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Integration of Noise and Coda Correlation Data into Kinematic and Waveform Inversions

May 18, 2010

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Mandatory Overview Slide

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- Timeline
  - Start: March 29, 2010, End date: June 30, 2012, 3.5% percent complete
- Budget
  - Total project funding: $902,852, DOE share: $708,000 awardee share: $248,312, funding received in FY10, $70,800
- Barriers
  - Reduce cost and improve quality of site characterization.
  - Improve coupled deformation-fluid-flow modeling and validation capabilities.
  - Improve imaging of fractures after stimulation
- Partners
  - Colorado School of Mines, Virginia Tech, Bureau of Reclamation, U.S. Geological Survey, Geothermal Program Office, China Lake.

Relevance/Impact of Research

This project will focus on using microearthquakes (MEQ) and noise correlation Green's functions (NCF) obtained from MEQs and ambient noise and coda-wave interferometry to image the physical properties of geothermal reservoirs and detect and map changes in reservoir properties with time.

•Specific objectives are to:

•1) Improve absolute earthquake location accuracy, improve focal mechanism resolution, and improve reservoir imaging capabilities prior to, and after EGS activities, including changes in related to injection and production, particularly mapping scattering associated with fracturing, and

•2) test the ability of an Abaqus finite-element coupled deformation-fluid-flow model of induced seismicity and fluid flow with data from the Paradox Valley injection well and the Coso geothermal field to predict first-order seismicity and fluid-flow characteristics.

Innovative Aspects of the Project

- Extracting high-frequency body and surface waves from MEQ coda and ambient noise for upper-crustal P- and S-wave velocity inversion constraints (O'Connell, 2007).
- Comparison of surface broadband with subsurface high-frequency three-component networks in terms of velocity and earthquake location resolving power (Paradox and Coso seismographic networks).
- Graphics Processing Unit (GPU) optimization of 3D viscoelastic finite-difference code for 3D waveform inversion kernels.
- Coda-wave interferometry to detect and map scattering changes associated with changes in reservoir properties through time.
- Abaqus finite-element coupled deformation-fluid-flow model analysis of injection, production, and seismicity.

Relevance/Impact of Research

- Accurate absolute earthquake locations are required to determine fracture positions and drilling targets. This project is focused on improving **absolute** earthquake location accuracy, not relative earthquake location accuracy.
- 3D waveform inversion is required to extract the maximum of information about lateral velocity variations that usually have the maximum value in geologic terms. Combining deeper body-wave ray paths from earthquakes with shallow surface-wave paths from station-pair NCFs provides an improved tomographic geometry.
- Coda-wave interferometry can resolve much smaller-magnitude scattering changes associated with injection-production than time-lapse tomography.
- The Abaqus modeling will test if EGS induced seismicity characteristics are predictable given information available from the typical quantity and quality of geologic and geophysical information available for an EGS project.

