Using Isotopic Alteration Modeling to Explore the Natural State of The Geysers Geothermal System, USA *

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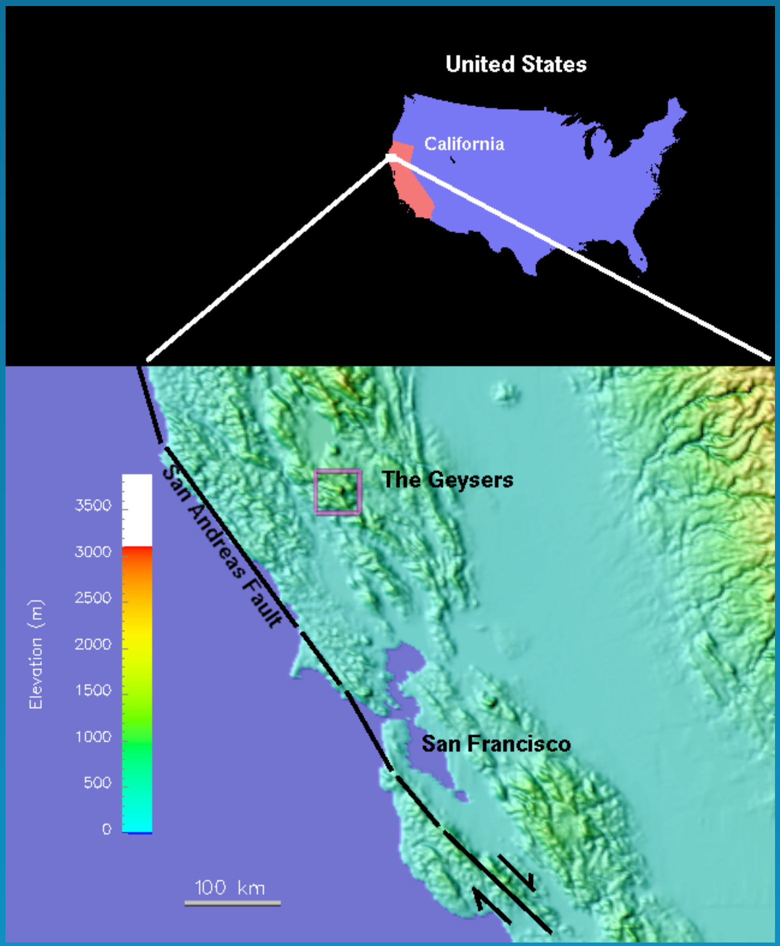
Introduction

- Project Goals
  - ⋆ Understand long-term evolution of The Geysers, past and future
  - ⋆ Provide a scientific basis for managing the system as a sustainable resource
- Presentation Goals
  - ⋆ Demonstrate the value of analyzing rock alteration for evaluating geothermal system behavior (natural state modeling)
  - ⋆ Provide important insights into the development of The Geysers geothermal system

Approach

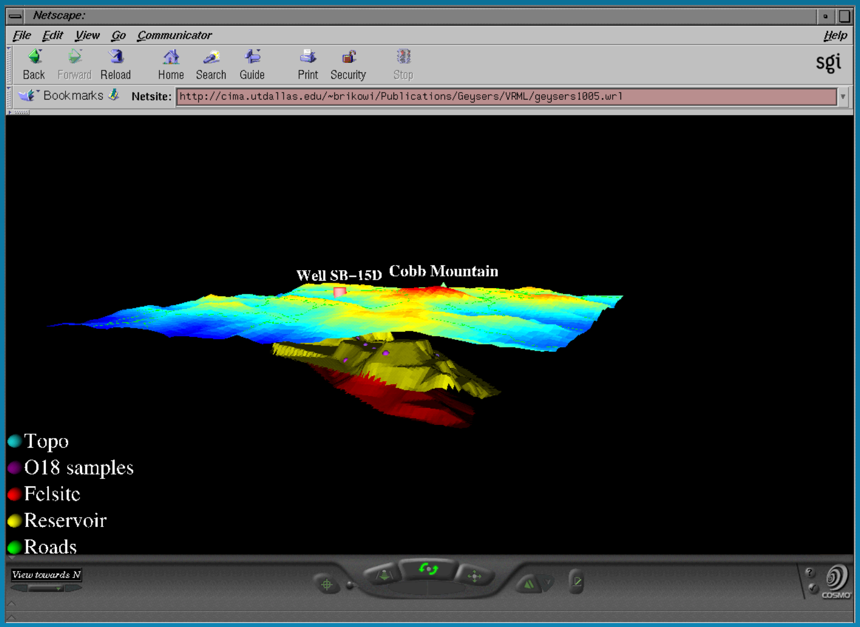
- Approach The Geysers as an active magma-hydrothermal system
- Must take a broader view than typical geothermal production models
  - ⋆ apply system-wide heat, fluid and chemical mass balances
  - ⋆ basic methodology is well-established, primarily applied in economic geology
  - ⋆ must start from the geologically best-known condition: the intrusion of the felsite (natural state)
- To predict sustainability, must understand the natural state of the system

