Predicting Fracture Characteristics In Volcanic Environments As A Guide To Locating Enhanced Geothermal System Reservoirs

Technical Quarterly Report
For Period Ending
March 31, 2005

DE-FG36-04GO14298

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Objectives: This project addresses the techniques required for locating and developing of EGS reservoirs in complex volcanic terrains. Work performed on this project represents a cooperative effort on the Glass Mountain geothermal unit, located on Medicine Lake Volcano in northern California between E&GI and the Calpine Corp.

Figure 1 shows the planned work program for this project.

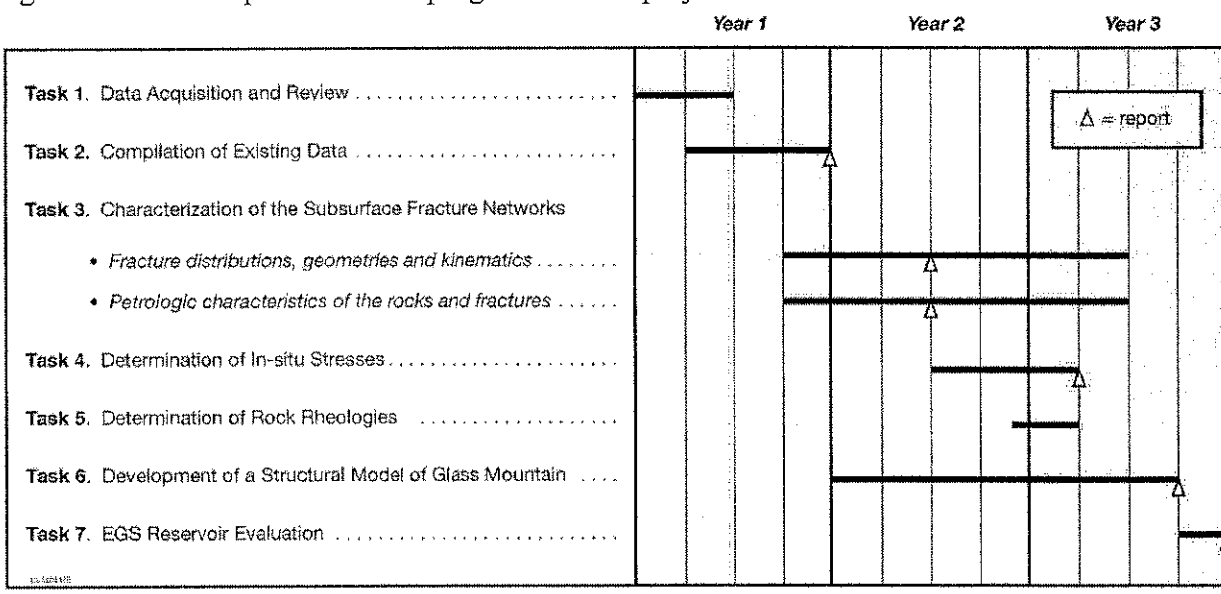

Fig. 1. Project work plan.

The figure shows that the Acquisition and review of existing data (Task 1) was scheduled for completion by the end of this quarter and that Compilation of Existing Data (Task 2) was to be initiated during the second quarter. Work on this project has proceeded as planned. The significant results of this work are discussed in the following section.

Significant Results

1. Development of an electronic data base.

Thermal, geophysical, geochemical, geologic and production data has been acquired from the Calpine Corp. and Cumming Geoscience. The Calpine Corp. is the owner of the Glass Mountain unit. Cumming Geoscience is working on the Glass Mountain project under a California Energy Commission award. Hundreds of documents, representing several thousand pages were scanned and cataloged. A GIS data base has been established and is being populated with well and geologic information. This data base will be used for mapping and structural geology studies and as input to Petrel, a commercially available program that allows visualization of geologic information, temperature surfaces and well courses in three dimensions.

