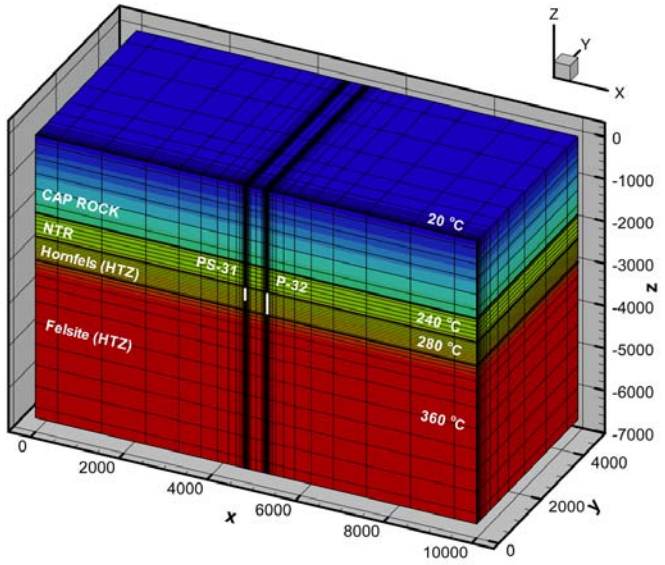
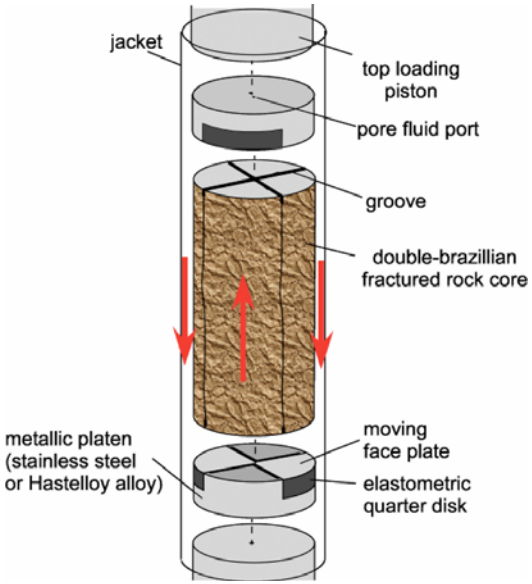
Field-Scale EGS <--> THMC Model < -- > Experiment

Coupled THMC Model EGS Test Case (Aidlin)



Double-Shear Triaxial Cell Design



Coupled Thermal-Hydrological-Mechanical-Chemical Model and Experiments for Optimization of Enhanced Geothermal System Development and Production

May 19, 2010

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Jonny Rutqvist, Seiji Nakagawa
Lawrence Berkeley National Lab

Track Name

Overview

- Coupled THMC Model and Experiments for EGS
  - Timeline
    - Project start-end: 9/01/2009-9/30/2011 (~ 20% complete)
  - Budget
    - Total project funding: $852,000 (for entire project period)
  - Principal barriers to EGS commercialization: Creating, sustaining and reducing the cost of reservoirs

    * Coupled THMC models will directly address barriers to sustaining permeability in EGS and allow for analysis of the long-term effect of alternative methods for permeability creation. Effective injection schemes that evaluate chemical and mechanical effects on fracture permeability will allow for better techniques to reduce costs

Relevance/Impact of Research

- Objective: Develop a novel Thermal-Hydrological-Mechanical-Chemical (THMC) modeling tool
- Benefits: Will directly allow for the analysis and prediction of the sustainability of reservoirs that are deficient in water and/or those having low permeability, and allow for more effective heat extraction strategies
- Relevance: EGS require fracture generation as well as fluid injection to extract energy. Continued fluid injection, coupled to changes in the stress regime owing to temperature and pressure changes, can lead to changes in fracture permeability via mechanical, chemical (mineral precipitation), and mechano-chemical processes (pressure solution at fracture asperities)
- Fully coupled THMC codes are not currently available for analysis of dynamic fractured, multiphase, high-temperature conditions in EGS

Scientific/Technical Approach

- Develop a simulator from the established THC code TOUGHREACT (Xu et al., 2006), TOUGH+ (Moridis et al., 2005) and incorporate THM processes based on the ROCMAS code (Noorishad et al., 1982) with added capabilities equivalent to those found in FLAC3D (Itasca)
- Incorporate small-scale processes in fractures through implementation of mechanistic crack growth and grain contact models for chemically induced subcritical crack growth and pressure solution, with porosity-permeability changes
- Conduct experiments to evaluate the long-term, coupled behavior of sheared fractures
- Validate the mechanistic THMC models of fracture aperture changes through comparison to experimental data on sheared fractures under stress under EGS-relevant temperature and chemical conditions

Scientific/Technical Approach - 2

- Planned milestones and go/no-go decisions for FY09 and FY10 and current status towards them.