Location and Tectonic Setting



- Extensional basin within Coast Ranges
- Young magmatism originally thought to be related to mantle hotspot [Donnelly-Nolan(1988)]
- More likely repeatedly supplied by crustal extension in pull-apart basin (Blackwell, 1999)

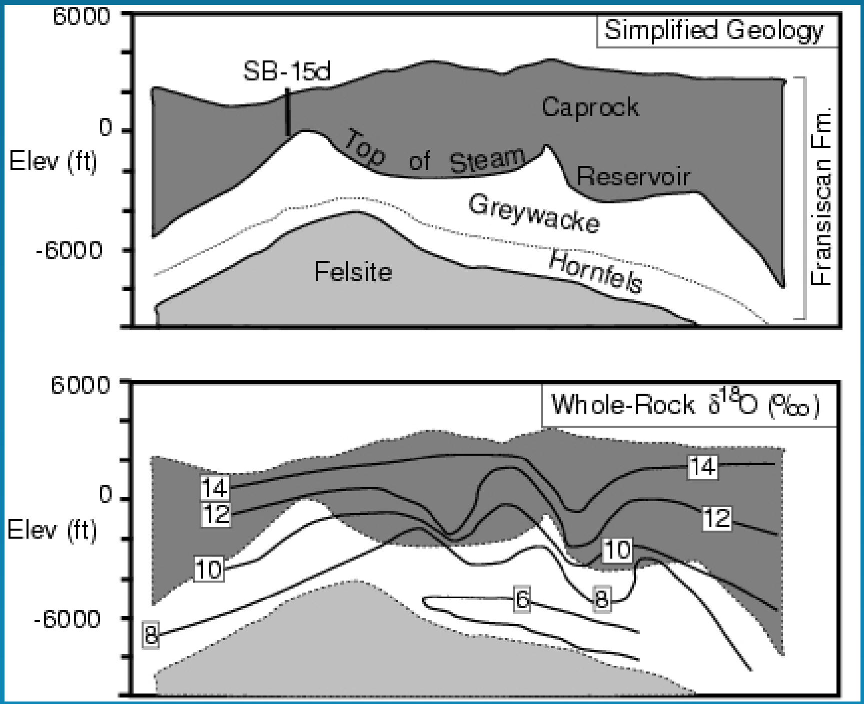
Geology



This web-accessible 3D interactive model available at http://www.utdallas.edu/~brikowi/Publications/Geysers

- heat source: “felsite” intrusive
- permeable host rock: secondary porosity developed by calcite vein dissolution in metagraywacke
- impermeable caprock: calcite deposition in overlying metagraywacke
- $\delta^{18}O$ alteration: concentrated low above northeastern flank of felsite

Cross-Sectional Representation



after [Moore and Gunderson(1995), Hulen and Moore(1996)]

