

# **New Horizons for Geothermal Energy in Sedimentary Basins in Colorado\***

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## **Abstract**

During the past decade, projects in Europe have demonstrated the feasibility of generating electricity from relatively low-temperature geothermal resources in sedimentary basins, including in conjunction with direct use projects. Major sedimentary basins in Colorado include the Denver Basin, the Piceance Basin, the San Luis Basin, the northern half of the Raton basin, and portions of the Paradox and San Juan Basins. All have significant hydrocarbon production, with the exception of the San Luis Basin. Most of the hydrocarbon production is natural gas. With the exception of coalbed methane wells, co-produced water volumes are relatively low. Co-produced water with coalbed methane originates at relatively shallow depths (<1000 m; 3280 ft.) at temperatures too low for electricity generation (<55°C; <130°F). For these reasons, the use of oil and gas co-produced water for geothermal electricity production is limited in Colorado. However, the European model could be adapted for use of sedimentary basin hydrogeothermal resources in Colorado. Where permeability is too low, fracturing technology can be used to increase flow rates for economic power generation.

Bottom-hole temperature (BHT) data are abundant in Colorado, but must be corrected for the cooling effect of drilling fluid circulation. Traditional methods of calculating equilibrium temperatures are not possible with available data. However, many BHTs from cement bond logs are recorded days to weeks after the cessation of drilling in some Colorado wells. These data have provided a useful estimate of equilibrium temperatures from which drilling disturbance corrections have been calculated for the Denver, Raton, and Piceance Basins. BHT data are being systematically re-corrected for the sedimentary basins of Colorado. Based on improved subsurface temperature models, we will investigate the feasibility of producing electricity from well doublets, either through natural aquifers or through enhanced permeability (EGS). The goal is to demonstrate that sedimentary basins have the potential to provide distributed geothermal power to much of the mid-continental US.

## **References**

Kaiser, W.R., and C.M. Tremain, 1994, Geologic and hydrologic controls on coalbed methane, Sand Wash Basin, Colorado and Wyoming: Colorado Geological Survey Resource Series 30, 151 p.

Topper, R., K. Spray, W.H. Bellis, J.L. Hamilton, and P.E. Barkmann, 2003, Ground Water Atlas of Colorado: Colorado Geological Survey Special Publication 53, p. 157-168.

## **Websites**

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European Geothermal Energy Council (EGEC), Combined geothermal heat and power plants: Web accessed 4 August 2011, [www.egec.org](http://www.egec.org).

# New Horizons for Geothermal Energy in Sedimentary Basins in Colorado

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Colorado Geological Survey

for the

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**Alternative Energy: Geothermal**

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COLORADO GEOLOGICAL SURVEY



# Heat Mining

- Colorado ranked #1 in MIT EGS report for heat in 3 to 4 km depth range (10,000 - 13,000 ft).
- **Crystalline rock** EGS are not economic at present.
- **Sedimentary basin** EGS are economic.

# Current Options for Geothermal Electricity Production in Colorado

- **Very low-temperature hydrothermal systems:**  
Indicated by hot springs ( $< 200^{\circ}\text{F}$ ,  $93^{\circ}\text{C}$ )
  - limited in number and potential power output.
- **Mid- to low-temperature hydrothermal systems:**  
Indicated by geochemistry of hot springs, recent volcanism and geologic structures
  - at present untested and ultimately limited.

# New Horizons for Geothermal Energy in Sedimentary Basins in Colorado

- Colorado Sedimentary Basins – Opportunities and Challenges
- Temperature Data and Drilling Disturbance Corrections
- RMOTC & Europe Low T Geothermal Electricity from Sedimentary Basins
- Geothermal Electricity Production in Colorado Possible in the Next 5 Years



# Colorado Principal Sedimentary Basins

Salt Wash  
Basin

Denver  
Basin

Piceance  
Basin

Cañon City  
Embayment

Paradox  
Basin

San Luis  
Basin

Raton  
Basin

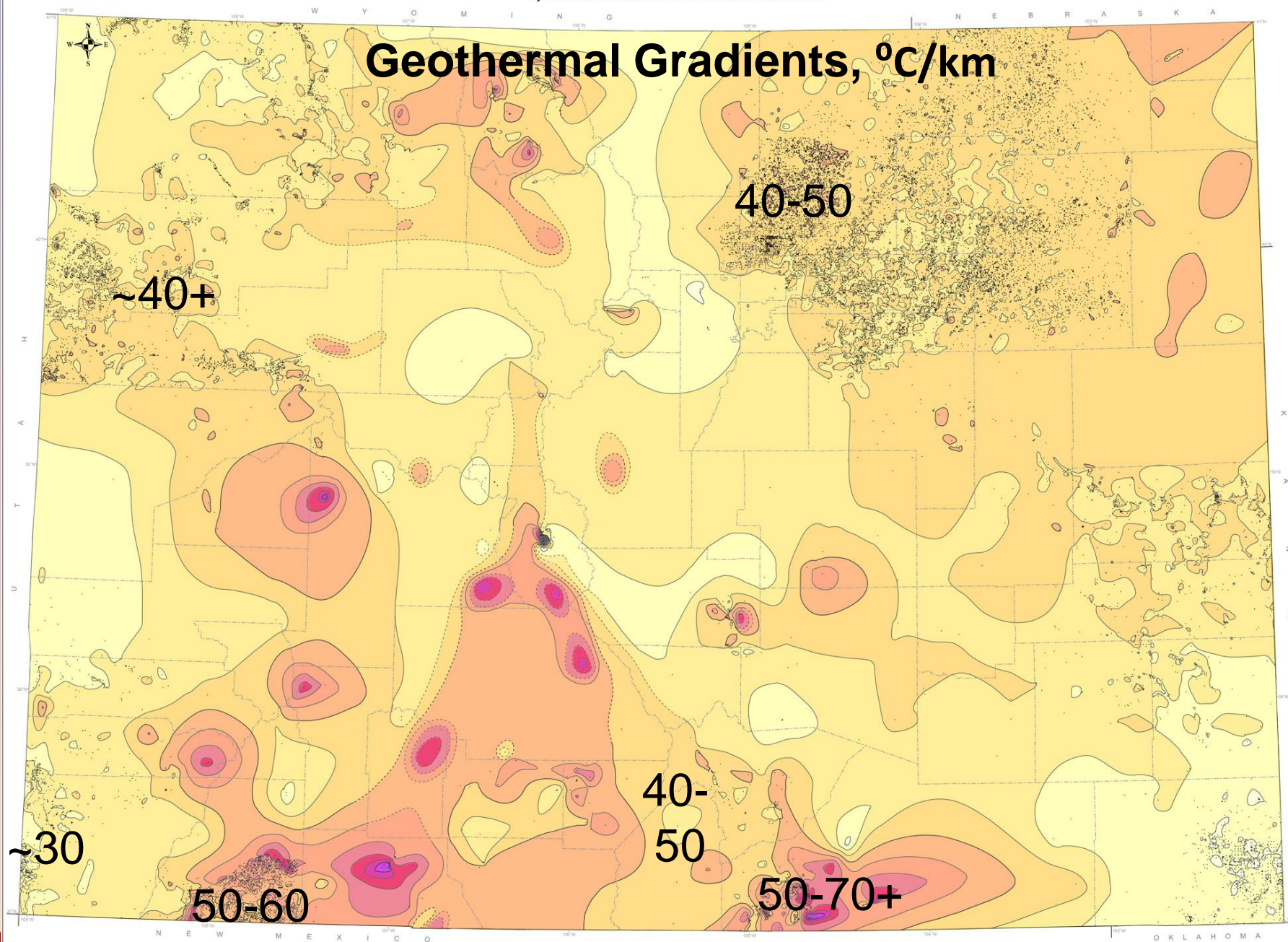
San Juan  
Basin



# Interpretive Geothermal Gradient Map of Colorado

by Frederick E. Berkman and Nicholas A. Watterson

## Geothermal Gradients, °C/km





# Source of Temperature Gradient Data

- Bottom-hole-temperatures (BHTs) recorded on log headers during routine logging runs
- Correct BHTs for effect of drilling disturbance
- Mean annual air temperatures from local climate stations – derive relationship for mean annual air temperature vs. elevation  $\pm$  latitude. Add 3°C for mean annual ground temperature (MAGT).
- Calculate temperature gradient as:  
$$(BHT - MAGT) / \text{depth of BHT}$$

# Correction of BHT Data I

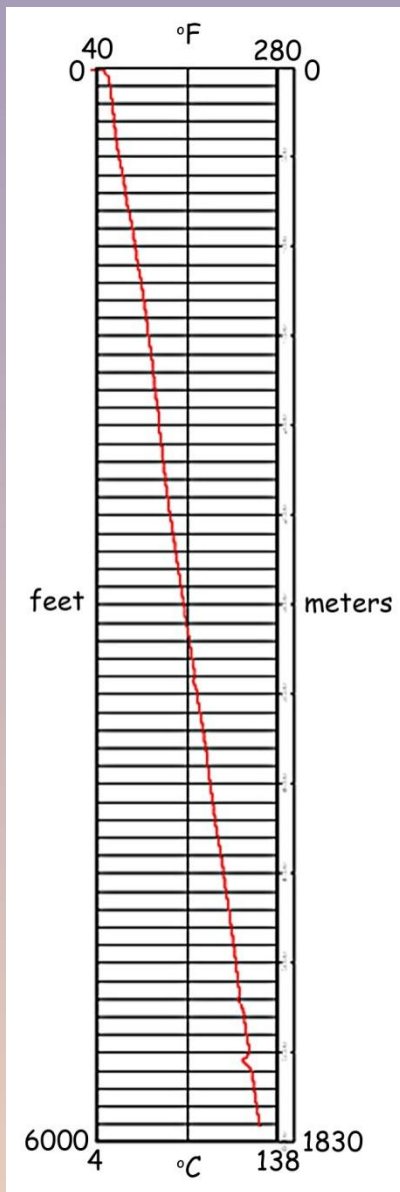
- Raw BHT data from log headers is usually collected within 24 hours of the cessation of the circulation of drilling fluid. This circulation causes a transient disturbance, most commonly a cooling of the bottom of the drill hole and difference between the recorded BHT and the undisturbed rock temperature.
- Ideally, independent measurements of the undisturbed rock temperatures are available from which to estimate this disturbance and from which to derive a drilling disturbance correction. If no such data are available, corrections derived from basins outside the study area may be used.

