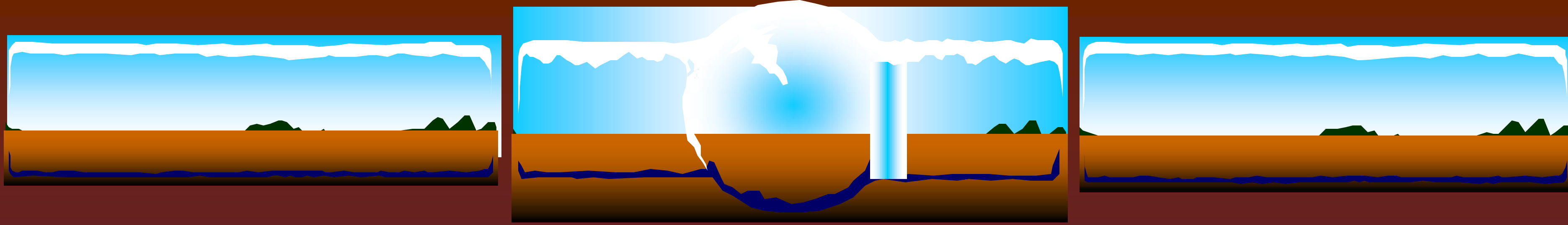

DOE’s EGS Program Review

❖ Geochemical Study of the Effects of Fluid Injection at EGS Sites

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Marriott Hotel
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Project Objective

- Probe the thermal and chemical evolution of natural and induced fractures using chemical and isotope techniques.
- Quantify heat extraction efficiencies from isotopic exchange between fluid and rock matrix.
- Monitor creation/loss of fracture permeability

EGS Problem

- *What is the average heat recovery rate of an EGS and how do we measure/monitor it?*
  - Power output of an EGS is the average heat recovery rate over the lifetime of the reservoir circulation loop(s).
  - Missing variable is the rock matrix surface area which, through contact with circulating fluids, supplies the heat.
- *Presently: No simple technique for measuring integrated surface area of fluid-rock exchange/interaction in a fracture dominated flow regime.*

Plans and Approach

Fracture Spacing in Enhanced Geothermal Systems

- Characterization of natural fluid-rock systems
  - Use isotopes as passive tracers (U, Nd, Sr, O, He, etc); dissolution of solid phases adds isotopically distinctive signatures to the fluid.
  - characterize reactions in the system at the scale of the element dependent "***reaction length***," which can be a few *cm* to many *km*.
- Use inter-element differences in "reaction length" to estimate fracture spacing and effective surface area of fluid-rock exchange.

What are (element specific) reaction lengths?

- For transport by fluid advection: The distance a fluid flows during the time it takes to dissolve sufficient rock or mineral to shift the fluid phase isotopic composition by (1-1/e) of the difference between the fluid and rock values $(v_{fluid}*t_{diss}*MK_i) = \boldsymbol{La_i}$

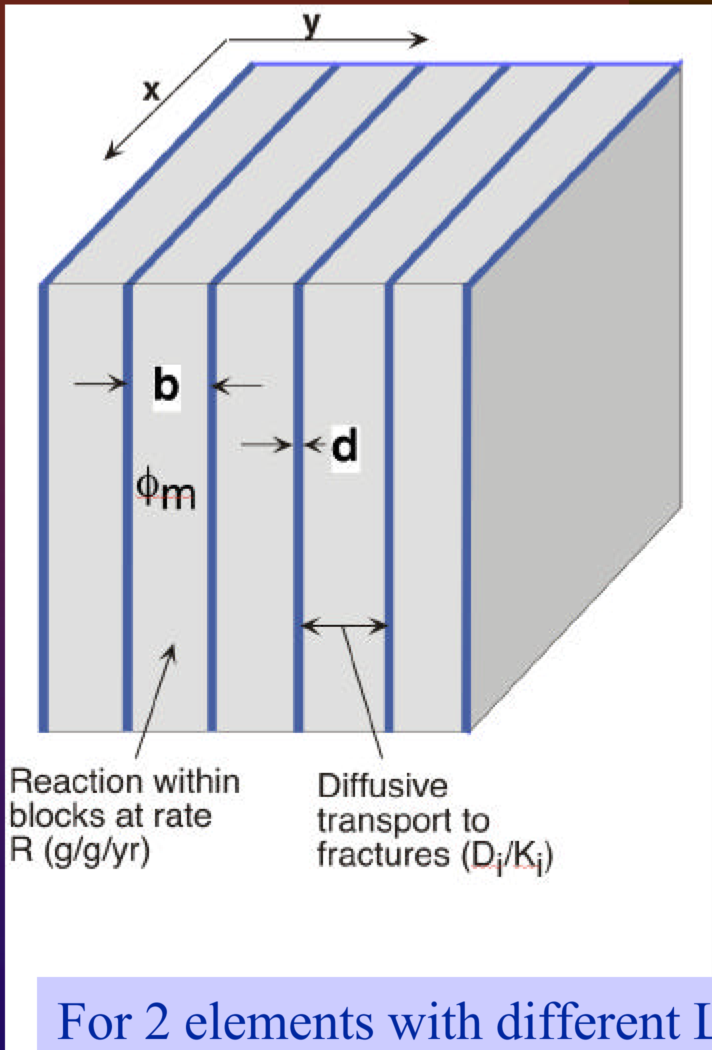
- For transport by diffusion within a fluid phase: The mean diffusion distance associated with the time it takes to dissolve sufficient rock or mineral to shift the fluid phase isotopic composition by (1-1/e) of the difference between the fluid and rock $(D_i*t_{diss}/MK_i)^{1/2} = \boldsymbol{Ld_i}$

