Effects of Volcanism, Crustal Thickness, and Large Scale Faulting on the Development and Evolution of Geothermal Systems: Collaborative Project in Chile

Project Officer: William Vandermeer
Total Project Funding: $105,000 (over 2 years)
April 24, 2013

This presentation does not contain any proprietary confidential, or otherwise restricted information.
Research Objectives

• Improve use of $^3$He/$^4$He isotope signature for geothermal exploration
  – Influence of crust (thickness and age)
  – Influence of volcanism (age, composition, proximity)
  – Influence of regional faults
  – Local indications of upflow and outflow zones

• Project will leverage previous He analyses and ongoing geothermal studies being conducted at the Universidad de Chile

• Innovative approaches include:
  – Selection of Chilean Andes, which has significant variations in crustal thickness and volcanism
  – Conducting detailed investigation of two areas to evaluate local vs. regional effects on He isotopic compositions

• The interpretive methodologies developed by this project could accelerate near term hydrothermal growth by lowering the risks and costs of development and exploration for hydrothermal resources
He Isotope Systematics

Three main reservoirs of He: mantle, crust, and atmosphere

- $^{3}\text{He}/^{4}\text{He}$ of air is $1.4 \times 10^{-6}$ (Ra)
- Mantle (magmatic) He values typically 6-8 Ra
- $^{4}\text{He}$ produced by radiogenic decay of Th, U, with crustal He ratios typically $\sim 0.02$ Ra

Kennedy and van Soest, 2007
Chile as a Test Site

- Many geothermal systems in Chile
- Decrease in crustal thickness from N to S
- Abundant active volcanism along Andean arc
- Presence of large regional faults in S. Volcanic Zone
- Four systems sampled during 2 field visits, with detailed sampling at El Tatio and Tolhuaca

Lahsen et al., 2010
El Tatio Geothermal System

- Located in graben within Central Volcanic Zone (CVZ)
- Drilling (1969-1974) encountered 260°C reservoir
- Abundant thermal activity
  - Geysers
  - Hot springs
  - Fumaroles
- He values between 1.39-2.94
Scientific/Technical Approach

**Tolhuaca Geothermal System**

- Holocene volcano located within SVZ
- GeoGlobal Energy LLC drilled 4 wells, one of which tested at 12 MW
- Thermal features consist of fumaroles and bicarbonate springs
- Area W of the Liquiñe Ofqui fault zone
- Numerous fractures, faults, and dikes strike N40W to N60E, with steep dips
Scientific/Technical Approach

Tolhuaca Conceptual Model

- High elevation bicarbonate springs located above shallow (100-300 m deep) steam zone
- These features have highest Rc/Ra values (6.64-6.71)
- Conceptual model of Melosh et al. (2012) suggests that upflow zone for system is beneath these features, with outflow to the NW
Scientific/Technical Approach

Crustal Thickness – Andes

Yuan et al., 2002
McGlashan et al., 2008
Fromm et al., 2004
Beck & Zandt, 2002
Gilbert et al., 2006
Hackney et al., 2006
Introcaso et al., 1992
Ramos et al., 2004
Martinez et al., 1994

Ramos et al., 2004
Volcanic vs. Geothermal He

- Most CVZ volcanic fumaroles have R/Ra values between 5-7
- Most CVZ thermal features for geothermal systems have R/Ra values between 0.1-3.5
- Hydrothermal fluids have longer residence time, thus have more prolonged interaction with crustal rocks and fluids
<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>Review literature on geothermal systems in Chile</td>
<td>Review completed and table constructed summarizing all published He isotopic data for geothermal features in Chile</td>
<td>Feb. 2012</td>
</tr>
<tr>
<td>Coordinate site selection with colleagues at UC Berkeley and the University of Chile</td>
<td>Four sites selected: one from CVZ (El Tatio) and three from SVZ (Tinguiririca, Chillán, Tolhuaca)</td>
<td>Mar. 2012</td>
</tr>
<tr>
<td>Conduct field sampling at selected sites in Chile</td>
<td>Samples collected from 10 different thermal features (fumaroles and bubbling hot springs) at the four selected sites.</td>
<td>Apr. 2012</td>
</tr>
<tr>
<td>Analyze initial suite of samples</td>
<td>Water samples analyzed for D/H, $^{18}\text{O}/^{16}\text{O}$ at UCB, gas samples analyzed for noble gases at LBNL</td>
<td>June 2012</td>
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## Accomplishments, Results and Progress

