DEEP ELECTROMAGNETIC SOUNDINGS NORTHEAST OF THE GEYSERS STEAM FIELD

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ABSTRACT

During the summer of 1981, a large-scale electromagnetic sounding survey was carried out northeast of The Geysers steam field in northern California, along the north and south sides of Clear Lake. The field data were interpreted to determine the probable resistivity distribution to a depth of about 15 kilometers. The normal behavior of the resistivity vs depth profile is that the resistivity decrease from values between 30 and 100 ohm-meters in the first kilometer of the subsurface to values as low as 3 to 5 ohm-meters at depths that vary from a few kilometers to as great as 12 kilometers. The resistivity at greater depth is high. This type of resistivity-depth profile does not support the concept of a partially molten batholith being present at these depths.

INTRODUCTION

The Geysers steam field lies approximately 55 miles north of San Francisco, California, on the south edge of the Clear Lake Volcanic Field. Up to the present time, production of steam in commercial quantities has been obtained only from a small portion of the area with elevated heat flow. Drilling and geophysical exploration has been carried out to the northeast of the initial producing area in hopes of finding additional production.

It has been hypothesized that the heat for the Geysers field is derived from a shallow, young batholith lying immediately north of the present producing area. Evidence for the location of the heat source is provided not only by heat flow data, but also by the presence of a well defined, high amplitude gravity low (see Fig. 1 for a portion of the U.S. National Gravity Map showing this feature). This batholithic mass giving rise to the gravity low may still be at least partially molten.

Because of the importance of the hypothetical batholith to models of heat flow in the area northeast of the Geysers, a deep penetration electromagnetic sounding survey was planned and carried out in the summer of 1981. It was expected that partially molten batholithic rock would have a resistivity in the range from 5 to 50 ohm-meters, and that such a low resistivity would be recognizable at depths between ten and twenty kilometers in the crust, where rocks at normal temperature would have resistivities many orders of magnitude greater.

ORGANIZATION OF THE SURVEY

The electromagnetic sounding method used was one in which the electromagnetic field was generated by passing a current square wave through a grounded length of cable, and at a receiver site, the vertical component of magnetic induction was measured. In order to provide coverage of the very large area of interest, an intense source system was used; it provided current steps with an amplitude of 2000 amperes to a grounded wire 1.1 kilometers in length. With this source system, signals could be recorded reliably at receiver sites at distances of 50 kilometers and more.

At the beginning of the survey, the source was established 50 kilometers to the east of Clear Lake (see Locations on Fig. 2), just west of Sacramento. However, signals from this source were severely distorted by a large mass of conductive rock in the hills to the west of the source, generally in the area of Knoxville. A second source was established at the northwest end of Clear Lake, but again, signals were severely distorted, this time by induction on a power line that passed near the source. A useful source, shown as Source No. 3 on Fig. 2, was finally obtained at the southeast end of Clear Lake.

A typical sounding curve for the northeast Geysers area is shown in Fig. 3. The apparent resistivity decreases gradually for both early and late time presentations, with there being relatively little expression of resistant basement rock even at the latest times for which measurements were made. In areas well away from the Geysers producing area, and particularly to the northwest of Clear Lake, the presence of resistant basement was clearly expressed on the sounding curves.

In the processing of field curves such as the one shown in Fig. 3, an equivalent resistivity-depth profile was obtained by assuming that only one-dimensional variations of resistivity were present in the subsurface (only a variation with depth). The response for this electromagnetic sounding system can be calculated easily for such a model. A rough estimate would be made of the resistivity and thickness of layers for each sounding site, and a curve would be calculated for comparison with the field data. Then, each of the parameters would be perturbed to find if the mismatch could be reduced. After numerous calculations, a good match between a field data set and a computed model curve could usually be obtained. By good, we mean that the usual rms error between the field data and the calculated curve would fall between 2 and 5 percent.

PRESENTATION OF RESULTS

Only some summary results can be presented here because of space limitations. The character of the results is demonstrated by the sets of resistivity-depth profiles shown in Figs. 4 through 6. Each of these plots has superimposed the interpreted resistivity-depth relationships observed within an area of one or two townships. They are plotted together because it is to be expected that the lateral resolving capability of the electromagnetic sounding method at 10 to 20 kilometers depth should be no better than $\pm$ 10 kilometers (the side dimension of a township), and so, all soundings within a single township should have much the same character.

All profiles show approximately the same behavior. Surface rocks have high resistivity, in the range from 30 to 100 ohm-meters. At greater depth, the resistivity decreases, often to values less than 10 ohm-meters. The lowermost region seen with the soundings has a relatively high resistivity.

