GL00839

DIPOLE-DIPOLE RESISTIVITY SURVEY OF THE LAVA MOUNTAIN AREA, SAN BERNARDINO COUNTY, CALIFORNIA

for

Hunt Energy Corporation

by

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SUMMARY AND CONCLUSIONS

A zone of low resistivity has been identified on four of the five dipole-dipole lines surveyed on the Lava Mountain Geothermal Prospect. The steam well is located within this zone. The electrical resistivity results support the concept of a fault zone saturated with thermal fluids. The low resistivity zone is thought to define the area containing the fault or faults.

INTRODUCTION

The Earth Science Laboratory, University of Utah Research Institute (ESL/UURI) conducted a dipole-dipole electrical resistivity survey during June, 1983 for Hunt Energy Corporation on their Lava Mountain geothermal prospect, San Bernardino County, California (Figure 1). This prospect is located in the Randsburg KGRA approximately six miles northeast of the small town Johannesburg. The prospect area is easily reached via dirt roads. The southern boundary of Wilderness Study Area 176 extends across the northern one-half of the prospect however, and access is subsequently restricted to well-established dirt roads.

A steam well is located on the prospect. This well is owned by Mr. Virgil Ramey who lives at the site. According to Mr. Ramey, the well was drilled in the early 1900's, has a temperature of 240°F and will hold pressure through a 3/4-inch choke.

The purpose of the electrical resistivity survey was to delineate the fault zone serving as the plumbing system for the rising steam noted in the drill hole in addition to testing for a shallow (< 2500 feet) hot water and/or steam reservoir on the prospect.

Figure 1. Index Map.

GENERAL GEOLOGY

The prospect area occurs in the Randsburg KGRA. This KGRA is so designated because of one well drilled to a depth of 238 meters with a maximum recorded temperature of 115°C (239°F).

The area is part of the Randsburg, Johannesburg and Red Mountain mining districts. Gold is the primary product of the districts with some mercury and tungsten also being produced.

The east northeast-trending Garlock Fault zone occurs only a few miles to the north of the KGRA. The northwest-trending Blackwater Fault forms the eastern boundary. A parallel fault zone trends northwest through the towns of Red Mountain and Johannesburg forming the western boundary. The intervening area contains numerous small faults trending north and northeast through the geothermal prospect area.

The prospect area is covered primarily by andesitic flows, tuff and volcanic breccias forming numerous ridges and small hills having 300-600 feet of relief. Some of the flows have been propyliticallly altered and one area immediately southwest of the steam well has volcanic rocks intensely coated with hyalite.

BACKGROUND ON THE RESISTIVITY METHOD

The electrical resistivity method is commonly applied to many types of exploration and engineering problems. Two essentially different techniques can be used to measure subsurface resistivity: (1) galvanic resistivity techniques, which use grounded electrodes to inject electrical current into the ground and to measure resulting voltage differences, and (2) electromagnetic (EM) techniques, which use electromagnetically induced currents and a magnetic sensor. The dipole-dipole method of making resistivity measurements is one of several of the galvanic resistivity techniques.

Conduction of Electrical Current in the Earth

None of the common rock-forming minerals conduct electricity well and only a few of the trace minerals (such as magnetite and pyrite) conduct to a signficant extent. Those conducting trace minerals that may be present are usually not interconnected because of their scarcity, and thus do not form current pathways. Only in ores, where conducting minerals are plentiful, does rock conduction normally take place. In other rocks and soils, electricity flows in the subsurface predominantly because of movement of chemical ions in the ground water contained within pores and fractures.

Ground water normally contains a few hundred to a few thousand parts per million (ppm) of dissolved ionized chemical constituents such as sodium, potassium, calcium, chlorite, sulfate and bicarbonate. It is movement of these charged ions through the ground water in the network of pores that causes conduction. Resistivity is a parameter that indicates how well the earth conducts electricity and it can yield information on amounts of dissolved constituents, extent of the pore network (porosity/permeability) and other factors of potential exploration interest.

To be more specific, the electrical resistivity of earth materials varies in the subsurface because of variation in a number of factors. Among these are:

1. Resistivity of the ground water. The higher the concentrations of dissolved salts in the ground water, the more ionic charge carriers there will be, and therefore the lower the resistivity of the ground water (lower resistivity denotes better electrical conduction). In addition, hot ground water has lower resistivity than cold ground water having the same dissolved salt content because the mobility of the ions increases as temperatures increases.
2. Porosity of the earth. Soil or rock having higher porosity contains more ground water and therefore has more available pathways for electrical current. This generally results in better electrical conduction, i.e. lower resistivity.
3. Clay and zeolite mineral content of the earth. Clay and zeolite minerals generally have unsatisified crystal lattice charges on their surfaces, and, due to their layered crystal structure, they present a high surface area to the ground water. The unsatisfied lattice charges attract and hold chemical ions from the ground water, but under the influence of a voltage gradient, these ions can migrate. Thus, soil and rock having a high content of clay or zeolite minerals have an abundance of ionic charge carriers, and are better electrical conductors (i.e. have lower resistivity) than clay- or zeolite-poor materials.

Resistivity Survey Techniques

Galvanic earth resistivity techniques always use four electrodes that are grounded (electrically connected to the earth). A controlled current is caused to flow between one pair of these electrodes by using an appropriately designed transmitter to apply a voltage difference to the electrodes. This sets up a potential field at all points within and on the surface of the earth. A voltage difference is then measured by an instrument called a receiver between the two electrodes of the other pair. By knowing the magnitude of the current in the transmitting electrodes, the voltage difference between the receiving electrodes and the relative locations of all four electrodes on the surface, a value of apparent resistivity can be calculated for the earth. This resistivity value is apparent and not real because the real resistivity in the subsurface exhibits both horizontal and vertical variation, and the apparent value is a form of average of all variations in the subsurface.

There are a number of common ways in which the electrodes may be arranged on the surface. In the usual case all four electrodes are placed in a straight line. Figure 2 shows four of the common linear electrode arrays.

In the Wenner array there is equal spacing between the electrodes. In Figure 2, the outer pair of electrodes are the transmitting electrodes, between which the current is I. The inner pair of electrodes are the receiving electrodes, between which a voltage of V is measured. The apparent resistivity is calculated from the formula shown to the right of the array. It can be shown for this and all other electrode arrays that the transmitting and receiving electrodes can be interchanged with no change in calculated apparent resistivity.

The Schlumberger array is an array in which the outer (usually transmitting) electrodes are separated by a great distance compared with the spacing of the receiving electrodes. The pole-dipole and dipole-dipole arrays are also shown in Figure 2.

There are two essentially different ways of moving the electrode array over the surface to make resistivity measurements. In the first method, called "profiling", all dimensions of the array are kept constant and the array is moved as a unit over the surface. In profiling, the search depth is often considered to be essentially constant, and observed apparent resistivity variations are often interpreted as horizontal changes in resistivity within the earth. However, vertical changes in the subsurface resistivity profile with horizontal distance also cause apparent resistivity changes, and it is usually not possible to separate vertical from horizontal changes in subsurface resistivity using this profiling technique alone.

The second method of surveying is to leave the center of the electrode array fixed and to expand the electrode spacing, thereby increasing search depth. Such a technique is termed "sounding", and it is often believed that the observed changes are due solely to vertical resistivity changes. Interpretation schemes generally incorporate this assumption. However, as the electrode spacing increases, the electrodes can cross horizontal boundaries between materials of contrasting resistivity, and these horizontal resistivity changes will affect the readings. It is generally not possible to separate reliability horizontal variations in subsurface resistivity from vertical changes using sounding techniques alone.

To help solve these problems, the dipole-dipole array can be easily adapted to perform both profiling and sounding in the same survey. This is