Relevance/Impact of Research

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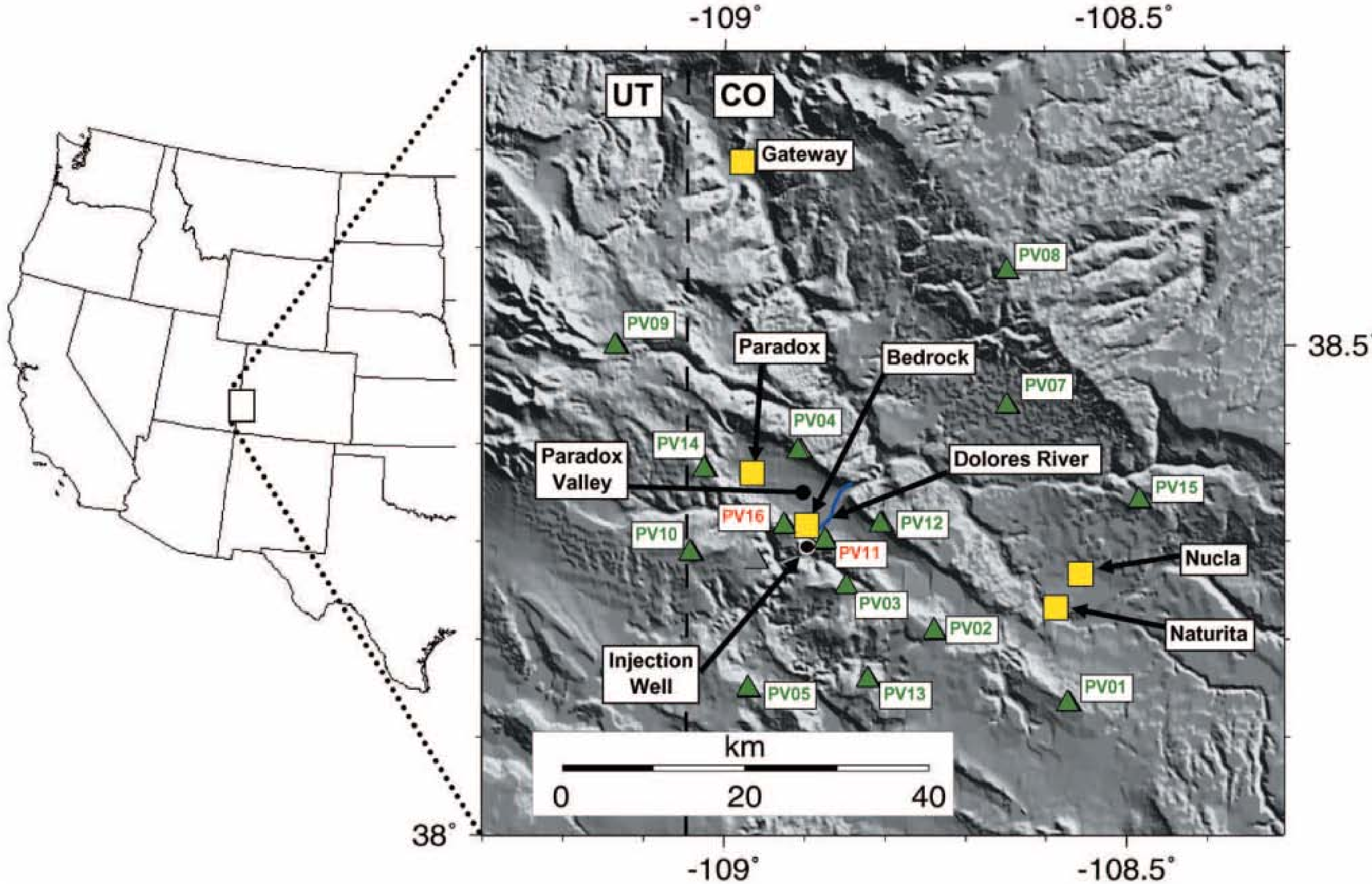