- Permeability zones
  - ⋆ Caprock
  - ⋆ Reservoir (lower greywacke and upper felsite)
  - ⋆ Hot intrusive (deep felsite)
- Alteration zones
  - ⋆ minimal in caprock
  - ⋆ widespread moderate (6-8‰) in reservoir
  - ⋆ concentrated strong (8-10‰) along low felsite flank

Alteration as a Constraint

- Oxygen isotope exchange reaction simple and ubiquitous
  - ⋆ surface exchange reaction (controlled by thermally-activated kinetics)
  - ⋆ rapid diffusion/advection away from interphase surface
- Modeled δ^{18}O alteration very sensitive to system conditions.
- Successful models must match temporal and spatial distribution of:
  - ⋆ chemical equilibrium/disequilibrium conditions (i.e. ^{18}O -depleted recharge fluids and ^{18}O -enriched reacted fluids)
  - ⋆ temperature (i.e. reactivity of the host rock)

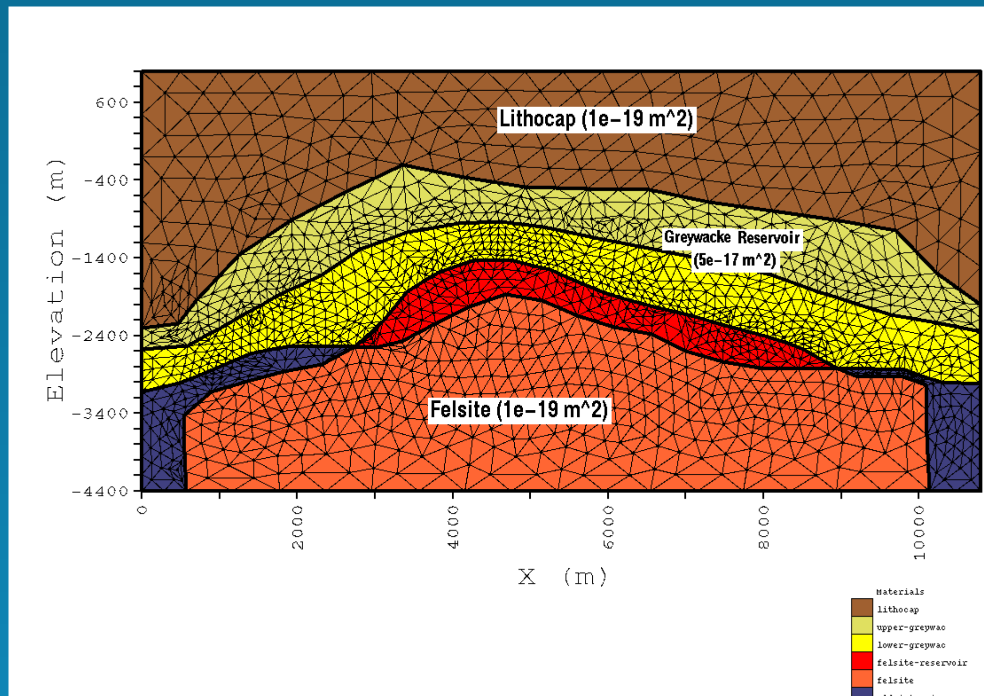
Principal Model Results

- Rapid hot water flow is strongly confined to the reservoir base by system geometry combined with the effects of fluid critical T-P properties.

- Rock alteration is concentrated in the upstream areas of the same zone low on the flanks of the felsite, by the influx of ^{18}O-depleted water into the rapid flow zone. This matches the distribution of observed alteration [Moore and Gunderson(1995)], and requires good horizontal connectivity at depth.

