Integration of Nontraditional Isotopic Systems Into Reaction-Transport Models of EGS For Exploration, Evaluation of Water-Rock Interaction, and Impacts of Water Chemistry on Reservoir Sustainability

Project Officer: Eric Hass Total Project Funding: $512K

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Track 3

Relevance/Impact of Research

Objectives: Extend reaction transport models to incorporate standard and nontraditional isotopic systems used in EGS and to validate the methodology with experimental work on geothermal reservoir rocks, and simulation of data from geothermal fields.

Challenges, barriers, knowledge gaps addressed:

1. *Design and development of improved geothermometers and geochemical tools to assist in discovering blind systems*
2. *Fluid rock interaction research to improve reservoir creation and reservoir sustainability*
3. *Understanding permeability using chemical signatures*
4. *Processing of different geochemical signatures to identify hidden geothermal systems*

Impacts to costs:

Primary impacts on the LCOE may come from an increased success rate in drilling and a decrease in drilling costs per hole during resource exploration. The potential in increased success rate can be attributed to better accuracy in determining the size and location of the geothermal resource.

Relevance/Impact of Research

Despite widespread use of isotopic systems in evaluation/exploration of geothermal systems, few are incorporated into reaction-transport (RT) models that can allow for equilibrium and kinetic fractionation mechanisms.

Project Innovations:

Ca, Sr, and Li are commonly analyzed in geothermal waters for tracing water sources, mixing processes, and in geothermometry. A whole class of isotopic systems (e.g. Li, Ca, stable Sr) known as "nontraditional" can add to this range of processes (DePaolo 2006, 2011). *Ca, Sr, and Li isotopic systems will be incorporated in geothermal models for Toughreact-V2 (Xu et al. 2011) and Toughreact-Rocmech (THMC), extending the number and complexity of isotopic systems treated in reactive-transport models of geothermal systems.*

Common Ca and Sr-rich minerals in geothermal systems (feldspars, epidote, and calcite) often control fracture permeability changes. *Measurements of Ca and Sr isotopic fractionation at high temperature during calcite precipitation and alteration of reservoir rocks (e.g. Bishop Tuff) have not been performed prior to this project, and will yield new data for determining fracture surface areas for heat transfer and water-rock interaction.*

Lithium isotopes (^{7}Li and ^{6}Li) show strong mass- and T-dependent fractionation, making them a powerful tool for evaluating reservoir temperatures, and water-rock interaction (Millot and Negrel, 2007). *Determination of high-T fractionation factors and incorporation into RT models and the integated geothermometry code geoT (Spycher et al. 2011) will greatly add capabilities for analyzing EGS and hydrothermal systems.*

Relevance/Impact of Research

Success within this project will impact the following Geothermal Technologies Programs' goals:

EGS: Lower drilling costs by improving characterization of fracture surface area generated during stimulation (Ca, Sr, and Li). Improve predictions of fracture permeability changes from mineral precipitation to optimize production.

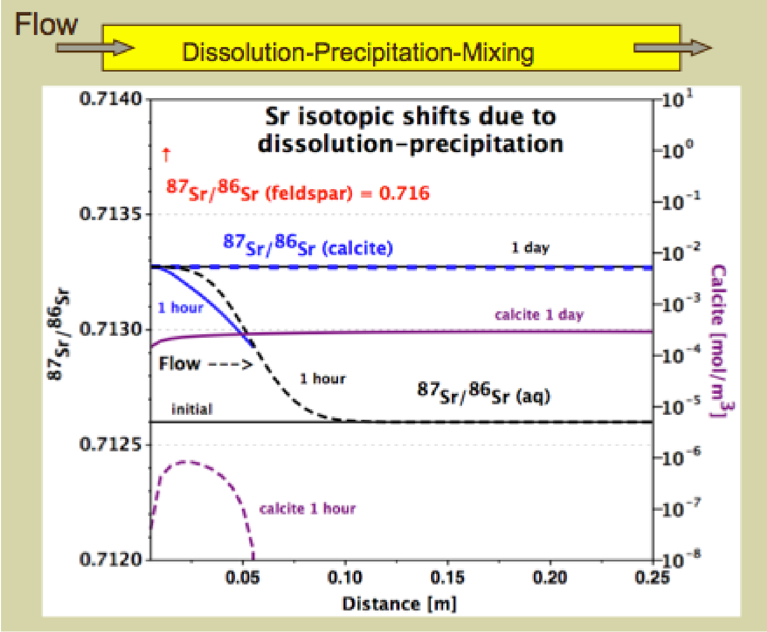
R&D: Ca and Sr isotopes Could be used to evaluate extent of temporary fracture sealing

