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Preliminary Results of Geoelectrical Investigations near Clear Lake, California

By

William D. Stanley, Dallas B. Jackson,

and B. Carter Hearn, Jr.

FC-USGS
Open-file report

1973 – 0270

This report is preliminary and has not been edited or reviewed for conformity with U. S. Geological Survey standards and nomenclature.

Contents

Illustrations

[Plates are in pocket]

Preliminary results of geoelectrical investigations near Clear Lake, California

By William D. Stanley, Dallas B. Jackson and B. Carter Hearn, Jr.

Introduction

The first stage of a series of geoelectrical investigations has been completed in the vicinity of the Clear Lake volcanic field in the northern Coast Range of California. These investigations are a part of the U.S. Geological Survey's geothermal research program, which is designed to provide basic data relating to the different types of geothermal systems and to develop techniques for locating and outlining geothermal areas. The region selected for these investigations (pl. 1) is of interest because of possible relationships between The Geysers dry steam field, a gravity low centered around Mount Hannah, and the Clear Lake volcanic field of Pliocene to Holocene age. Geoelectrical investigations have not been completed, but because of the timely nature of the data obtained thus far, current results are being placed on open file.

Methods and procedures

Resistivity measurements were made using total-field dipole mapping (Keller, 1966; Risk and others, 1970) and vertical electrical sounding techniques (Keller and Frischknecht, 1966; Bhattacharya and Patra, 1968). In the total-field dipole mapping technique employed, the total electric field about a long (3 to 5 km) dipole was measured using short (30 to 200 meters), quasi-orthogonal grounded measurement dipoles. Apparent resistivities were computed from the input current and the measured electric field by relating the electric field magnitude to the magnitude which would be measured over a homogeneous half-space. Contour maps of apparent resistivity for the five separate source dipole locations were compiled (pls. 2-6) and a generalized geology and composite apparent resistivity map (pl. 7) was constructed. These maps were used to investigate the possible occurrence of highly conductive bodies which might represent regions of combined high salinity, high temperature, and high effective porosity. Such bodies are common in many geothermal areas of the world (Keller, 1970; Meidav, 1970; McNitt, 1965; Cheng, 1970). Anomalies observed on these maps were probed using the vertical electrical sounding (VES) technique to obtain information on the distribution of resistivity as a function of depth. Several facts about apparent resistivity measurements using dipole mapping techniques should be stated:

1. The depth of investigation at a measurement point depends on:
   a. The distance and azimuth of the measurement point from the source dipole
   b. The length of the source dipole
   c. The geology
2. The definition with which a particular geologic unit can be mapped is dependent in part upon the electrical properties of the surrounding geologic units.
3. The total-field mapping technique is well suited for locating large electrical heterogeneities. The anomalies then should be investigated using an electrical or electromagnetic sounding technique to find the resistivity distribution with depth.
4. In the presence of steeply dipping contacts, apparent resistivities measured over a large conductive body with the source dipole located over resistive material will be higher than the true resistivity of the conductive body (Al'pin, 1966; Risk and others, 1970). Conversely, the apparent resistivity measured outside the body, with the source dipole located over the conductive body, will be lower than the true resistivity at the measurement point. In compiling the apparent resistivity maps presented in this report, no adjustments were made for such effects. Some control was provided by making many measurements with more than one source dipole.

Results

Repeat measurements from separate dipole sources indicated that the data on plates 2-6 could be qualitatively combined into a composite apparent resistivity map (pl. 7) to aid interpretation of the data. The composite map was constructed by smoothing contours between areas of overlap on the five separate maps and by qualitatively removing the effects of shallow layering around the source dipoles. For the earth model of a thin, resistive layer overlying a very thick conductor, a theoretical anomaly with steep gradients will be centered about the dipole. Examination and comparison of the apparent resistivity maps with the geology and VES curves usually make possible the identification of anomalies caused by shallow layering. The most significant anomaly caused by near surface layering is a resistivity high near source dipole no. 1.

A large resistivity low of 1-5 ohm-meters, trending NW-SE is evident on the composite map. The bulbous northwest portion of the anomaly is centered about Mount Hannah and the southeast portion of the anomaly about Boggs Mountain. The true resistivity gradients at the edge of the low are in reality higher than the apparent resistivity gradients shown because of the effects of location of the source dipole mentioned above. The apparent resistivities inside the low are probably close to, but slightly higher than, the true resistivities. The trend and boundaries of the anomaly seem to indicate a relationship to the Soda Creek and Collayomi faults and the edge of the Clear Lake volcanic field on the west and southwest, and to the Childers Peak fault on the east (pl. 7). Comparison of the composite apparent resistivity map with the gravity map (pl. 8) shows that the bulbous portion of the resistivity anomaly centered about Mount Hannah coincides with the center of the gravity low, suggesting a relationship between the causes of the two anomalies.

In order to investigate the nature of the resistivity low, seven vertical electrical soundings using the Schlumberger array were made (see pls. 6 and 7 for location) and source dipole no. 4 was used to make a deep sounding along the axis of the electrical low. The VES curves are shown in figures 1-7 with the interpreted models. The Schlumberger spacing and the interpreted depths in feet are plotted on the abscissa, whereas the computed apparent resistivities in ohm-meters are plotted on the ordinate. The numbers in the logarithmically plotted model layers are the interpreted true resistivities in ohm-meters. The curves were interpreted using curve-matching and auxiliary-point techniques (Orellana and Mooney, 1966; Zohdy, 1965). The graphically obtained models were tested with computer-generated sounding curves using a numerical integration program developed by W. L. Anderson of the U.S. Geological Survey. The data from the deep sounding is shown on the same plot (fig. 1) as VES 1, because VES 1 was located about in the middle of the deep sounding line (see pl. 7). For these points the abscissa represent the distances from the center of the source dipole to the center of the measurement dipole. The deep sounding points were in a quasi-polar direction (Al'pin, 1966) and were used only to obtain a minimum depth to the bottom of the conductive body (Zohdy, 1969). The apparent minimum expressed on the deep sounding points may not be caused by horizontal layering, because the edge of the conductive body was being approached at the larger distances and also because the width of the body is much less than the dimensions of the sounding.

