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

Creation of an Engineered Geothermal System through Hydraulic and Thermal Stimulation

May 18, 2010

Principal Investigator (always include)
Peter Rose
University of Utah

Track Name

Mandatory Overview Slide

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- 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

Relevance/Impact of Research

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

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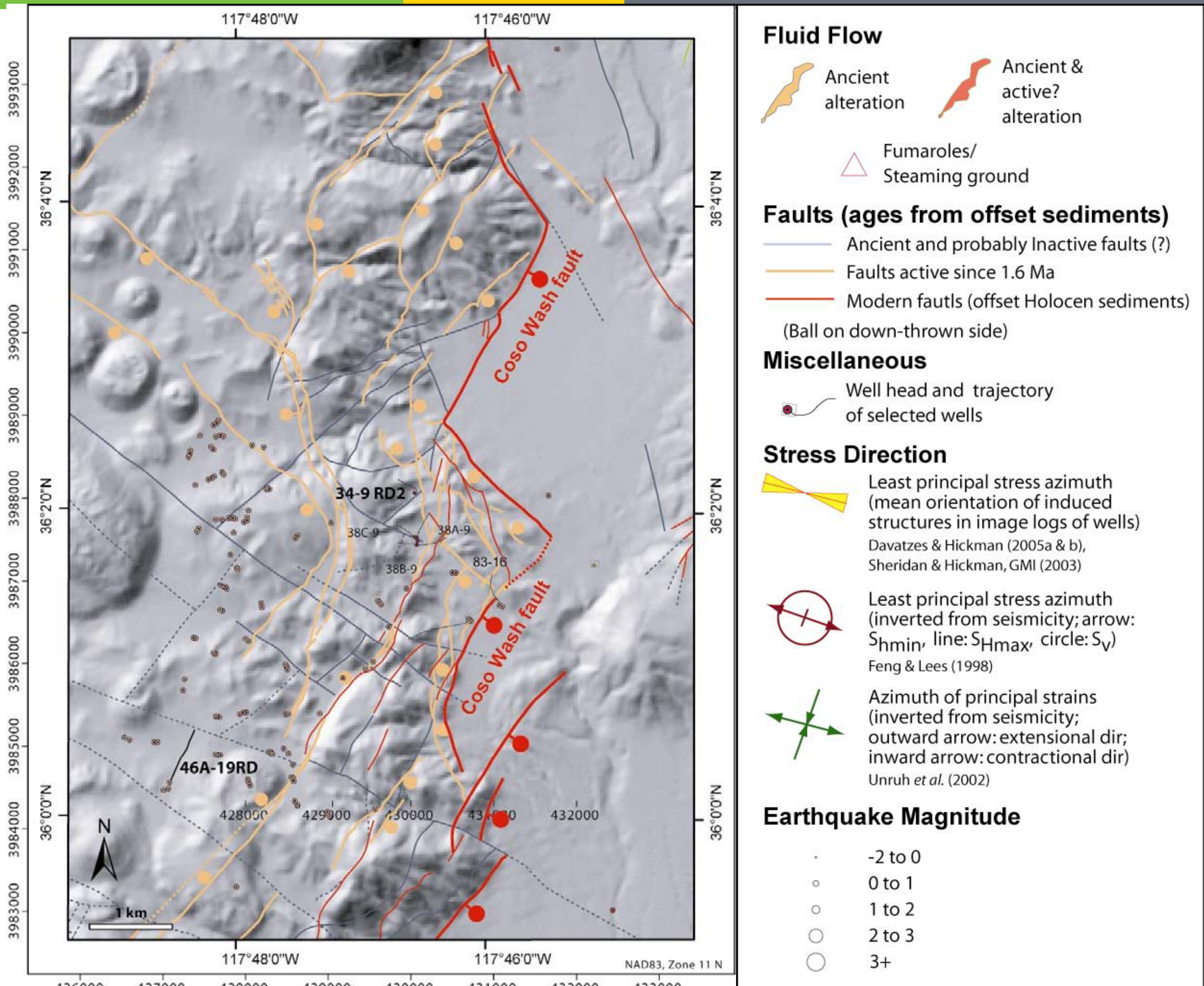
Regional Stress Mapping and Analysis

(Nick Davatzes, USGS)



Regional Stress Mapping and Analysis

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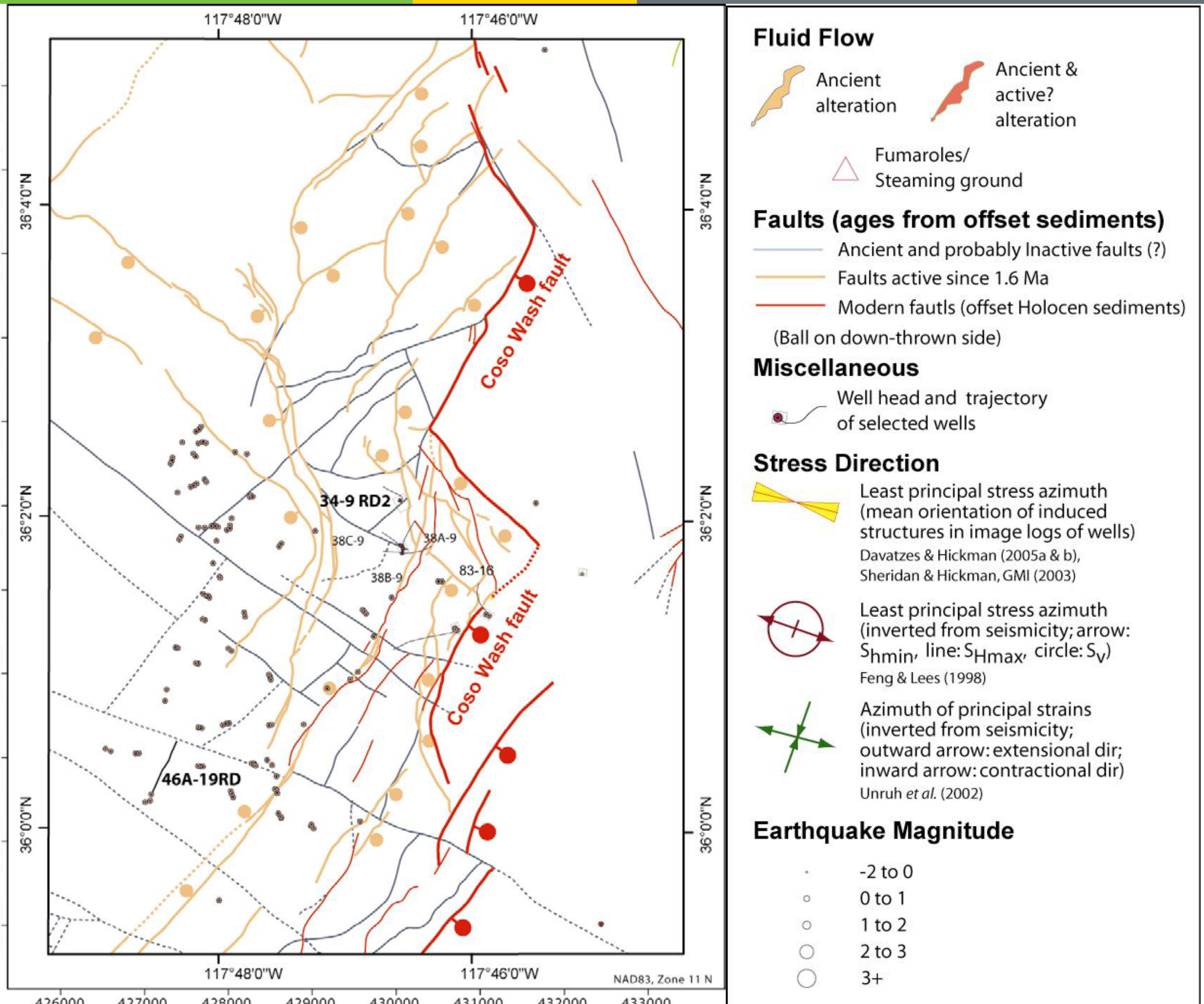

Accomplishments, Expected Outcomes and Progress

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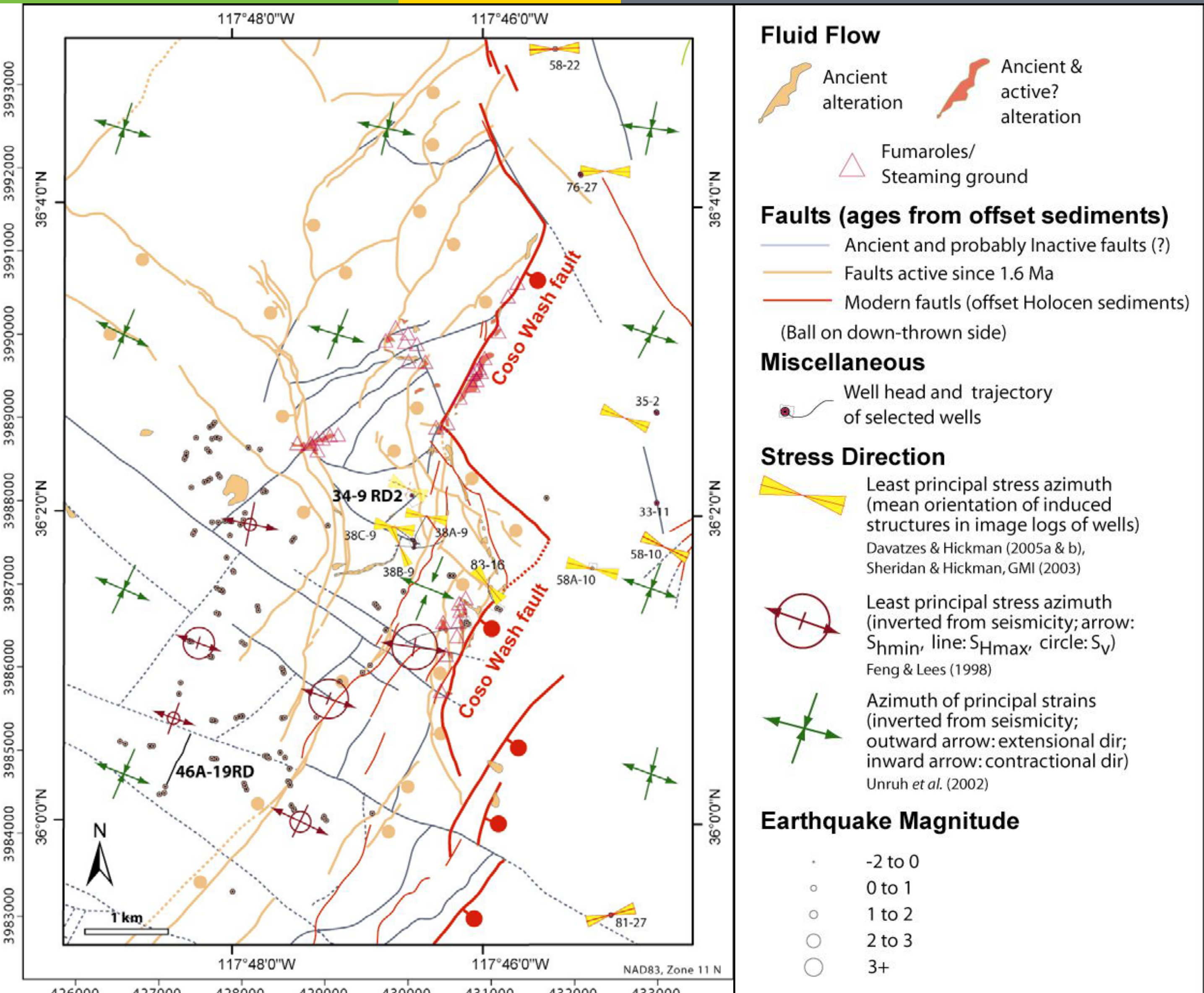

