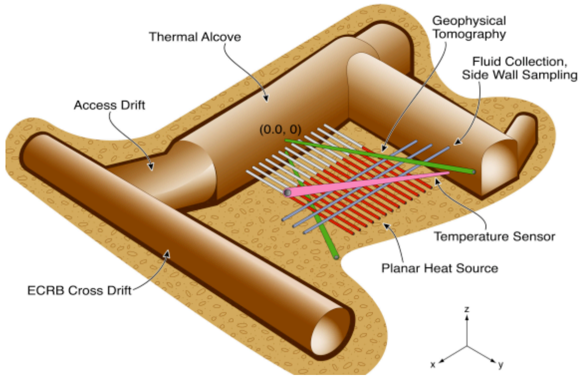
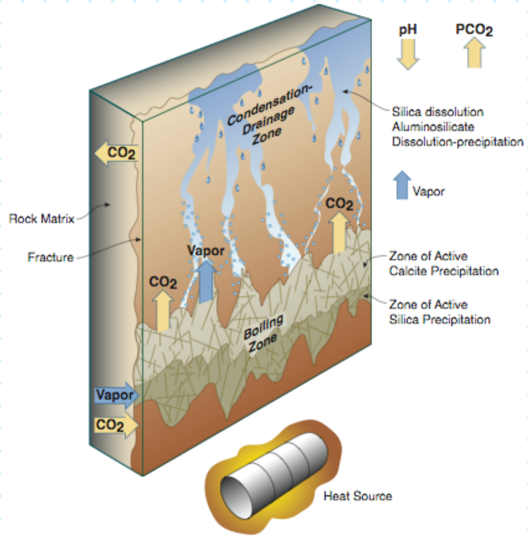
NSF S4 Proposal: Collaborative Research: Coupled Thermal-Hydrological-Mechanical-Chemical-Biological Experimental Facility at DUSEL Homestake

Eric Sonnenthal (UCB/LBNL), Derek Elsworth (PSU), Barry Freifeld (LBNL),Robert Lowell (VA Tech), Kate Maher (Stanford), Brian Mailloux (Barnard), Nuri Uzunlar (SDSMT)





THMCB Experiment Team

Principal Investigators

Eric Sonnenthal (UCB/LBNL) - Coupled THMC processes and modeling, geochemistry

Derek Elsworth (Penn State Univ.) - Thermo-hydro-mechanical-chemical process models and experiments, fracture mechanics

Barry Freifeld (LBNL) - Hydrology, experimental design, in-situ measurements for temperature, pressure, permeability, mineralogy, chemistry, fluid collection, and remote data acquisition

Bob Lowell (Virginia Tech) – Hydrothermal systems and modeling, multiphase flow, permeability evolution in the oceanic crust

Kate Maher (Stanford University) - Radiogenic isotope measurements to infer effective reaction rates in geologic systems

Brian Mailloux (Barnard College) - Bacterial transport, ^{13}C and ^{14}C signature of DNA, arsenic geochemistry

Nuri Uzunlar (SDSM&T) Block siting, Homestake alteration history, relation to hydrothermal system

Collaborators + others

Eoin Brodie (LBNL) - Microbiological population dynamics, sensors for biological responses

Mark Conrad (LBNL) – Stable isotope chemistry

Alison Keimowitz (Columbia Univ.) - Trace metal geochemistry

Rohit Salve (LBNL) - Hydrological monitoring, liason with LBNL Engineering Group

Nicolas Spycher (LBNL) - Aqueous geochemistry, metal speciation and reactive transport, thermodynamics

Joe Wang (LBNL) - Multiphase flow, field site evaluation, experimental design and measurements, relation to site-scale hydrological processes