# Correction of BHT Data II

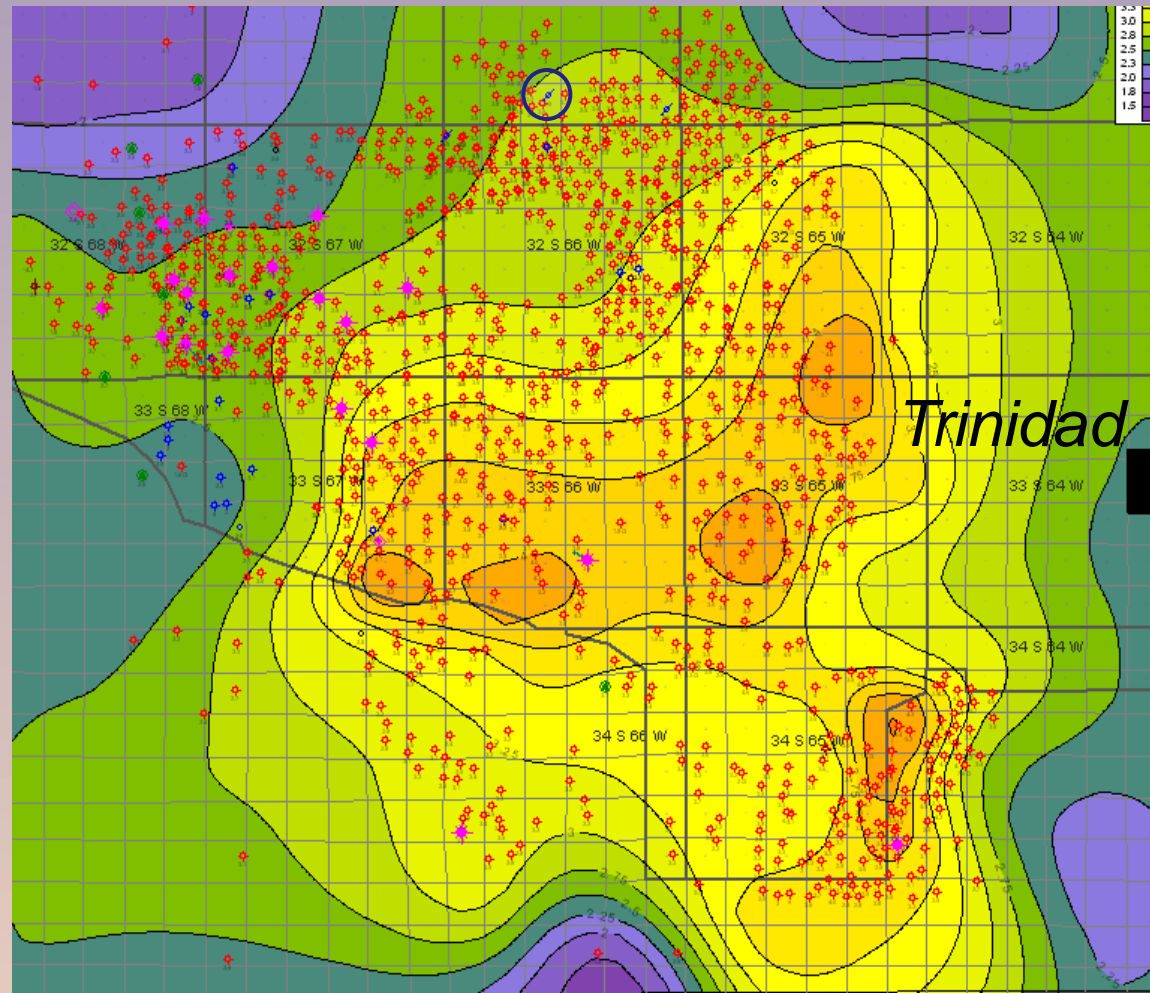
- In Colorado, many of the common data sets used to estimate undisturbed rock temperatures do not exist. However, many cement bond logs have been found with BHTs recorded weeks or even months after drilling. These data, together with DST T-data from newer wells are providing estimates of undisturbed rock temperature.
- A significant result is that the correction appears to vary from basin to basin, not only with the average basin gradient, but also with different drilling techniques.



# Raton Basin Bottom-Hole-Temperature Data



Precision temperature log



Diagrams courtesy of Hal Macartney, Pioneer Natural Resources, Denver

# Heat “Mining” in Sedimentary Basins

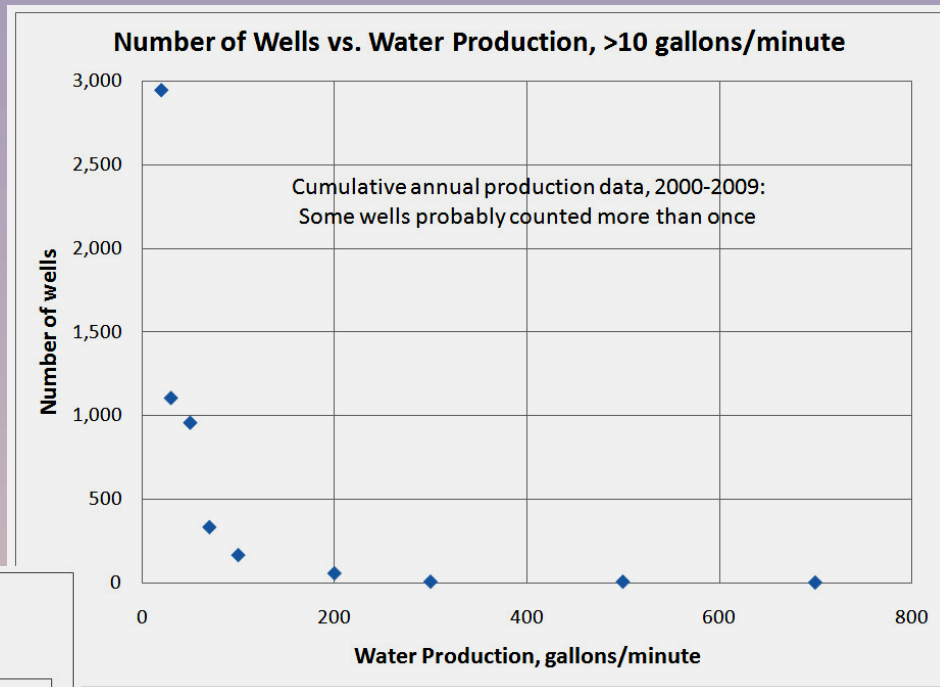
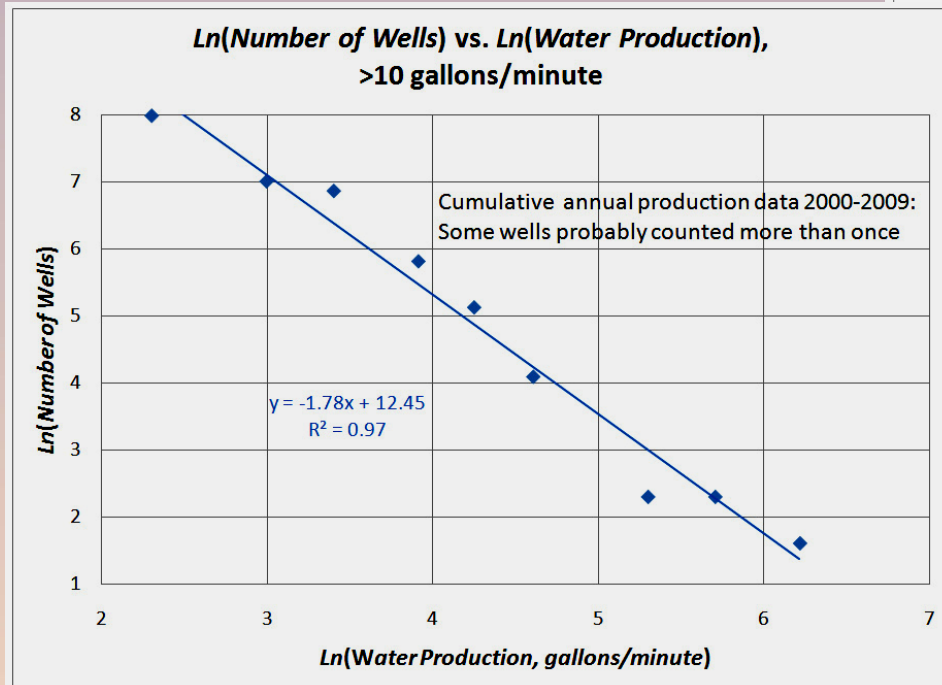
- Co-produced Water:  
Geothermal secondary to another product.
- Pumped Low-T Hydrothermal:  
Geothermal primary:
  - *Engineered Geothermal Systems* – insufficient natural permeability, significant enhanced permeability: Greatest potential for widespread application
  - *Natural Geothermal Systems* – very high natural permeability: Potential for a limited number of high-yield systems