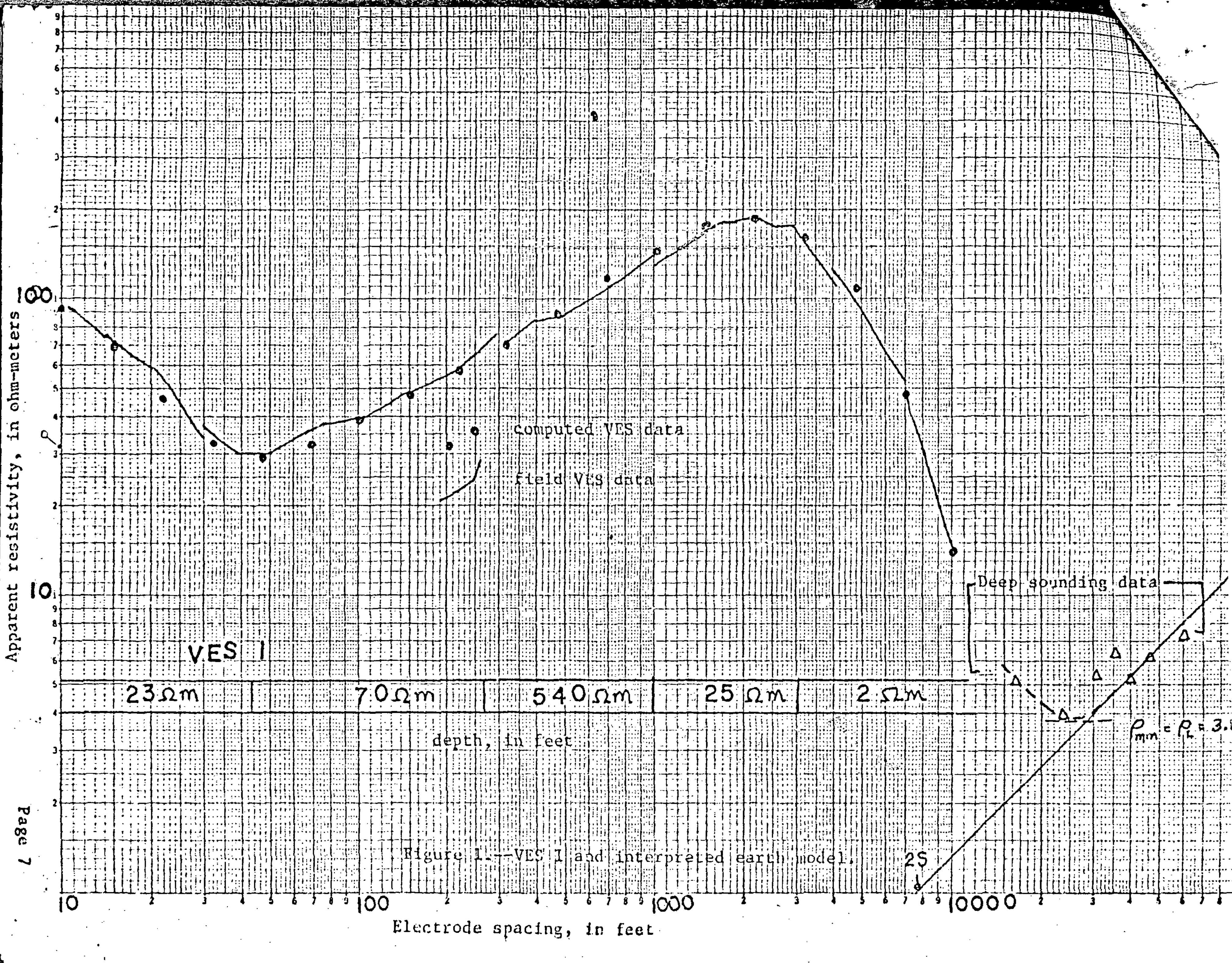

Figure 1.--VES 1 and interpreted earth model.

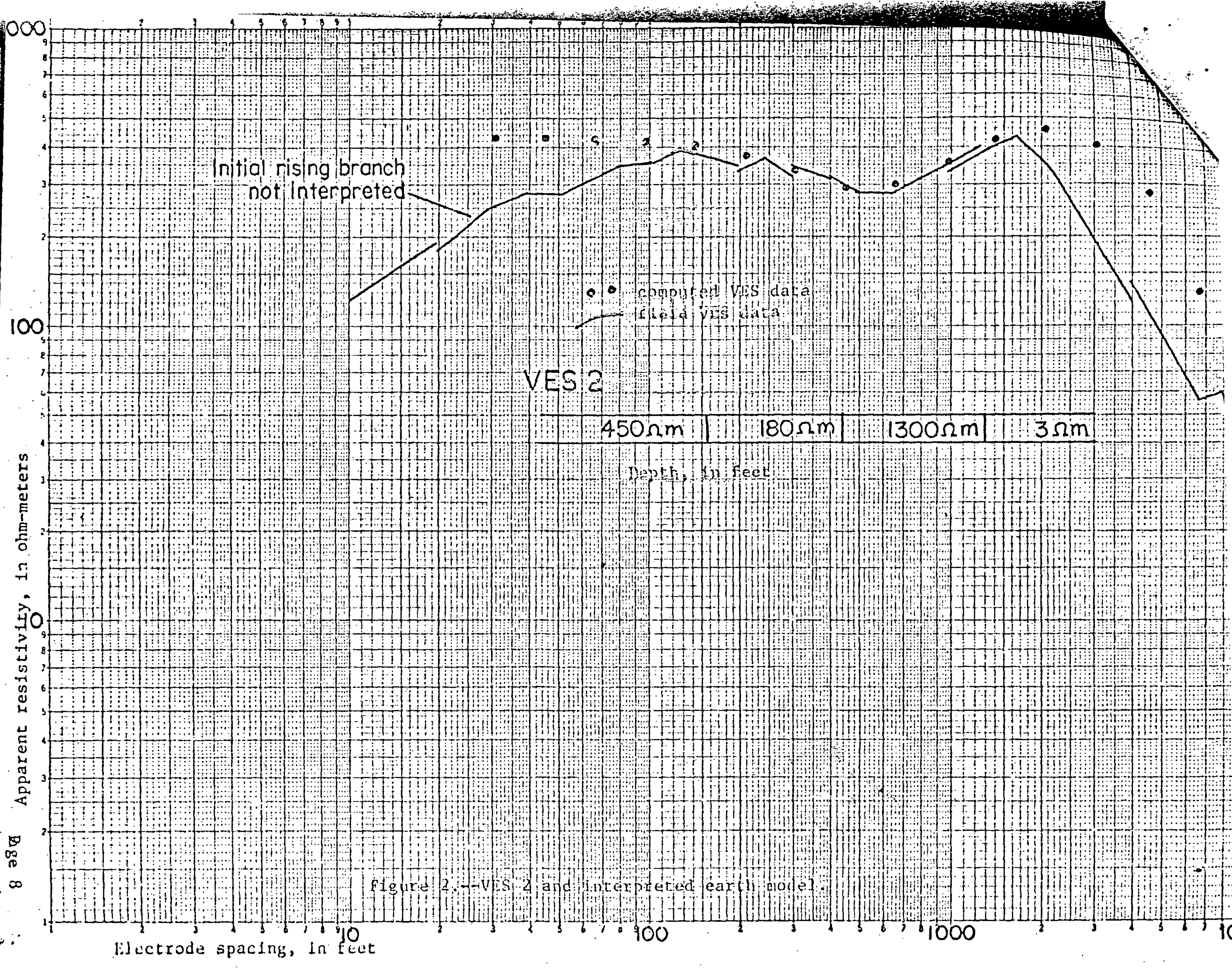

Figure 2.--VES 2 and interpreted earth model.

