DOE’s EGS Program Review

Prediction and Control of Attributes of Induced Fractures in EGS

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Project Objective

- Maintaining or increasing fracture permeability is critical to effective EGS implementation.
- Mechanisms that lead to alterations of fracture permeability include:
  - Mechanical deformation
  - Geochemical alteration

  Initial objectives
  - Thermal stress → **Added objective**
- We are integrating laboratory experiments and model development lead to:
  - Improve understanding of coupled processes in fractured rocks under reservoir conditions
  - Develop scalable tools for predicting the impact of coupled processes on fracture permeability evolution

EGS Problem

- Effective operation of EGS reservoirs requires improved tools for predicting the effect of coupled chemical / mechanical / thermal stresses on the long term evolution of fracture permeabilities.
- Such tools can directly aid in:
  - Development of operation plans to extend a well's lifetime
  - Maximizing net thermal output by maintaining / increasing fracture surface area.
  - Assessing the potential for developing / maintaining adequate fracture permeability in prospective EGS formations.
- Development of effective computational tools requires experimental data to test the models.
- We measure permeability evolution in EGS rocks at reservoir conditions under carefully controlled conditions to:
  1) determine how the physical and chemical properties of rocks and fluids control the permeability evolution of induced fractures in geothermal fields;
  2) suggest optimal strategies for sustaining permeability; and
  3) apply this knowledge in support of DOE EGS field experiments.
- Efforts support the Desert Peak East EGS project and include direct collaboration with ORMAT and GeothermEx.
- Because the conceptual and numerical models developed explicitly incorporate the relevant mechanisms, they are applicable to any EGS effort provided adequate knowledge of the rock and fluid properties.

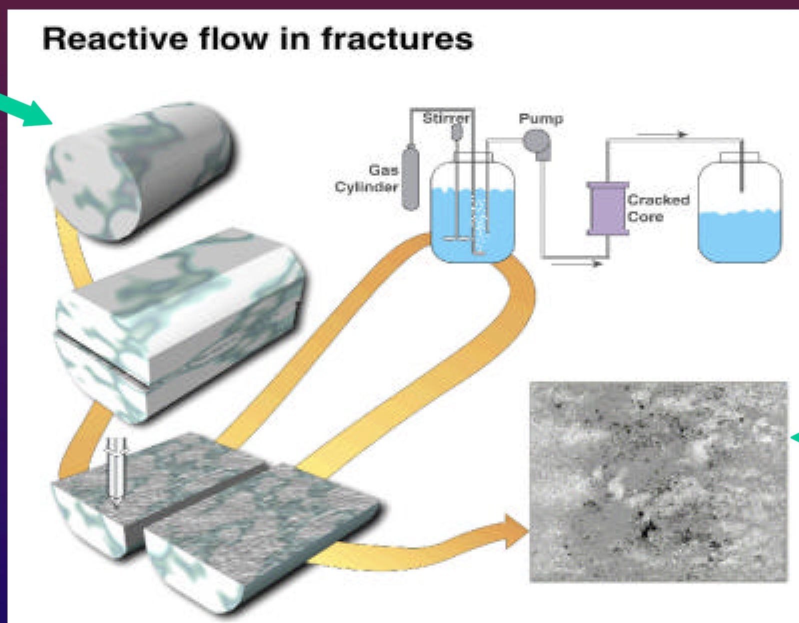
Background/Approach

Integrated experimental/computational study to develop enhanced models of mechanisms that alter fracture transmissivity in EGS Systems

