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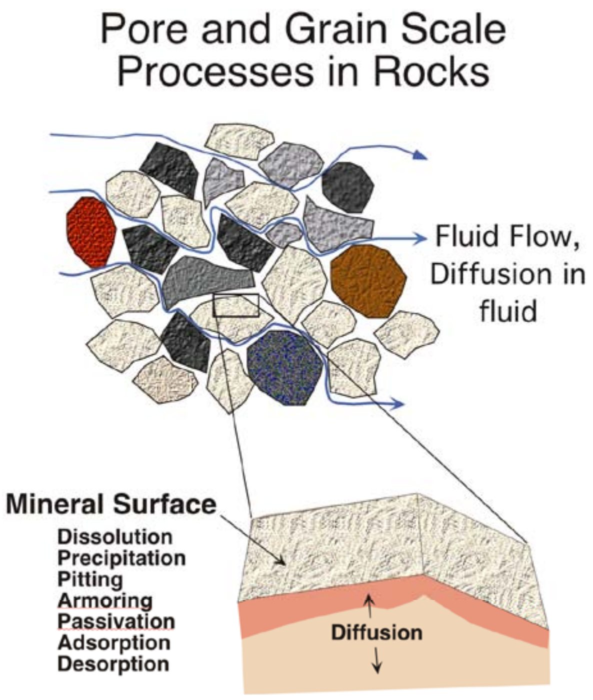

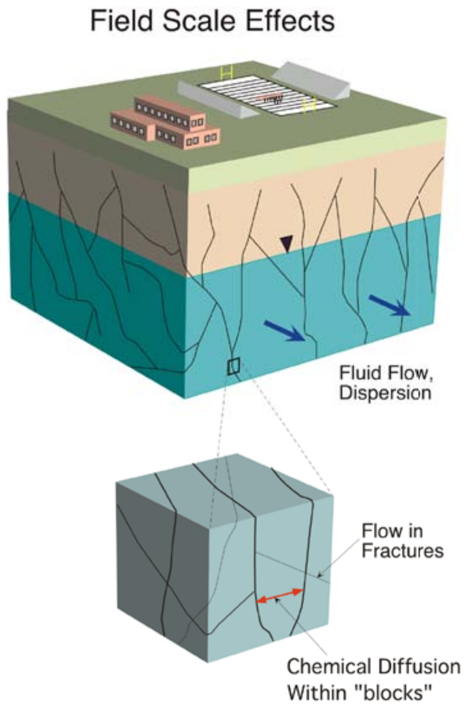

Integrated Approach to Use Natural Chemical and Isotopic Tracers to Estimate Fracture Spacing and Surface Area in EGS Systems

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Track Name

Project Overview

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- Project overview:
  - Timeline
    - Project started in FY2010 and will end on Sept. 30, 2011
    - Percent complete: 30%
  - Budget
    - Total project funding received: $941,000
  - Barriers
    - Interwell Connectivity
      - Barrier J: Tracers
    - Reservoir Sustainability
      - Barrier M: Long-term sustainability
  - Partners: N/A
  - Acknowledgement: Ormat Technologies, Inc. (core samples)

Relevance/Impact of Research

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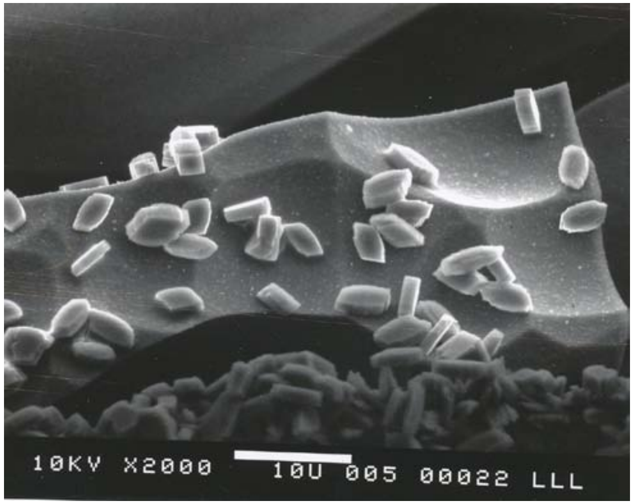
Objective of the project

Develop an innovative approach to estimate fracture surface area and spacing through interpretation of signals of natural chemical and isotopic tracers.