$$K_i = C_{si}/C_{fi} \qquad\qquad M = \rho_s(1-\phi)/\rho_f\phi$$

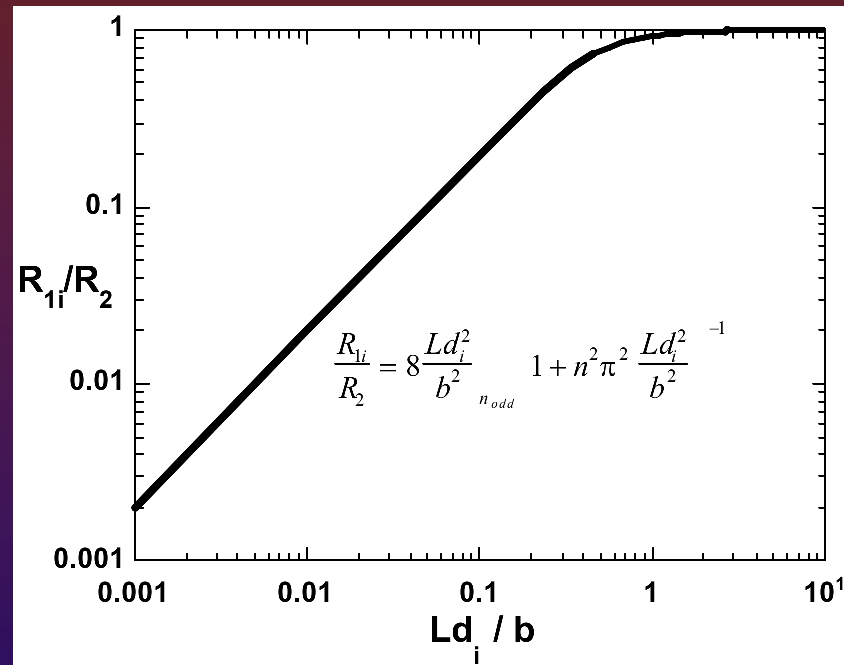
Inter-element differences in rock-fluid partitioning can be used to investigate fractured rock "dual porosity" systems

- Diffusive reaction lengths can differ by orders of magnitude for different elements (e.g. Sr *vs*. O, or Nd *vs*. Sr)
- For fluids flowing through fractures, interaction with the rock matrix can be limited by diffusion through the rock matrix pore fluid
- A parallel-plate model formulation shows that the fluid flowing in fractures effectively sees only to a depth of Ld_i into the matrix blocks; this depth varies between elements ($Ld_i \propto D_i K_i^{1/2}$)
- For a system with a fracture spacing of "b", the dissolution rate (R_1) as sensed by the fluid flowing in the fractures (for element i) is different from the actual rate (R_2), and depends on the ratio Ld_i/b:

$$\frac{R_{1i}}{R_2} = 8\frac{Ld_i^2}{b^2} \sum_{n_{odd}} \left[1 + n^2 \pi^2 \frac{Ld_i^2}{b^2} \right]^{-1}$$