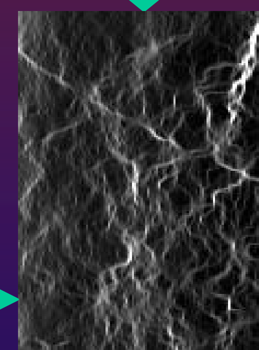
Controlled experiments

Geochemical modeling

Input from industry collaborators



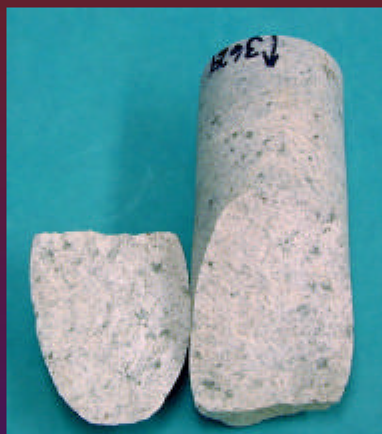
Pre- and post-flow characterization



Ongoing: Thermal and mechanical modeling

Hydrological modeling

Background/Approach



QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

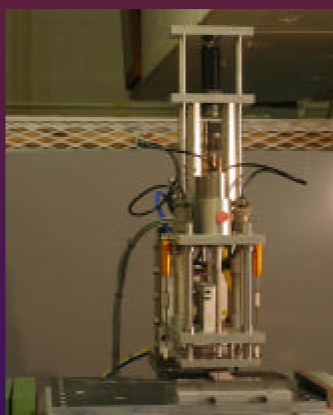
- Quartz Monzonite major mineralogy:
  - Plagioclase 44%
  - Potassium feldspar 23%
  - Quartz 7%
  - Mica 3%

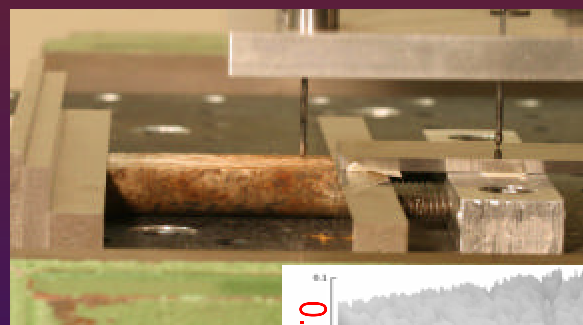
- Planar fractures with one roughened surface:
  - Reproducible aperture field statistics
  - Realistic surface mineralogy
  - Insensitive to small registration errors when reconstructing aperture fields from surface measurements

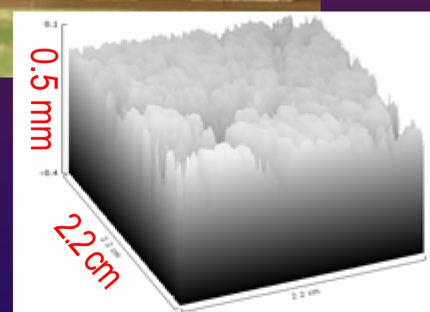
Background/Approach

Fracture surfaces analyzed before and after flow experiments using:

