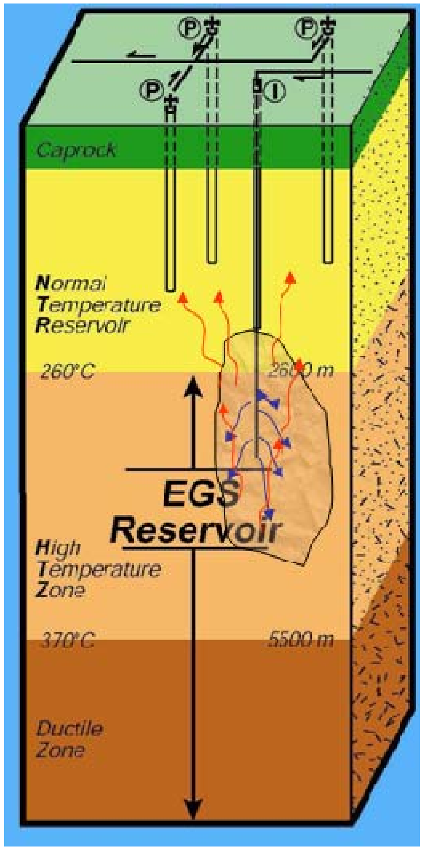

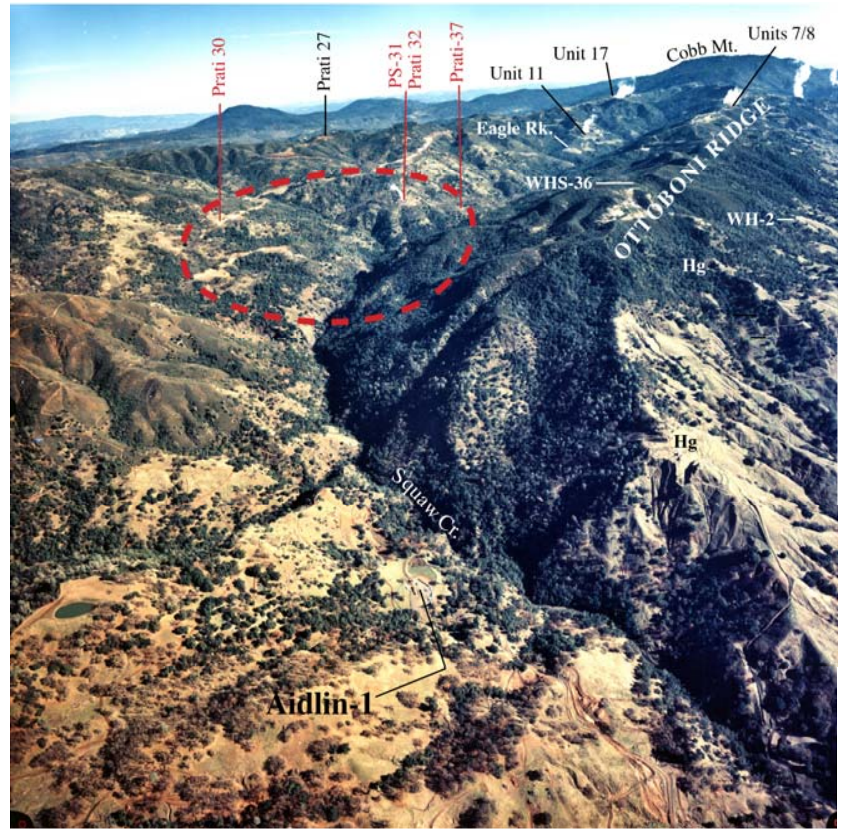

Demonstration of an Enhanced Geothermal System at the Northwest Geysers Geothermal Field, California

May 18, 2010

Mark Walters - Calpine

Patrick Dobson - Lawrence Berkeley National Laboratory

Engineered Geothermal Systems Demonstration Projects

Project Overview

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- Demonstration project organized into two phases: Pre-Stimulation (Phase-1) and Stimulation (Phase-2)
- Collaborative effort between scientists and engineers at Calpine and Lawrence Berkeley National Laboratory
- DOE Notice of Financial Assistance Award dated February 17,2009 was received by Calpine. Subsequently, a Calpine Authority for Expenditure (AFE) for Calpine's cost share was approved.
  - Project Start Date: 3/1/2009
  - Project End Date: 6/30/2012
- Total project funding: $8,498,401 (DOE: $5,226,952 / Calpine: $3,271,449)
  - FY09 DOE Funds received:$ 0 --- FY10 DOE Funding obligated: $3,969,750
- EGS demonstration is on hold until approval of environmental findings are made pursuant to the requirements of NEPA. These are anticipated in late May 2010.