# Colorado Water Co-Production 2000-2009, >10 gpm

$$\ln(\# \text{ wells})$$

$$= -1.8 \ln(\text{H}_2\text{O, gpm}) + 12.4$$

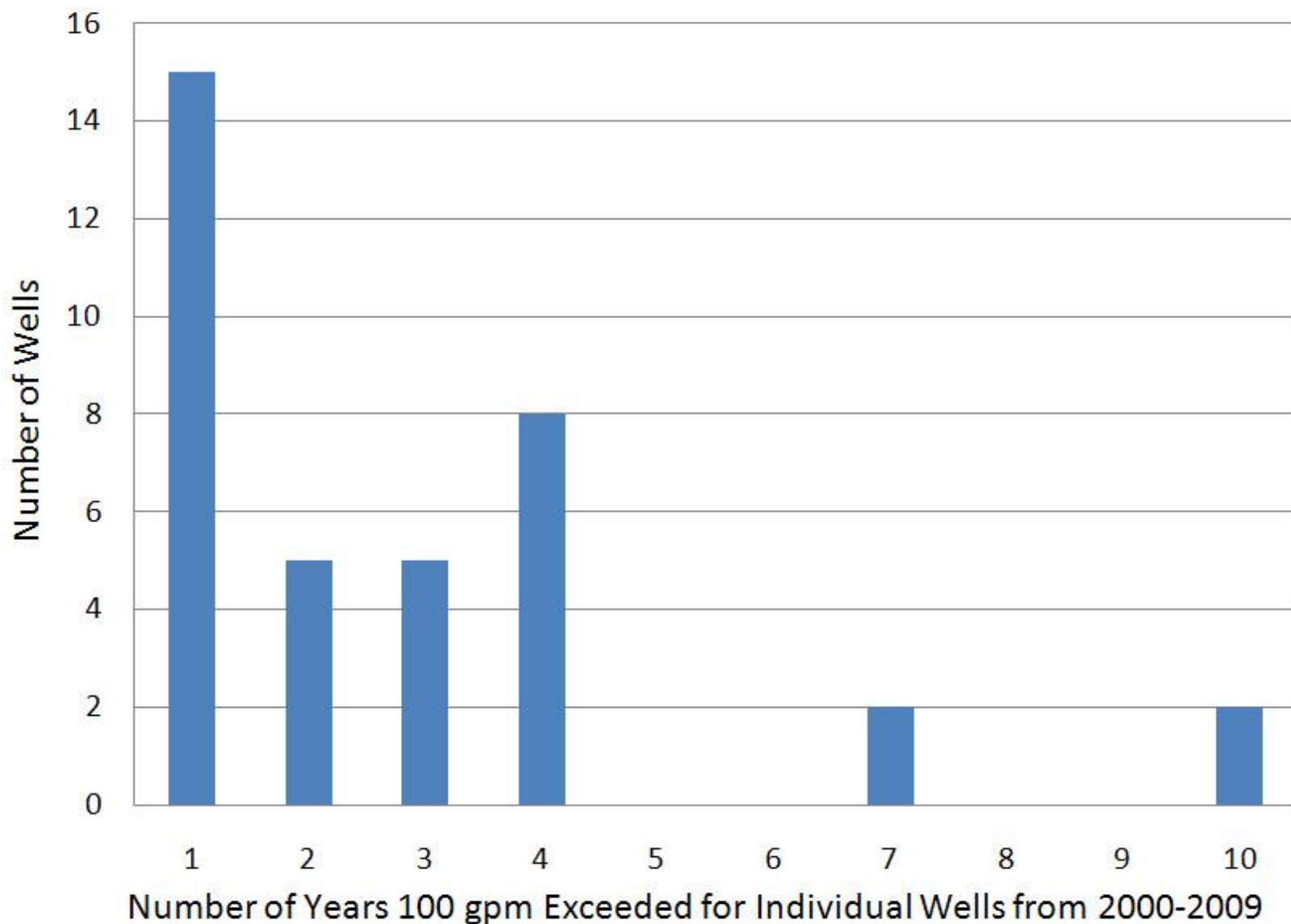
$$[R^2 = 0.97]$$



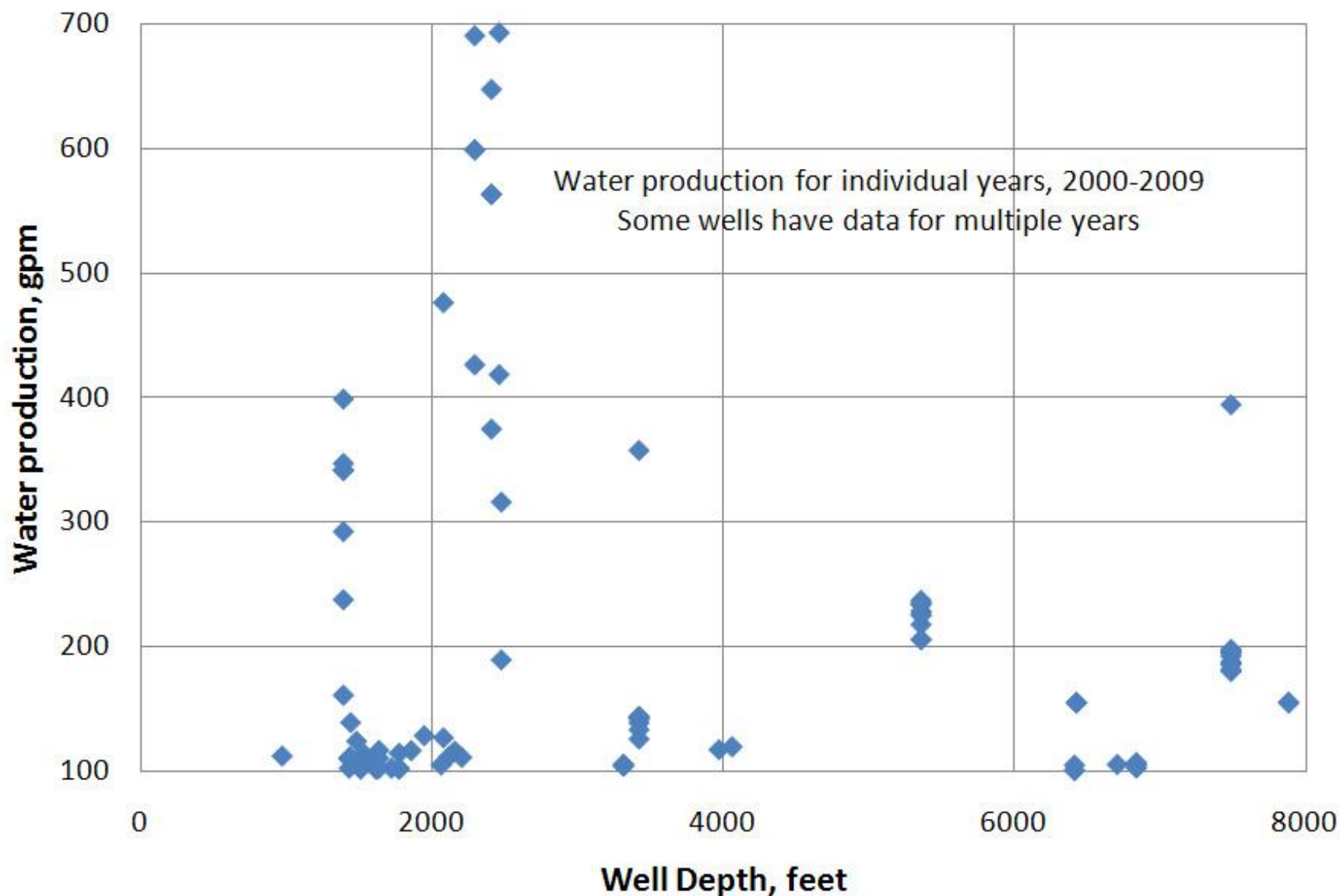
H <sub>2</sub> O, gpm	# wells	# wells/yr
100	70	7
300	10	1
500	4	0.4



### Number of Years Individual Wells Produced $\geq 100$ gpm from 2000-2009



## Water Production vs. Well Depth



# Colorado Counties with Wells Producing >100 gpm Average Over 12 months During at Least 1 Year in 2000-2009



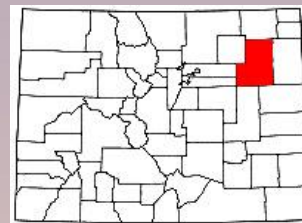
Moffat County  
6 wells; Max 394 gpm  
Mean  $191 \pm 101$  gpm