Surface profilometry



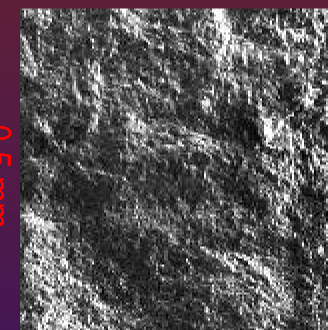




x-y resolution: ?30 μm,
z resolution: ?5μm

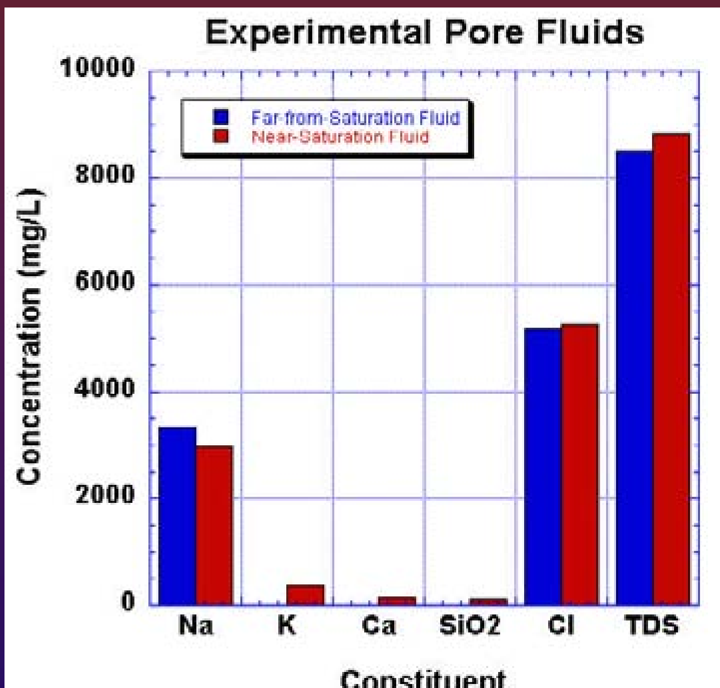
Surface profiles allow reconstruction of initial / final fracture aperture fields for input into models

SEM



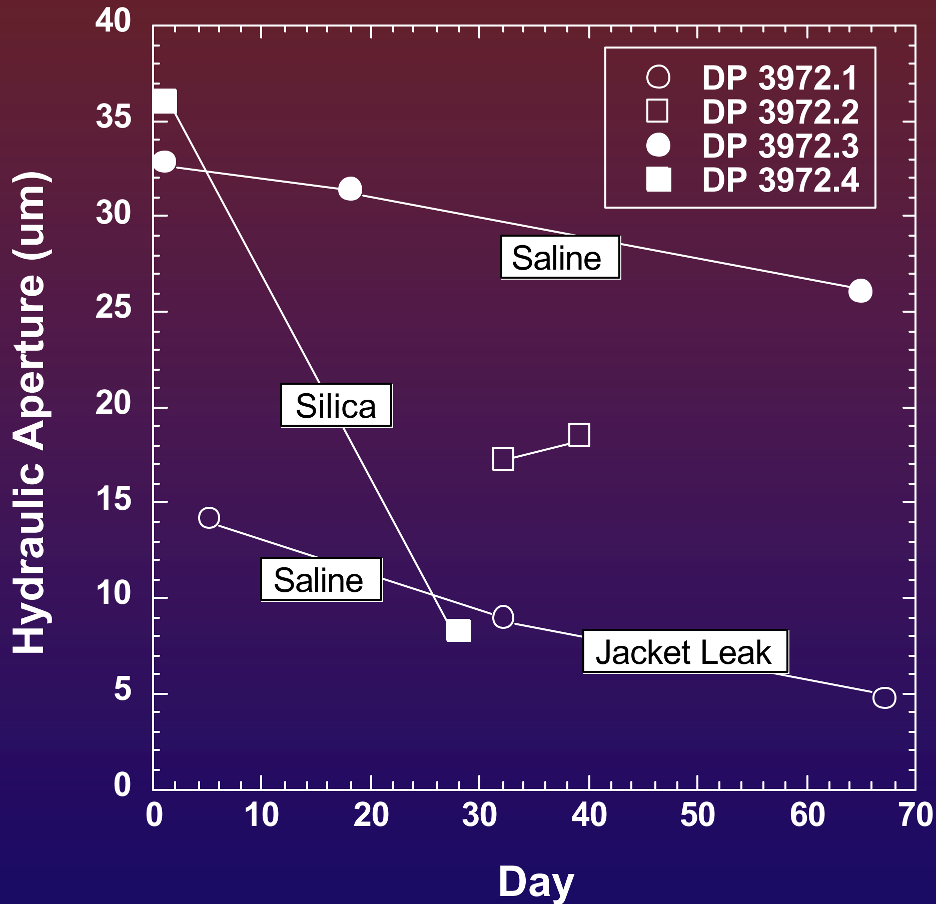
SEM images provide detailed measurement of surface characteristics / mineralogy

