Monitoring and Modeling Fluid Flow in a Developing EGS Reservoir

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Track Name

Mandatory Overview Slide

- 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

Awibengkok (Salak) Geothermal Field, Indonesia

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

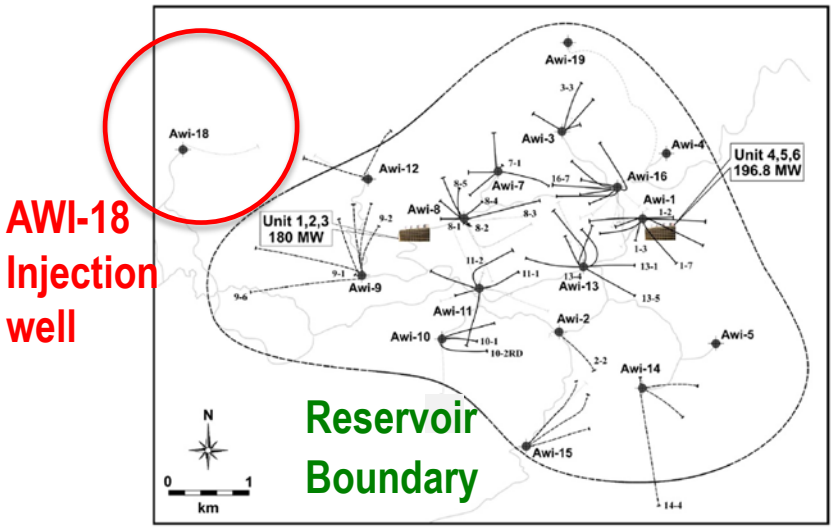


Figure modified from *J.A. Acuna et al. / Geothermics 37 (2008) 332–346*

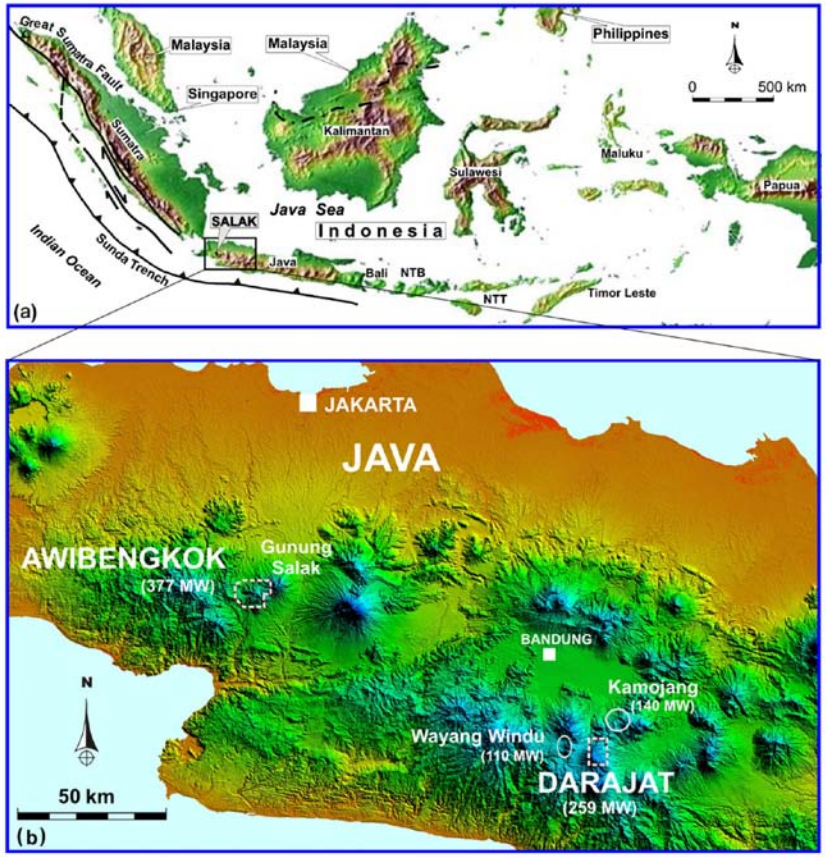
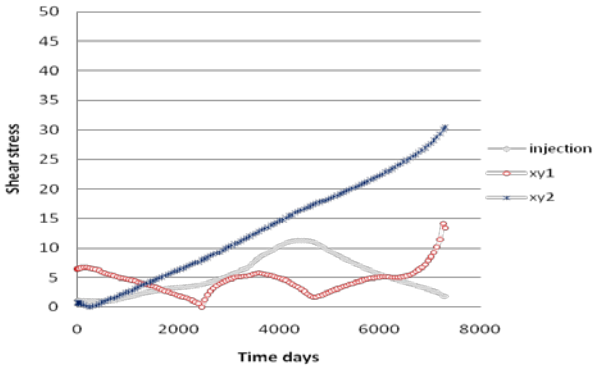


