Stratigraphic Control of Temperatures in the Wattenberg Field, Denver Basin, Colorado*

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Search and Discovery Article #80066 (2009)
Posted November 10, 2009

*Adapted from oral presentation at AAPG Annual Convention, Denver, Colorado, June 7-10, 2009
Please refer to companion article, "A Preliminary Analysis of Geothermal Resources in the Central Raton Basin, Colorado, from Bottom-Hole Temperature Data," Search and Discovery Article #80065 (2009).

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Abstract

The Wattenberg Field has been reported as a thermal hot spot, but a new geothermal gradient map of Colorado does not show it to be anomalous with respect to other areas of the Denver Basin. We have re-analyzed bottom-hole temperature (BHT) data from logs from over 2500 wells in the Wattenberg Field to investigate the modern temperature structure of the gas-producing formations in this field and to evaluate the potential for electricity generation with water from the depth of existing wells. BHT data were corrected for the effects of drilling using standard-correction techniques to give estimates of the undisturbed formation temperatures. An initial analysis of the data indicated no coherent temperature structure in the field, but an apparent statistical negative correlation of geothermal gradient with well depth. This correlation was found to be probably without significance, as, upon closer examination, the BHT data had no correlation with depth, but gradient is inversely proportional to depth. Attempts to find correlations among the BHT data and other parameters were unsuccessful, until remarkably strong correlations were found between BHTs and depth for wells that were completed in the "Sussex" and the driller's "Dakota" units. Wells that were completed in other units showed no significant correlations. The "Sussex" and "Dakota" essentially bracket the main producing units in the Wattenberg Field, but differ from other units in that they are outside the overpressured zone that characterizes the main production. We speculate that gain and loss of drilling fluid in the overpressured zone causes disturbances to the BHTs not corrected by standard techniques. The corrected temperatures in the "Sussex" and "Dakota" are valid and may be interpolated through the intervening units using stratigraphic information. Temperatures in the producing zone range from about 100-120°C (210-250°F) at depths ranging from 2100 to 2600 m (6900 to 8500 ft). Using binary technology with small modular power plants, water from this zone could be used to produce electricity to power production operations in this field, probably with power to spare. The origins of reports of the Wattenberg Field as a hot spot were probably based on unreliable temperature data. Vitrinite reflectance data and consideration of gas maturation require higher temperatures than at present: higher past temperatures could have been associated with greater burial depth and/or higher heat flow.

References

Higley, D.K., D.L. Gautier, and M.J. Pawlewicz, 1992, Influence of regional heat flow variation on thermal maturity of the Lower Cretaceous Muddy (“J”) Sandstone, Denver Basin, Colorado, *in* U.S. Geological Survey Bulletin, p. 66-69.

Meyer, H.J. and H.W. McGee, 1985, Oil and gas fields accompanied by geothermal anomalies in Rocky Mountain region: AAPG Bulletin, v. 69, p. 933-945.

Weimer, R.J. and S.A. Sonnenberg, Guide to the petroleum geology and Laramide Orogeny, Denver Basin and Front Range, Colorado: Bulletin Colorado Geological Survey Department of Natural Resources, Report #51, 127 p.

Presenter's Notes:

Introduction

Oil and gas basins are a somewhat ignored area in the search for geothermal resources. During the past nine months we have examined data from three Colorado oil and gas basins--the Denver, Raton, and San Juan basins, and found that there is a high potential for finding geothermal resources in this type of basin, and wells commonly exist to the depth of the resource.

Presentation Outline:

- Bottom Hole Temperatures (BHTs)
  - The Good, The Bad, The Ugly
- The Wattenberg Field, Denver Basin
  - The Wattenberg Field "Hot Spot"
- Wattenberg Field BHTs
  - The Worst BHT Data Set on Earth
- Wattenberg Gas and Geothermal Energy

COLORADO GEOLOGICAL SURVEY

Presenter's Notes: This presentation first briefly discusses the collection of bottom-hole-temperature or BHT data, the primary data source for this study. Data from a small portion of the Denver Basin, focusing on the Wattenberg Field, are then discussed and presented, followed by a study from the central Raton Basin and preliminary results from the northern San Juan Basin.

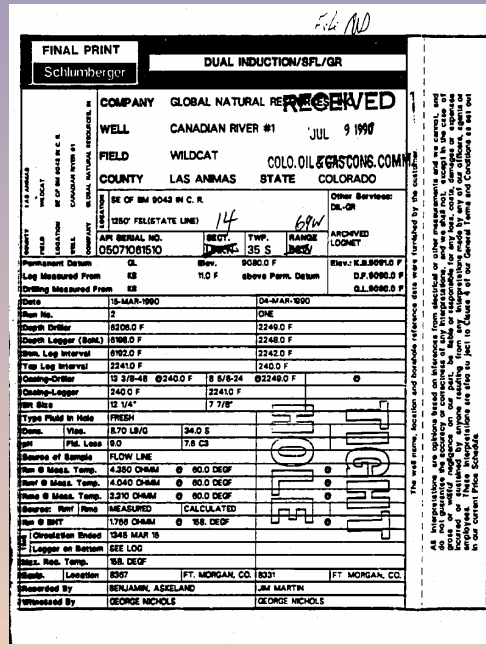
Bottom-Hole Temperatures

COLORADO GEOLOGICAL SURVEY

Presenter's Notes: Sometimes during different stages of drilling, but almost always at the end of drilling, one or more geophysical logs is run in the well after pulling the drill string. These logs indicate the depths to changes in rock type and other physical properties of the rocks. One useful set of properties that is commonly measured is the electrical properties, and as electrical properties change with temperature, the temperature at the bottom of the well, or BHT, is measured and recorded on these logs, and sometimes on other logs.