Weld County  
2 wells; Max 155 gpm  
Mean  $155 \pm 0$  gpm



Rio Blanco County  
3 wells; Max 106 gpm  
Mean  $104 \pm 2$  gpm



Washington County  
1 well; 119 gpm



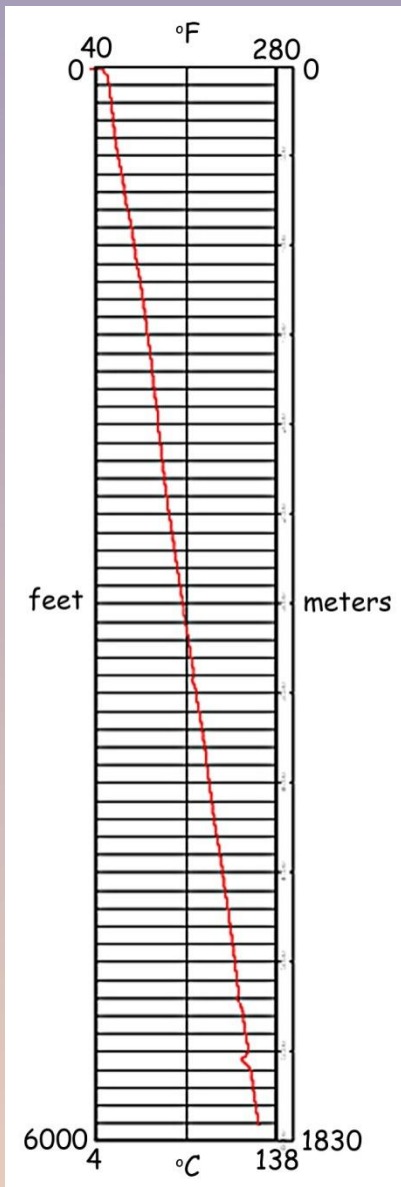
Huerfano County  
24 wells; Max 690 gpm  
Mean  $189 \pm 154$  gpm