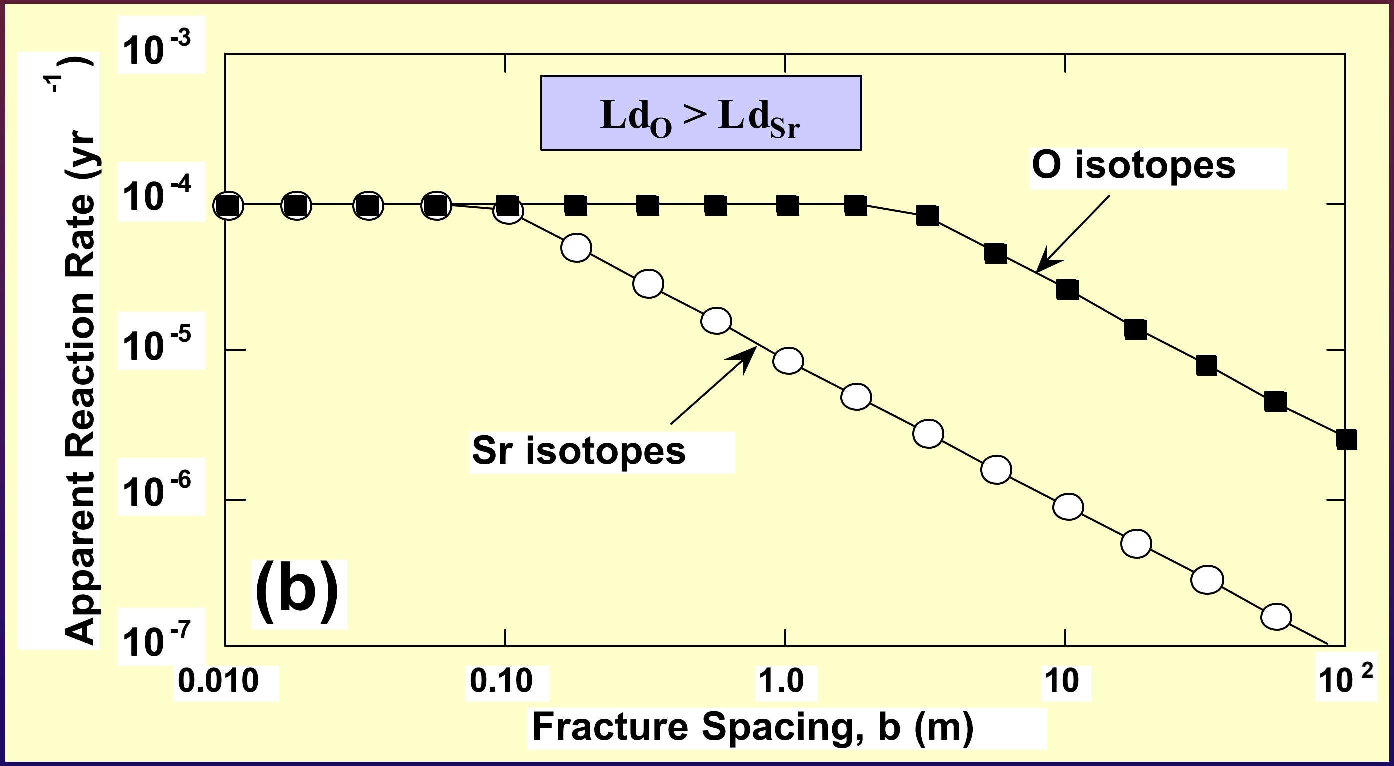


In the limit $Ld_i \ll b$, the apparent exchange rate is lowered by $2Ld_i/b$.



For 2 elements with different Ld_i values, the element with the smaller Ld_i will appear to be interacting more slowly with the rock. This effect can be used to evaluate whether matrix diffusion is a limiting factor, and in some cases, could be used to estimate fracture spacing.

Inter-element comparison of apparent fluid-rock exchange rate and fracture spacing