Project Objectives

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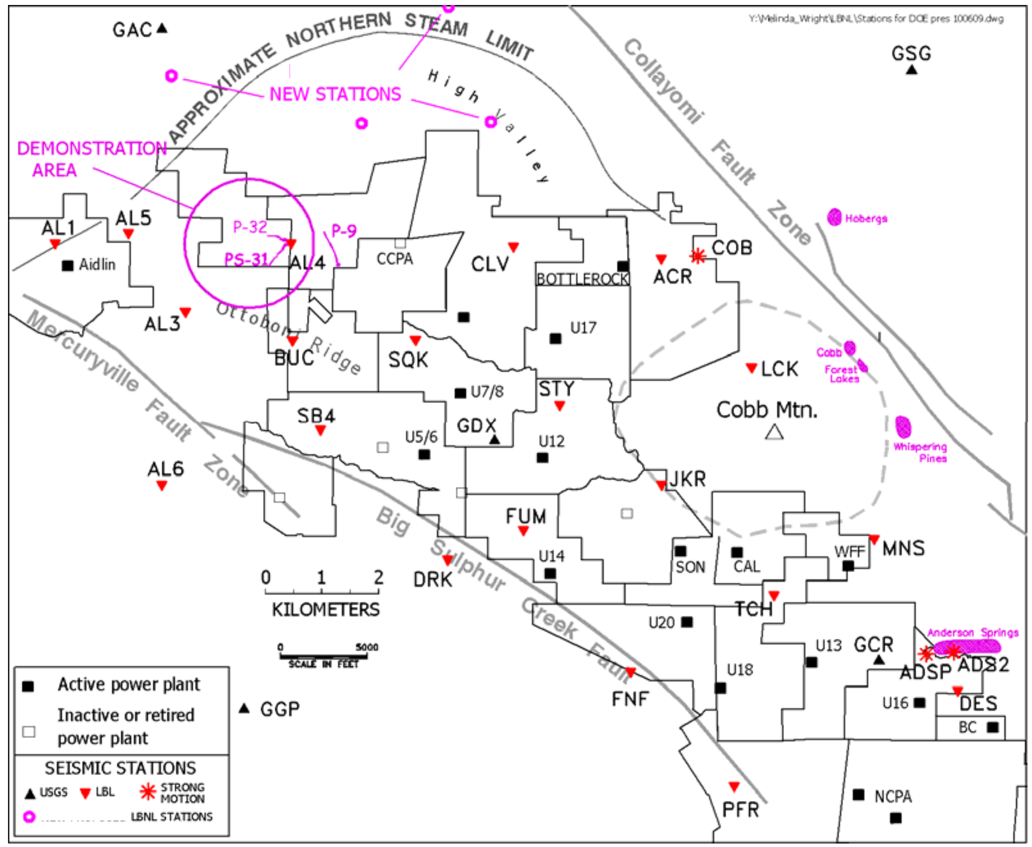
- Create an Enhanced Geothermal System (EGS) by directly and systematically injecting low volumes of "cold" water into NW Geysers high temperature zone (HTZ)
  - Similar to "inadvertently" created EGS in the oldest Geysers production area to the southeast of the EGS demonstration area
- Other objectives are:
  - Investigate how cold-water injection mechanically and chemically affects fractured high temperature rock systems
  - Demonstrate the technology to monitor and validate stimulation and sustainability of such an EGS
  - Develop an EGS research field laboratory that can be used for testing EGS stimulation and monitoring technologies including new high temperature tools developed by others.

- Increase steam production
  - Use under-produced NW Geysers region
- Mitigate seismicity
  - Shift new injection to NW Geysers
- Abate NCG concentrations in high temperature reservoir
- Stimulate wells to enhance permeability.
- Achieve 100% mass replacement to support sustained electrical production for future development.



