Creation of an Engineered Geothermal System through Hydraulic and Thermal Stimulation

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Principal Investigator (always include)
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University of Utah

Track Name

This presentation does not contain any proprietary confidential, or otherwise restricted information.
Mandatory Overview Slide

- **Timeline**
  - Project start date = 8/15/2001
  - Project end date = soon
  - Percent complete = 99.8%

- **Budget**
  - Total project funding = $11,646,361
  - DOE share = $5,746,361
  - Awardee share = $5,900,000

- **Partners**
  - Coso Operating Company
  - USGS
  - Kansas State University
  - Q-con
  - GMI
Objectives

• To create an Enhanced Geothermal System on the margin of the Coso field through the hydraulic, thermal, and/or chemical stimulation of one or more tight injection wells
• To increase the productivity of the Coso field by 10 MWe
• To develop and calibrate geomechanical, geochemical, and fluid flow models in order to extend the Coso/EGS concepts to wherever appropriate tectonic and thermal conditions apply
Scientific/Technical Approach

- Wellbore stimulation produces permeability enhancements due to a combination of hydraulic, thermal and chemical effects.
- Hydraulic effects are first order.
  - Fractures *re-open* through shear failure.
  - Fractures that fail in shear are self-propping.
- Thermal and chemical effects are second order.
  - Fracture apertures increase due to rock thermal contraction.
  - Fracture apertures change due to mineral dissolution and/or precipitation.
- These concepts can be extended to other geologic settings *where appropriate tectonic and thermal conditions exist.*
Scientific/Technical Approach

- **FY 2002**
  - Fracture/stress analysis
  - Petrology and petrography
  - Selection of stimulation targets

- **FY 2003**
  - Drilling of production well 38C-9
  - MT survey of east flank study area
  - Continued fracture/stress analysis, petrology/petrography
  - Modeling to predict effects of shear failure, chemical dissolution/precipitation, thermal contraction on porosity and permeability

- **FY 2004**
  - Low-pressure stimulation of target EGS injector 34A-9
  - Microseismic survey
  - Continued fracture/stress analysis, petrology/petrography, and modeling to predict effects of shear failure, chemical dissolution/precipitation, thermal contraction on porosity and permeability

- **FY 2005**
  - Redrilling and hydraulic stimulation of 34-9RD2
  - Continued modeling to predict effects of shear failure, chemical dissolution/precipitation, thermal contraction on porosity and permeability
  - Hydraulic stimulation of 46A-19

- **FY 2006**
  - Continued hydraulic stimulation of 46A-19
  - Continued modeling to predict effects of shear failure, chemical dissolution/precipitation, thermal contraction on porosity and permeability
Accomplishments, Expected Outcomes and Progress

Regional Stress Mapping and Analysis
(Nick Davatzes, USGS)
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Regional Stress Mapping and Analysis (Nick Davatzes, USGS)

Fluid Flow
- Ancient alteration
- Ancient & active? alteration
- Fumaroles/Steaming ground

Faults (ages from offset sediments)
- Ancient and probably inactive faults (?)
- Faults active since 1.6 Ma
- Modern faults (offset Holocene sediments)
  (Ball on down-thrown side)

Miscellaneous
- Well head and trajectory of selected wells

Stress Direction
- Least principal stress azimuth
  (mean orientation of induced structures in image logs of wells)
  Davatzes & Hickman (2005a & b),
  Sheridan & Hickman, GWR (2003)
- Least principal stress azimuth
  (inverted from seismicity; arrow: S_{min}, line: S_{Hmax}, circle: S_{p})
  Feng & Lees (1998)
- Azimuth of principal strains
  (inverted from seismicity;
   outward arrow: extensional dir;
   inward arrow: contractional dir)
  Unruh et al. (2002)

Earthquake Magnitude
- -2 to 0
- 0 to 1
- 1 to 2
- 2 to 3
- 3+
Accomplishments, Expected Outcomes and Progress