2. Investigations of corehole 88-28 TGH

We have continued our structural evaluation of fractures and mineral fillings (veins and amygdules) in corehole 88-28 TGH, which was drilled to a depth of 1346 m at Fourmile Hill (Figs. 2). Figure 3 shows some of the representative fracture types encountered in the well. A nearly vertical, sealed dilational breccia from a depth of 1900 ft. is shown in Figure 3A. Figure 3B is a large cavity partially filled with quartz and bladed calcite from a depth of 2160 ft. This mineral assemblage is diagnostic of deposition from a boiling fluid. The large amount of remaining pore space indicates the zone is poorly connected to the rest of the geothermal system. Fluid inclusions trapped in the quartz crystals yielded homogenization temperatures of 193-235°C. Comparison with the modern temperatures (Fig. 4) indicates that the rocks have cooled by 70°C since mineral deposition. The mineralizing fluids had low salinities (<~0.2 wt. % NaCl equivalent). Figure 3C shows stockwork veins from a depth of 3177. Here the overall orientation of the vein appears to be relatively steep. Large crystals of quartz are present, like those shown in Figure 3B. However, here, the remaining open space was subsequently infilled with later zeolilte.

Figure 4 shows the temperature profiles for the core hole and the deeper production test drilled on the same pad. The profiles indicate that the caprock extends to a depth of about 3000 ft. The production well encountered fluids below 6000 ft.

The distribution of rock types, vein and fracture orientations and the extent of mineral fillings are shown in Figure 5. The plot demonstrates that rock type has had a strong control on fluid circulation. Virtually all of the veins and fractures occur in the brittle felsic (rhyolite and dacite) and andesite-basalt lava flows. The relatively weak pyroclastic, tuff and lahar deposits, in contrast, do not support fractures, even near the top of the reservoir section. Thus, rock type has had a significant effect on fluid circulation.

The veins show a wide range of orientations in the caprock but on average, dip more steeply in the deep parts of the well. Fractures, in contrast show a wider range of dips in the deeper rocks. Three factors appear to be important in controlling the orientations of the veins and fractures. Our logging of the core indicates that, at shallow depths, the primary fabric of the rocks has had a strong influence on the orientations of the structures. At greater depths, changes in the magnitudes of the stresses, due to an increase in the overburden thickness, are likely to become increasingly important, as was documented by our investigations of core from the geothermal field at Karaha-Telaga Bodas, Indonesia. Finally, the older, deeper rocks may have experienced a greater number of tectonic events, which has influenced their fracture densities.

Many amygdules and cavities are only partially filled, particulary above a depth of 760 m (ft). This suggests that the rocks in the present-day caprock region of the geothermal system have never been well connected to the thermal waters circulating in the deeper parts of the reservoir. This pore space may be important for fluid storage, however, in the development of an EGS reservoir.

Fracture geometries and displacement senses will be mapped in the coming months and incorporated into a kinematic model of the system developed under this project.