Data Collection

Bottom-hole temperatures are recorded with varying degrees of reliability on geophysical logs run in oil and gas wells



FINAL PRINT
Schlumberger

DUAL INDUCTION/SFL/GR

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JUL 9 1990
COLO. OIL & GAS CONS. COMM

COMPANY	GLOBAL NATURAL RESOURCES, INC.
WELL	CANADIAN RIVER #1
FIELD	WILDCAT
COUNTY	LAS ANIMAS
STATE	COLORADO

LOCATION: SE OF BM 9043 IN C. R.
1250' FEL(ESTATE LINE) 14 69W
API SERIAL NO. 05071061510 SECT. 14 TWP. 35 S RANGE 69W
Other Services: DIL-GR
ARCHIVED LOGNET

Permanent Datum	GL	Elev.	9080.0 F	Elev.: K.B.9091.0 F
Log Measured From	KB	11.0 F	above Perm. Datum	D.F.9090.0 F
Drilling Measured From	KB			G.L.9080.0 F

Date	15-MAR-1990		04-MAR-1990	
Run No.	2		ONE	
Depth Driller	8306.0 F		2249.0 F	
Depth Logger (Schl.)	8198.0 F		2248.0 F	
Btm. Log Interval	8192.0 F		2242.0 F	
Top Log Interval	2241.0 F		240.0 F	
Casing-Driller	13 3/8-48 @240.0 F	8 5/8-24	@2249.0 F	@
Casing-Logger	240.0 F	2241.0 F		
Bit Size	12 1/4"	7 7/8"		
Type Fluid in Hole	FRESH			
Dens. / Visc.	8.70 LB/G	34.0 S		
pH / Fld. Loss	9.0	7.8 C3		
Source of Sample	FLOW LINE			
Rm @ Meas. Temp.	4.350 OHMM @ 60.0 DEGF			@
Rmf @ Meas. Temp.	4.040 OHMM @ 60.0 DEGF			@
Rmc @ Meas. Temp.	3.310 OHMM @ 60.0 DEGF			@
Source: Rmf / Rmc	MEASURED	CALCULATED		
Rm @ BHT	1.780 OHMM @ 168. DEGF			@
Time Circulation Ended	1345 MAR 15			
Time Logger on Bottom	SEE LOG			
Max. Rec. Temp.	168. DEGF			
Equip. Location	8357	FT. MORGAN, CO.	8331	FT. MORGAN, CO.
Recorded By	BENJAMIN, ASKELAND		JIM MARTIN	
Witnessed By	GEORGE NICHOLS		GEORGE NICHOLS	

The well name, location and borehole reference data were furnished by the customer.

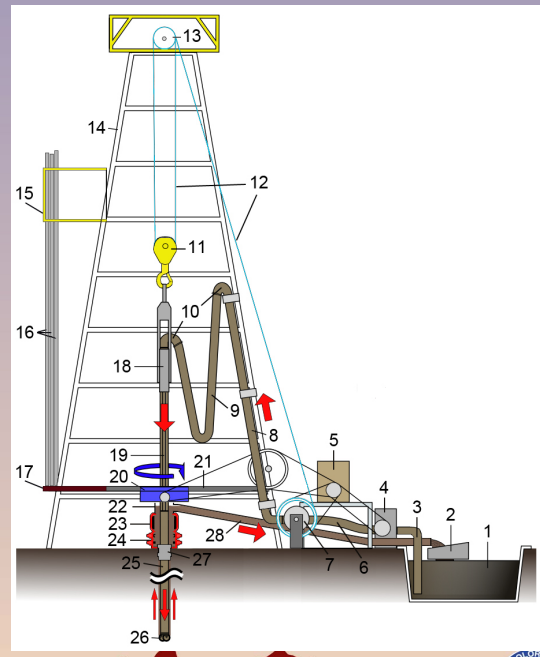
All interpretations are opinions based on inferences from electrical or other measurements and we cannot, and do not guarantee the accuracy or correctness of any interpretations, and we shall not, except in the case of gross or willful negligence on our part, be liable or responsible for any loss, costs, damages or expenses incurred or sustained by anyone resulting from any interpretations made by any of our officers, agents or employees. These interpretations are also to be subject to Clause 4 of our General Terms and Conditions as set out in our current Price Schedule.

