A COMPARISON OF DIPOLE-DIPOLE RESISTIVITY AND ELECTROMAGNETIC INDUCTION SOUNDING OVER THE PANTHER CANYON THERMAL ANOMALY, GRASS VALLEY, NEVADA

M. Wilt*, J. H. Beyer+ and N. E. Goldstein*

*Lawrence Berkeley Laboratory, Berkeley California 94720
+Woodward-Clyde Consultants, San Francisco, California

ABSTRACT

A comparison is made between the dipole-dipole resistivity method and electromagnetic sounding method based on surveys over a geothermal anomaly near Panther Canyon, Grass Valley, Nevada. Dipole-dipole data were taken in conjunction with large-scale geothermal studies in the area. Two orthogonal lines were measured over the heat flow anomaly and two-dimensional modeling was performed on the data. EM sounding data were taken with the Lawrence Berkeley Laboratory EM-60 system which is a large-moment, frequency-domain, horizontal-loop system. Relative to single 50-meter-radius transmitter coil, eight soundings were made with detectors at distances of 0.5 to 1.6 km from the loop. Interpreted results from the two surveys indicate substantial agreement in the depth to and thickness of a conductive zone that may be associated with the thermal anomaly. The dipole-dipole method is inherently better for resolving resistive basement beneath the conductive anomaly, and dc resistivity interpretation techniques are presently better able to handle the complex two-dimensional geology. However, the EM method is far less labor intensive, requiring only one-third the field time for similar areal coverage.

INTRODUCTION

Electrical methods are commonly used for geothermal exploration and have often proved effective for locating areas of low resisitivity associated with geothermal reservoirs. However, controlled source electromagnetic (EM) induction soundings have not been widely used. This paper compares field data acquisition and interpretation for EM sounding with a more conventional method, dipole-dipole resistivity. Data for both methods were acquired at identical locations over a thermal anomaly in the Panther Canyon region of Grass Valley, Nevada (Figure 1).

GEOLOGY

Grass Valley is a northerly-trending Basin and Range valley located in north-central Nevada (Figure 1). The region is characterized by higher than normal heat flow (Sass et al., 1977), active hot springs (Olmsted et al., 1975) and recent faulting (Noble, 1975). Surface geologic studies consist of regional photogeology (Noble, 1975) and detailed field mapping (Olmsted et al., 1975). Grass Valley has been an area of fairly active geothermal exploration for about the past eight years, but to date no deep wells have been drilled.

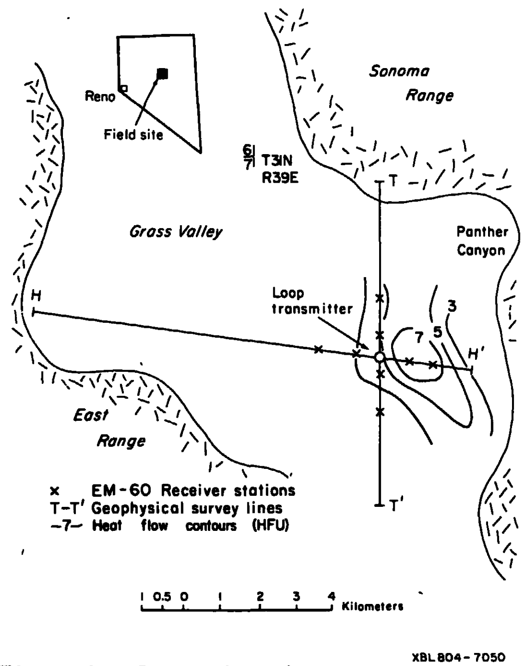

Figure 1. Survey location map Panther Canyon area, Grass Valley, Nevada.

The Panther Canyon area is located in the southwestern portion of Grass Valley near the intersection of the Tobin and Sonoma Ranges. Exposed rocks in these ranges consist mainly of the Paleozoic Havallah sequence of cherts, argillites and sandstones. Figure 2 is an idealized geologic cross section along one of the orthogonal survey lines shown in Figure 1.

DIPOLE-DIPOLE RESISIVITY

Dipole-dipole resistivity data were acquired in conjunction with large scale geothermal exploration and technique evaluation studies in Grass Valley (Beyer, 1977). Using a 25 kw transmitter and synchronous-detection receivers, we obtained high quality data for dipoles 250 to 1000 m in length and transmitter-receiver separations exceeding ten dipole lengths (>10 km).