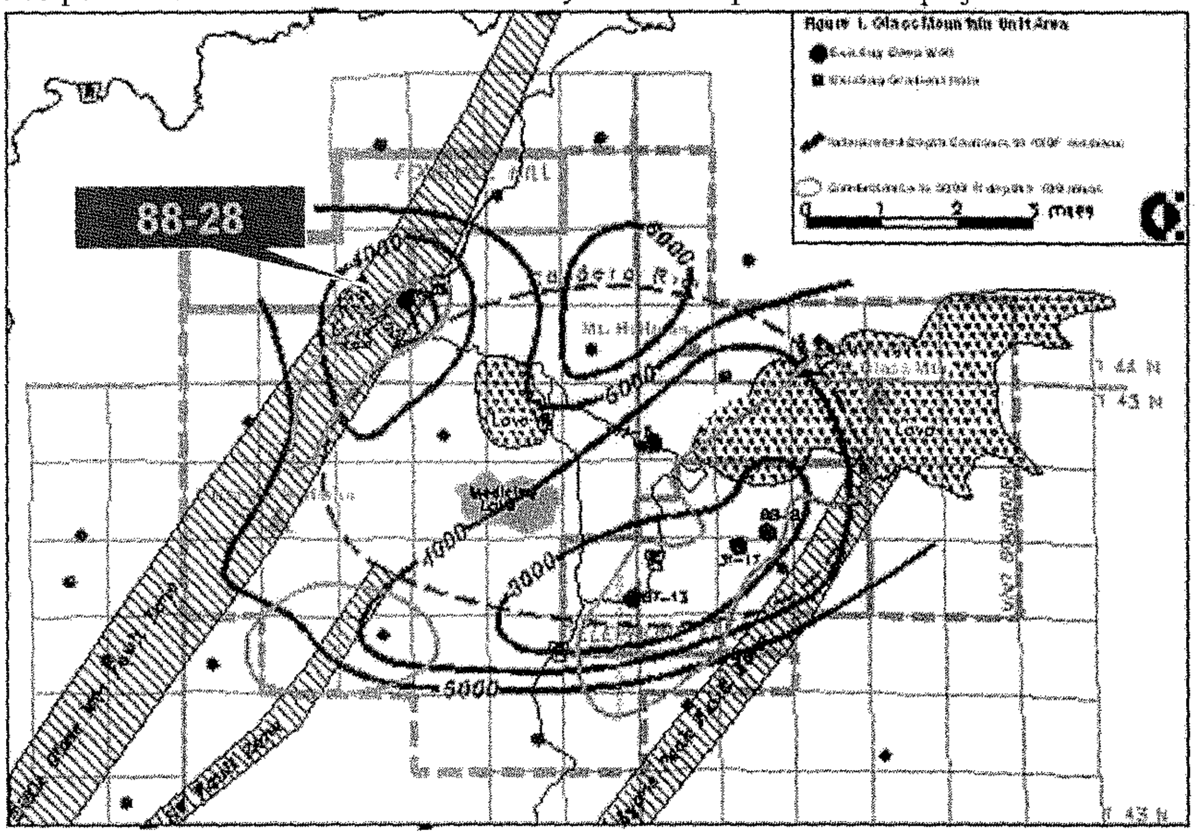

Fig. 2. Map of the Glass Mountain area showing the major geologic features, well locations and depth in feet to the 450°F isotherm. Drawn by Calpine Corp.

Fig. 3A. Steeply dipping dilational breccia from a depth of 1900 ft.

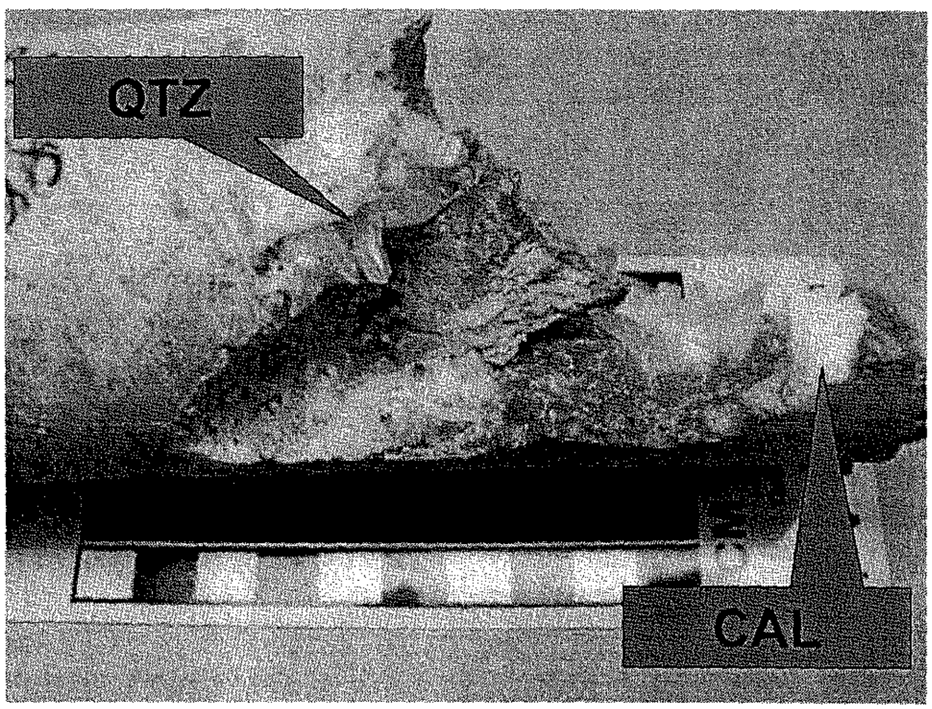

Fig. 3B. Cavity from a depth of 2160 ft. that is partially filled with quartz (qtz) and calcite (cal).