Soundings in R7W-T12N, which are located closest to the producing area of the Geysers are shown in Fig. 4. These soundings show the least depth to the conductive portion of the section -- with the presence of resistant rock beginning at 3 to 4 kilometers depth.

Conductive rocks lie at greater depths along the south shore of Clear Lake (in T8&9W, R13N), and north of Clear Lake (T8W, R15N) (see Figs. 5 and 6, respectively). Low resistivities begin at depths of 6 to 10 kilometers, and resistant rocks are present again at depths beyond 12 to 16 kilometers.

EVALUATION

The electrical unit of most interest in terms of geothermal potential is probably the zone with resistivity of 2 to 10 ohm-meters which lies between 1 and 4 kilometers depth just northeast of the present producing field. At these shallow depths, it is most likely to consist of hot, fractured, and water saturated rock. Further to the north, east and west, the same unit appears to be present at greater depths, ranging up to 16 kilometers, but with the same thickness and resistivity. In this area also, the conductive unit is underlain by highly resistant rock.

The low resistivity unit has an appropriate resistivity for partially molten batholithic rock, but the form of the unit does not favor the interpretation that it is molten. A more reasonable interpretation would be that the conductive unit is fractured and saturated with hot saline water. The underlying resistive rock can well be a batholith, but in view of its high resistivity, it is not likely to be partially molten. At depths reached by the electromagnetic survey, its temperature is probably less than 600°C.

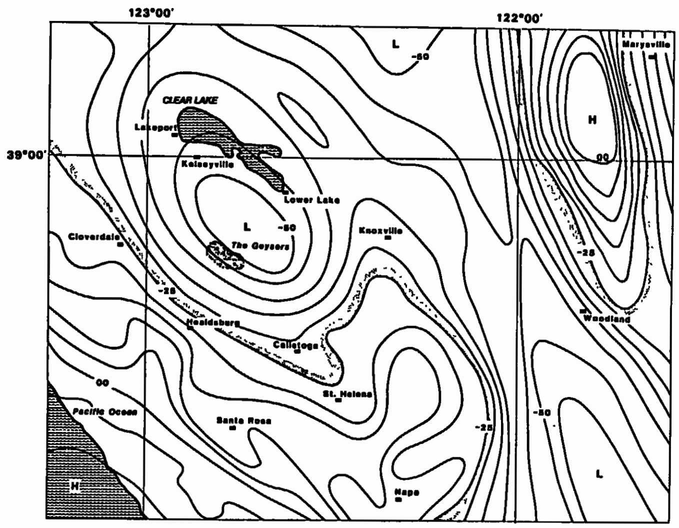

Figure 1. Gravity Map of the Greater Geysers Area (from U.S. National Gravity Map)

