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# MAGNETOTELLURICS: APPLICATIONS TO GEOTHERMAL EXPLORATION

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## ABSTRACT

The magnetotelluric method has become widely accepted as a geophysical tool for geothermal exploration. This application is based on the tool's ability to detect electrically conductive zones in the subsurface that typically characterize geothermal prospects.

This paper will discuss some of the implications derived from magnetotelluric data acquired in the Socorro Peak KGRA, New Mexico, and in the Railroad Valley, Nevada. The magnetotelluric data in Socorro show the response to a shallow (5 Km) magma body. The data from Railroad Valley, indicate a classical basin and range, two-dimensional boundary response and strong indications of potential geothermal anomalies, even in the presence of the highly two-dimensional complex structure.

## INTRODUCTION

Geothermal exploration utilizing the magnetotelluric method has been actively pursued by Geotronics Corporation. In particular, during the last five years, data has been acquired at over 1,500 magnetotelluric recording locations in the western United States. The examples included here demonstrate some of the applications and usefulness of the magnetotelluric method in geothermal exploration. The data point out the advantages of utilizing magnetotellurics in well-planned geothermal exploration efforts.

## SOCORRO, NEW MEXICO

The detection of crustal upwarps and intrusive magma bodies has become a recognized application of the magnetotelluric sounding method. In Socorro, New Mexico, several shallow magma bodies (at depths of 5 - 7 Km) have been detected. These bodies have been investigated by Dr. Alan Sanford and others at NMIMT based on P-S wave velocity changes. The COCORP seismic reflection profiles have also detected some of these features. A regional magnetotelluric survey was performed by Geotronics Corporation to evaluate the geothermal potential of the area and specifically to locate anomalously conductive zones in the subsurface. One of the objectives, therefore, was to locate and define these magma bodies.

These magma bodies, as delineated by Sanford et. al., are narrow linear features primarily trending in a north-south direction. One of these features is detected by the magnetotelluric data at several sites but most strongly at site A (Figure 1).

Figure 1 is a plot of the apparent resistivity versus frequency for the parallel (RTE) and perpendicular (RTM) to strike modes for the magnetotelluric tensor for site A. The response of the magnetotelluric data to the magma body is evidenced by a flattening or depressing of the RTE curve between .08 and .5 Hz. The strength of this feature is most pronounced at sites directly over this body with a weaker effect at sites located near but laterally from this body. The interpreted depth to this feature at site A is approximately 5 - 6 Km. Sites that are located approximately 3 - 4 Km from the magma body indicate continuous increasing resistivity on the RTE data with no discernable change in resistivity (slope) that would be indicative of a magma body.

The interpretation of this feature is aided by a two-dimensional model study. This study modeled a magma body at 5.25 Km below the surface and 1 KM in width and thickness. In comparing the model to site A there is good agreement of the field data to the modeled data. The model indicates that site A is lateral to, but less than .5 Km from, the magma body. Several other sites are indicated to be approximately 1 Km laterally from this feature. The magnetotelluric data and the model study also show that the depth to a deeper regional magma body near these sites is very great and is probably greater than 40 Km.

