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)

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Patrick Dobson

Lawrence Berkeley National Laboratory

Geochemistry

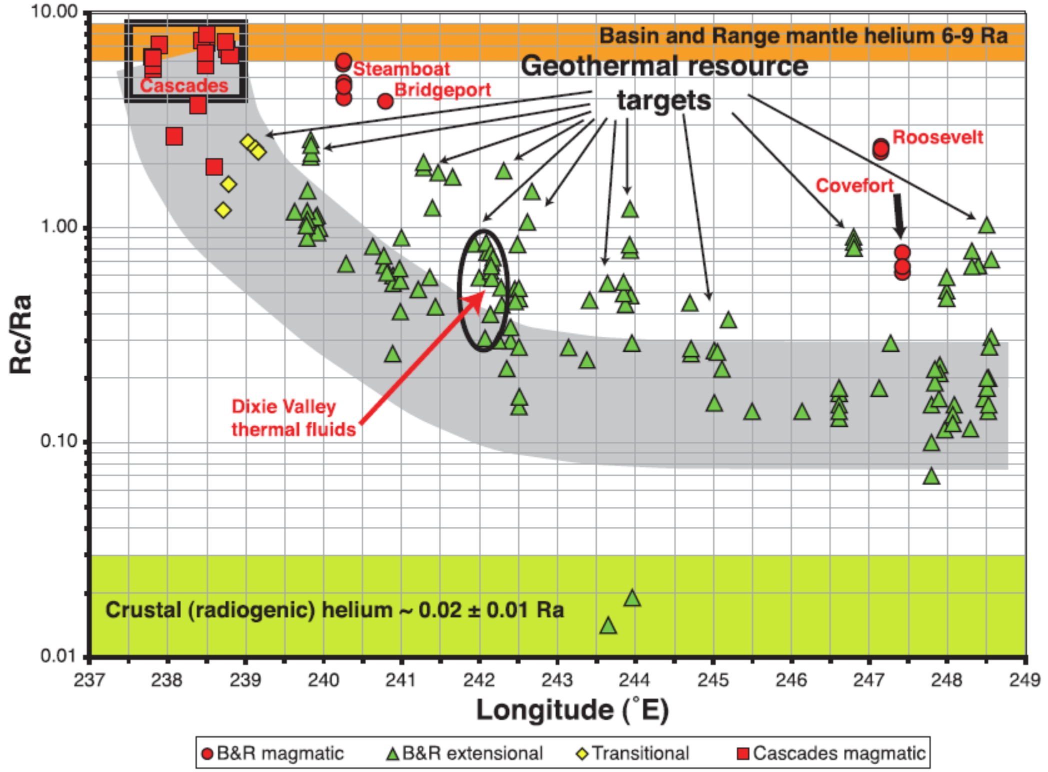
Research Objectives

- Improve use of $^3He/^4He$ 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 lowing the risks and costs of development and exploration for hydrothermal resources