<table>
<thead>
<tr>
<th>Original Planned Milestone/Technical Accomplishment</th>
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<th>Date Completed</th>
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<tbody>
<tr>
<td>Conduct He sampling of additional geothermal systems in Chile</td>
<td>Six new samples were collected at El Tatio to provide more extensive coverage and the fumarole at Chillán was resampled</td>
<td>Nov. 2012</td>
</tr>
<tr>
<td>Develop interpretive methodology that could be applied to other geothermal systems</td>
<td>Influences of crustal thickness and volcanism were evaluated for Chilean geothermal systems</td>
<td>Feb. 2013</td>
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<tr>
<td>Interpret data in context of regional and local geology</td>
<td>Initial interpretation completed – analysis ongoing</td>
<td>Ongoing</td>
</tr>
<tr>
<td>Milestone or Go/No-Go</td>
<td>Status &amp; Expected Completion Date</td>
<td></td>
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<td>------------------------------------------------------------------------------------</td>
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<tr>
<td>Add to existing LBNL compilation of He isotope data for geothermal systems in OR, CA, NV, UT, and ID</td>
<td>References obtained and data compilation in progress (Expected completion date March 2013)</td>
<td></td>
</tr>
<tr>
<td>Based on data gap analysis, conduct (if needed) He sampling of geothermal features in western US</td>
<td>Remaining funds not sufficient to support additional sampling</td>
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<tr>
<td>Analyze new samples (from Nov. 2012 field work)</td>
<td>Stable isotope analyses completed (Feb. 2013), noble gas analyses pending (Apr. 2013)</td>
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<tr>
<td>Interpret local variations at El Tatio and Tolhuaca in context of Yellowstone, Ohaaki examples</td>
<td>References obtained, interpretation pending new analytical results (May 2013)</td>
<td></td>
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<tr>
<td>Interpret US He data using factors of crustal thickness, volcanism and faulting, write journal article</td>
<td>Pending (Sept. 2013)</td>
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A wide range of He isotopic compositions (0.1 to 7.3 R/Ra) are observed for geothermal features in the CVZ and SVZ – all demonstrate a clear mantle gas component.

In general, $^3$He/$^4$He values for geothermal systems in CVZ are lower than those in SVZ, where the crust is not as thick.

He from fumaroles associated with active volcanoes in CVZ have elevated R/Ra values relative to geothermal systems in CVZ.

Local variations in He values may help identify upflow and outflow zones.
Timeline:

<table>
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<tr>
<th>Timeline</th>
<th>Start Date</th>
<th>End Date</th>
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<tbody>
<tr>
<td>Planned</td>
<td>10/1/2012</td>
<td>9/30/2013</td>
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<tr>
<td>Actual</td>
<td>11/1/2012</td>
<td>9/30/2013</td>
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Budget:

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<tr>
<th>Budget</th>
<th>Federal Share</th>
<th>Cost Share</th>
<th>Planned Expenses to Date</th>
<th>Actual Expenses to Date</th>
<th>Est. Value of Work Completed to Date</th>
<th>Funding needed to Complete Work</th>
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<tr>
<td></td>
<td>$105</td>
<td>$0</td>
<td>$85</td>
<td>$69</td>
<td>$79</td>
<td>$36</td>
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- Charges relating to analysis of new He samples still pending
- Field work in Chile received financial and logistical support from the Universidad de Chile (the Centro de Excelencia en Geotermia de los Andes is supported by CONICYT) and the Fulbright Specialist Program
- Project is leveraging geologic studies being conducted by graduate students at the Universidad de Chile and UC Berkeley
• Project Collaborators
  – Mack Kennedy (LBNL)
  – Diego Morata (Universidad de Chile)
  – Martin Reich (Universidad de Chile)
  – Pablo Sánchez (Universidad de Chile)
  – Carolina Muñoz (UC Berkeley)