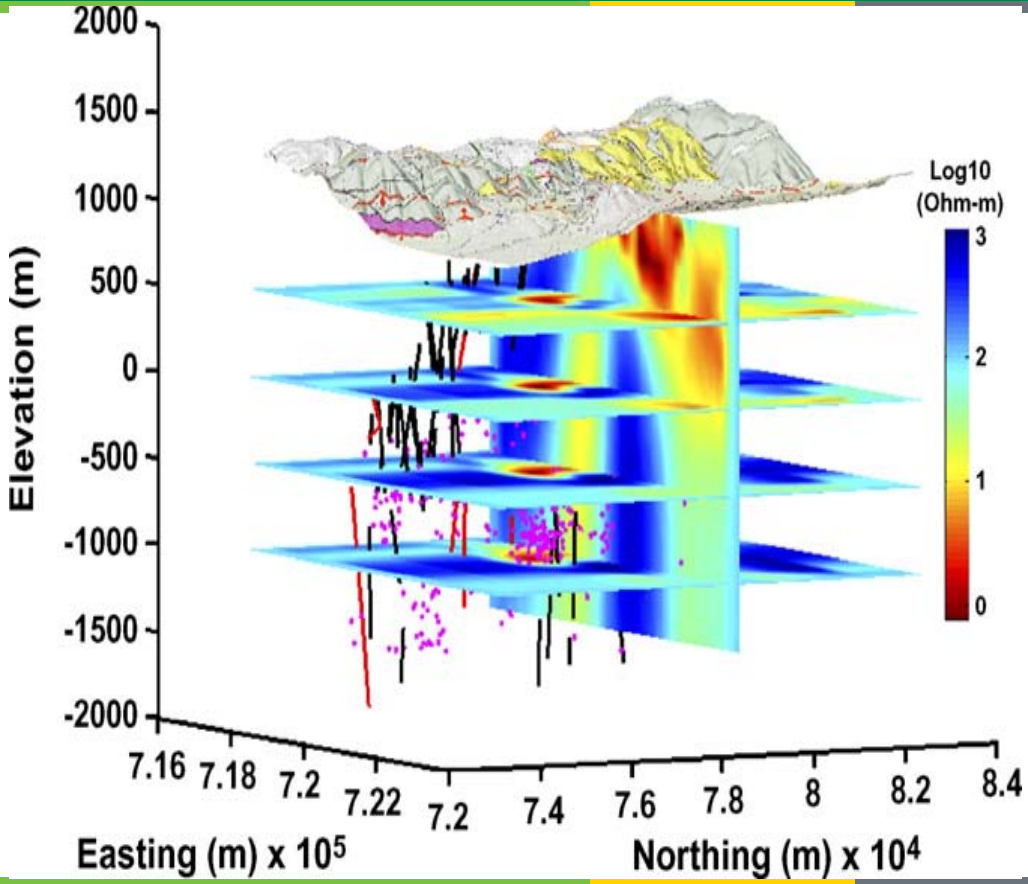

Fluid Imaging of Enhanced Geothermal Systems

May 18 2010

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Lawrence Berkeley Laboratory

Track Name

Fluid Imaging of Enhanced Geothermal Systems

- Project Timeline
  - Project start date, October FY10
  - Project end date, September FY11
  - Percent complete 25%
- Budget
  - Total project funding, DOE Award $1,025,000
- Barriers
  - Monitor reservoir creation
  - Flow rates
  - Enhance EGS reservoir productivity
- Collaborators
  - Univ. Utah Energy and Geosciences Institute