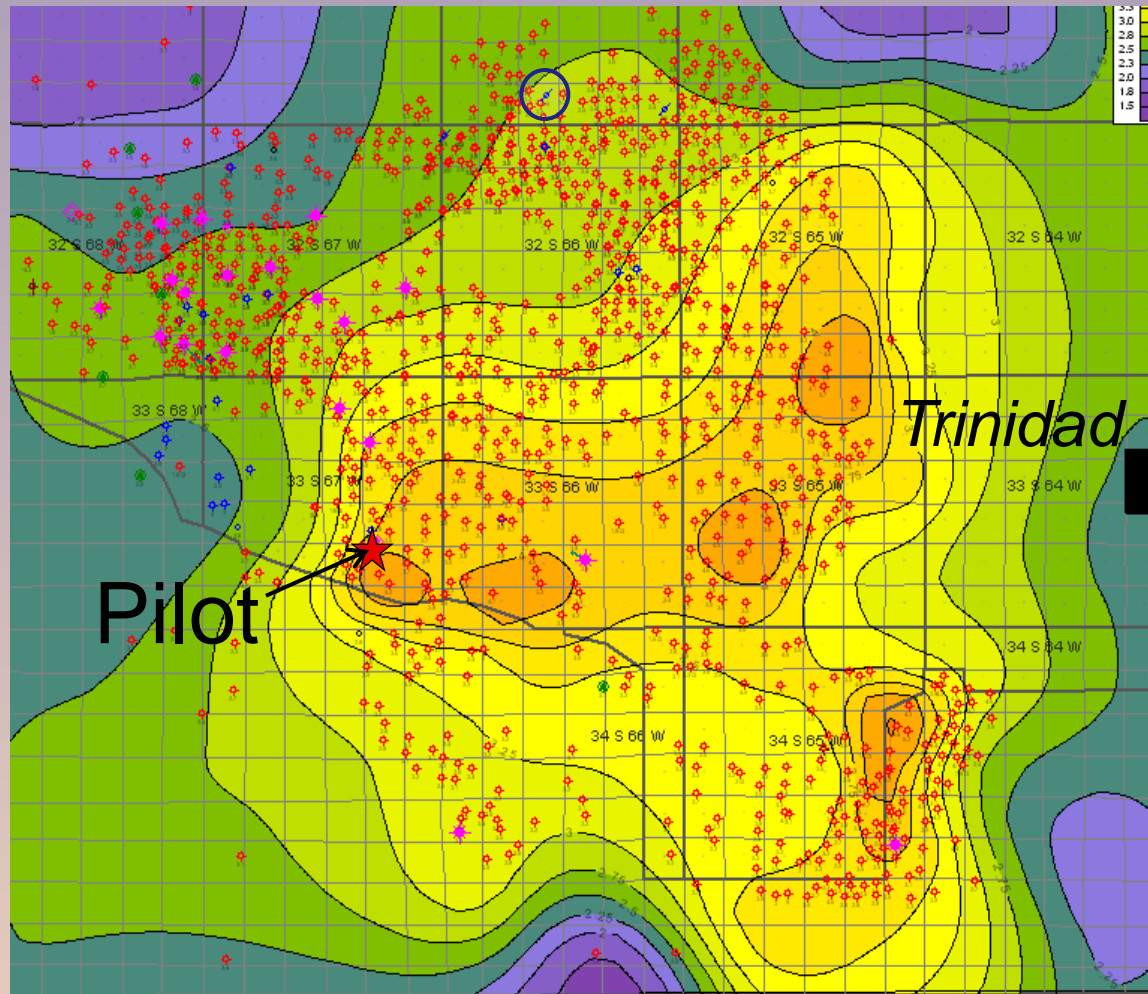
Las Animas County  
1 well; 112 gpm



# Colorado Sedimentary Basin EGS Raton Basin Bottom-Hole-Temperature Data



Precision temperature  
log

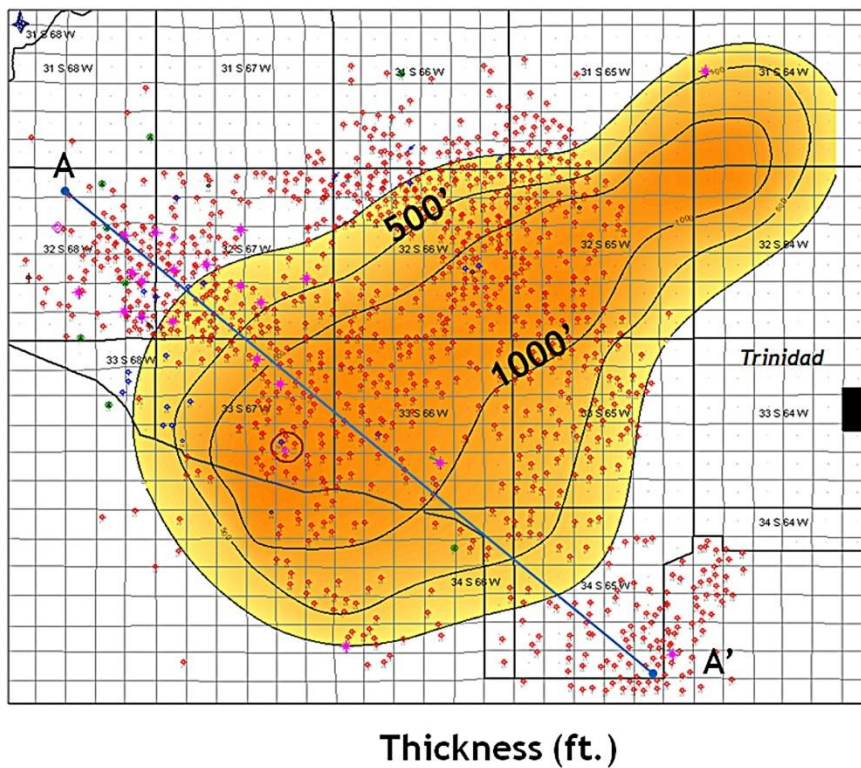


Diagrams courtesy of Hal Macartney, Pioneer Natural Resources, Denver

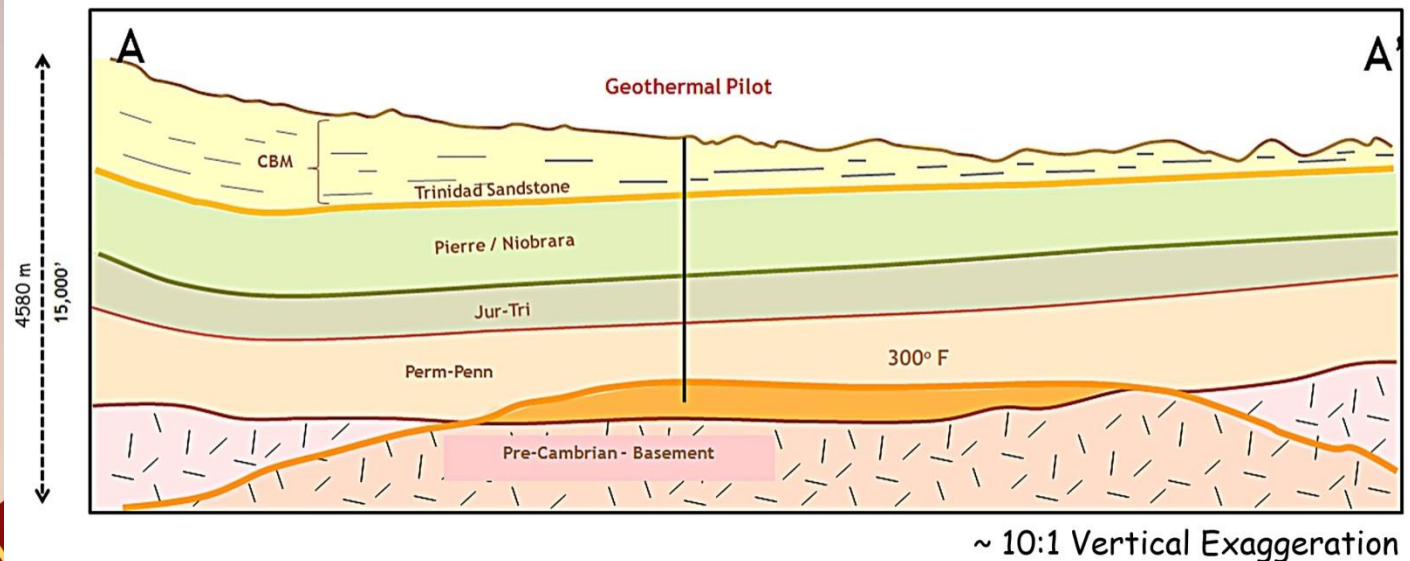
# Raton Basin

Thickness of Paleozoic  
Sedimentary Rocks Above  
Basement Hotter Than  
300°F (150°)

Total Volume ~40 cubic  
miles (~230 km<sup>3</sup>)



Diagrams courtesy of Hal  
Macartney, Pioneer  
Natural Resources,  
Denver



# Proposed Engineered Geothermal System Raton Basin, Colorado

## Pilot Project

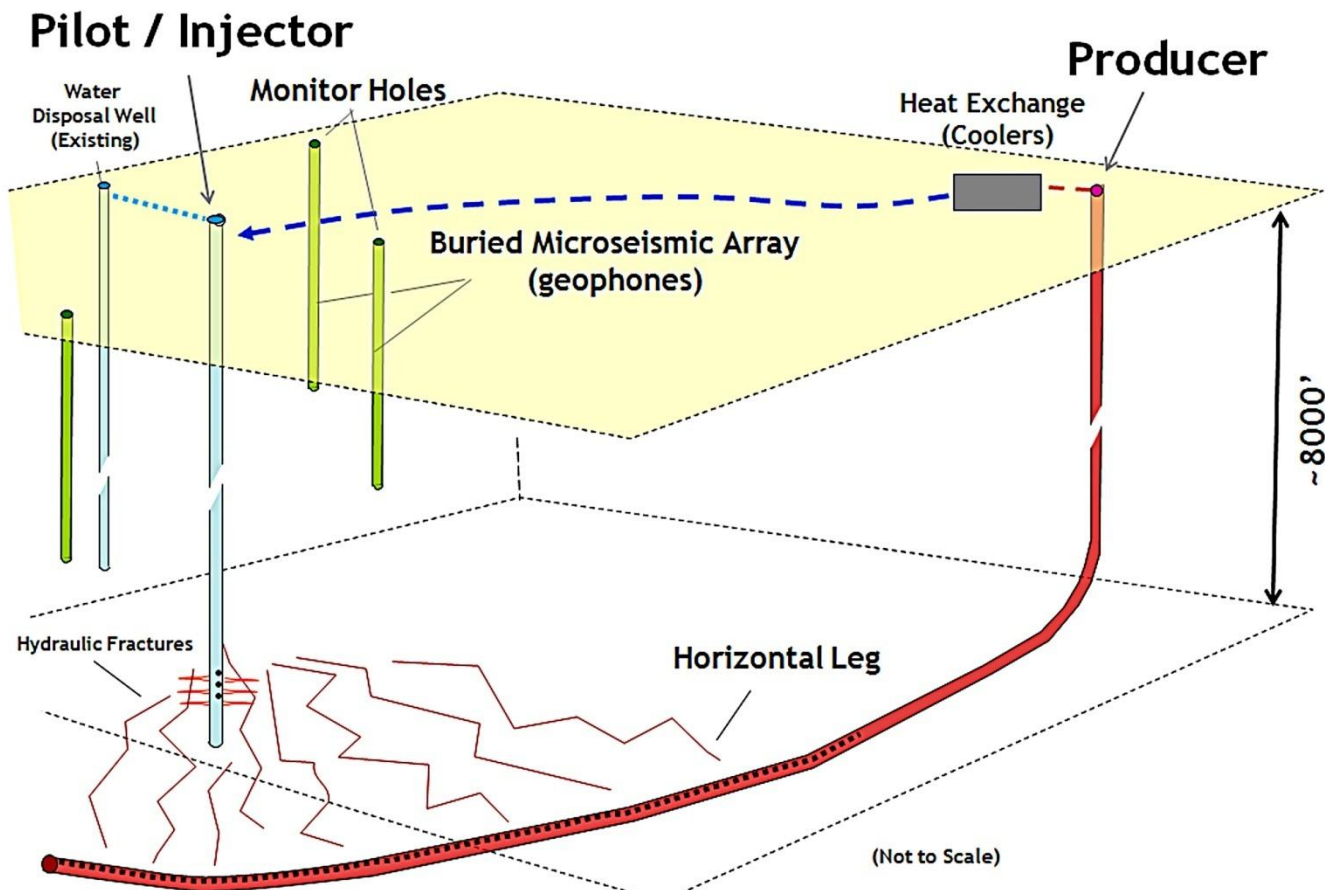
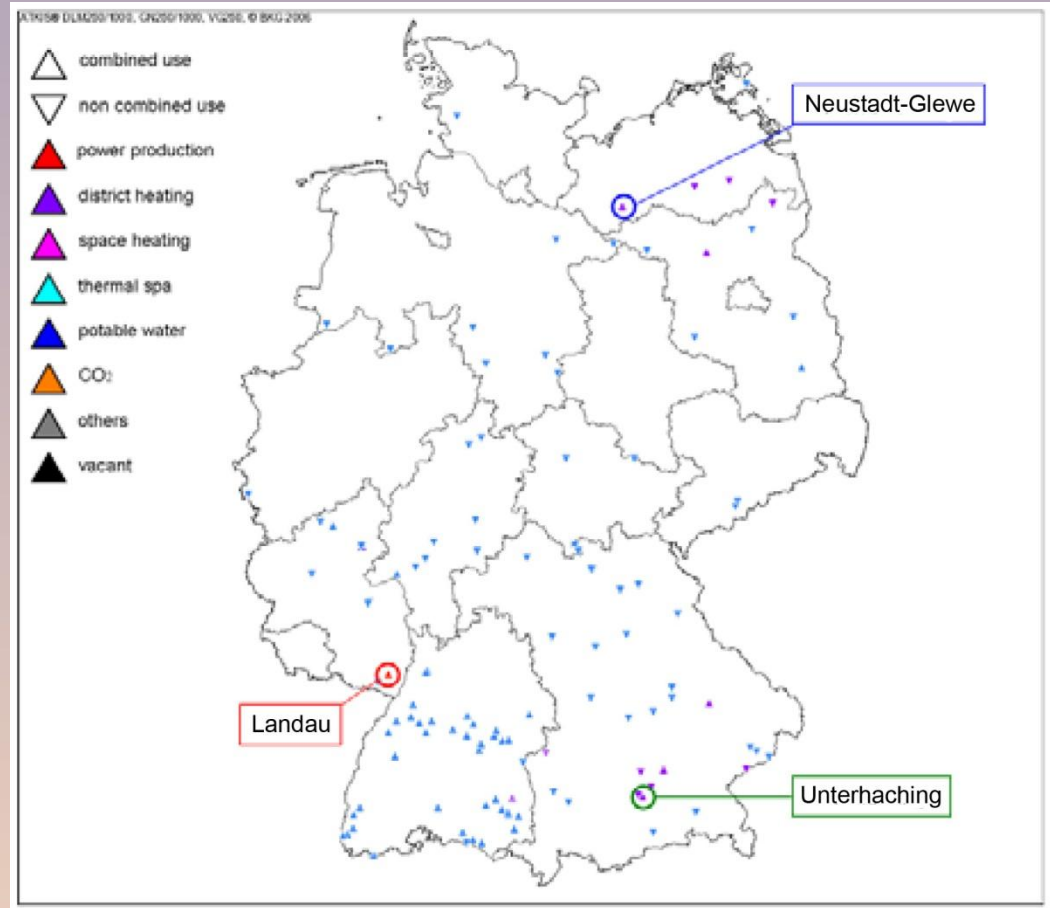
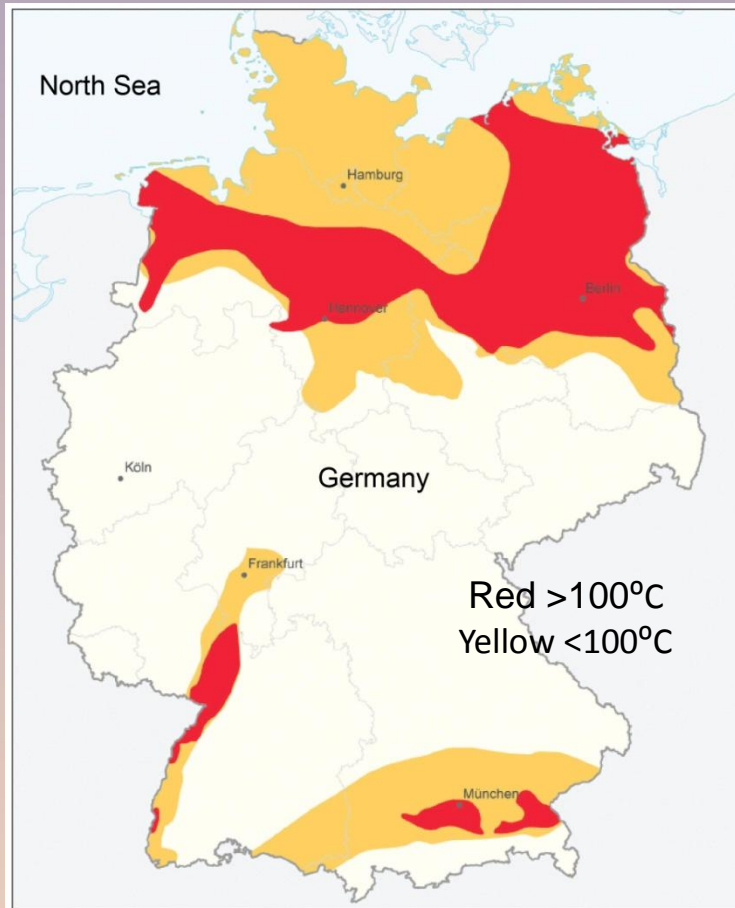