Scientific/Technical Approach

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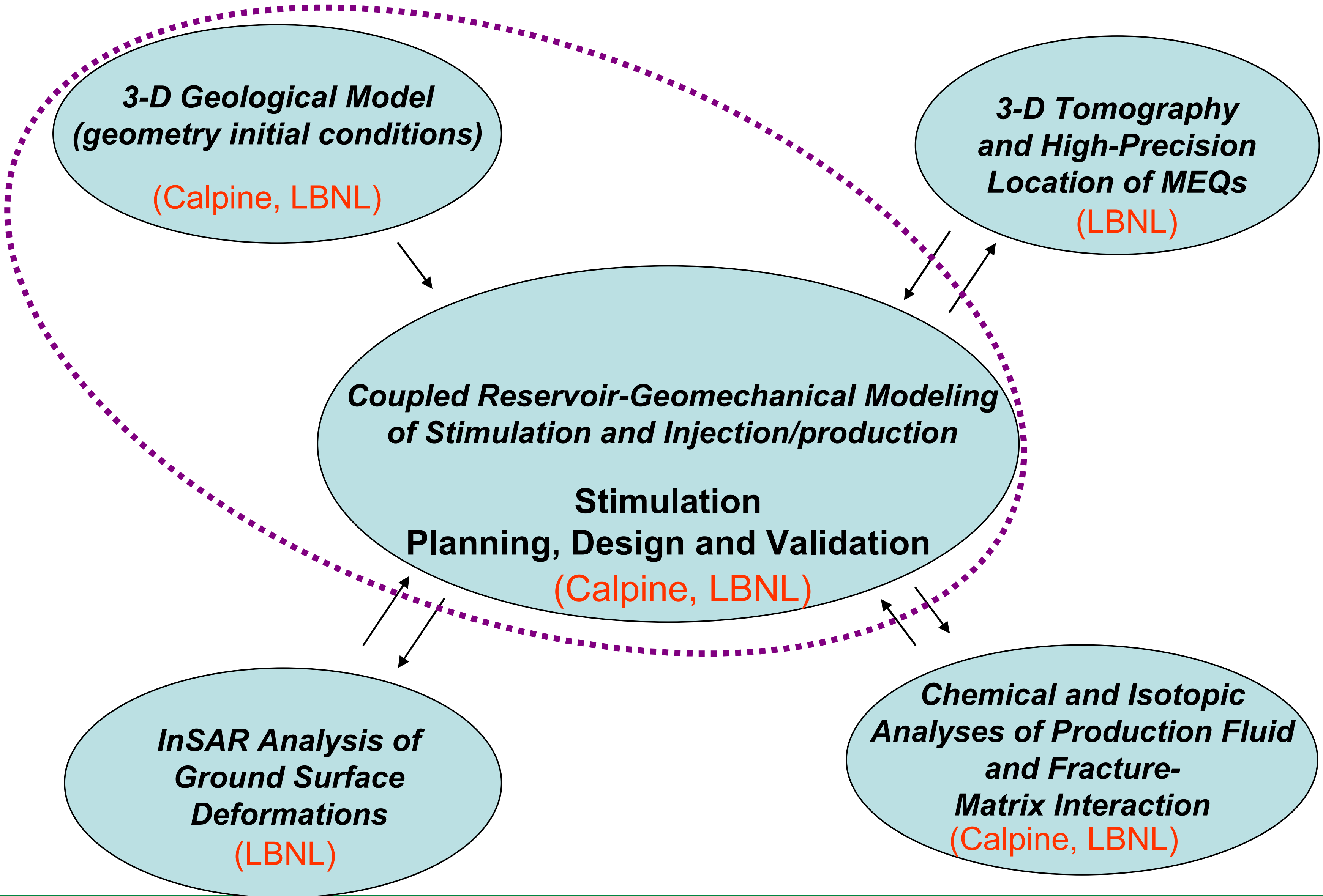
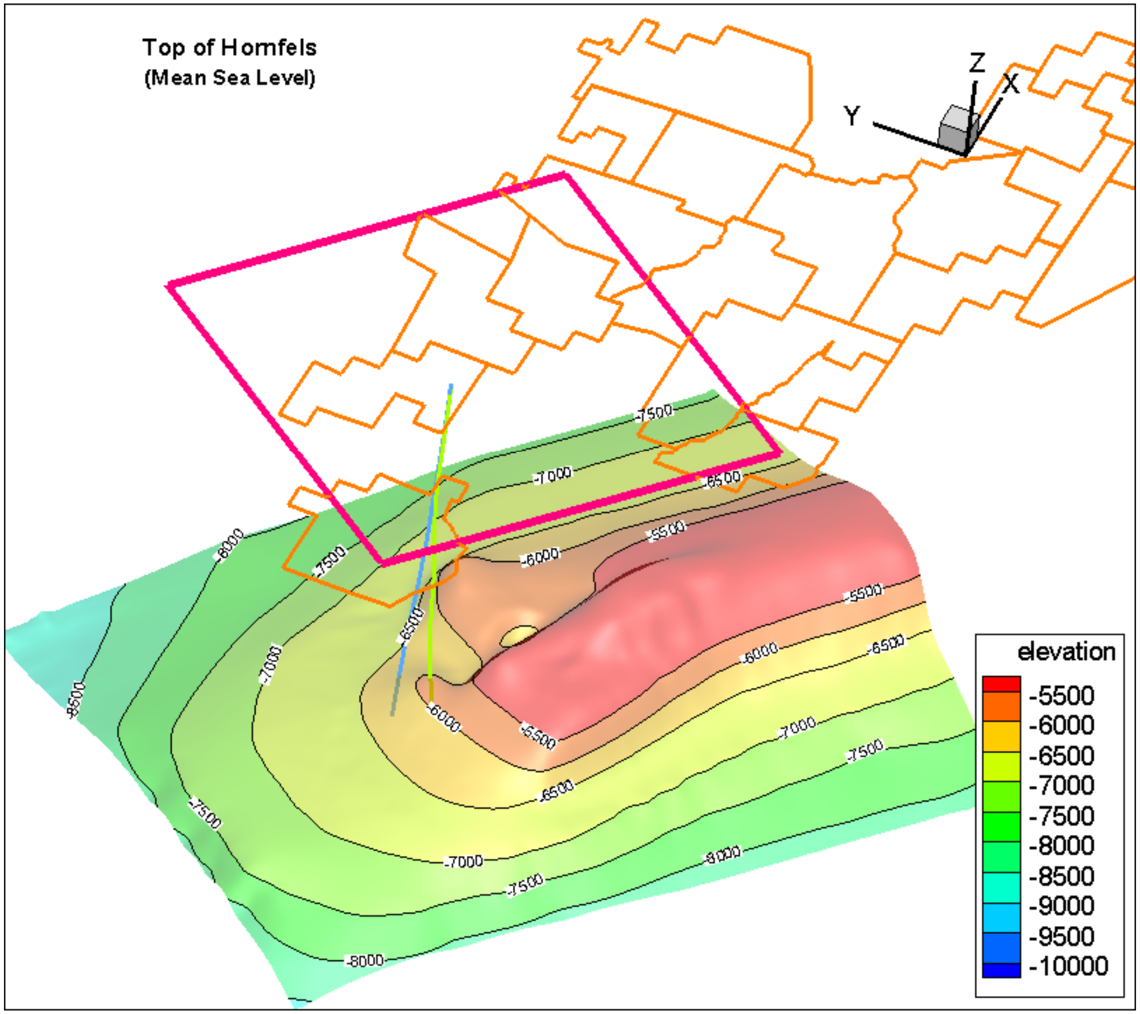
- Fieldwork (drilling, pipeline construction, monitoring) will be managed by Calpine.
- LBNL with collaboration of Calpine is conducting coupled thermal, fluid flow, and geomechanical modeling:
  - Gain insights into underlying mechanisms of micro-earthquake events (MEQs) and their role in enhancing permeability.
  - Investigate stimulation, injection and production strategies
- Field monitoring and data analysis will be focused on 3-D tomography and high-precision location source studies of MEQs.
- Calpine will repeatedly log the demonstration wells with its own Pressure-Temperature (PT) tools during pre-stimulation and the stimulation experiments.

Modeling Project Components



Three Dimensional Geological Model

- Mapped features include:
  - Caprock
  - Metagraywacke
  - Hornfelsic graywacke
  - Hot Felsite intrusion
  - Top of normal temperature (convective) reservoir
  - Top of high temperature (conductive) reservoir
- Rock property data (ρ,ϕ, k) used for reservoir model



NW Geysers Geomechanical Modeling Approach

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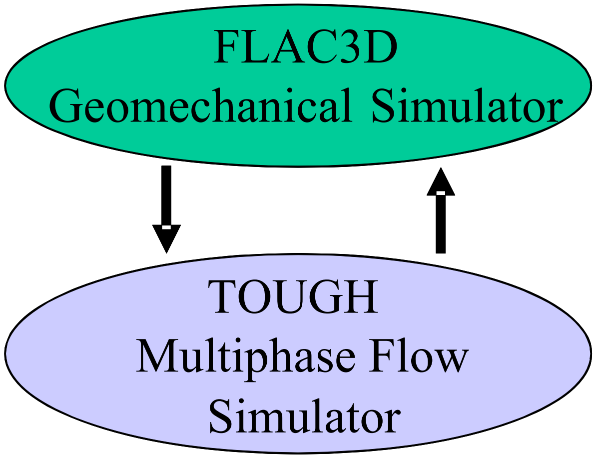