COLORADO GEOLOGICAL SURVEY

Presenter's Notes: The BHT is one of the parameters that is recorded on the log header, a page at the top of all well logs, an example of which is shown here. The collection of BHT data is basically reading the temperature and depth data from these headers and correlating the BHTs with the well locations. Temperature does not need to be know accurately for correction of electrical properties, and in general BHTs are not carefully recorded. However, what they lack in quality is made up in quantity.

Need for BHT Corrections

Circulation of drilling fluid changes rock temperatures. Need to make a correction to obtain undisturbed BHTs. Individual BHTs suspect, but large data sets useful.



COLORADO GEOLOGICAL SURVEY

Presenter's Notes: For geothermal studies we would like to measure the undisturbed rock temperatures at depth. However, during drilling, water, mud, air or foam is circulated through the drill string and back through the hole to the surface to remove rock chippings and cool the drill bit. The basic circulation pattern is shown by the red arrows. Depending on the relative temperatures of the drilling fluid and the rock, the rock is either heated or cooled. If details of the circulation time and fluid temperature are known, or if a series of BHTs are available for a hole at different times, then the undisturbed rock temperature can be extrapolated from these data. However, from the Colorado BHT data, these parameters were not available, and corrections were estimated from average disturbances calculated for other oil and gas fields.

BHT Data

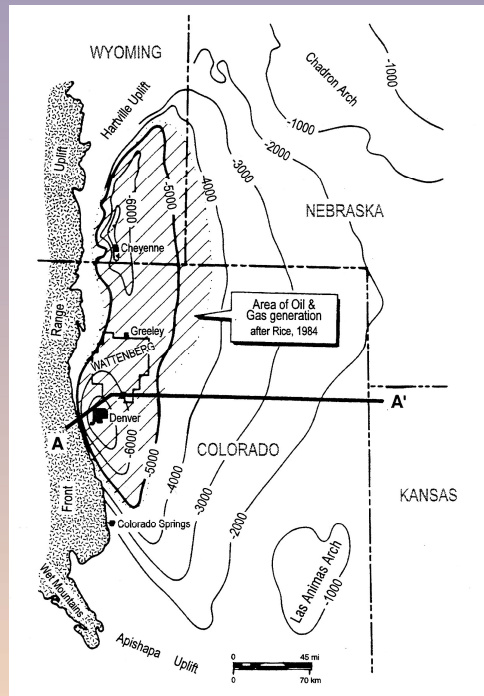
- The Good
  - Data are “Free”
- The Bad
  - Data not really collected for use as temperatures
- The Ugly
  - Data need correction to estimate formation temperatures

Presenter’s Notes: This presentation first briefly discusses the collection of bottom-hole-temperature or BHT data, the primary data source for this study. Data from a small portion of the Denver Basin, focusing on the Wattenberg Field, are then presented and discussed, followed by a study from the central Raton Basin and preliminary results from the northern San Juan Basin.

BHT Corrections

- Ideal
  - All wells have multiple BHT measurements at different times
- Good
  - Many wells with equilibrium T-logs to calibrate corrections
- Common Reality
  - Must use corrections derived for data from other basins – the case with the Wattenberg BHT data

Presenter's Notes: This presentation first briefly discusses the collection of bottom-hole-temperature or BHT data, the primary data source for this study. Data from a small portion of the Denver Basin, focusing on the Wattenberg Field, are then discussed and presented, followed by a study from the central Raton Basin and preliminary results from the northern San Juan Basin.



The Denver Basin and the Wattenberg Field

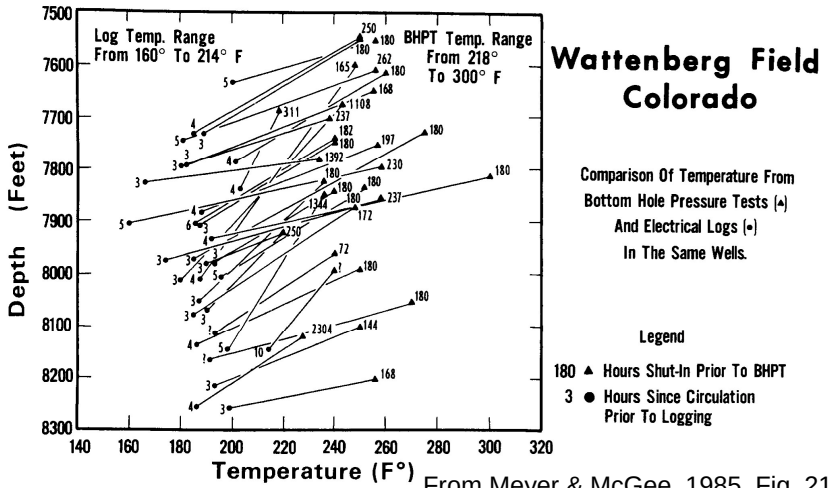
Figure from Weimer (1996)

COLORADO GEOLOGICAL SURVEY

Presenter's Notes: Hundreds, and commonly thousands of wells are drilled in a basin during oil exploration and production. This figure shows the Denver basin which extends from Colorado into Wyoming and Nebraska. The study focused on the Wattenberg Field, a gas field north-northeast of Denver.