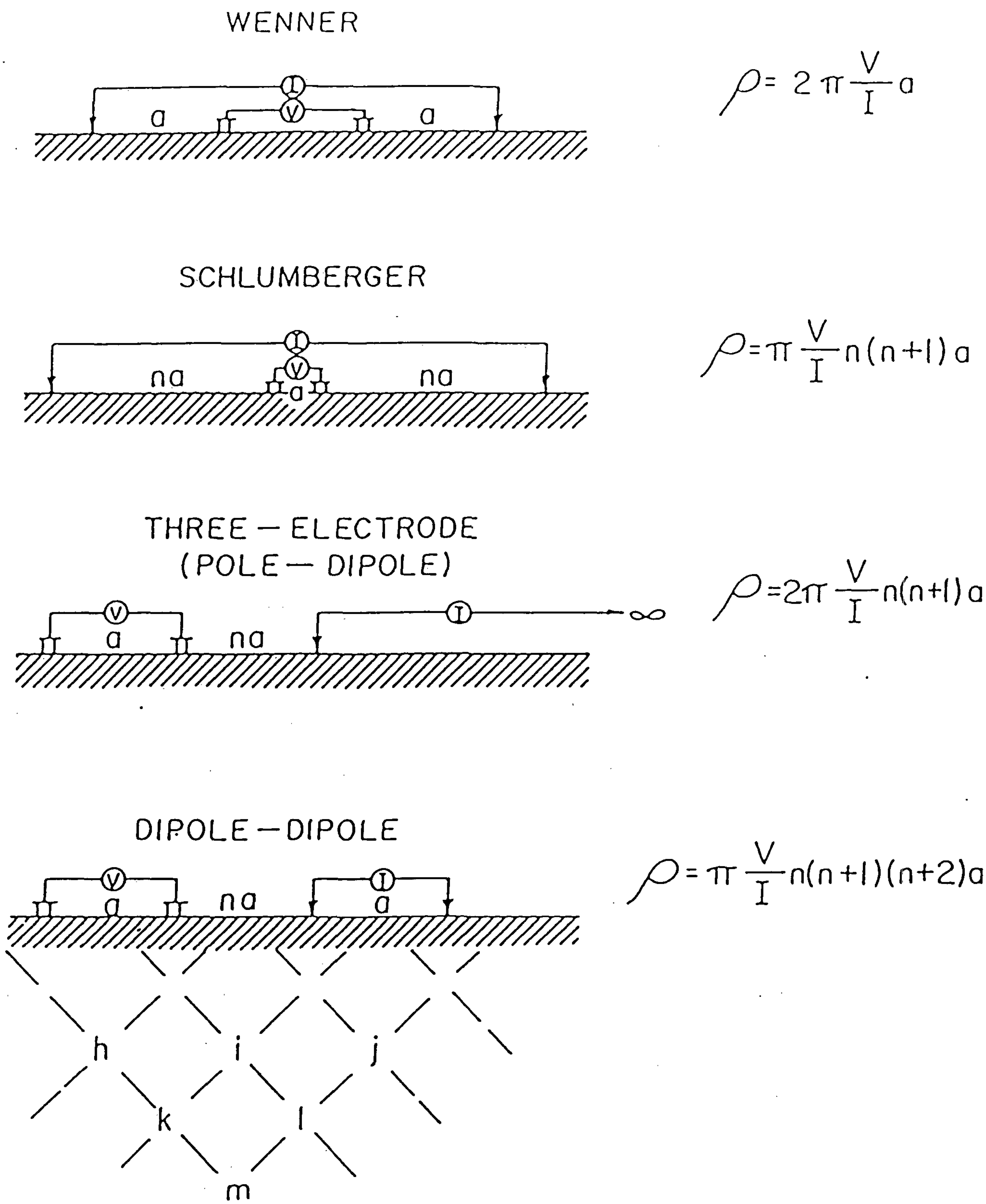

Figure 2. Common electrode arrays for electrical resistivity surveys.

done by measuring resistivity using a variety of values for n in the diagram, and also moving the positions of the electrodes in profile. In this way a whole series of data points is generated (h, i, j, k, l, m, in Figure 2) that contains both profiling and sounding information, and shows both lateral and vertical resistivity variations.

Each of the electrode arrays shown in Figure 2 has certain advantages and certain disadvantages. The Wenner and Schlumberger arrays are usually less susceptible to effects of unimportant resistivity changes nearby one of the electrodes than are the three-array or the dipole-dipole array, and this can be an advantage. On the other hand, the three-array and the dipole-dipole array give better resolution, both vertically and horizontally, for resistivity contrasts in the subsurface.

The dipole-dipole electrical resistivity method has been highly developed by the mining industry. It has more recently found acceptance for petroleum, geothermal and environmental work because of the detailed resolution of both lateral and vertical resistivity contrasts that it offers. With the dipole-dipole array, traverses are generally laid out normal to the feature under investigation. Sites are prepared at uniform intervals where electrical current can be transmitted directly into the ground. These sites, normally 7 in number, consist of a small hole which has a piece of conduit or some other conductive metal driven into the bottom. The hole is then salted and watered to lower contact resistance and enhance the flow of current into the ground. The interval between these sites, called the "a-spacing", is chosen such that adequate sampling depth and spacial resolution will be achieved to delineate the target of interest. The a-spacing can vary from a few feet to 2,000 feet or greater. In general, the greater the a-spacing the greater the sounding depth, although there is a corresponding decrease in resolution of both vertical and lateral resistivity changes with increase in a-spacing. Thus the a-spacing must be carefully chosen to optimize both depth penetration and anomaly resolution.

Current is transmitted through pairs of electrodes and the voltage drop is measured along the traverse at stations one or more a-spacing apart. The separation between the transmitting electrodes and the receiving electrodes is denoted as "n". It is usually an interger, although it does not have to be, and as n gets larger the depth of current penetration in general becomes greater. Normal procedure is to read out along the traverse at all integral values of n to the 6th separation (n = 6). This allows for a sampling depth 2-3 times the a-spacing.

Figure 2 shows the plotting convention for dipole-dipole survey data. The point marked "i" in the figure is the plotting point for the apparent resistivity value obtained with the electrodes positioned on the surface as shown, i.e. the data point is plotted at the intersection of the two 45° diagonals from the transmitting and receiving dipoles. This forms a type of pseudosection, but one must be careful not to view this as a section of resistivity vs. depth. Appropriate interpretation procedures must be applied to the pseudosection before the subsurface configuration of resistivity can be determined.

Figure 3 shows a comparison between three of the more commonly used arrays over a buried horizontal cylinder. The greater resolution and larger response of the dipole-dipole array is quite apparent.

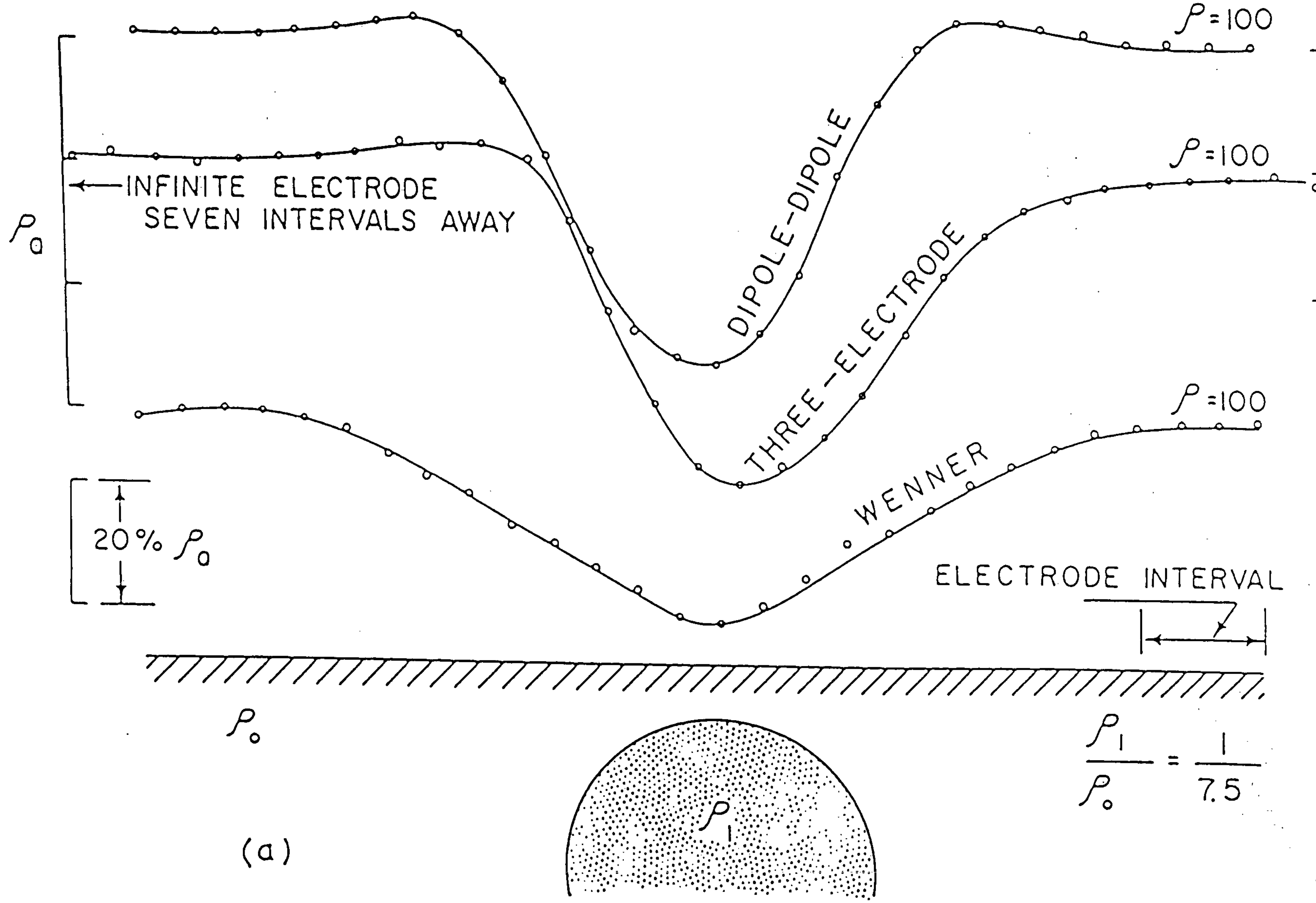

Figure 3. Detection of buried horizontal cylinder using three different arrays.

Interpretation of Resistivity Data

Interpretation of any type of geophysical data is essentially a two-step process. The first step involves the use of the observed data to form a picture of the subsurface variation in the physical property being measured. In the case of the Lava Mountain survey, this physical property is electrical resistivity, and the objective of the first-step interpretation is to determine vertical and lateral variations in subsurface resistivity over the survey area. Two ingredients are essential to success in this task: (1) a geophysicist experienced in resistivity interpretation, and (2) availability of interpretation aids for the electrode array being used.

The second step in the interpretation of geophysical data is the process of interpreting the subsurface geophysical model of step one in terms of the local geology. In the case of the Lava Mountain project, the second step is to interpret the vertical and lateral variations in resistivity as determined in step one in terms of subsurface geology and hydrology. In this step the geophysicist and geologist must work very closely together to assure that the most accurate picture of the subsurface evolves.