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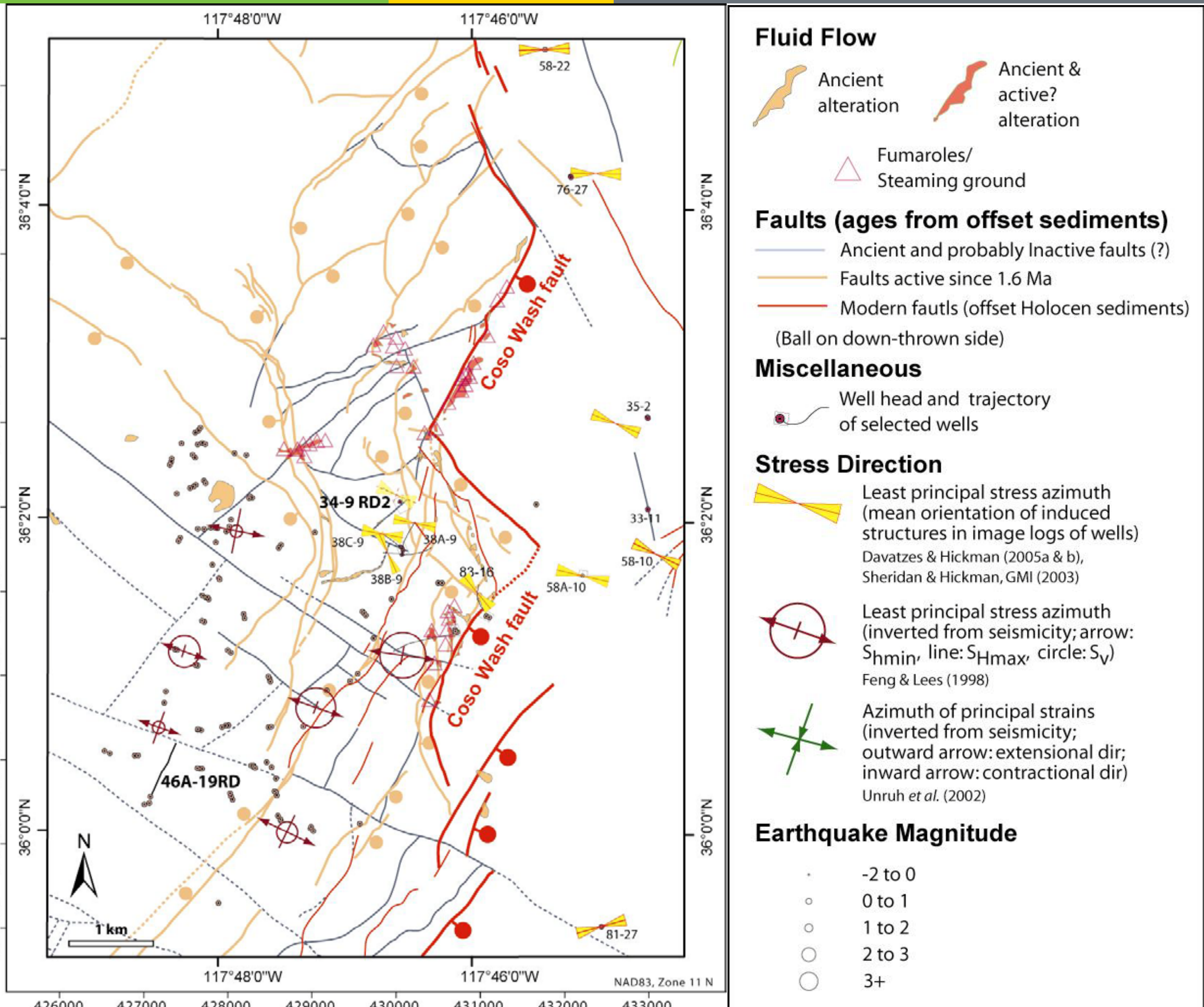

Accomplishments, Expected Outcomes and Progress

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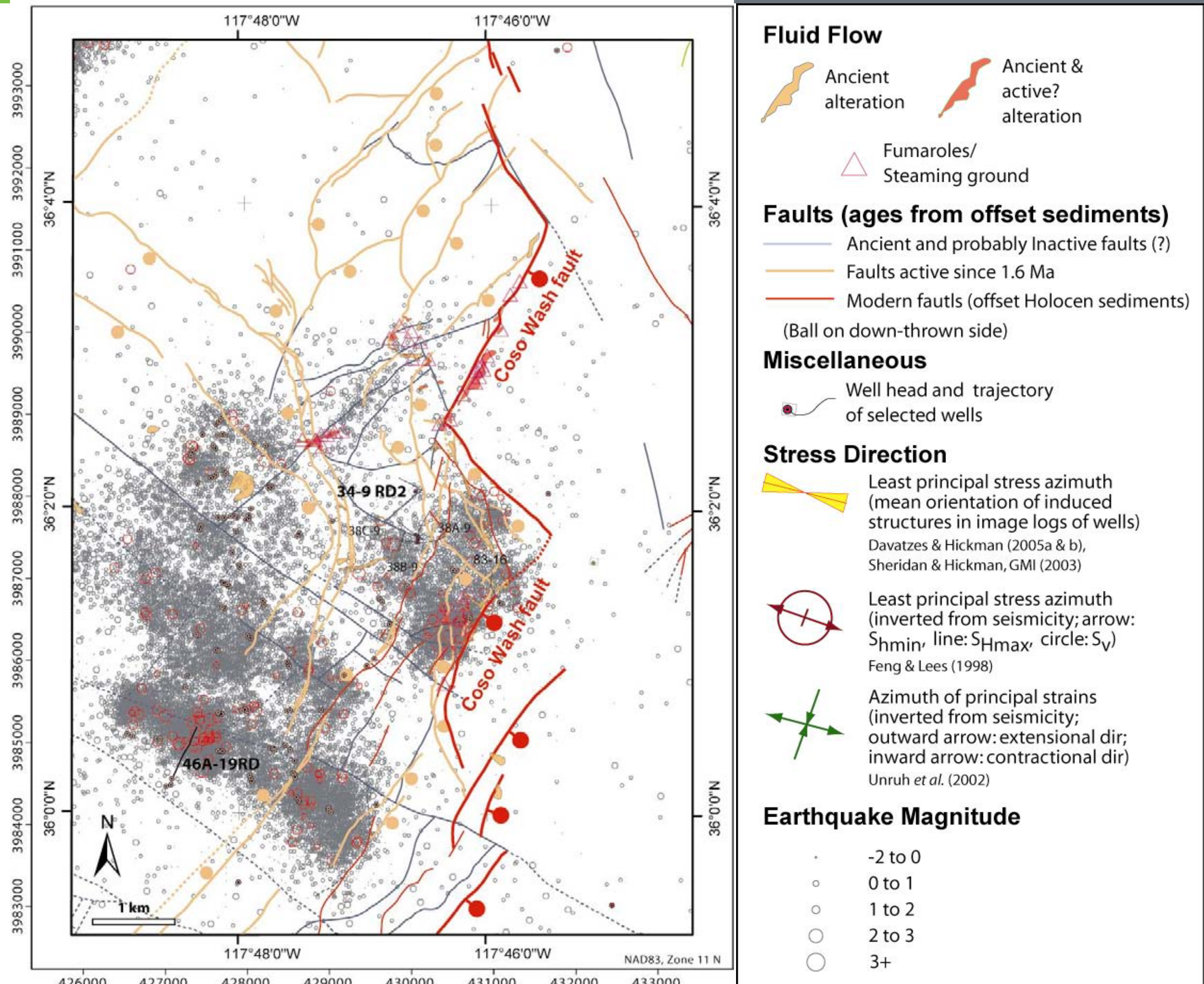
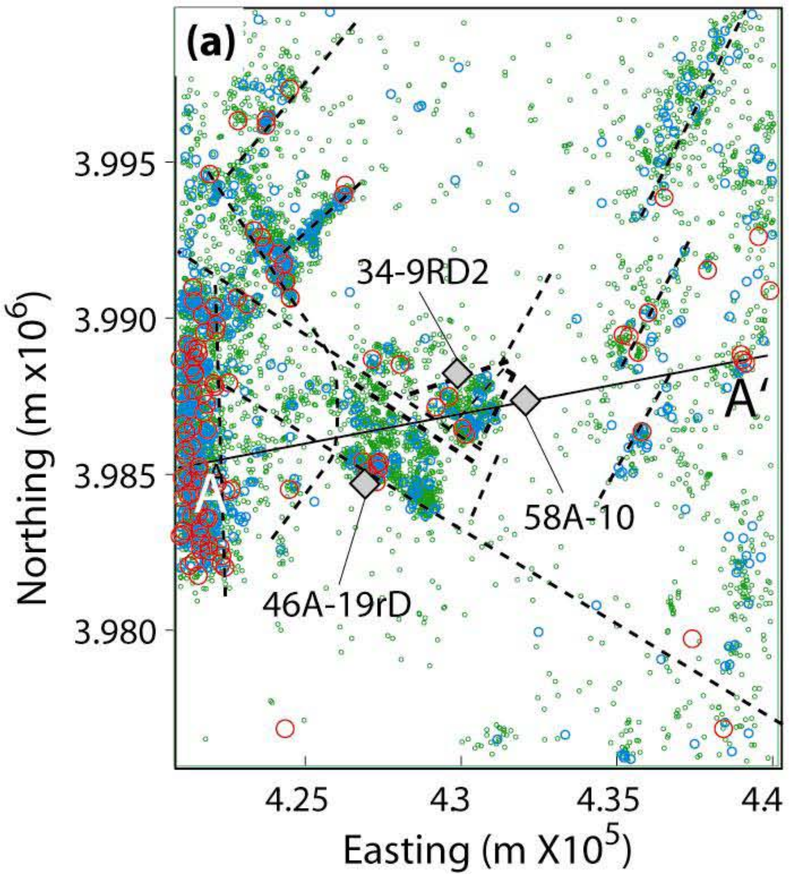
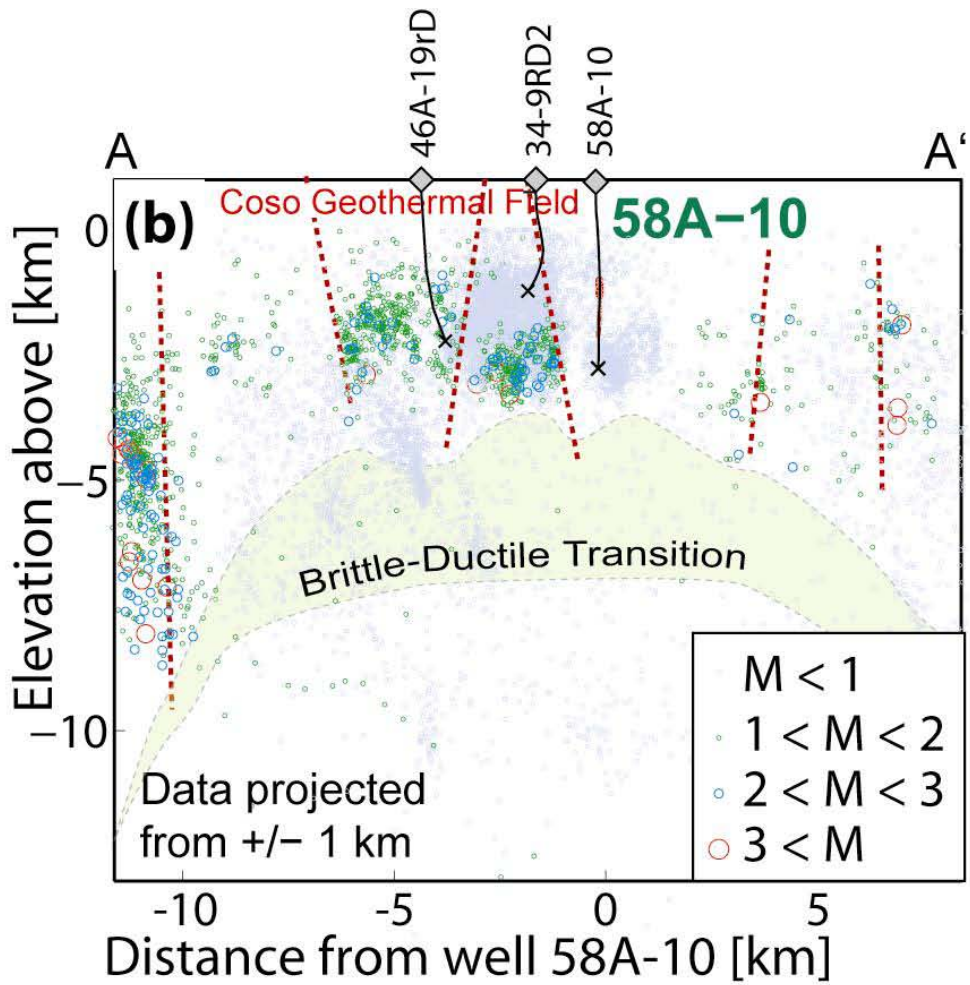
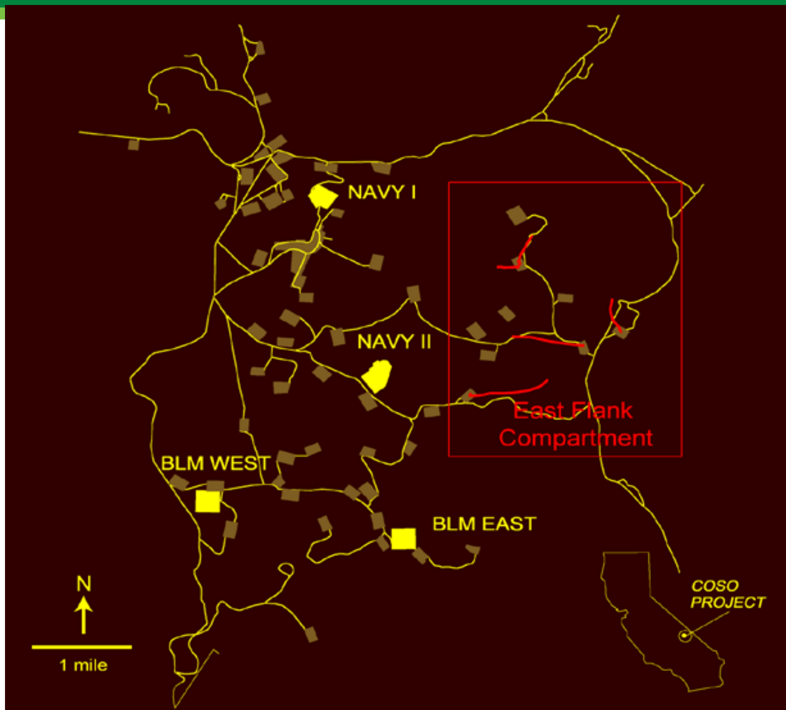