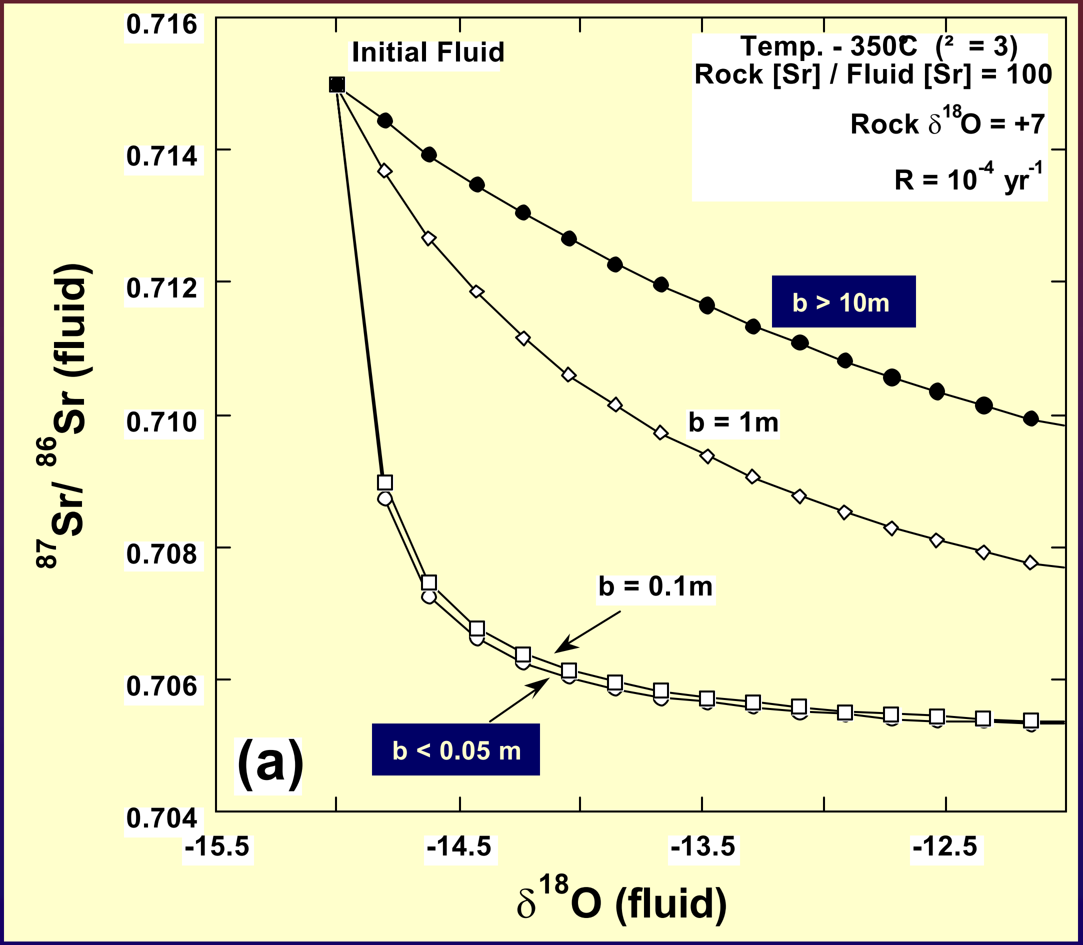


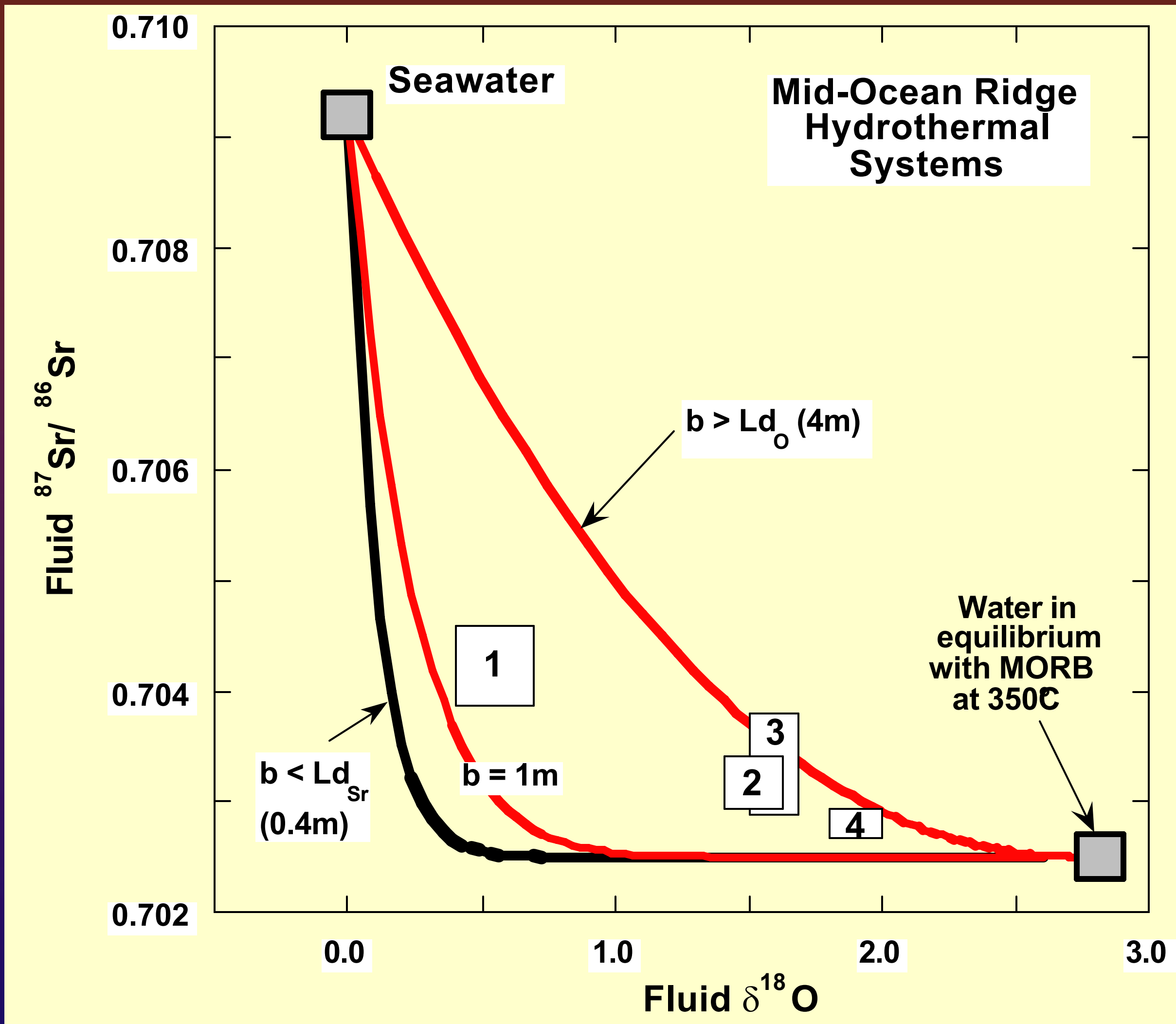
Example Calculation Showing Matrix Diffusion Effects on Relative Isotope Shifts for Hypothetical Hydrothermal System

The trajectory of changing isotopic compositions depend on the fracture spacing.