Reconnaissance geophysics and shallow heat flow holes located a low resistivity, high heat

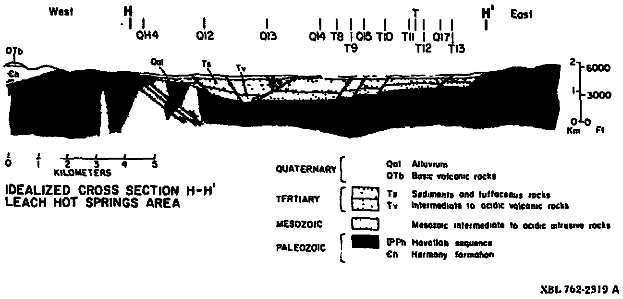

Figure 2. Idealized geologic cross section for survey line H-H' (after Sass et al., 1977).

flow anomaly near the mouth of Panther Canyon. To better define the anomaly, orthogonal dipole-dipole resisitivity lines were run across the feature. For Line H-H', as shown in Figure 3, the data were interpreted in terms of a two-dimensional model. The model data were fit by trial and error, requiring about a dozen iterations using a finite difference algorithm (Dey, 1976). The model clearly indicates the low resisitivity zone corresponding to the heat flow high and indicates a fairly shallow basement.

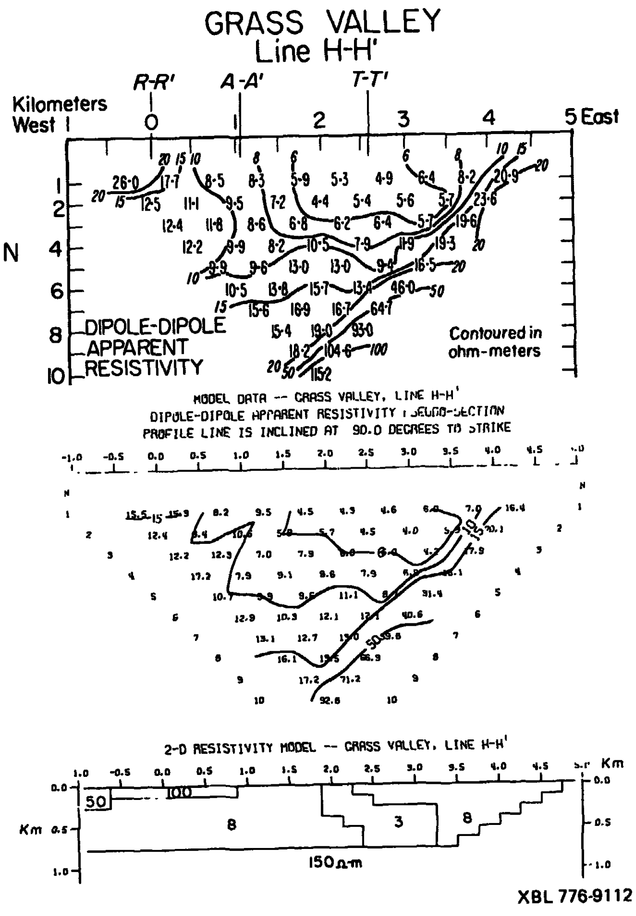

Figure 3. Dipole-dipole apparent resistivity pseudo-section for 1 km dipoles along line H-H': field data, model generated data, and two-dimensional model.

EM INDUCTION SYSTEM

The LBL EM-60 frequency-domain induction system shown schematically in Figure 4, includes two major components: (1) a transmitter section consisiting of a power source, control and timing electronics, and a transistorized switch capable of handling large current; and (2) a receiver section consisting of magnetic field detectors, signal conditioning amplifiers and anti-alias filters, and a multi-channel programmable receiver (spectrum analyzer) (Morrison et al., 1978).

The EM-60 transmitter is powered by a Hercules gasoline engine linked to a 60 kW, 400 Hz, 3ϕ alternator. The system is capable of transmitting square-wave current pulses from 10^{-3} to 10^{3} Hz at up to 400 Amps into a coil of wire. Four turns of #6 wire in a circular loop 50 m in radius provide adequate signal for soundings where transmitter-receiver separations are less than about 5 km. This corresponds roughly to a maximum depth of exploration of about 5 km.