Hydrothermal: Incorporation of Li isotope geothermometers into geoT will lower risks of exploration and improve resource evaluation

Scientific/Technical Approach

1. Integrate isotope systematics (e.g. Ca, Sr, and Li) into reactive-transport models of mineral-water-gas reactions in geothermal systems
2. Include dissolution, precipitation, gas exsolution and fractionation, kinetic and equilibrium isotopic fractionation
3. Consider sorption, ion exchange, and aqueous kinetics
4. Determine Ca, Sr, and Li isotopic fractionation factors and rates under geothermal temperatures using batch & flow-through experiments
5. Evaluate models using experimental data on reservoir rocks (Desert Peak, Long Valley)
6. Evaluate parameters and models on field sites (Newberry EGS, Dixie Valley, and Desert Peak)

Toughreact simulation of $^{87}Sr/^{86}Sr$ evolution in water and precipitated calcite during tuff alteration at 240°C



Accomplishments, Results and Progress

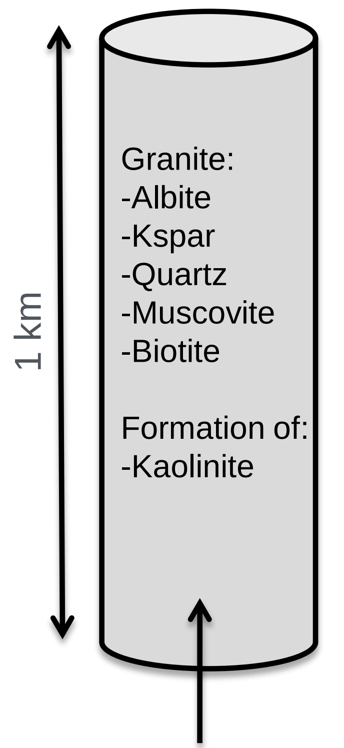
Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
1.1 Develop thermodynamic and kinetic data	Sr & Rb in Desert Peak rhyolite, Li isotopes in Newberry EGS	3/2013 - ongoing
1.2 Implement models for kinetic isotopic fractionation into TOUGHREACT	Published paper on kinetic fractionation: Wanner & Sonnenthal, Chem. Geol. 2013	11/2012 – ongoing
1.3 Carry out batch and plug-flow calcite precipitation experiments	Experimental set-up complete. Delayed due to laboratory being moved to location	Delayed till late Spring 2013
1.5 Simulate calcite precipitation experiments and determine fractionation factors	Simulated Desert Peak rhyolite dissolution-reaction experiments while new lab is being setup	3/2013
1.6 Develop 2-D reaction-transport model for the Long Valley Caldera	Based on review comments, and interest, a detailed 2-D model of Desert Peak was developed	Model 3/2013, Simulations ongoing.