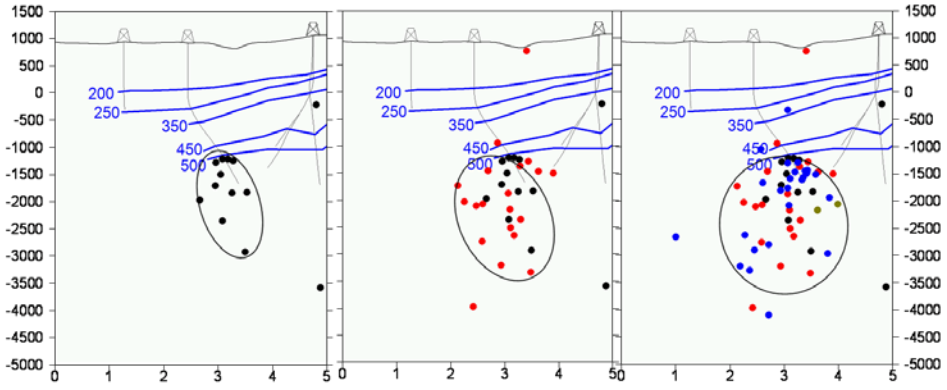
Figure from *J. Stimac et al. / Geothermics 37 (2008) 300–*

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)



Changes in Geothermal Reservoir Shear Stress Predicted with New Sub-Grid Model

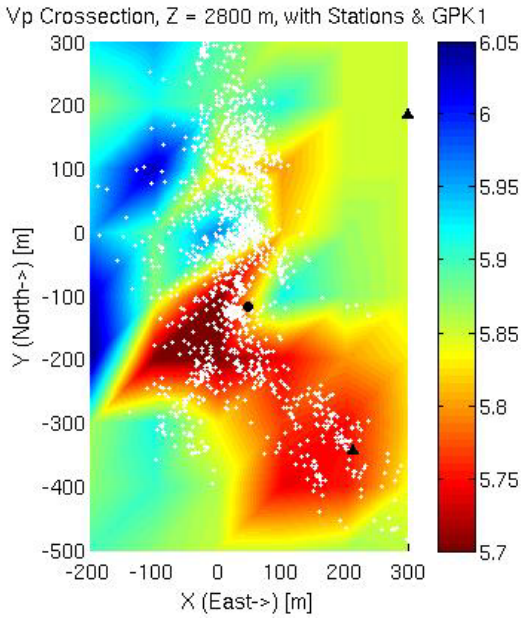


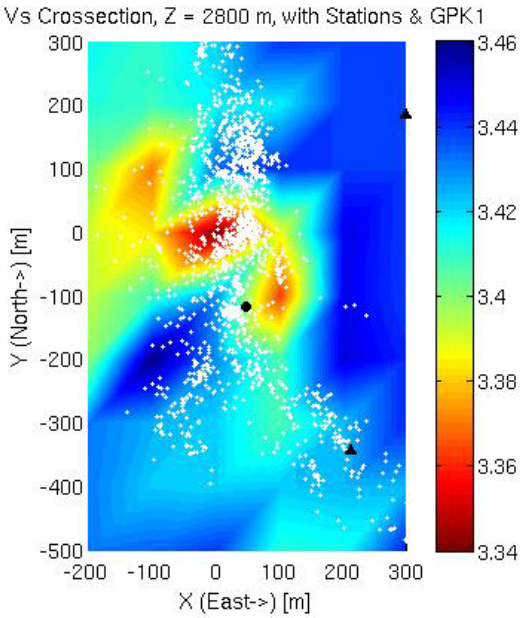
Salak MEQs

Apparent downward seismicity may be predicted with new fracture Permeability-displacement models