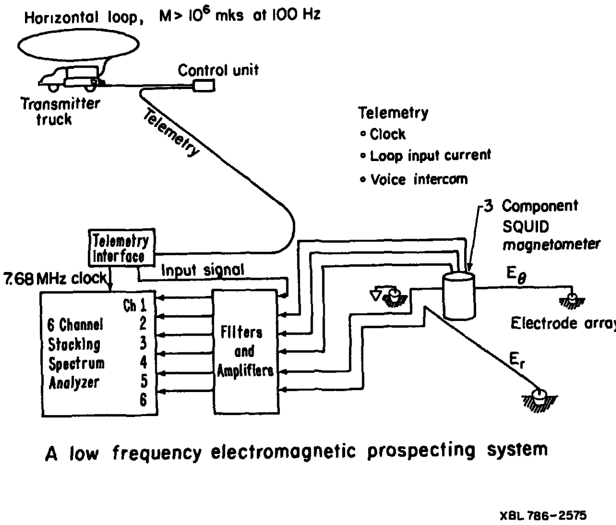

Figure 4. Schematic diagram of the EM-60 horizontal loop electromagnetic prospecting system as used in Nevada in 1979.

The magnetic field is detected at receiver sites by means of a three-component SQUID magnetometer oriented to measure the vertical, radial and tangential components with respect to loop. Signals are amplified, anti-alias filtered and input to a six-channel, programmable, multi-frequency, phase-sensitive receiver (Fig. 1). Data processing yields a raw amplitude estimate for each component and a phase estimate with respect to the phase of the current in the loop. Phase referencing at the receiver is maintained with a hard-wire link to a shunt resistor in the loop. Raw amplitude estimates must be later corrected for dipole moment (strength) and the distance between loop and magnetometer.

In practice, the hard-wire link was found to be a source of noise, particularly above 50 Hz. This has required the elimination of the absolute phase reference at high frequencies in favor of relative phase measurements between vertical and radial components. With relative phase measurements, interpretation is based on the ellipticity and tilt angle of the magnetic field rather than on the amplitude and phase of the vertical and radial components.

Basic interpretation is accomplished by direct inversion of observed data to fit one-dimensional models. The program fits amplitude-phase and/or ellipse polarization parameters jointly or separately to arbitrarily layered models. This program allows the use of both: (1) ellipse polarization parameters to fit high frequency points where absolute phase data are unreliable, and (2) absolute phase data at the lower frequencies where the phase reference may allow for better parameter resolution.

EM INDUCTION RESULTS

The EM-60 field survey in Panther Canyon consisted of eight soundings arranged in two orthogonal profiles about a central 4-turn, 50-m-radius horizontal loop. Transmitter-receiver separations varied from 400 m to 1.6 km, and data at each site were recorded over at least two frequency decades within the frequency band 0.033-500 Hz. Because the depth of penetration for EM induction sounding is proportional to both the transmitter-receiver separation and the period of the transmitted wave, we occupied receiver sites at varying distances from the transmitter loop. At Panther Canyon, four receiver locations were about 500 m from the loop source for shallow information, and four sites were at a distance of about 1.6 km for better resolution of deeper horizons.

An example of an EM-60 amplitude spectra sounding is given in Figure 5. The error bars signify one standard deviation. The fit to a three-layer model is fairly good, but the data were interpreted only to 50 Hz because of high noise resulting from the reference wire. Ellipticity data, however, could usually be interpreted to 500 Hz.

DISCUSSION

Figures 6 and 7 are resistivity cross sections along orthogonal lines over the Panther Canyon thermal anomaly. Each figure gives a comparison between dipole-dipole resisitivity and EM-60 electromagnetic interpretations. Along the north-south line (Fig. 6) the EM and dipole-dipole interpretations are similar. Both cross sections indicate resistive surface material overlying an irregular southward-dipping conductive body. Depth to resistive basement (Havallah formation?) is shown to vary between 250 and 800 m below the surface. The depth to and lateral extent of the conductive body, which may be associated with the thermal anomaly, is well resolved by both methods. The two profiles disagree somewhat on the depth to resistive basement beneath the conductor. Because the EM method is less sensitive to resistive formations and because the dipole-dipole transmitter-receiver separations were five times