1) Use TOUGH-FLAC to calculate the thermo-elastic and poro-elastic stress evolution as a result of "cold" water injection
2) Determine whether the injection causes the stress state to move toward failure (high likelihood of MEQs)
3) Key assumptions include:
   a) Fractures are randomly oriented
   b) Fractures are critically stressed
   c) Slip is estimated using zero cohesion and a friction angle, $\varphi = 30°$

Shear Slip Analysis

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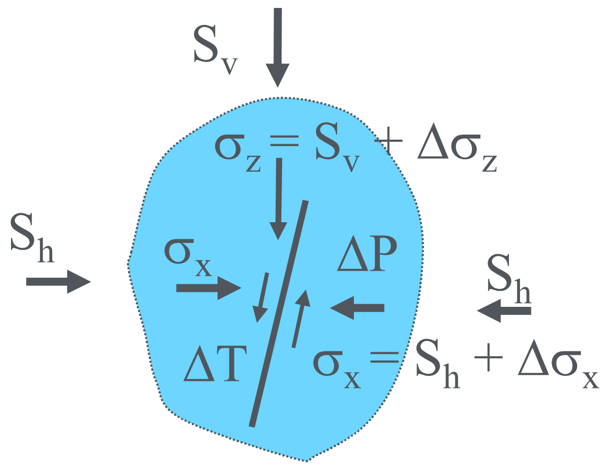
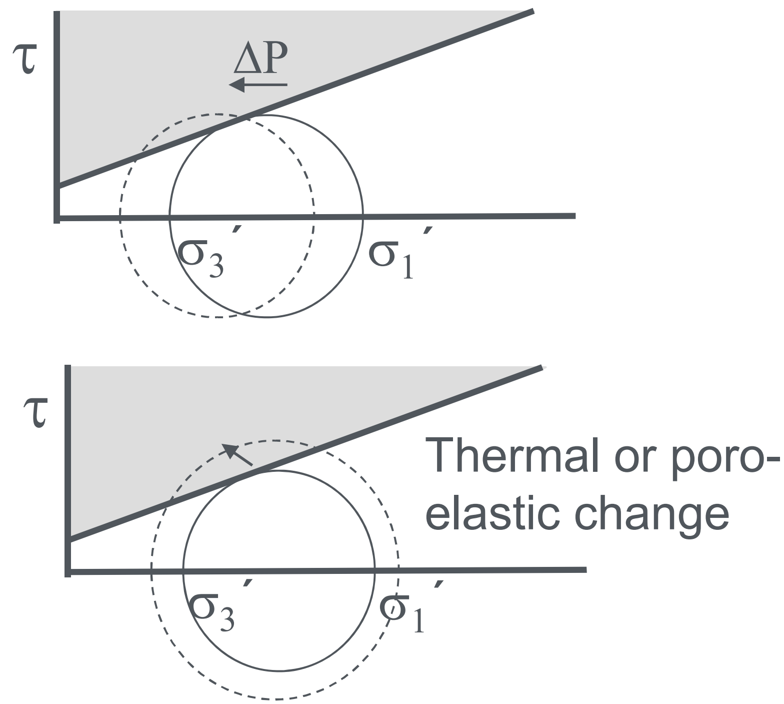
The Coulomb criterion:

$$\tau = C + \mu(\sigma_n - p)$$

Shear Stress (τ), **Cohesion** (C), **Coefficient of friction** (μ), **Normal stress** (σ_n), **Fluid pressure** (p)

Fractures on the verge of shear-slip :





Evaluate the MEQ potential:

$$\Delta\sigma'_{1m} = \Delta\sigma'_1 - 3\Delta\sigma'_3$$

$\Rightarrow$ a small change in the stress field can cause slip

Calibration of Geomechanical Model

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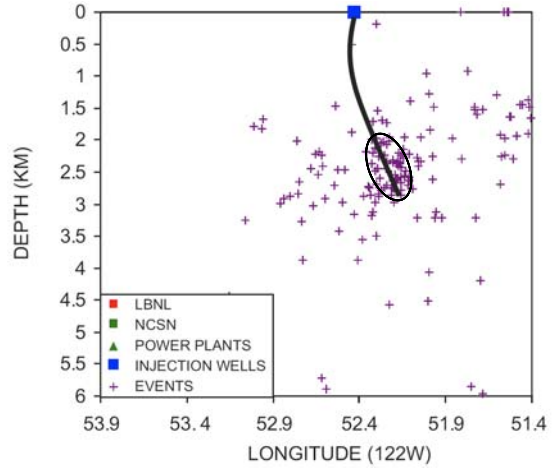
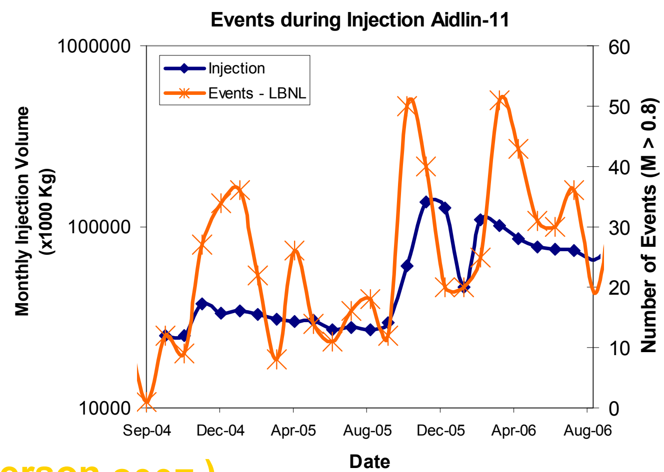