He Isotope Systematics

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

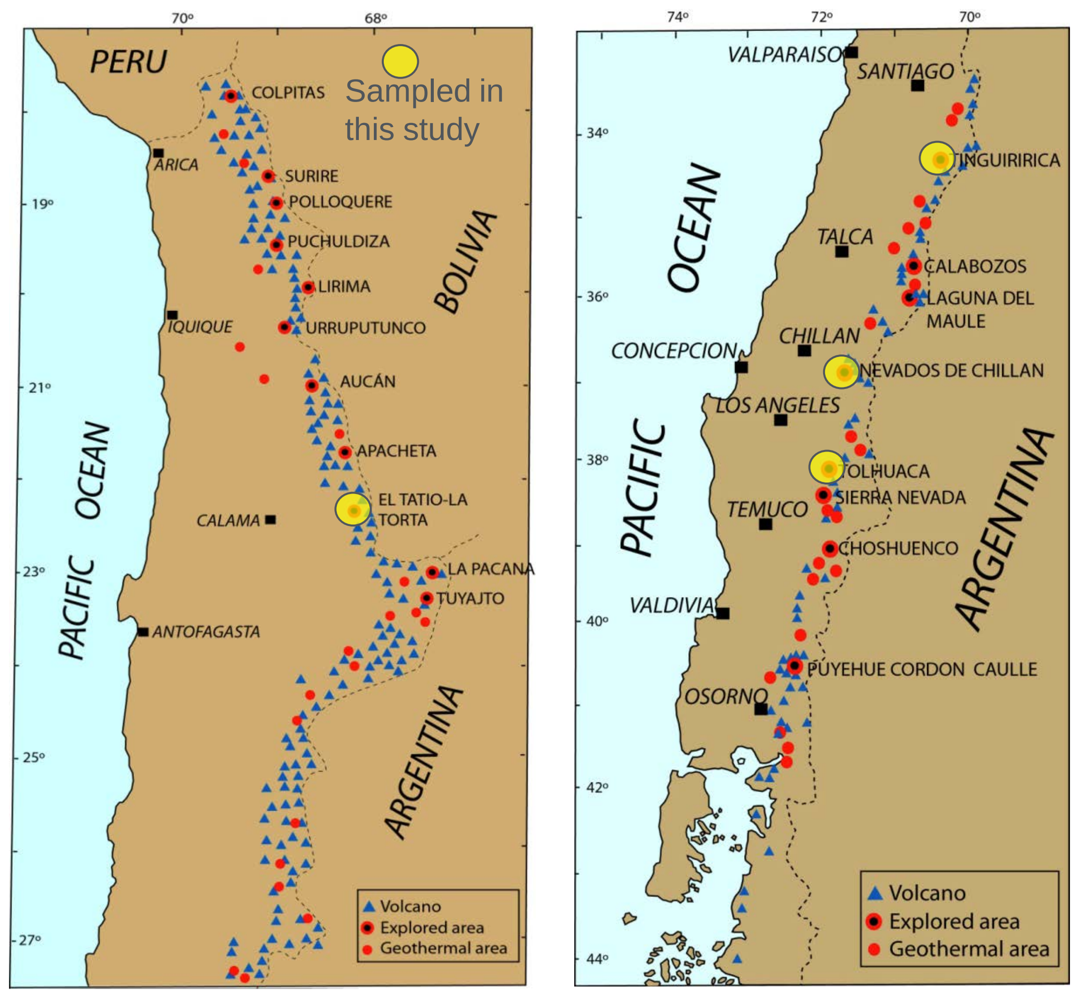
- $^{3}He/^{4}He$ of air is 1.4×10^{-6} (Ra)
- Mantle (magmatic) He values typically 6-8 Ra
- ^{4}He produced by radiogenic decay of Th, U, with crustal He ratios typically ~ 0.02 Ra