SURVEY RESULTS

Five lines of dipole-dipole electrical resistivity data totaling 13.5 line-miles of coverage were obtained across the prospect area. These lines trend generally N35°W and have 1,000-foot dipole spacings. The lines were selected to cross normal to the mapped faulting trend. The line centers are all located on well traveled dirt roads. Most of the lines however required walking along the traverse to avoid vehicle damage to the ground surface.

Data were obtained using an Elliot Geophysical Company Model 15A Time Domain Transmitter capable of maximum current output of 5 amps. The electric current was supplied to the transmitter by a gasoline driven motor-generator. Voltages were measured along the lines using a Fluke Digital Multimeter.

Results obtained on each line are discussed in the following section. The line locations are presented as Plate I.

Line 1

This line (Figure 4) was centered just west of the steam well. It trends N33°W. A well-defined apparent resistivity low with values as low as 4 ohm-meters is present in the interval covered by stations 1NW to 2SE. This resistivity pattern is typical of a dipping fault zone. The dip appears to be southeast and the very low apparent resistivity is thought to represent the steam and/or hot water occurring at a shallow depth within or adjacent to the fault zone. There are subtle indications that the hot fluids may be leaking into either sediments or volcanic aquifers southeast of the steam well at a depth of approximately 500 to 1,000 feet.

Northeast along the line the apparent resistivity data are representative

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DIPOLE – DIPOLE ARRAY APPARENT RESISTIVITY

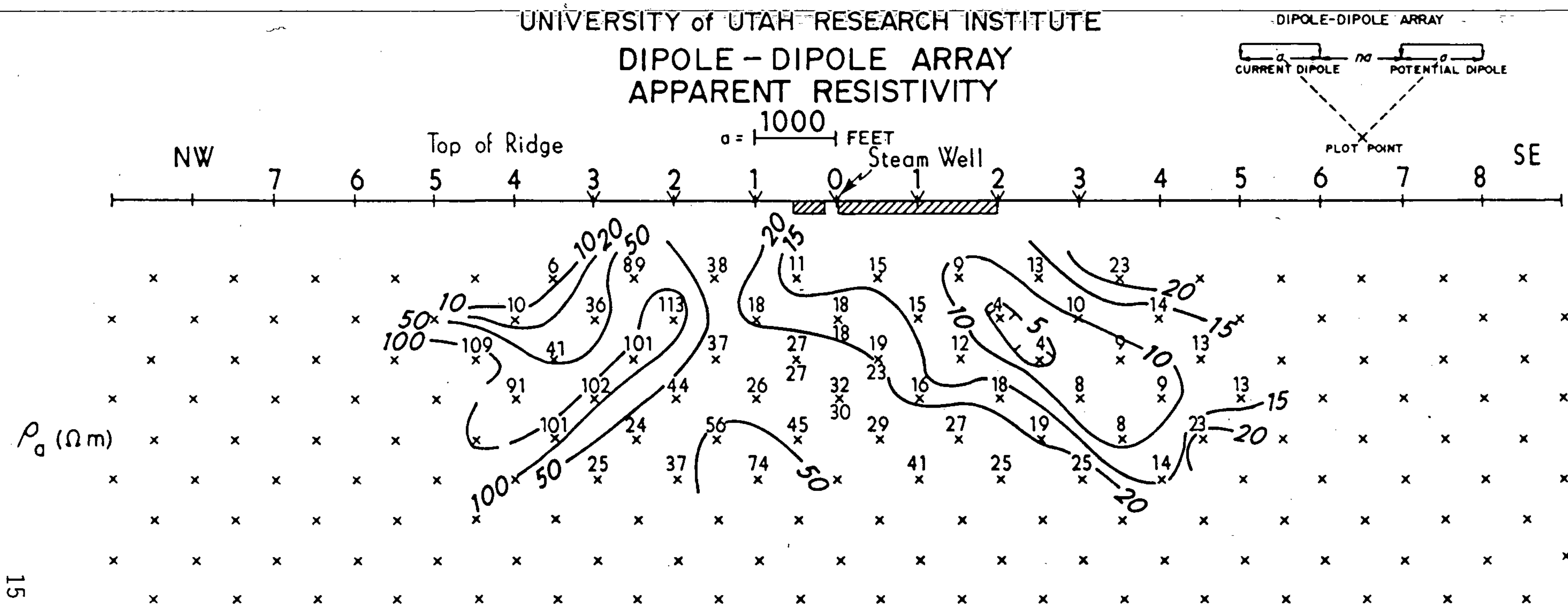

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Figure 4.

AREA LAVA MTN. STATE Calif. LINE 1 N33W DATA BY CEM DATE 7-10-83 TRANSMITTER ELLIOT T.D RECEIVER FLUKE of more resistive rocks and do not show any indication of other zones where thermal fluids might be present.

Line 2

This line (Figure 5) is centered approximately 2,500 feet east of the steam well. It trends N30°W. A well-defined apparent resistivity low with values as low as 6 ohm-meters is again present over the station interval 3NW to 1SE. The resistivity minimum occurs within the station interval 1-2NW and probably represents the location of the fault zone. Further to the southeast the resistivity data show what appears to be an increase in the gravel cover as the line extends out into the valley. The station interval 5-6SE is of additional interest. Resistivity values are very low on this diagonal and may represent another fault zone near the edge of the mountain front.

Back to the northwest, the apparent resistivities increase beyond station 3NW and undoubtedly are an indication of the volcanics comprising the small low-lying hills.

Line 3

This line (Figure 6) is centered near the southwest corner of Section 26 on a road leading into a large drainage. The line trends N40°W. A conductive zone occurs between stations 1NW and 1SE. The apparent resistivity minima is on the interval 0-1SE and a fault zone may be indicated. Northwest of station 1NW the apparent resistivity data are typical of the volcanics sampled in the area.

The low apparent resistivity data shown on the diagonal northwest from stations 5-6SE is suspicious and may result from topographic effects.

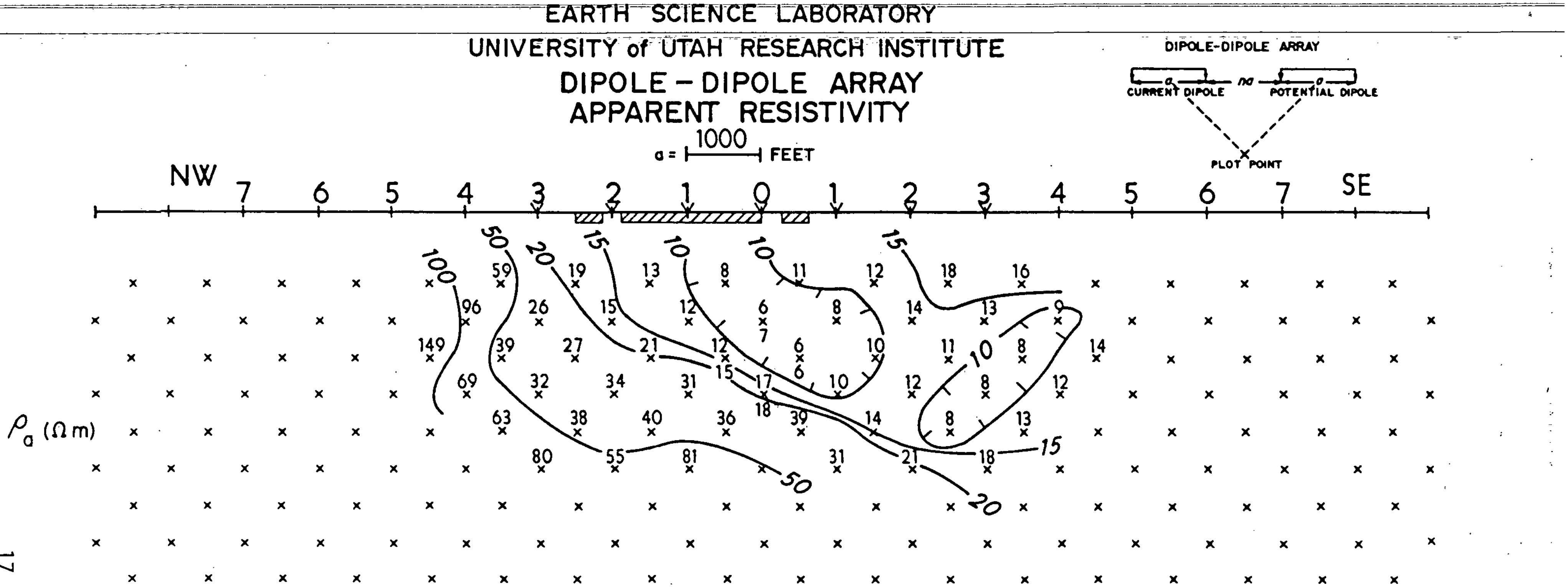

Figure 5.