Key Science Objectives

- Fundamental: How does rock, fluids, and microbes evolve in the Earth's crust under elevated temperatures, stress, and flow (water, gases)?
- What are the effective mineral-water reaction rates in fractured rock under stress and over time? (govern the evolution of reservoirs, faults, alteration, ore deposits)
- Biological Gradient Test (How microbe population changes over temperature gradients imposed over over long time periods)
- Which microbes repopulate rocks during cool-down and what is the importance of different transport mechanisms
- The overall objective of this THMCB experiment will be:
  - Allow scientists to perturb rock at depth under *in-situ* conditions
  - Test and develop new models for the coupling between fluid flow, heat transport, chemical transport and reaction, mechanical deformation, and biological processes
  - Test *in-situ* measurement techniques under "extreme" conditions
- Quantitative understanding of these processes is essential for long-term prediction of CO_2 sequestration, nuclear waste isolation, water resources, resource recovery

Scientific Merit

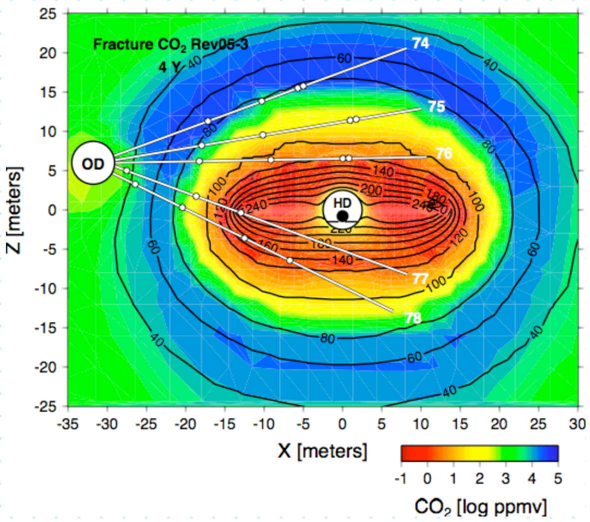
- A long term coupled process THMCB experiment can be used to test many problems of scientific interest and societal benefit
- Ideal opportunity for student projects and theses of various durations
- Will involve testing of new geochemical and geophysical monitoring methodologies, computer modeling tools, and data acquisition
- Basic Science:
  - **Reactive transport processes in fractured heated rock under stress**
  - **Microbiological activity at elevated temperatures**
  - **Development/validation of next generation THMCB numerical models**
- Applications:
  - **Evolution of hydrothermal flow in fractured anisotropic rocks**
  - **CO_2 transport and sequestration**
  - **Mobilization (ore mineral dissolution) of metals and transport**
  - **Permeability evolution in geothermal reservoirs**
  - **Efficiency of heat recovery in enhanced geothermal systems**
  - **Bioremediation of metals**

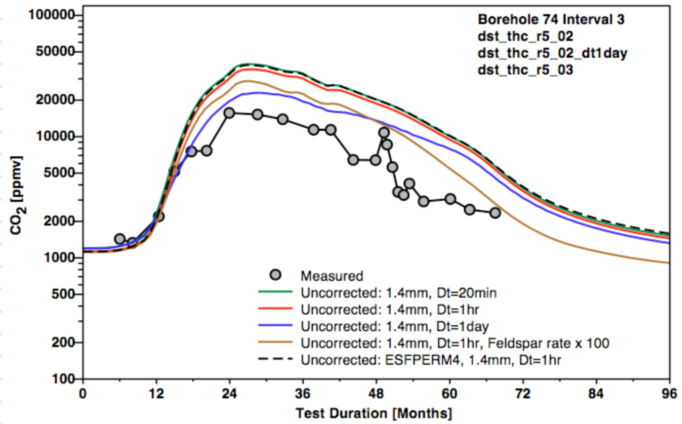
Broader Impacts

- Barnard College:
  - Undergrad
    uate senior thesis each year
  - Harlem Children Society under-represented high school student (http://www.harlemchildrensociety.org/)
  - Technician that is part
    of the Bridge Program at Columbia College
- UC Berkeley/LBNL, Penn State, Stanford
  - PhD students