(a)
34-9RD2
58A-10
46A-19rD
A
A'
3.995
3.990
3.985
3.980
Northing (m x10^6)
4.25
43
4.35
4.4
Easting (m X10^5)

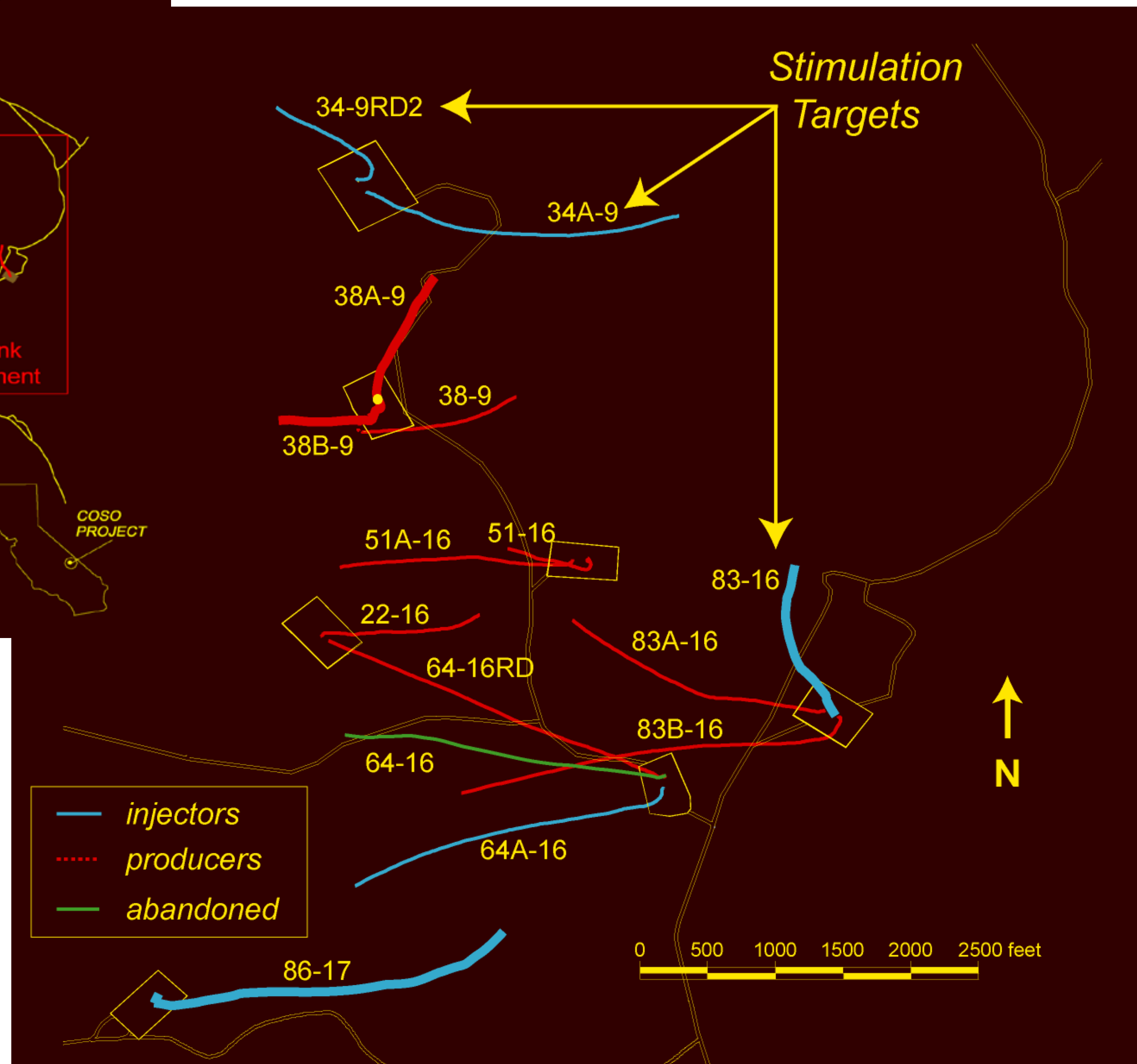

46A-19rD
34-9RD2
58A-10
A
A'
(b)
Coso Geothermal Field
58A−10
Brittle-Ductile Transition
Elevation above [km]
0
−5
−10
Data projected
from +/− 1 km
M < 1
1 < M < 2
2 < M < 3
3 < M
-10
-5
0
5
Distance from well 58A-10 [km]

Accomplishments, Expected Outcomes and Progress



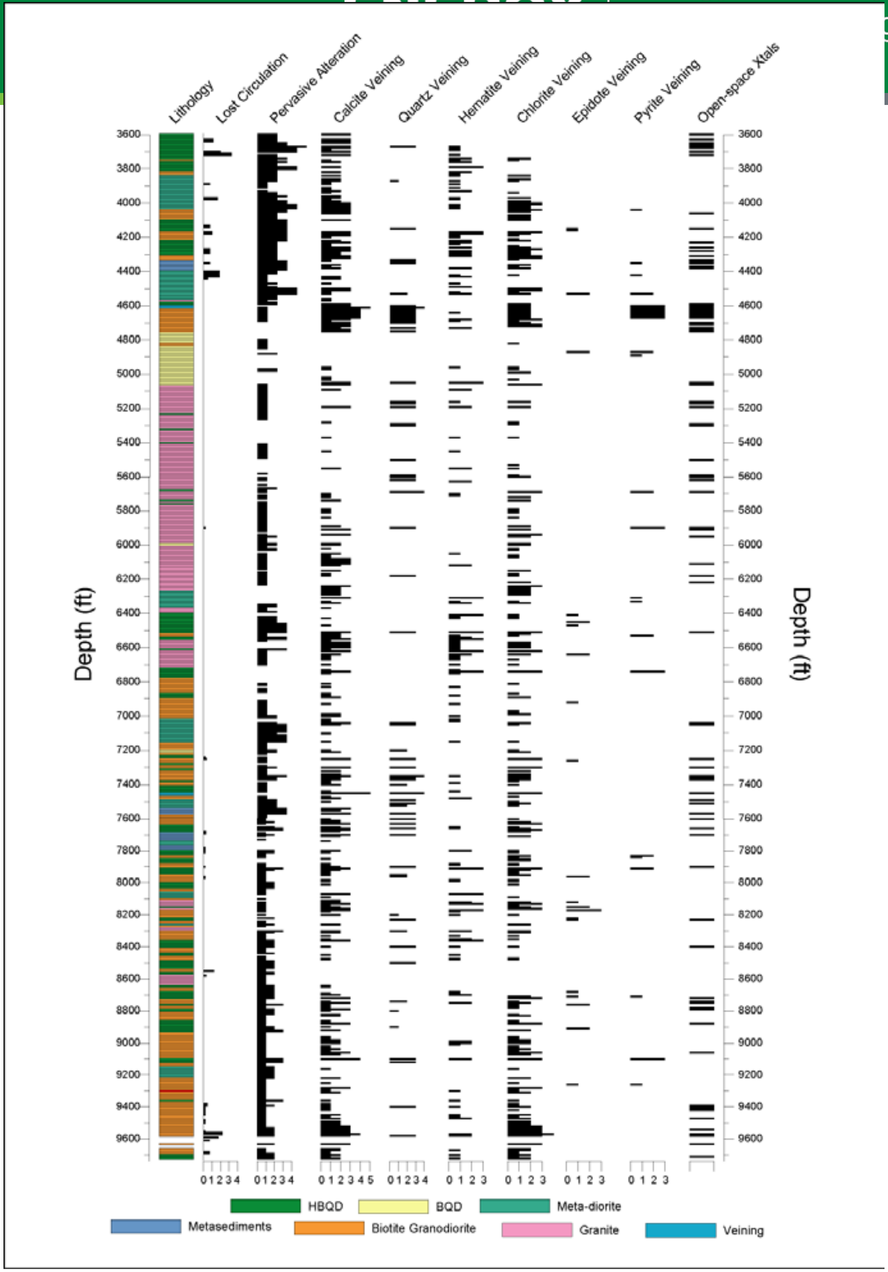
The Coso Field

The Coso East Flank EGS Study Area:



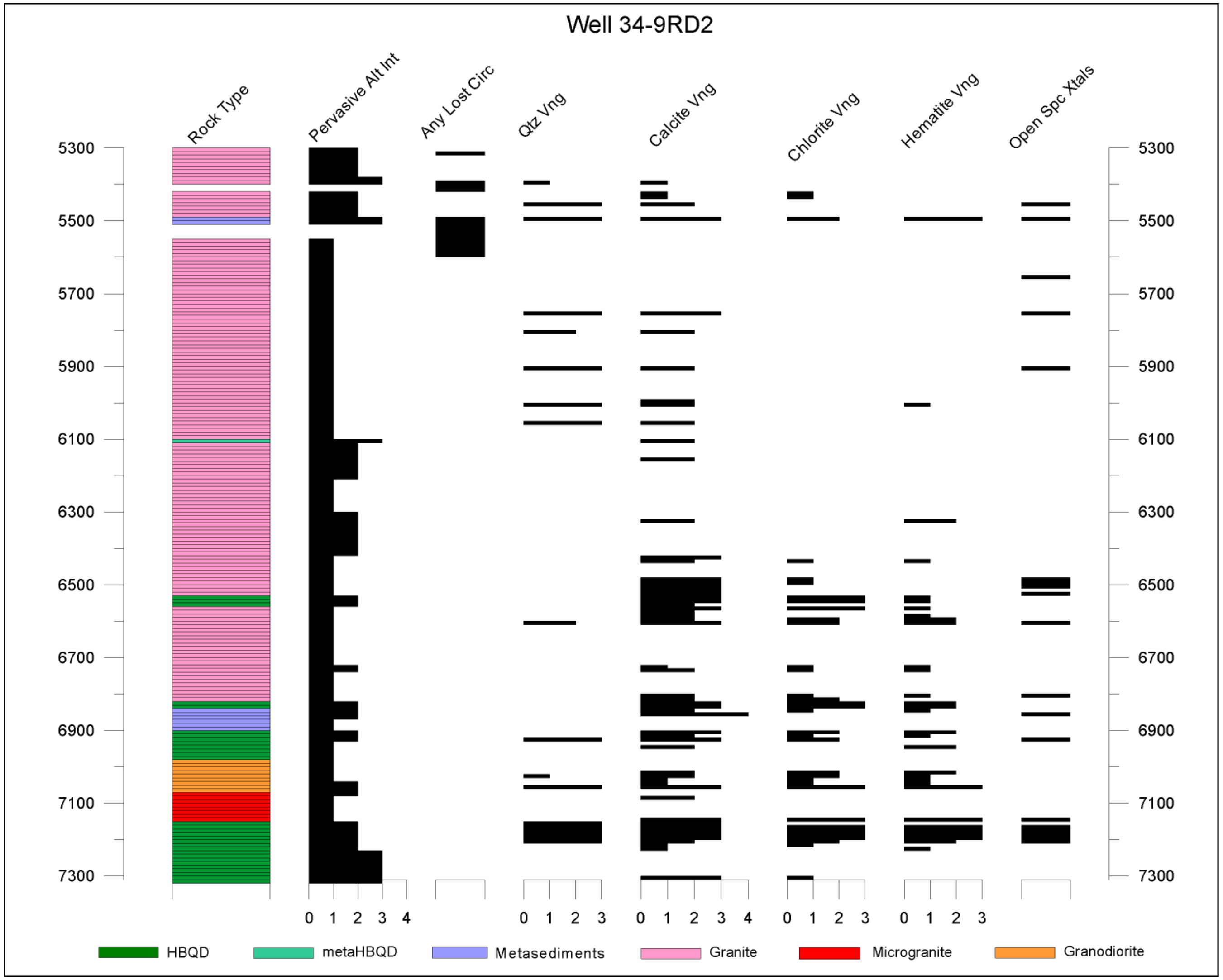
Accomplishments, Expected Outcomes and Progress

