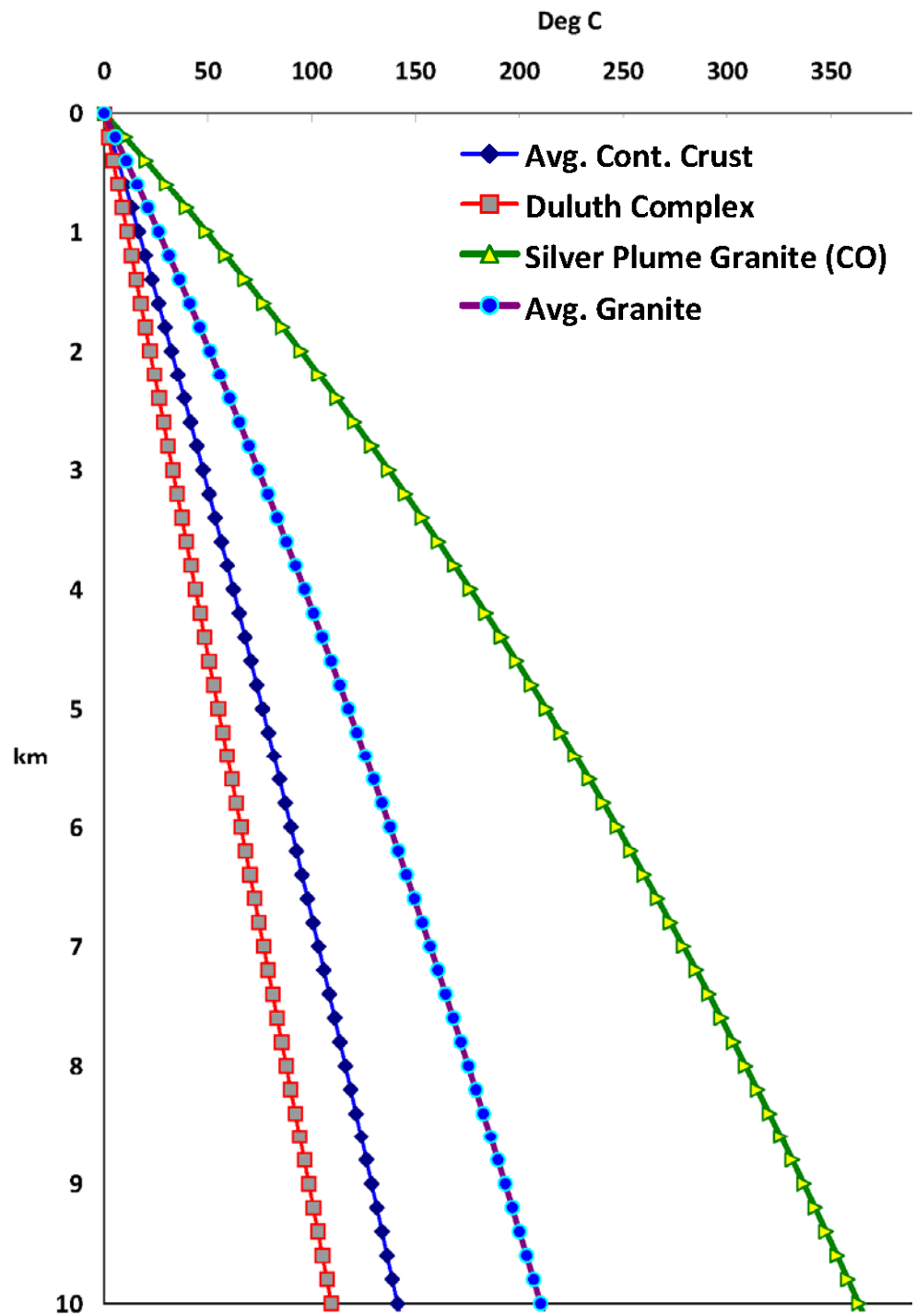


Temperature vs. depth plots based on the exponential model for the vertical distribution of crustal radioactivity.