Prior *In-Situ* Heater Experiments

Test	Location	Depth	Rock type	Buffer	T °C	Processes
Stripa[1]	Stripa, Sweden	330 m	Quartz monzonite	None	~90	THM
Kamaishi Mine Expt.[2]	Kamaishi, Japan	260 m	Granodiorite	Bentonite	~100	THM
Single Heater Test[3]	Yucca Mtn., NV	~250 m	Rhyolitic tuff	None	~300	THMC
Drift-Scale Heater Test[4]	Yucca Mtn., NV	~250 m	Rhyolitic tuff	Air/concrete	~200	THMC
Temperature Buffer Test[5]	Äspö, Sweden	420 m	Granodiorite	Bentonite	~170	THMCB
FEBEX[6]	Grimsel, Switzerland	~450 m	Granite/ lamprophyre	Bentonite	~100	THMC

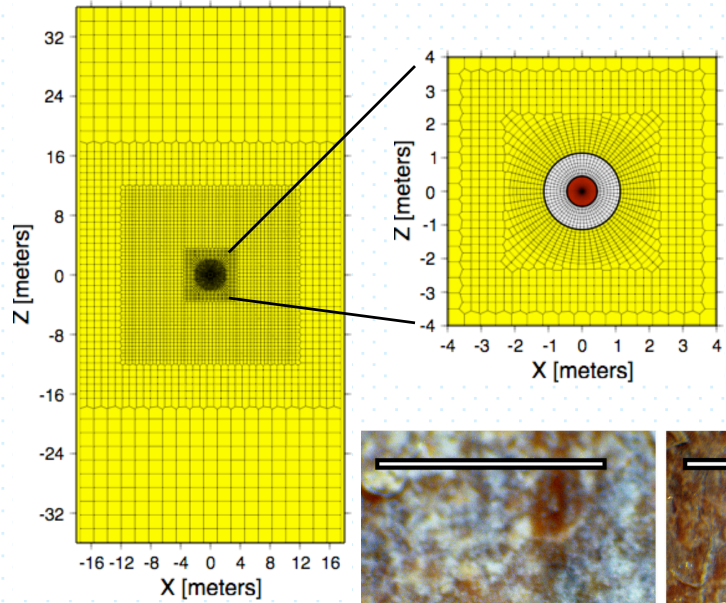


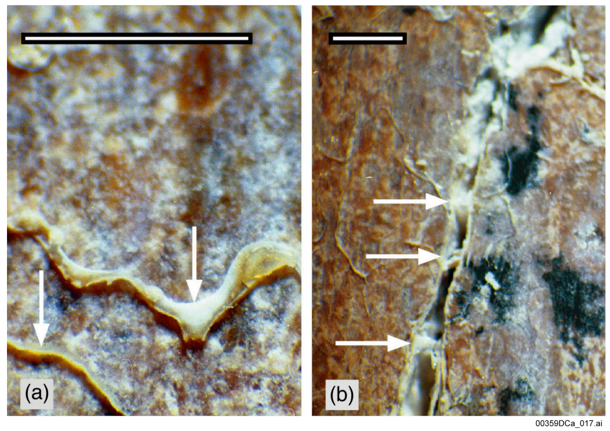


Coupled Mineral-Water-Gas Reactions, Transport, Heat, Mechanics, Biology

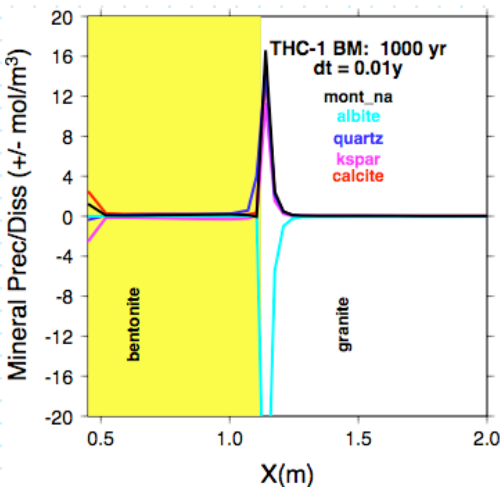
Processes

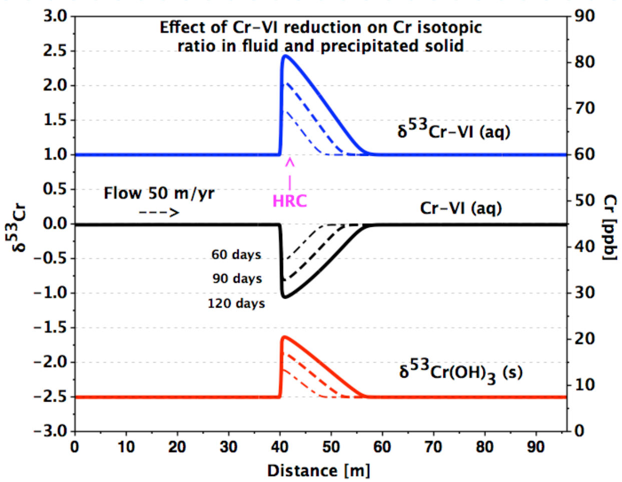
- Multiphase flow
- Thermal deformation
- Advection- and diffusion-limited reactions between the rock matrix and fractures
- Mineral dissolution, nucleation, growth
- Fracture sealing, slippage under shear stress, strengthening
- Effects on local microbiological populations