Diagram courtesy of Hal Macartney, Pioneer Natural Resources, Denver



# Natural Sedimentary Basin Geothermal Systems

## Germany: Co-Produced District Heat & Electricity in Sedimentary Basins



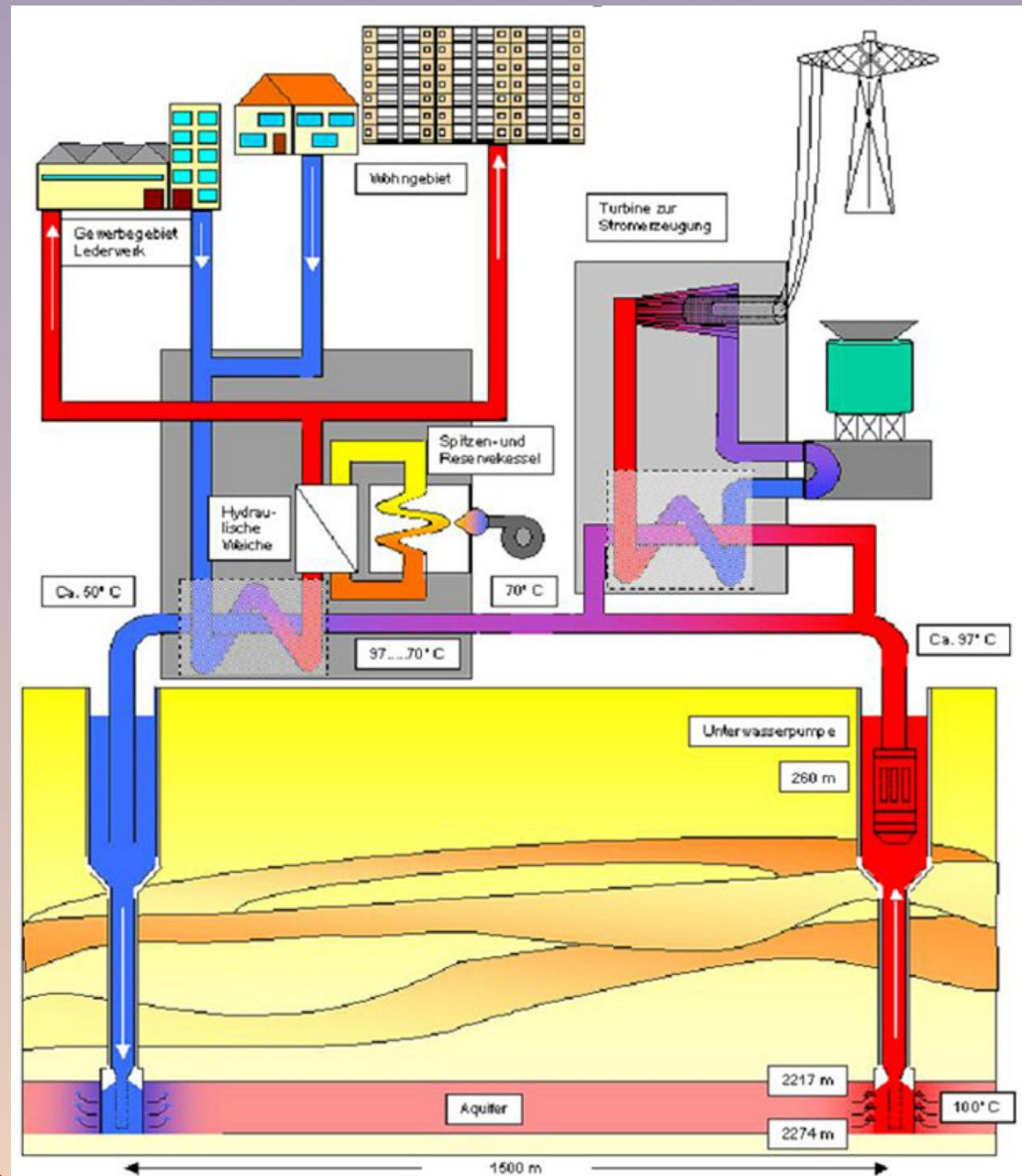
# Germany: Sedimentary Basin Geo-Hydrothermal Power Production

- All systems use well doublets, one production well, one injection well
- Neustadt-Glewe: 98°C; 35 l/s (555 gpm); 2217-2274 m; 250 kW; ORC
- Landau: 150°C; 70 l/s (1,110 gpm); 3000-3400 m; 3.0 MW; ORC
- Unterhaching: 127°C; 150 l/s (2,378 gpm); 3350-3590 m; 3.36 MW; Kalina

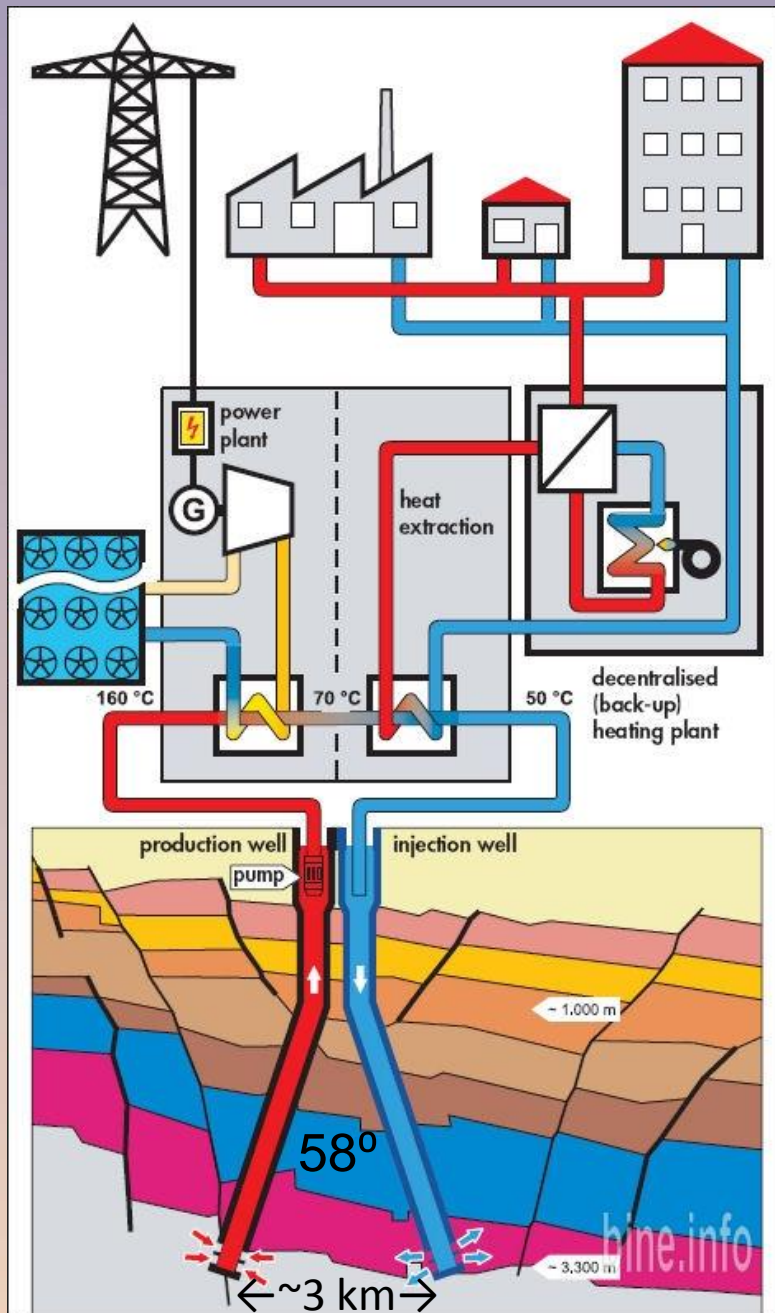
# Neustadt-Glewe

- Co-produced heat & electricity plant schematic
- Water production from sandstone

