Numerical Modeling of Thermal Convection in Multiple Fractures

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Natural Convection

- **Soultz-sous-Forêts**
  - Geothermal gradient in crystalline basement cannot be entirely due to conduction
  - Basement rock permeability too low for Rayleigh convection
  - Fractures provide conduit for fluid

- Convection thought to occur within fractures
Single Fracture

- Natural convection forms “cells”
- Key Factors:
  - Fracture aperture (0.5 & 0.75 mm)
  - Basal heat flow (85 mW/m²)
  - Rock thermal conductivity (2 W/m/K)
- Low permeability host rock (10⁻¹⁸ m²)
  - Closed loop system
  - Upward flow offsets downward flow

- Model: 4km height, 5km length, 5km width
- Fracture: 1km height, 2km length, variable aperture
Single Fracture

Fracture aperture = 0.50 mm
Model time ≈ 20,000 years

Fracture aperture = 0.75 mm
Model time ≈ 4,000 years

White arrow = upward flow
Black arrow = downward flow
Single Fracture – slice through middle

Fracture aperture = 0.50 mm
Single Fracture – slice through middle

Fracture aperture = 1.0 mm

Temperature Change (°C)

-12 -6 0 6 12

2000 m

Fracture face

Top-down (middle)

Top-down (top)
Multiple Fractures

- Fractures and faults typically come in sets
- Does a convecting fracture influence non-connected, neighboring fractures?

Left: Faulds et al. 2010. Characterizing Structural Controls of Geothermal Reservoirs in the Great Basin, USA, and Western Turkey
Right: Rouse et al. 2012. An exceptional rocky shore preserved during Oligocene (Late Rupelian) transgression in the Upper Rhine Graben (Mainz Basin, Germany)
Multiple Fractures

Fracture aperture = 0.50 mm
Model time ≈ 20,000 years

Fracture aperture = 0.75 mm
Model time ≈ 4,000 years

Temperature Difference (°C)

5 km
Multiple Fractures – Heterogeneous Aperture

Fracture Aperture (mm)

μ = 0.75 mm

Temperature Difference (°C)

0.40 0.75 1.0 1.6

5 km
Multiple Fractures – Heterogeneous Aperture
Heat Flow Through Fractures

- Increasing fracture perm...
  - convection initiates earlier
  - transports more heat
Heat Flow Through Fractures

- Increasing fracture perm...
  - convection initiates earlier
  - transports more heat

- Decreasing fracture spacing...
  - convection initiates earlier
  - Enhanced heat flow in low-perm fractures
  - Reduce heat flow in high-perm fractures
Conclusions

- Convection “syncs” across fractures
- Large-scale convection and temperature anomaly patterns emerge
- Fundamental behavior of convection in basement rock
- Aid in site selection
Thank you