Petrography and Petrology of 34A-9 from Wellbore Cuttings



Accomplishments, Expected Outcomes and Progress

Petrography and Petrology of 34-9RD2 from Wellbore Cuttings



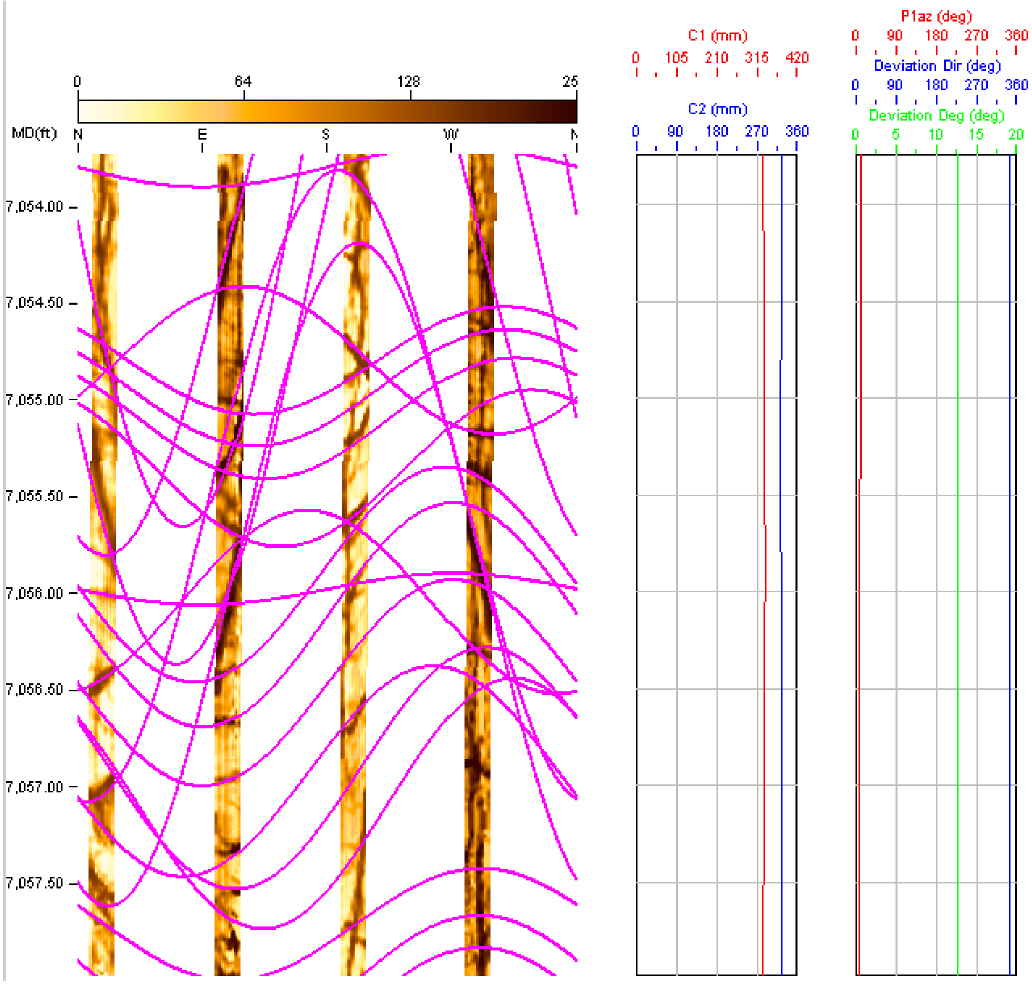
Fracture/Stress Analysis

Judith Sheridan and Steve Hickman

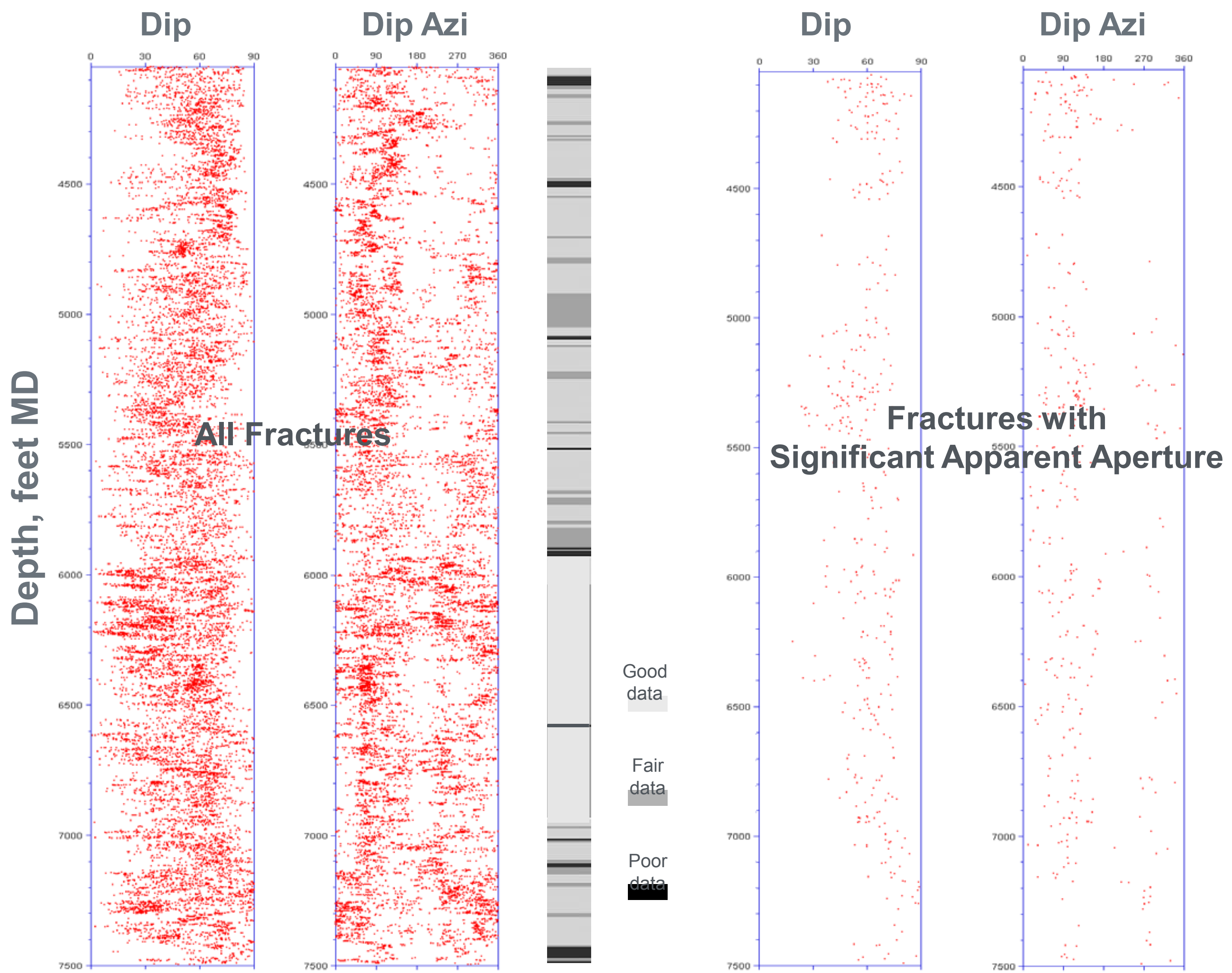
Objective:

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

Fracture/Stress Analysis



Accomplishments, Expected Outcomes and Progress



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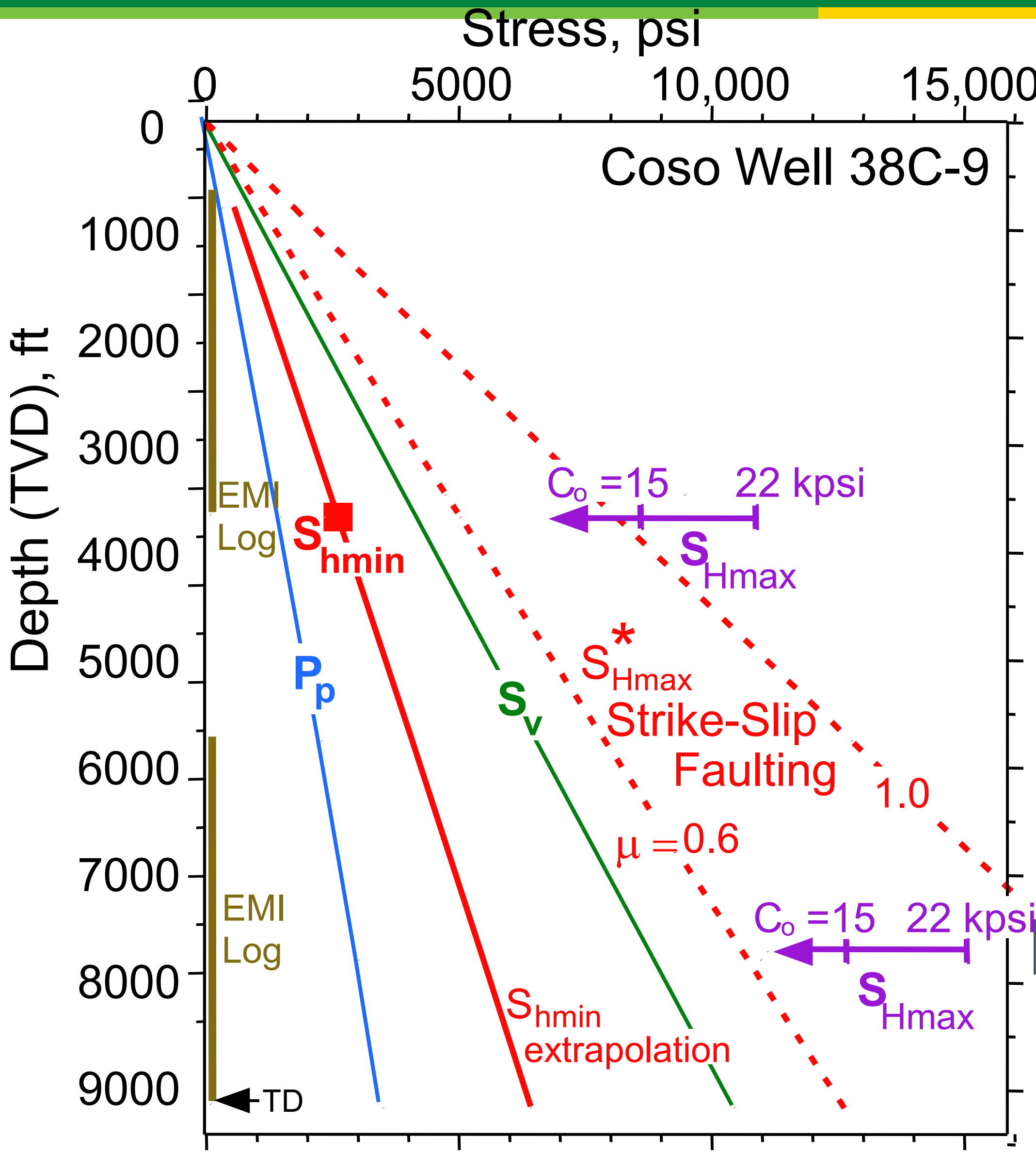


P_p and **Failure Envelope** drawn for surface hydrostat (pre-production)

S_{Hmax} bounds from S_{hmin} extrapolation and general absence of breakouts, assuming *minimum* C_o shown (22 kpsi preliminary Coso strength tests, 15 kpsi typical granites [Lockner, 1998])

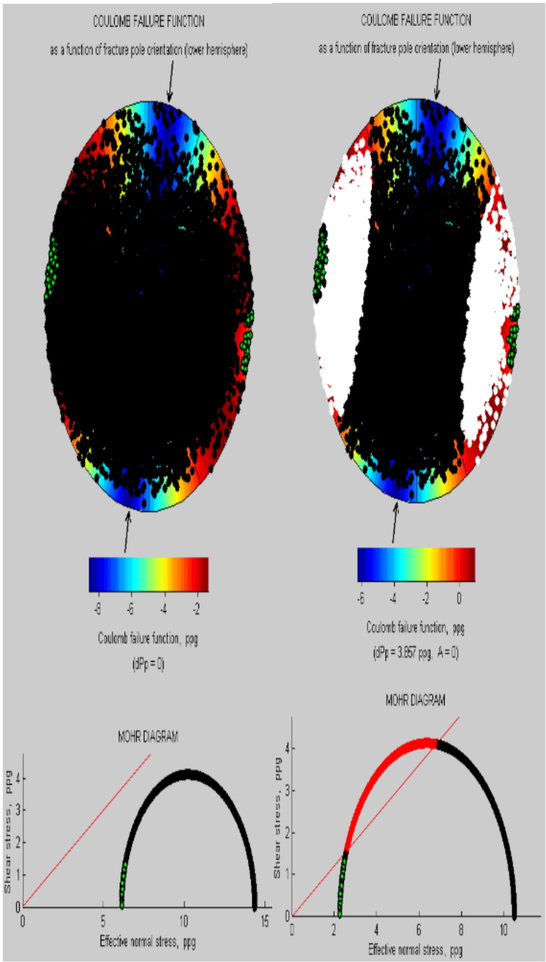
EGS Target Depth (Well 34-9RD2)