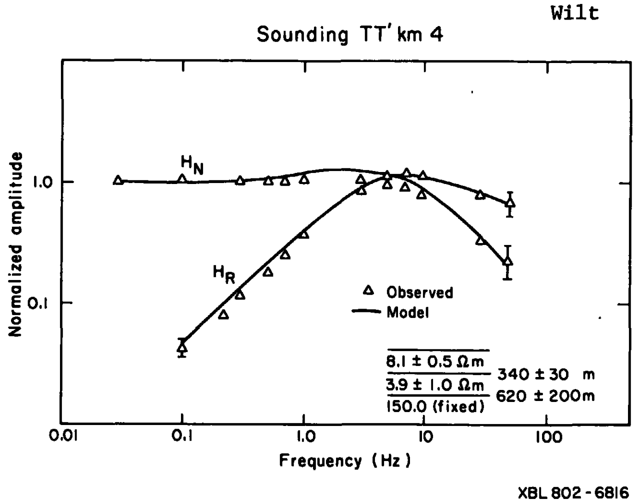

Figure 5. Normalized magnetic field amplitude spectra normal and radial fields sounding TTS Panther Canyon.

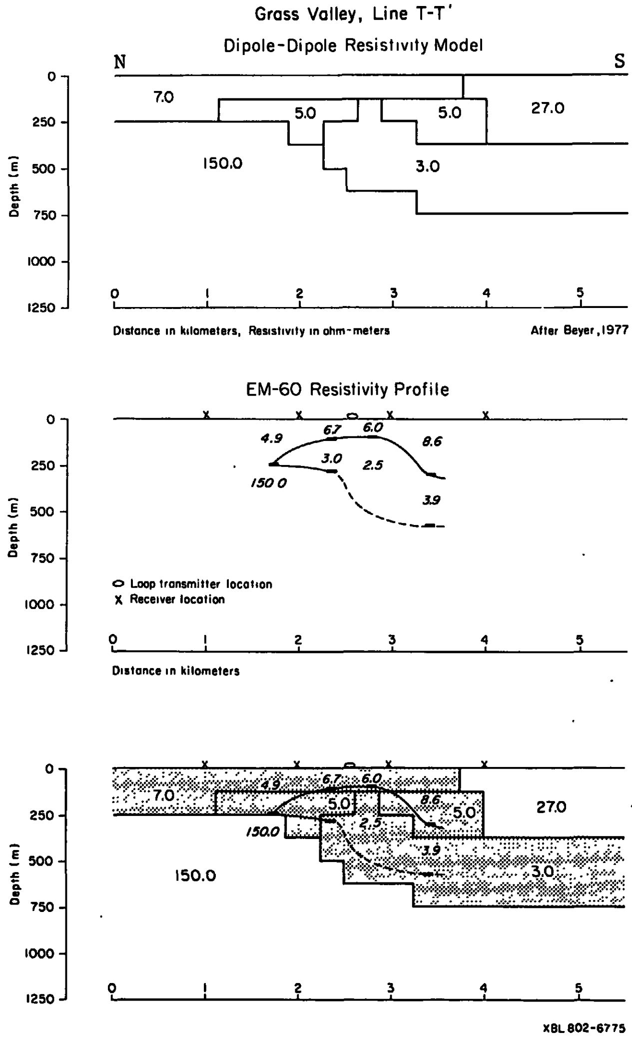

Figure 6. Resistivity cross section over line H-H' in Panther Canyon (a) two-dimensional dipole-dipole resistivity model (b) profile of one-dimensional EM-60 electromagnetic soundings; (c) comparison of parts a and b.

greater than for the EM survey, the conventional resistivity section is probably more accurate in determining this parameter.

Figure 8 shows results for an east-west line over the central portion of the thermal anomaly. For this cross section the EM and dc resistivity interpretations show moderate agreement. Both cross sections indicate the presence of an irregularly shaped conductive body near the central portion of the thermal anomaly. The EM data place the thickest portion slightly west of the thermal maximum. The dc resistivity data indicate that basement dips steeply westward from 250 m to