$$A = A_0 e^{\frac{-z}{D}}$$

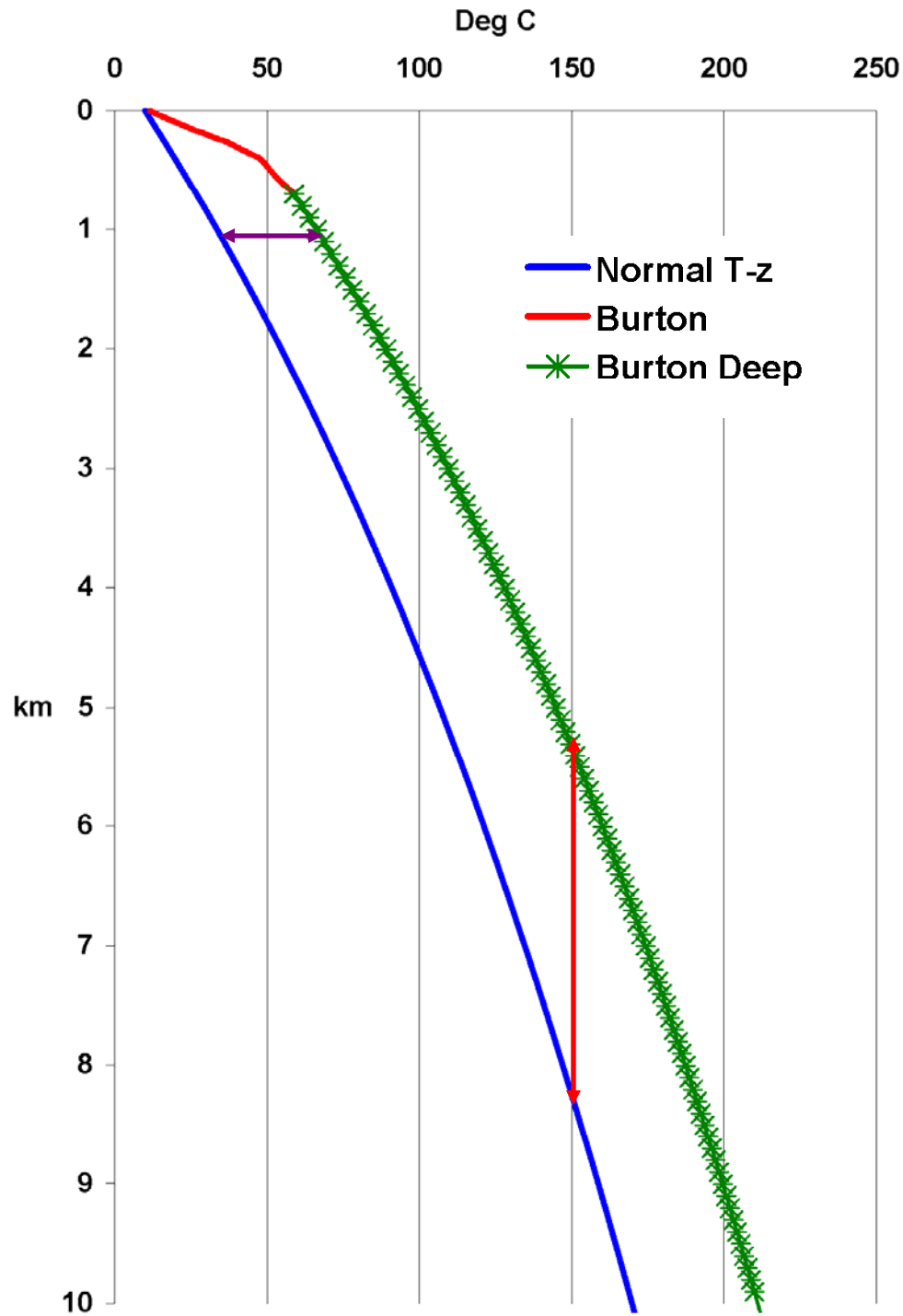
$$q = q_0 + AD$$

$$T(z) = T_0 + q(z)/\lambda$$



The temperature at a depth of 1 km in the SD/NE heat flow anomaly is 48 ºC higher than outside the anomaly.

The depth to 150 ºC is 2.9 km less in the anomaly than outside the anomaly.