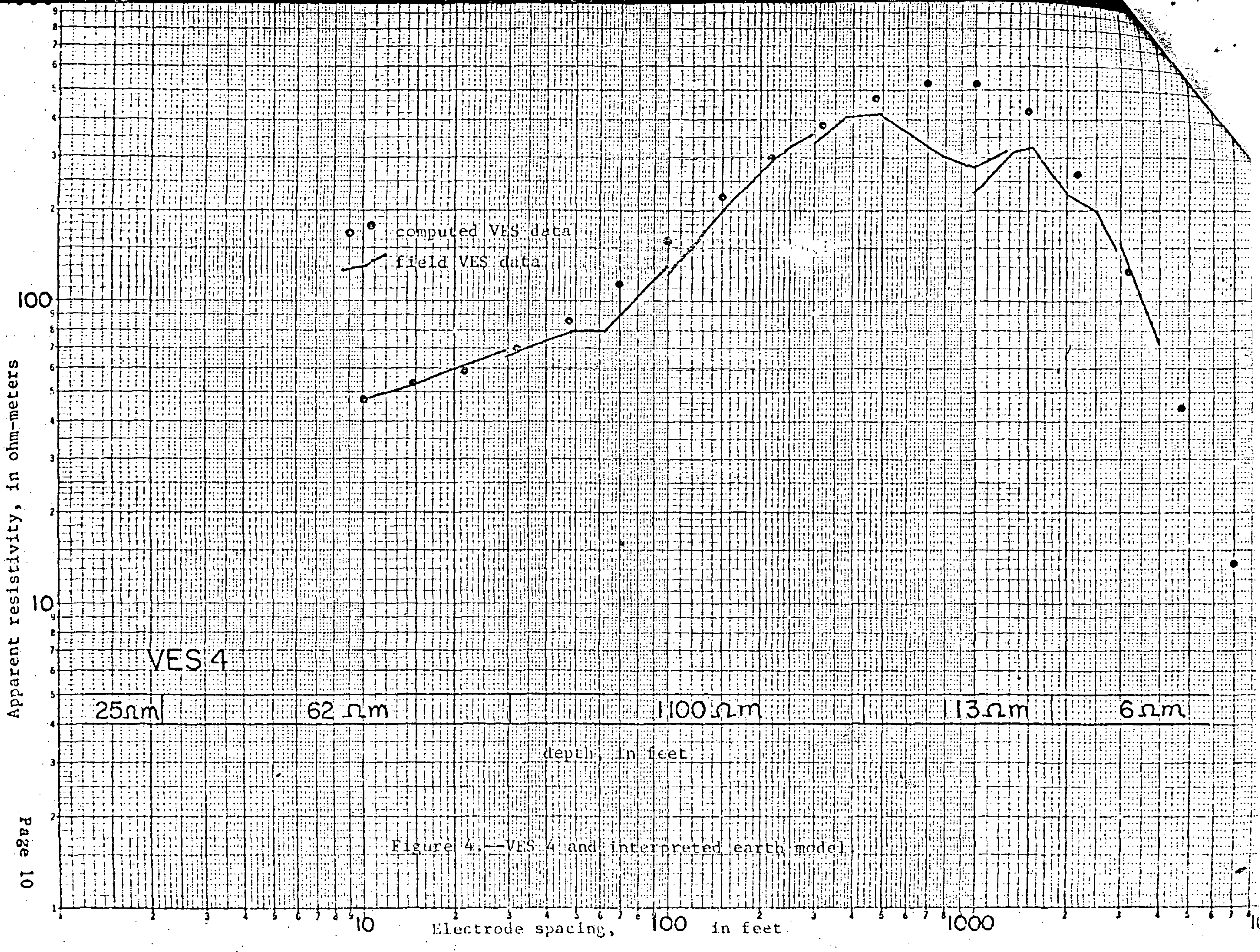

Figure 4.--VES 4 and interpreted earth model

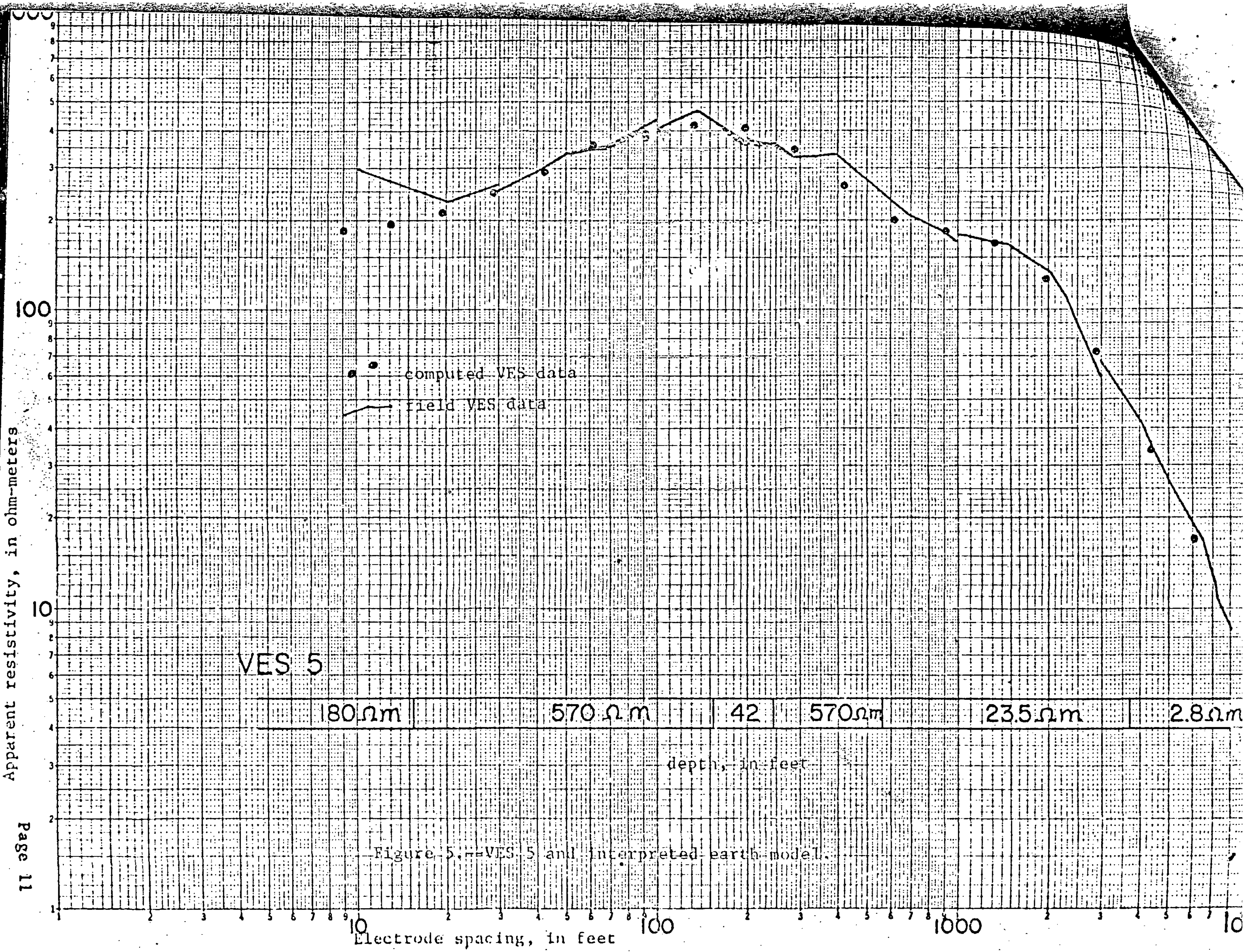

Figure 5.--VES 5 and interpreted earth model.