Background/Approach



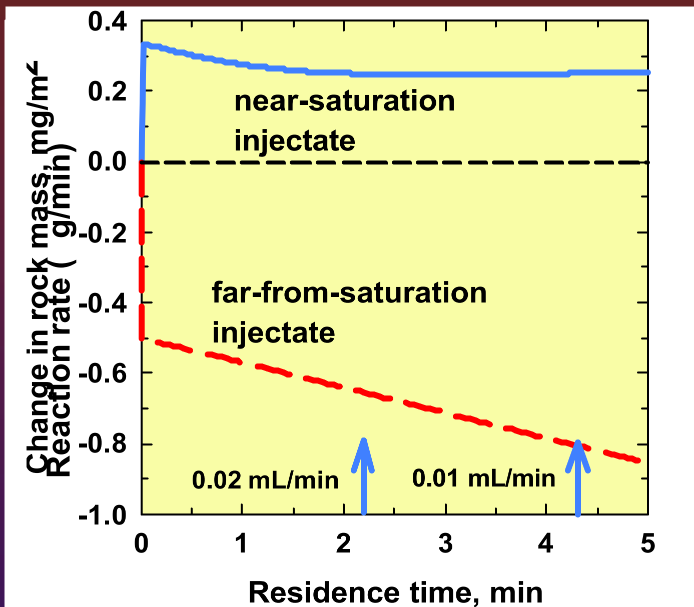
- Experiments to date use two fluids with different Si-saturation states:
  - Far-from-SiO_2 saturation fluid (Na, Cl) - e.g., near injection well
  - Near SiO_2 saturation fluid (Na, Ca, K, Cl, SiO_2) - e.g., far from injection well
- Flow experiments approximate reservoir conditions:
  - Temperature: 167 C
  - Confining pressure: 800 psi (5.52 MPa)
  - Pore pressure: 250 psi (1.73 MPa)

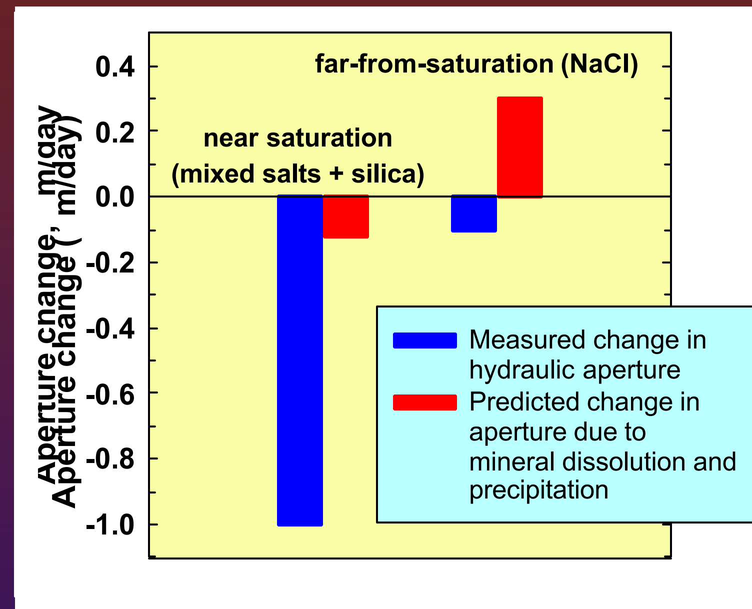
Results/Accomplishments



- Long term flow experiments at reservoir pressure / temperature:
  - Far-from-SiO_2 saturation fluid
    - Rock surfaces experience net dissolution
    - Slow decrease in b_{eff} may be due to dissolution of contacts between surfaces
  - Near SiO_2 saturation fluid
    - Surfaces experience net precipitation
    - This leads to a much faster reduction in b_{eff}