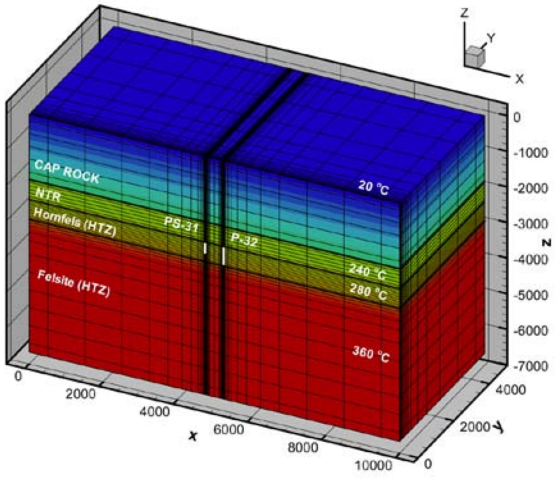
		Year 1				Year 2			
TASKS		1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q
Process Model, Code & Experiment Planning/Design/Fabrication									
1.1	Development of key code requirements		◆						
1.2	Evaluation of key existing and to be developed features			◆					
1.3	Implementation of process-level constitutive models								
1.4	Experimental design requirements and setup		◆						
1.5	Completion of Fabrication/construction								
Code Development/Implementation and Experiment Initiation									
2.1	Evaluate preliminary code on benchmark tests						◆		
2.2	Initiate experiments					◆			
Code CompletedCode Testing, Implementation and Experiment									
3.1	Code testing on EGS								

Task Timeline

◆ Stage-Gate Go - No Go Points (green – completed - go)

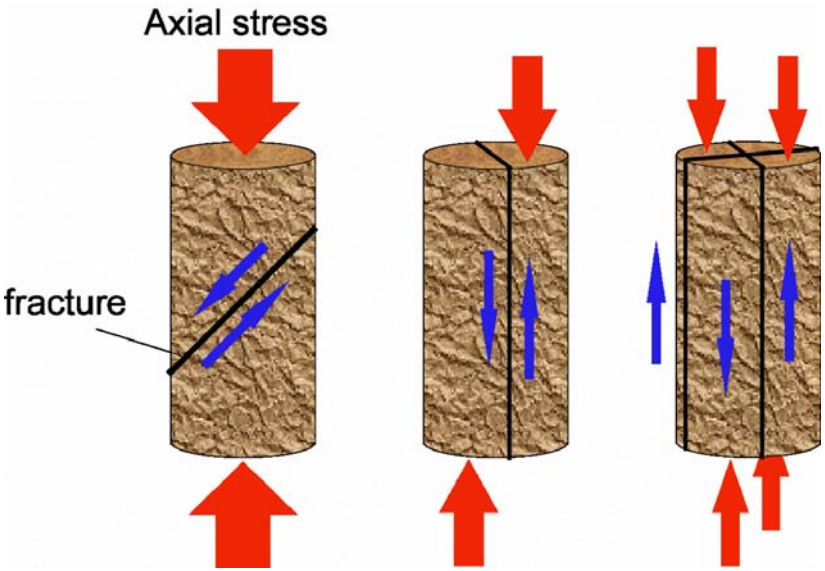
Accomplishments – Model/Code Development

- Coupled latest development version of Toughreact (V2.0) to FLAC-3D for test case analyses and as benchmark for coupled THMC code (run test validation)
- Evaluation of key features in ROCMAS for fully coupled THMC code
- Progress in setting up benchmark dual-permeability test case (Aidlin field) – grid shown below