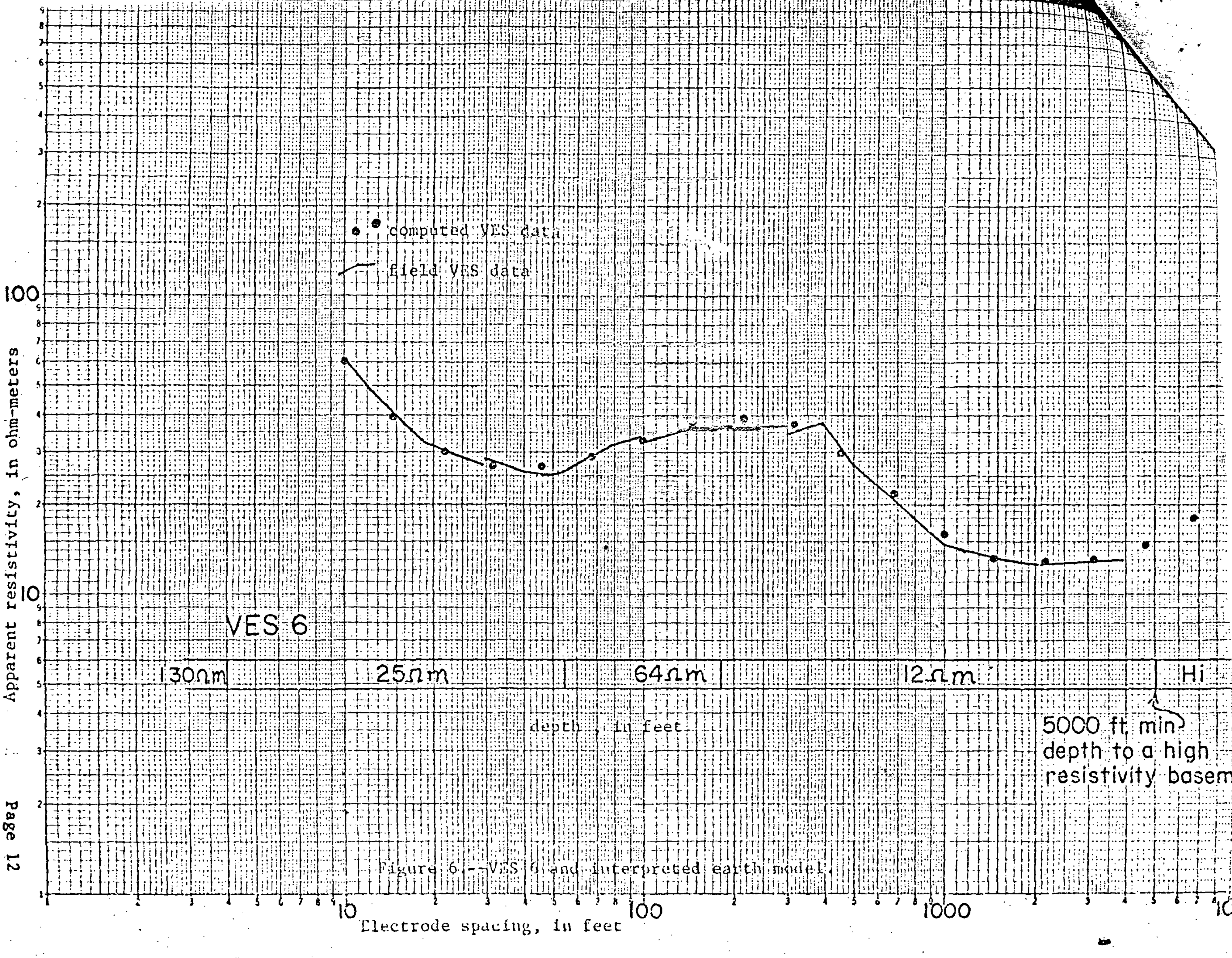

Figure 6.--VES 6 and interpreted earth model.

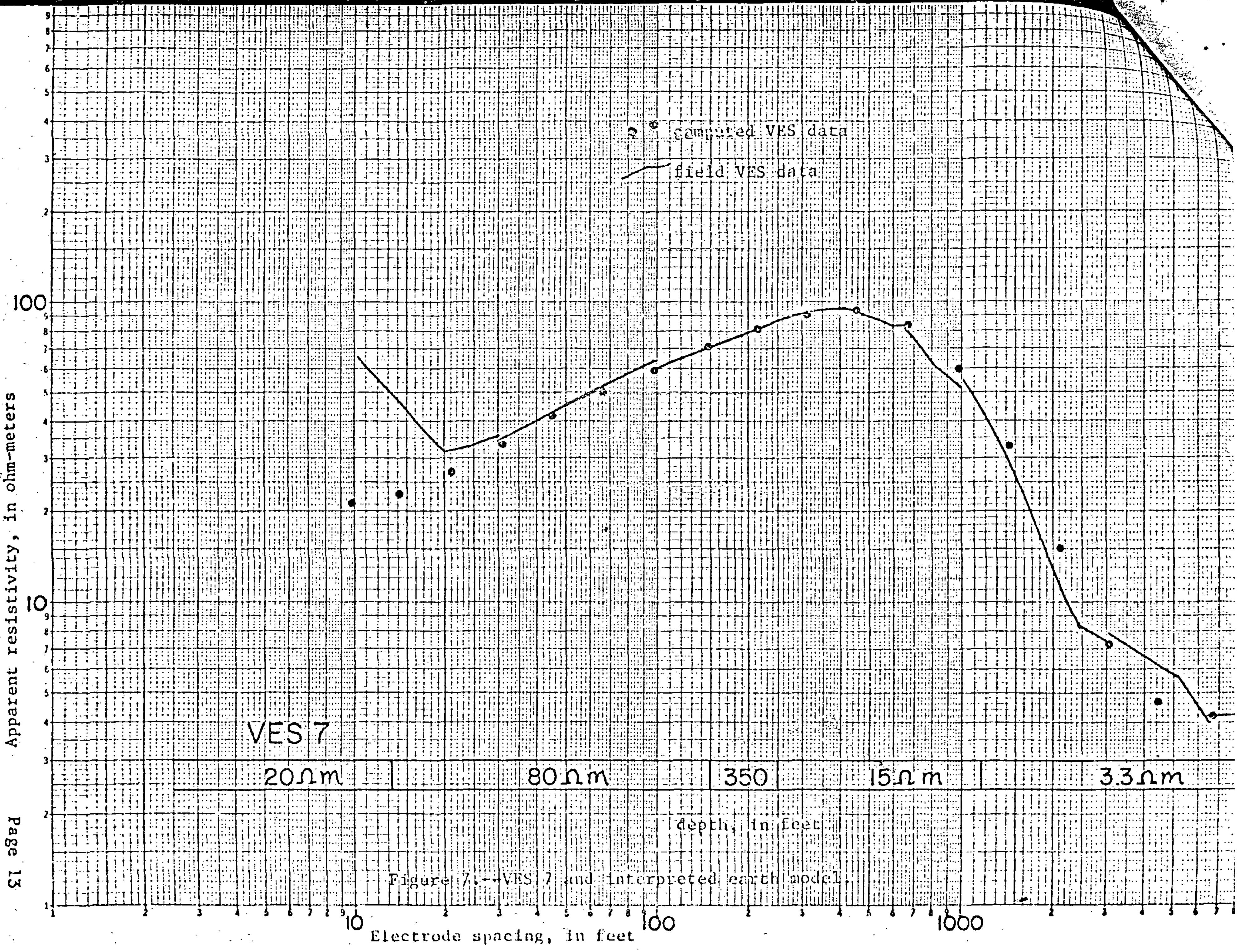

Figure 7.--VES 7 and interpreted earth model.

A cross-section was constructed across the electrical anomaly using the sounding data (fig. 8). Note that the bottom of the conductive body was probably observed only on VES 7, but minimum depth to the bottom was computed from the deep sounding for the area beneath VES 1 and 5. Minimum depth to the bottom of the 12 ohm-meter layer at VES 6 was also computed. The minimum depths are primarily dependent upon the interpreted resistivity for the conductive layer and on the assumed location of a rising terminal branch to the curve (Al'pin, 1966; Zohdy, 1969). Note that the approximate minimum depth to the bottom of the conductive body under VES 1 and 5 is about 15,000 feet. The near-surface, high-resistivity layer (350-570 ohm-meters) shown on the cross-section and models is most likely unaltered volcanic rocks, and the second layer of intermediate values (15-31 ohm-meters) probably represents either Tertiary-Upper Cretaceous sedimentary rocks or altered volcanics. The conductive layer of 2-3 ohm-meters probably represents Great Valley marine sedimentary rocks with pore waters of high salinity and possibly anomalously high temperatures. The Great Valley sequence contains large amounts of marine shales or mudstones and could be quite conductive even without high temperatures.