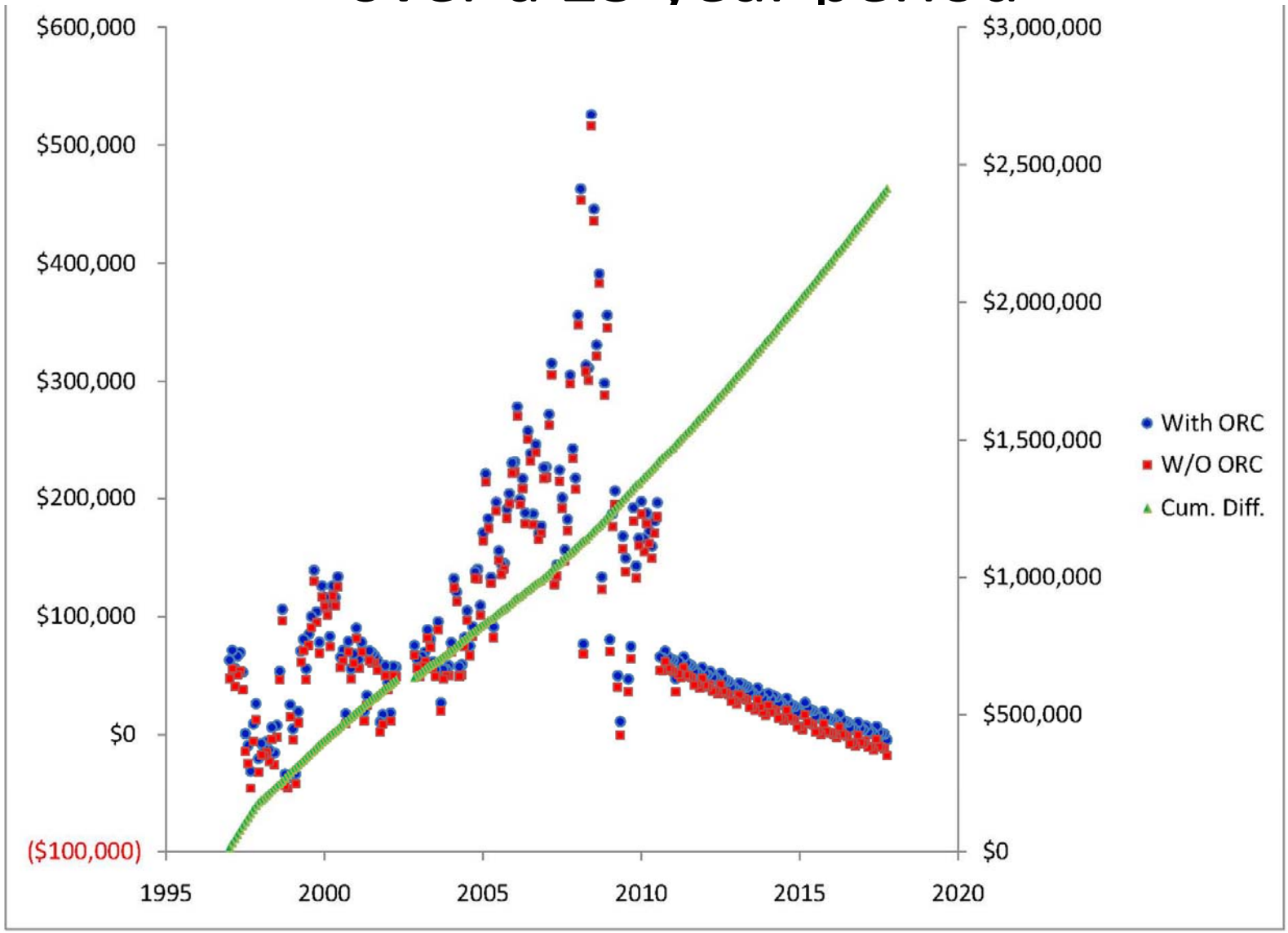
Impact on Oil Fields

Cost factors for economic model

1997 - 2017

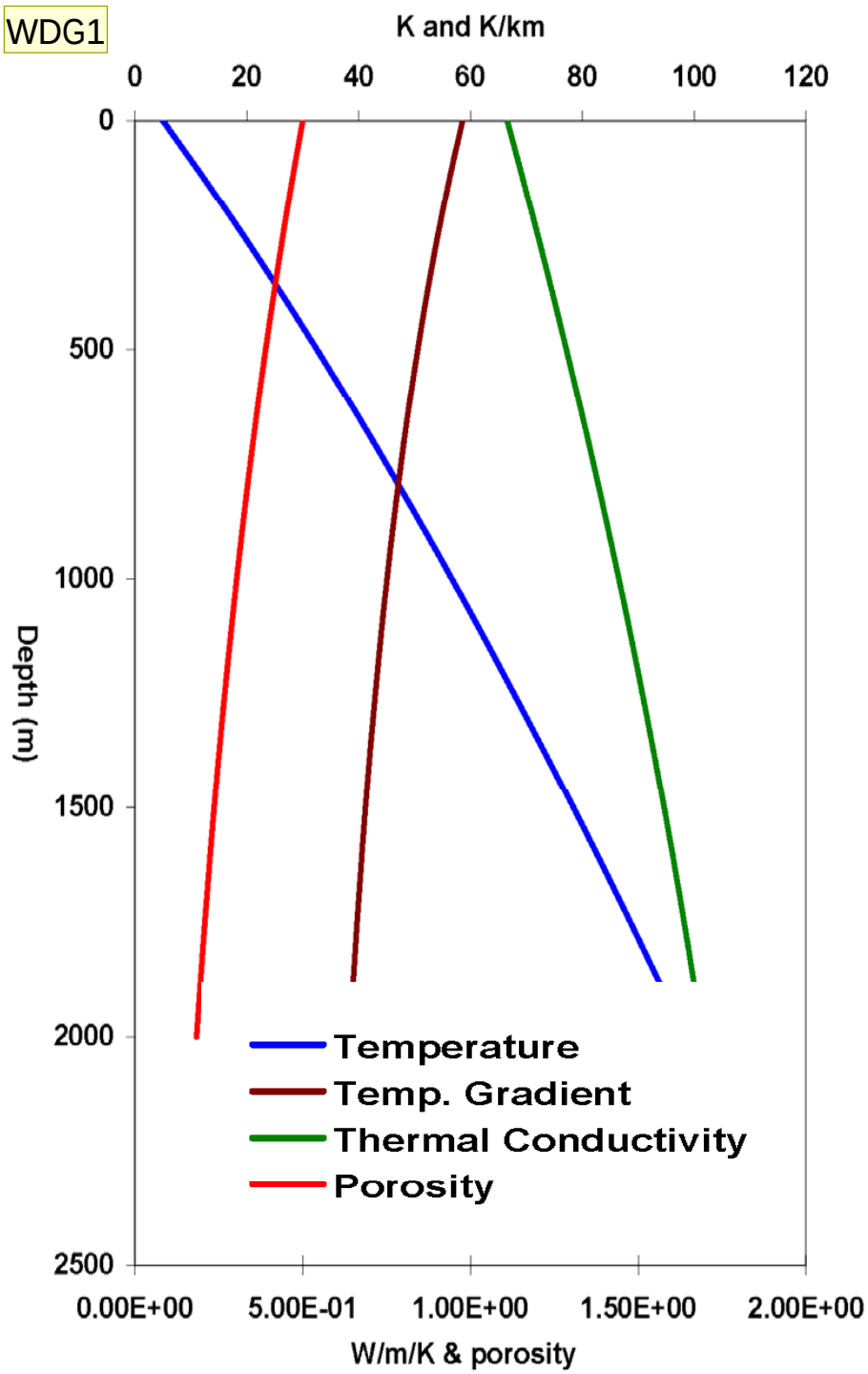
- BBLS Oil
- BBLS Water
- MCF
- SWD - Disposal at $0.56/BBL
- kW/hr used (based on $.06)
- $ Electrical
- Crude Oil $/BBL
- Crude Sales
- kW produced
- Electricity Sales
- Other O&M costs (at $137/day)

Monthly income and cumulative difference over a 25 year period



Making Cents

- Installing binary power systems for power generation using co-produced oil field fluids has potential to make a positive impact on oil field economics.
- Extend well life
- Providing an inexpensive and environmentally benign electrical power source.
- An economic model based on oil and water production rates, water temperature, O & M, oil futures, and electrical cost, show that power generation using co-produced fluids could generate millions of dollars in additional revenue by saving on electrical costs, extending the Estimated Ultimate Recovery (EUR), and facilitating early development of the field.