Accomplishments, Expected Outcomes and Progress

Transitional NF—SS Stress Model

Strike-slip Faulting Stress Model

Ambient | +1000 psi | Ambient | +500 psi



Accomplishments, Expected Outcomes and Progress

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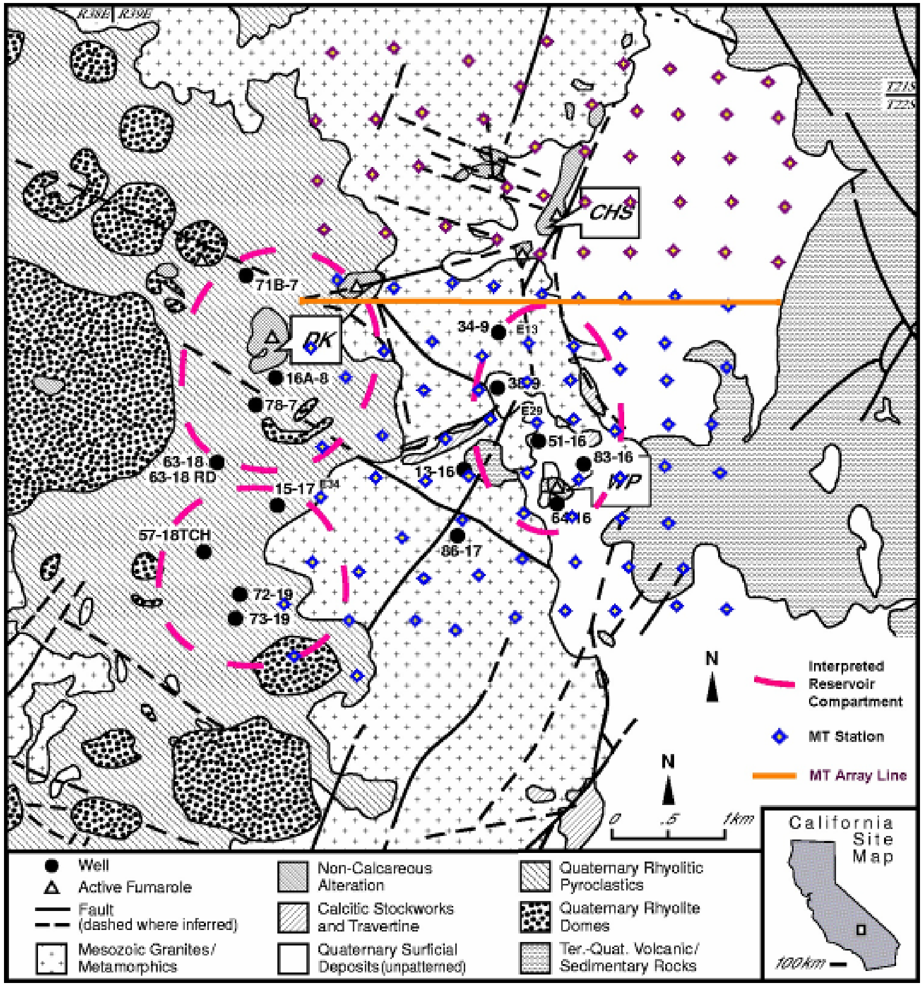
Magnetotelluric Survey of the Coso East Flank

Phil Wannamaker



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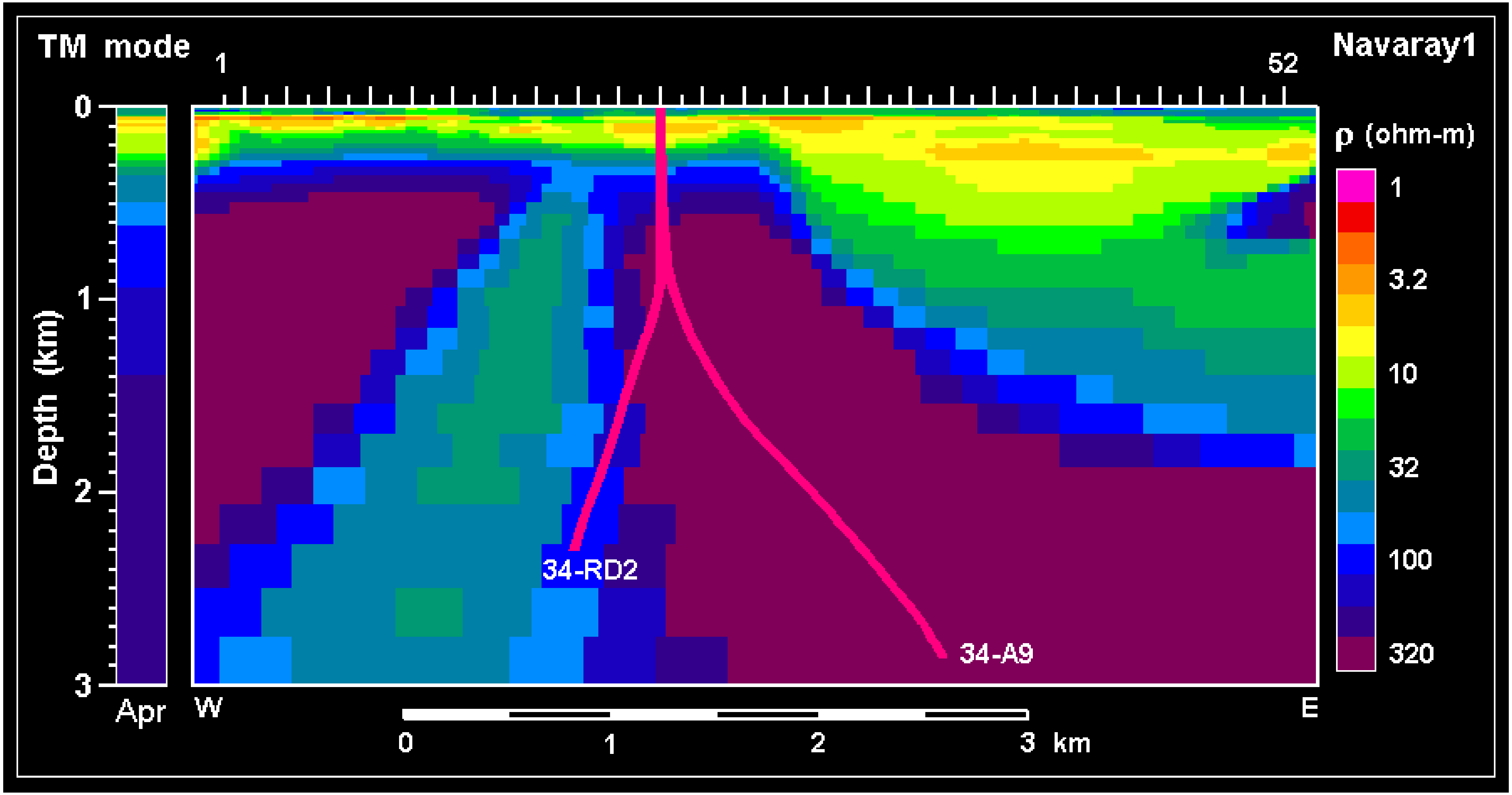
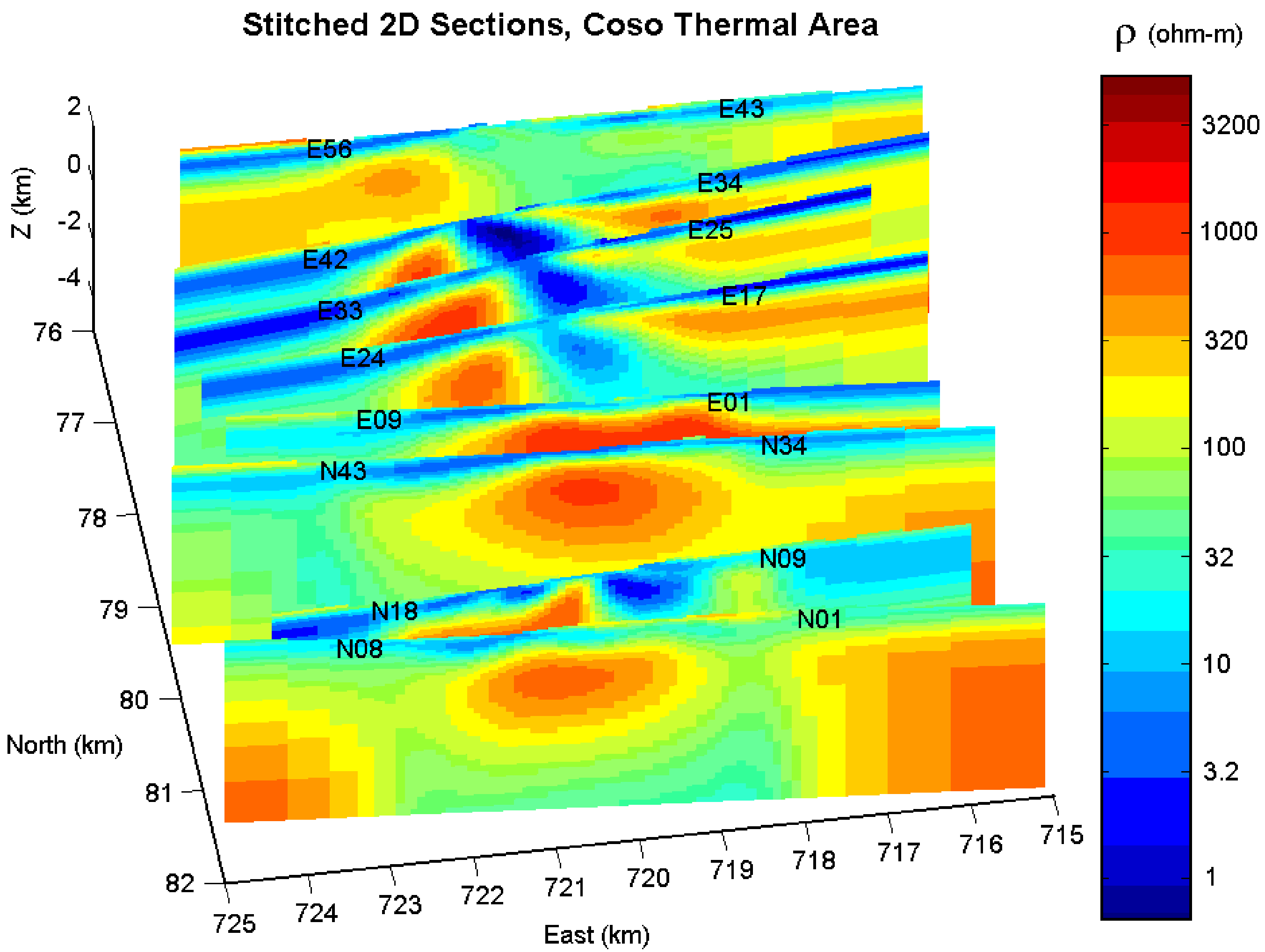
Cross-Section of East Flank Compartment