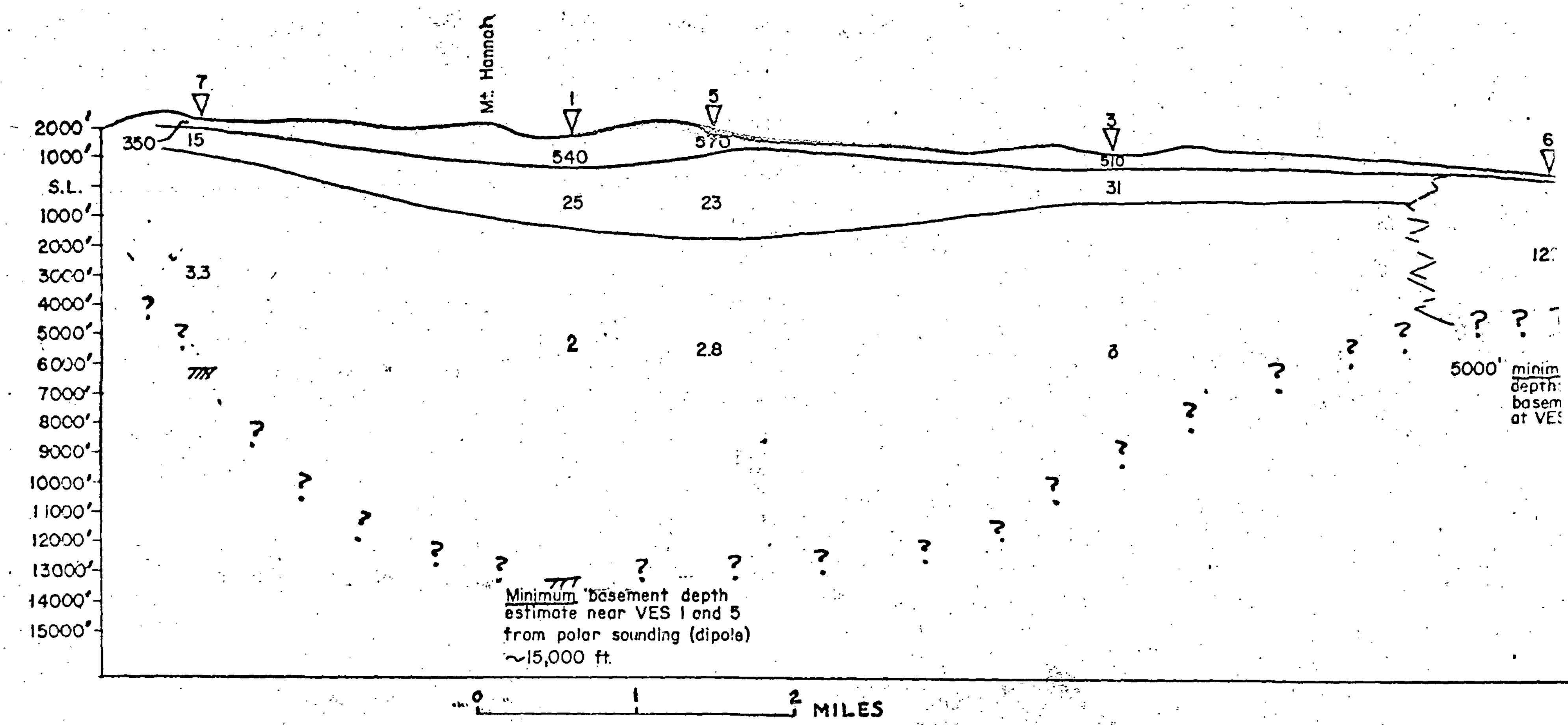

Figure 8.--Geoelectrical cross-section compiled from VES interpretations. Numbers in layers are interpreted resistivities, in ohm-meters.

In order to investigate the electrical properties of the Great Valley sequence, two electrical well logs were obtained. The first of the logs (pl. 9) is from Western Gulf Co. Knowles No. 1 (see pl. 1 for location). This well was drilled through more than 10,000 feet of very shaly Great Valley sedimentary rocks. Resistivities from the 19 foot lateral log are 15-30 ohm-meters for the upper 3,200 feet, 9-12 ohm-meters for the zone from 3,200 to 4,200 feet, and 6-9 ohm-meters from 4,200 to 10,200 feet. Basal units of the Great Valley may have been encountered at about 10,400 feet with resistivities climbing to 20 ohm-meters and more. Maximum mud temperatures were 196°F and formation salinities are not known.

The second log (pl. 10) is from Bailey Mineral Corp. No. 1 (pl. 1), a geothermal steam test which penetrated a zone from 600 to 1,800 feet consisting mostly of gray shales and having an induction log resistivity of 3-6 ohm-meters. This zone is probably equivalent to unit Ia of Swe and Dickinson (1970). Serpentinites were logged from about 1,800 feet to the bottom of the hole at about 3,700 feet and had induction log resistivities of 9-18 ohm-meters. Water samples indicate that the pore waters contain at least 20,000 ppm dissolved solids (D. E. White, U.S. Geol. Survey, written commun., 1972). A thermal log shows temperatures that range from 183°F at 600 feet to more than 270°F below 2,700 feet (D. E. White, U.S. Geol. Survey, written commun., 1972).

Conclusions

A large low-resistivity body centered around Mount Hannah with an extension to the southeast was mapped. The bottom of the body must be at least 15,000 feet below the surface although it was probably detected only at VES 7 on the western edge of the anomaly. The extremely low resistivities could be caused in part by very thick marine sedimentary rocks with warm, saline, pore waters similar to those observed at Bailey Mineral Corp. No. 1. If the material in the resistivity low is not as shaly nor as saline as the material at Bailey No. 1, then it is reasonable to expect even higher temperatures at equivalent depths. The correspondence of the inner part of the gravity low and the resistivity low could be caused by one of two factors or a combination of the two:

1. A thick body of Great Valley sedimentary rocks would have enough density contrast (McNitt, 1968) with the surrounding buried Franciscan masses to account for the magnitude of the inner part (-45 and -50 milligal contours) of the observed gravity anomaly and might explain its shape in relation to the regional faulting.

2. A magma chamber at depth centered under the gravity and electrical lows could be the direct or indirect cause of both anomalies, although we feel that the electrical anomaly and possibly the gravity anomaly are influenced by low density, low resistivity Great Valley sedimentary rocks. We feel that the occurrence of the lowest resistivity values (1-3 ohm-meters) within the center of the gravity low and the Clear Lake volcanic field is evidence that pore waters are warmer there due to abnormally high heat flow.

Acknowledgments

We wish to thank Cordero Mining Co. and Gulf Oil Co. for making well logs available to us and for permission to publish them. The cooperation of land owners and lease holders in the survey area is acknowledged and appreciated.

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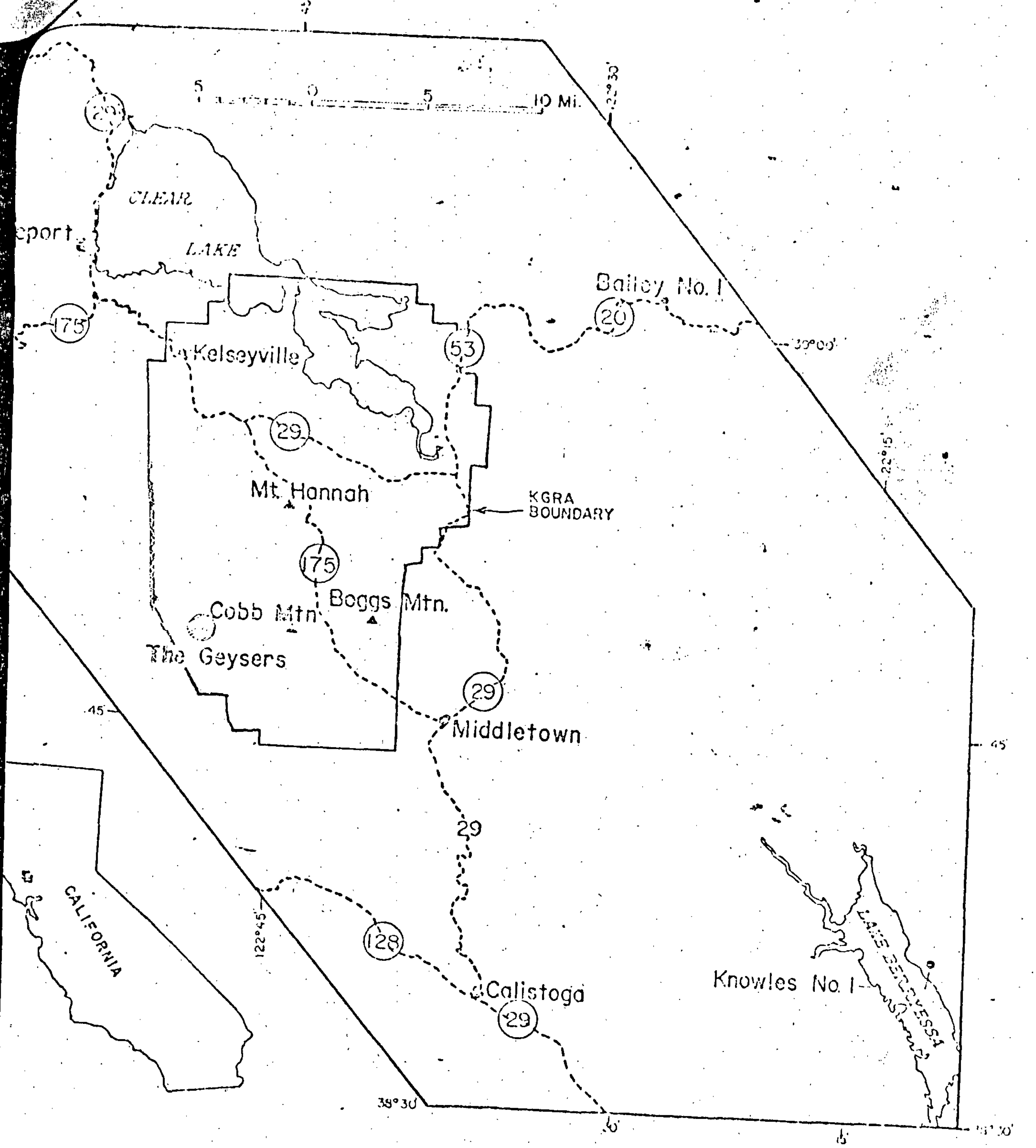