Relevance and Impact

Project results will be crucial for

- Evaluating the effectiveness of well stimulation for creating new fracture surface areas
- Characterizing the heat extraction potential and sustainability of an EGS reservoir

Scientific/Technical Approach

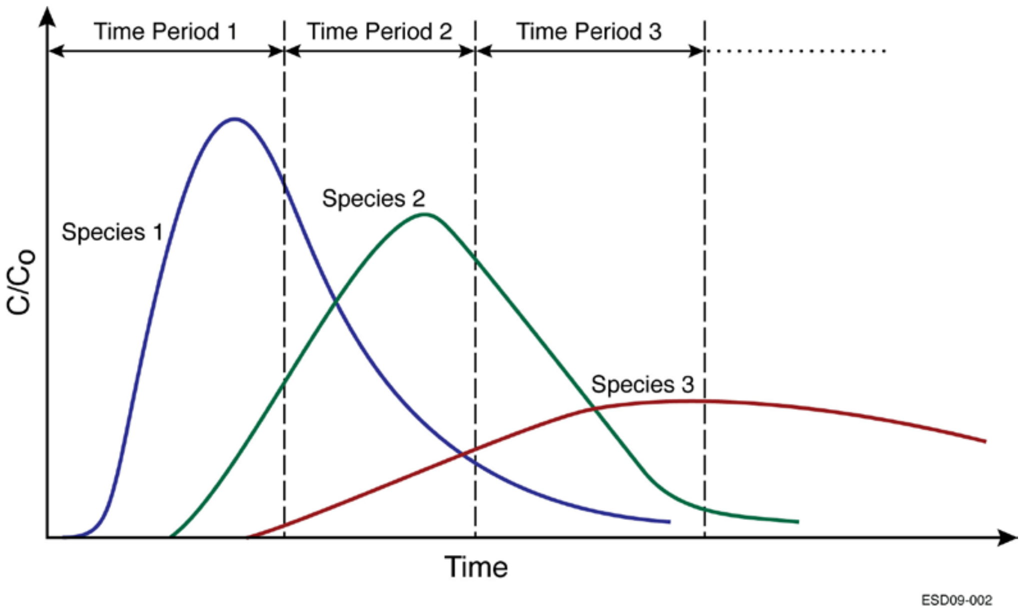
- **Task 1: Reactivity Measurements**
  - Laboratory experiments to determine reactivity of different solutes tracked by chemical and isotopic changes in fluid equilibrating with bulk rocks as a function of SA, T, x_i and time
  - Quantify solute/isotope reactivities for incorporation into numerical models
- **Task 2: Development of Tracer-Interpretation Technique**
  - Develop coupled inverse and reactive transport modeling technique to estimate surface area of fluid-rock exchange using bulk reactivities determined in Task 1.

TASK 1: Reactivity

- Post reservoir stimulation fluids and fresh fracture surfaces will be out of chemical equilibrium

- Subsequent dissolution and precipitation of minerals will generate solute dependent chemical and isotopic “pulses” that can be monitored at production/observation wells.

- “Pulse” shape is a measure of solute “reactivity”, the degree of disequilibrium and the impact of fresh surface area on fluid-rock exchange.