Kennedy and van Soest, 2007

Chile as a Test Site

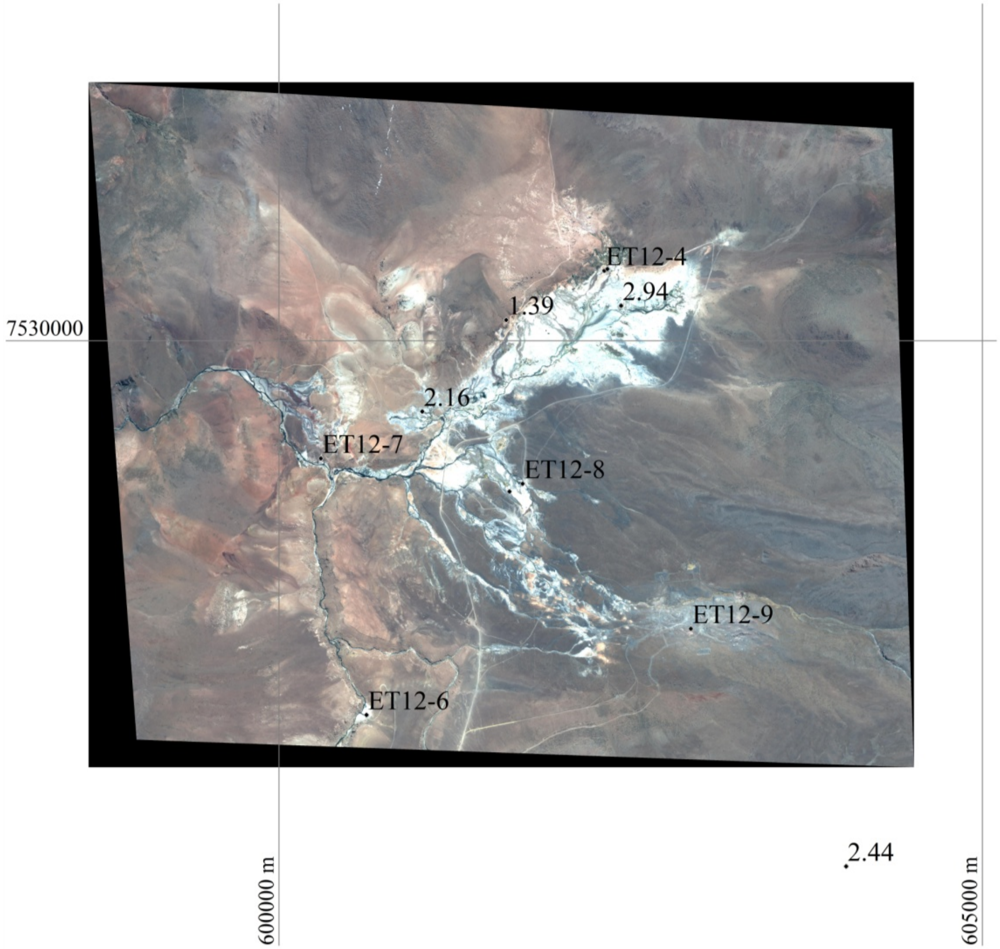
- Many geothermal systems in Chile
- Decrease in crustal thickness from N to S
- Abundant active volcanism along Andean arc
- Presence of large regional faults in S. Volcanic Zone
- Four systems sampled during 2 field visits, with detailed sampling at El Tatio and Tolhuaca