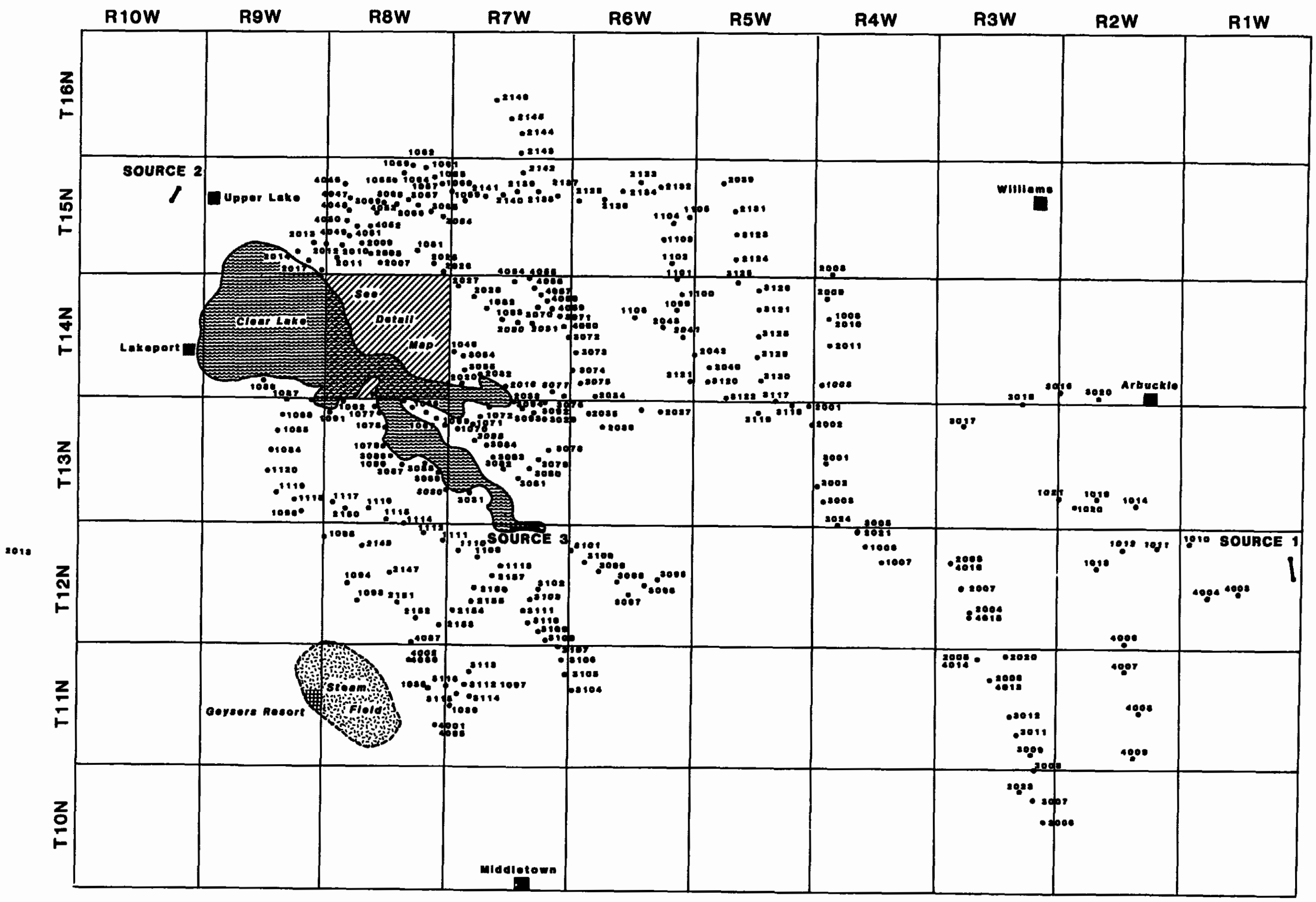

Figure 2. Layout of the Electromagnetic Sounding Survey of the Greater Geysers Area

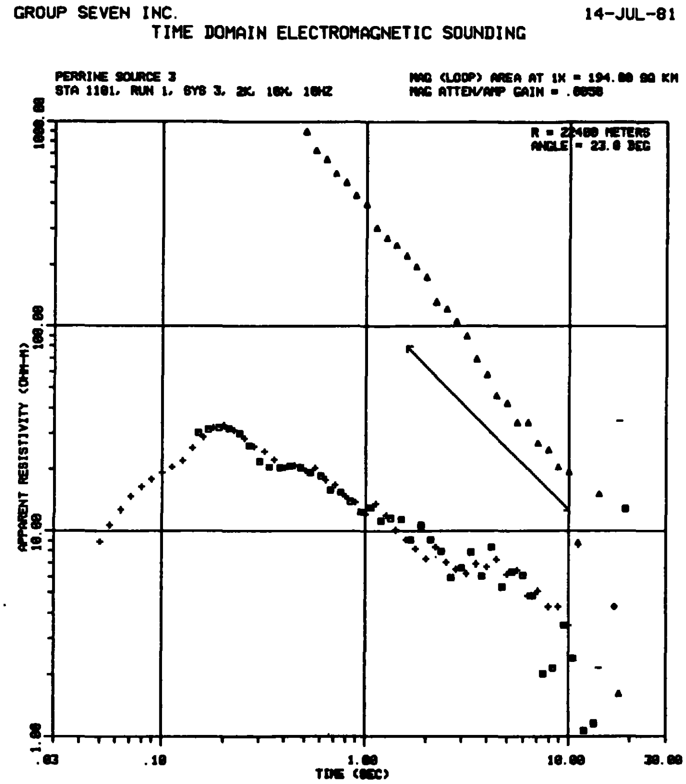

Figure 3. Example of a Processed Electromagnetic Sounding Curve from the Greater Geysers Area