AREA LAVA MTN. STATE Calif. LINE 2 S30E DATA BY C.E.M. DATE 7-12-83 TRANSMITTER ELLIOT T.D. RECEIVER FLUKE

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DIPOLE – DIPOLE ARRAY APPARENT RESISTIVITY

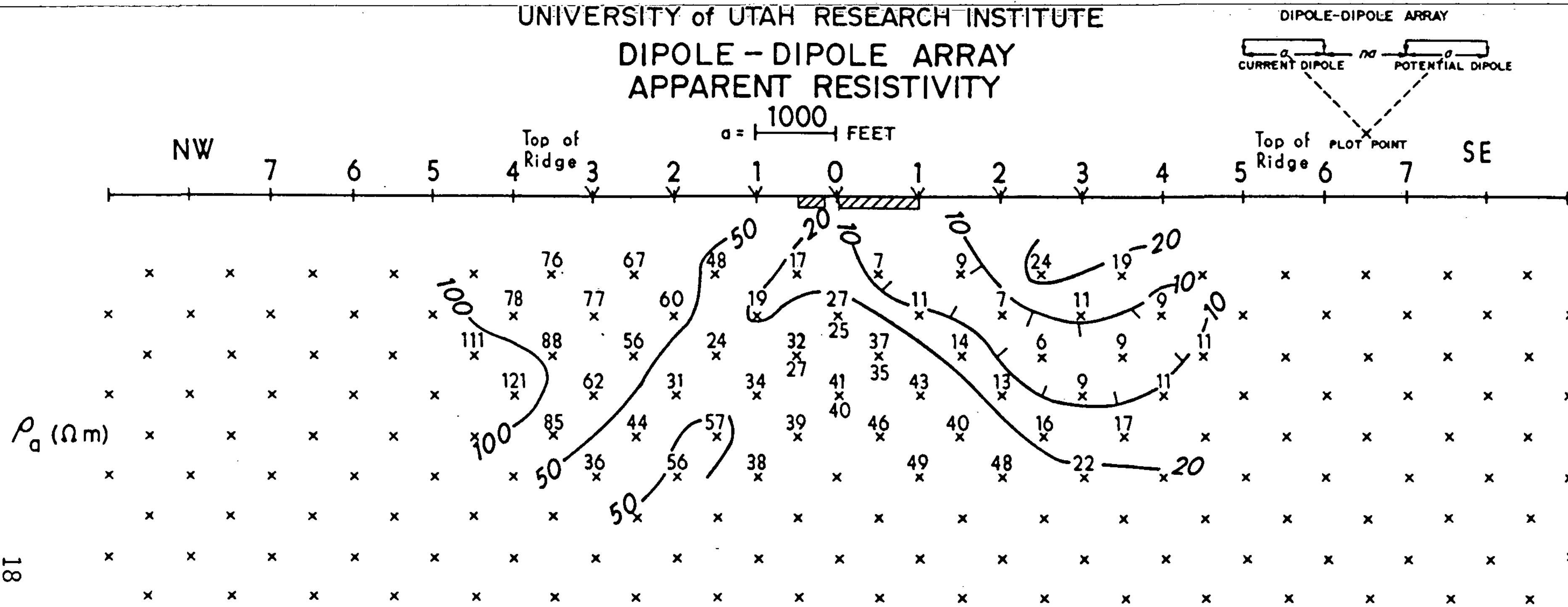

Figure 6.

AREA LAVA MTN. N40W STATE Calif. LINE 3 DATA BY CEM DATE 7-14-83 TRANSMITTER ELLIOT T.D. RECEIVER FLUKE

Line 4

This line (Figure 7) is centered on the main dirt road leading to the steam well and is placed roughly midway between lines 1 and 3. The line trends N43°W and S35°E and was placed to test for continuity of the conductive zone noted on lines 1, 2 and 3.

As suspected the conductive zone is evident between stations 1NW and 2SE. In traversing the line, the area between stations 1SE to 3SE was noted to contain abundant volcanic breccia and most strikingly a heavy coating of hyalite on the andesite flows. This might be indicative of a zone where geothermal fluids have leaked to the surface in the past.

Northwest of center the apparent resistivity increases to over 100 ohm-meters and again is thought to indicate the more resistive lava flows.

Line 5

This line (Figure 8) is located approximately 1.5 miles northeast of the steam well. It traverses through the canyon located in the northeast corner of section 19. The southeast half of the line trends S50°E.

No indication of the conductive zone noted on lines 1 to 4 is clearly evident on this line. The apparent resistivity data in general shows the conductive gravels of the valley resting on the more resistive volcanics. A resistivity contact appears to occur at about station 6NW. Between stations 5 and 6NW there is a low apparent resistivity value of 7 ohm-meters on the second separation. It does not appear to extend to depth. This may be the only indication of the conductive zone noted on the other lines. The zone does appear to be turning more to the north between line 1 and line 2 and the continuation might be projected into the northern end of line 5. This is only speculation at this time however.

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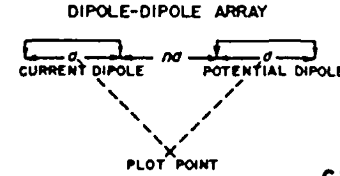
DIPOLE – DIPOLE ARRAY APPARENT RESISTIVITY



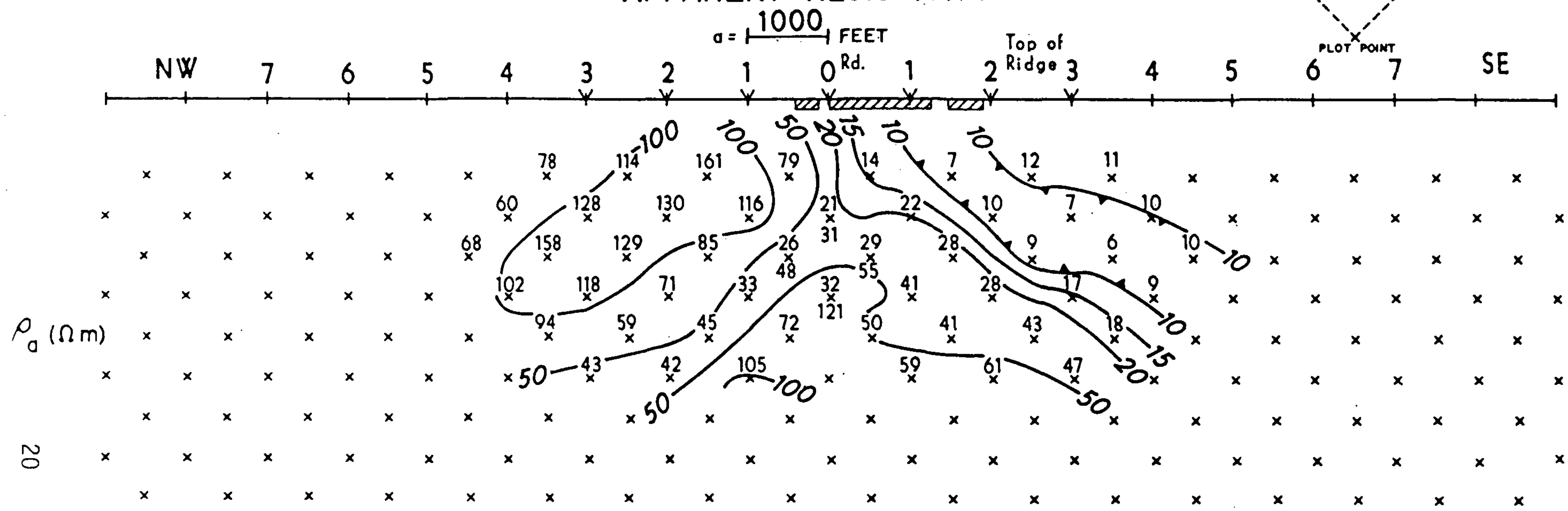


Figure 7.

AREA LAVA MTN. STATE Calif. LINE 4 DATA BY C.E.M. DATE 7-17-83 TRANSMITTER ELLIOT RECEIVER FLUKE

N43W S35E T.D.

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DIPOLE – DIPOLE ARRAY APPARENT RESISTIVITY

DIPOLE-DIPOLE ARRAY

CURRENT DIPOLE — na — POTENTIAL DIPOLE

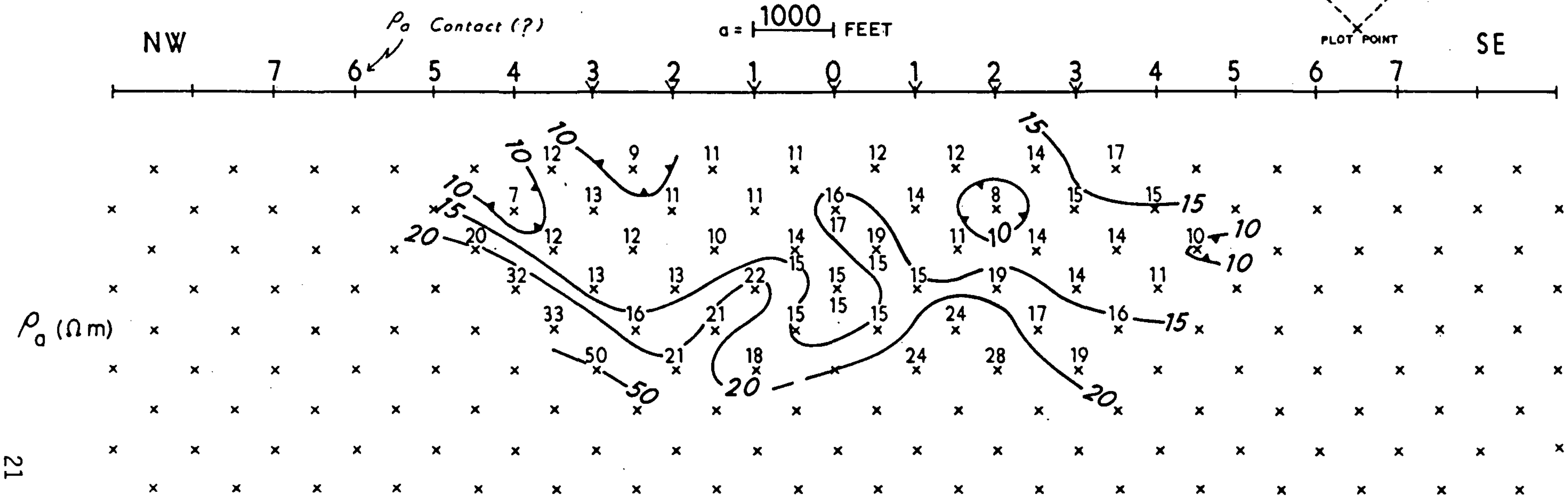

Figure 8.