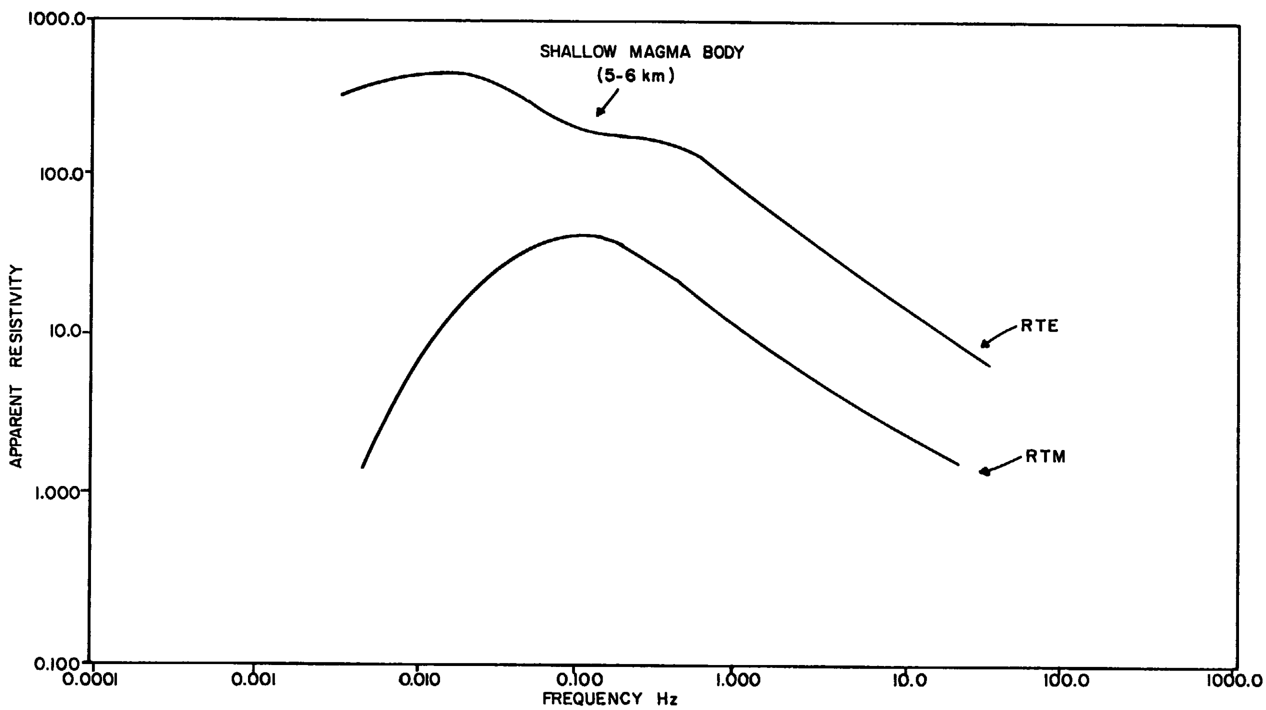
The magnetotelluric data have also delineated several other potential shallow magma bodies as well as defining a regional shallowing of the deeper magma body throughout much of the survey area to depths of approximately 20 Km.

In summary the magnetotelluric method has proved extremely useful in detecting possible heat sources in the Socorro KGRA. The magnetotelluric data support and are in turn supported by additional geophysical and geological information. This survey strongly indicates that the potential for geothermal resources at drillable depths is real but potential reservoir parameters remain to be delineated for this complex area.

## RAILROAD VALLEY, NEVADA

A regional magnetotelluric survey was performed in Railroad Valley, Nevada, to investigate the subsurface in the vicinity of the Trap Spring and Eagle Springs Oil Fields and also to study the effects on the magnetotelluric data of structural complexity (basin and range) in a setting thought to be clearly two-dimensional. The results of the investigation were consistent with known geology and provided insight into the structural configuration and electrical properties of the rock units within the valley. A secondary result of this survey, which is pertinent to this paper, is the detection and definition of a potential geothermal source and reservoir area.

Railroad Valley is near the center of the Great Basin in eastern Nevada. The deeper portion of Railroad Valley was developed by a series of step-faults that exhibit from 10,000 to 15,000 feet of displacement. Abnormally high bottom-hole

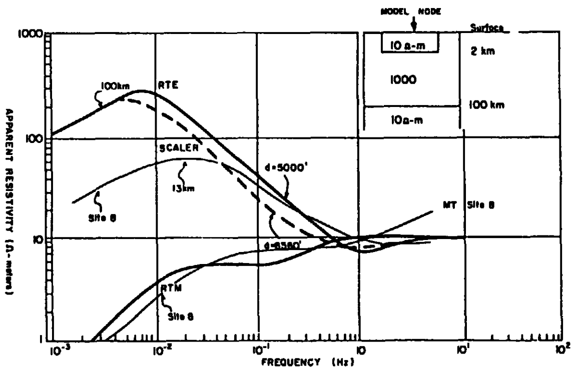



SITE A-APPARENT RESISTIVITY VERSUS FREQUENCY PLOT

FIGURE 1

temperatures are found in the wells at Eagle Springs and numerous thermal springs occur in the valley.