Lahsen et al., 2010

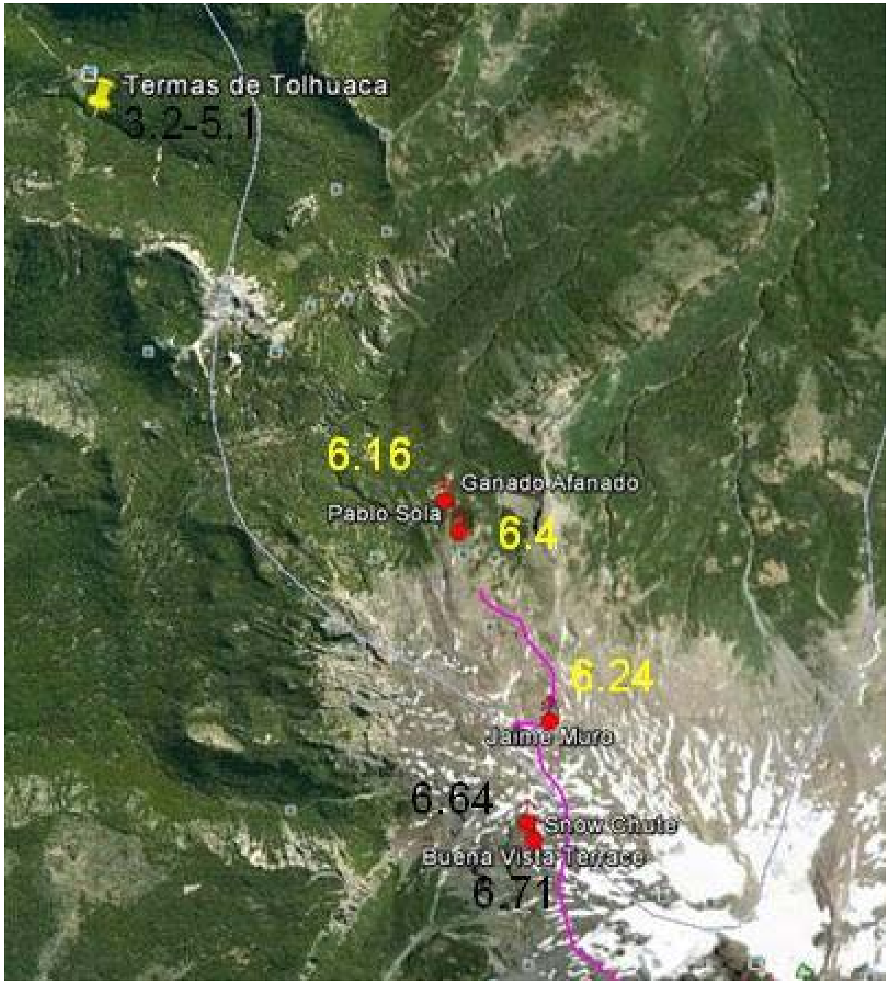
El Tatio Geothermal System

- 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



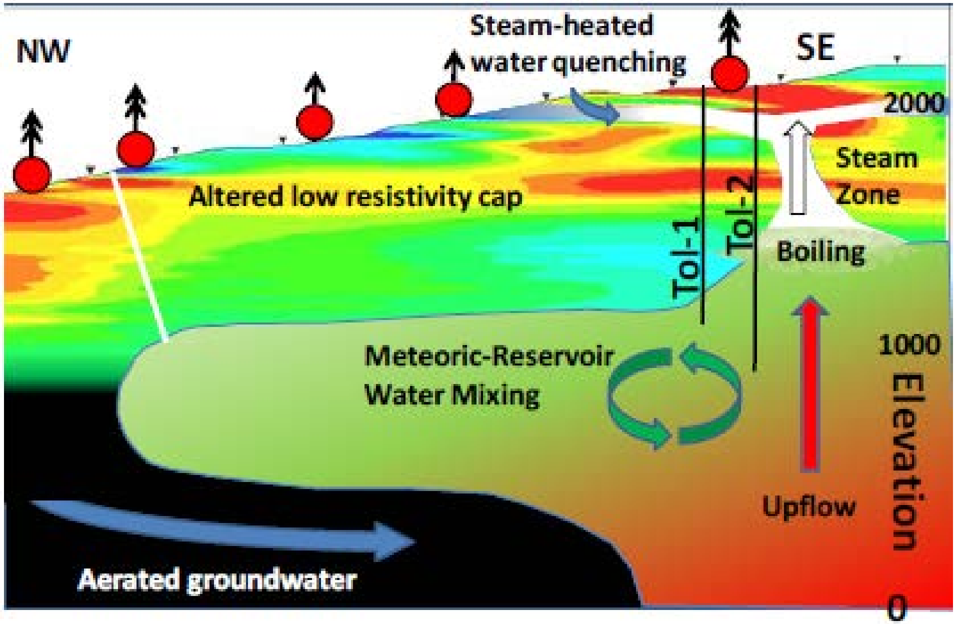
Tolhuaca Geothermal System