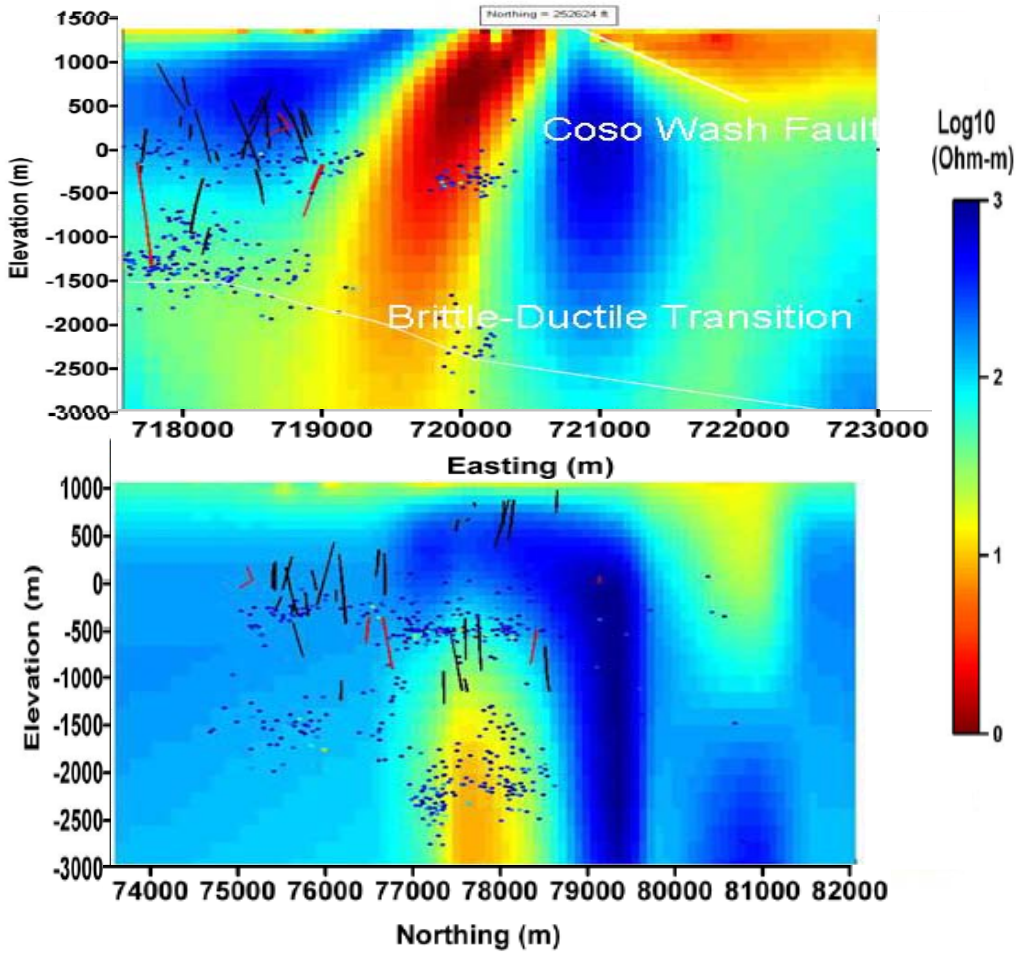
EGS FLUID IMAGING

- Manipulation of EGS fluids
  - **Use geophysical imaging**
    - MEQ and electrical resistivity imaging (MT & CSEM)
    - established geophysical technologies; long history in geothermal exploration
  - **Map changes in volume and location of fluid bearing fractures**
    - predict locations, movements and concentrations
  - **Ultimate Goal: Manage injection strategies**
    - step out wells (number and location)
    - ratio of production to injection

EGS FLUID IMAGING

- Small fractures control the permeability over a large area
  - High resolution imaging of fractures needed to map EGS fluids
- Permeability likely to be transient on reservoir scale
  - Fractures open and close due to EGS stimulation, mineral precipitation/solution
  - Need to image stimulation zones, before, during and after fluid injection
- Reservoir parameters do not give unique signals
  - Zones of low resistivity can be either water saturated or have high clay content
  - Micro seismicity may be associated with fluid saturation changes or stress drops
  - To reduce ambiguities employ joint geophysical imaging/modeling methodologies