Source: European Geothermal Energy Council, 2005



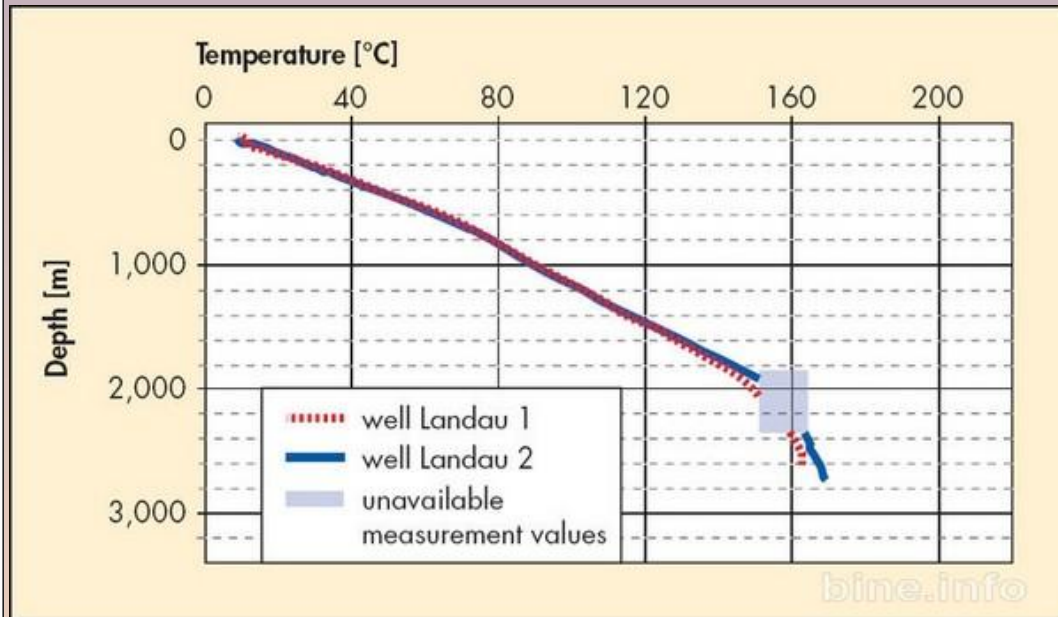




# Landau

- Primarily power production
- Water production from limestone

Source: BINE Informationsdienst



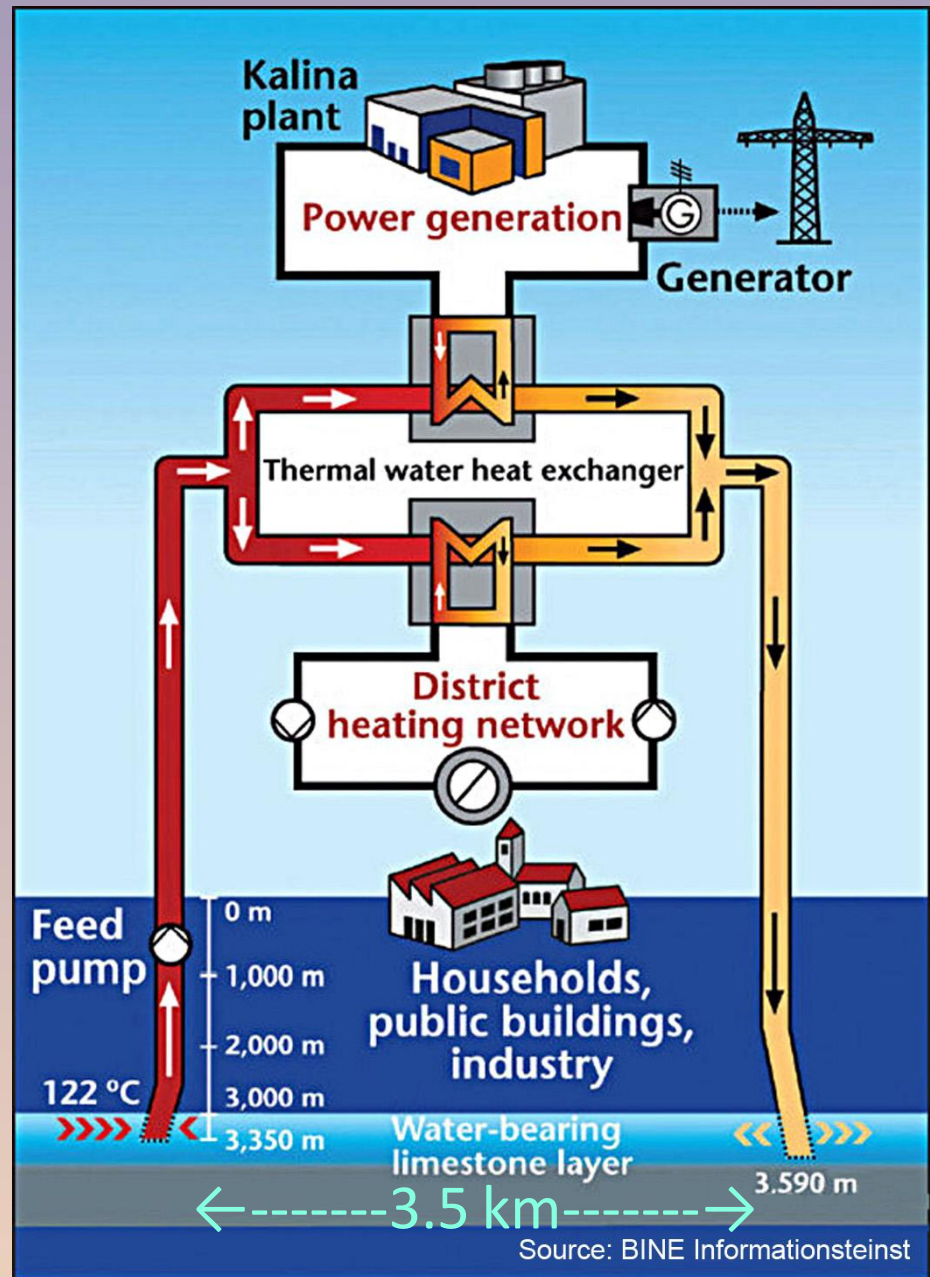


# Unterhaching S. Germany

- Water production from fissure in karst aquifer

Source: BINE Informationsdienst

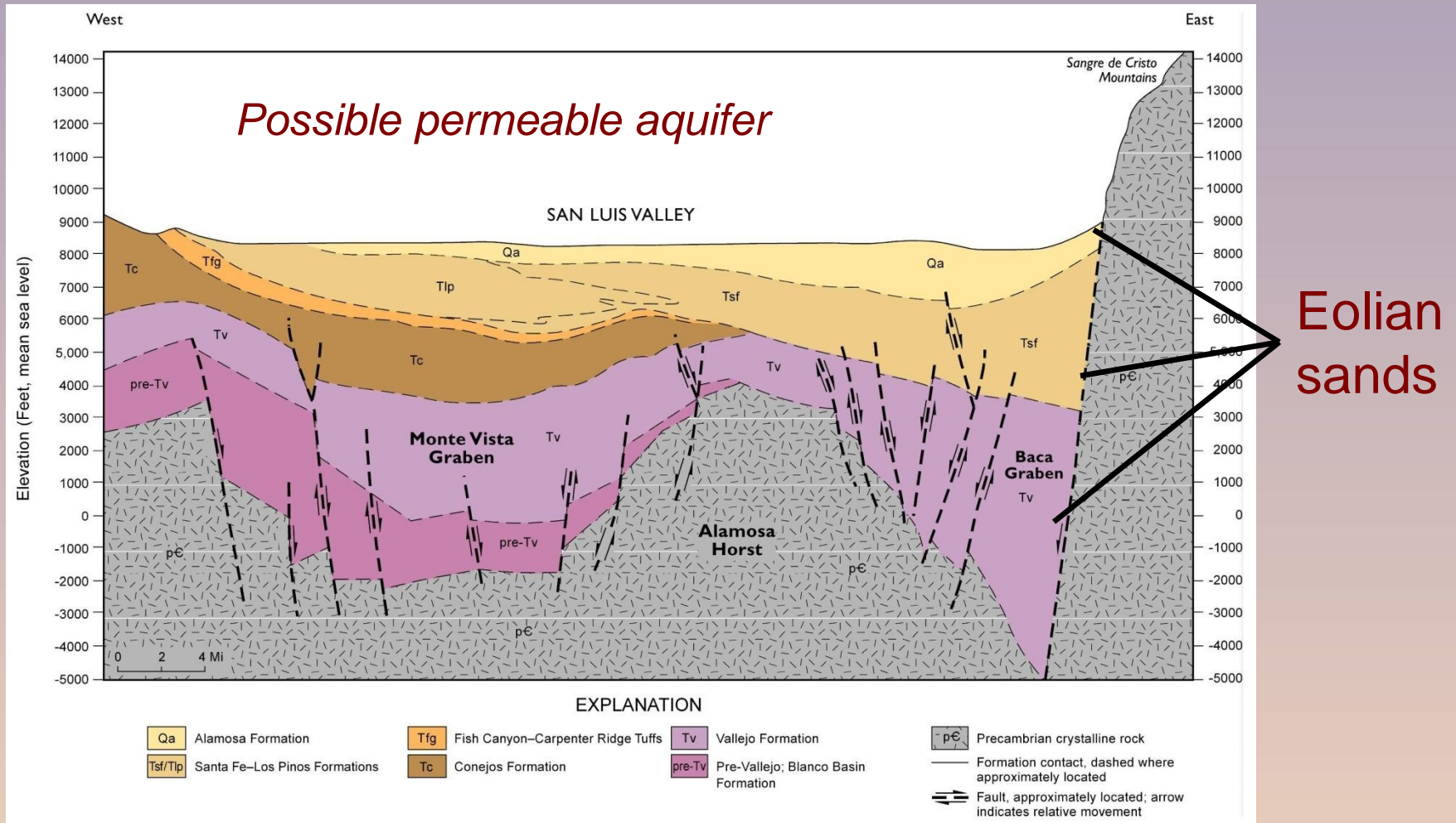
Stratigraphy	Uha 1a m b.s. TVD	Uha 2 m b.s. TVD	Lithology
Quaternary	-28	-20	gravel, sand
Miocene	-1690	-1685	sand, marl, schluff, limy
Oligocene	-2845	-2785	clay marl, lime marl, claystone
Eocene	-2910	-2875	Limestone, lime marl, sandstone
Upper Cretaceous	-2930	-2905	lime marl
Lower Cretaceous	-3002	-2977	Limestone, lime marl, claymarl, sandstone, breccia, limestone
Jurassic (Malm)	-3350 (f.d.)	-3590 (f.d.)	limestone, dolomite