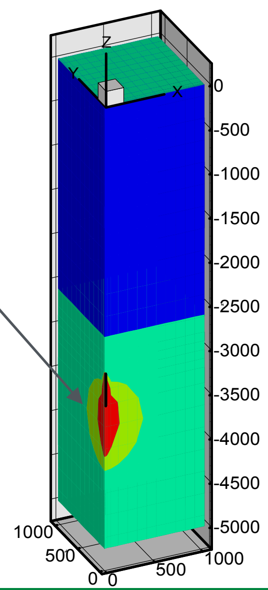


Oct 04 to Sept 05

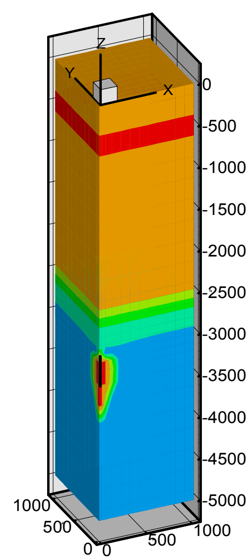
(Majer and Peterson, 2007)

"Cold" water injection

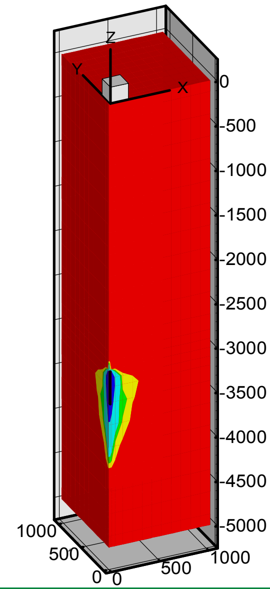
Pressure



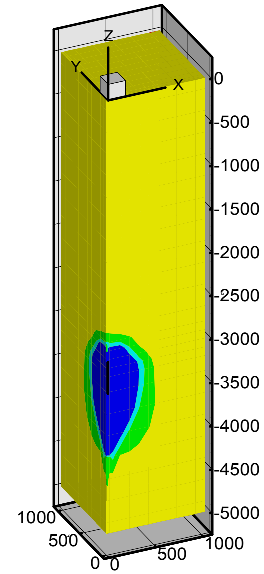
Saturation



Temperature



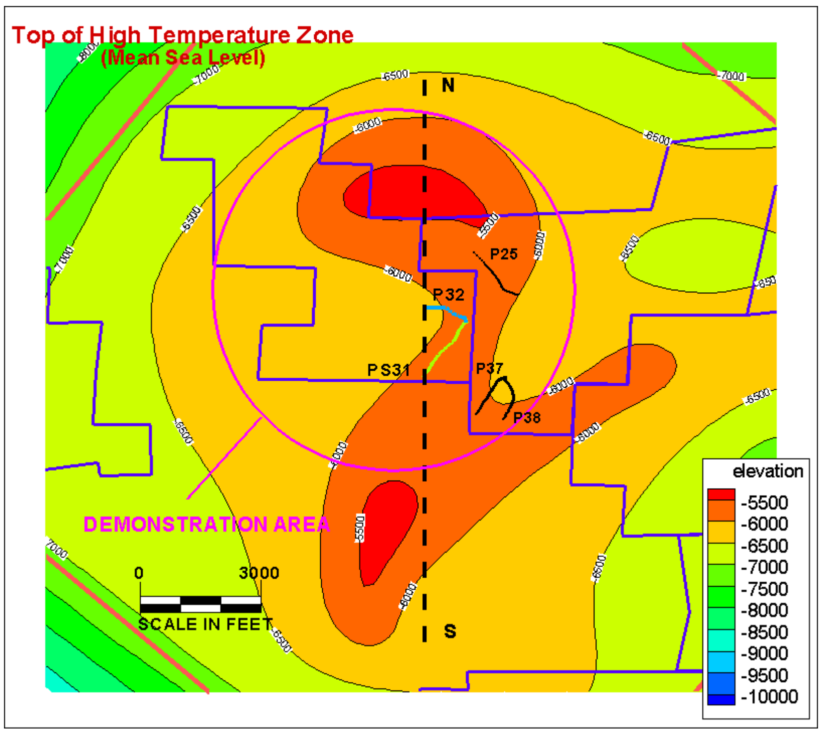
MEQ potential

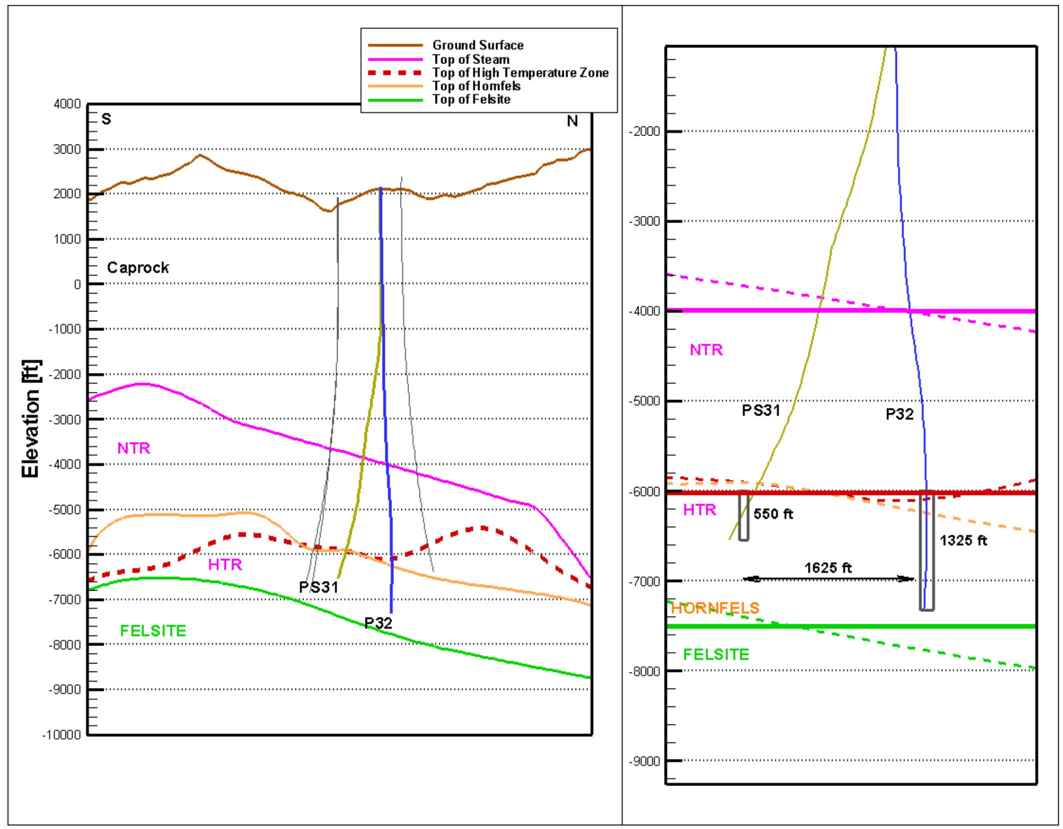


A simplified representative geomechanical model of the site:

1) Simplified 3D geometry

