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


Websites


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Paul Morgan & Matthew Sares
Colorado Geological Survey
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Alternative Energy: Geothermal
12 April, 2011
Houston, Texas
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°F, 93°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
- Piceance Basin
- Denver Basin
- Cañon City Embayment
- Paradox Basin
- San Juan Basin
- San Luis Basin
- Raton Basin
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 ± latitude. Add 3°C for mean annual ground temperature (MAGT).
- Calculate temperature gradient as:
  \[
  \frac{(BHT - MAGT)}{\text{depth of BHT}}
  \]
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

\[ \ln(\text{# wells}) = -1.8 \ln(\text{H}_2\text{O}, \text{gpm}) + 12.4 \]

\[ R^2 = 0.97 \]

<table>
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<tr>
<th>H(_2)O, gpm</th>
<th># wells</th>
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Water Production vs. Well Depth

Water production for individual years, 2000-2009
Some wells have data for multiple years
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 ± 101 gpm

- **Weld County**
  - 2 wells; Max 155 gpm
  - Mean 155 ± 0 gpm

- **Rio Blanco County**
  - 3 wells; Max 106 gpm
  - Mean 104 ± 2 gpm

- **Washington County**
  - 1 well; 119 gpm

- **Huerfano County**
  - 24 wells; Max 690 gpm
  - Mean 189 ±154 gpm

- **Las Animas County**
  - 1 well; 112 gpm
Colorado Sedimentary Basin EGS
Raton Basin Bottom-Hole-Temperature Data

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 km³)

Diagrams courtesy of Hal Macartney, Pioneer Natural Resources, Denver
Proposed Engineered Geothermal System
Raton Basin, Colorado

Pilot Project

Diagram courtesy of Hål Macartney, Pioneer Natural Resources, Denver
Natural Sedimentary Basin Geothermal Systems
Germany: Co-Produced District Heat & Electricity in Sedimentary Basins

Red >100°C
Yellow <100°C

North Sea

Neustadt-Glewe
Landau
Unterhaching
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

<table>
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<tr>
<th>Stratigraphy</th>
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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 with 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

Possible permeable aquifer

Eolian sands

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

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.
Acknowledgements:
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For Further Information
- http://geosurvey.state.co.us/
  - Programs & Projects
    - Minerals & Energy Resources
      - Geothermal
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THANK YOU