AREA LAVA MTN. S50E STATE Calif. LINE 5 DATA BY C.E.M. DATE 7-16-83 TRANSMITTER ELLIOT T.D. RECEIVER FLUKE

COMPUTER MODELING RESULTS

An interactive IP-resistivity modeling computer program has been developed at ESL (Killpack and Hohmann, 1979). This program is used to model arbitrary two-dimensional IP-resistivity structures for comparison with field data from dipole-dipole surveys.

Three lines (1, 2 and 4) were selected for computer modeling. Model results for each line are discussed individually below. Copies of the two-dimensional models are found in Appendix A. It is understood that the models and results are only close approximations to the actual earth resistivity structures which are in reality three-dimensional. Efforts were made to obtain two-dimensional models that produced computed resistivity values that agreed to within ± 10% of the observed field data.

Line 1

A computer model that gives a coarse fit to the observed data presented on Figure 4 is shown as Figure A1. The results of this model do not however agree with the observed values everywhere to the normally acceptable accuracy of ± 10%. This is thought to result from a combination of topographic effects and non-two-dimensionality of the area along the line. This model was constructed after completion of the models for lines 2 and 4 and as a result is reasonably compatible to them.

The results shown by the model in general identify a zone of very low resistivity (2 ohm-meters) within the station interval of 0-1SE. This conductive zone is shown to dip to the southeast and have a depth extent of approximately 1000 feet. The steam well occurs within the same station interval being very near station 0. Slightly higher resistivities (10 ohm-meters) are adjacent to the conductive zone and many be clay rich volcanics or sediments which may also contain thermal fluids that have leaked out of the fault zone.

Southeast of station 0 the near surface material is represented on the model by a thin 100 ohm-meter layer. These higher values are thought to represent the effects of the drier near-surface alluvium. A small valley is present between stations 1 and 3SE and the 10 ohm-meter material shown beneath these stations, as previously mentioned, likely represents alluvial fill. The major valley occurring south of the prospect starts at about station 55E. The near-surface 10 ohm-meter material extending southeast of this station represents the alluvium in this valley.

The thick section of 15 ohm-meter material under most of the southeast end of the line is not clearly attributable to a particular rock unit. A ridge was crossed between stations 3 and 5SE. This ridge is composed, according to the geologic map, of hydrothermally altered volcanics and older gravels. It is therefore thought that the two units are indistinguishable electrically, and their combination gives rise to the thick 15 ohm-meter zone.

The northeast end of the line crosses hydrothermally altered volcanics and volcanic sediments. Topography becomes rougher and a ridge crests at about station 5NW. The volcanics are represented in the model by the 100-500 ohm-meter zones. A fault zone is shown on the geologic map at about station 1NW. This fault appears to be represented on the model by the 15 ohm-meter material located between stations 1 and 2NW.

Line 2

Figure A2 shows the model and computed results that agreed best with the field data shown by line 2 (Figure 5). Very low intrinsic resistivity (2 ohm-meters) values are present in what is modeled as a fracture zone located between stations 1-2NW. These very low values are thought to indicate clays or hot water within the fracture zone. This zone appears to have a southeast dip and is apparently enclosed in low resistivity volcanics and/or alluvial fill with intrinsic resistivities varying between 15 and 50 ohm-meters. The model shows this material thickening to the southeast as the line extends into the large valley.

The 5 ohm-meter layer present at intermediate depth (1000-1500 feet) on the southeast end of the model is necessary to achieve the computed fit to the observed data. Sensitivity tests show the model can sense the difference between 5 and 15 ohm-meters for this layer. Figure A3 shows this distinction. This 5 ohm-meter layer can be explained at least two different ways: 1) either an increase in clay content, probably below the water table, or 2) thermal fluids leaking into an aquifer within the sediments.

The model is also sensitive to horizontal changes in resistivity particularly in the station interval 3NW to 3SE. Note this interval contains the transmitting electrodes. Outside this interval the model is not as sensitive but can still sense large resistivity variations especially near surface. Many of the sharper resistivity contacts shown by the model are thought to represent faulting. Two such locations occur between stations 0-1SE, at depth, and stations 5-6SE. The latter apparently comes near surface.

The vertical zone of 5 ohm-meter material between stations 5-6SE is of particular interest. This inferred fault zone extends to a greater depth than the one shown between stations 1-2NW. Figures A4-A6 are iterations of the model testing the presence of this fault zone. As can be seen the fault zone is required in order to fit the observed data along the diagonal between stations 5-6SE. This poses another possible interpretation; that this zone with its greater depth extent is the actual plumbing for the thermal fluids. These could move laterally through the aquifer shown on the model at depths between 1000 and 1500 feet before rising along another fault zone into the area of the steam well. At present, there is no way to tell which of the two fault zones is the actual plumbing for the rising thermal fluids based upon the resistivity data.

Finally, the model depicts the more resistive (> 100 ohm-meter) volcanics occurring at the surface on the northwest end of the line. These extend southeast beneath the Quaternary alluvium.

Line 4

The computed model for this line is shown as Figure A7. Calculated results can be compared to the observed data presented as Figure 7. The model results are reasonable fits to the observed data although agreement within ± 10% is not achieved everywhere. Part of this discrepancy can be explained by topographic variations along the line that were not accounted for in the model.

The model shows the resistive (unaltered?) volcanics extending along the entire length of the line. These volcanics deepen sharply northwest from station 3NW and appear to be overlain by hydrothermally altered sedimentary volcanics possibly containing abundant clay. The resistive volcanics appear to deepen slowly to the southeast until station 3SE. An abrupt resistivity contrast (fault?) occurs at this station with the resistive volcanics appearing to be displaced downward. The line climbs along the site of a high ridge between stations 1 to 5SE. Station 3SE is well below the ridge crest hence topographic effects may be causing part of the apparent sharp resistivity contrast modeled below this station. Beyond station 3SE (3SE-7SE) the line traverses along a small ridge consisting of older gravels. The model depicts these as being more conductive (5-10 ohm-meters) probably because of a higher clay content.

Several conductive zones are shown on the model and these likely represent faults. The resistivities are very low (2 ohm-meters) in two areas: 1) between stations 0-1SE, and 2) stations 1.5-2SE. The conductive zone shown on the other models and interpreted to relate to the steam well trends through the first area. The strong hyalite coating noted on the surface volcanics appears to be associated with the second area.

One other area with more moderate (50 ohm-meters) resistivity occurs beneath station 1NW. In checking with the geologic map it is noted that a fault has been mapped very near this location and probably accounts for the resistivity variation.

DISCUSSION

It is difficult if not impossible to construct two-dimensional computer models that will agree uniquely with observed data taken from a three-dimensional earth. Therefore, the approach is to obtain a model that closely approximates observed results and which can be considered representative of several similar models. In all cases however, appropriate models will all show similar resistivity structure in that resistivity lows will always be lows and resistivity highs will always be highs. The intrinsic resistivity and thickness of individual layers (bodies) can however vary slightly and still yield comparable results. Compounding this inherent uncertainty are effects of topographic irregularities along the survey lines which are themselves difficult to model.

The electrical resistivity data taken on the Lava Mountain Geothermal Prospect are complex in that they show to varying degrees all of the above uncertainties. No attempt has been made at this stage of the data interpretation to account for topographic effects which do not appear to be severe. Because of this the computer model shown for line 2 (Figure A2) is thought to be the most accurate since this line has the least amount of topographic variation.

The presence of a low resistivity zone detected on four of the five lines supports the idea that the thermal fluids are fault controlled. Several individual faults may be present within the low resistivity zone however. These would not be distinguishable from a single fault because of the 1000-foot dipole spacing. This spacing was chosen as the most feasible for a reconnaissance survey and necessarily sacrifices some sensitivity to horizontal resistivity variations for depth of exploration.

The indication of additional faulting located on the southeast end (station 5-6SE) of line 2 is also intriguing. Several sensitivity tests were conducted to substantiate the need in the model for the conductive zone in order to agree with the observed data. These tests are shown as Figures A4 to A6 in the Appendix and confirm the need for the conductive zone. However the importance of this zone cannot be deduced from the electrical resistivity data alone.

Finally one additional figure (Figure A8) is presented. This figure shows interpreted sections along the three lines that were modeled in a schematic that allows for easy comparison.

REFERENCES

Killpack, Terry J., and Hohmann, Gerald W., 1979, Interactive Dipole-Dipole Resistivity and IP Modeling of Arbitrary Two-Dimensional Structures, Univ. of Utah Research Institute, Earth Science Laboratory Report 15, 120 p.

LIST OF ILLUSTRATIONS

PLATES

FIGURES

APPENDIX A

Calculated Models - Lines 1, 2 and 4.

Computer Output - Lines 1, 2 and 4.

Interpreted Sections - Lines 1, 2 and 4.

Sensitivity Tests - Line 2.