2) Existing modeling approach to evaluate MEQ potential using criterion developed from modeling of historic MEQs at Aidlin steam field





Well Stimulation Plan

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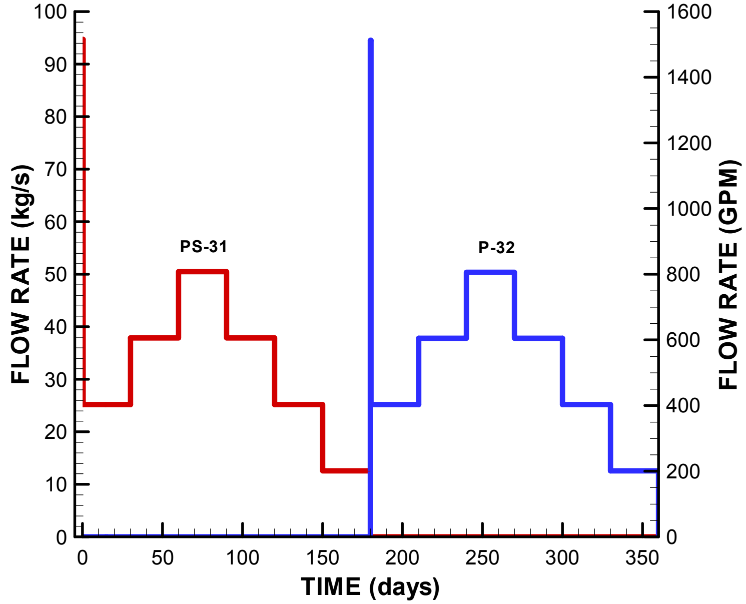
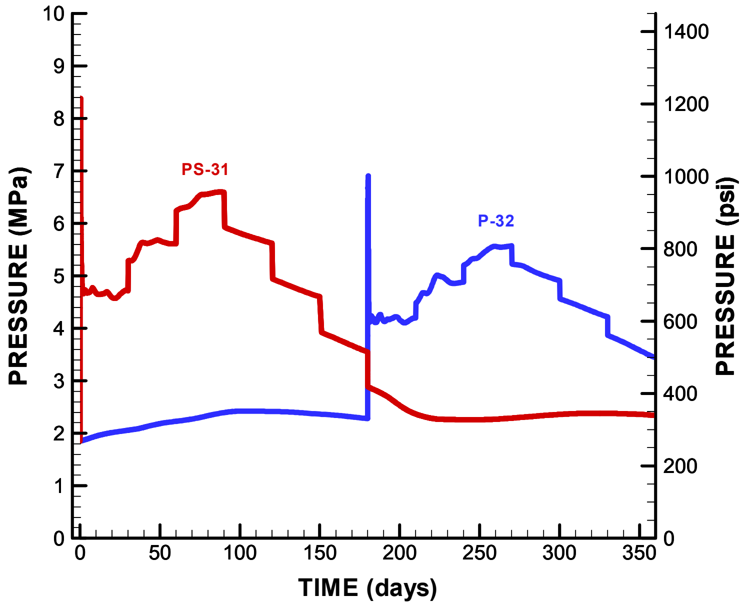
Calculated evolution of downhole well pressure





- Maximum downhole pressure of 8 MPa < σ_3, (≥ 24 MPa)
- Staged injection rates over 6 months for each well
- “Gentle” progressive stimulation of the HTZ in 200 gpm steps

