Joint inversion of electrical and seismic data for Fracture char. and Imaging of Fluid Flow in Geothermal Systems

Project Officer: Eric Hess
Total Project Funding: $1,246,579
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Michael Batzle, PI
Colorado School of Mines

Track Name: Fluid Imaging

This presentation does not contain any proprietary confidential, or otherwise restricted information.
Relevance/Impact of Research

Project objectives

• Use combined inversion of geophysical data to characterize geothermal reservoirs

• Apply the combined data to quantify hydrothermal fluid flow.

• Develop and train the next generation of geothermal professionals.

• Results extend our ability to understand and utilize geothermal resources
  - Approximately 240 students educated in geothermal assessment
  - New, previously unknown fluid paths identified
  - Drill sites identified for EGS production
  - Resource plan developed for use of hydrothermal fluids

• Involve local groups and individuals in geothermal development
Relevance/Impact of Research

SEG Foundation
Rutt Bridges
Global Geophysical
Chaffee County
Donald S. Reimer, Chaffee Co Engineer
City of Poncha Springs
U.S. Bureau of Land Management
U.S. Forest Service
Becky and Thomas Massey
Dr. Roberta Edwards
Robert Butler
Fred Henderson
Steve Lundgren
Young Life Frontier Ranch
City of Vale and the Community
Vale Elementary School
Sagebrush Saloon
Vale High School
CGGVeritas
Sercel
Local Land Owners
US Geothermal
Spencer Wood & Mark Ferns
Archuleta County: Mike Whiting and Greg Schulte
Stevens Airport: Mark Lavato and Chris Torres
Archuleta School District 50 Joint: Linda Reed
Pagosa Springs Geothermal District: Phil Starks
Zonge
CSU Archuleta Extension: Terry Schaaf

Pagosa Baking Company: Kathy Keyes, Kirsten Skeehan
Pagosa High School: Laura Rand and kitchen staff
San Juan Motel: Kiel Steck
Chimney Rock Archaeological Area: Wendy Smith, US Forest Service
Chimney Rock Interpretive Volunteers – Tannis and Allan
Davis Ranch
Geothermal Greenhouse Partnership
Goodman Ranch
Gerry Huttner
Ken Levine
Kevin Khung, US Forest Service
KWUF
Pam Leschak, BLM Durango
Matt Mees
Overlook Hot Springs
Pagosa Springs Chamber of Commerce: Mary Jo Coulehan
Pagosa Springs Community Development Corp: Rich Lindblad
Pagosa Springs Golf Club
Pagosa Sun: Jim McQuiggin
Reservoir River Ranch: Levine Family
Jerry & Sally Smith
Southern Ute Indian Nation: Nathan Strong Elk
Spring Creek Ranch: Donald Shahan
The Springs Resort: Carla Shaw
Kristen Swaim Pierce, BLM
First Inn: Lou Woodard
Scientific/Technical Approach

• Collect geophysical data sets of multiple types
  - Resistivity
  - Gravity
  - Self Potential
  - Magnetics
  - Seismic

• Conduct joint inversion on these data (below)