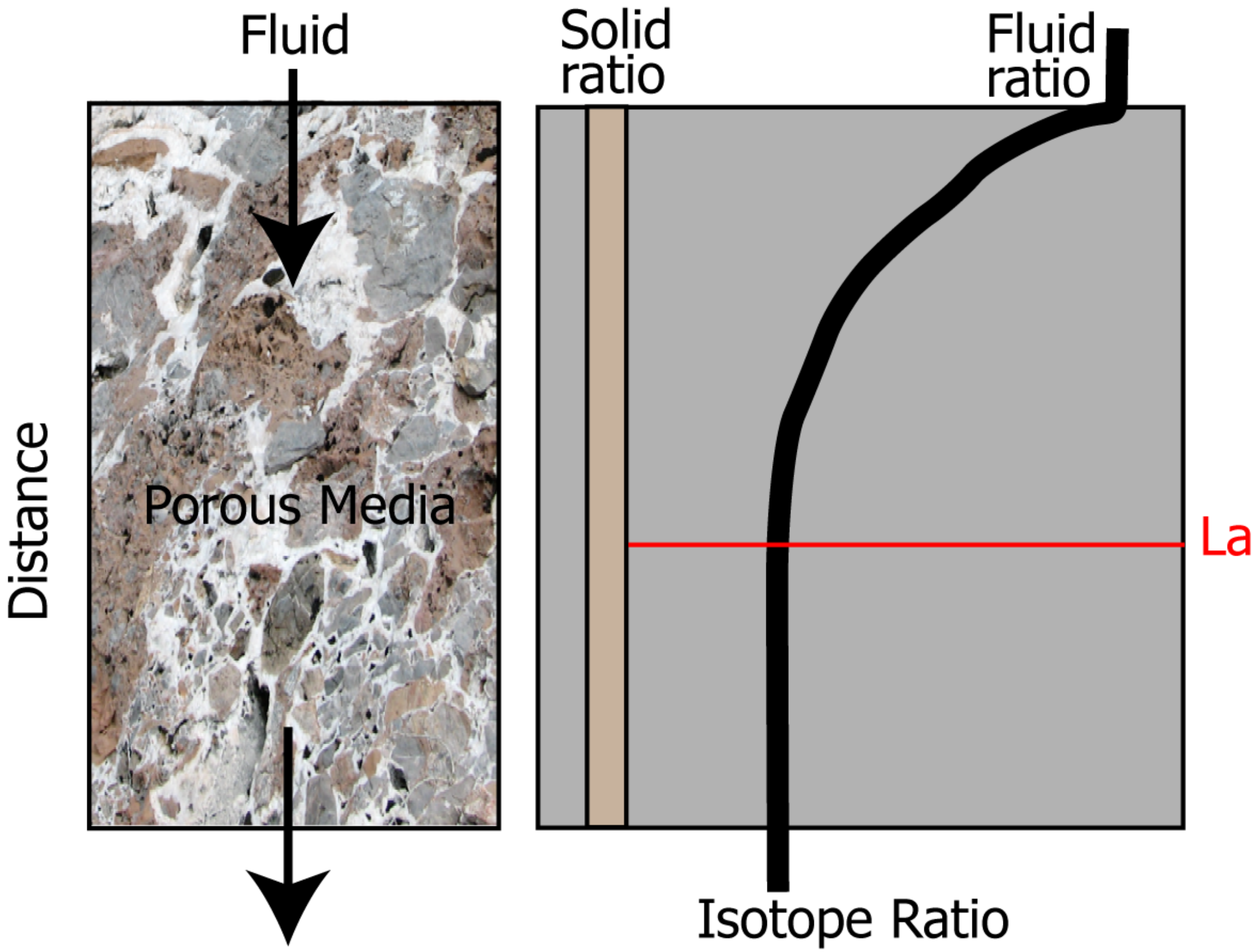


Experimental Results:
Amorphous Silica in a Boiling Fracture
(Kneafsey et at., 2001, HLRWMC;
Dobson et al., 2003, JCH, Vol. 62-63)





Isotopic measurements can be used to quantify flow and reaction rates in natural systems