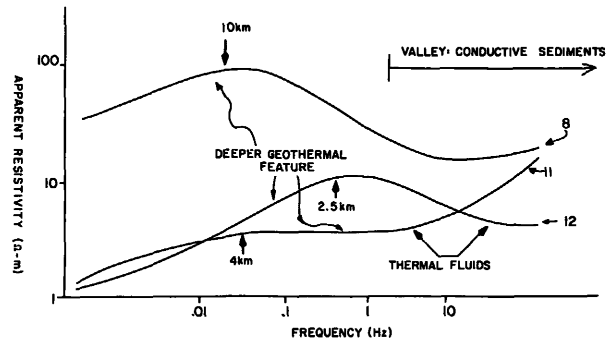
The magnetotelluric data indicate a Basin and Range environment with the data for site 8 (Figure 2) exhibiting a typical response. The RTM component turning highly conductive at low frequencies (at depth) is a response that is related to the boundary between the conductive valley and the more resistive ranges. This can be seen from the model study (Figure 2) where the RTM component shows marked low resistivity turn-down that is boundary related. On both the model and the magnetotelluric data the RTE component detects conductive valley sediments at high frequencies which overlie a resistive 'basement'. At site 8 detection of a conductive feature relating to a crustal upwarp is at a depth of approximately 13 Km.




COMPARISON MT SITE 8 TO BASIN AND RANGE 2-D MODEL

Figure 2

Magnetotelluric sites 11 and 12 are in the same geologic environment as site 8 but with the additional effect of a shallow geothermal feature present beneath the site. The RTE data indicate increased conductivity of the porous valley sediments which is interpreted as being related to the presence of thermal fluids (Figure 3). Because of the increased conductivity the RTM data exhibits even lower resistivities than at site 8. This is due to the increased resistivity contrasts at the basin boundary. At site 8 a thick resistive section was detected overlying a conductive 'basement' at a depth of approximately 13 Km. Site 12, on the other hand, exhibits a thin resistive section underlain by a more shallow conductive ('basement') feature at a depth of approximately 2.5 Km. Site 11 is very conductive and does not strongly detect a resistive section. The data response at site 11 is interpreted as being related to the presence of a thicker and shallower section of very conductive hydrothermally saturated sediments and a much shallower conductive 'basement' feature. Increased fracture porosity may also have an effect in reducing the bulk resistivity of the subsurface. A depth contour map to the 'deep' conductor also indicates that the area near site 11 exhibits an anomalously shallow conductive zone. The interpretation for this area indicates a regional crustal upwarp at depths of 10 - 15 Km with a shallower intrusive feature beneath sites 11 and 12. The potential geothermal reservoir is at a depth of approximately 2.5 Km near site 12 and much shallower at site 11. Communication from this reservoir to the valley sediments along faults and fracture zones are more clearly seen near site 11.




RTE MAGNETOTELLURIC DATA

Figure 3

In summary the magnetotelluric data indicate the heat source to be a regional feature covering the entire survey area with this feature much shallower in the southern portion of the area. The shallower portions of this feature appear to be controlled by faults present in the valley. Increased fracturing due to these faults has provided a conduit for possible upwelling of molten materials and for the circulation of fluids to depth that would establish a hydrothermal convective system. The magnetotelluric data indicate that this area is sufficiently prospective to warrant further geothermal exploration including more detailed magnetotelluric surveying. The data also have indicated areas of potential increased thermal gradients which have implications for both geothermal and petroleum exploration.

## CONCLUSION

This paper has briefly described how

magnetotelluric surveys have aided in exploring for potential geothermal resources in several varied environments. The magnetotelluric data have greatly added to our understanding of these areas and have proven to be a useful exploration tool. Magnetotellurics can significantly enhance and add to the knowledge of a prospect area and as such should be utilized in geothermal exploration programs.

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