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LAVA MOUNTAIN AREA,SAN BERNARDINO CO.,CALIFORNIA
LINE 1
MEDIA RESISTIVITY (OHM-METERS)
        2.00         5.00        10.00        15.00        50.00
      100.00       500.00       300.00
MEDIA PFE (%)
        0.00         0.00         0.00         0.00         0.00
        0.00         0.00         0.00

  88   77   66   55   44   33   22   11   00   11   22   33   44   55   66   77   88
•••••••••1•••••••••2•••••••••3•••••••••4•••••••••5•••••••••6•••••••••7   "a"
2222222222222222222222222266444444444466666666666666666333333333333333   - 0.1
2222222222222222222777722666644564433113333666644444444333333333333333   - 0.3
2222222222222222222777777777744445666361133334444444444443333333333333   - 0.6
8888888888888777777777777777777766677666661173344444444444444444444444   - 1.0
8888888888888777777777777777777766776666677666444444444444444444444444   - 1.5
8888888888887777777777777777777777777777766664444444444444444448888888   - 2.0
7777777777777777777777777777777777777777666664444444444444444488888888   - 3.0
7777777777777777777777777777777777777777788888888888888888888888888888   - 4.0
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7777777777777777777777777777777777777777777788888888888888888888888888   - 11.0
7777777777777777777777777777777777777777777777888888888888888888888888
•••••••••1•••••••••2•••••••••3•••••••••4•••••••••5•••••••••6•••••••••7
                                                                          DEPTH (feet)
```

```
                          CALCULATED RESISTIVITY (OHM-METERS)

 -5      -4      -3      -2      -1       0      +1      +2      +3      +4      +5
  :-------:-------:-------:-------:-------:-------:-------:-------:-------:-------:


observed   -> 6           89      38      11      15      9       13      23
Calculated -> 14.         79.     27.     30.     13.     7.      10.     21.

             10      36      113     18      18      15      4       10      14
             14.     65.     90.     21.     29.     35.     6.      15.     16.

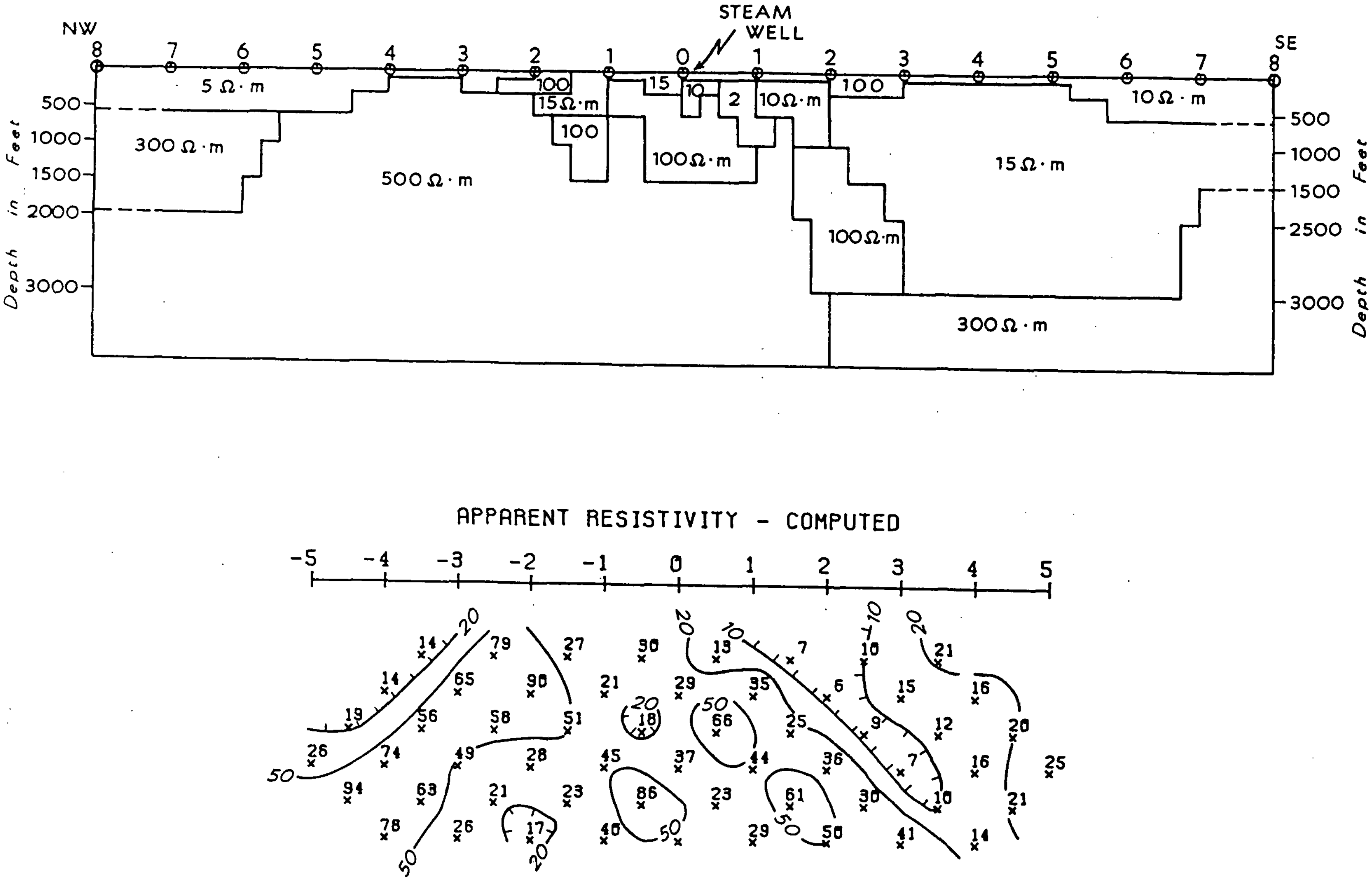
      109     41      101     37      27      21      12      4       9       13
      19.     56.     58.     51.     18.     66.     25.     9.      12.     20.

              41      102     44      26      31      16      18      8       9       13
  26.         74.     49.     28.     45.     37.     44.     36.     7.      16.     25.

                  101     24      56      45      29      27      19      8       23
      94.         63.     21.     23.     86.     23.     61.     30.     10.     21.

                      25      37      74              41      25      25      14
              78.     26.     17.     40.             29.     50.     41.     14.
```

Figure A1. Line 1 Calculated Model Lava Mountain Area, San Bernardino County, California.



LINE 1

CALCULATED MODEL

LAVA MOUNTAIN AREA

SAN BERNARDINO COUNTY, CALIF.

Figure A1.

```
LAVA MOUNTAIN AREA,SAN BERNARDINO CO.,CALIFORNIA
LINE 2
MEDIA RESISTIVITY (OHM-METERS)
        5.00       15.00       30.00       50.00      100.00
      200.00        2.00      300.00
MEDIA PFE (%)
        0.00        0.00        0.00        0.00        0.00
        0.00        0.00        0.00

  88  77  66  55  44  33  22  11  00  11  22  33  44  55  66  77  88
.........1.........2.........3.........4.........5.........6.........7
8888888888665555555333333332223344333111222222222333222111222222222222
8888888888866555555555333332773331133112222222222332222211122222222222
8888888888886655555555533332277331111222222222222222222211122222222222
8888888888886666666555533555227711222112222222222222222211112222222222
8888888888888666688888866666666666888111111111111111111111111222222222
8888888888888666688888888888888888888888888888888888888888111122222222
8888888888888888888888888888888888888888888888888888888888888888888888
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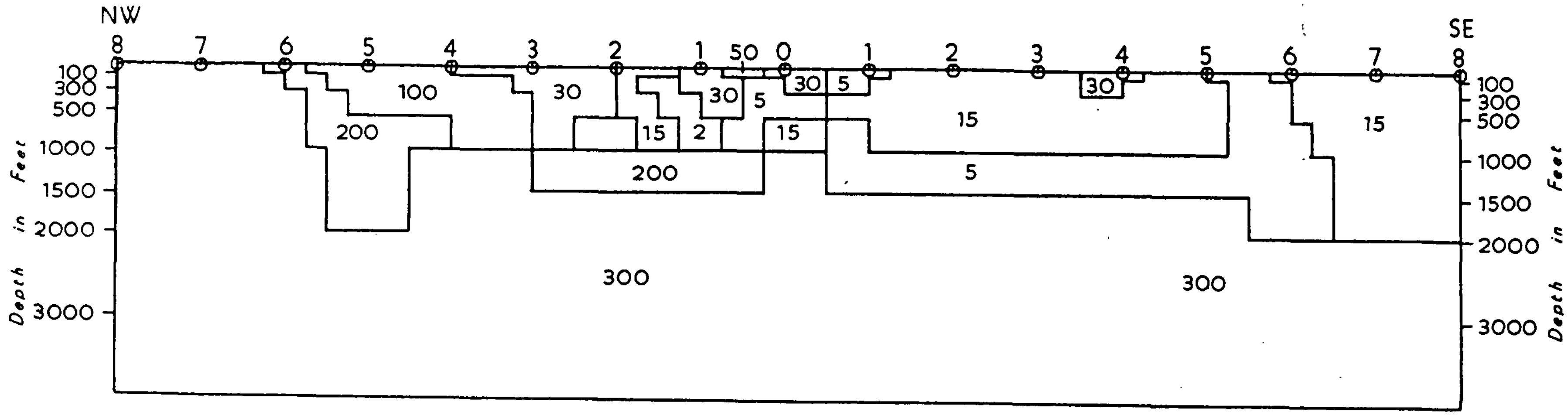
.........1.........2.........3.........4.........5.........6.........7


                    APPARENT RESISTIVITY (CALCULATED)

