Geophysics and Geothermal Energy
Colorado School of Mines

- End of students junior year
- 4 week field camp
- Learning experience for undergraduates
Acknowledgments

Ben Northcutt

All the students of Summer Field Camp

Richard Krahebuhl – Advisor / Research Professor

Mike Batzle - Field Camp Head

Terry Young - Geophysics Department Head

Andre Revil – Associate Professor

Robert Raynolds - Field Camp Head Geologist

Rachel Vest Woolf
Locations

Neal Hot Springs

Upper Arkansas Valley
Finding Geothermal Resources

Geophysics:
- Variety of properties to characterize resource
- Basic physical properties
- Imaging the subsurface structure
- Imaging fluids
# Physical Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>Gravity, Seismic</td>
</tr>
<tr>
<td>Magnetic Susceptibility</td>
<td>Magnetics</td>
</tr>
<tr>
<td>Conductivity</td>
<td>DC Resistivity, Self Potential, Electromagnetic</td>
</tr>
<tr>
<td>Velocity</td>
<td>Seismic</td>
</tr>
</tbody>
</table>
General Surveying Tactics/Commentary

- Run lines perpendicular to (supposed) anomaly
- 3D vs. 2D
- Non-unique solutions = many methods
- Surface clues
Geophysics and Geothermal Systems

- Where is the hot water?
- How can it flow to the surface?
DC Resistivity

Where is the water?

- Inject current into ground
- Measure potential difference
- Calculate apparent resistivity
- Invert for resistivity/conductivity model
- Water = conductive!

Figure: The set up and theory behind DC resistivity (Northwest Geophysical Associates Inc.)
Self Potential Theory

Ground water flow is responsible for an electrical field

Revil, 2011
Self Potential

Positive self potential anomaly

Negative self potential anomaly

[Diagram showing positive and negative self potential anomalies with corresponding graphs and geological layers.]
Frequency Domain Electromagnetics

Transmitter coil (Tx)

Receiver coil (Rx)

current

Primary field

Secondary field
Time Domain Electromagnetics

TEM acquisition setup from North Carolina Division of Water Resources

Station 2 Central Sounding
Gravity

Gravity: local subsurface density changes

Change in Gravity Over a Dense Anomaly

Relative Gravity (mGals)

Depth (m)

$\rho > \rho_0$
Magnetics

- Magnetics: subsurface composition, magnetic susceptibility changes
Seismic

Reflections from velocity contrast between beds
Upper Arkansas Valley Investigations

Courtesy of Dr. Andre Revil
Aeromagnetics

V.J.S. Grauch & Benjamin Drenth, Airborne Geophysical Results, USGS, April 2009
Aeromagnetics

Survey Area

Aeromagnetic Map

V.J.S. Grauch & Benjamin Drenth, Airborne Geophysical Results, USGS, April 2009
Aeromagnetics

Gradient Window Residual Analysis

V.J.S. Grauch & Benjamin Drenth, Airborne Geophysical Results, USGS, April 2009
Aeromagnetics

Fault Interpretation

V.J.S. Grauch & Benjamin Drenth, Airborne Geophysical Results, USGS, April 2009
Aeromagnetics

V.J.S. Grauch & Benjamin Drenth, Airborne Geophysical Results, USGS, April 2009
Joint Gravity, Magnetic and Seismic Interpretation

Survey Line

Google Earth Courtesy of Dr. Andre Revil

Mount Princeton

Upper Arkansas valley

Buena Vista

Salida

Poncha Springs

Chaffee County

 Courtesy of Dr. Andre Revil
2009 Field Camp Gravity, Magnetics, and Seismic Joint Interpretation

Grav, Mag, Seismic integration with GM-SYS under academic license for course use only
DC Resitivity and Self Potential Joint Interpretation

Survey Line

Chalk Cliffs

Google Earth
Temperature Data

Self-Potential Data

Resistivity Model

Courtesy of Dr. Andre Revil
$4 \pm 1 \times 10^3 \text{ m}^3/\text{day of thermal water upwelling}$

Courtesy of Dr. Andre Revil
Neal Hot Springs Investigation

Raynolds, 2011
Gravity

3D inversion of 2007 gravity data (Geothermal, Inc.). Inverted with Gzinv3D, created at UBC-GIF based on (Li and Oldenburg, 1998); Algorithm Teaching License provided to CSM-CGEM for academic use only.
Raynolds, 2011

3D inversion of 2007 gravity data (Geothermal, Inc.). Inverted with Gzinv3d, created at UBC-GIF based on (Li and Oldenburg, 1998); Algorithm Teaching License provided to CSM-CGEM for academic use only.
Gravity and Seismic Data

Gravity

Seismic Velocity and Elevation Profile

Surface Topography

First Seismic Refractor
EM Results

EM-34 Apparent Conductivity

EM-31 Apparent Conductivity

Neal Hot Spring
Resistivity: Profile 3 Results
Resistivity: Profile 3 Results

SP

Time-domain EM

Resistivity

Distance along profile (m)
Resistivity: Profile 4 Results

Self Potential Profile 4

Positive anomaly

Distance along the Line (m)

West
N 4874459
E 0462979

Horst
Hot Springs
Warm Springs

East
N 4876027
E 0464899

Basin

Resistivity

Resistivity (ohm m)
What are we looking for?

“It’s the fluids that count” – Mike Batzle

Using data to find Geothermal sources

Gravity/Magnetic/Seismic Integration

![Graphs and diagrams showing temperature, self-potential, and geologic log with annotations such as 'Fault Zone', 'Warm Aquifer', 'Oz Monzonite', 'B3', 'Profile P3', and 'Resistivity (in ohm m)'].

Courtesy of Andre Revil
Correlation: Geology, Gravity, DC
Correlation is Confidence