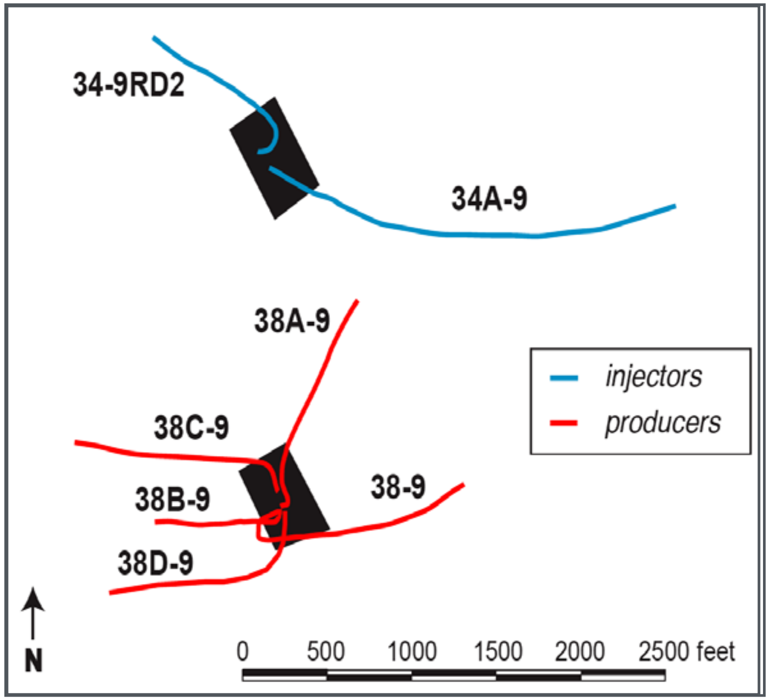


3-D View of East Flank Compartment

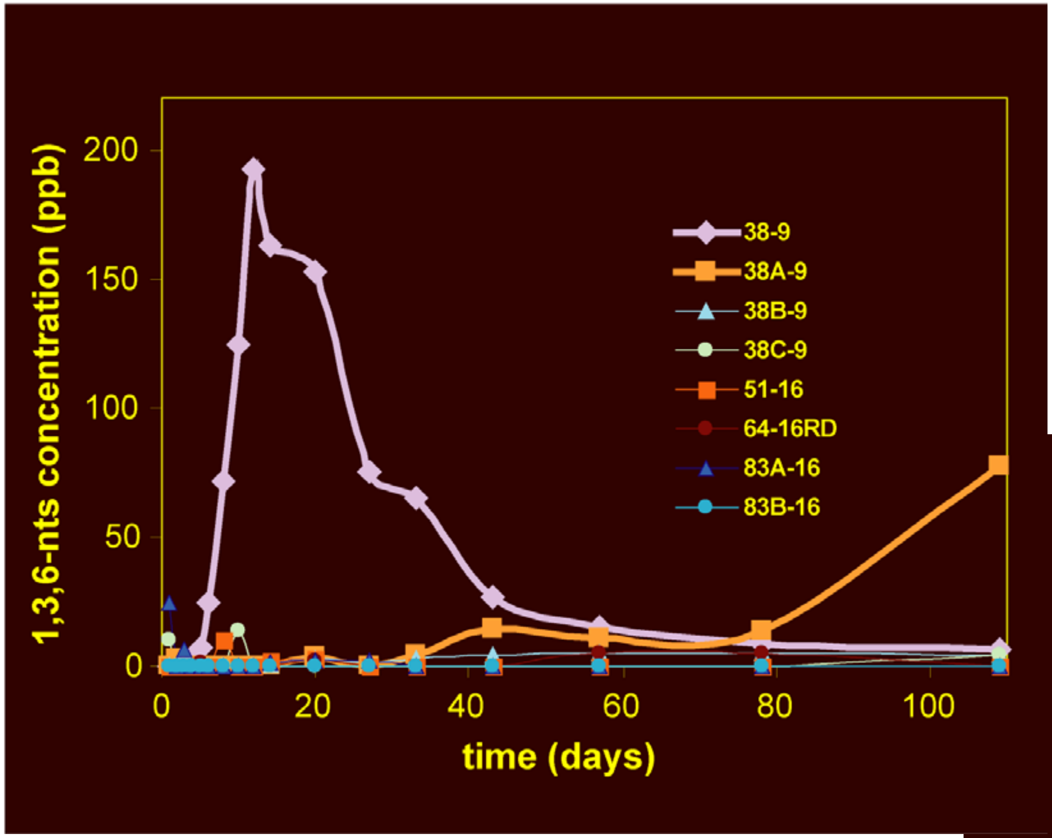


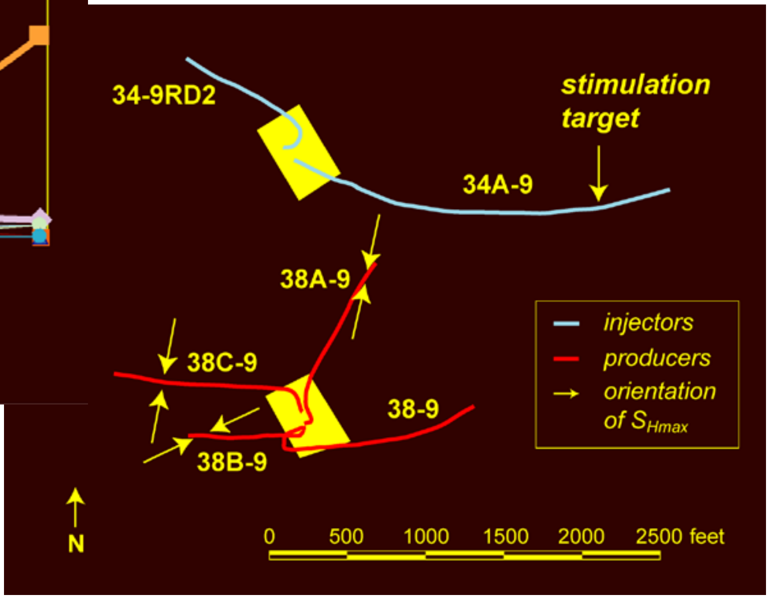
Low-Wellhead-Pressure Stimulation of 34A-9

- 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

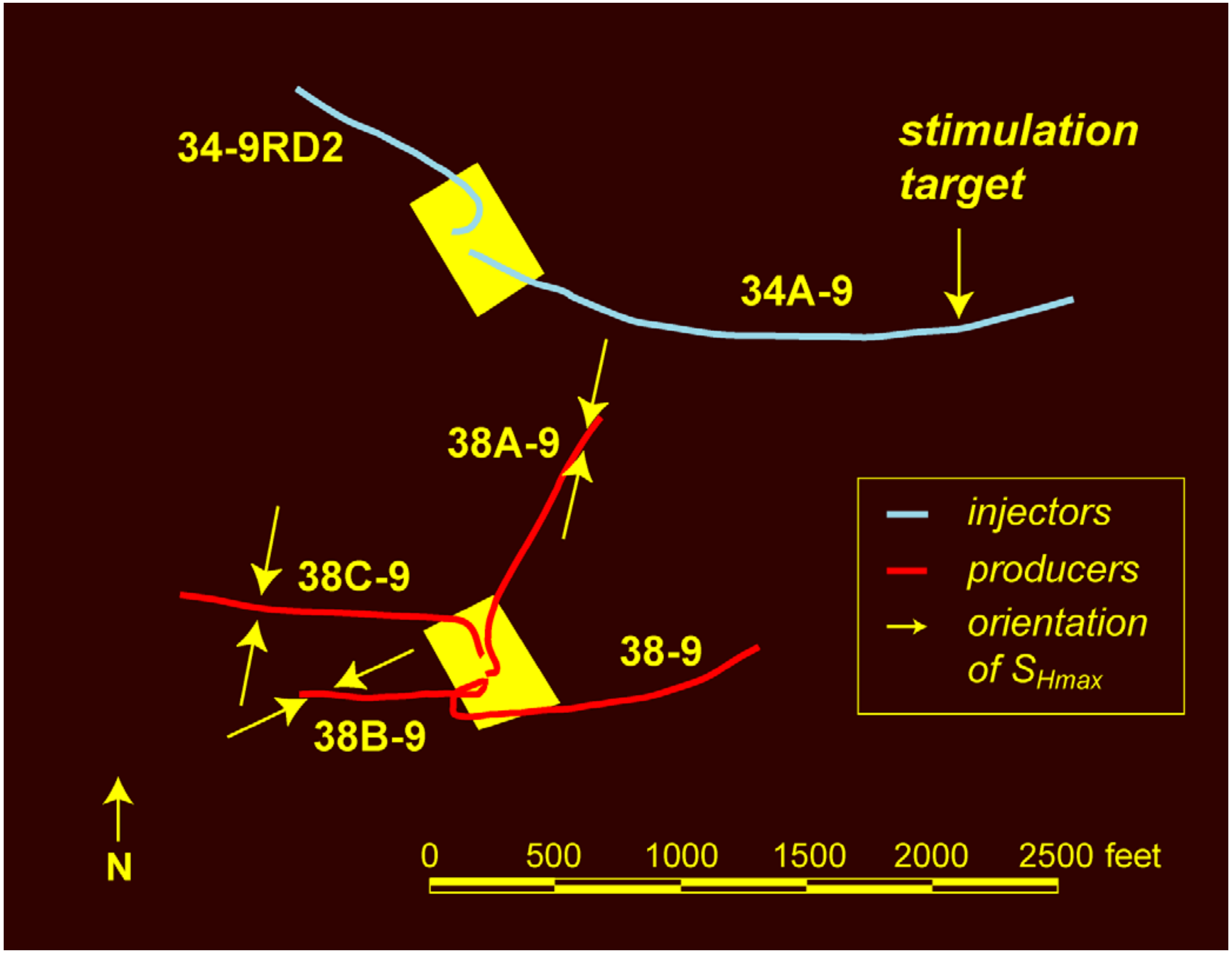


Tracer Testing of Stimulated Well 34A-9





Workover, Drilling, and Stimulation of the EGS Injector 34-9RD2



34-9RD2 Workover, Redrilling and Stimulation While Drilling

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

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

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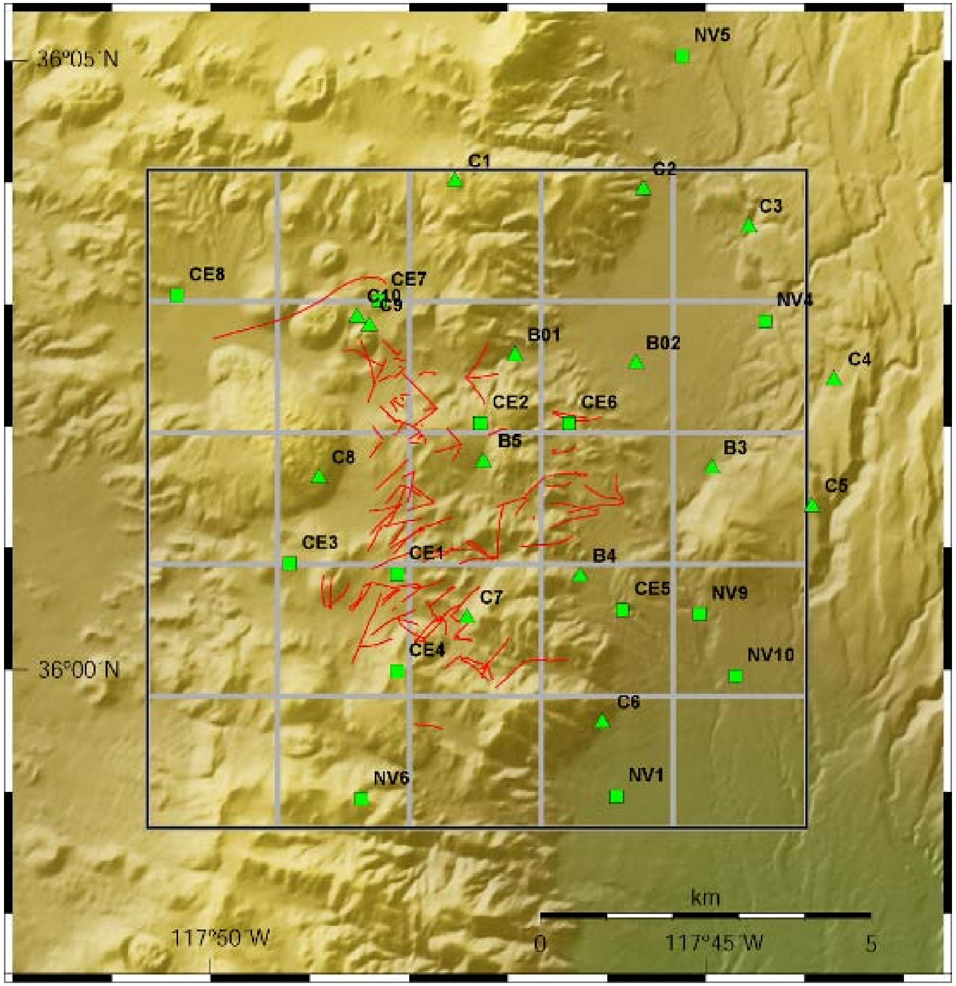
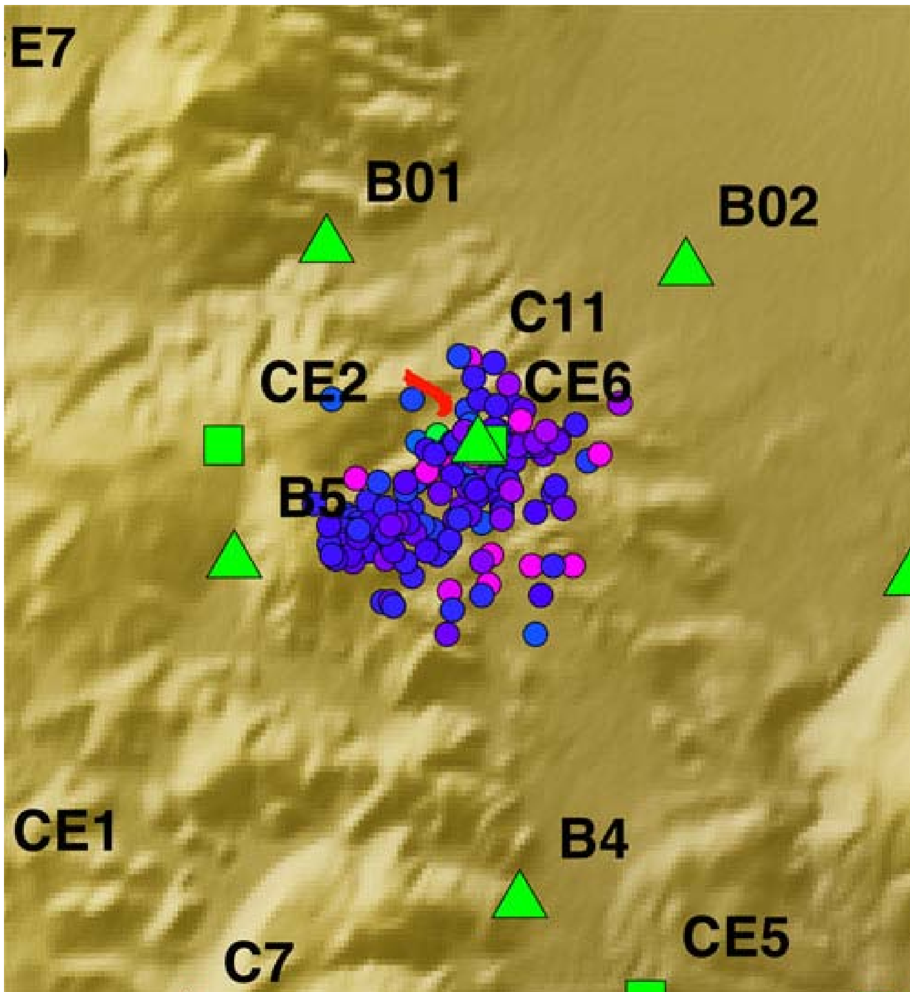
Sensor Locations for the Coso/EGS Microseismic Experiments