Scientific/Technical Approach



COUPLING MEQ & MT

Coso Geothermal Reservoir

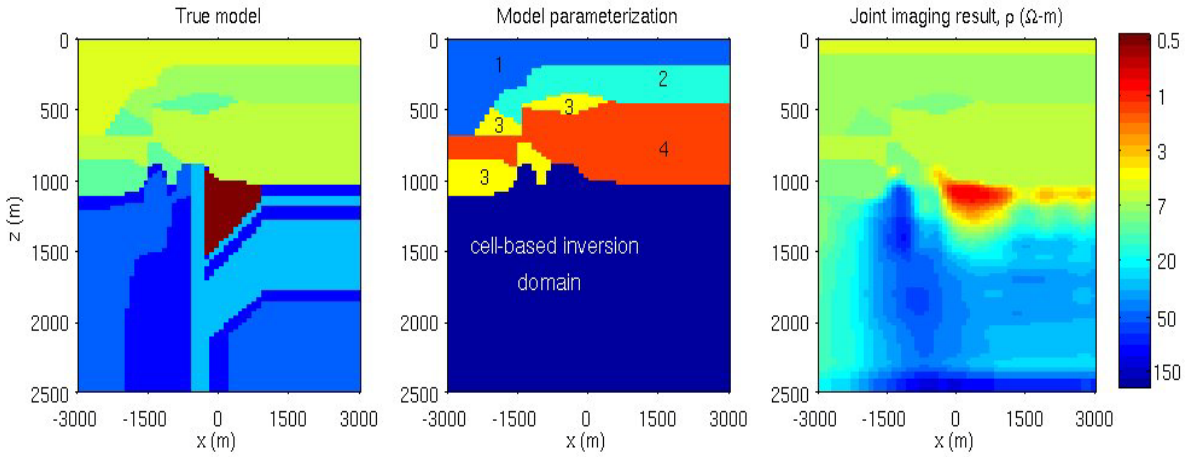
Observations:
Production Intervals associated with seismicity
Resistivity not detailed enough to map fractures
Implications for EGS

Needs:
Better Understanding MEQ focal mechanisms
Enhanced Images Resolution for Fluids & Fractures
- time lapse MT/CSEM for fluid imaging
- joint CSEM-MT/seismic imaging ???
- use MEQ focal information with EM Imaging

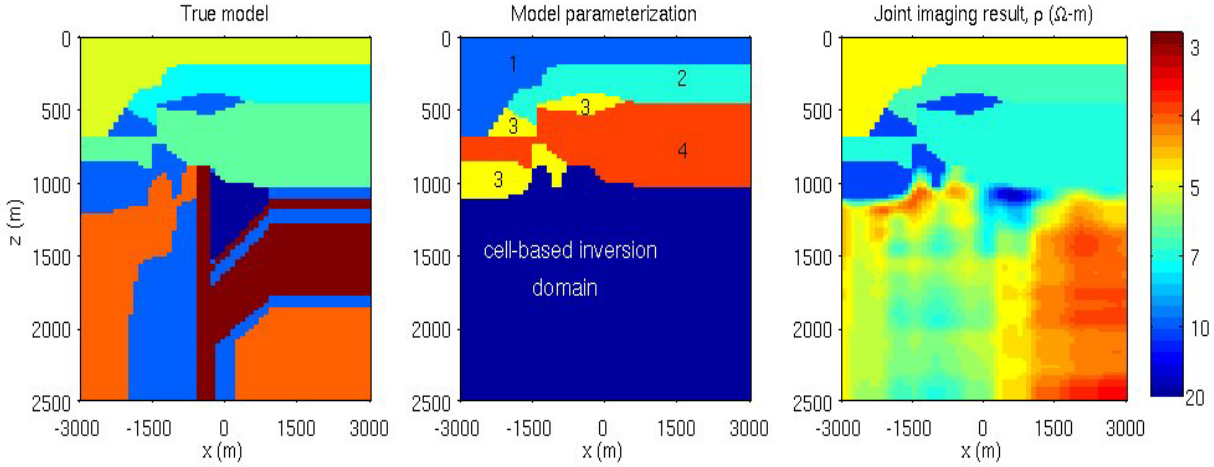
Micro earthquake (MEQ) focal points: blue circles
Well production intervals: black linear segments
Well injection intervals: read linear segments

TIME- LAPSE FLUID IMAGING – Desert Peak (MT &CSEM)

