• Project Start Date: 1 February, 2009; Completion: 1 February 2013 (4-year project)
• DOE Budget: $508,633 (MIT); $200,000 (LANL); $450,000 (Cost Share)
  – DOE Budget for years 1-2: $226,002
• Barriers
  – Improved reservoir characterization from geophysical data
  – Constraining reservoir models using geophysical data
  – Improved reservoir development scenarios
• Partners
  – Los Alamos National Laboratory
  – Chevron Energy Solutions
Project Objectives

• Better understand and model fluid injection into a tight reservoir on the edges of a hydrothermal field
• Use seismic data to constrain geomechanical/hydrologic/thermal model of reservoir
• Model for flow network to predict injection and production response of reservoir
• Use model and data analysis to develop improved stimulation methodologies leading to improved production during EGS development
Scientific/Technical Approach

• Combine analysis of seismic, well log, and flow data to develop improved reservoir model
  – Develop and test new analysis and modeling approaches

• Milestones:
  – 2009: obtain data and make preliminary assessment
    • Completed but a little late due to legal agreement challenge
  – 2010: Preliminary assessment of field seismic data
    • Application of seismic analysis methodologies to data
    • Begin comparison to reservoir data
    • Ongoing reservoir model development and application to preliminary seismic data results
Accomplishments to Date

- Obtained complete catalog of microseismic data from Salak field
  - Waveforms, arrival time picks, preliminary locations
  - Also includes relevant well information
- Developed sub-grid scale model of fracture permeability as a function of normal and shear displacements
  - Installed in the fully coupled thermal-hydrologic-mechanical (THM) simulator FEHM
- Initiated application of TomoDD tomography code to induced seismic data
  - Simultaneously finds microearthquake location and 3D velocity model
- Initiated development of interferometric imaging method for detecting scattering between earthquake pairs
Accomplishments, Expected Outcomes and Progress

Awibengkok (Salak) Geothermal Field, Indonesia

- Operated by Chevron
- Water-dominated system
- > 370 MWe

Figure modified from J.A. Acuna et al. / Geothermics 37 (2008) 332–346

Figure from J. Stimac et al. / Geothermics 37 (2008) 300–
Developed Sub-Grid Scale Model of Fracture Permeability as a Function of Normal and Shear Displacements

- Verified with comparison to analytical solution
- Accounted for volume changes from thermal and pore pressure developed stresses
- Installed the sub-model in the fully coupled thermal-hydrologic-mechanical (THM) simulator FEHM
- Started sensitivity testing of parameters (particularly to fracture shear displacements)

Apparent downward seismicity may be predicted with new fracture Permeability-displacement models
Accomplishments, Expected Outcomes and Progress

Double-Difference Tomography for Spatial Velocity Variations

- Image structure of EGS reservoirs
- Example images:
Double-Difference Tomography

What/Why?
- Simultaneously invert for event locations and 3D velocity structure

Relative times:
- Improved relative event locations
- Less sensitive to heterogeneity outside the reservoir
- Very sensitive to reservoir heterogeneity
- Not sensitive to station corrections

Absolute and relative arrival times give info about velocity variations inside zone of seismicity even if the variations outside aren’t well known
Double-difference Tomography

- **Absolute times** → initial event location estimates
  - Improve initial locations (relative) and avoid using station corrections

- **Relative times** → further refine relative locations and find velocity structure
  - Use relative times from CC and catalog

- **Iterative weighting scheme during inversion**
• P and S velocity structures show some correlation with seismicity
  – Both consistent with NNW-NW trend of seismicity
Accomplishments, Expected Outcomes and Progress

Interferometry For Characterizing Structure (fractures, anisotropy) Between Microearthquakes

Interferometry concept: Characterize scattering within region between microearthquakes by correlating waveforms

Suboptimal station geometry leads to misleading results
Use of SVD improves results and Yields better interpretation

Upper left-hand Figure from Curtis, et al., 2006, The Leading Edge, 25, 1082–1092.
• **Management activities**
  – Communication with collaborators
    • Fehler visited Chevron Geothermal in Jakarta
  – Finalize and sign agreement to obtain data; obtain data
  – Visitor from Indonesia to MIT helped understand framework of region; continues to collaborate

• **Schedule & ongoing activities**
  – Activities were ongoing even before receiving seismic data
  – Model development between Chevron and LANL
  – Ph.D. student at MIT working on development of interferometric method for evaluating scattering within reservoir
  – Masters student at MIT working on application of double difference tomography to induced seismic data
  – Undergraduate student at MIT helping to stage Salak data for analysis
Future Directions

- **Planned activities for 2010**
  - Analyze microseismic data from 2007 – 2008 injection
  - Continue development of interferometric method; apply to field data
  - Provide seismic analysis results to modelers and to field operators
  - Project meeting

- **Key milestone**
  - Complete assessment of locations of induced seismic events
    - end of 2010

- **Decision point: Do location data provide sufficient information to proceed with reservoir modeling?**
Salak data is a rich dataset for understanding EGS potential on the edge of a producing geothermal field.

Field operator is considering expansion outside of producing geothermal field with new wells.

Excellent scenario for expanding capacity of existing field using EGS technology.

Seismic, well log, and reservoir data provide excellent opportunity to understand field expansion into tight surrounding rock:
- Combined evaluation of data with state-of-the-art geomechanical/hydrologic/thermal model.

Project will provide methods to help make EGS development successful on margins of producing geothermal reservoir.
Supplemental Slides
Paper/workshop presentation


Note: This slide is for the use of the Peer Reviewers only – it is not to be presented as part of your oral or poster presentation. These Supplemental Slides will be included in the copy of your presentation that will be made available to the Reviewers.