Results/Accomplishments



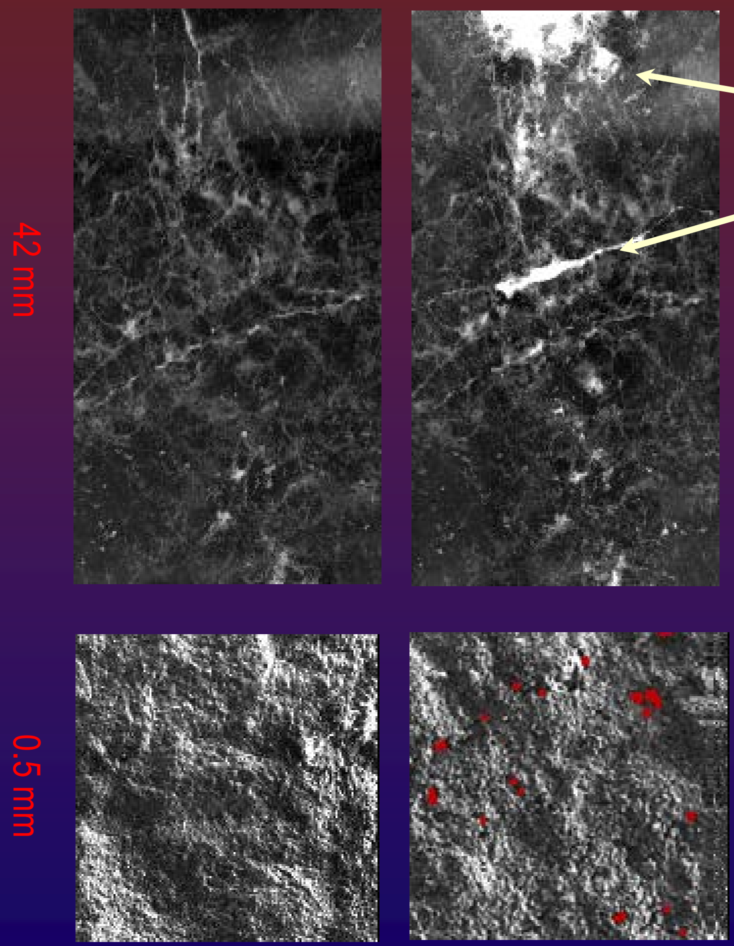


- Far-from-saturation-injectate
  - 65 days @ 0.02 – 0.01 mL/min removed ~20 ?m
- Near-saturation-injectate
  - 37 days @ 0.02 mL/min added ~4 ?m

- Batch geochemical model overestimates change in fracture aperture for both cases.
- May be due to localized variability due to
  - Flow channeling
  - Mineral heterogeneity