Simulation of Li isotope fractionation using TOUGHREACT

1D Flow through column

Li isotope fractionation

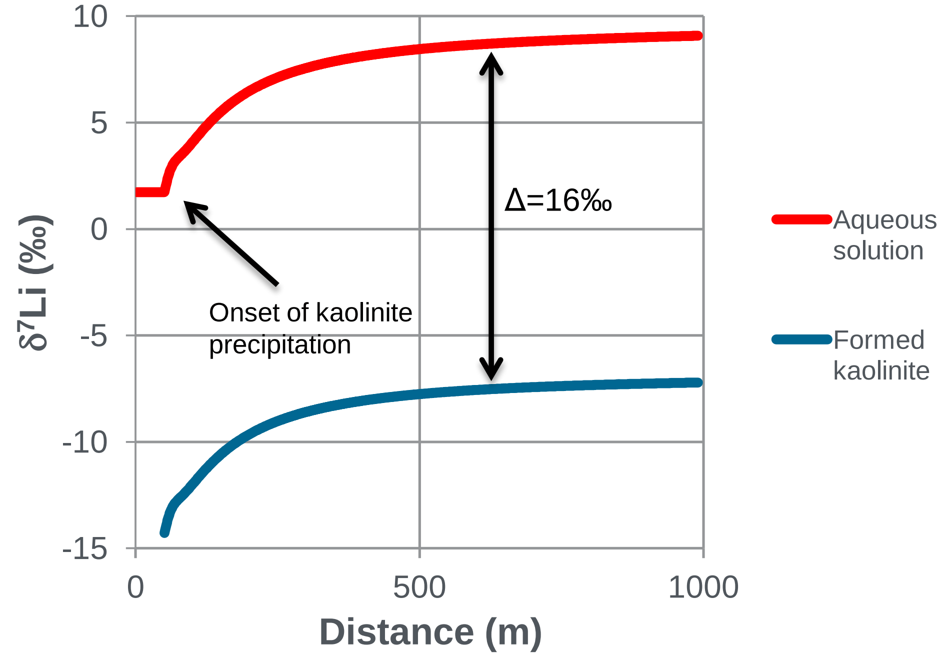
- Albite=Li source (δ^7Li=0‰)
- Congruent dissolution of ^{6}Li and ^{7}Li (no fractionation)
- Li incorporation in forming kaolinite
- $\Delta^7Li_{aq.solution-kaolinite}$=16‰