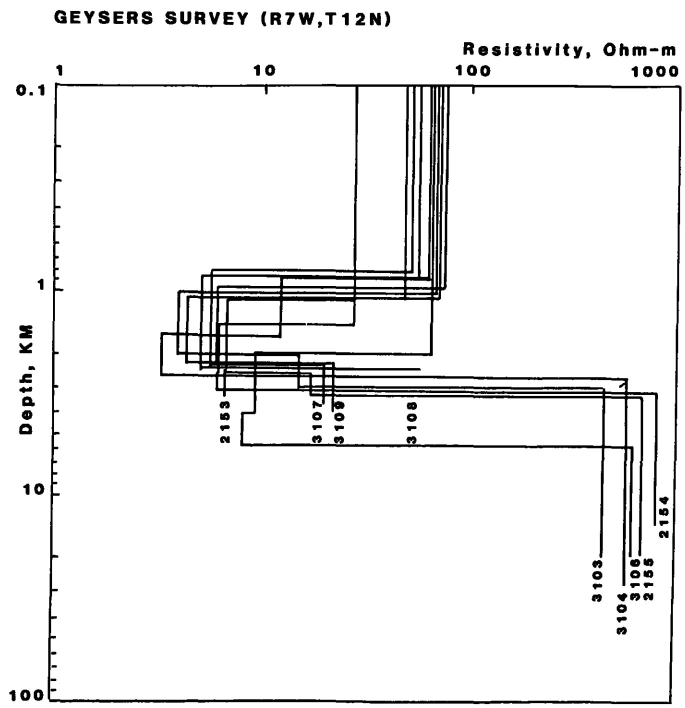

Figure 4. Summary Presentation of Interpreted Resistivity-depth Profiles for Sounding made in R7W- T12N (near the Geysers Producing Field)

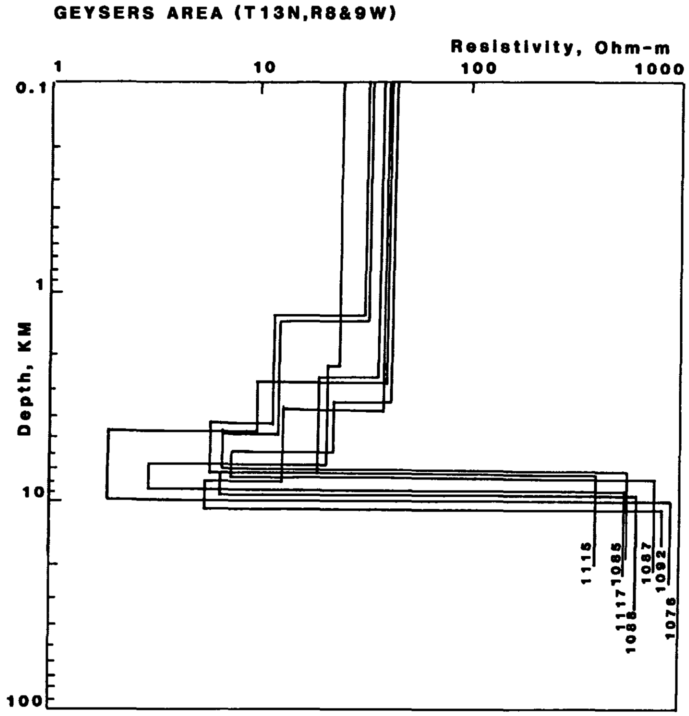

Figure 5. Summary Presentation of Interpreted Resistivity-depth Profiles for Soundings Made in T13N, R8&9W (Vicinity of Mt. Konocti)

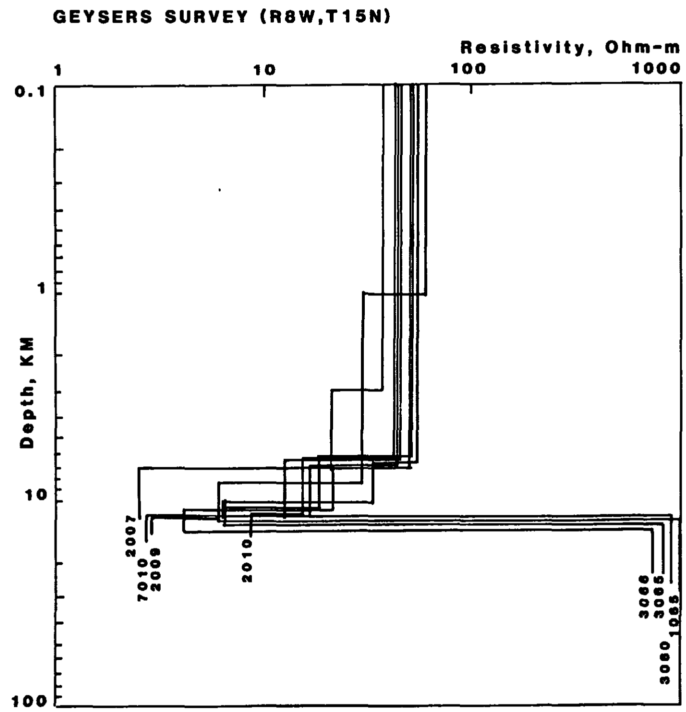

Figure 6. Summary Presentation of Interpreted Resistivity-depth Profiles for Soundings Made in T15N, R8W (North of Clear Lake).

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