Single porosity applies when
b < 0.05m

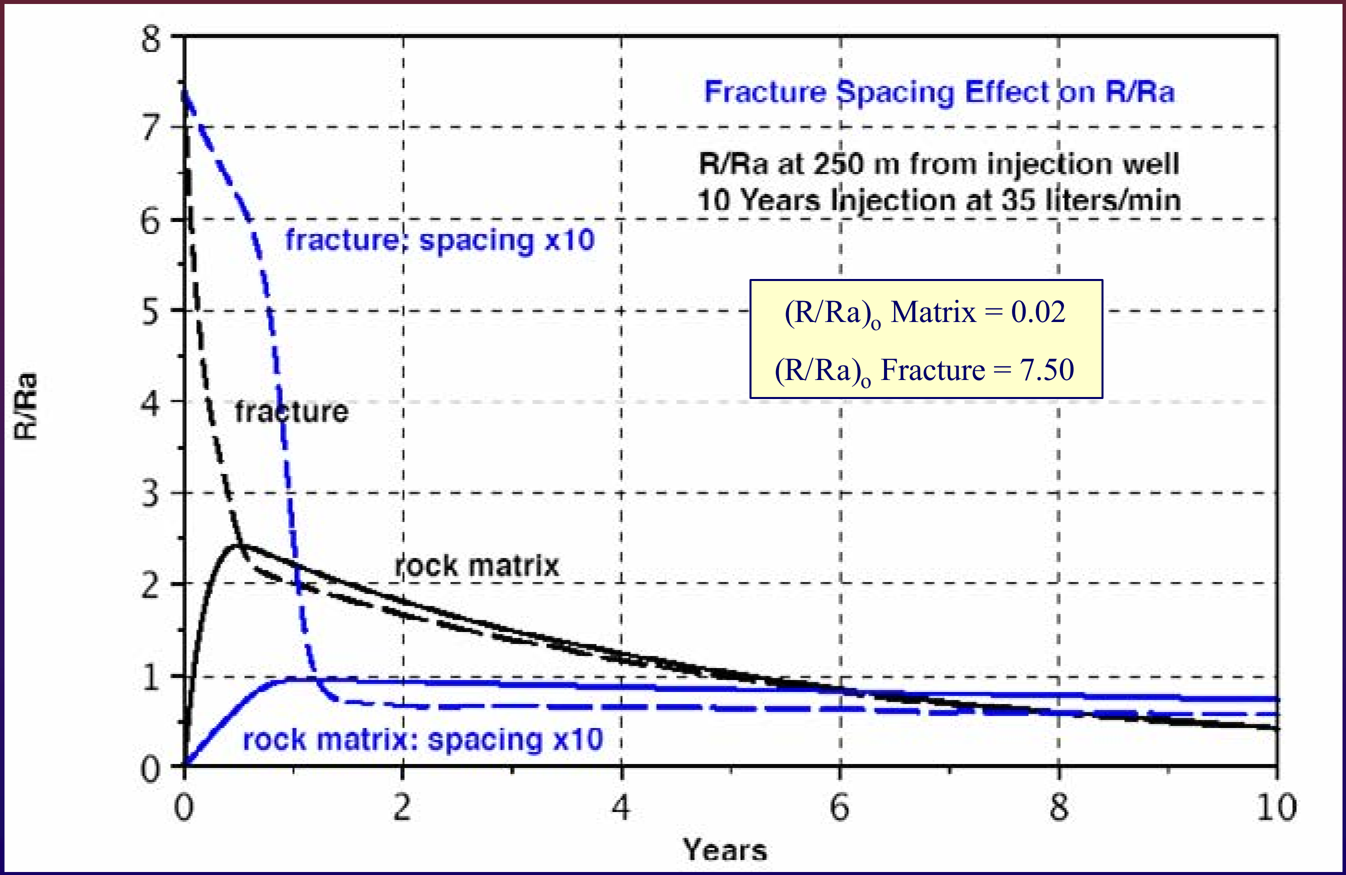
For increasing fracture spacing (up to b~10m) the Sr shifts decrease relative to O causing trajectories to deviate substantially from singe porosity end member





When applied to mid-ocean ridge hydrothermal systems, existing data show some of the expected effects for Sr *vs.* O isotopes. Fracture spacing appears to be up to several times the value of Ld_{Sr}, which is estimated to be about 40 cm.

Helium Isotope Exchange Between Fracture and Matrix as a Function of Fracture Spacing