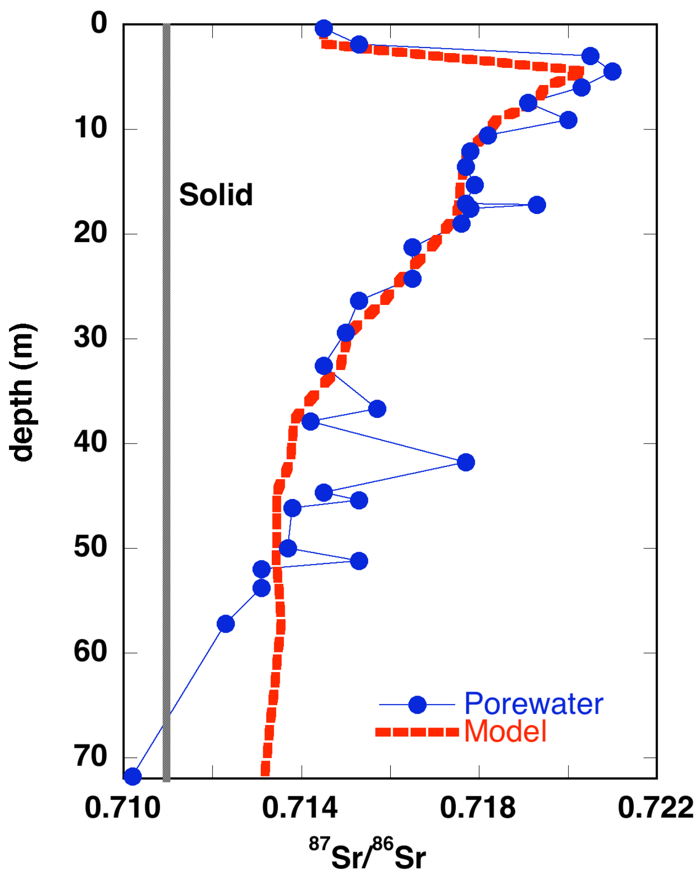


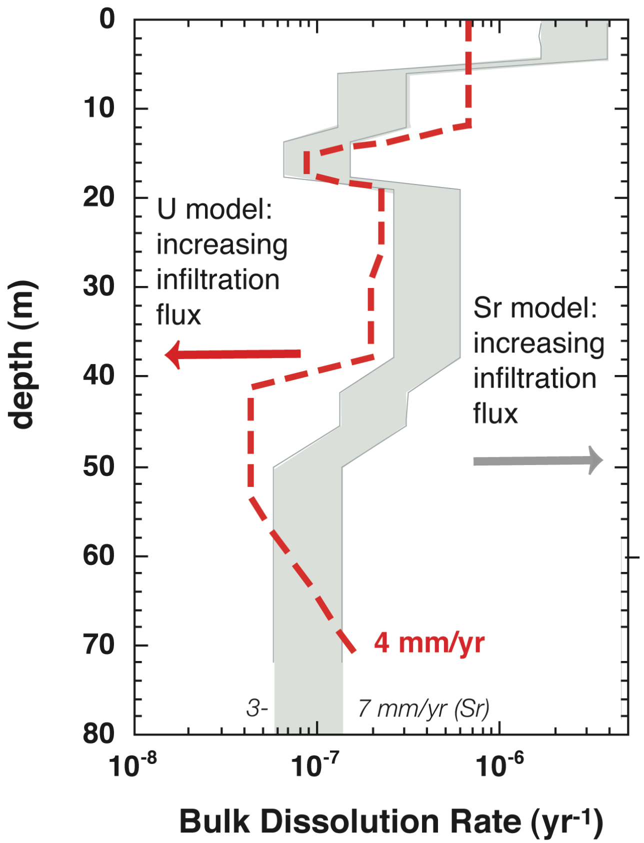
Gradient and length of isotope profile depend on the ratio:

reaction rate/ flow rate

From Kate Maher, Stanford, Univ.