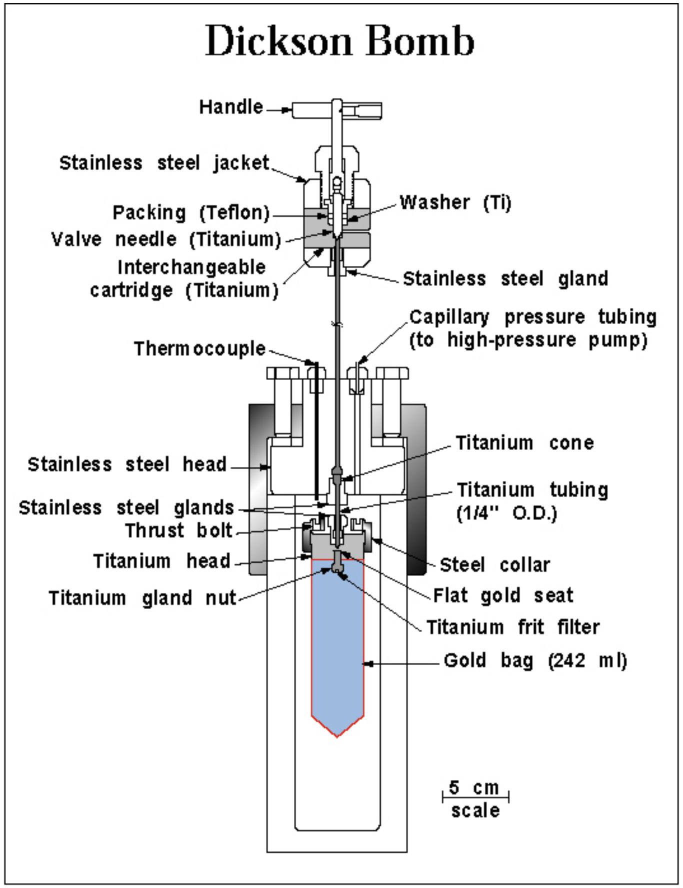


Conduct series of lab experiments on EGS reservoir rocks designed to quantify the reactivity of a suite of natural tracers

(e.g. Ca, O, H, Sr, PB, U, Th, noble gases)