Pure water, equilibrated with atmos. P_{CO2}, v=1 m/d

Wanner et al., in prep

Steady state δ^7Li profiles

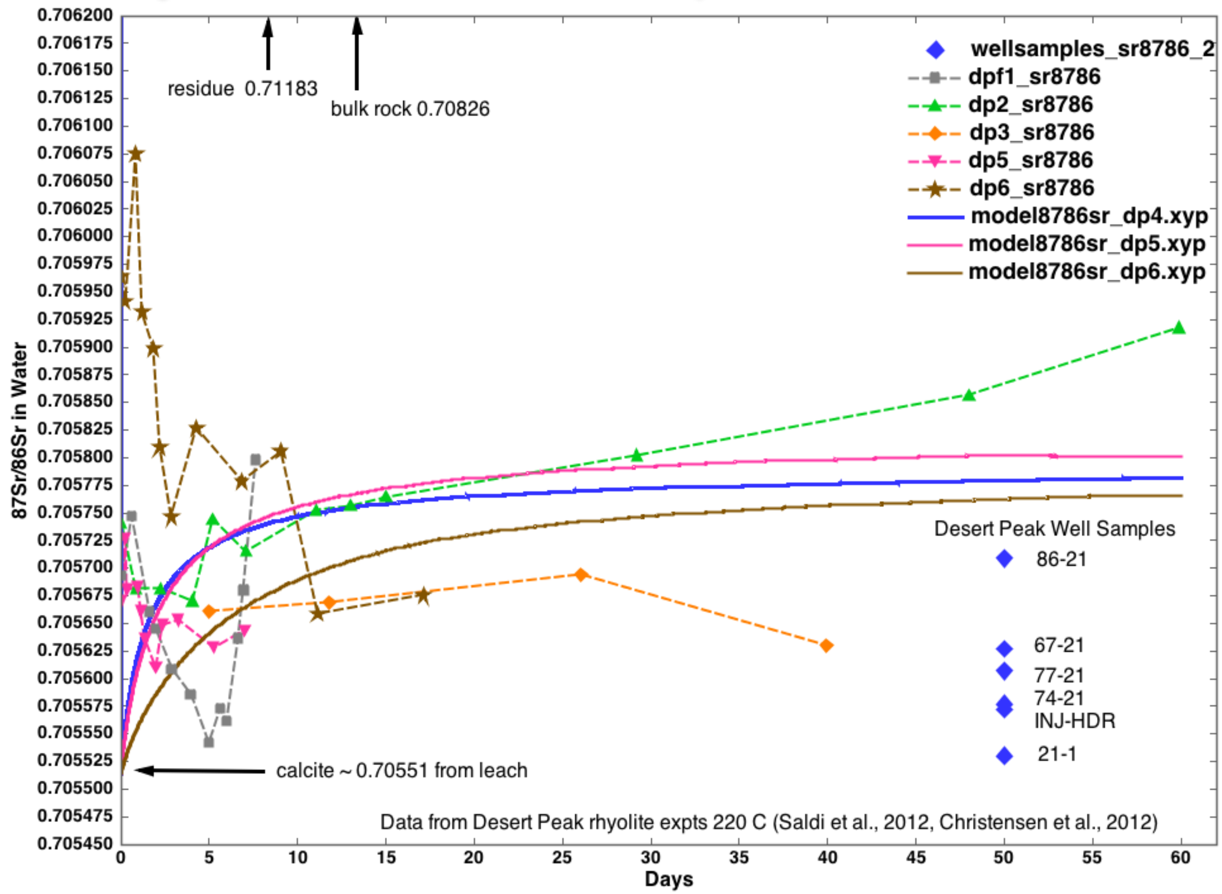


- **δ^7Li values: proxy for water-rock interaction processes**
- **Alteration of newly generated fracture surfaces in EGS systems produce a significant shift of fluid δ^7Li values to more positive values**

Reactive Transport Model of Sr and Rb Isotopes For Desert Peak

- Developed thermodynamic-kinetic reactive transport model for evolution of 87Sr/86Sr for water-rock reaction in complex hydrothermal mineral assemblages
- Simulated 220C batch and flow-through experiments on Desert Peak altered rhyolitic ash flow tuff
- Simulations captured the overall trend in the isotopic ratios that is far lower than the bulk rock ratio
- Reaction of freshly crushed tuff shows somewhat higher values than well waters, which might be expected after EGS stimulation
- Method could aid in evaluating shallow fluids for exploration

Rhyolitic Tuff 220C Reaction Experiments and Simulations



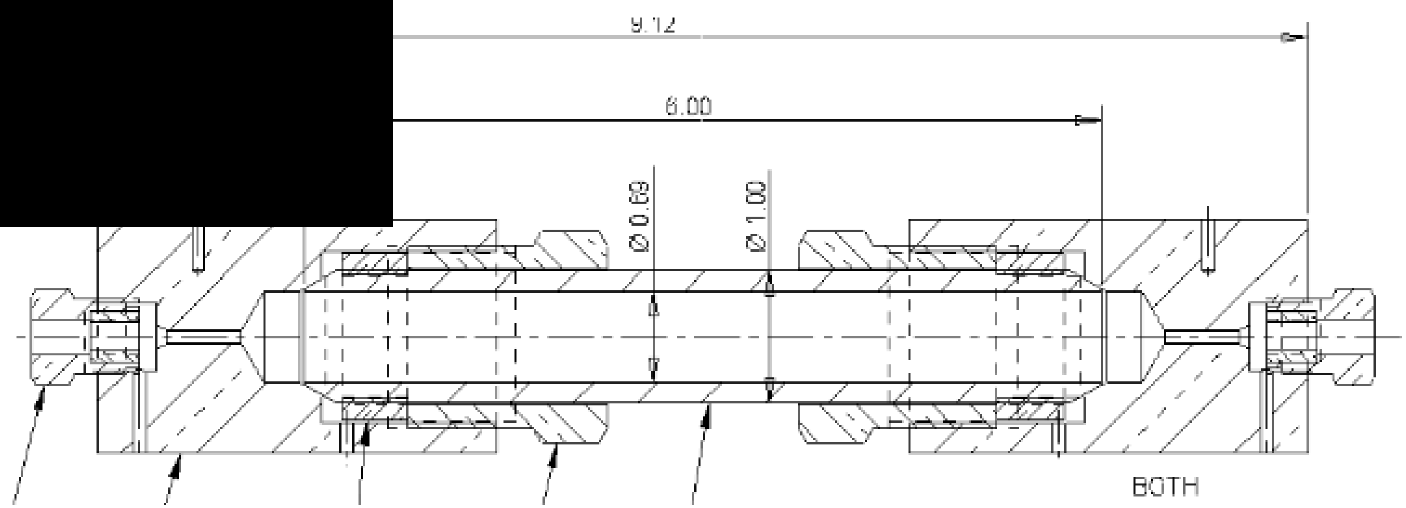
Batch and Flow-Through Experimental Setups