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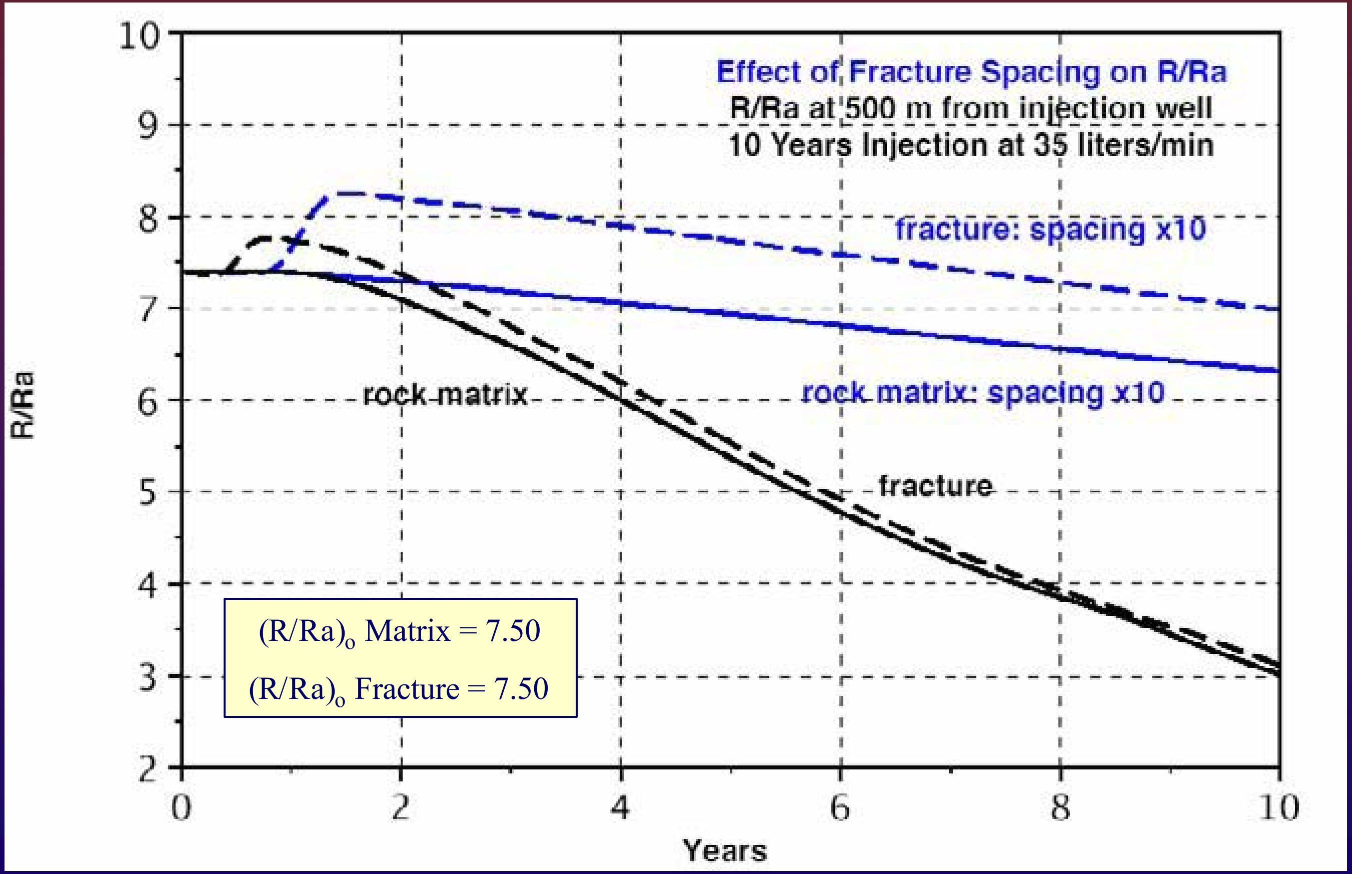
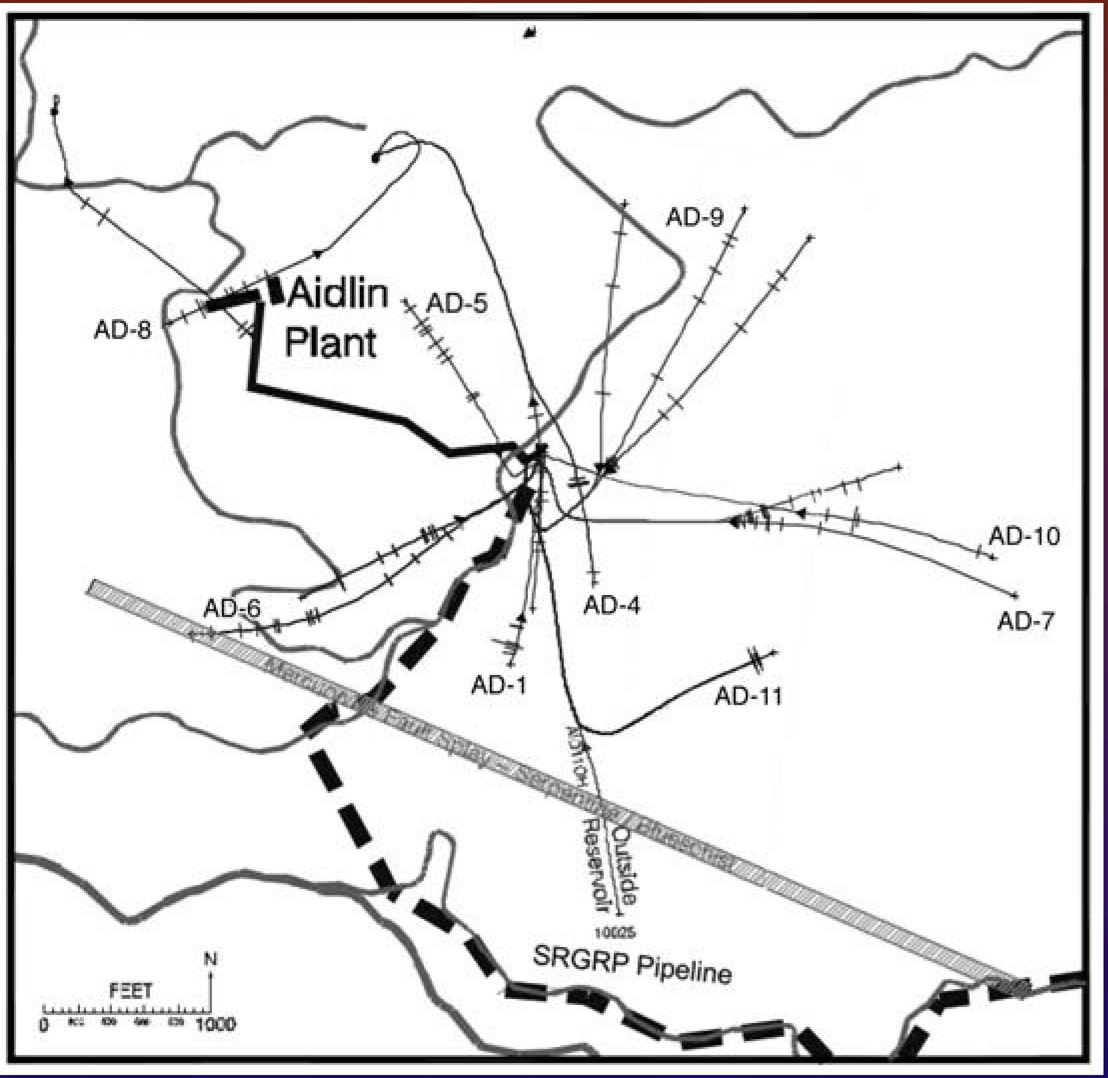