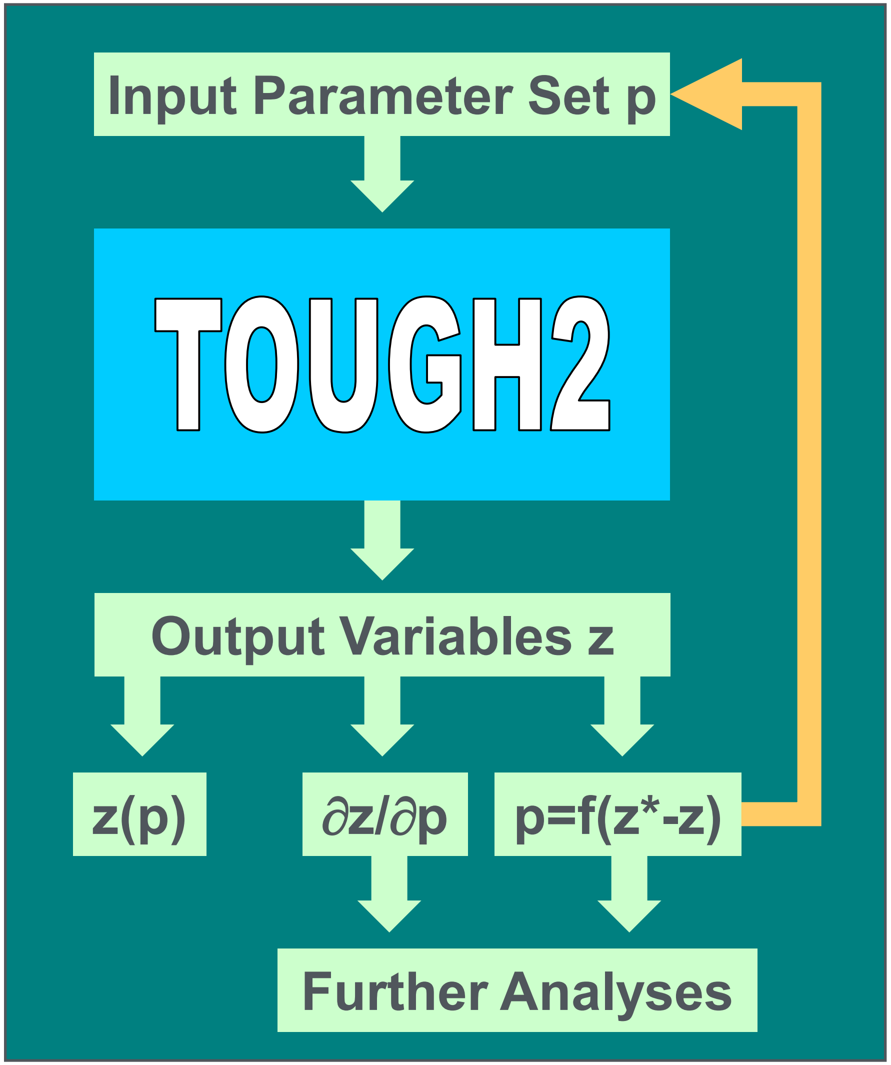
TASK 1: Reactivity

- Task 1.1: Reactivity and Surface Area:
  - Range of size fractions with calibrated surface areas will be reacted with water under same relevant P,T condition.
  - Samples will be w/drawn periodically for analysis
  - Each experiment will run long enough to for system to attain equilibrium (defined by an asymptotic decline in rate of chemical/isotopic change).
- Task 1.2: Reactivity and Temperature:
  - Surface area experiments will be repeated under different equilibration temperatures (100-250 ^{o}C)
- Task 1.3: Reactivity and Fluid Chemistry:
  - Surface area experiments will be repeated using different initial fluid compositions ranging from distilled water to the expected equilibrium compositions



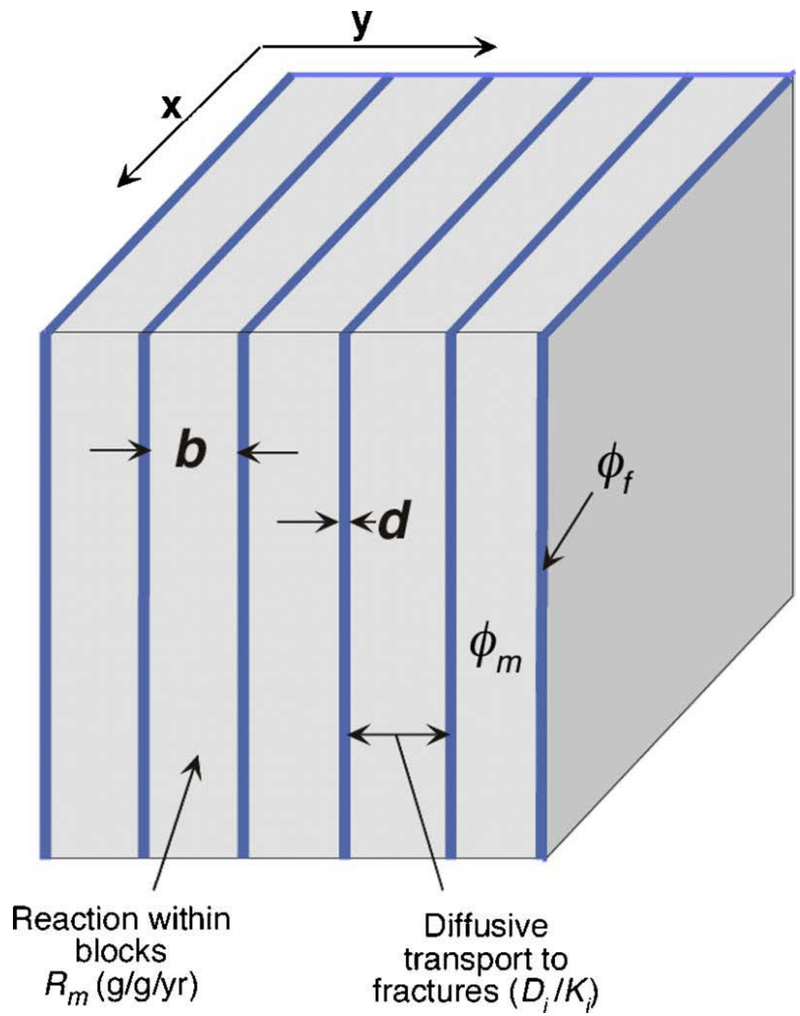
TASK 2: Modeling

- iTOUGH2 code (developed at LBNL) has been widely used for inverse modeling and uncertainty analysis.
- Signals for different chemical and isotopic tracers will be simultaneously inversed to estimate fracture rock properties between injection and production wells.
- Hydraulic properties (such as fracture aperture) will also be used to constrain property estimation.



Scientific/Technical Approach

- Reactive transport modeling is based on the concept of bulk reactivity and will be incorporated into iTOUGH2 for parameter estimation.
- For an approximately constant reactivity, analytical solutions will be developed for tracer transport. TOUGHREACT code will be used to model general cases.
- Modeling team has expertise in fracture hydrology, inverse modeling, geochemistry and reactive transport modeling.