The Wattenberg "Hot Spot"

Max. Anomaly: 2.8-2.9°F/100 ft (51-53°C/km)



From Meyer & McGee, 1985, Fig. 21

Wattenberg Field

The Wattenberg Field has been reported as a “hot spot”. The contour lines here are lines of equal isoreflectance, a measure of past heating of carbon in the sediments. The basin shows a history of heating to the west. CMB is the extension of the Colorado Mineral Belt. Box outlines study area in subsequent figures.

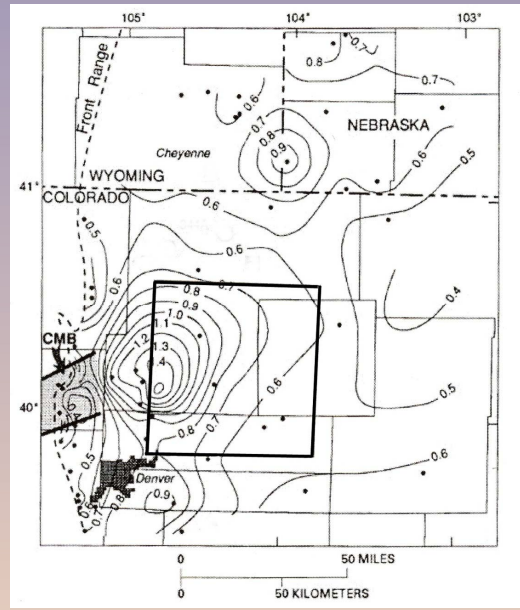
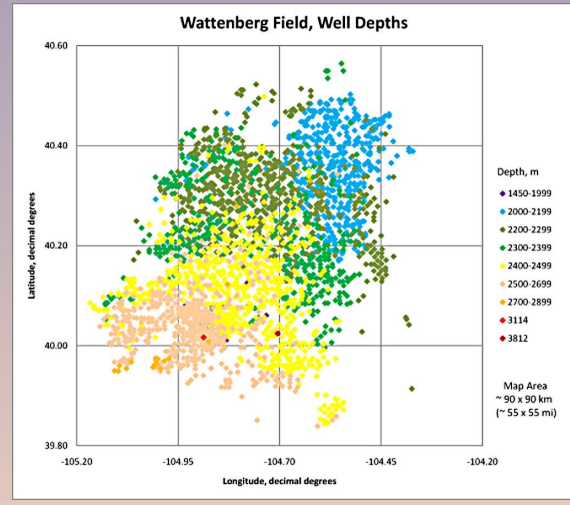


Figure modified from Higley et al., (1992)

Depths of wells in Wattenberg Field

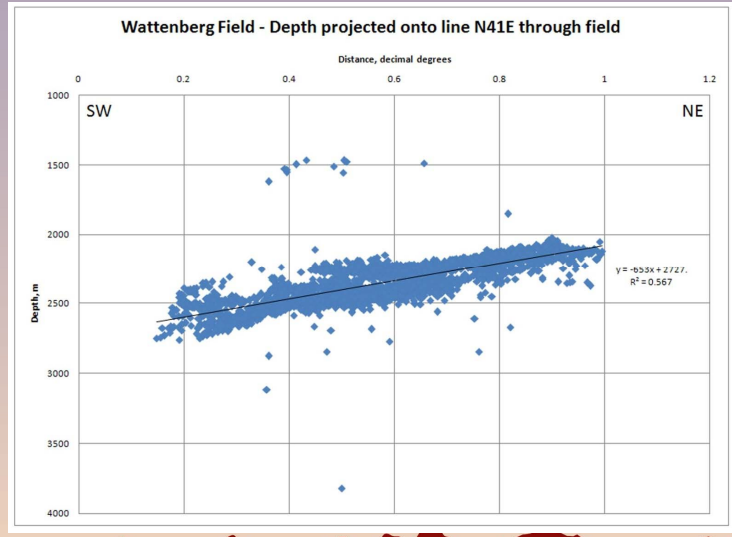
Wells generally increase in depth from NE to SW, increasing from about 2000 to 2900 m (~6500 to 9500 feet)



COLORADO GEOLOGICAL SURVEY

Presenter's Notes: The depths of BHT data collected range from slightly over 1450 m (4750 feet) to 3812 m (12,506 feet), but most were in the range of 2000 to 2900 m (6500 to 9500 feet), increasing in depth from the northwest to the southeast with the dip of the beds in the basin.

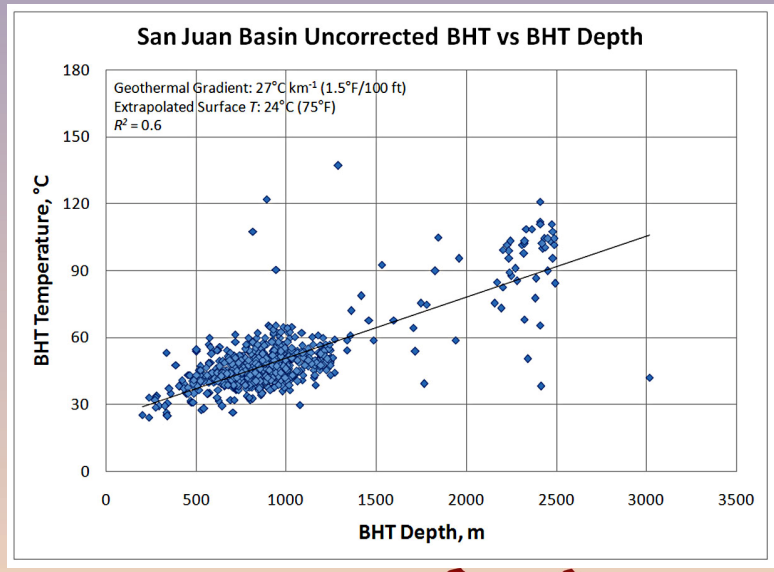
Projection of Well Depths onto Vertical Plane Trending N41°E