Pre-Stimulation Modeling – MEQ Potential

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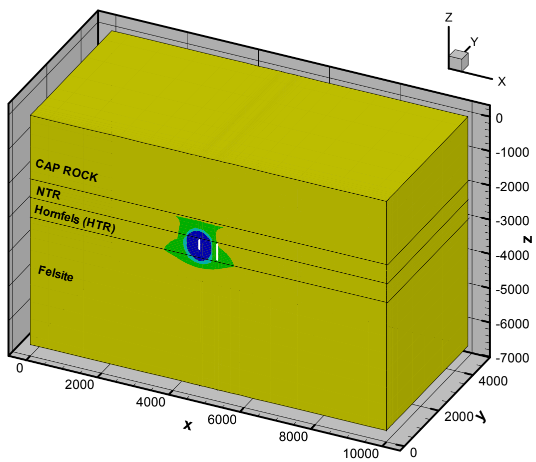
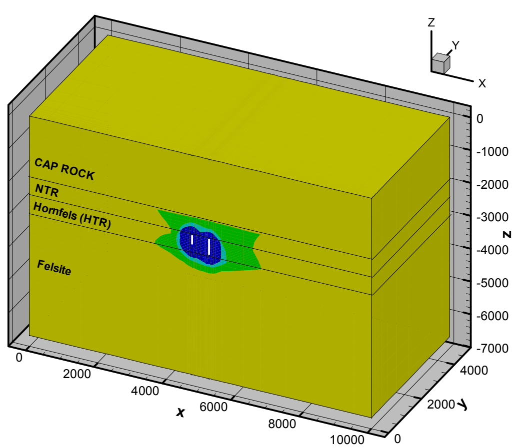
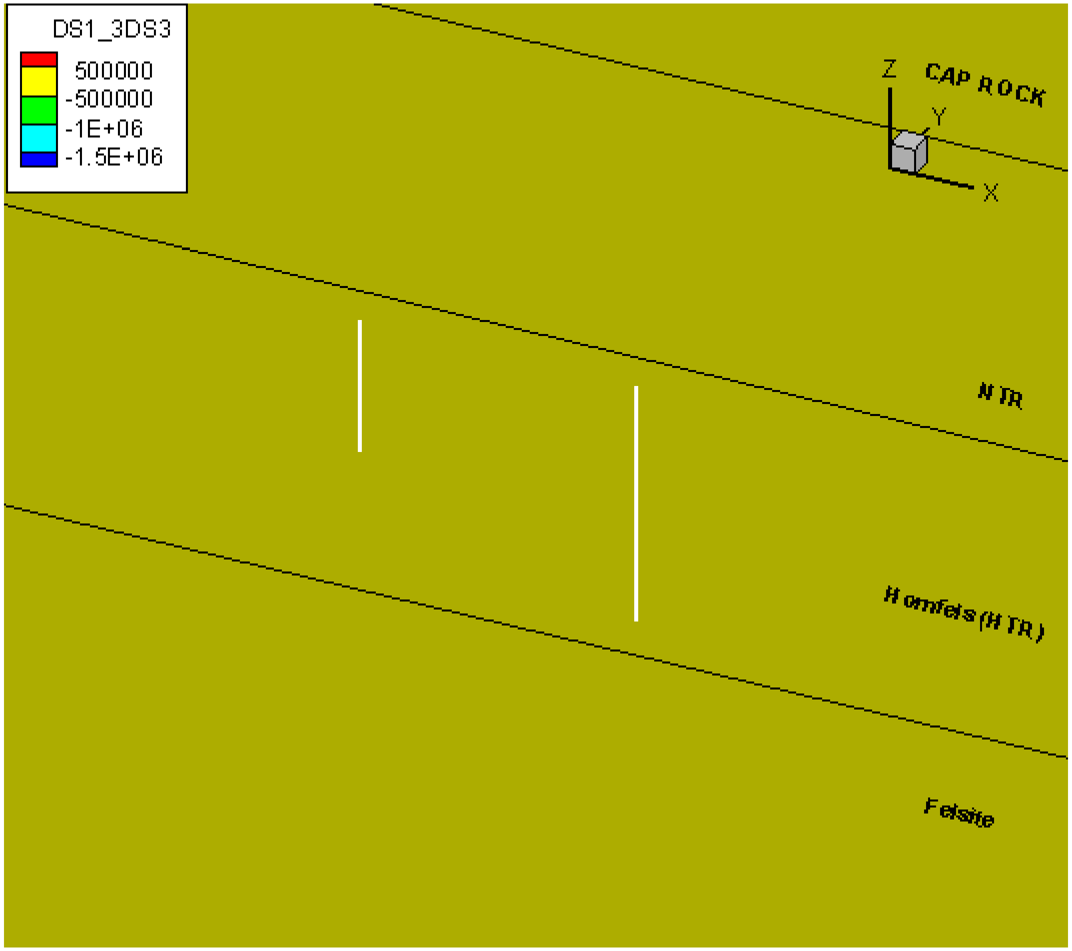
180 days



360 days





By comparison to Aidlin we can expect that the extent of the MEQ area roughly correspond to the blue contour in which $\Delta\sigma_m$ < -1.5 MPa

Injection-Induced Changes (1 year)

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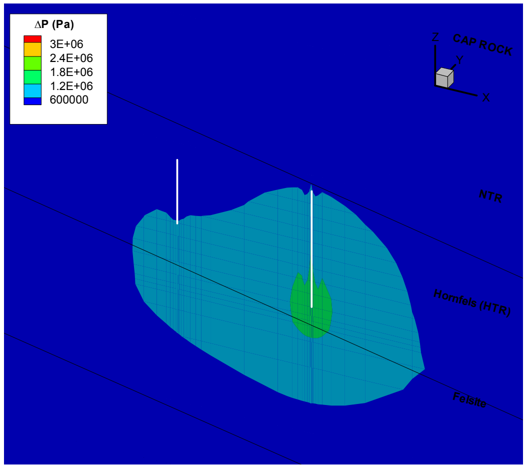
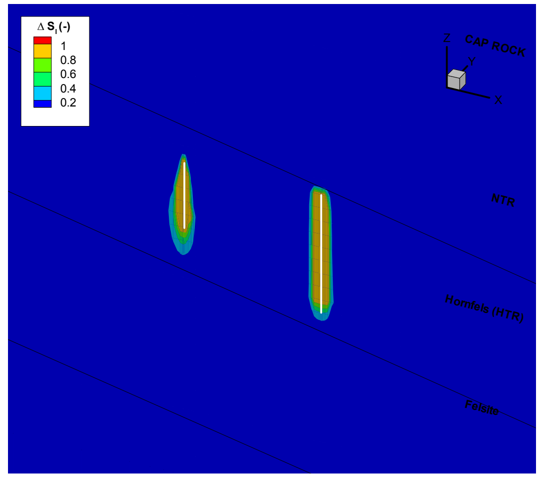
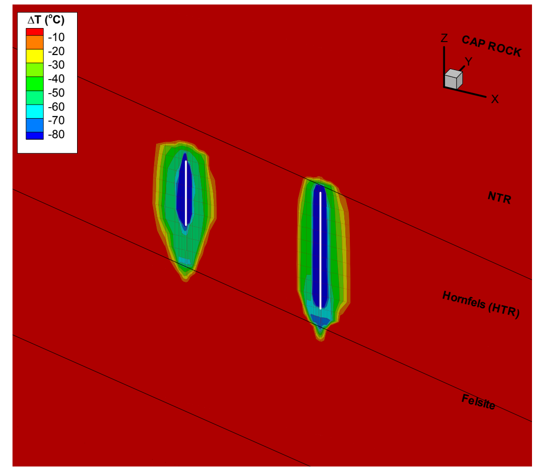
Pressure