Sr and U isotopes used to quantify flow and reaction rates



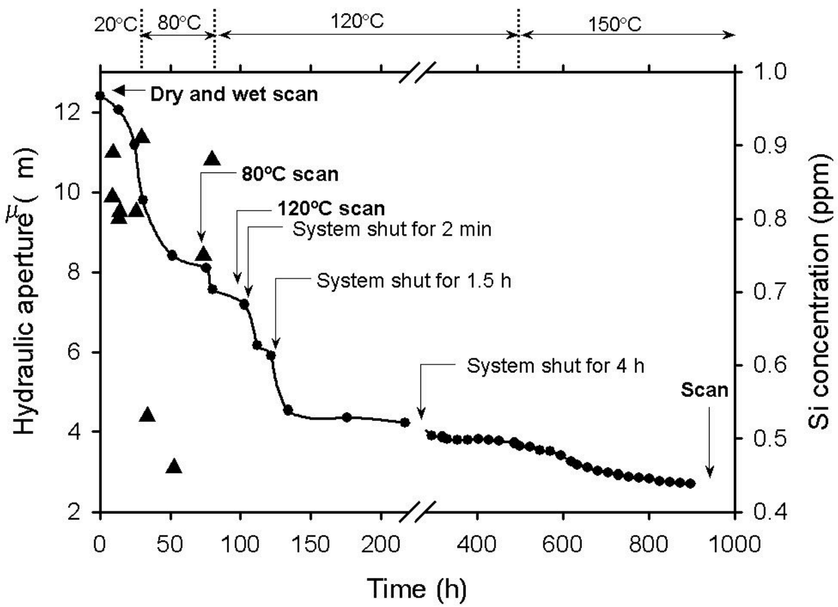


(Maher et al, 2003, 2006)

Coupling of different isotopes can uniquely constrain both transport and reaction rates.