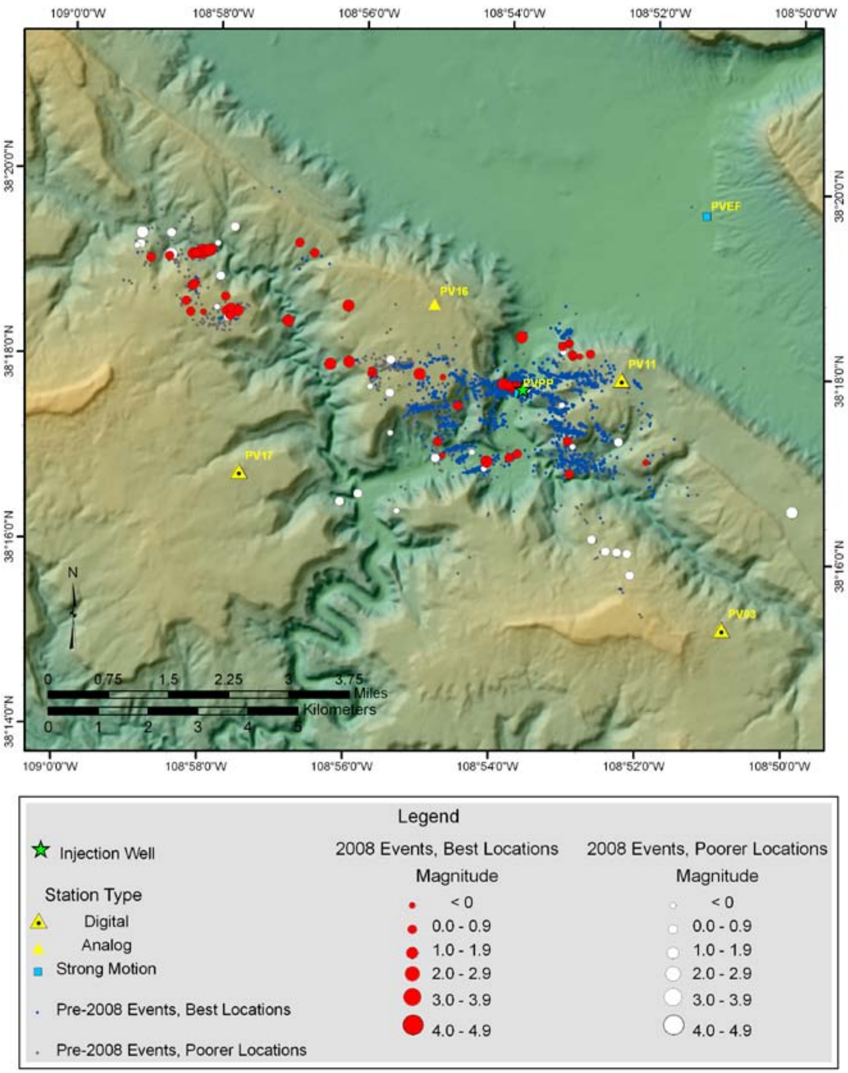
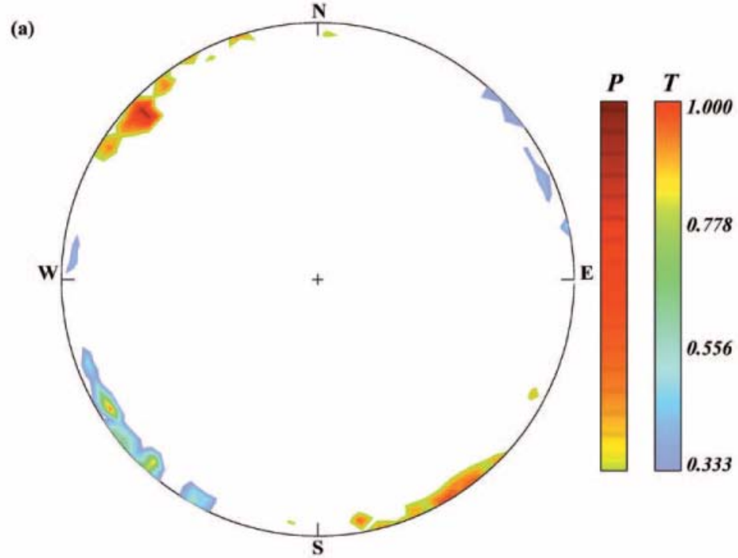
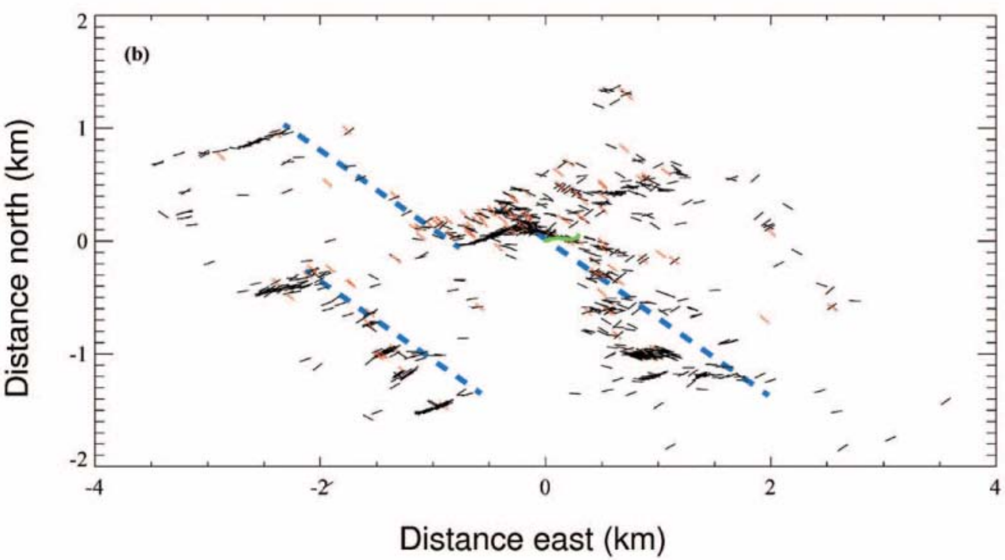