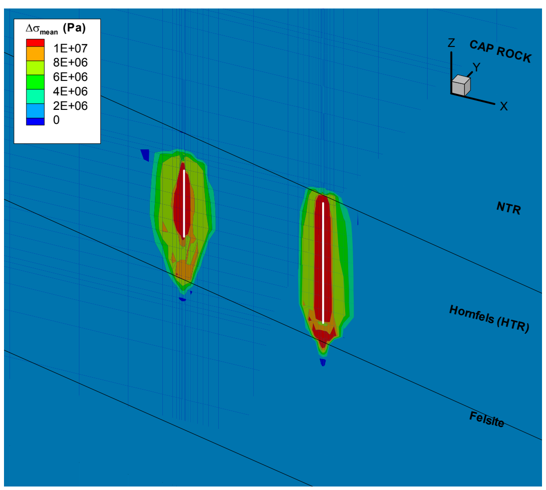
Liquid Saturation



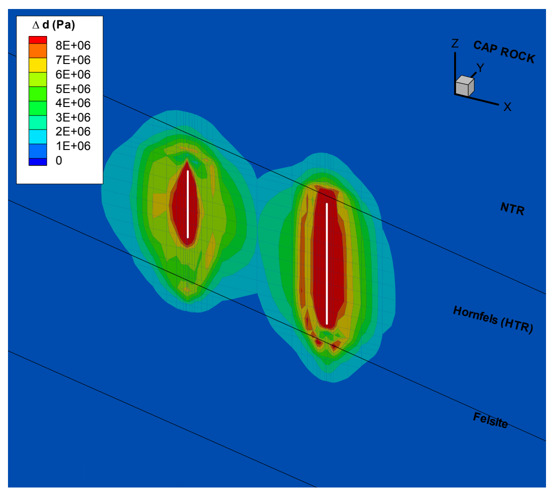
Temperature



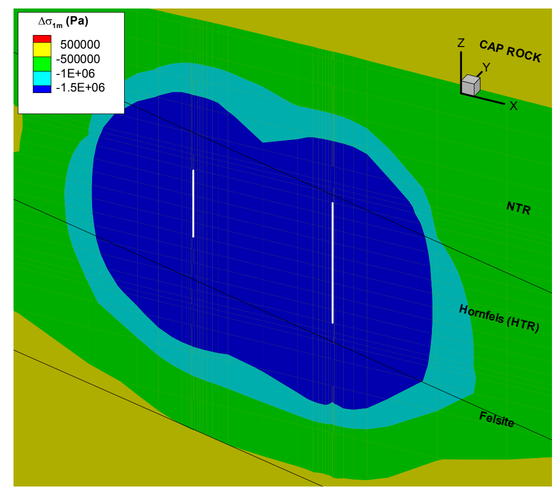
Mean Effective Stress



Deviatoric (Shear) Stress



MEQ Potential



MEQ potential results from increased shear stress caused by cooling shrinkage.

Accomplishments, Expected Outcomes and Progress

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- 3-D geologic and pre-stimulation geomechanical models are completed.
- Stimulation plan is completed.
- PS-31 and P-32 drilling and completion plans are ready.
- Well pad is ready for drilling rig.
- Injection pipeline extension from Prati 9 pad to PS-31 pad ready to go.
- Five additional MEQ stations were added to seismic monitoring array.
- All permits ready & DOE Environmental Assessment (EA) is complete.
- Project is on hold until DOE NEPA findings are made.

Project Management/Coordination

Schedule:

- Drilling and completion of Prati State 31 and Prati 32 for injection anticipated by end of FY2010. An injection pipeline is already designed and will be constructed during drilling. Funding for pipeline ($1.2 million) may be authorized if re-opening of PS-31 is successful.

Application of resources and leveraged funds/budget/spend plan:

- No funds received by Calpine to date but $3,969,770 is obligated for Phase 1 studies and drilling (not including injection pipeline)

Coordination with other DOE programs is primarily through LBNL including induced-seismicity research.

All existing data and studies for this demonstration will be non-proprietary and available to the National Geothermal Data System.

Future Directions

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- Calpine is ready to proceed with the re-opening and re-completion of Prati State 31 and Prati 32. This is anticipated to occur in Q4 of FY10 assuming DOE makes the required NEPA findings.
- DOE Authorization of the injection pipeline is anticipated after a Go/No go decision is made on the suitability of Prati State 31 as an injection well immediately after it is completed and prior to re-opening Prati 32.
- The stimulation experiments and monitoring will occur throughout FY2011.

Supplemental Slides

Summary Slide

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The drilling of this project has been on hold by the DOE since October 2009 and is waiting for DOE to complete its required NEPA review.

Calpine is ready to complete Phase 1 of the EGS demonstration this summer by re-opening and re-completing Prati State 31 and Prati 32 for injection into a high temperature zone. This <u>assumes</u> the required NEPA findings are made by the DOE by the end of May 2010.

Publications

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- J. Rutqvist, C.M. Oldenburg, P.F. Dobson, J. Garcia, and M. Walters, Predicting the Spatial Extent of Injection-Induced Zones of Enhanced Permeability at the Northwest Geysers EGS Demonstration Project. Paper selected for presentation at the 44th US Rock Mechanics Symposium to be held in Salt Lake City, UT June 27-30, 2010.