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### Imaging, Characterizing, and Modeling of Fracture Networks and Fluid Flow in EGS Reservoirs

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Seismicity and Reservoir Fracture Characterization

### Mandatory Overview Slide



### • Timeline

- Project start date: LANL 10/01/2009; NETL 03/01/2010;
- Project end date: 09/30/2011;
- Percent complete: LANL ~33%; NETL ~5%

### Budget

Total project funding: LANL \$501,000 (~41% of the original budget); NETL \$504,893

### Partners

- National Energy Technology Laboratory
- Ormat
- Lawrence Berkeley National Laboratory
- GeothermEx
- Hi-Q Geophysical Inc



### **Project Objectives:**

- Improve image resolution for microseismic imaging and time-lapse active seismic imaging
- Enhance the prediction of fluid flow and temperature distributions and stress changes by coupling fracture flow simulations with reservoir flow simulations, and integrating imaging into modeling

This work will help optimizing the operation of injection and production wells and the placement of new wells in EGS reservoirs.

### Scientific/Technical Approach

- Develop a multi-scale thermal-hydrologic-mechanical modeling code: coupling FEHM & CFD codes (ongoing)
  - FEHM: LANL's finite-element/control-volume computational code (modeling at the reservoir scale)
  - CFD: NETL's computational fluid dynamics code (modeling at the fracture scale)
- Develop fat-ray double-difference tomography for microseismic imaging (planned)
- Develop double-difference waveform inversion for quantifying reservoir geophysical property changes (code developed)
- Develop a super-resolution seismic imaging method (ongoing)

### Scientific/Technical Approach



- Conduct laboratory core studies to obtain modified Gassmann equations (seismic velocities vs fluid saturation and temperature) (ongoing)
- Quantify fluid flow & temperature changes (planned)





### **Milestones:**

- Verify a 2D imaging code for quantify reservoir geophysical property changes (09/30/2011)
- Verify a multi-scale thermal-hydrologic-mechanical code (with a candidate sub-grid scale model) for reservoir flow modeling (09/30/2011)

# Accomplishments, Expected Outcomes and Progress

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### Double-difference waveform inversion of synthetic time-lapse seismic data



# Accomplishments, Expected Outcomes and Progress

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### 3D simulation of cold fluid injection into a hot reservoir

- 3D grid, 100 m cube
- Initially at 200°C
- Injection of fluid at 90°C for 6.5 days
- Initial Permeability 10<sup>-13</sup> m<sup>2</sup>
- Permeability increased by a factor of 100 in damage zone (vertical stress <0)</li>





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#### Heating of fluid in a rough fracture

- To determine the coupled thermal hydrological effects on fluid transport, we convert CT scanned fracture geometries to computational fluid dynamics models.
- Aperture map and midplane of a fracture in Berea sandstone.
  - Width 2.5 cm, length 9.2 cm
- Simulation results of water flowing through this fracture.
  - Wall temperature = 440K(170°C)





- Teleconferences among LANL and NETL researchers
- Meeting with the other collaborators during 2009 AGU Fall meeting
- Visit Ormat and Brady's EGS site in April, 2010
- Planned a project meeting at NETL in 2010, and a meeting at LANL in 2011 in addition to teleconferences
- Data and model sharing: Ormat, GeothermEx, and projects led by Ernest Majer (Berkeley Lab) and John Queen (Hi-Q Geophysical Inc)

### **Future Directions**

- Develop and test imaging codes using time-lapse synthetic data for the Brady's EGS reservoir model.
- Develop fat-ray double-difference tomography code and apply it to Desert Peak and Brady's microseismic data.
- Conduct laboratory studies of core samples from Brady's EGS site.
- Carry out coupled fracture flow and reservoir flow simulations for a Brady's EGS reservoir model.
- Meet milestones by 09/30/2011.



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Brady's velocity model (Courtesy of John Queen)

- Our new imaging methods using passive and time-lapse active seismic data will improve image resolution for fracture characterization and flow imaging.
- Our coupled fracture-scale and reservoir-scale flow modeling will enhance thermal-hydrologic-mechanical simulations.
- Integrating imaging results in reservoir modeling will improve the prediction of fluid flow, temperature distributions, and stress changes in enhanced geothermal reservoirs.



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### **Supplemental Slide**

### Lab Facilities at NETL

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- CT Scanner & Core Lab
  - 4<sup>th</sup> generation CT medical CT scanner, with 250 µm voxel resolution, flow pumps, temperature controls and pressure transducers.
  - Years of experience scanning and post-processing variety of cores, from coal to cement.



- PS2 Ultrasonic Transducer
  - Measures shear waves and waveforms at confining pressures, pore pressures, and temperatures within cores.

### NER's Zmeter

- Measures the complex electrical resistance of cores, i.e. the formation factor.
- Spin Track NMR
  Spectrometer
  - Measures the pore size distribution within samples

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