# Natural Sedimentary Basin Geothermal Systems in Colorado

- High permeability aquifers – in general permeability decreases with depth and is likely to be relatively low where temperature is high enough for power production.
- Exceptions, e.g.:
  - Possible high K associated w/ sands on eastern margin of San Luis Basin
  - Very high K as may be found associated with channels in Paleozoic limestones (Leadville and Madison), especially where faulted karst structures exist, e.g., possibly Sand Wash Basin

# Generalized Cross-Section of San Luis Basin

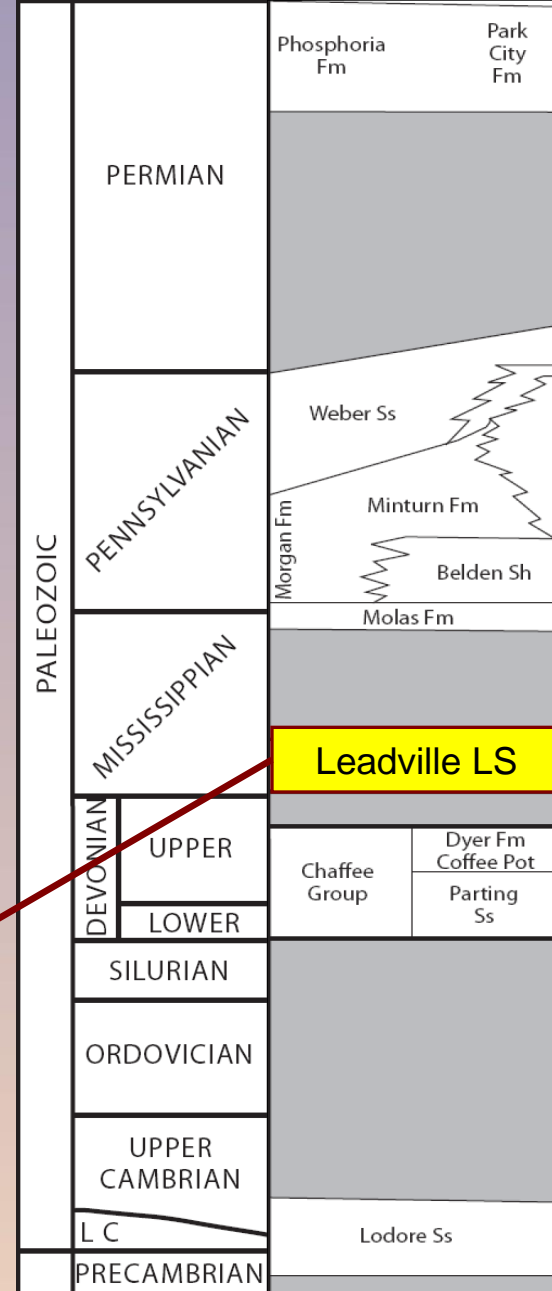


Source: Topper *et al.*, 2003, Colorado Geological Survey Special Publication 53, pp. 157-168, Figure 7.1-3

# Sand Wash Basin Stratigraphy (Paleozoic)

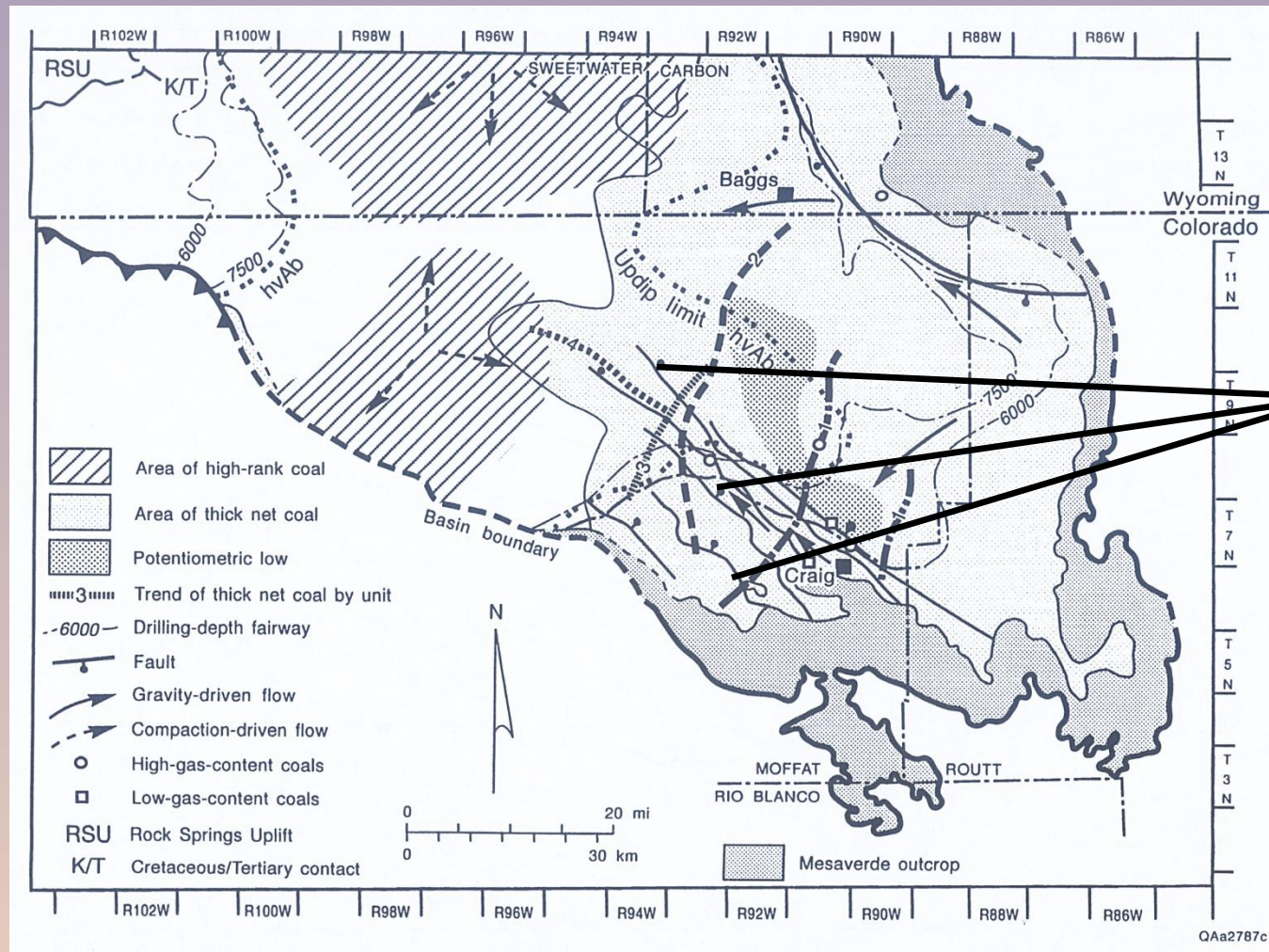
Possible channel aquifer  
(karst & fracture permeability)

Mississippian Leadville Limestone  
-- up to 700 ft thick





# Faults in Colorado Sand Wash Basin



Faults

Source: Kaiser *et al.*, 1994, Colorado Geological Survey Resource Series 30, pp.129-151, Fig. 80.

# Conclusions

- ❖ Untapped potential exists for large geothermal resources for electricity generation in Colorado's sedimentary basins, and, by extension in other similar sedimentary basins.
- ❖ The potential for the greatest potential energy recovery (not including geopressured systems of co-produced fluids) is probably in engineered geothermal systems.
- ❖ Natural permeable systems, such as permeable aquifers and natural channel permeability are the low-hanging fruit, but probably only localized.

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# THANK YOU