Relevance/Impact of Research







Scientific/Technical Approach

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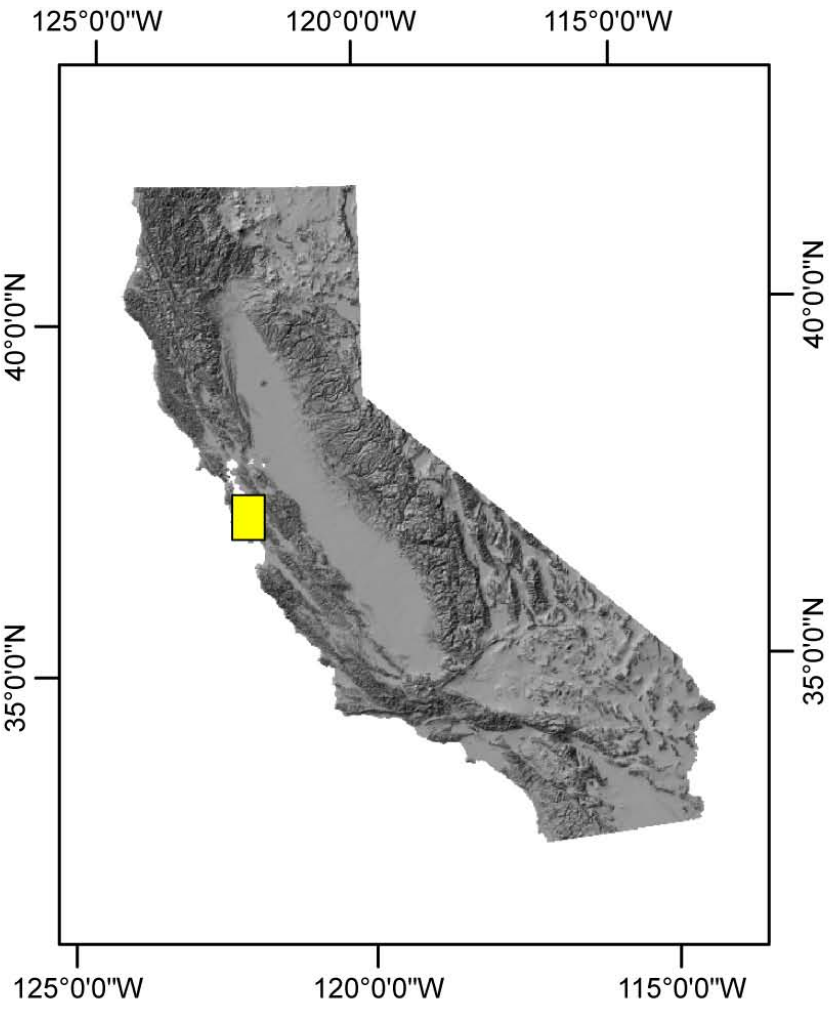
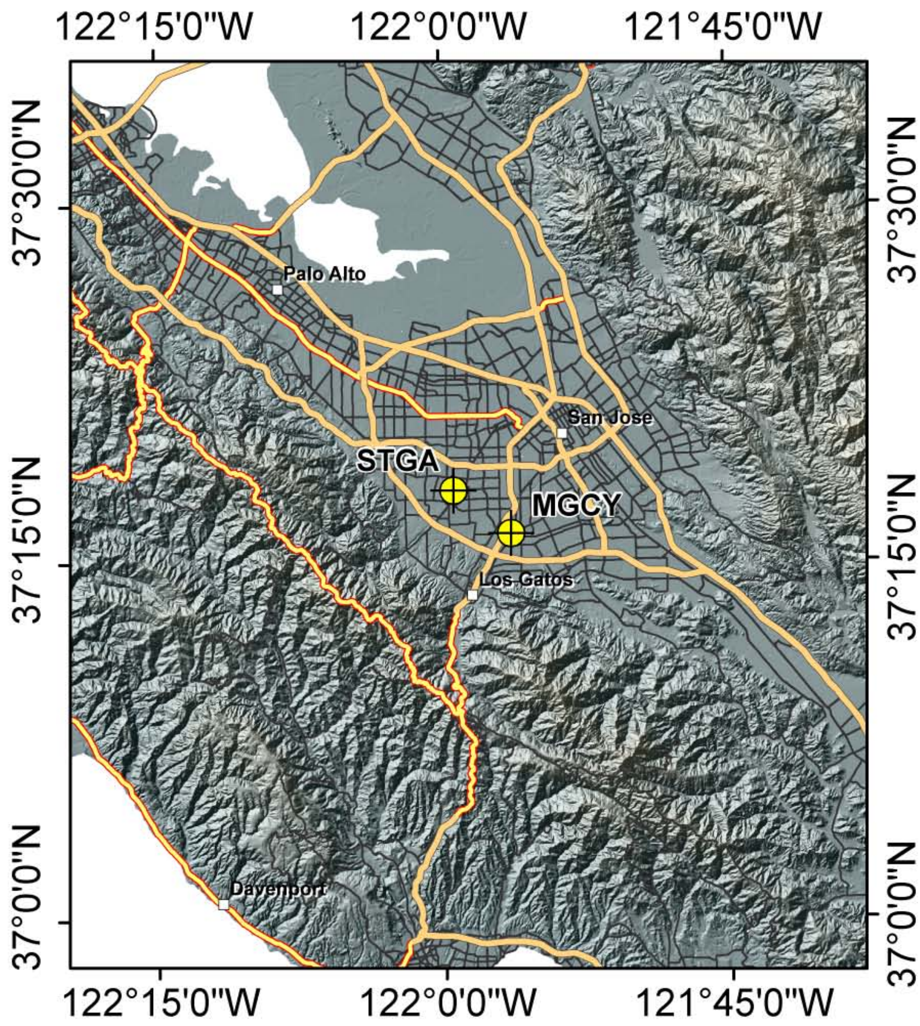
- Break the problem into small, specific problems, the solution of which support the next set of more complex inversions and model construction.
- Leverage existing project personnel experience
  - Experience with passive and active NCF processing to extract high-frequency body and surface waves and velocity and moment tensor inversions (O'Connell),
  - 3D visocelastic finite-difference and finite-element code parallelization and waveform inversion testing results (Liu).
  - GPU optimization (Feng).
  - Seismic interferometry theory and applications (Snieder)
  - 3D velocity-hypocenter inversion and tomography (Block)
  - Coupled 3D deformation-fluid-flow modeling (Roellofs and Denlinger).