(R/Ra)$_o$ Matrix = 7.50

(R/Ra)$_o$ Fracture = 7.50



Aidlin Field

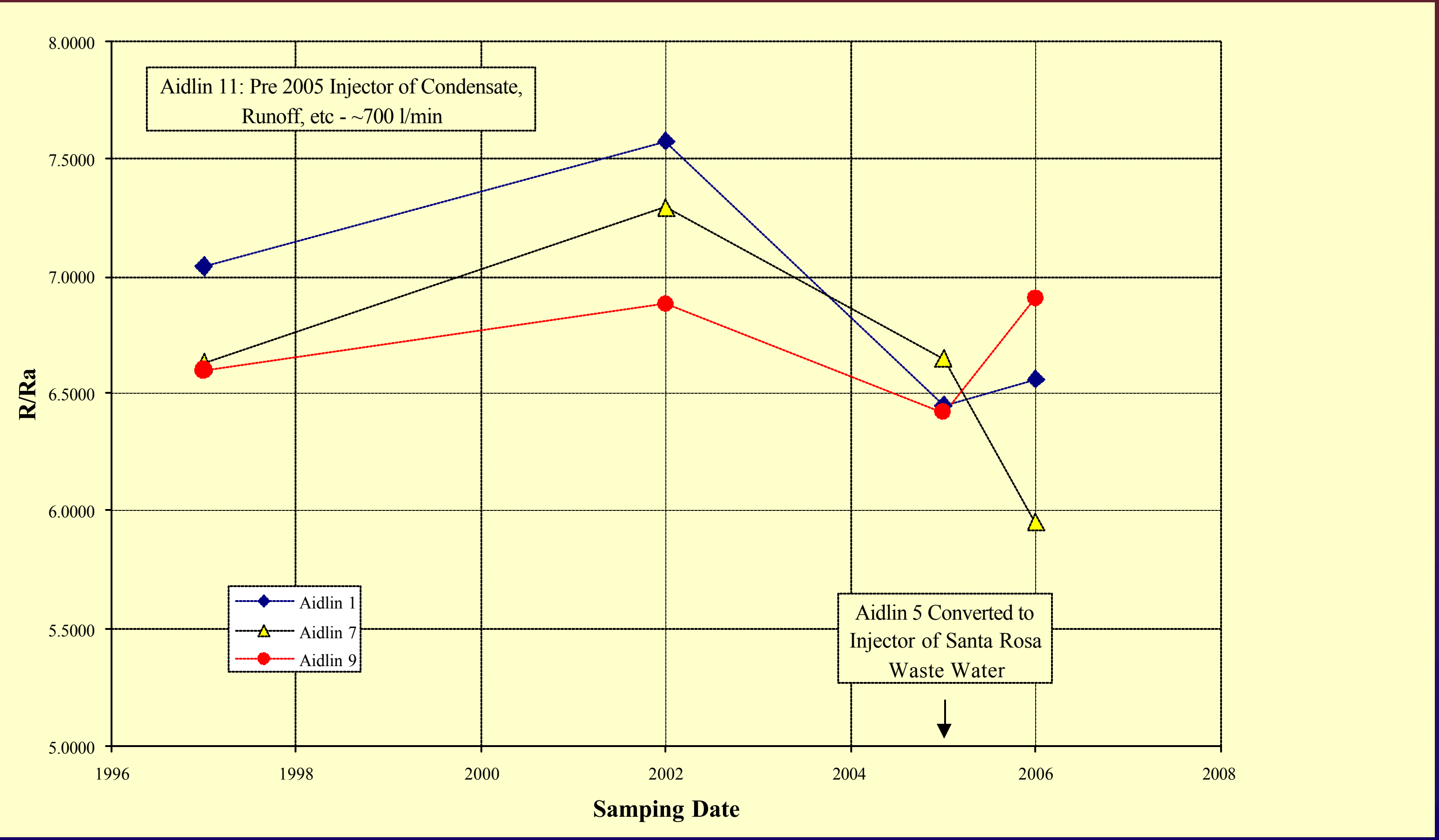
Northwest Geysers

Production from HTR and NTR

Aidlin 11 – Injector of condensate, run-off, etc.

Aidlin 5 – Converted in 2005 to Inject Santa Rosa Waste Water

Helium Isotopic Compositions for Selected Aidlin Wells: 1997 - 2006



Impact

GENERAL IMPACTS

- Surface area of rock matrix that supplies heat in EGS circulation loop.
- Develop techniques for monitoring formation and evolution of induced and or natural fracture permeability and heat exchange efficiency.
- Develop a better understanding of the relationship between injection and induced seismicity
  - Induced seismicity, regional and local stress, and fluid flow.