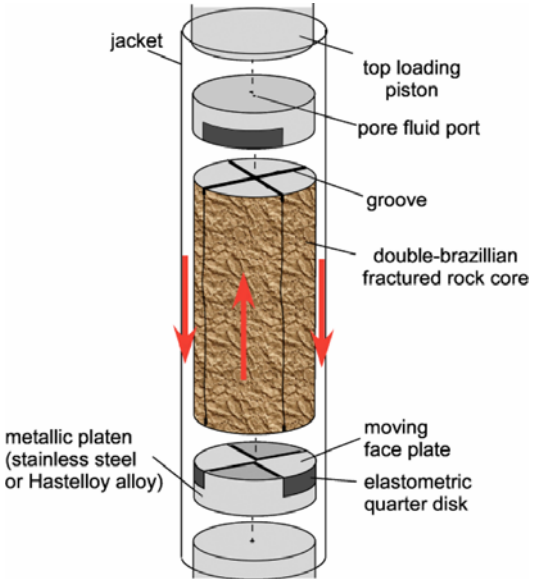


Accomplishments/Progress – THMC Fracture Experiment

- Designed a new experimental setup (double-shear) for a fracture shear experiment in a conventional triaxial cell
- Flow-through up to 10,000 psi and 204° C
- Currently being manufactured



Diagonal fracture Single-shear Double-shear



Team Qualifications:

Eric Sonnenthal (PI): Geochemistry/Reaction-Transport Modeling. Twenty years experience in modeling THC processes for geological and engineered systems. Developer of coupled THMC codes and co-developer of TOUGHREACT

Jonny Rutqvist (Co-PI): Rock Mechanics/Hydrology. Developed TOUGH-FLAC coupling, 16 years experience in modeling THM processes, 2009 American Rock Mechanics Association Applied Rock Mechanics Research Award

Seiji Nakagawa (Co-PI): Geophysics, Rock Mechanics. Development of new techniques for hydraulic fracturing, seismic measurements on sheared fractures, pressure solution in granular media

Jihoon Kim (new Postdoctoral Fellow): Expertise in numerical formulations for coupled geomechanics and multiphase flow

Project Management/Coordination

Overall project management, THC and THMC constitutive models (Sonnenthal)

Development of THM model capabilities, test case (Rutqvist)

Experimental Design, Analysis, and Shear fracture behavior (Nakagawa)

Numerical model testing and development (postdoc - Kim)

- Schedule: GANTT Chart on Slide 5
- Performance Measures/Key Dates – next slide (10)

Project Management/Coordination

- **Performance Outcomes and Measures:**
- 1. Outcome: THMC code (preliminary version) must be able to model published THMC laboratory experiments on single fractures. Measures: Ability to model the permeability changes in a single fracture within uncertainty ranges relevant to EGS. Ability to include relevant fluid and mineralogical properties in coupled THMC model, and at the same time capture mechanical-hydrological effects in experiments. **3/30/2011**
- 2. Outcome: Working shear T-P cell. Measures: Ability of the cell to apply independent normal and shear stresses and flow fluid within a rock sample while controlling the temperature. **3/30/2011**
- 3. Outcome: Initial data set relating applied normal and shear stresses to resulting permeability of a rock fracture. Measure: Correlation between stress and permeability, which can be used for the THMC modeling effort. **6/30/2011**

Future Directions

- FY-10
  - Implementation of process-level constitutive models for pressure solution (9/30/2010).
  - Complete THMC test case and perform benchmark simulations with Toughreact v2.0 – Flac3D
  - Add basic mechanical capability to Toughreact v2.0
  - Complete fabrication of shear T-P cell (6/30/10) – Test cell under experimental conditions. If pass, then continue with experiment. If not, redesign and/or refabricate cell, or use other experimental facilities for scaled-down experiment
- FY-11
  - Complete preliminary version of coupled THMC code
  - Perform shear fracture expts evaluating stress-permeability
  - Model experiments using THMC code and Toughreact-Flac
  - Begin application of code to other funded DOE EGS projects

Summary

- Quantitative evaluation of coupled THMC processes in EGS will be tackled using a combined approach:
  - New code development for more efficient coupled analysis of THMC processes in multiphase fractured rocks
  - Process model improvements for mechanical-chemical effects in fractures, particularly shear fractures
  - Benchmark EGS problems that can be used to test codes and their applicability to EGS
  - Experiments that allow quantification of THMC processes in fractures under EGS conditions for direct model validation/refinement