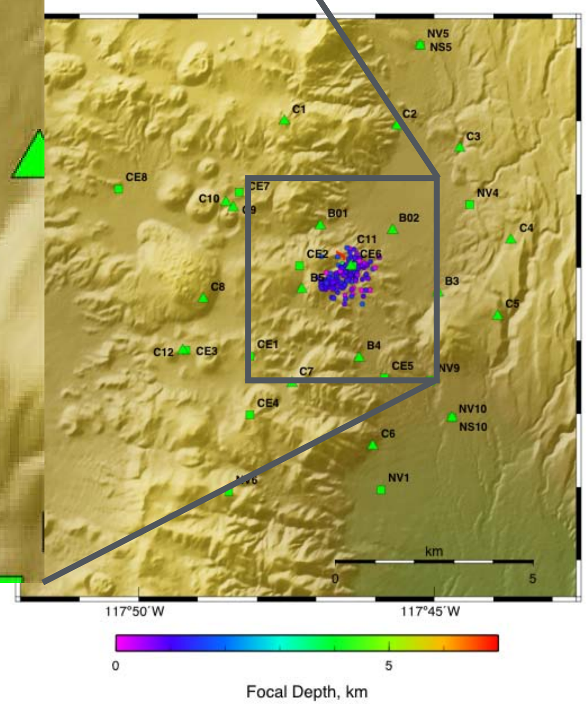
Moment tensors of injection-related MEQs

- 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

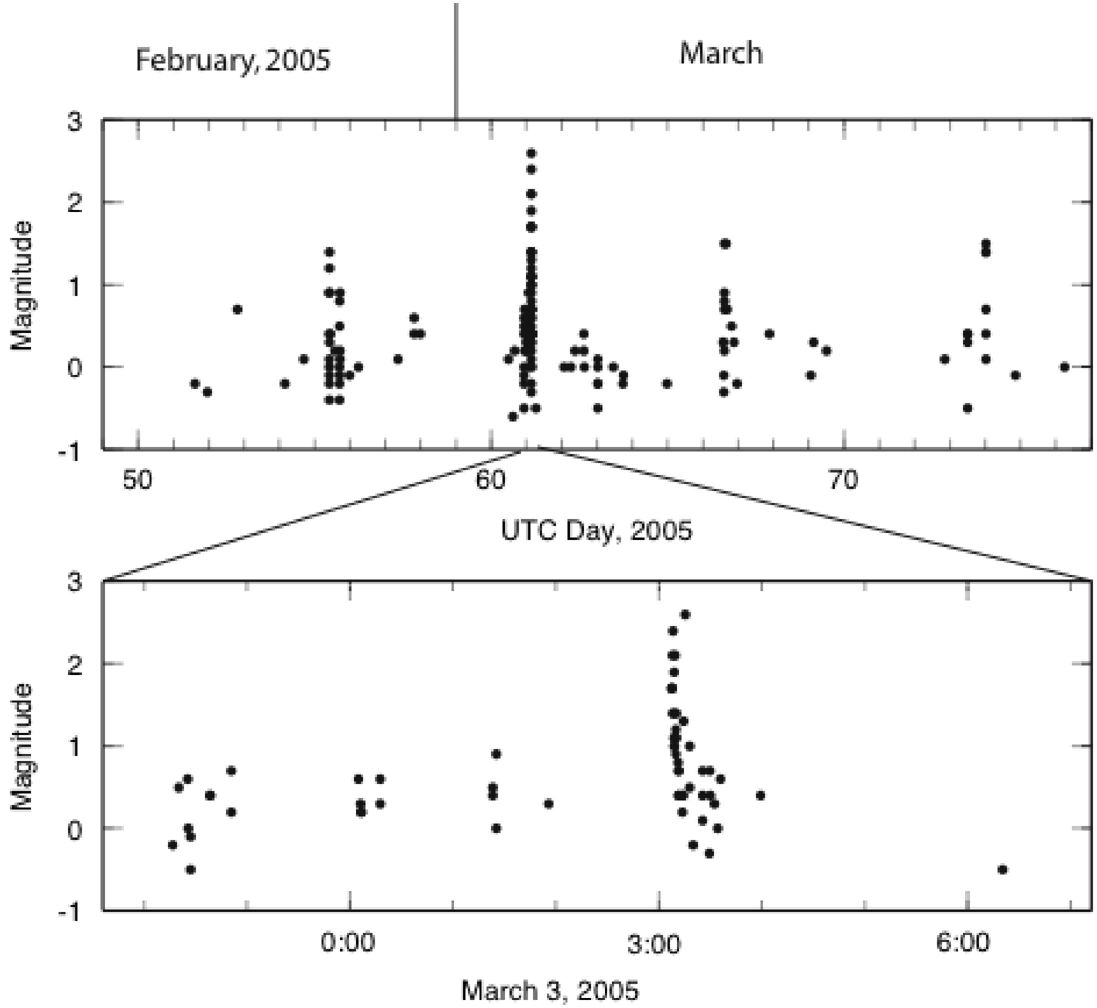
Accomplishments, Expected Outcomes and Progress



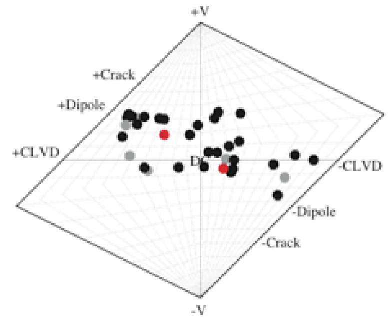
Stimulation-while-drilling experiment February-March 2005: MEQs induced



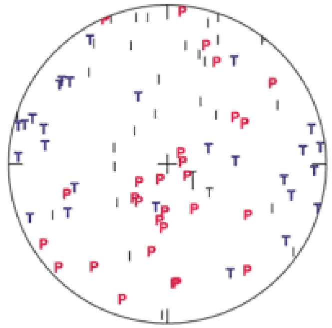
Microsceismic Events: Time History



Accomplishments, Expected Outcomes and Progress

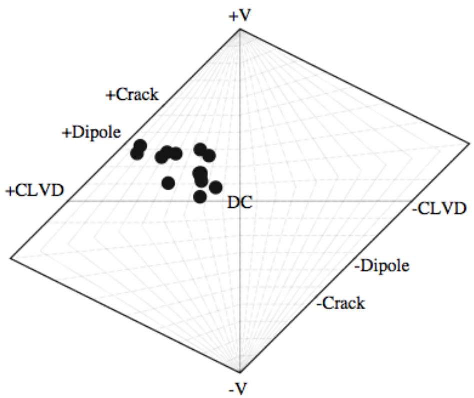


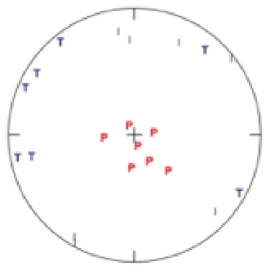
Pre-injection (February 2005)



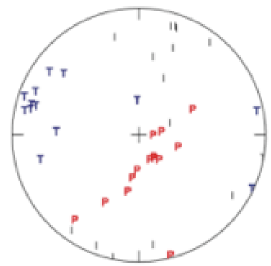
Pre-injection (February 2005)

February

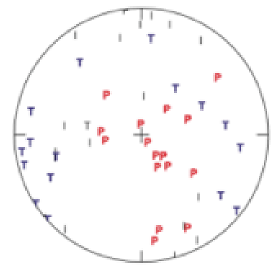




Pre-swarm

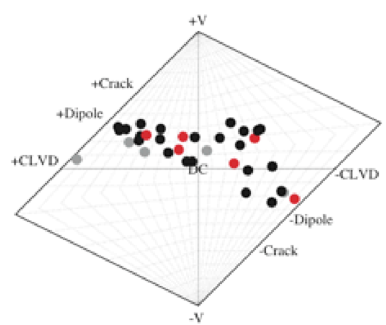


Co-swarm

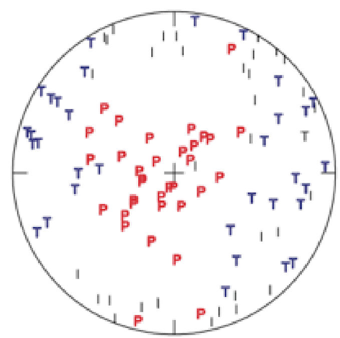


Post-swarm

March



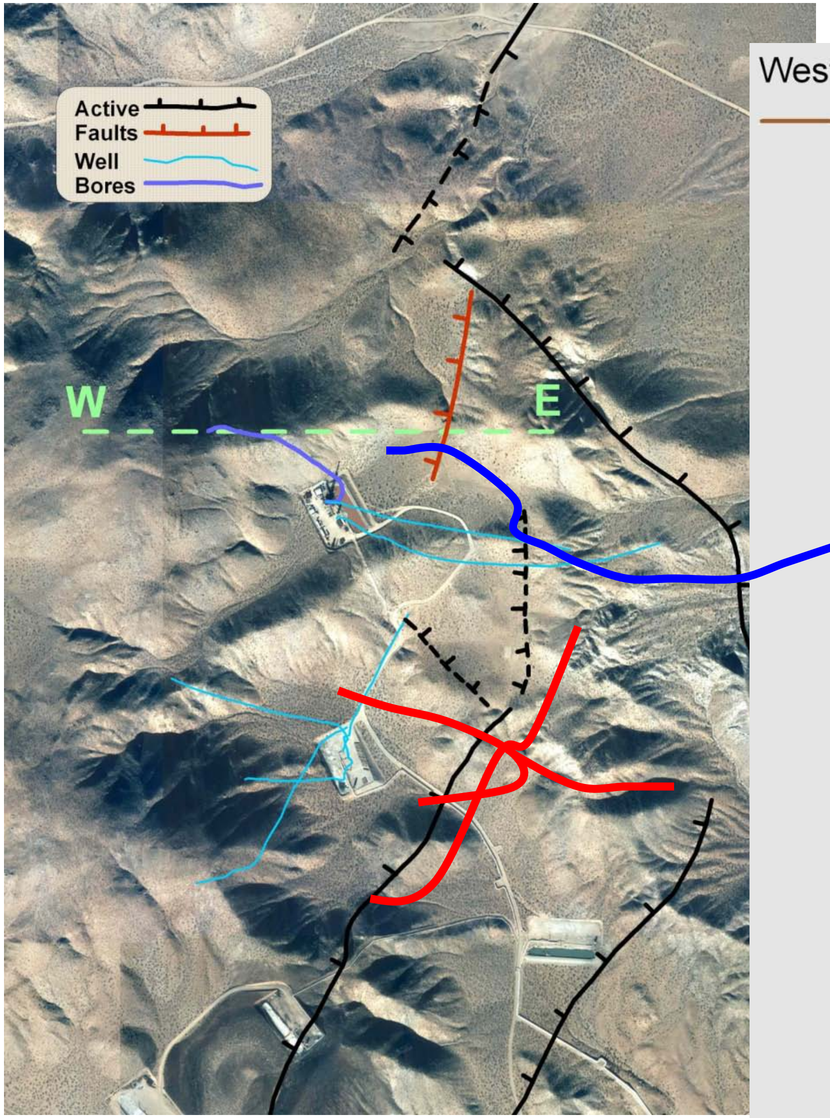
Post-injection (April 2005)