conductive fluid



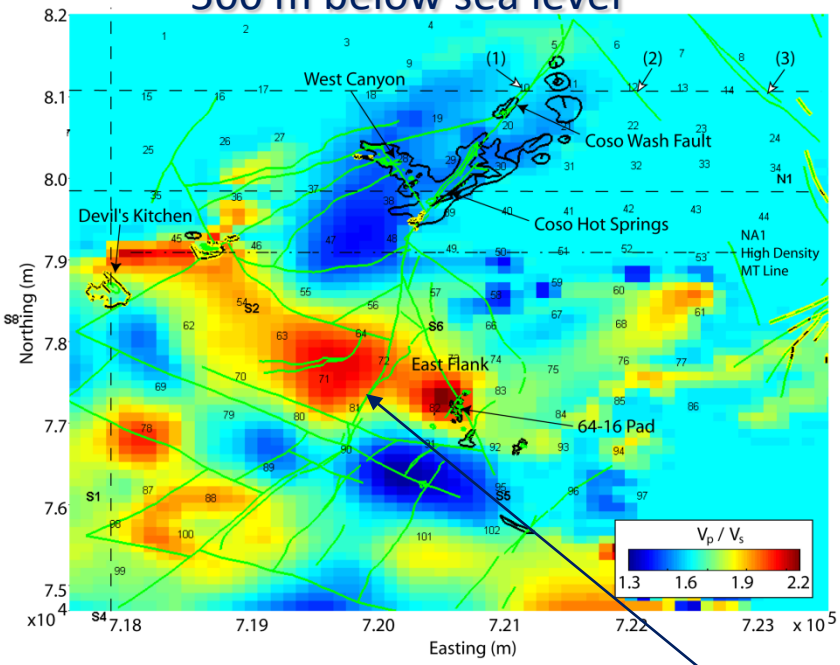
resistive fluid



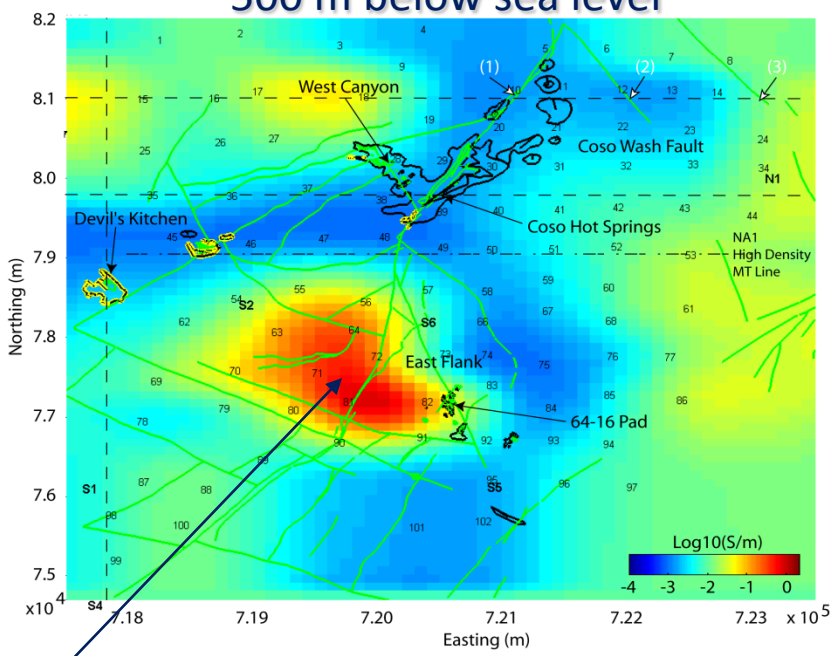
Velocity & Resistivity Imaging

Possibility & Potential

Vp/Vs Ratio Map
500 m below sea level



Conductivity Map
500 m below sea level



Fluid Filled Fracture Network?