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Fig. 1

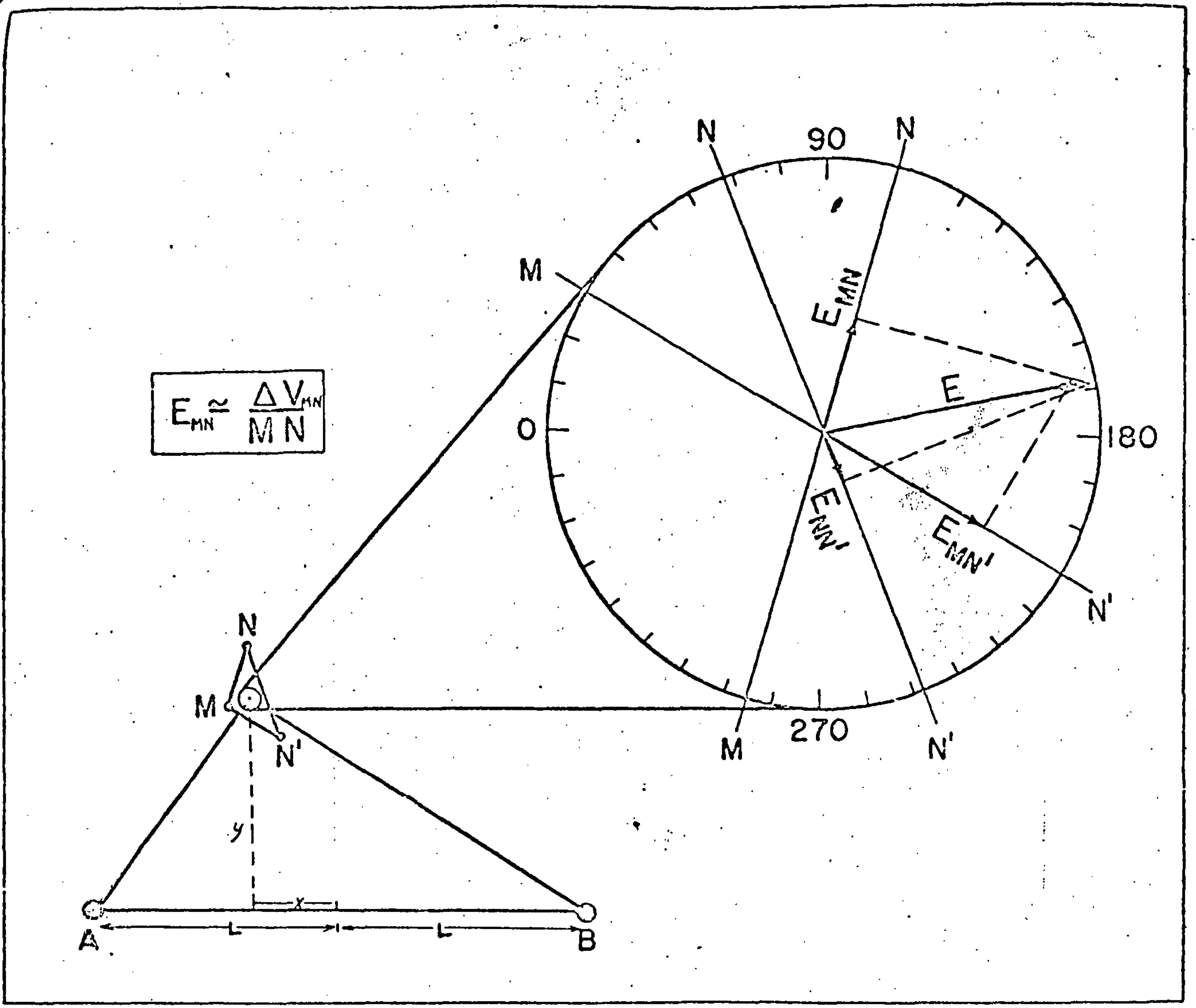


Figure ~~1~~ 3.--Bipole-dipole array. A and B are ground electrodes for the bipole transmitter; M, N, and N' are the potential electrodes used to measure the electric field. In the polar plot, E_{MN}, $E_{MN'}$, and $E_{NN'}$ are the measured electric fields and E the maximum field resolved from these components.

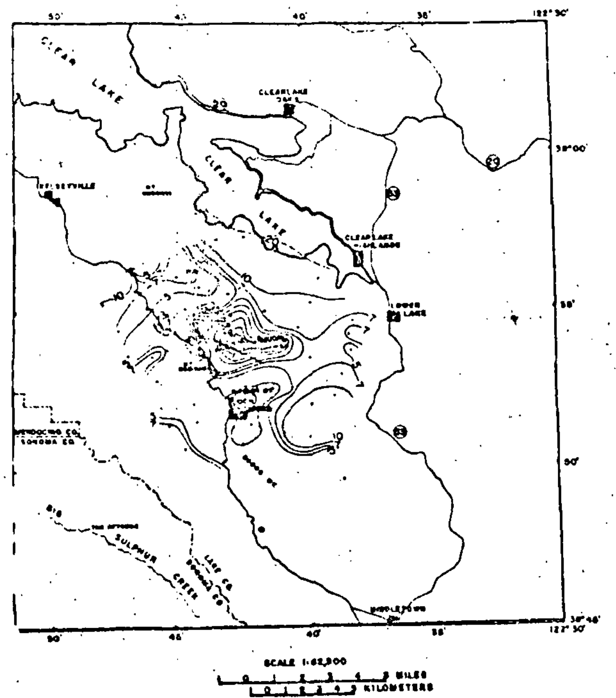

50'
45'
40'
35'
122° 30'
CLEAR LAKE
CLEARLAKE OAKS
20
CLEAR LAKE
CLEARLAKE HIGHLANDS
KELSEYVILLE
LOWER LAKE
38°00'
55'
50'
38°45'
10
5
MENDOCINO CO.
SONOMA CO.
LAKE CO.
SONOMA CO.
BIG SULPHUR CREEK
MIDDLETOWN
SCALE 1:62,500
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS

FIG. 4

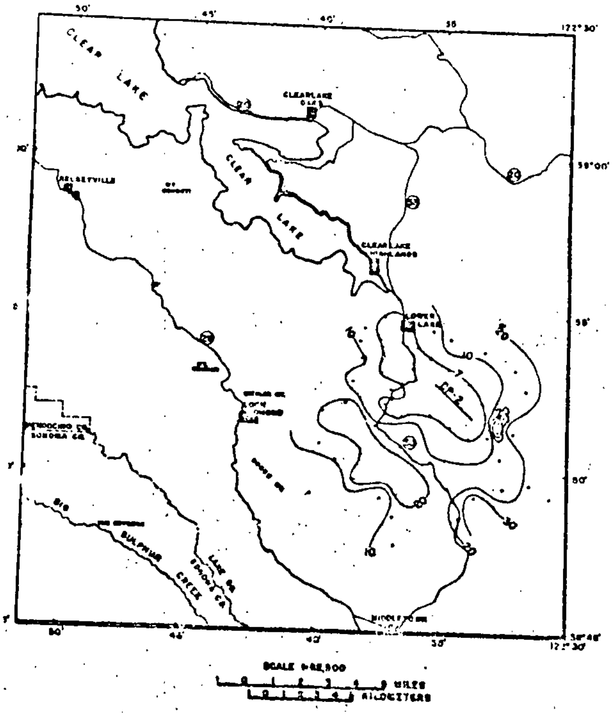

50'
45'
40'
35
122°30'
CLEAR LAKE
CLEARLAKE OAKS
39°00'
KELSEYVILLE
CLEAR LAKE
CLEARLAKE HIGHLANDS
LOWER LAKE
20
10
7
CP-2
20
30
10
MENDOCINO CO.
SONOMA CO.
BIG SULPHUR CREEK
LAKE CO.
SONOMA CO.
MIDDLETOWN
38°48'
50'
45'
40'
35'
122°30'
SCALE 1:62,500
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS

FIG. 5

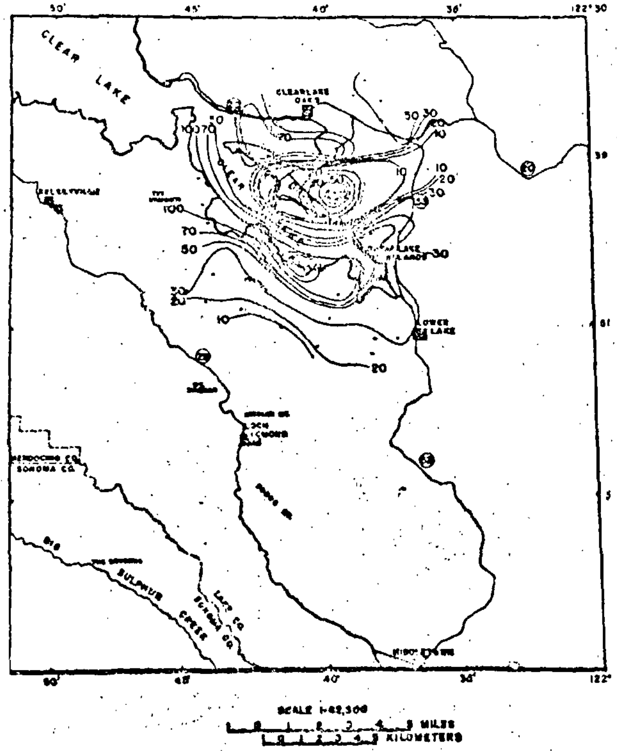

50'
45'
40'
36'
122°30
CLEAR LAKE
CLEARLAKE OAKS
CLEAR LAKE
100
70
50
30
20
10
LOWER LAKE
MENDOCINO CO.
SONOMA CO.
BIG SULPHUR CREEK
LAKE CO.
SONOMA CO.
122°
SCALE 1:62,500
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS

FIG. 6

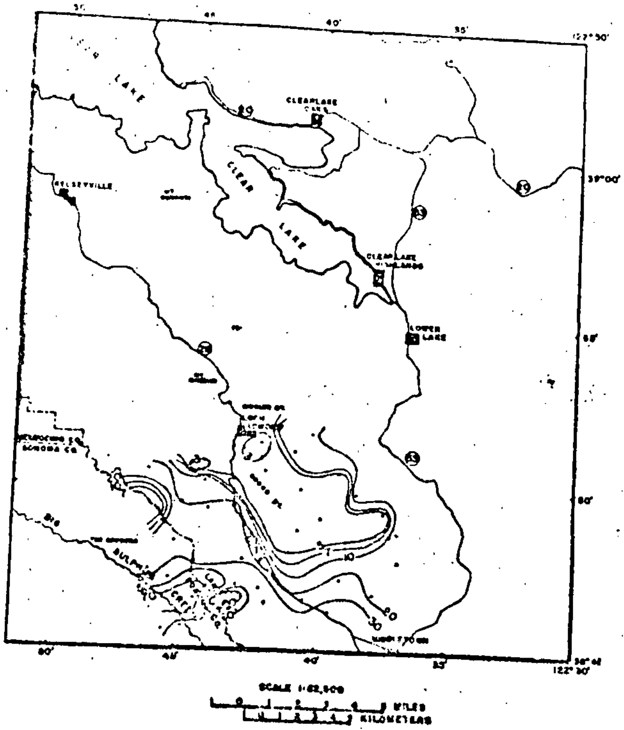

LAKE
29
CLEARLAKE OAKS
CLEAR
LAKE
KELSEYVILLE
39°00'
53
CLEARLAKE HIGHLANDS
LOWER LAKE
55'
29
MENDOCINO CO.
SONOMA CO.
53
50'
BIG
SULPHUR
CREEK
10
20
30
40'
35'
122°30'
SCALE 1:62,500
MILES
KILOMETERS

FIG. 7

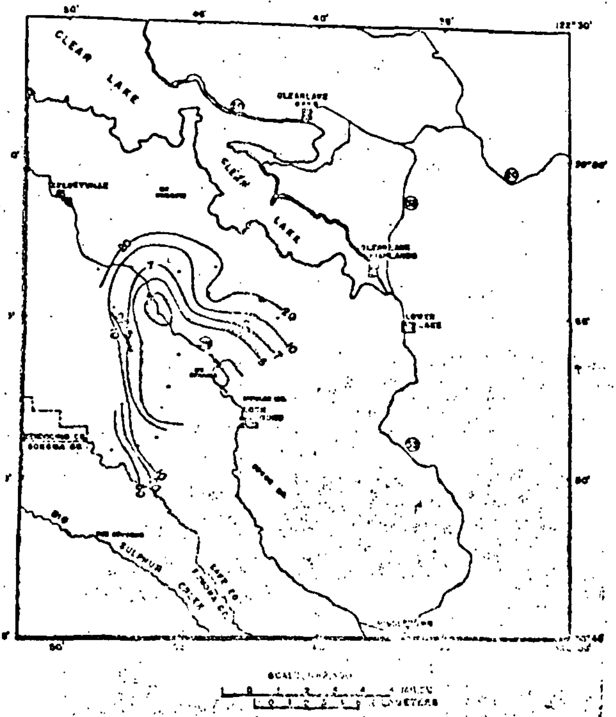

50'
45'
40'
35'
122°30'
CLEAR LAKE
CLEARLAKE OAKS
CLEAR LAKE
CLEARLAKE HIGHLANDS
LOWER LAKE
39°00'
55'
50'
20
10
BIG SULPHUR CREEK
LAKE CO.
SONOMA CO.
MILES
KILOMETERS