Results/Accomplishments

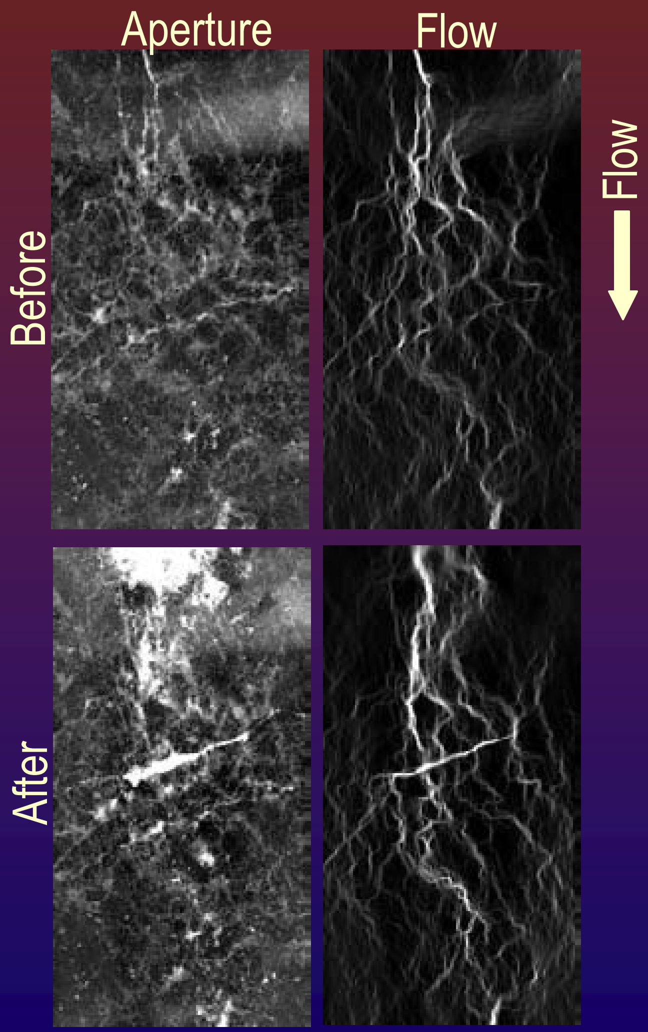
Before After



- Measured aperture fields (far from saturation):
  - Aperture growth localized near inflow not uniform over surfaces
  - Significant dissolution along cemented cross-cutting fracture
  - Mean aperture ~30 μm (~40%) larger after flow, agreeing with geochemical model
- SEM images:
  - Variability in surface mineralogy leads to localized pitting

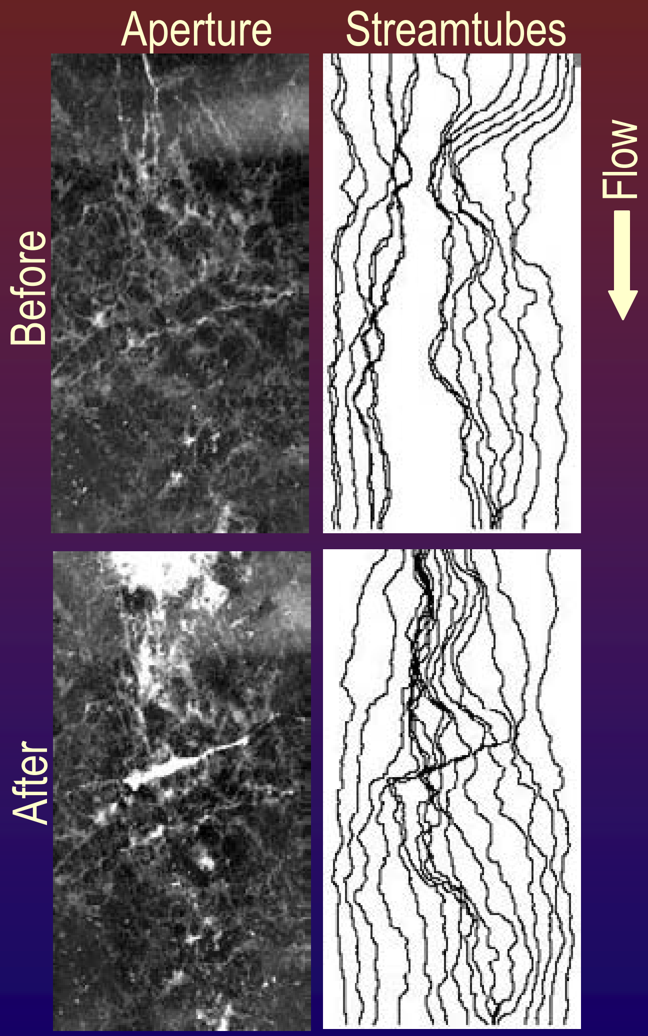
- Local features are not predicted by the batch model or 1D reactive transport models but may play important role in fracture evolution.