Coso Geothermal Reservoir

clear correlations observed

images independently derived

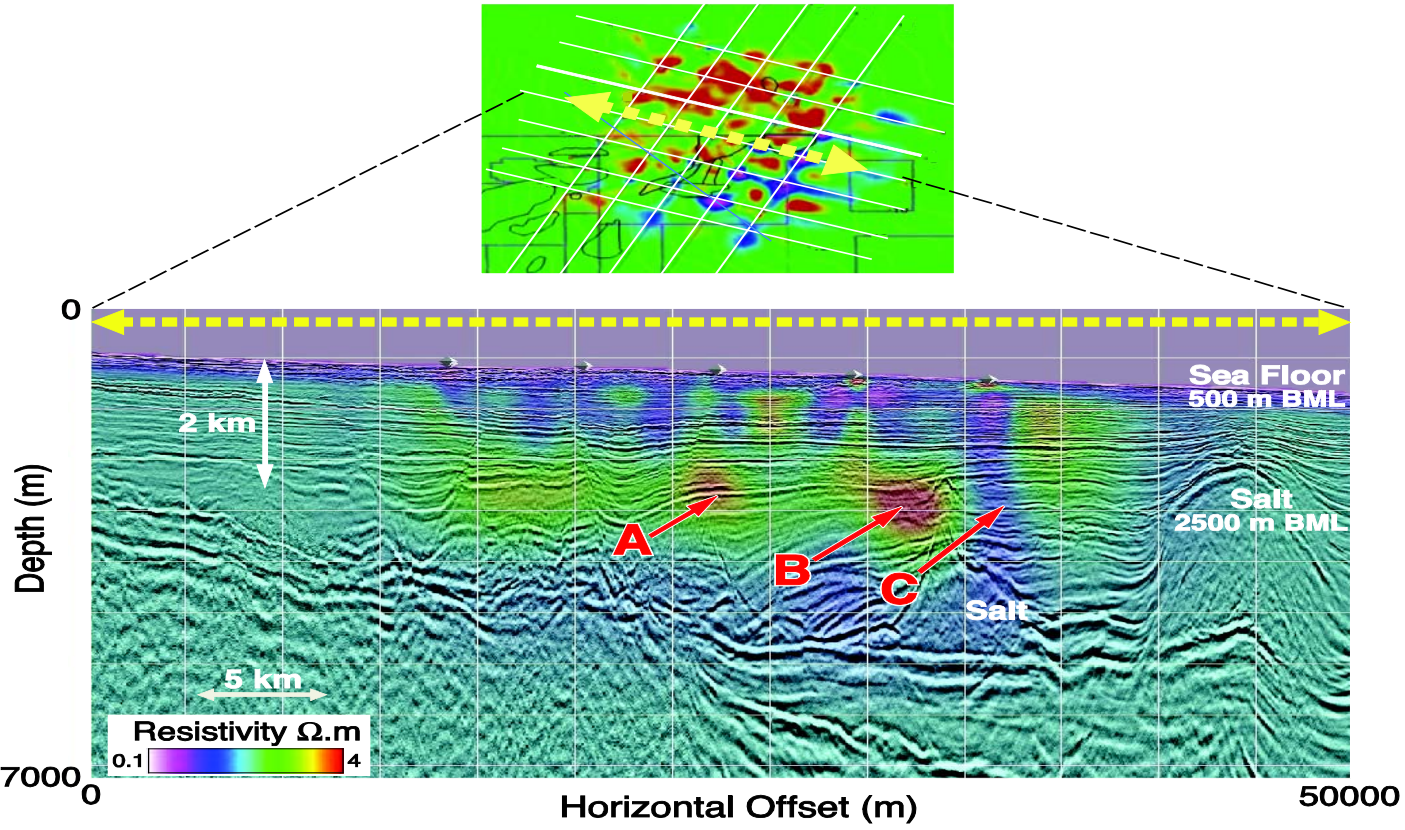
joint imaging better approach

Scientific/Technical Approach

- USE 3D MEQ, MT and CSEM Imaging Approaches
  - Employ MEQ tomographic imaging & hypocenter event location
    - standard & double difference (hypoDD) approaches
  - 3D MT/CSEM Resistivity Imaging Algorithms
    - full wave equation approach, finite difference approximations, adjoint state methods, gradient decent methods
    - use in time lapse mode
  - Joint resistivity and velocity imaging
    - use structural constraint => velocity and resistivity images
    - seek similar spatial patterns
  - Focused EGS Imaging
    - Use hypocenter clusters to focus resistivity/velocity imaging zone

Scientific/Technical Approach

- Technical Feasibility
  - Established track record in applying imaging technologies
    - geothermal exploration
    - oil & gas for fluid identification