SITE SPECIFIC IMPACTS (The Geysers)

- Expand geothermal energy output of The Geysers -- ~1/3 of available resource remains untapped.
  - Improved understanding of the relationship between fluid injection and changing compositions of production fluids: fluid-rock heat and chemical exchange, fluid mixing, impact of "pressure bubbles".
  - NW Geysers HTR – effect of fluid injection on deleterious high non-condensable gases and HCl.

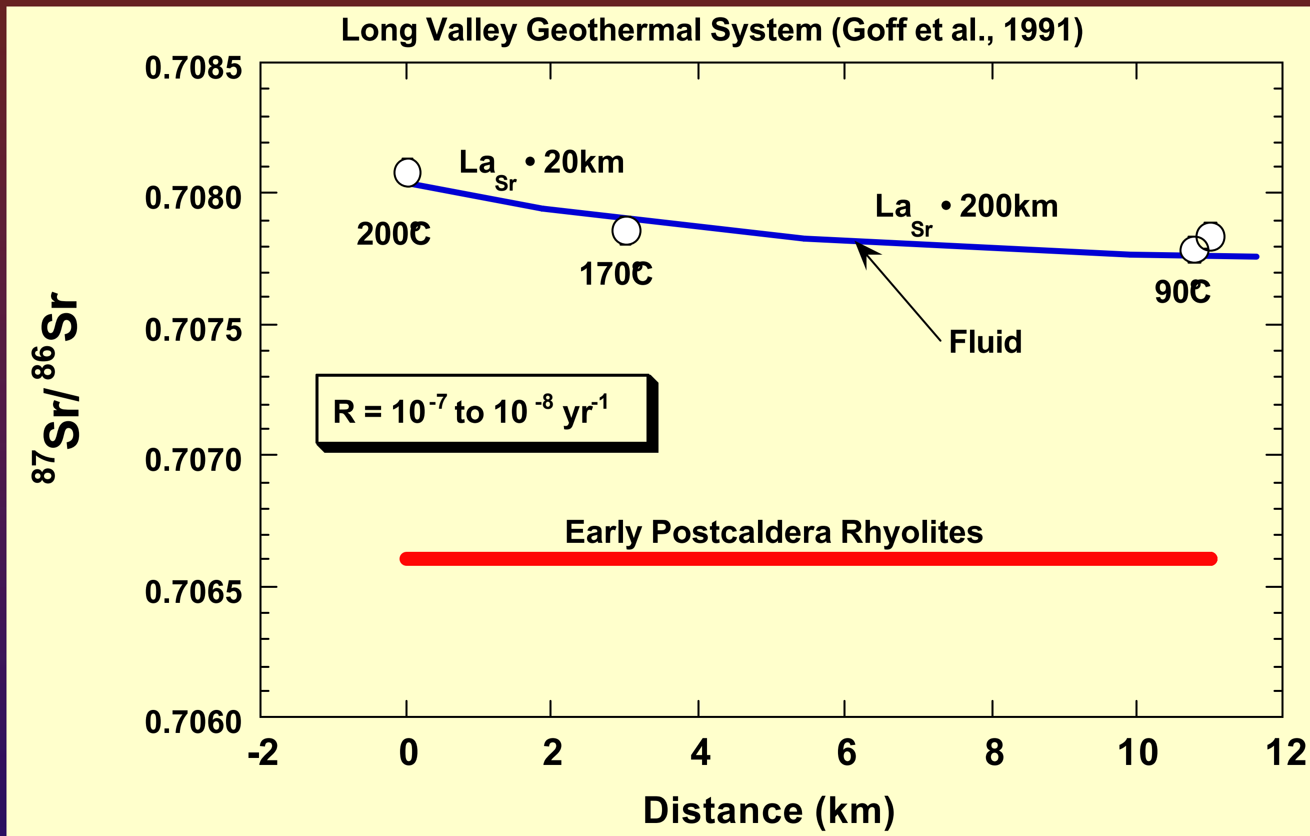
Plans for Completion

- **Field verification of isotope technique for estimating fracture spacing and heat exchange surface area**
  - Participate in Coso EGS project.
  - Long Valley/Casa Diablo system
  - Continue development of isotope capability for TOUGHREACT

- **Seek further opportunities for collaborative EGS projects.**
  - Rock-fluid interactions: chemical and mechanical
  - Inter-element isotope techniques to determine heat transfer area between fractures and rock matrix

- **Work with Calpine and NCPA on EGS CEC project in Northwest Geysers.**
  - Fluid-matrix interaction and the impact of increased injection
  - Complete ^{14}C-CO_2 study
  - Chemistry and mitigation of non-condensable gases and HCl
  - Can we couple induced seismicity to changes in fluid chemistry

Advective example from Long Valley geothermal system



Deduced rhyolite dissolution rates are 10^{-7} to10^{-8} yr^{-1} at T = 200° to 100°C

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Conclusion

- Will the project objective (slide 3) be achieved by the project completion date?
  - Probably not –
    - Proof of concept is nearly "complete"
    - Successful application will require moderate to long term monitoring (1 to several years) of fluids during controlled injection programs – e.g. Coso, Desert Peak, etc.