High-T Batch Setup

[redacted]

- Batch cell to determine Ca and Sr isotopic fractionation as a function of temperature
- Flow-through cell to determine Ca, Sr and Li isotopic fractionation as a function of reactive surface area, rate

Flow-Through Titanium Vessel



Reactive Transport Model Developments/Accomplishments

- TOUGHREACT V2 Release June 2012 (http://esd.lbl.gov/research/projects/tough/software/toughreact.html)
- Development of high-performance TOUGHREACT V2.2G Hybrid MPI-OpenMP with improvements for geothermal system modeling
- 2012 Director's Award For Exceptional Tech Transfer Achievement

Future Directions

Milestone or Go/No-Go	Status & Expected Completion Date
1.3 Ca isotopic fractionation to 200 ºC batch and plug flow experiments Go-No go: If either batch or flow-through experiments fail, work will shift to those that succeed. If all experiments fail, will shift work to field demonstration projects	Experimental set-up complete. Delayed till Spring 2013 due to laboratory being moved Expected completion of batch Ca isotopic expts: 9/2013.
1.6 Simulate isotopic effects at Desert Peak	Model setup, simulations underway. Expected completion of Sr isotope simulations: 7/2013
1.8 Simulation of Newberry isotopic effects. Go-No go: If water samples are not collected from 55-29, will simulate isotopic effects expected for different potential well locations for spring waters	Changed from Long Valley, for the opportunity to collect samples for Ca, Sr, and Li isotopes. Expected Completion: 9/2013 for Sr, 12/2013 for Li, and 3/2013 for Ca isotopes.

Summary Slide

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Despite widespread use of isotopic systems in evaluation of geothermal systems, few are incorporated into reaction-transport (RT) models, and none with a full consideration of thermodynamic-kinetic effects, mineral solid solutions, gases, and in a full reservoir model. Data and models for Ca, Sr, and Li isotopes developed from this project will enable a new class of RT models to evaluate fracture surface areas, reservoir temperatures, water rock interaction, fracture sealing mechanisms and extent.

A full reactive-transport model (using TOUGHREACT)of mineral alteration and Li isotopic evolution in fluids and individual minerals has been developed and simulations demonstrate very strong shifts during alteration of feldspars to kaolinite (possibly to be seen after stimulation)

A model for Sr and Rb isotopic evolution during water-rock interaction has been developed and applied to alteration of Desert Peak rhyolitic tuff experiments at 220C. Simulations capture the overall trends of the experiments to much lower isotopic ratios than that of the bulk rock, which is also observed in waters collected from geothermal wells, and which cannot be explained by simple bulk reactivity models.

New batch and flow-through experiments on secondary minerals and geothermal samples will greatly expand the basic data needed to apply these new models to geothermal system development and exploration

Detailed THC reservoir models incorporating mineral-water-gas reactions and isotopes for Newberry EGS and Desert Peak will add quantitative constraints to evaluating fracture-surface areas, permeability changes during stimulation/production, and evaluating fluid migration and mixing for hydrothermal exploration, which will be tested and refined against field data.

Project Management

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Timeline:

Timeline:	Planned Start Date	Planned End Date	Actual Start Date	Actual /Est. End Date		
	1/1/2012	9/30/2014	3/1/2012	9/30/2014		

Budget:

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
$K	$512	$0	$120	$50	$128	$462

- Funds are leveraged with other DOE-funded projects – Newberry EGS, multicomponent geothermometry, Penn State Univ.
- Close coordination with AltaRock on Newberry EGS and Dixie Valley
- Starting some interactions with Geothermix on Desert Peak
- Some experiments delayed due to labs being moved.