- 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



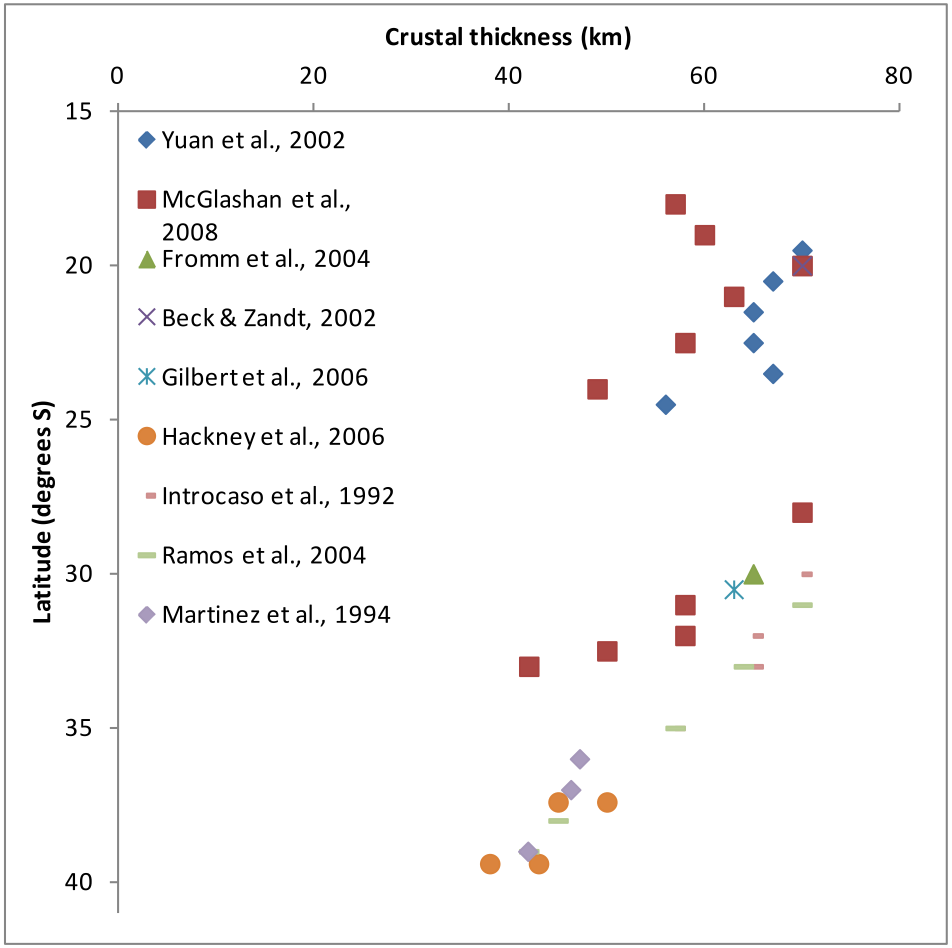
Tolhuaca Conceptual Model

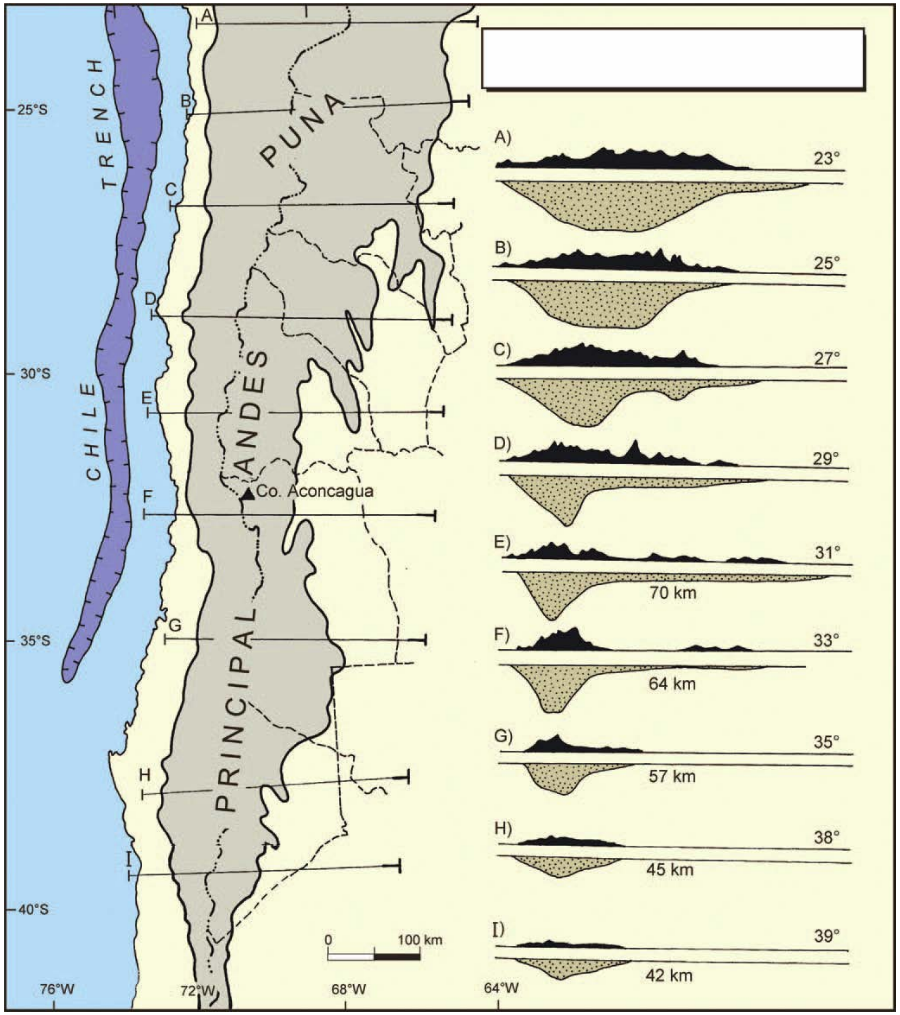
- High elevation bicarbonate springs located above shallow (100-300 m deep) steam zone
- These features have highest Rc/Ra values (6.64-6.71)
- Conceptual model of Melosh et al. (2012) suggests that upflow zone for system is beneath these features, with outflow to the NW