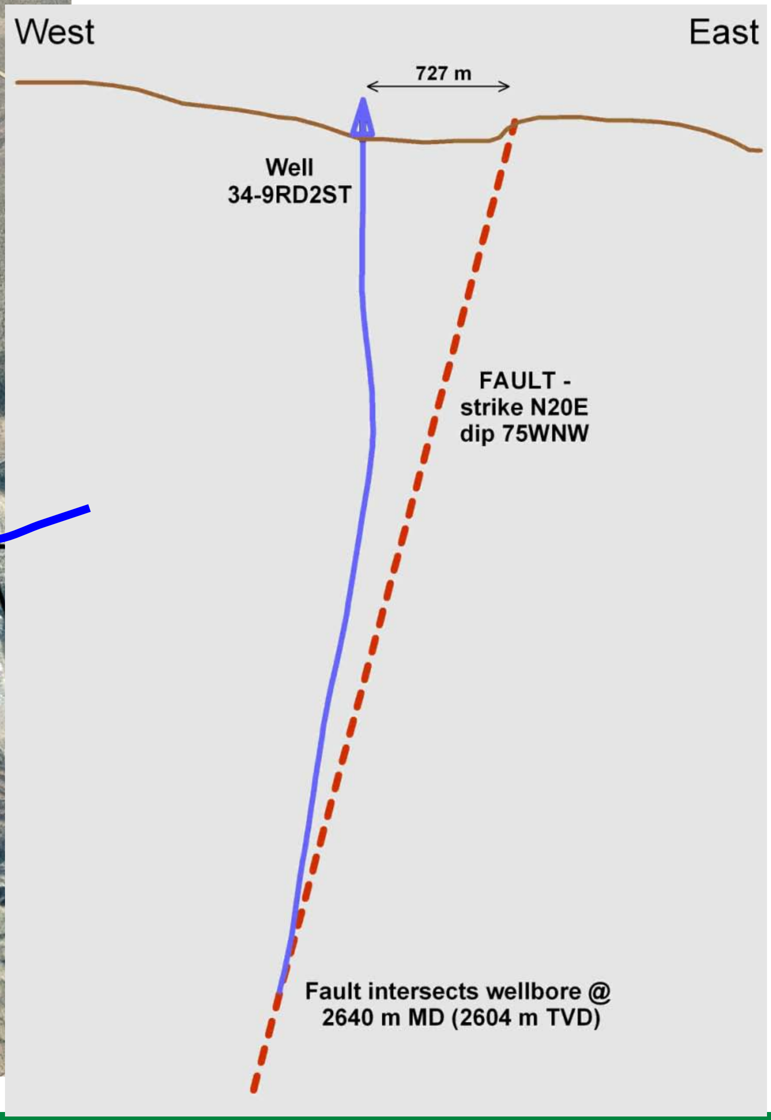


Post-injection (April 2005)

April

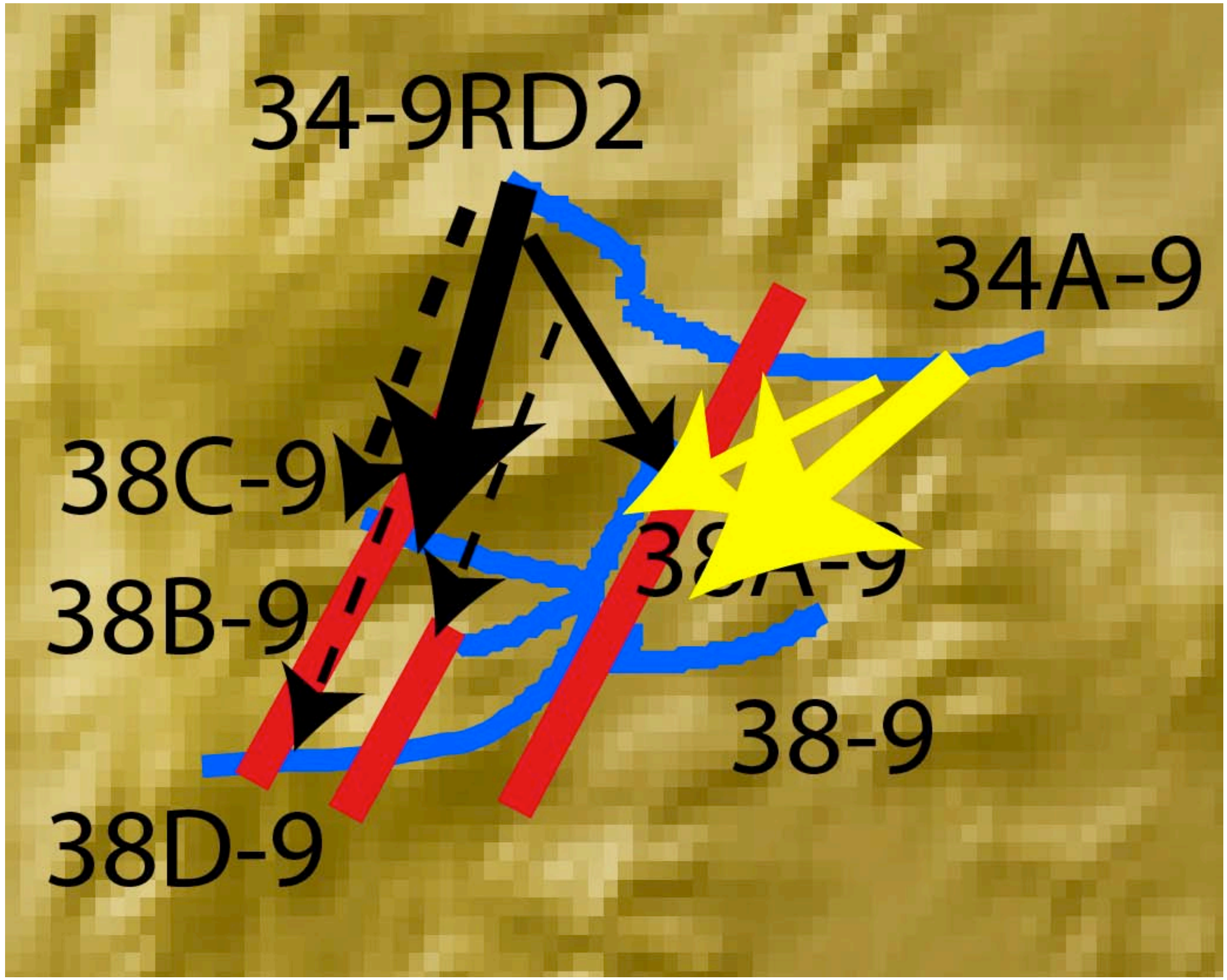
Accomplishments, Expected Outcomes and Progress





Accomplishments, Expected Outcomes and Progress

Tracer testing



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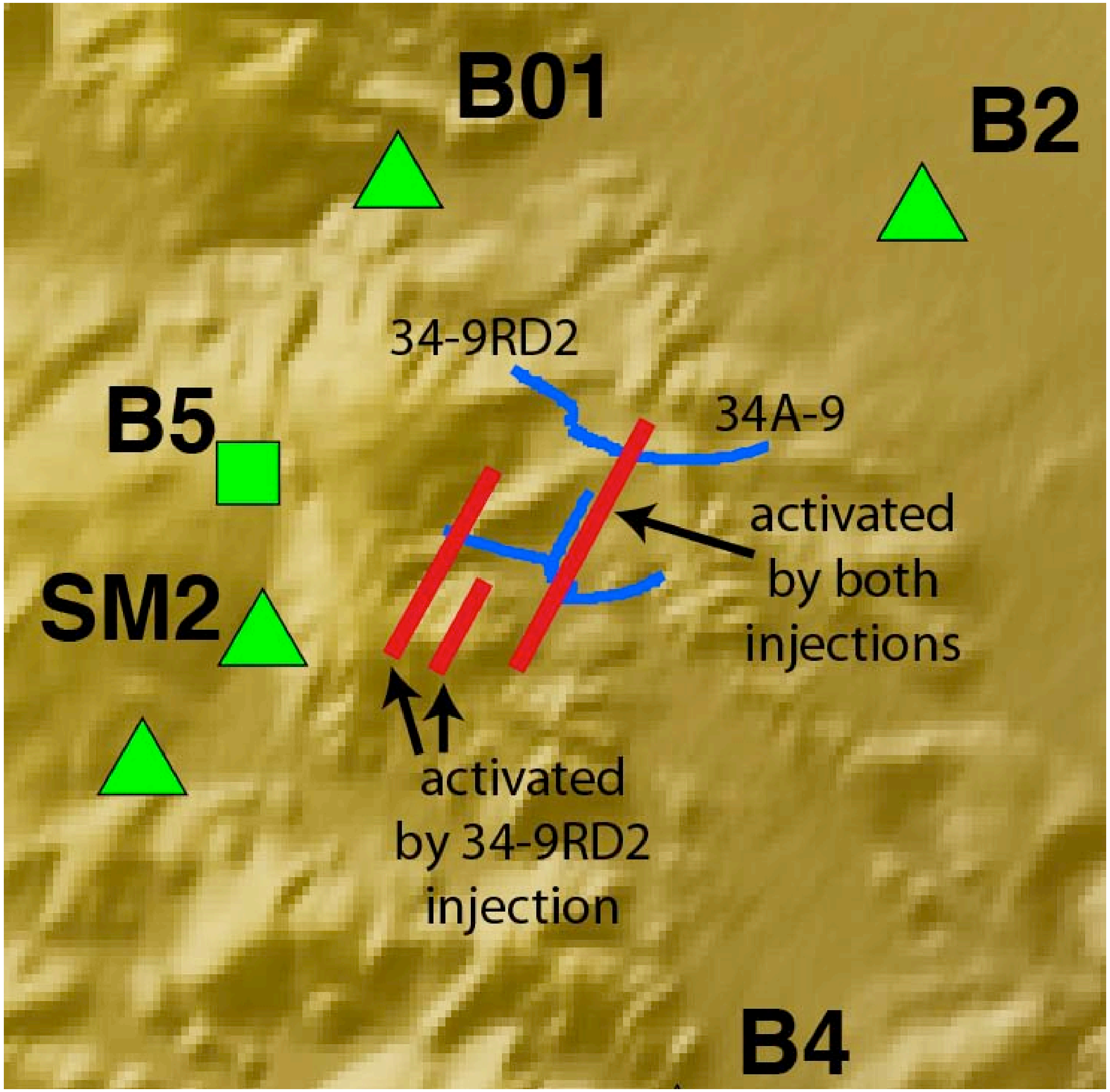
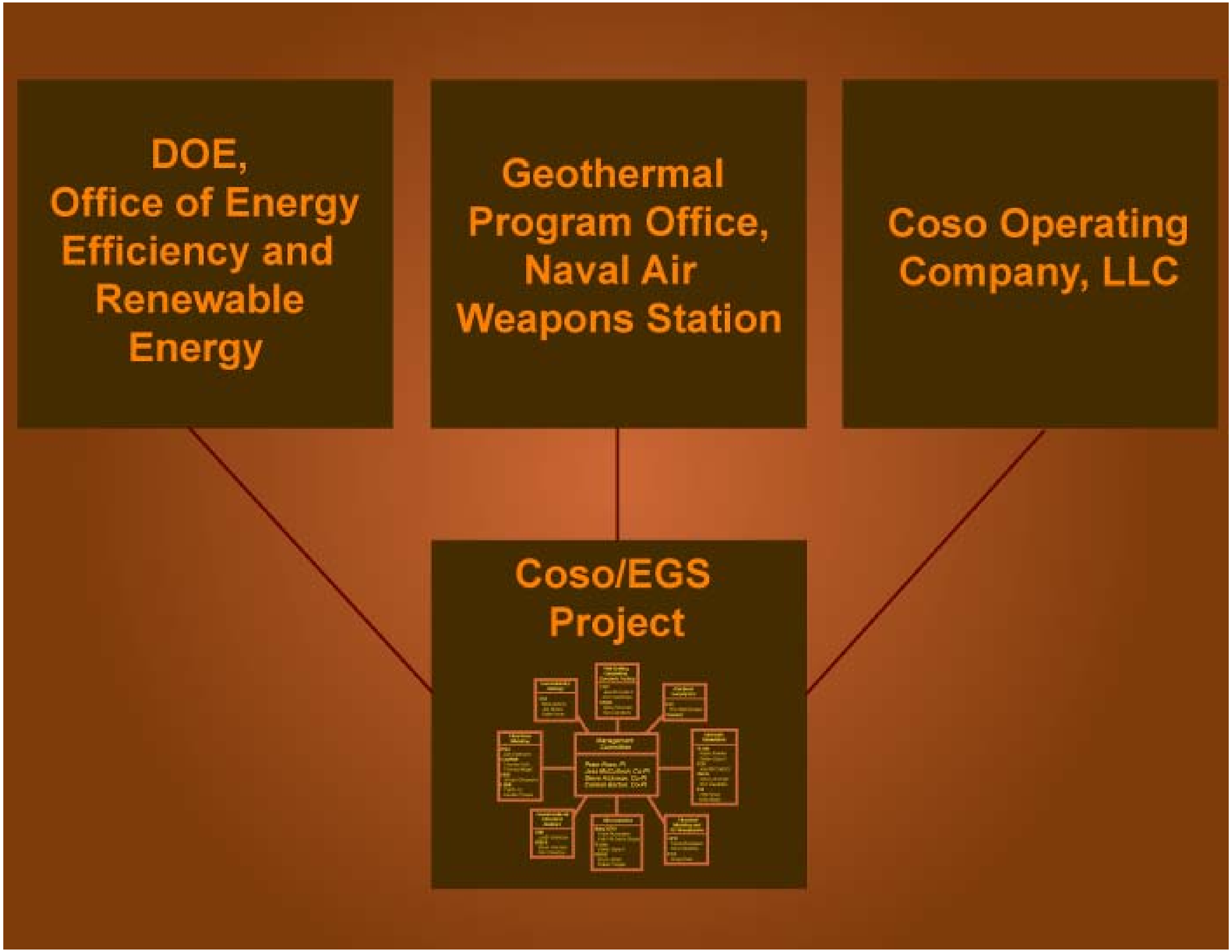


Project Management/Coordination



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