Porosity varies with depth as $\Phi=\Phi_0 e^{-cz}$

Thermal conductivity, K, varies with porosity and as a function of the conductivity of the solid rock and water as $K = Kr^{1-\Phi}Kw^{\Phi}$

With constant heat flow

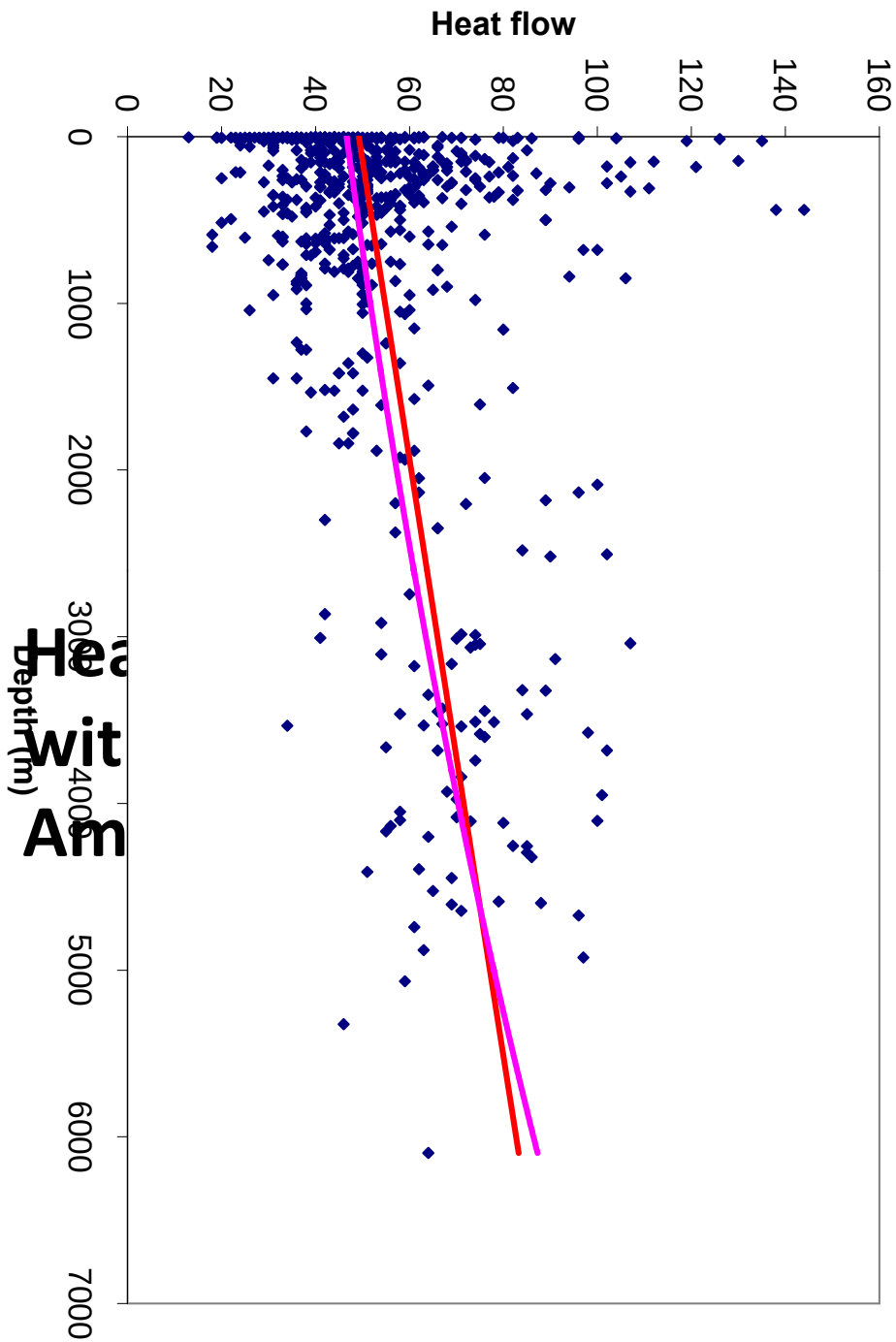
$$T = T_0 + \Sigma\Gamma_i z_i \text{ where } \Gamma_i = q/K_i$$