3D CSEM Imaging
Compos Basin
Offshore Brazil

A: known oil field
B: possible HC trap
C: brine

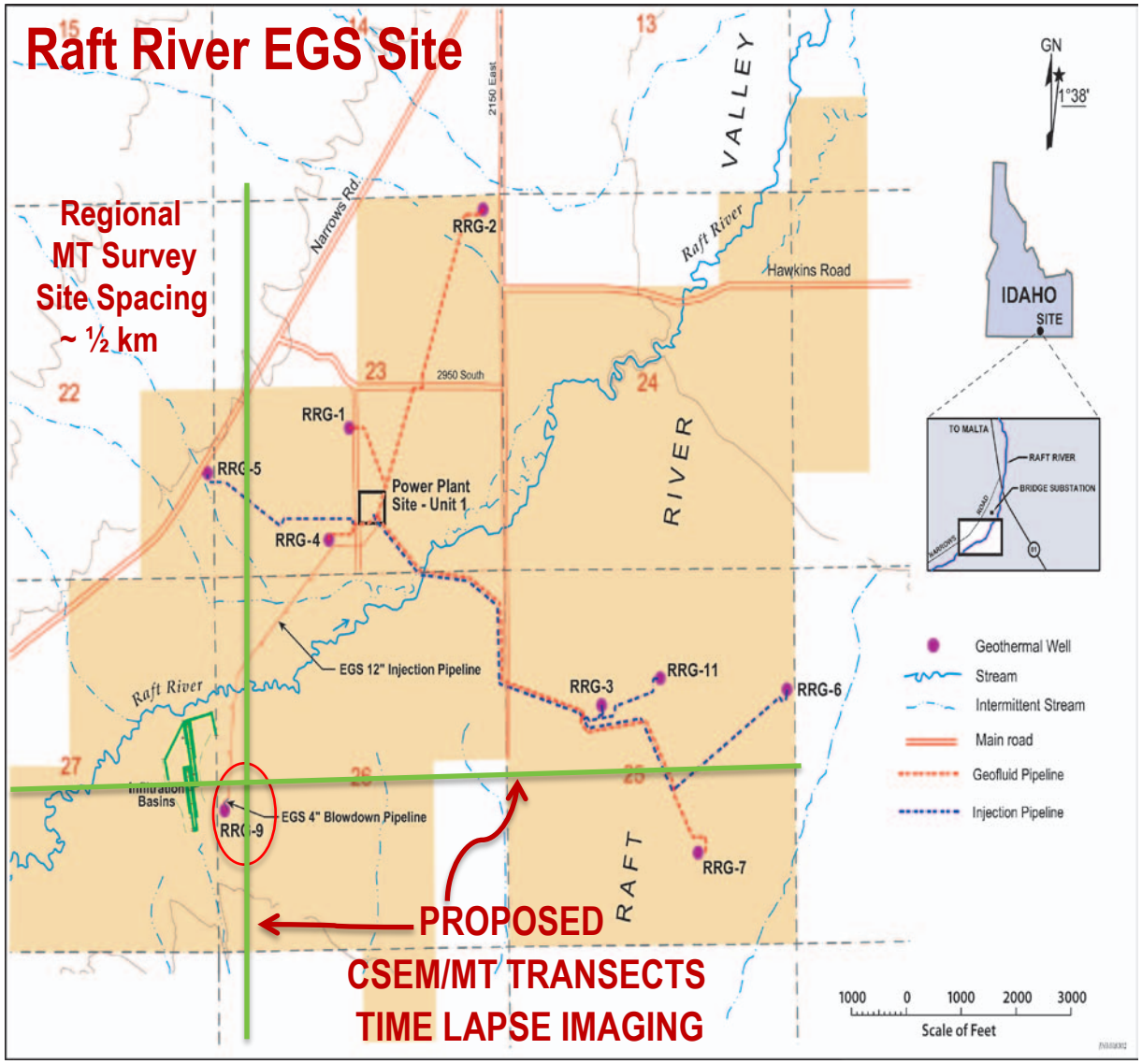
Scientific/Technical Approach

- Planned Milestones in FY10
  - Identify EGS Site (Raft River, Idaho)
  - Carry out model studies at the Raft River EGS site
  - Implement Joint Velocity-Resistivity Imaging Approach
    - common structure constraint (cross gradients)
  - Instrument Raft River MEQ Network (8 Stations) in Late Spring
  - Image MT/MEQ Data to Characterize Regional Geology
    - collaborative effort with Univ. Utah Energy and Geoscience Institute
  - Begin Time Lapse EM Data Acquisition in Summer 2010
    - collect baseline EM data over EGS injection well RRG-9