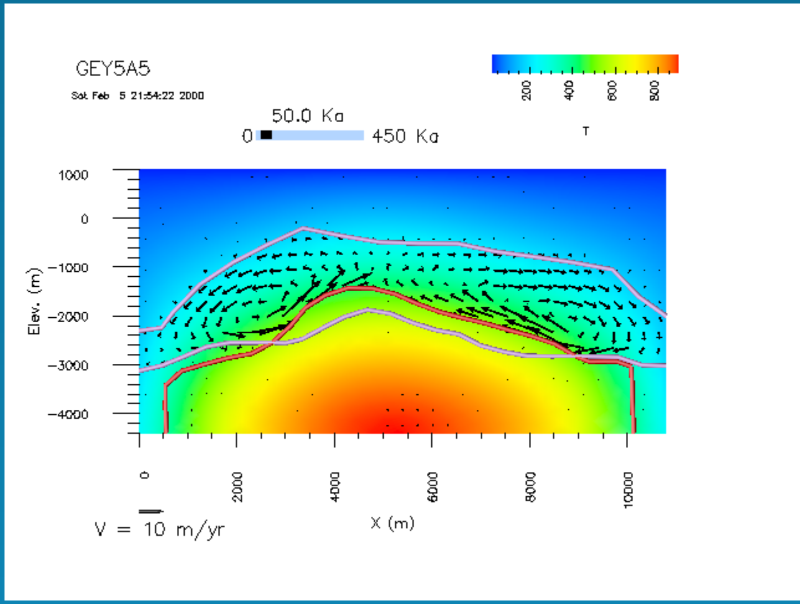
- Rapid cooling requires much younger or repeated heat source than indicated by radiometric dating [Dalrymple *et al.*(1999)].

Finite Element Grid



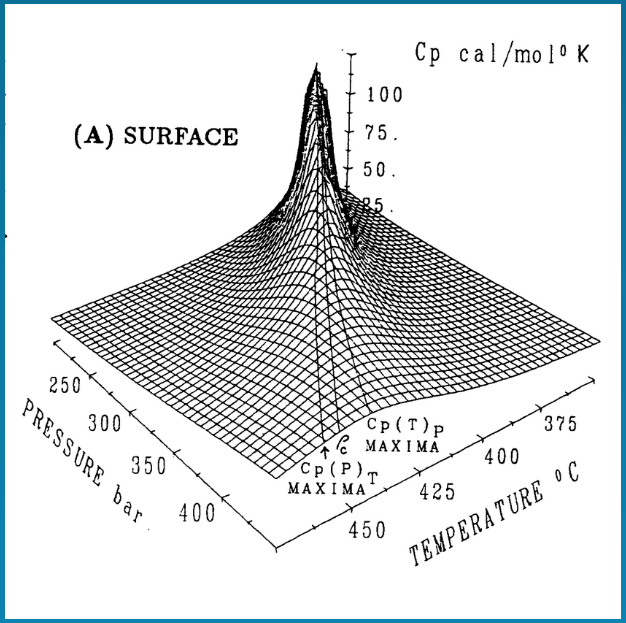
Cross-sectional geometry used in finite element modeling. Section is oriented SSE-NNW. Geysers Coring Project Hole SB-15d (not shown) is located at X = 3250 m, with TD at +85 m. Elements shown in black, grid contains 3380 quadratic triangular elements, 6839 nodes.

Temperature and Flow Fields



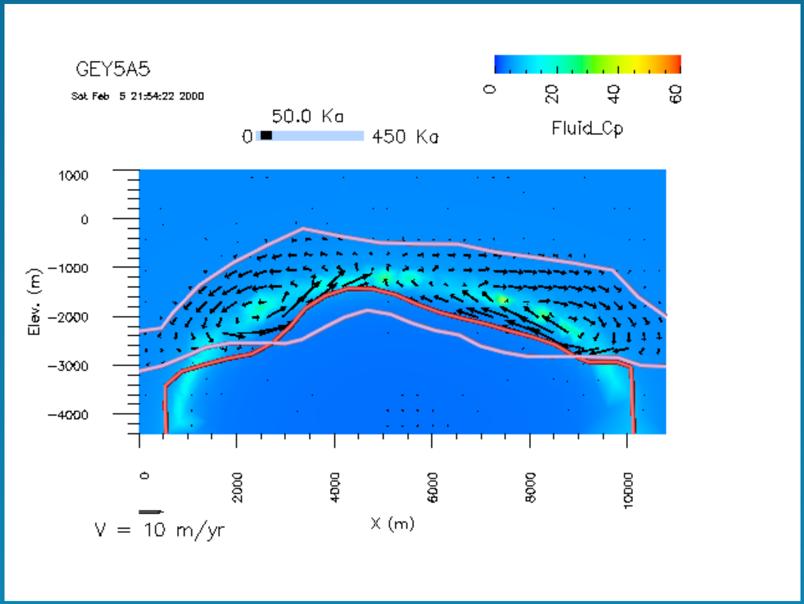
Temperature (shading) and flow (black vectors, max V=8 m/yr) fields at 50 Ka for *mariah* model results, SW-NE cross-section, The Geysers. Lines show margins of present-day steam reservoir. Select image to see an animation of temperature and velocity.