Double-Difference Tomography for Spatial Velocity Variations

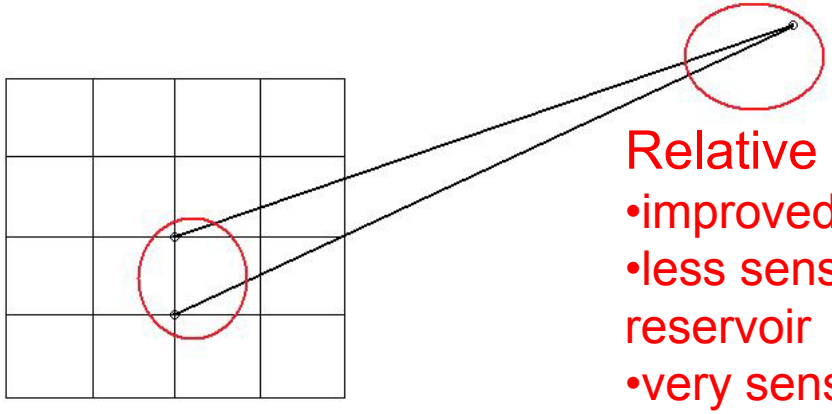
- Image structure of EGS reservoirs
- Example images:





Double-Difference Tomography

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



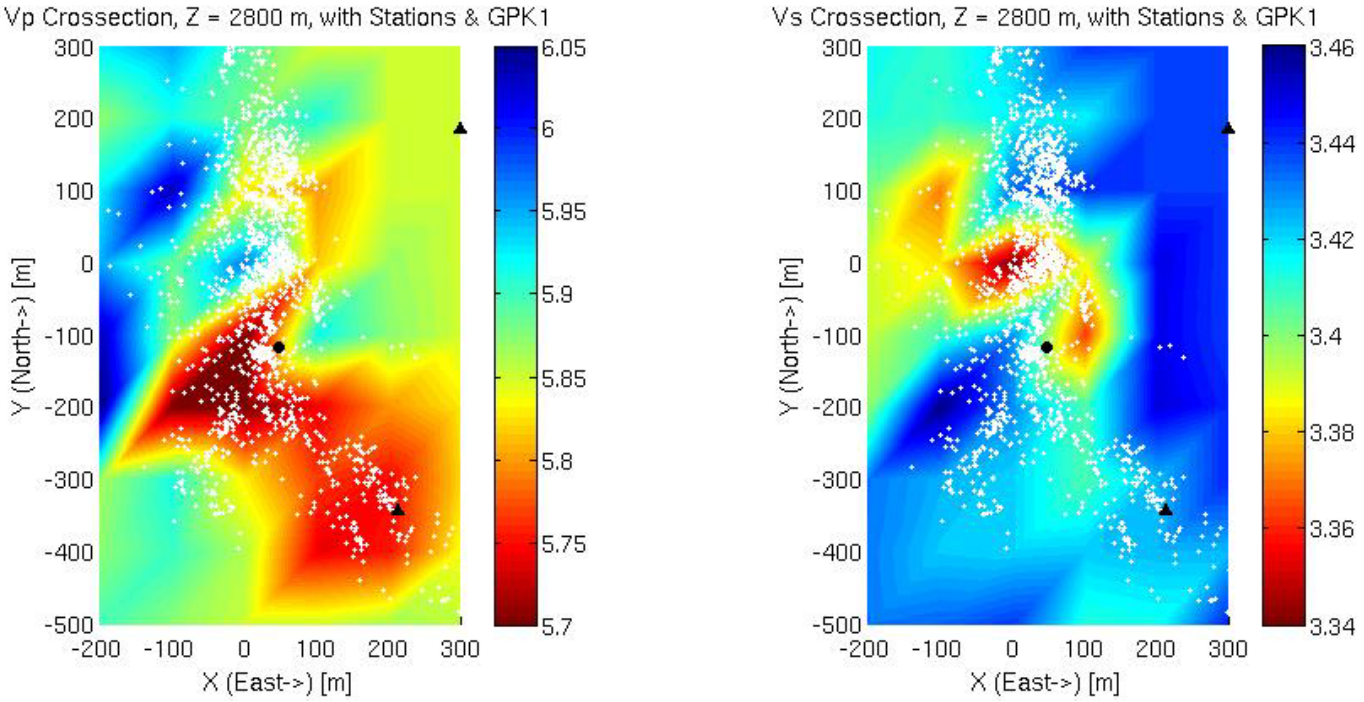
Relative times:
- improved relative event locations
- less sensitive to heterogeneity outside the reservoir
- very sensitive to reservoir heterogeneity
- not sensitive to station corrections