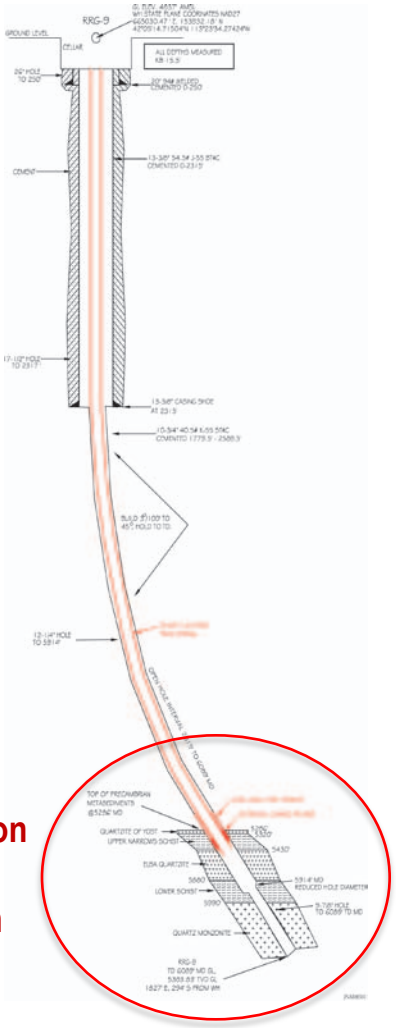
Scientific/Technical Approach

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

Raft River EGS Site



Well RRG-9

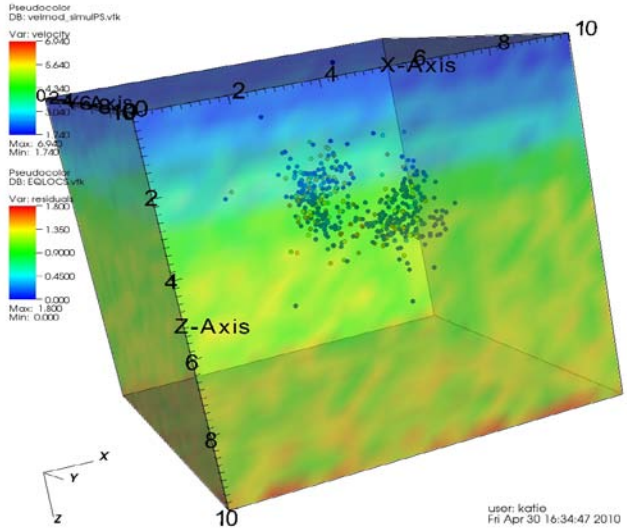


stimulaiton zone ~ 1.6 km depth

Technical Accomplishments to Date:

Seismic Component

- developed program to create synthetic seismic data sets
- testing for resolution and accuracy of MEQ imaing methods
- literature search on MEQ methods for inversion, cross-gradient, ray tracers, resolution and accuracy
- modifying SimulPS code for joint attenuation and MEQ inversion with cross-gradient constraint
- preparing new visualization capability (VisIT)
- create synthetic 3D velocity models of any chosen dimensions
- calculate synthetic arrival times for earthquake locations with specified noise
- preparing publication on resolution and accuracy



Technical Accomplishments to Date:

EM Component

- Joint MT/CSEM Imaging codes operational and tested
- Time lapse –focused- imaging successfully demonstrated on EGS test models
- Implementation structural constraint for joint seismic and EM imaging

EGS Field Site Recently Identified

- Raft River, Idaho
- Stimulation to begin in Fall 2010
- Planned injection - 1 Million gallons of water

Project Participants and Collaborators:

- G. Newman, E. Majer, L. Hutchings & M. Commer (LBL)
- J. Moore and P. Wannamaker Colloborators U. Utah Energy & Geoscience Institute

Project Management/Coordination Future Directions

Summary of Project Management Plans & Schedule:

- Algorithm Developments and Model Studies
  - To be completed by fall 2010
- Raft River
  - 3D MT Imaging of the Raft River Site to characterize background geology
    MT data acquisition now underway - Spring & Summer 2010
  - Installation of MEQ network Spring 2010
  - Coordinate time lapse imaging experiments with stimulation schedule – Fall 2010
  - Contractor to acquire baseline EM data over well RRG 9 – Summer 2010
  - Analyze fist set of time lapse data in Summer & Fall 2010
  - Acquire second set of data after RRG 9 stimulation & injection during FY11
  - Carry out time lapse imaging of the RRG 9 data sets in FY11
  - Project ends in Fall 2011
- Anticipated Results
  - Map of the stimulated fluids and fractures
- Documentation of Results
  - Meeting Presentations & Technical Publications
  - All Data Will be Uploaded to the National Geothermal Data System

Mandatory Summary Slide

- Attempting to Image EGS Fracture & Fluid Networks
- Employing joint Geophysical Imaging Technologies
  - needed to reduce image ambiguity
- Using Time Lapse and focused Imaging
  - necessary to enhance detection of fluid-fracture network
- Test Technical Concepts at Raft River EGS Site
  - Planned fluid and stimulation injection this fall
- Project is collaborative