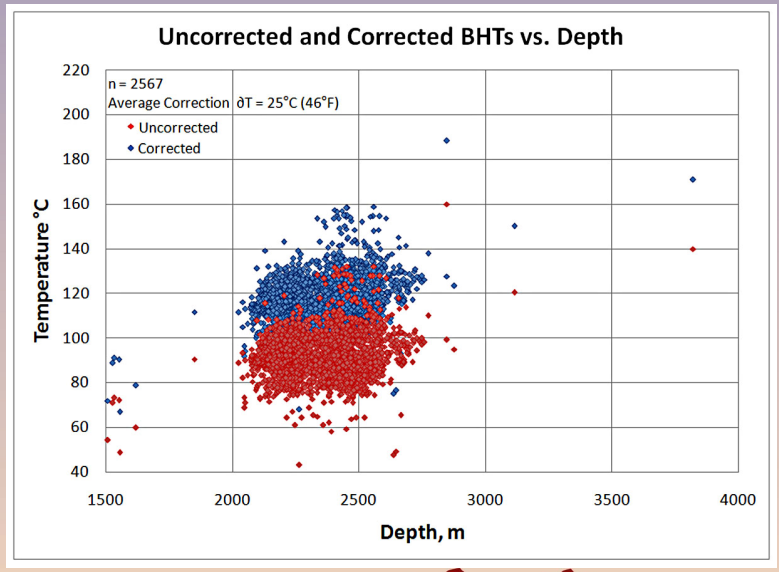
COLORADO GEOLOGICAL SURVEY

Presenter's Notes: The general dip of the beds in the basin is shown here by a projection of the well depths onto a vertical plane trending N41°E.