Melosh et al., 2012

Crustal Thickness – Andes

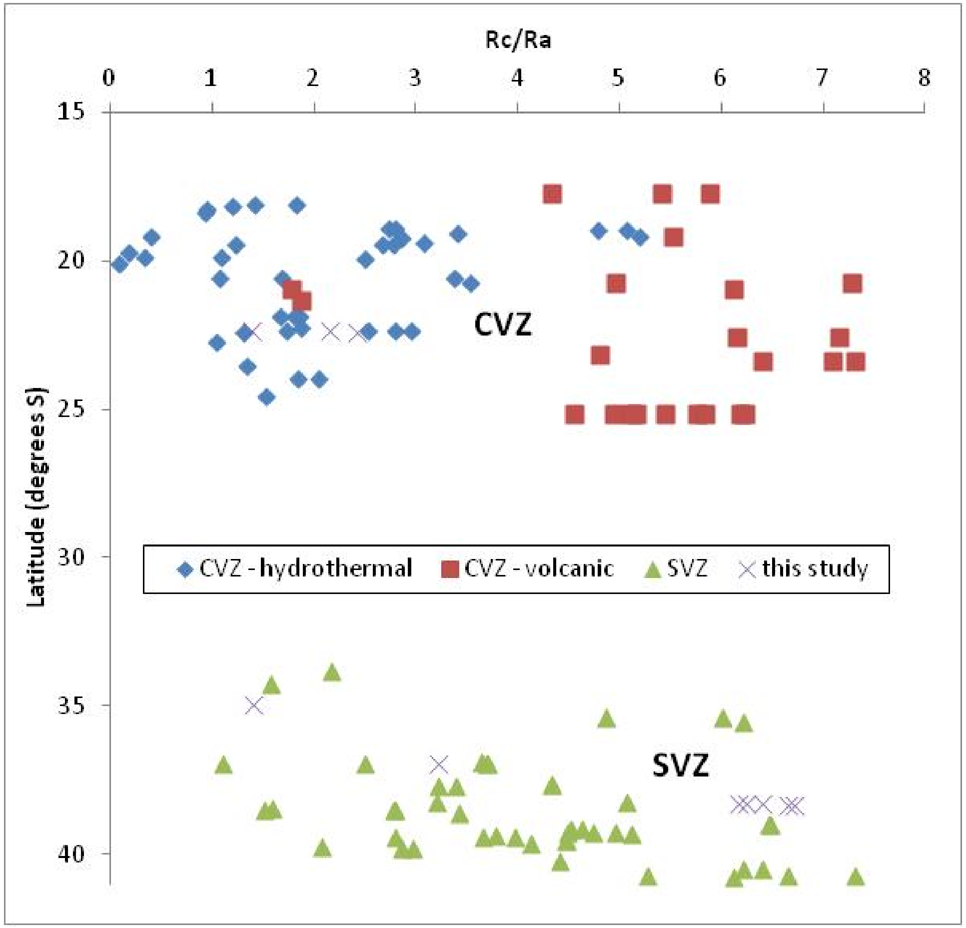




Ramos et al., 2004

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



Accomplishments, Results and Progress

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Review literature on geothermal systems in Chile	Review completed and table constructed summarizing all published He isotopic data for geothermal features in Chile	Feb. 2012
Coordinate site selection with colleagues at UC Berkeley and the University of Chile	Four sites selected : one from CVZ (El Tatio) and three from SVZ (Tinguiririca, Chillán, Tolhuaca)	Mar. 2012
Conduct field sampling at selected sites in Chile	Samples collected from 10 different thermal features (fumaroles and bubbling hot springs) at the four selected sites.	Apr. 2012
Analyze initial suite of samples	Water samples analyzed for D/H, $^{18}O/^{16}O$ at UCB, gas samples analyzed for noble gases at LBNL	June 2012

Accomplishments, Results and Progress

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Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Conduct He sampling of additional geothermal systems in Chile	Six new samples were collected at El Tatio to provide more extensive coverage and the fumarole at Chillán was resampled	Nov. 2012
Develop interpretive methodology that could be applied to other geothermal systems	Influences of crustal thickness and volcanism were evaluated for Chilean geothermal systems	Feb. 2013
Present paper at the Stanford Geothermal Workshop	Paper presented at Stanford Geothermal Workshop	Feb. 2013
Interpret data in context of regional and local geology	Initial interpretation completed – analysis ongoing	Ongoing

Future Directions

Milestone or Go/No-Go	Status & Expected Completion Date
Add to existing LBNL compilation of He isotope data for geothermal systems in OR, CA, NV, UT, and ID	References obtained and data compilation in progress (Expected completion date March 2013)
Based on data gap analysis, conduct (if needed) He sampling of geothermal features in western US	Remaining funds not sufficient to support additional sampling
Analyze new samples (from Nov. 2012 field work)	Stable isotope analyses completed (Feb. 2013), noble gas analyses pending (Apr. 2013)
Interpret local variations at El Tatio and Tolhuaca in context of Yellowstone, Ohaaki examples	References obtained, interpretation pending new analytical results (May 2013)
Interpret US He data using factors of crustal thickness, volcanism and faulting, write journal article	Pending (Sept. 2013)

Mandatory Summary Slide

- 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

Project Management

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Timeline:

Planned Start Date	Planned End Date	Actual Start Date	Actual /Est. End Date
10/1/2012	9/30/2013	11/1/2012	9/30/2013

Budget:

Federal Share	Cost Share	Planned Expenses to Date	Actual Expenses to Date	Est. Value of Work Completed to Date	Funding needed to Complete Work
$105	$0	$85	$69	$79	$36

- 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

Additional Information

- Project Collaborators
  - Mack Kennedy (LBNL)
  - Diego Morata (Universidad de Chile)
  - Martin Reich (Universidad de Chile)
  - Pablo Sánchez (Universidad de Chile)
  - Carolina Muñoz (UC Berkeley)