Results/Accomplishments



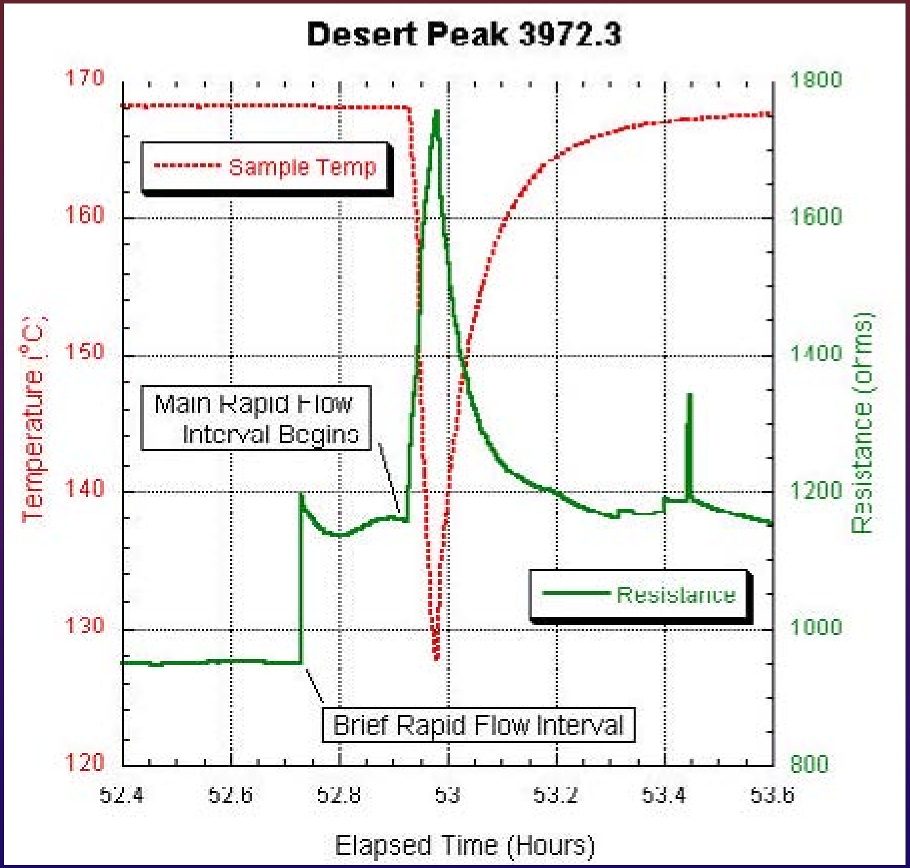
- Flow simulations in the measured aperture fields demonstrate enhanced channeling caused by dissolution.
- Despite 40% increase in measured mean aperture, simulations predict negligible change in hydraulic aperture.
- Remaining discrepancy between measured and simulated permeabilities likely due to measurement error and depth-averaging assumptions.
- Predicting long-term evolution of fracture reservoir permeabilities will require incorporating constitutive relationships that can effectively represent the role of localized mechanisms.

Results/Accomplishments



- Adequately representing the influence of flow channeling on dissolution / precipitation processes requires 2D reactive transport modeling.
- Ongoing efforts involve solving 1D reactive transport along evolving streamtubes predicted by the flow model.
- This effort leverages current LLNL research (BES, LDRD) on coupled reactive transport / mechanical deformation in variable aperture fractures.
- Recent development of parallelized discrete fracture network reactive transport model will allow us to extrapolate experimental results to larger scales.

Results/Accomplishments



- Thermal stress experiments are ongoing.
- Injection of cold water leads to a rapid drop in effluent temperature.
- Moderate increase in permeability observed for this test.
- Future experiments aimed at evaluating the relative magnitude of permeability alterations due to thermal effects and geochemical effects.

Conclusion

- Ongoing experiments provide a controlled data set for evaluating scalable computational models of chemical / mechanical mechanisms that lead to fracture alteration and meet our FY06 objectives.
- Recently initiated thermal stress experiments (FY07 objectives) will provide comparison between thermal effects and previously measured geochemical effects.
- We are developing mechanistic models that will allow us to extend results to a broader range of parameter space than is experimentally feasible.
- These efforts will lead to currently unavailable constitutive relationships for these coupled processes in fractured rocks that can be incorporated into large scale reservoir models.