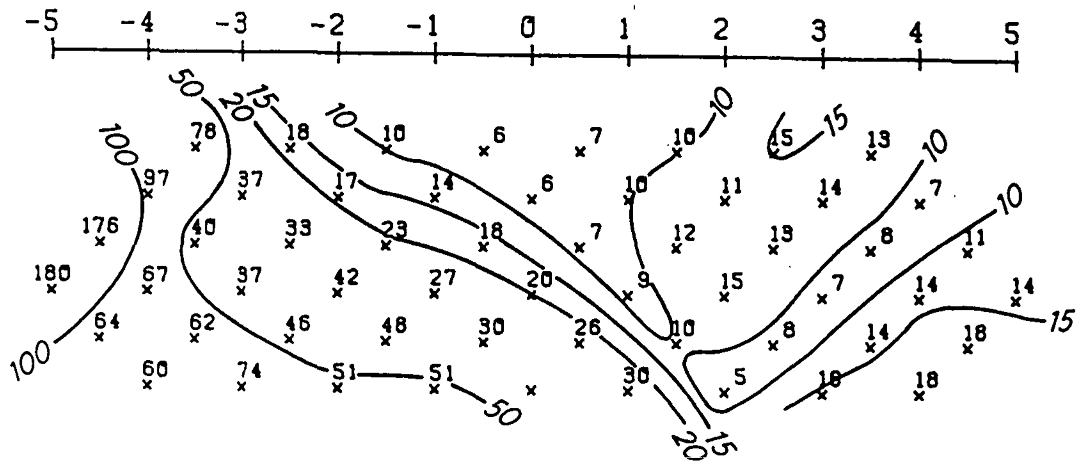
  -5     -4     -3     -2     -1      0     +1     +2     +3     +4     +5
   :------:------:------:------:------:------:------:------:------:------:


Observed →   59      19      13       8        11      12      18      16
             78.     18.     10.      6.       7.      10.     15.     13.
Calculated → 96      26      15      12       6        8      14      13       9
             97.     37.     17.     14.      6.      10.     11.     14.      7.
       149      39      27      21      13        6      10      11       8      14
       176.     40.     33.     23.     18.       7.     12.     13.      8.     11.
                69      32      34      31      18      10      12       8      12
   180.         67.     37.     42.     27.     20.      9.     15.      7.     14.     14.
                63      38      40      36      39      14       8      13
          64.   62.     46.     48.     30.     26.     10.      8.     14.     18.
                80      53      81                      31      21      18
          60.   74.     51.     51.             30.      5.     16.     18.
```

Figure A2. Line 2 Calculated Model Lava Mountain Area, San Bernardino County, California.



APPARENT RESISTIVITY - COMPUTED



LINE 2

CALCULATED MODEL
LAVA MOUNTAIN AREA
SAN BERNARDINO COUNTY, CALIF.

Figure A2.

```
LAVA MOUNTAIN AREA,SAN BERNARDINO CO.,CALIFORNIA
LINE 2
MEDIA RESISTIVITY (OHM-METERS)
        5.00       15.00       30.00       50.00      100.00
      200.00        2.00      300.00
MEDIA PFE (%)
        0.00        0.00        0.00        0.00        0.00
        0.00        0.00        0.00

  88  77  66  55  44  33  22  11  00  11  22  33  44  55  66  77  88
.........1.........2.........3.........4.........5.........6.........7
8888888888665555555333333332223344333112222222222333222111222222222222
8888888888866555555555333332773331133112222222222332222111222222222222
8888888888888665555555555333322773311112222222222222222221112222222222
8888888888888666666555533555227722222222222222222222222211112222222222
8888888888888666688888866666666666668882222222222222222222211112222222
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.........1.........2.........3.........4.........5.........6.........7
```

```
                         APPARENT RESISTIVITY (CALCULATED)

    -5      -4      -3      -2      -1       0      +1      +2      +3      +4      +5
     :-------:-------:-------:-------:-------:-------:-------:-------:-------:-------:



                 78.     18.     11.      6.      10.     11.     16.     15.

             96.     37.     20.     14.      9.      15.     15.     20.      9.

         175.    41.     40.     23.     22.      10.     22.     20.     12.     14.

     178.    68.     45.     43.     34.     27.      14.     28.     11.     19.     18.

          65.     76.     47.     61.     40.      37.     16.     14.     18.     24.

             74.     77.     65.     69.              43.      8.     22.     21.
```

Figure A3. Line 2 Sensitivity Test Lava Mountain Area, San Bernardino County, California.

```
LAVA MOUNTAIN AREA,SAN BERNARDINO CO.,CALIFORNIA
LINE 2
MEDIA RESISTIVITY (OHM-METERS)
        5.00      15.00      30.00      50.00     100.00
      200.00       2.00     300.00
MEDIA PFE (%)
        0.00       0.00       0.00       0.00       0.00
        0.00       0.00       0.00

  88  77  66  55  44  33  22  11  00  11  22  33  44  55  66  77  83
.........1.........2.........3.........4.........5.........6.........7
8888888888665555555533333332223344333111222222222333222222222222222222
8888888888866555555555333332773331133112222222222332222222222222222222
8888888888886655555555553332277331111222222222222222222222222222222222
8888888888888666666655533555227711222112222222222222222222222222222222
8888888888888866668888866666665556688811111111111111111122222222222222
8888888888888666688888888888888888888888888888888888888882222222222222
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.........1.........2.........3.........4.........5.........6.........7
```

```
                       APPARENT RESISTIVITY (CALCULATED)

 -5      -4      -3      -2      -1       0      +1      +2      +3      +4      +5
  :-------:-------:-------:-------:-------:-------:-------:-------:-------:-------:


           78.     18.     10.      6.      7.     10.     15.     12.

       97.     37.     17.     14.      6.      9.     11.     12.     12.

   176.    40.     33.     23.     18.      7.     12.     11.     14.     14.

 180.    67.     37.     42.     27.     20.      8.     13.     14.     18.     17.

     64.     62.     45.     47.     29.     25.      8.     17.     18.     21.

         59.     73.     50.     49.             26.     11.     20.     20.
```

Figure A4. Line 2 Sensitivity Test Lava Mountain Area, San Bernardino County, California.

```
LAVA MOUNTAIN AREA,SAN BERNARDINO CO.,CALIFORNIA
LINE 2
MEDIA RESISTIVITY (OHM-METERS)
        5.00      15.00      30.00      50.00     100.00
      200.00       2.00     300.00
MEDIA PFE (%)
        0.00       0.00       0.00       0.00       0.00
        0.00       0.00       0.00

  88   77   66   55   44   33   22   11   00   11   22   33   44   55   66   77   88
.........1.........2.........3.........4.........5.........6.........7
8888888888665555555333333322233443331112222222222333222211222222222222
8888888888866555555555333332773331133112222222222332222211222222222222
8888888888886655555555533332277331111222222222222222222222222222222222
8888888888886666666555533555227711222112222222222222222222222222222222
8888888888888666688888866666666566888111111111111111111122222222222222
8888888888888666688888888888888888888888888888888888888382222222222222
8888888888888888888888888888888888888888888888888888888888888888888888
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.........1.........2.........3.........4.........5.........6.........7
```

```
                         APPARENT RESISTIVITY (CALCULATED)

  -5      -4      -3      -2      -1       0      +1      +2      +3      +4      +5
   :-------:-------:-------:-------:-------:-------:-------:-------:-------:-------:


                78.     18.     10.      6.       7.     10.     15.     13.

            97.     37.     17.     14.      6.      9.     11.     13.     10.

       176.     40.     33.     23.     18.      7.     12.     11.     12.     15.

   180.     67.     37.     42.     27.     20.      8.     13.     12.     18.     17.

        64.     62.     45.     47.     29.     25.      9.     14.     18.     20.

            59.     73.     50.     49.              28.      9.     21.     20.
```

Figure A5. Line 2 Sensitivity Test Lava Mountain Area, San Bernardino County, Califonia.

LAVA MOUNTAIN AREA,SAN BERNARDINO CO.,CALIFORNIA
LINE 2

```
MEDIA RESISTIVITY (OHM-METERS)
        5.00       15.00      30.00      50.00     100.00
      200.00        2.00     300.00
MEDIA PFE (%)
        0.00        0.00       0.00       0.00       0.00
        0.00        0.00       0.00

  88  77  66  55  44  33  22  11  00  11  22  33  44  55  66  77  88
.........1.........2.........3.........4.........5.........6.........7
8888888888665555555333333332223344333111222222222333222211222222222222
8888888888866555555555333332773331133112222222222332222211222222222222
8888888888886655555555533332277331111222222222222222222211222222222222
8888888888886666666555533555227711222112222222222222222211222222222222
8888888888886666888888866666666666888111111111111111111111222222222222
8888888888888666688888888888888888888888888885888888888882222222222222
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8888888888888888888888888888888888888888888888888888888888888888888888
.........1.........2.........3.........4.........5.........6.........7
```

APPARENT RESISTIVITY (CALCULATED)

```
 -5     -4     -3     -2     -1      0     +1     +2     +3     +4     +5
  :------:------:------:------:------:------:------:------:------:------:


          78.    18.    10.     6.      7.    10.    15.    13.

       97.    37.    17.    14.     6.    10.    11.    13.     9.