Regional Stress Mapping and Analysis
(Nick Davatzes, USGS)

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Accomplishments, Expected Outcomes and Progress
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Petrography and Petrology of 34A-9 from Wellbore Cuttings
Petrography and Petrology of 34-9RD2 from Wellbore Cuttings
Objective:
To characterize reservoir fracturing and stresses in order to model and predict fracture shear failure and the subsequent increases in permeability that result from hydraulic stimulation.
Accomplishments, Expected Outcomes and Progress

Fracture/Stress Analysis
Accomplishments, Expected Outcomes and Progress

- **Good** data
- **Fair** data
- **Poor** data

Fractures with Significant Apparent Aperture

**Depth, feet MD**

- All Fractures
- Fractures with Significant Apparent Aperture
Accomplishments, Expected Outcomes and Progress

**Pp** and **Failure Envelope** drawn for surface hydrostat (pre-production)

**S_{Hmax} bounds** from **S_{hmin} extrapolation** and general absence of breakouts, assuming minimum \( C_0 \) shown (22 kpsi preliminary Coso strength tests, 15 kpsi typical granites [Lockner, 1998])
Accomplishments, Expected Outcomes and Progress
Magnetotelluric Survey of the Coso East Flank

Phil Wannamaker
Accomplishments, Expected Outcomes and Progress

Cross-Section of East Flank Compartment
Accomplishments, Expected Outcomes and Progress

3-D View of East Flank Compartment

Stitched 2D Sections, Coso Thermal Area

\( \rho \) (ohm-m)
Accomplishments, Expected Outcomes and Progress

Low-Wellhead-Pressure Stimulation of 34A-9

- Drilled in 1993, 34A-9 had temperatures approaching 350°C but very low injectivity.
- After a series of condensate injections totaling 72,000 bbls, the injection rate was 800 gpm at 0 psi WHP.
- A flow test indicated moderately high productivity.
- The well was used for injection, but damage in the shallow casing required that it be shut in.
- After a ‘tie-back’ repair of the shallow casing, 34A-9 was placed on injection
  - 2000 gpm of hot, separated brine
  - 60 psi WHP
- Tracer test initiated
- Microseismicity monitored during the stimulation
Accomplishments, Expected Outcomes and Progress

Tracer Testing of Stimulated Well 34A-9

![Graph showing tracer testing results](image)

**Legend:**
- Dots: Injectors
- Squares: Producers
- Arrows: Orientation of $S_{Hmax}$

**Key Points:**
- Time (days) on the x-axis.
- 1,3,6-nts concentration (ppb) on the y-axis.

**Well Locations:**
- 34-9RD2
- 34A-9
- 38C-9
- 38-9
- 38A-9
- 38B-9

**Stimulation Target:**

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eere.energy.gov
Workover, Drilling, and Stimulation of the EGS Injector 34-9RD2