Fluid Heat Capacity at Near-Critical Conditions



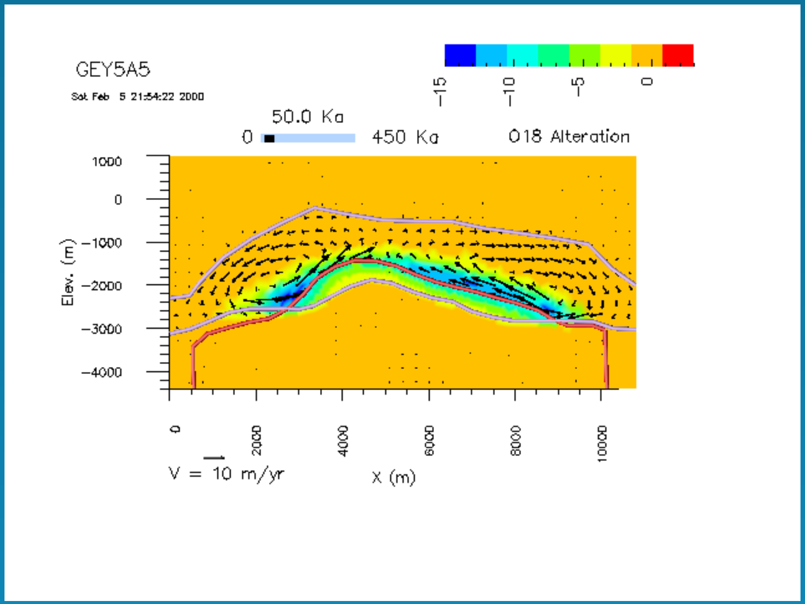
Fluid (H_2O) properties exhibit sharp extrema near the critical point of water (374 $^\circ\mathrm{C}$, 22 MPa). Heat capacity (Cp) reaches infinite value at the critical point.

Critical Fluid Conditions and Flow Field



Fluid heat capacity (Cp KJ/kg, shading) and flow (black vectors, max V=8 m/yr) fields at 50 Ka for *mariah* model results, SW-NE cross-section, The Geysers. Lines show margins of present-day steam reservoir. Select image to see animation of Cp and velocity for 0-450Ka (382Kb download).

Rock Alteration



Plagioclase δ^{18}O alteration (colors, initial - current) and flow (black vectors) fields at 50 Ka for $mariah$ model results, SW-NE cross-section, The Geysers. Select image to see animation of alteration and velocity for 0-450Ka.

Summary

- Conclusions
  - ⋆ As-yet undiscovered younger heat source required at The Geysers, or reinterpretation of significance of Geysers radiometric ages. Repeated magma intrusion is consistent with extensional tectonic setting.
  - ⋆ Alteration patterns require well-connected deep circulation. This connectivity likely persists under single-phase conditions.
  - ⋆ Isothermal reservoir structure of The Geysers long-lived, initially formed by enhanced heat transport by near-critical liquid.

- Website: This presentation, 3D interactive Geysers model, and other results viewable on the World-Wide Web at http://www.utdallas.edu/~brikowi/Publications/Geysers

References

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[Donnelly-Nolan(1988)] Donnelly-Nolan, J. M., 1988. A magmatic model of Medicine Lake Volcano, California. J. Geophys. Res. 93, 4412–4420.

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