• Additional zones of hydrothermal fluid flow identified

• All tasks complete
## Accomplishments, Results and Progress

<table>
<thead>
<tr>
<th>Original Planned Milestone/Technical Accomplishment</th>
<th>Actual Milestone/Technical Accomplishment</th>
<th>Date Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collect multiple geophysical data sets</td>
<td>Chaffee County, Data Collected</td>
<td>May, 2008</td>
</tr>
<tr>
<td>Integrate and Interpret data</td>
<td>Interpreted</td>
<td>June, 2008</td>
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<tr>
<td>Collect multiple geophysical data sets</td>
<td>Chaffee County, Data Collected</td>
<td>May, 2009</td>
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<tr>
<td>Integrate and Interpret data</td>
<td>Interpreted</td>
<td>June, 2009</td>
</tr>
<tr>
<td>Collect multiple geophysical data sets</td>
<td>Chaffee County, Data Collected</td>
<td>May, 2010</td>
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<tr>
<td>Integrate and Interpret data</td>
<td>Interpreted</td>
<td>June, 2010</td>
</tr>
<tr>
<td>Drilling and development plan</td>
<td>Plan complete &amp; presented</td>
<td>Sept., 2010</td>
</tr>
<tr>
<td>Collect multiple geophysical data sets</td>
<td>Vail Hot Spr., Data Collected</td>
<td>May, 2011</td>
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<tr>
<td>Integrate and Interpret data</td>
<td>Interpreted</td>
<td>June, 2011</td>
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<tr>
<td>Collect multiple geophysical data sets</td>
<td>Pagosa Springs, Data Collected</td>
<td>May, 2012</td>
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<tr>
<td>Integrate and Interpret data</td>
<td>Interpreted</td>
<td>June, 2012</td>
</tr>
<tr>
<td>Preliminary results completed</td>
<td>Presented</td>
<td>June, 2012</td>
</tr>
</tbody>
</table>
Example Results

Gauss Newton Inversion algorithm

Ground water flow pattern at Chalk Cliff

E

Distance (in m)

W

Self-potential (in mV)

Inverted self-potential data (in mV)

Measured self-potential signals

Inverted Self-potential data (in mV)

Observed self-potential data (in mV)

1:1

Altitude (in m)

2400 2500 2600 2700

Shallow aquifer

U2 Quartz Monzonite

U3

Fault Zone

U1

U2 Quartz Monzonite

Darcy velocity (x10^-7 m/s)

2 4 6 8 10 12 14
$4 \pm 1 \times 10^3$ m$^3$/day thermal water upwelling
Deep Seismic lines

SP & Resistivity lines

North line

E-W line

2 km
Gravity/Magnetic/Seismic Integration

Magnetic Field (nT)

-232 to 464 nT

Gravity (mGal)

3225 to 3375 mGal

Depth (m)

0 to 2697 m

Distance (m)

0 to 9609 m
Proposed Well

Proposed Well Path
Development Plan

Source: Chaffee county recreational map, 2004
Future Directions

• With DOE on this particular project - none
  – Continue related activities at Jersey Valley, Nevada
    (see Andre Revil, April 23)
• Continue Geothermal assessment at :
  - Pagosa Springs, CO
  - Assist with proposed drilling near Buena Vista, CO
  - Poncha Springs, CO (?)
• Continuation Goals
  - Identify hydrothermal conduits
  - Continue to train geothermal professionals

<table>
<thead>
<tr>
<th>Milestone or Go/No-Go</th>
<th>Status &amp; Expected Completion Date</th>
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</thead>
<tbody>
<tr>
<td>Project Results</td>
<td>All Complete and Delivered</td>
</tr>
</tbody>
</table>
Summary

• Geothermal flow imaged and identified
• 240 new professionals trained in assessment of geothermal systems
• Drilling and distribution system outlined and presented
The purpose of this slide is to provide some context for evaluating your project.

Please prepare one overview slide containing the following information:

### Timeline:
<table>
<thead>
<tr>
<th>Planned Start Date</th>
<th>Planned End Date</th>
<th>Actual Start Date</th>
<th>Current End Date</th>
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</table>

### Budget:
<table>
<thead>
<tr>
<th>Federal Share</th>
<th>Cost Share</th>
<th>Planned Expenses to Date</th>
<th>Actual Expenses to Date</th>
<th>Value of Work Completed to Date</th>
<th>Funding needed to Complete Work</th>
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</thead>
<tbody>
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<td>375,533</td>
<td>1,246,932</td>
<td>1,247,836</td>
<td>1,623,396</td>
<td>- $0 -</td>
</tr>
</tbody>
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### Management activities:
- Data acquired and interpreted in conjunction with field class
- Coordinated with dozens of local agencies and individuals (slide 3)
- 240 professionals trained
- Similar assessment requested at other locations