34-9RD2

34A-9

38A-9

38C-9

38B-9

38-9

stimulation target

inectors
producers
orientation of $S_{Hmax}$

0 500 1000 1500 2000 2500 feet

N
## 34-9RD2 Workover, Redrilling and Stimulation While Drilling

<table>
<thead>
<tr>
<th>Task as Planned</th>
<th>Task as Accomplished</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pull 7” liner</td>
<td>Liner easily removed</td>
</tr>
<tr>
<td>Conduct FMS log</td>
<td>FMS log mostly successful</td>
</tr>
<tr>
<td>Cement 5400’ zone</td>
<td>Extensive cementing needed</td>
</tr>
<tr>
<td>No re-drilling anticipated</td>
<td>Hole lost. COC redrills between 4600’-7900’</td>
</tr>
<tr>
<td>Cement 7” casing</td>
<td>Casing successfully reverse cemented from surface to 7900’</td>
</tr>
<tr>
<td>Take 30’ of spot core</td>
<td>Only 6’ of core obtained due to extensive formation fracturing, small diameter of core barrel, hole, 3.5” drill pipe, etc.</td>
</tr>
<tr>
<td>Conduct mini-hydrofrac</td>
<td>RTTS fails but mini-hydrofrac successful</td>
</tr>
<tr>
<td>Drill open hole</td>
<td>Open hole is successfully drilled: 7900’—8625’</td>
</tr>
<tr>
<td>Log open hole</td>
<td>Velocity, density gamma successful, but borehole televiewer run fails—retry planned for following day</td>
</tr>
<tr>
<td>Deepen hole by 150’</td>
<td>Large lost-circulation zones encountered with total mud losses at 8685’. Drill to T.D. of 8775’. Install slotted liner: 7900’—8775’</td>
</tr>
</tbody>
</table>
Microseismic Analysis
Bruce Julian and Gillian Foulger, USGS

Objectives:
• To measure the locations and magnitudes of earthquakes associated with the hydraulic stimulations of 34A-9 and 34-9RD2 of 46A-19RD in order to characterize the effect of the stimulation process on microseismicity and apparent fracture creation.

• To calculate moment tensors as calculated from the earthquakes measured during the hydraulic stimulations of 34A-9 and 34-9RD2 in order to characterize failure mechanisms.
Accomplishments, Expected Outcomes and Progress

Sensor Locations for the Coso/EGS Microseismic Experiments
Moment tensors of injection-related MEQs

- Planned to pressurize well with 1000 psi differential pressure at the wellhead
- when 2,654 m (8625 feet) reached large fractures encountered
- total mud losses at ~2,670 m
- obviated need to stimulate well, but still induced many MEQs
Accomplishments, Expected Outcomes and Progress

Stimulation-while-drilling experiment February-March 2005: MEQs induced
Accomplishments, Expected Outcomes and Progress

Microseismic Events: Time History

February, 2005

March

UTC Day, 2005

March 3, 2005
Accomplishments, Expected Outcomes and Progress

February

March

April

Pre-injection (February 2005)

Pre-swarm

Co-swarm

Post-swarm

Post-injection (April 2005)
Accomplishments, Expected Outcomes and Progress
Accomplishments, Expected Outcomes and Progress

Tracer testing
Accomplishments, Expected Outcomes and Progress

- B01
- B2
- B5
- SM2
- B4

Features:
- 34-9RD2
- 34A-9
- Activated by both injections
- Activated by 34-9RD2 injection

Diagram details include geographical markers and connections between locations.
Project Management/Coordination

DOE, Office of Energy Efficiency and Renewable Energy

Geothermal Program Office, Naval Air Weapons Station

Coso Operating Company, LLC

Coso/EGS Project
Project Management/Coordination

Management Committee

Peter Rose, PI
Jess McCulloch, Co-PI
Steve Hickman, Co-PI
Colleen Barton, Co-PI

Well Drilling, Completion, Borehole Testing
COC
Jess McCulloch
John Gastineau
USGS
Steve Hickman
Nick Davatzes

Electrical Geophysics
EGI
Phil Wannamaker
Quantec

Hydraulic Stimulation
Q-con
Ralph Weidler
Stefan Baisch
COC
Jess McCulloch
USGS
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Nick Davatzes
EGI
Pete Rose
Mike Mella

Geomechanical/Structural Analysis
GMI
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USGS
Steve Hickman
Nick Davatzes

Microseismics
Navy GPO
Frank Monastero
Keith Richards-Dinger
Q-con
Stefan Baisch
USGS
Bruce Julian
Gillian Foulger

Structural Modeling and 3-D Visualization
GPO
Frank Monastero
Nick Davatzes
EGI
Doug Ekart

Fluid-Flow Modeling
KSU
Dan Swenson
GeoWatt
Thomas Kohl
Thomas Megel
UND
Ahmad Ghassemi
LBNL
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Joe Moore
Katie Kovac