DePaolo (2006)

Scientific/Technical Approach

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- **Project milestones and go/no-go decisions**:
  - Tracer Transport Simulation (10/30/2010)
  - Quantification of Reactivity and Surface Area (3/30/2011)
  - PRIMARY GO/NO-GO: Success of the reactivity and surface area experiments. Generating reactivity curves for different solutes and surface areas: 18 months = 3/30/2011
  - iTOUGH2 Module Development for Interpretation of tracer transport with analytical solutions (7/30/2011)
  - Quantification of Reactivity and Temperature for single grain size fraction (9/30/2011)

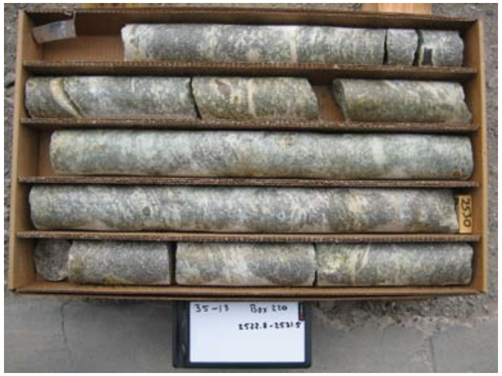
Scientific/Technical Approach

- **Technical feasibility of the project approach**:
  - The approach is based on a proven conceptual model
  - Parameter estimation uses data from multiple natural tracers, each with their own empirical reactivity
  - Hydraulic measurements (such as fracture aperture) are incorporated into the analysis
  - The approach builds on existing and widely used software codes

Accomplishments, Expected Outcomes and Progress

TASK 1: Reactivity Measurements

- Relevant core samples have been identified and acquired from Desert Peak Well 35-13 (Ormat Technologies, Inc.)
  - Similarity to lithologies in planned Well 27-15 stimulation zone
  - Siliceous rhyolite
  - Devitrified rhyolite
  - Illitic/siliceous mudstone
  - Meta-volcanics
- Suitable size fractions based on estimated surface area have been selected
  - Mesh 230-200: ~320 cm^2/gm
  - Mesh 80-100: ~135 cm^2/gm
  - Mesh 25-30: 34 cm^2/gm
- Sample preparation is underway



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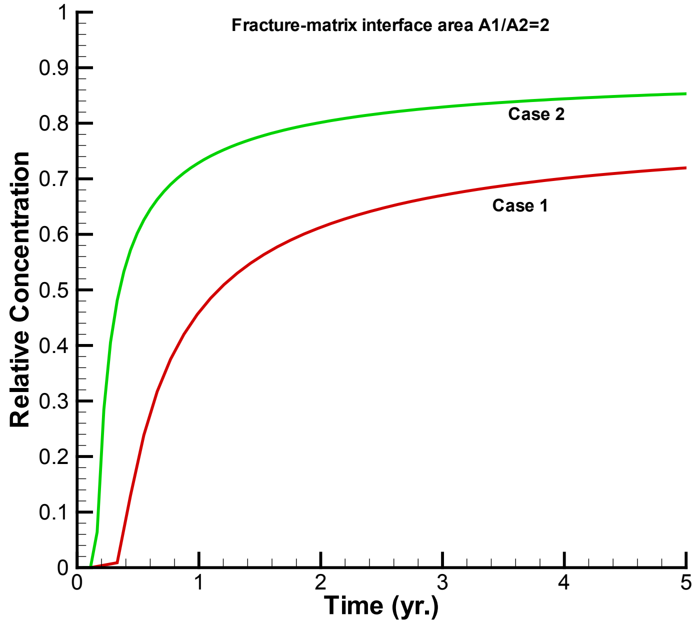
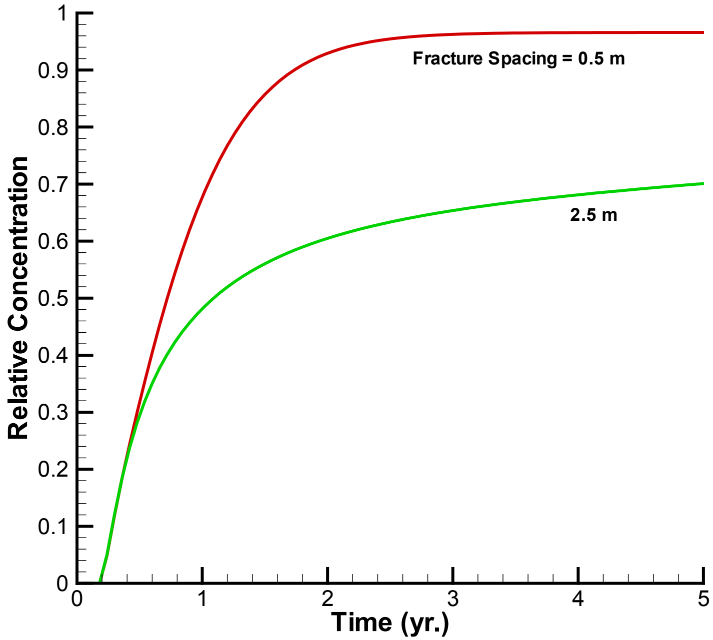
TASK 2: Modeling