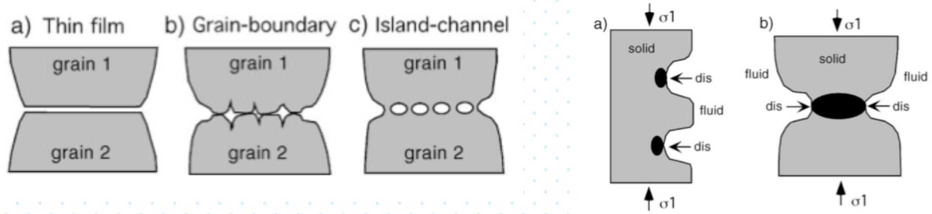
Coupled Mechanical-Chemical Deformation in Fractures

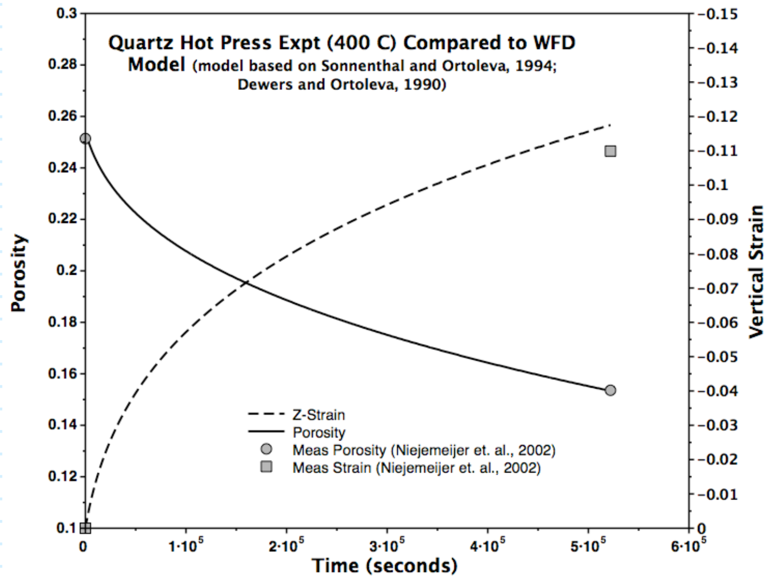
Premise: Long-term rock behavior is governed by chemical-mechanical interactions (e.g., pressure solution, mineral alteration, dissolution/precipitation creep, etc.)



Polak et al., 2003

Possible Grain Contact Evolution (Koehn et al., 2006)