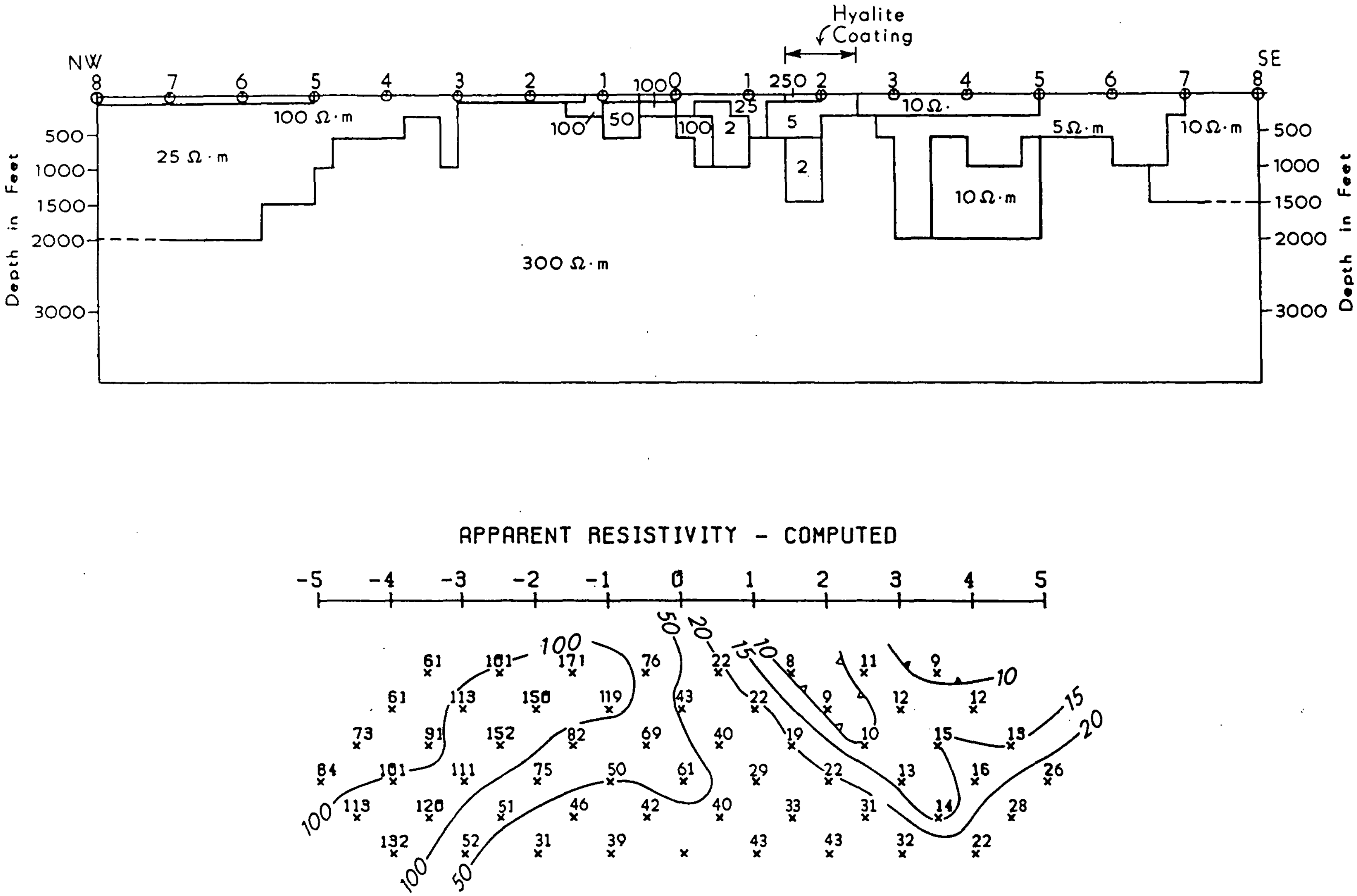
   176.    40.    33.    23.    18.      7.    12.    11.    10.    13.

 180.    67.    37.    42.    27.    20.     8.    13.    10.    17.    16.

     64.    62.    46.    48.    29.     25.     9.    12.    17.    20.

        60.    74.    50.    50.             27.     7.    19.    20.
```

Figure A6. Line 2 Sensitivity Test Lava Mountain Area, San Bernardino County, California.



LINE 4

CALCULATED MODEL

LAVA MOUNTAIN AREA
SAN BERNARDINO COUNTY, CALIF.

Figure A7.

```
LAVA MOUNTAIN AREA,SAN BERNARDINO CO.,CALIFORNIA
LINE 4
MEDIA RESISTIVITY (OHM-METERS)
        2.00        5.00       10.00       25.00       50.00
      100.00      200.00      300.00
MEDIA PFE (%)
        0.00        0.00        0.00        0.00        0.00
        0.00        0.00        0.00

  88   77   66   55   44   33   22   11   00   11   22   33   44   55   66   77   88
.........1.........2.........3.........4.........5.........6.........7
3333333333333334444444444444446565554444455223333333333222222223333333
4444444444444444444444488888866556651144222223333333333222222223333333
4444444444444444444488488888888558866118222888222222222222222233333333
4444444444444444888888488888888888886118811888822332223888822233333333
4444444444444448888888888888888888888888811888822333333888886333333333
4444444444448888888888888888888888888888888888822333333888888888888888
8888888888888888888888888888888888888888888888888888888888888888888888
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.........1.........2.........3.........4.........5.........6.........7
```

APPARENT RESISTIVITY (CALCULATED)

```
 -5      -4      -3      -2      -1       0      +1      +2      +3      +4      +5
  :-------:-------:-------:-------:-------:-------:-------:-------:-------:-------:
```

Observed → 78 114 161 79 14 7 12 11

Calculated → 61. 101. 171. 76. 22. 8. 11. 9.

60 128 130 116 26 22 10 7 10

61. 113. 150. 119. 43. 22. 9. 12. 12.

68 158 130 85 37 42 28 9 6 10

73. 91. 152. 82. 69. 40. 19. 10. 15. 15.

102 118 71 33 77 41 28 17 9

84. 101. 111. 75. 50. 61. 29. 22. 13. 17. 25.

94 59 45 72 50 41 43 18

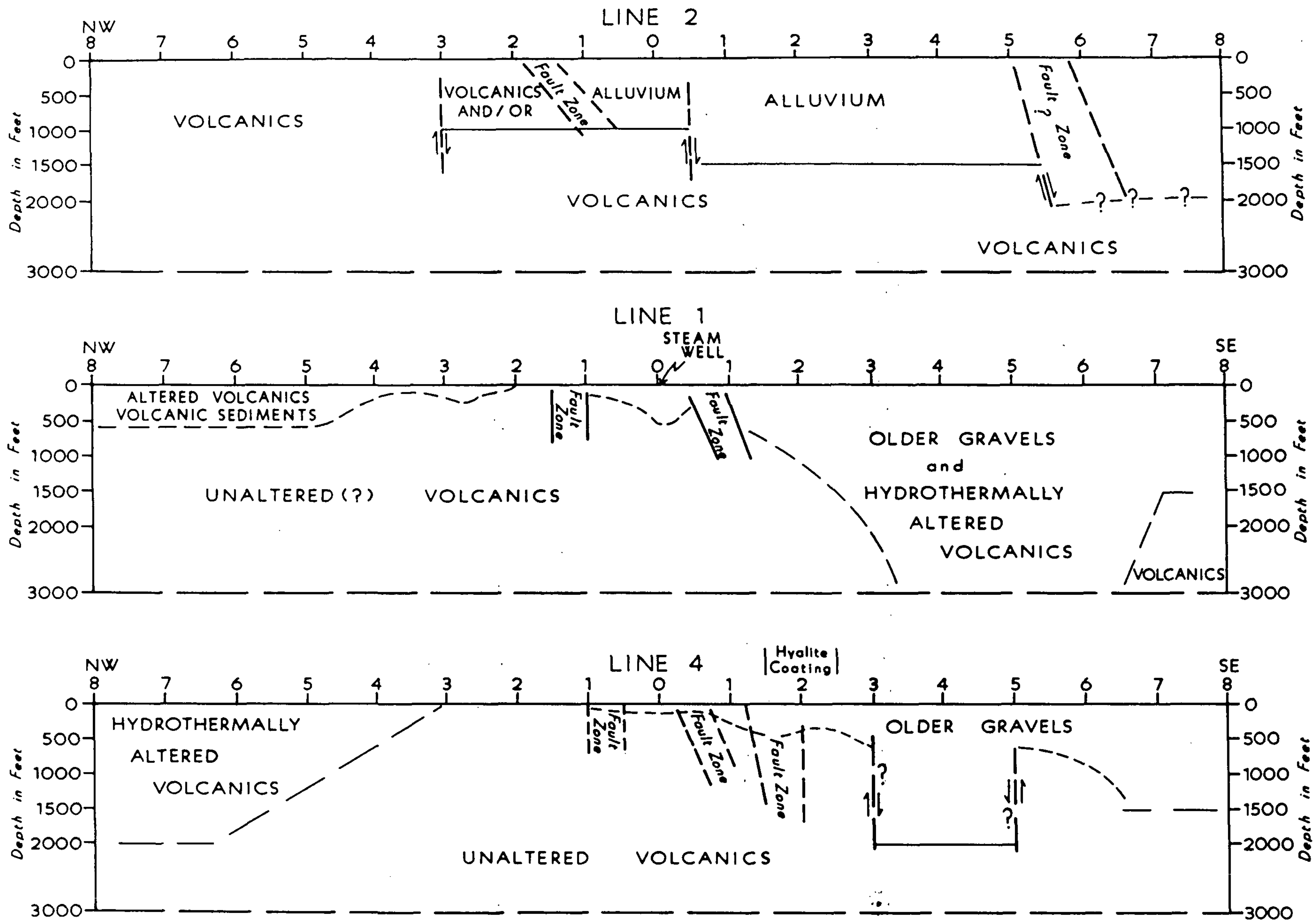
113. 120. 51. 46. 42. 40. 33. 31. 13. 28.

43 42 105 59 61 47

132. 52. 31. 39. 43. 43. 32. 22.

Figure A7. Line 4 Calculated Model Lava Mountain Area, San Bernardino County, California.

Figure A8.



INTERPRETED SECTIONS
LAVA MOUNTAIN AREA
SAN BERARDINO COUNTY, CALIFORNIA
scale 1"=2000'