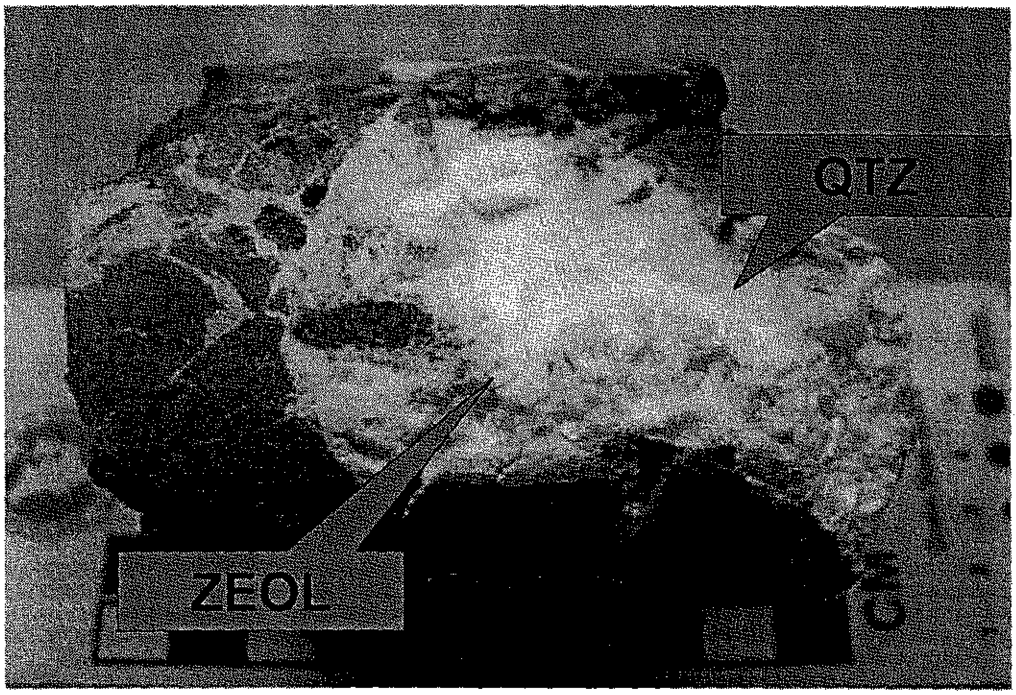

Fig. 3C. Stockwork veins containing early quartz (qtz) infilled with later zeolite (zeol).

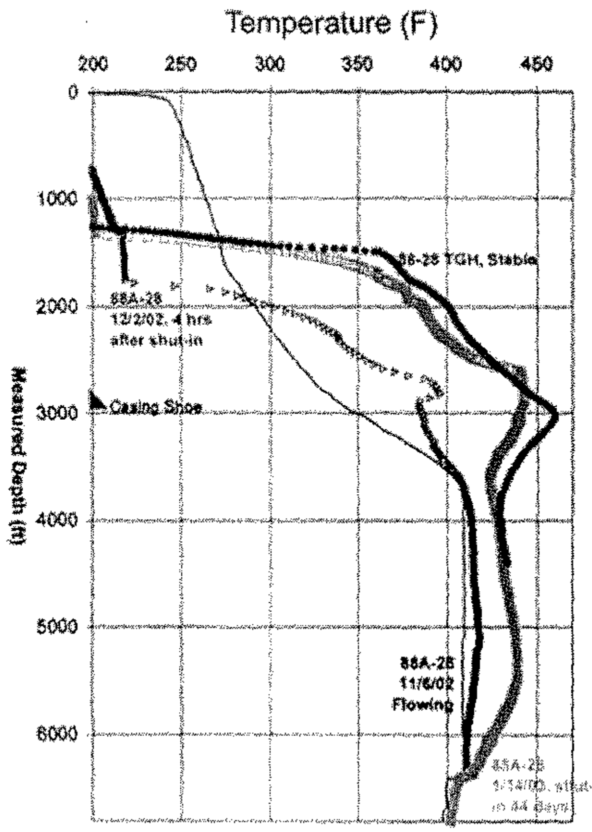

Fig. 4. Temperature profiles from the corehole 88-28 TGH and production well 88A-28.