San Juan Basin BHT versus Depth



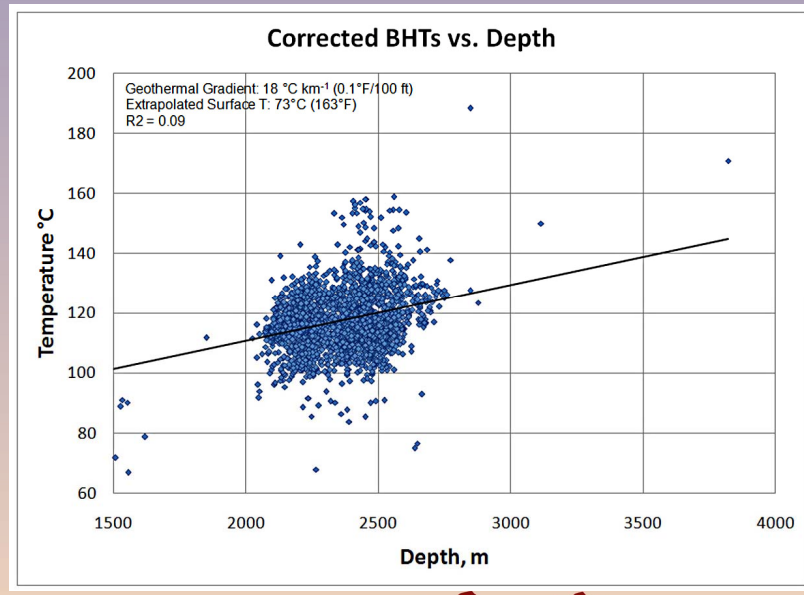
Wattenberg Field BHT versus Depth

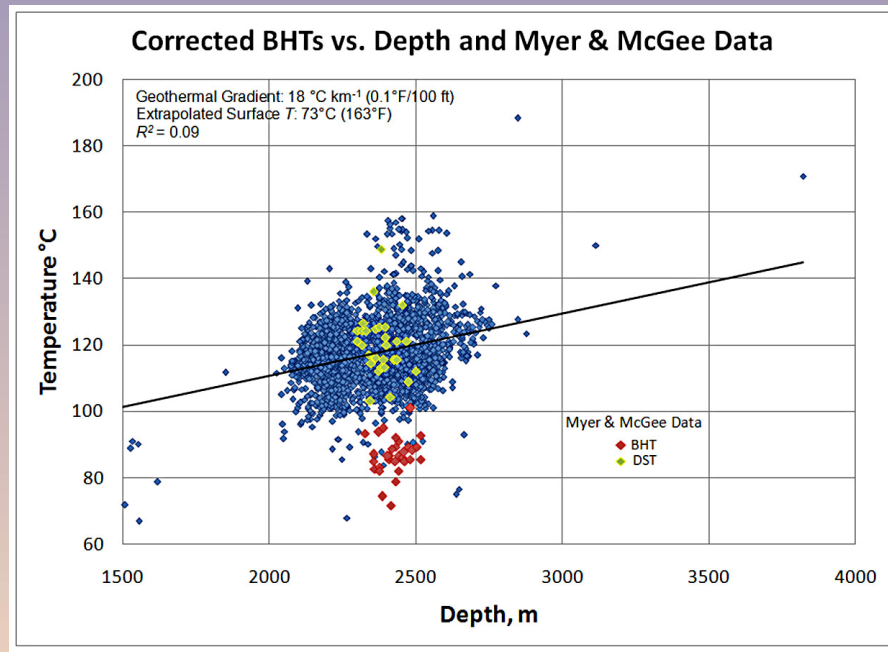


COLORADO GEOLOGICAL SURVEY

Presenter's Notes: When the BHTs from the Wattenberg Field are plotted against depth they, define no meaningful trend. This scatter is much worse than is normally found in BHT data. Numerous attempts to separate the data into different groups, such as area within the field, date of drilling, etc., to find a better correlation between BHT and depth were tried, without success.

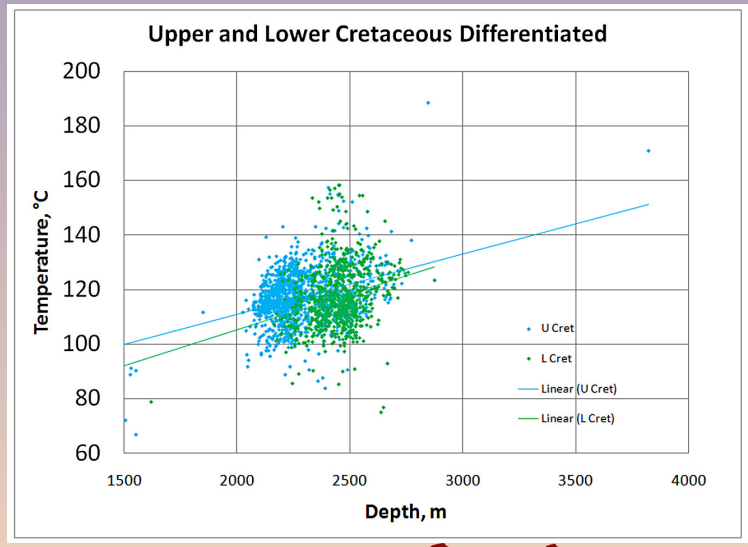
Wattenberg Field BHT Geothermal Gradient



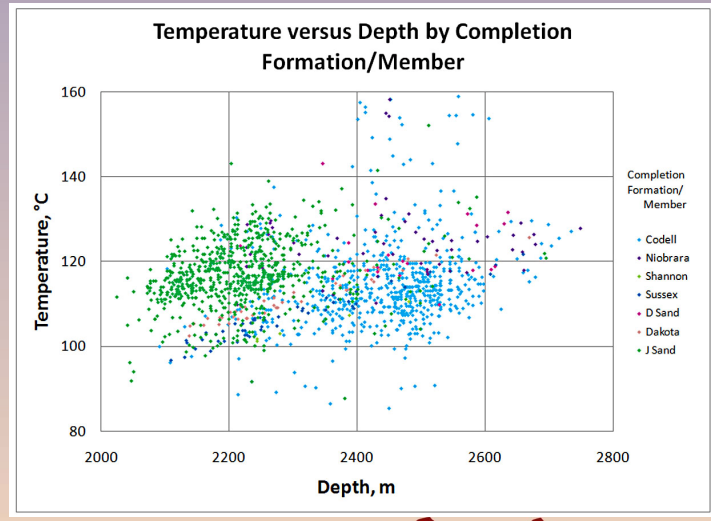


COLORADO GEOLOGICAL SURVEY

Attempts at Subdividing Data to Resolve Trends



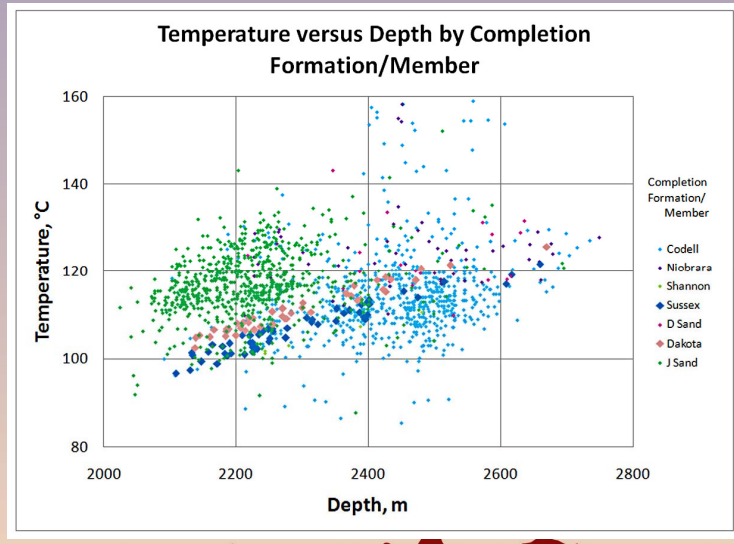
Corrected BHT versus Depth: Coded by Completion Unit