FIG. 8

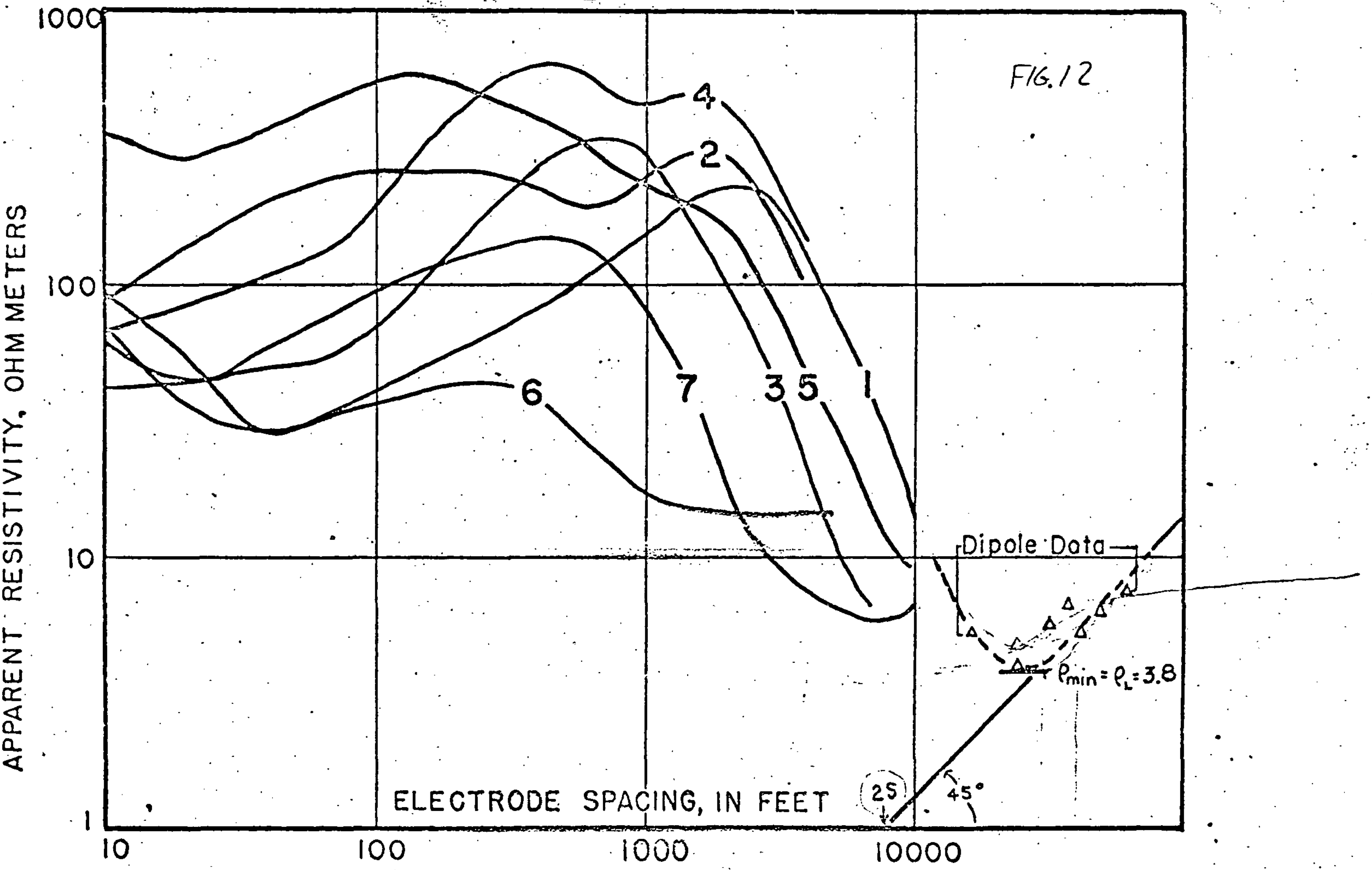


FIG. 12

SCHLUMBERGER SOUNDING CURVES

FIG. 13 Fi

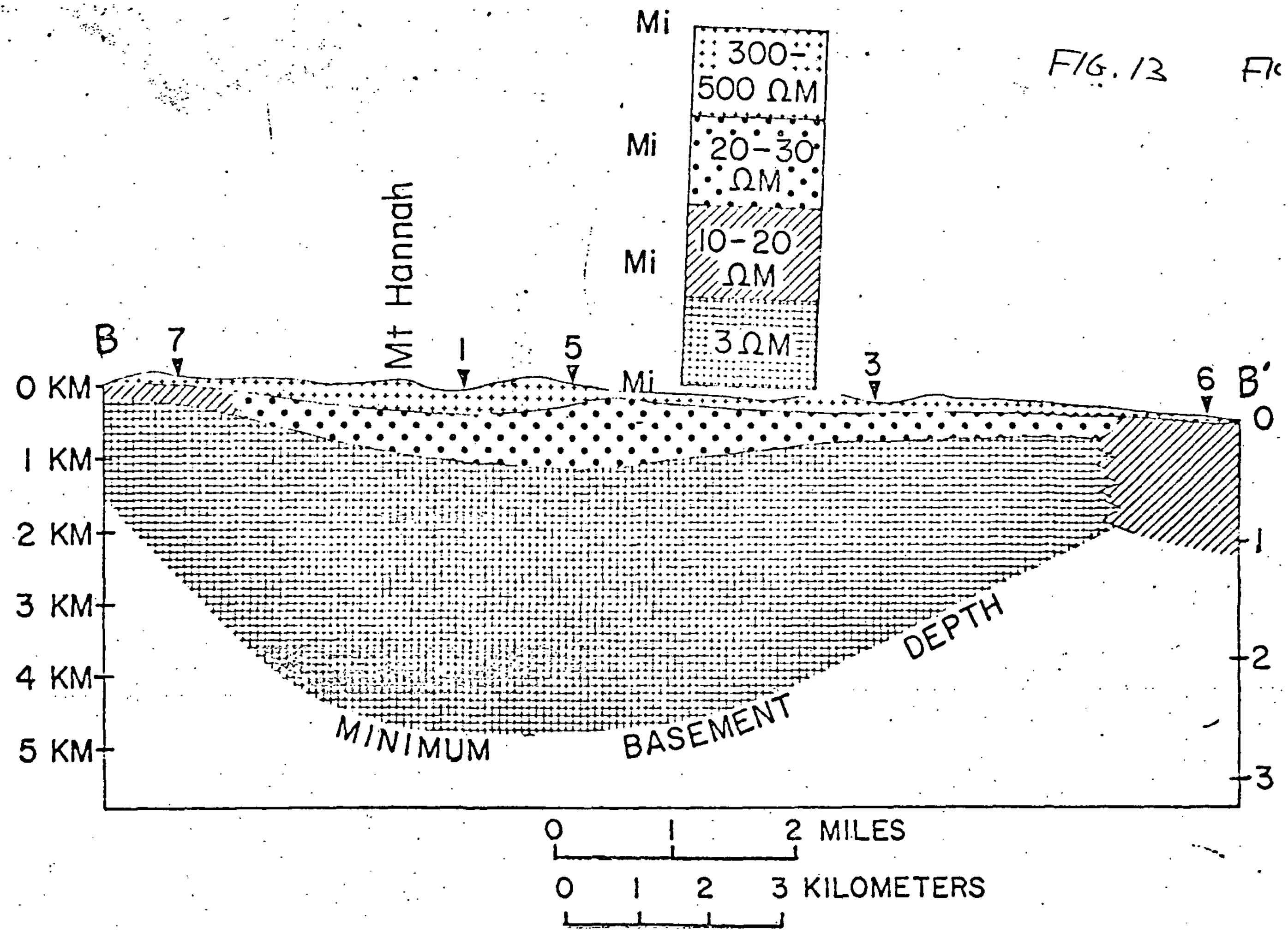
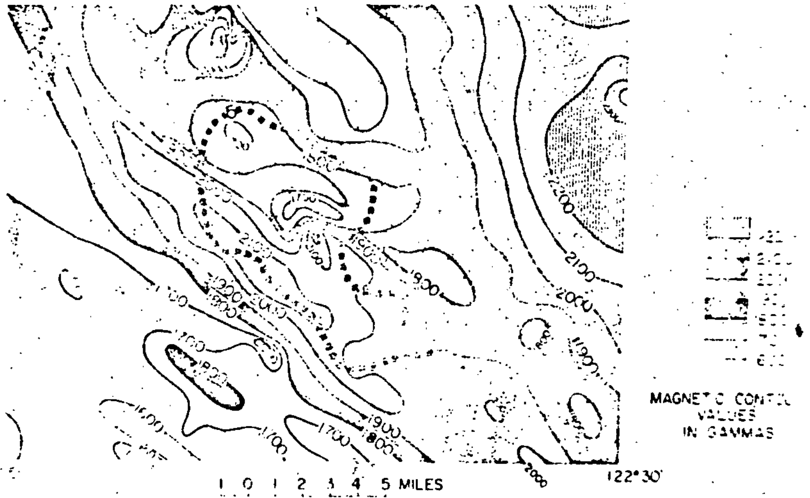


FIG. 13



AEROMAGNETIC MAP OF THE CLEAR LAKE AREA, CALIF

FIG 17c