Scientific/Technical Approach

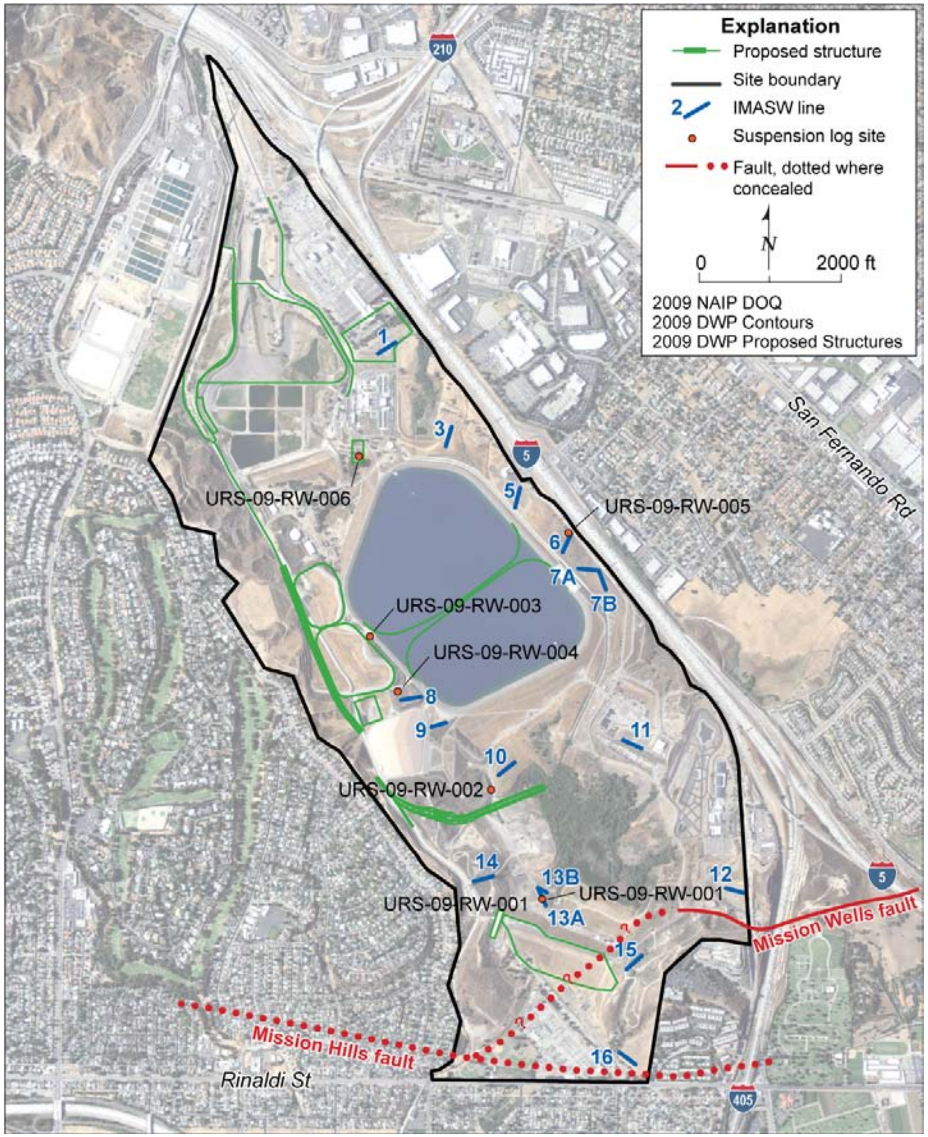
- Example: Initial Surface-Wave Processing.
- 1D P- and S-wave Dispersion Slowness Inversion
- This example uses a sequential multi-stage simulated-annealing Monte Carlo relative-weighting approach to combine whole network or subnet phase and group slowness constraints to obtain initial whole-or-subnet-based 1D estimates of upper crustal P- and S-wave velocities.
- In these cases the data are obtained from linear multi-channel arrays and processed for phase and group slownesses using a non-stationary noise-correlation approach to accommodate moving sources.

Scientific/Technical Approach





Scientific/Technical Approach



6 P-S suspension logs

16 IMASW profiles

12-channel 88-m array

Active sources on each end

Steep dips (45-70 degrees)