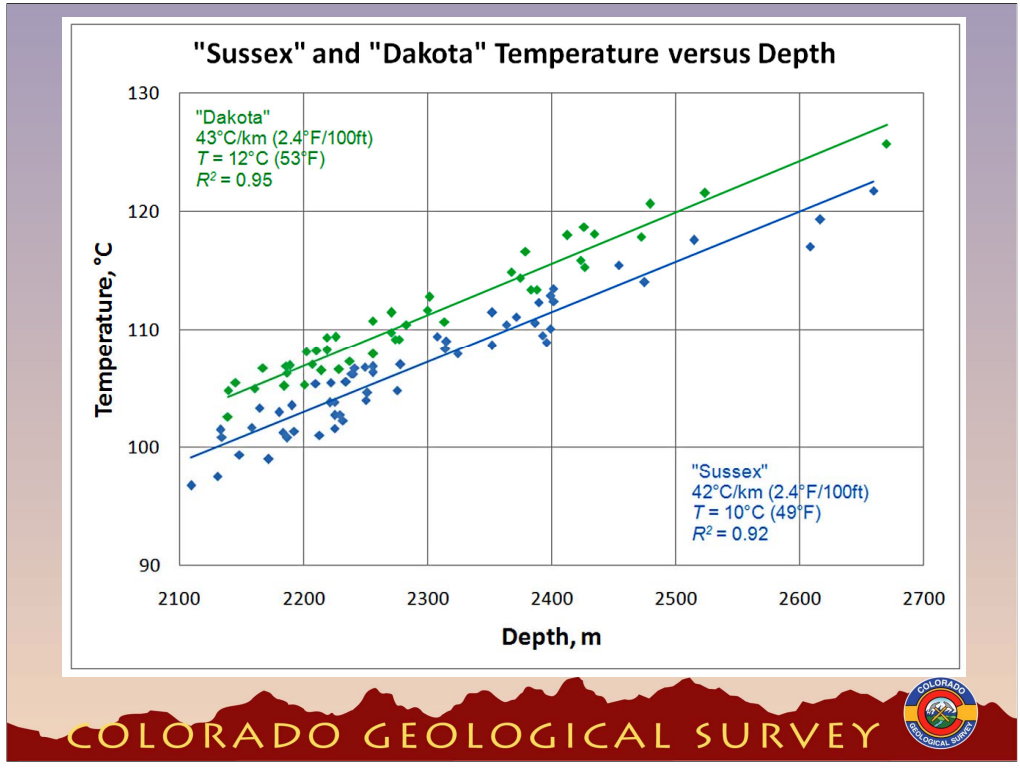


COLORADO GEOLOGICAL SURVEY

Presenter's Notes: The only separation that gave any correlation was separation by the formation in which the well was completed, and then wells completed in only two formations showed a significant correlation. Those formations were the "Sussex" and "Dakota," shown with larger symbols in the next plot. The data shown here were corrected for the effects of the drilling disturbance. The corrected data gave more realistic surface intercept values in the next plot.

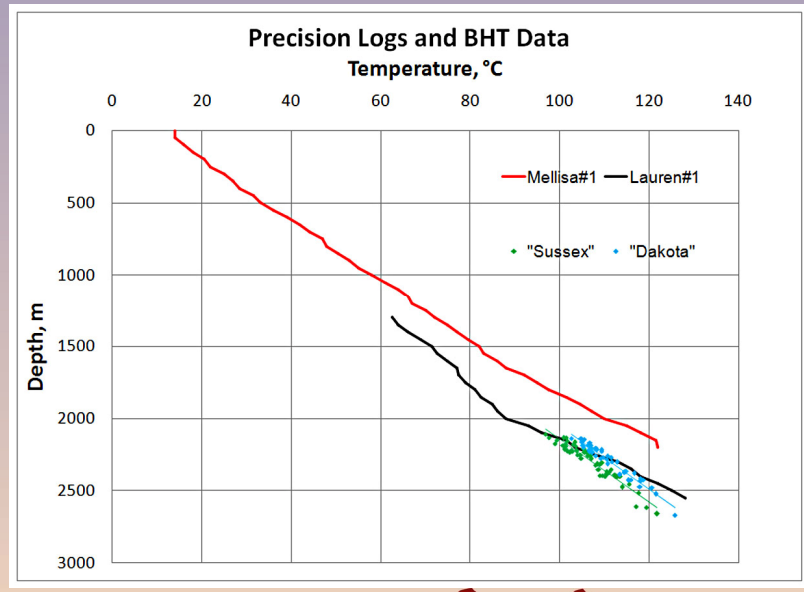
Corrected BHT versus Depth: Coded by Completion Unit: Take 2





Presenter's Notes: The "Sussex" and "Dakota" data are shown here with linear fits made in an Excel® spreadsheet. The scatter shown by these data are very acceptable as the data do not come from a single point but from wells spread throughout the field. The "Sussex" data indicate a geothermal gradient of 43°C km^{-1} (2.36°F/100 ft) and a surface intercept of 11.6°C (53°F); the "Dakota" data indicate a geothermal gradient of 42°C km^{-1} (2.30°F/100 ft) and a surface intercept of 9.6°C (49°F). These gradients are consistent with other data for the Denver basin, and the surface intercepts are consistent with the mean annual surface temperature of the Denver area. [Names in quotation marks indicate drillers' log names, not approved geological names.]

