4.6.3 Detection and Characterization of Natural and Induced Fractures for the Development of Enhanced Geothermal Systems

Presentation Number: 030
Investigator: Toksoz, Nafi (Massachusetts Institute of Technology)
Objectives: To combine geophysical methods for reservoir and fracture characterization with rock physics measurements made under in-situ conditions (up to 350 °C) for development of geothermal systems; to apply the model to the Cove Fort-Sulphurdale geothermal field in Utah; and to generalize the reservoir characterization model for application to other EGS sites.
Average Overall Score: 3.6/4.0

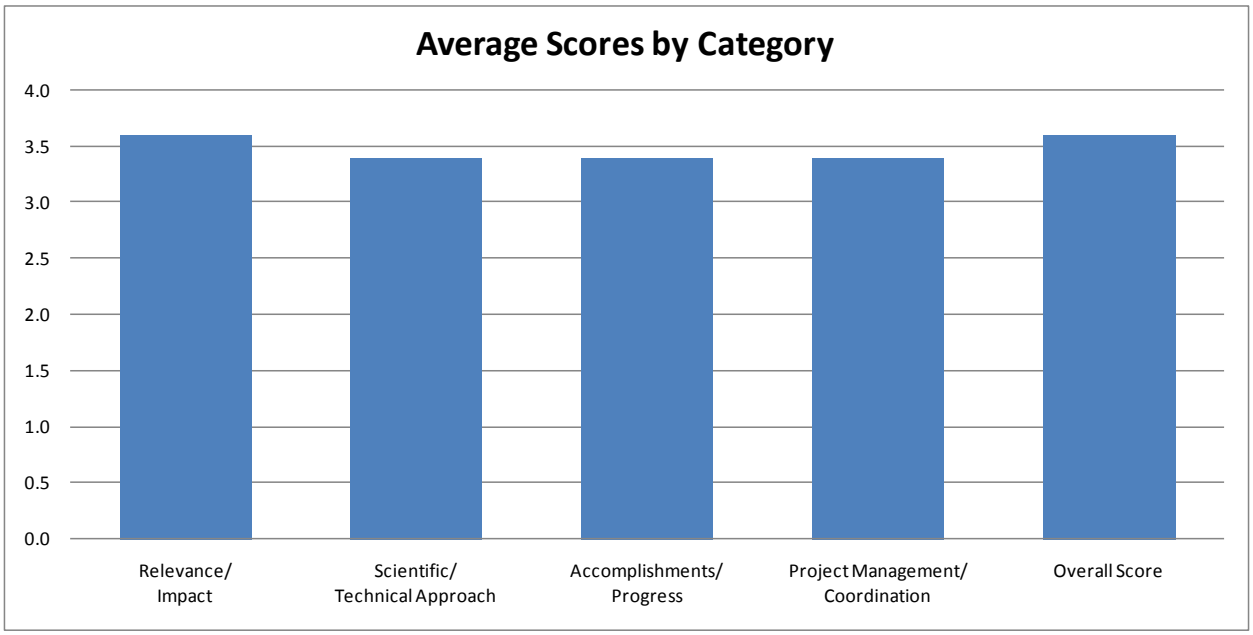

Figure 39: Detection and Characterization of Natural and Induced Fractures for the Development of Enhanced Geothermal Systems

4.6.3.1 Relevance/Impact of the Research

Ratings of Five-member Peer Review Panel: Outstanding (4), Good (3), Outstanding (4), Outstanding (4), Good (3)

Supporting comments:

- This project has made excellent progress on key reservoir characterization that can be accomplished by seismic tomography. Petrophysical property measurements are highly relevant for converting seismic surveys into usable subsurface thermal images. Fracture imaging did not seem to have been done yet. A significant amount of data had been collected from other sources.

- The project objective is to combine geophysical methods for reservoir and fracture characterization with rock physics measurements made under in-situ conditions (up to 350 °C) for development of geothermal systems. The methods will be tested on a specific reservoir before being extended to other reservoirs.

- This project addresses a significant technical barrier relating to the detection and characterization of fractures, an essential component of EGS, as well as site characterization and reservoir validation. Geophysical methods are used to image controlling parameters such as the fracture distribution, stress regime and reservoir temperature in a field site while direct measurements of rock properties will be made under reservoir P-T conditions. The study is multi-component with well-established field, lab and theoretical contributions.

- Investigates the use of various geophysical techniques (seismic, MT) with laboratory rock physics experiments to characterize a possible geothermal site (Cove Fort). An important field test of the extent to which these measurements accurately characterize a site.

- About 50% completed, so early to judge ultimate impact, but investigators making good progress.

4.6.3.2 Scientific/Technical Approach

Ratings of Five-member Peer Review Panel: Good (3), Good (3), Outstanding (4), Outstanding (4), Good (3)

Supporting comments:

- The seismic tomography done on the collected data was excellent, and provided tangible views of the subsurface. The petrophysical properties section was good for the seismic velocity characterization, but was less well developed, and additional assessment of porosity and permeability should be made on the high-P-T apparatus. The porosity could be important for comparing measured seismic velocities from different core samples. Some of the methods could have been more fully explained.