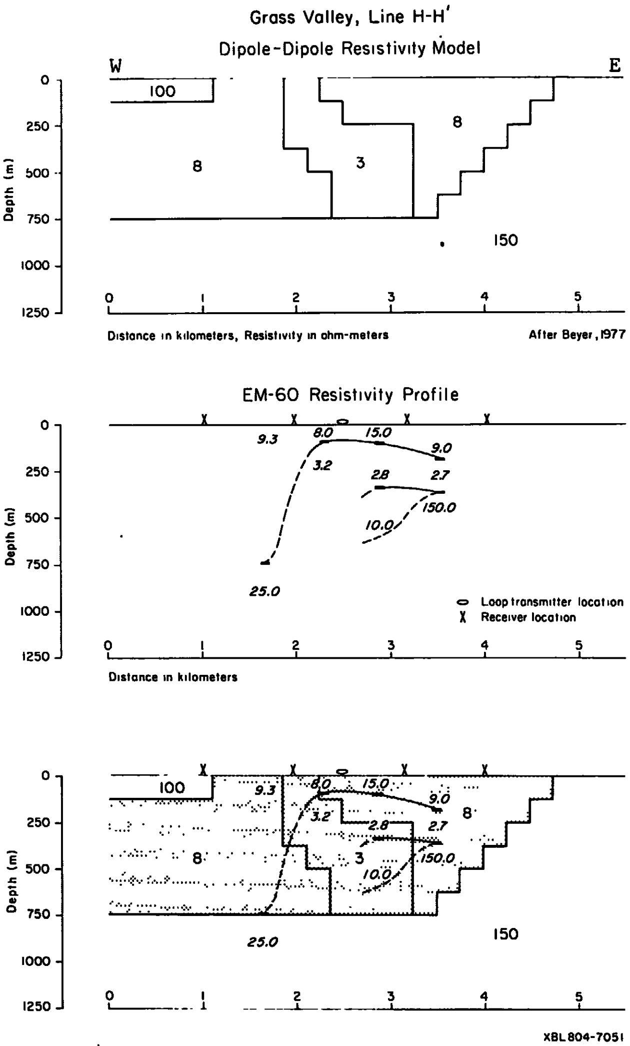

Figure 7. Resistivity cross section over line H-H' in Panther Canyon (a) two-dimensional dipole-dipole resistivity model (b) profile of one-dimensional EM-60 electromagnetic soundings; (c) comparison of parts a and b.

about 800 m adjacent to the edge of the Tobin Range; the EM induction data show a similar behavior, but with fewer points and larger uncertainty.

Although the interpreted sections in both cases are similar, the EM results show a smoother variation, a consequence of one-dimensional interpretation. However, there are other differences between the EM and dc resistivity surveys that are not apparent in the data and interpretations. The dipole-dipole sections required a crew of four working for more than 19 field days whereas the same size crew collected the EM data in six field days. The dc resistivity data cover an area about 50 percent larger, but far more labor was required to achieve coverage comparable to that of the EM survey. Interpretation techniques for dipole-dipole data are presently better able to handle complex geology, and the method is inherently better able to resolve resistive formations. However, deep EM interpretations required much shorter transmitter-receiver separations, thus reducing the effects of lateral inhomogeneities on interpretations. The two cross sections suggest that, even in regions of two- and three-dimensional geology, EM data will adequately resolve major features without severe distortion.

This work was supported by the Department of Energy under Contract W-7405-ENG-48.

REFERENCES

Beyer, J. H., 1977, Telluric and dc resistivity techniques applied to the geophysical investigation of Basin and Range geothermal systems, Part III: The analysis of data from Grass Valley, Nevada: Lawrence Berkeley Laboratory, Report LBL-6325, 3/3, 115 p.

Dey, A., 1976, Resistivity modeling for arbitrarily shaped two-dimensional structures, Part II: Users guide to the FORTRAN algorithm RESIS2D: Lawrence Berkeley Laboratory, Report LBL-5283.

Morrison, H. F., Goldstein, N. E., Hoversten, M., Oppliger, G., and Riveros, C., 1978, Description, field test and data analysis of a controlled-source EM System (EM-60): Lawrence Berkeley Laboratory, Report LBL-7088.

Noble, D. C., 1975, Geological history and geothermal potential of the Leach Hot Springs area, Pershing County, Nevada: Preliminary report to the Lawrence Berkeley Laboratory.

Olmsted, F. H., Glancy, P. A., Harrill, J. R., Rush, F. E., Van Denburgh, A. S., 1975, Preliminary hydrologic appraisal of selected hydrothermal systems in northern and central Nevada: U.S. Geological Survey Open File Report 75-56.

Sass, J. H., Ziagos, J. P., Wollenberg, H. A., Munroe, R. J., DiSomma, D., and Lachenbruch, A. H., 1977, Application of heat flow techniques to geothermal energy exploration, Leach Hot Springs, Grass Valley, Nevada: Lawrence Berkeley Laboratory, Report LBL-6809 also U.S. Geological Survey Open File Report 77-762.