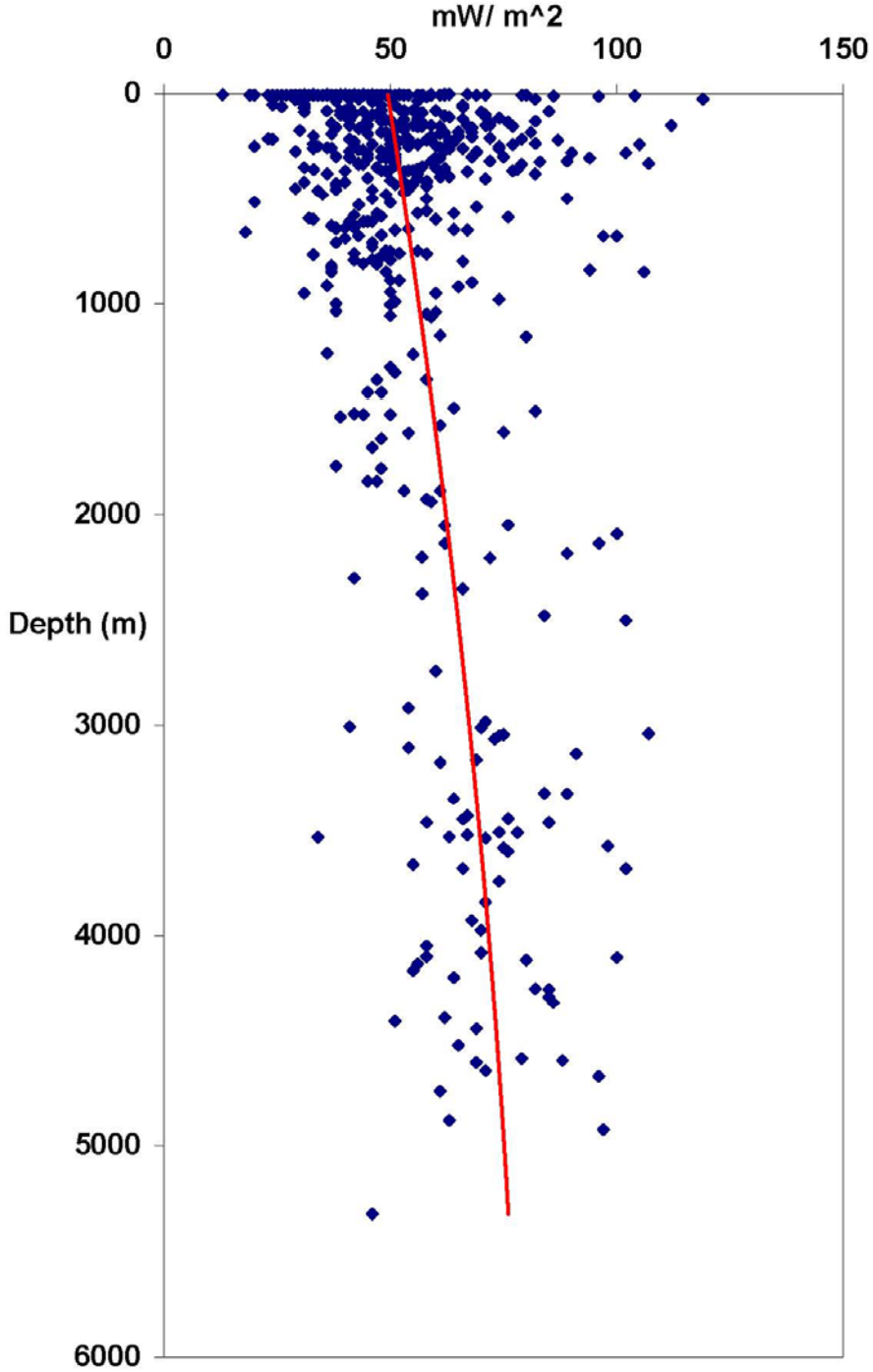
The normal temperature vs. depth profile in a thick clastic sedimentary section has a convex curvature due to the increase in thermal conductivity with depth caused by compaction which reduces porosity.