One P-S suspension log at IMASW midpoint

Comparison of 6 P-S suspension log Vs30-depth estimates with IMASW lines

Scientific/Technical Approach

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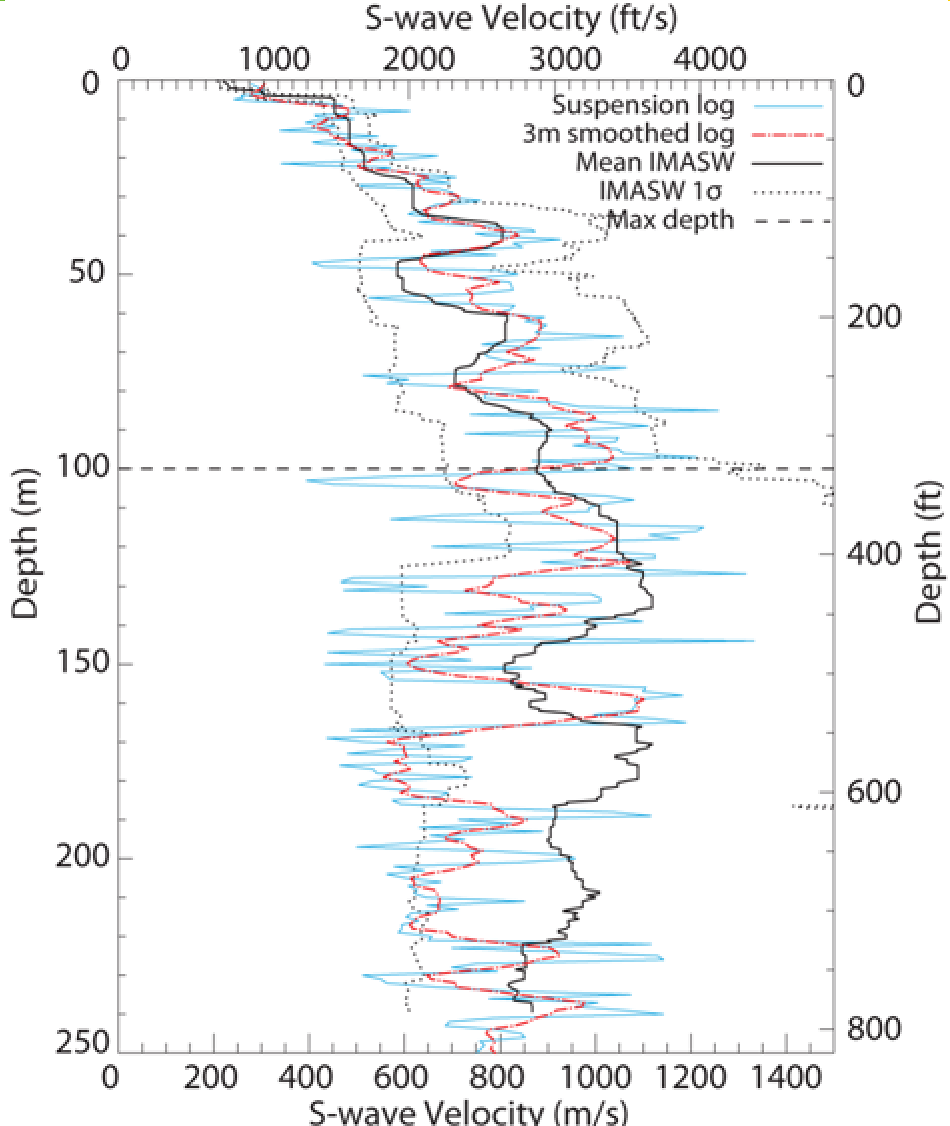
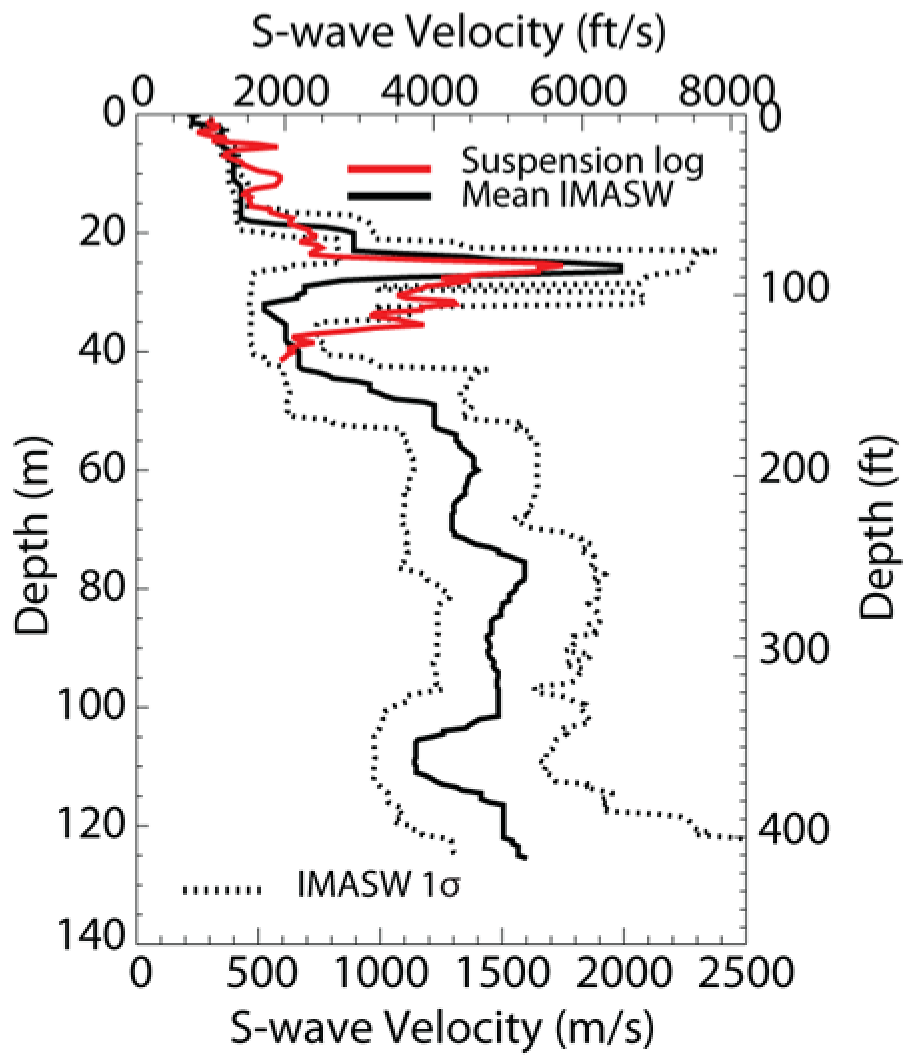