- Very little information was provided as to the specifics of the conducted research. In particular, I am concerned that a single site validation may not provide enough information to generalize the techniques to other EGS sites.

- The approach combines relevant geophysical data with petrophysical measures of the rocks to characterize fracture locations and apply these data to a field site to generate a reservoir model. Previously acquired geophysical data such as heat flow, gravity, MT, and various types of seismic data have been synthesized and provide a baseline for rock properties as a function of depth and suggest areas to target for field deployment of seismic stations. These data are to be coupled with measures of reservoir rocks to characterize their petrophysical properties.

Properties are dependent on rock composition which needs to be determined. Tools have been developed for measuring in-situ properties. With seismic methods, these field and lab datasets will theoretically allow fracture location, orientations and flow properties to be evaluated. It remains unclear what proportion of the fracture network microearthquakes can detect.

- Although the techniques (Vp/Vs measurements) are not new, there have been significant refinements. In particular, accurate waveform comparison makes possible determination of the mechanism of small seismic fractures in unprecedented detail. Laboratory apparatus has been designed to conduct experiments to calibrate the wave speed measurements.

- Overall good progress. PI needs to become more familiar with the details of the MT survey. Critical that details of the MT survey be included in future reviews, such as how is the static shift accounted for.

4.6.3.3 Accomplishments, Expected Outcomes and Progress

Ratings of Five-member Peer Review Panel: Outstanding (4), Good (3), Good (3), Outstanding (4), Good (3)

Supporting comments:

- The project has advanced considerably, and the group seems very productive. The successful identification of subsurface geothermal reservoirs as applied to Cove Fort would have obvious applications to any other potential geothermal site. The quality of the work is excellent. A number of papers and conference presentations has been submitted/given.

- This project has reached its mid-point. Its progress is slightly behind schedule, compared to the original timeline, but this should not be a concern. It has lead to a large number of publications. The assessment that 30% of energy released during crack growth is volumetric while 70% is released at the crack tip can lead to a better understanding of induced seismicity.

- Planned tasks and milestones have been met largely. Theoretical tasks are all on target. Previously acquired geological and geophysical data have been analyzed and used to develop tomographic images of the area. A new measurement tool has been developed. Theoretical methods have been developed for fracture and microseismic event characterization.

  Studies have been completed to focus the next study phase of direct measurement of petrophysical properties and microseismic analysis. Lab measurements of rock properties were not presented although they were reported to have been underway. These data need to be incorporated more fully into the current state of the study. Quality of the researchers is excellent and collaborators increase the range of disciplinary experts.

- Quality of team is excellent. Project has already accomplished much and many results have been reported in the scientific literature. I expect that completion of the project will provide a benchmark for the characterization of a possible geothermal site by geophysical methods. Laboratory apparatus has been designed and fabricated. Tests will be conducted during remainder of project.

- PI is very well qualified and accomplished in this field. Good initial results.

4.6.3.4 Project Management/Coordination

Ratings of Five-member Peer Review Panel: Good (3), Outstanding (4), Good (3), Outstanding (4), Good (3)

Supporting comments:

- The management plan and project coordination was well constructed and presented. A couple aspects of fraction detection and use of anisotropy seemed behind schedule, but joint inversion work was ahead of schedule.

- The project is on track, has lead to significant findings. I therefore see no reason to question the adequacy of its management and coordination.

- Management appears to be effective. Lab measurements of properties are likely underway at NER but have not yet been incorporated into the study. It is unclear if the data have come from NER.

- Coordination of field observations, modeling and laboratory is well organized and progressing along a realistic schedule. Project management appears to be exemplary.

- Overall good, but PI needs to become more involved in the MT analysis, which, I believe, will be a critical component of this project.

4.6.3.5 Overall

Ratings of Five-member Peer Review Panel: Outstanding (4), Good (3), Outstanding (4), Outstanding (4), Good (3)

Supporting comments:

- This presentation of the use of seismic tomography to image the subsurface has excellent potential application to geothermal reservoir site characterization. When combined with results from the high PT apparatus, thermal structures of the subsurface should be possible. Future work on detection of fractures using microseismic signals will also be a valuable addition. Porosity and permeability measurements of the core samples should be attempted. I wondered why only Coso data on core samples were presented, but hopefully the Cove Fort

samples can be used in the future. These techniques have obvious application to other potential geothermal sites.

- Both the presentation and the documents provided were quite vague as to the specific methods used, making it difficult to assess the overall scientific quality of the project.
- The geophysical and theoretical foundation for the project could enhance reservoir characterization and fracture detection substantially. The study is insightful, overarching and complete. Peer-reviewed papers have been published and presentations made at international meetings.
- No comments.
- Important project for geothermal energy.

4.6.3.6 PI Response

No response.