- Several new analytical solutions to transient isotopic tracer transport in fracture systems (containing single or multiple fractures) have been developed for a constant bulk reactivity.
- Preliminary results from analytical solutions indicate that tracer signals are sensitive to fracture rock properties for typical values of flow and transport parameters.
- The numerical code TOUGHREACT is being evaluated for modeling tracer transport based on the concept of bulk reactivity.





Project Management/Coordination

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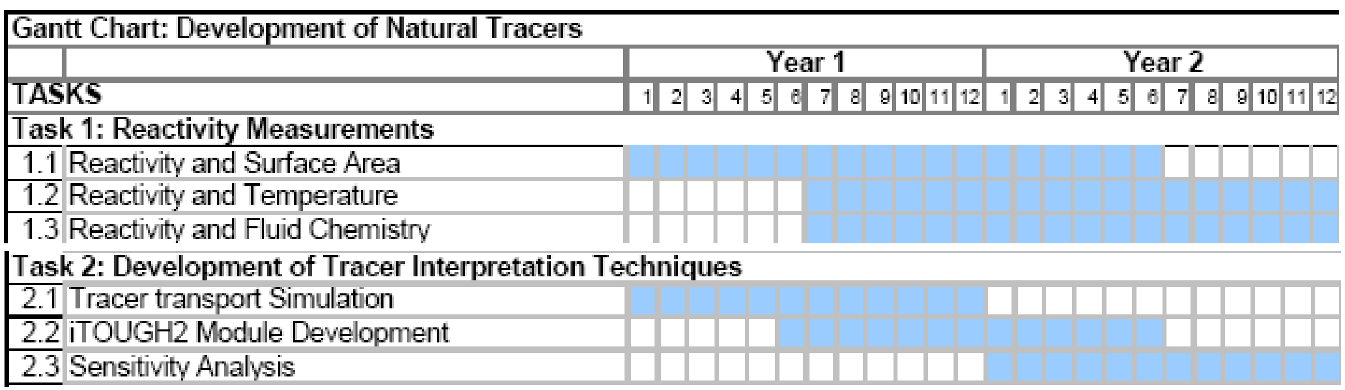
- To quantify mineralogy of the rock and the chemical composition of the fluid for incorporation into the numerical models, LBNL will conduct a series of laboratory experiments using reservoir rocks from EGS systems.
- Using iTOUGH2, surface areas will be varied to match the laboratory chemical and isotopic reactivity tests.
- The project is broken into 2 main tasks:
  - Reactivity measurements (Kennedy, Knauss)
  - Development of the tracer-interpretation technique (Liu)



Future Directions

- Current development of numerical solutions is based on an assumption of relative small bulk reactivity (DePaolo, 2006). Improved analytical results will be developed to remove this limitation.

- An iTOUGH2 module will be developed for estimating fracture rock properties from chemical and isotopic signals. Sensitivity studies will be performed to identify tracers and their combinations that are sensitive to rock properties changes.

- Deployment of the technique at an EGS Field Demonstration Project
  - Test scaling from laboratory to real world environs.

Summary

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- Fracture properties (surface area and spacing) are crucial for determining the capacity and longevity of EGS systems. At present, there are no proven techniques for quantifying these properties.
- This project will evaluate an innovative approach to estimate fracture properties through interpretation of signals of natural chemical and isotopic tracers.
- The project consists of two main tasks: reactivity measurements and development of inverse modeling approach for tracer interpretation.
- Considerable progress has been made with this project. The preliminary results support the usefulness of the project approach.
- Ultimately feasibility of technique will require field testing.