MGCY (Line B)



Accomplishments, Expected Outcomes and Progress

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Progress to date

- Initial surface-wave processing and inversion software developed, tested, and a manuscript submitted to BSSA.
- Established a schedule to acquire data from the Bureau of Reclamation and the Coso geothermal field. Triggered data will be available first, followed by continuous data.
- Negotiating to acquire another proprietary dataset from a 61 station three-component downhole network and collaborate with the data acquisition and processing component on software implementation in a commercial system.

Project Management/Coordination

- A key aspect of project management is coordination of the partners. Meetings have already been held with all partners to establish agreement on tasks and schedules. The plan is two meet with all partners at least two a year in addition to more frequent email and phone communications.
- The schedule will follow the two-phase project plan, with more intensive data processing in the first year and software development, followed by continued software develop and applications of inversions to the processed data in the second year.
- The partners will be working in parallel on most subtasks, with FWLA coordinating and integrating the outputs.
- As per DOE’s request, the primary data processing hardware will be purchased prior to September 2010 and serve as the primary compute resource for the project.

Mandatory Summary Slide

- Earthquakes are a critical issue for EGS. Developing a sound physical understanding and the capability for predictive modeling of seismogenesis associated with injection and production is a key project goal.
- Earthquakes are also a valuable EGS tool to map fracture and flow processes.
- Accurate absolute earthquake locations are needed to map fractures and reservoirs for production drilling.
- This project is focused on extracting the maximum amount of information contained in source and ambient noise waveforms to constrain earthquake locations, focal mechanisms, velocity structure, and changes velocities and scattering over time, to provide the maximum information for modeling of coupled deformation-fluid-flow behavior.

Supplemental Slides

Optional Slide

- D.R.H. O’Connell and J.P. Turner, “Interferometric Multichannel Analysis of Surface Waves (IMASW),” Seism. Res. Lett. 81, 357-358 (2010).

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GTP Goals not outlined in MYRD&D

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- EGS Demonstration Projects
  - Demonstrate reservoir creation that achieves a flow rate of 20 kg/s by 2015
  - Achieve a 10% increase in flow rate for EGS field site demonstration by 2011
  - Model the reservoir conductivity at an EGS system demonstration by 2011
  - Determine actual (baseline) pre-stimulation reservoir flow rate for at least one EGS field site by 2010
- EGS R&D
  - Complete the testing of a transducer for high temperature (up to 300 Degrees Celsius) ultrasonic fracture imaging tool by 2011

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GTP Goals not outlined in MYRD&D (continued)

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- Validation of Innovative Exploration Technologies
  - Confirm 400 MW of geothermal energy capacity
  - Validate two new exploration methods
- Low Temperature Demonstration Projects
  - Demonstrate the development of at least 20 MW using low temperature, co-production with oil and gas and/or geopressured resources
- Ground Source Heat Pumps
  - Reduce levelized cost of electricity ($/ton) by 30% by 2016

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