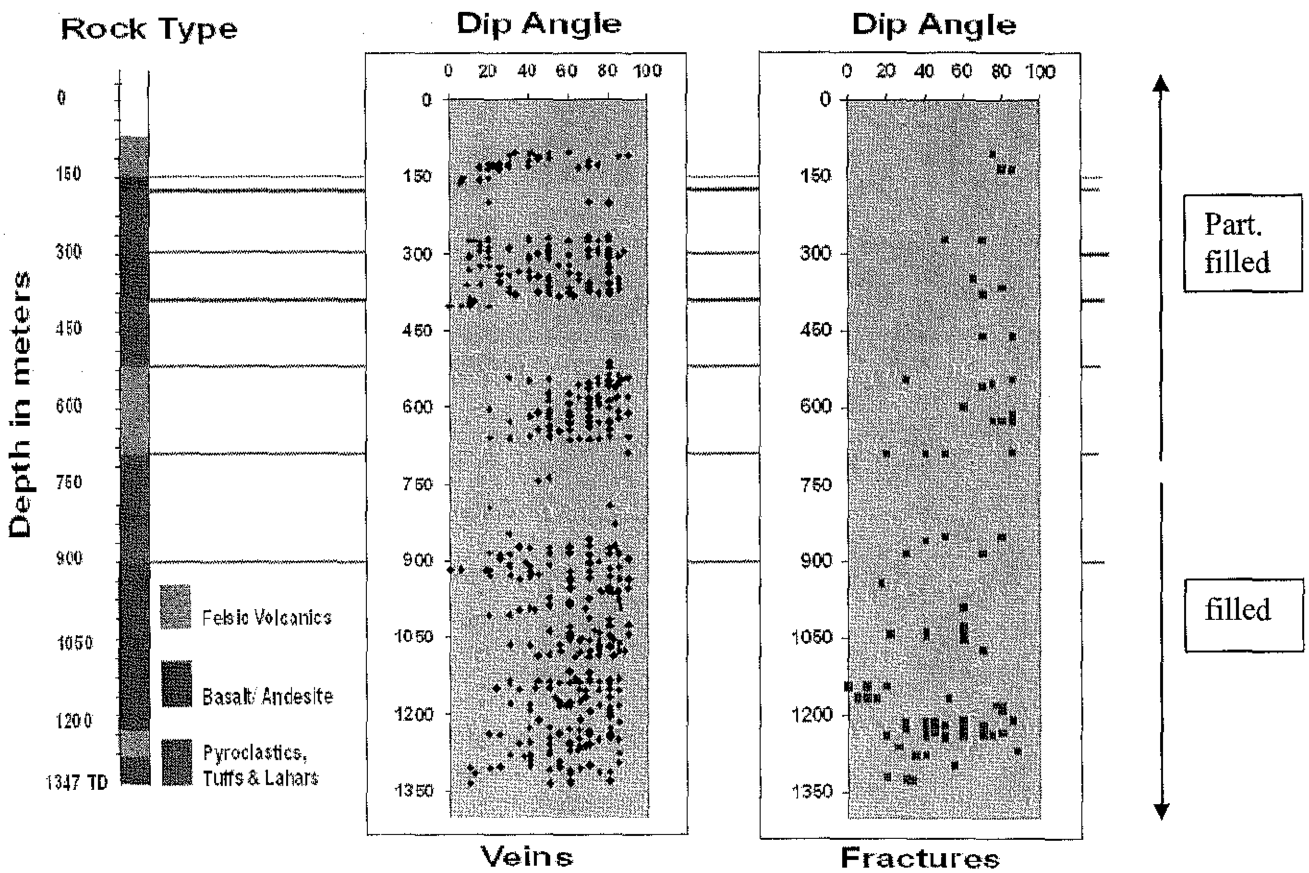

Fig. 5. Orientations of fractures and veins with respect to depth in well 88-28. The arrows on the right show the distribution of partially filled and completely filled amygdules.

3. Peer Review

A significant effort was expended in preparing for the DOE Peer Review. These efforts included the preparation of a 6 page summary report and a powerpoint presentation on this project.

Cost Status

	2nd Quarter Actual	2nd Quarter Planned
DOE	$34,524	$35,146
Cost-Share	$1,260	$1,260
TOTAL	$35,784	$36,406

Milestones: The following are the year 1 milestones proposed for this project:

1. Prepare initial 3-dimensional maps of geologic, thermal and available structural data — Aug. 31, 2005
2. Prepare fracture and lithologic logs of at least 3 selected

coreholes Sept. 30, 2005

We anticipate completing these milestones as planned.

Changes in Approach or Aims: None

Actual or Anticipated Problems: None

Personnel Changes: None

Products: A significant collection of thermal, geophysical, geochemical, geologic and production data has been scanned and catalogued. The original documents have been returned to the Calpine Corp.