Slide 36

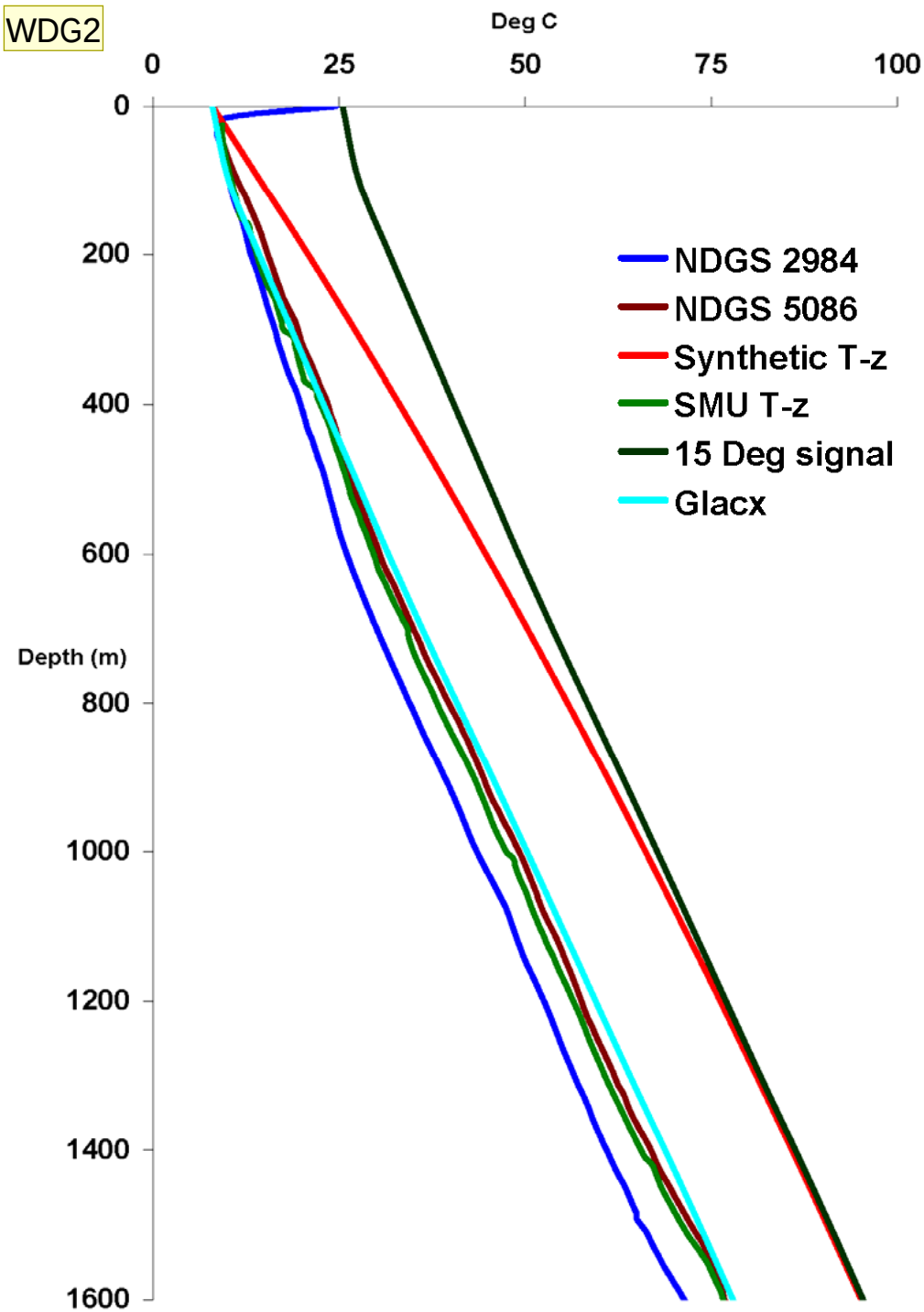
WDG1 The normal temperature vs. depth profile in a thick clastic sedimentary section is show by the blue curve. Convex curvature in the curve is due to the increase in thermal conductivity (green curve) with depth caused by compaction which reduces porosisty (red curve).

Will Gosnold, 2/5/2008


Heat flow
0
20
40
60
80
100
120
140
160
Depth (m)
0
1000
2000
3000
4000
5000
6000
7000


mW/ m^2
0
50
100
150
Depth (m)
0
1000
2000
3000
4000
5000
6000

Hea
wit
Am



Three equilibrium T-z profiles that penetrate the thick shale section in the Williston Basin show curvature suggesting either a thermal conductivity decrease with depth or a heat flow increase with depth.

Interestingly, calculations of the theoretical T-z profiles for normal compaction, red curve, and for the effect of 15 degrees of warming since the Pleistocene combine to produce a T-z profile (Glacx) that matches the observed profiles.

It appears that heat flow has been underestimated in periglacial areas by more than 60 percent.

Slide 38

WDG2 All three equilibrium T-z profiles that penetrate the thick shale section in the Williston Basin show curvature suggesting either a thermal conductivity decrease with depth or a heat flow increase with depth.

Interestingly, calculations of the theoretical T-z profiles for normal compaction and for the effect of 15 degrees of warming since the Pleistocene combine to produce a T-z profile that matches the observed profiles.

Will Gosnold, 2/5/2008