  - 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

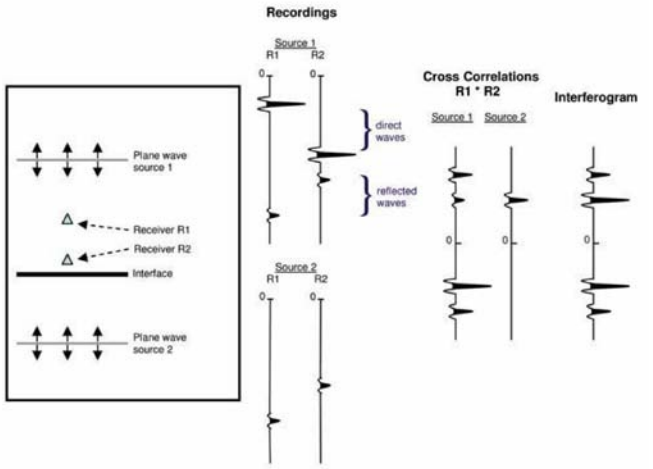
- Absolute times → initial event location estimates
  - Improve initial locations (relative) and avoid using station corrections
- Relative times → further refine relative locations and find velocity structure
  - Use relative times from CC and catalog
- Iterative weighting scheme during inversion

2800 Meter Depth Slices

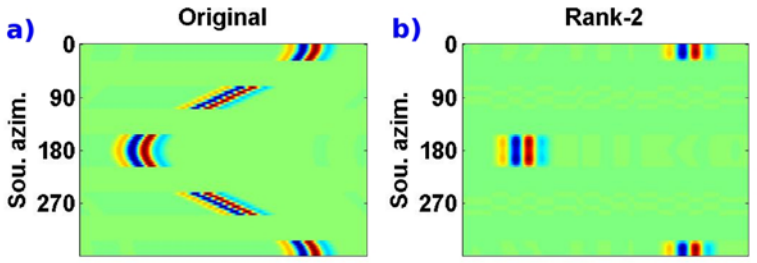


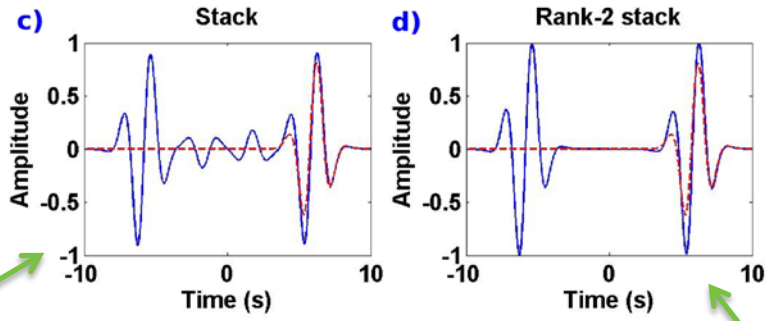
- P and S velocity structures show some correlation with seismicity
  - Both consistent with NNW-NW trend of seismicity

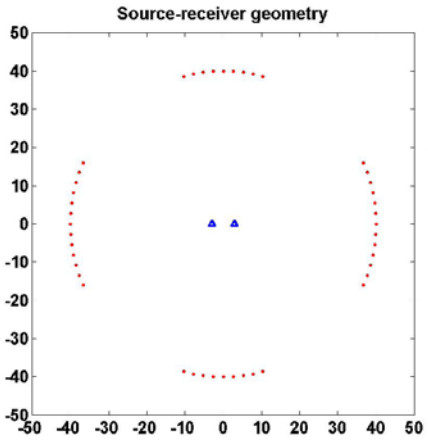
Interferometry For Characterizing Structure (fractures, anisotropy) Between Microearthquake



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.

Project Management/Coordination

- 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?

Mandatory Summary Slide

- 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

Optional Slide

- Paper/workshop presentation
  - G. Mello, and A. Malcolm, Using SVD to extract more information form correlograms for seismic interferometry, abstract, American Geopysical Union Fall Annual Meeting, (2010).
  - D. Concha, M. Fehler, H. Zhang, and P. Wang, “Imaging of the Soultz Enhanced Geothermal Reservoir Using Microseismic Data”, Stanford Geothermal Conference, http://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2010/concha1.pdf ,(2010).

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