Precision Logs Compared With BHTs

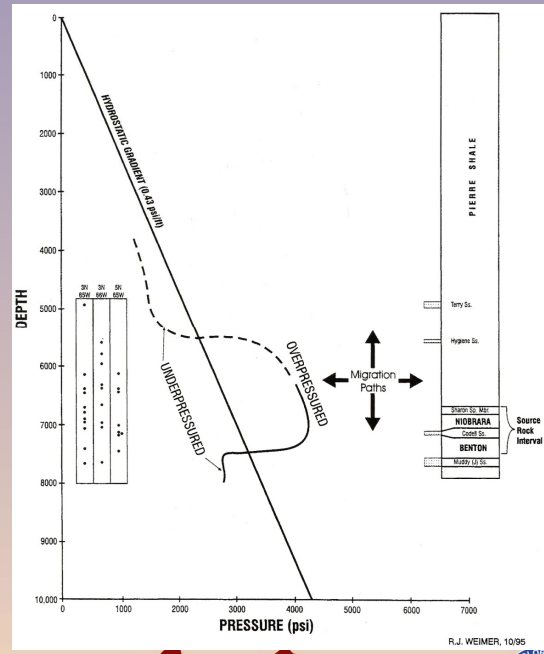


COLORADO GEOLOGICAL SURVEY

Presenter's Notes: The "Sussex" and "Dakota" data also plot close to a precision geotherm recorded in the Lauren 1 well in the Denver Basin, supporting the validity of these data.

What is Different about the "Sussex and "Dakota"?

They are the only units with abundant data outside the overpressured zone. Either drilling in the overpressured zone significantly disturbs temperatures, or temperatures are naturally heterogeneous in this zone.



COLORADO GEOLOGICAL SURVEY

Presenter's Notes: Most of the formations in the Wattenberg field are overpressured"; that is, the fluid pressure in the formations is higher than that of a water column from the surface (hydrostatic). To prevent the formation pressure from blowing the drilling fluid to the surface in overpressured zones, the drillers increase the "weight" of the drilling mud so that the drilling mud has an equal pressure to the overpressure. However, exact balance is difficult, and sometimes the drilling mud is too heavy, and drilling fluid is forced into the formation, overcooling the rocks; other times the drilling fluid is too light, and fluid enters the drilling mud from the formation; the rocks are cooled less than assumed by the drilling disturbance correction. In either case, the drilling correction does not match the drilling disturbance. Above and below the overpressure zone, there is no significant loss nor gain of drilling fluid by the formation, and the drilling disturbance correction is reasonable.

Wattenberg Field – Conclusions I

- The corrected BHT temperatures in this study confirm the DST temperatures of Myer and McGee (1985). The geothermal gradients in the range of 40-50 °C km^{-1} are typical of the Denver Basin in Colorado, however, and probably represent cooler formation temperatures than recorded by the isoreflectance values.
- Measured temperatures in the overpressured zone are heterogeneous, and probably disturbed.

Presenter's Notes: The geothermal gradients of 42 to 43°C km^{-1} (2.30 to 2.36°F/100 ft) determined for the "Sussex" and "Dakota" units in the Wattenberg Field are within the range of 40 to 50°C km^{-1} (2.19 to 2.74°F/100 ft) calculated for other regions of the Denver Basin and indicate that the Wattenberg Field is not currently a hot spot. However, corrected measured temperatures in the field are in the range of 100-120°C (210-250°F) at depths of 2100-2500 m (6900-8200 feet). These temperatures could be used for generating electricity, using binary power plant technology

Wattenberg Field – Conclusions II

- Data from the "Sussex" and "Dakota" indicate temperatures in the range of 100-120°C (210-250°F) at depths of 2100-2500 m (6900-8200 feet).
- Water produced at these temperatures could be used for generating electricity using binary power plant technology.

FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

U.S. Department of Energy
Golden Field Office

Recovery Act: Geothermal Technologies Program

Topic Area 1: Validation of Innovative Exploration Technologies

Topic Area 2: Geothermal Energy Production from (A) Low Temperature Resources, (B) Coproduced Fluids from Oil and Gas Wells, and (C) Geopressured Resources

Topic Area 3: Geothermal Data Development, Collection, and Maintenance

Funding Opportunity Announcement Number: DE-FOA-0000109

Announcement Type: Initial

CFDA Number: 81.087

Issue Date:	**05/27/2009**
Final Application Due Date:	**07/22/2009, 11:59 PM Eastern Time**