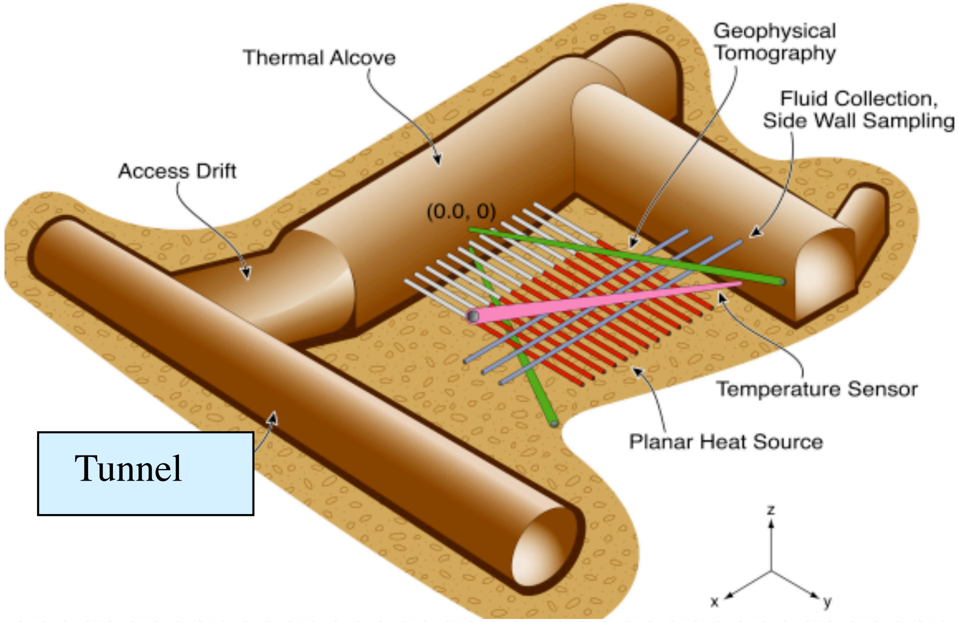




THMCB Experiment Conceptual Design

Attributes

- Block Size: ~ 50x40x40m +
- Planar heat source (vertical plane would set up rapid upward convective flow)
- Scalable: Nominally heaters are 10 m x 10 m in area
- Heated rock dimensions ~ 10^4 m^3
- Temperature Max (~ 150-200C)
- Sample collection and observation boreholes (geochemistry, thermal, mechanics, biological)
- Geophysical/thermal measurements

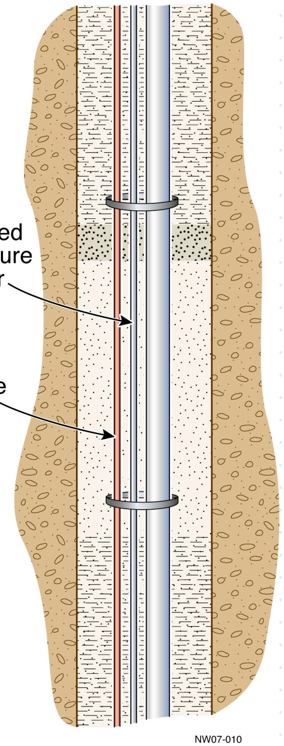


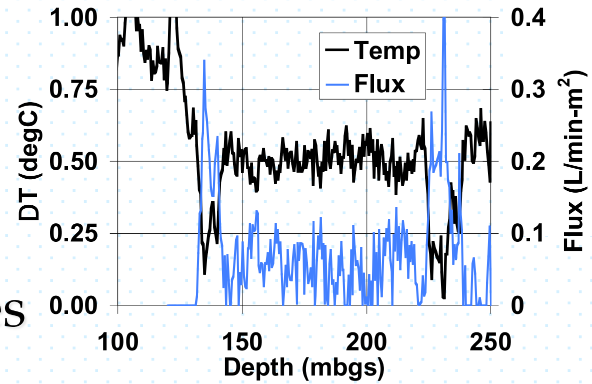
Based on Proposed Thermal Test

In-Situ Measurements

The Distributed Thermal Perturbation Sensor

- DTPS consists of a borehole length electrical resistance heater and fiber-optic DTS
- Apply constant heating along wellbore
- Temperature transient is recorded
- Estimate
  - formation thermal properties
  - fluid advection
  - saturation





The fluid flux distribution along the length of 24PB is shown. The DTPS high flux zones corroborate the FEC logging results

From Barry Freifeld, LBNL

Infrastructure Requirements and Impacts

- Size: Nominally, a 50x40x40 m block relatively isolated from other labs
- Power: On the order of 100 kW for heaters, plus other equipment
- Timescale: Heating for ~10+ years
- Test block could be used for 20+ years (post-test analyses and re-use of the test block for related experiments
- Potential Impacts:
  - Power usage
  - Increased humidity and temperature would require area to be insulated/sealed
  - Radon increases (?)
  - Water mobilization in the rock, and potentially some seepage locally
  - Increased fracturing by heat and fluid pressure (microseismicity)

S4 Approach

1. Selection of candidate rock mass and tunnel complexes to perform experiments. (2009-2010)
2. Preliminary design of experiments, which would be refined through the following steps of characterization and pre-test modeling (2009 -->))
3. Rock mass characterization (2009 -->)
4. Laboratory experiments on physical, hydrological, and thermal properties. Experiments on fracture closure/pressure solution (2009 -->)
5. Refine/finalize experimental design (2010-2011)

- **MAJOR SYNERGIES**
  - Transparent Earth (Glaser and others)
  - Fault Rupture (Germanovitch and others)