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EXP/GEOPHYSICS

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MEMORANDUM ON THE DIPOLE-DIPOLE RESISTIVITY RESULTS OVER THE EAST MESA GEOTHERMAL ANOMALY IMPERIAL VALLEY, CALIFORNIA

BY

PHILIP G. HALLOF, PRESIDENT
McPHAR GEOPHYSICS LIMITED

AND

BRUCE S. BELL, GENERAL MANAGER
McPHAR GEOPHYSICS INCORPORATED

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MEMORANDUM ON THE DIPOLE-DIPOLE RESISTIVITY RESULTS OVER THE EAST MESA GEOTHERMAL ANOMALY IMPERIAL VALLEY, CALIFORNIA

In recent years there has been an upsurge of interest in the use of naturally occurring steam and hot water sources for the production of electrical power. Power plants of this type already exist in Iceland, New Zealand, Italy, Mexico and at the Geysers in California. A considerable amount of time and money has been spent in the study of exploration techniques that can be used in exploration programs to locate and outline these "geothermal" deposits.

Most of the areas of interest are located near recent volcanic activity and they are characterized by high surface temperatures and high surface heat flow. Other geophysical measurements, such as seismic noise activity and gravity, have also been found to be useful in certain cases. Of all the conventional geophysical tools, electrical resistivity surveys appear to be the most used, and useful, technique for geothermal exploration. [1]

In most of the field cases reported in the literature, the resistivity survey has been conducted using grounded current and potential electrodes and one of the conventional, large interval, electrode configurations. A few researchers have made resistivity measurements using some electromagnetic technique. (i.e. loop-loop coupling or audio-frequency magnetotelleric determinations). There seems to be some promise in these non-grounded source techniques for reconnaissance resistivity surveys in simple earth geometries, and McPhar is currently developing equipment to be used in this way.

In making conventional resistivity measurements for geothermal exploration, the usual practice has been to use a large, bulky, high-powered source of commutated d.c. current to create the potentials in the earth. The resulting potentials are usually recorded on some type of chart recorder. The current is reversed several times, and natural electrical noise is eliminated by eye or by some sort of computer assisted mathematical analysis of the recorded wave-form.

Due to the size of the necessary equipment and the time necessary to make the measurement, these resistivity surveys have usually been limited to widely separated measurements at specific locations. Information concerning the variations in resistivity with depth is obtained by changing the electrode interval, centered at the measurement location.

The presence of elevated temperatures in the rocks of geothermally active areas almost always results in a decrease in the absolute resistivity level of the rocks. A temperature change of 100°C will cause a resistivity reduction in the order of 250% relative to the cooler surrounding region, [1) Meidev, page 43.] There are many other factors that can affect the resistivity level in a volume of rock (i.e. porosity, salinity, etc.). In practice, no ambiguities from these other parameters create severe problems. Where an outstanding geothermal reservoir does exist, the electrical resistivity across it usually varies by a factor of at least three to ten.

The staff of McPhar Geophysics Ltd. has thousands of crew months of experience in the use of resistivity measurements in exploration for mineral deposits. Since mineral deposits have smaller lateral extent than geothermal deposits and usually occur at shallower depths, most of our past resistivity surveys have been done using relatively short electrode separations (100 feet to 5,000 feet). In doing exploration for geothermal sources, electrode separations of 10,000 feet to 15,000 feet are often necessary.

Our experience has shown us that the Dipole-Dipole electrode configuration has definite advantages in doing general exploration for zones of low resistivity. The short wire lengths necessary for the measurements are easy to handle in the field. When the data is plotted in a "pseudo-section" manner (see Notes), it is possible to separate the effects of vertical resistivity variations from lateral changes. Continuous profiles for four or five values of (N) give complete information concerning the resistivity variations along the line surveyed. If the geometry of the earth is simple enough to be approximated by horizontal layering, curve matching techniques can be used to do quantitative interpretation of the resistivities and thicknesses of the layers.

Our experience in mineral exploration has also indicated to us that it should be possible to use our standard induced polarization and resistivity survey equipment to make large interval resistivity measurements for geothermal exploration. This equipment uses a 5,000 watt, 400 cps motor-generator and a square-wave current source that will transmit up to 5.0 amperes with a maximum voltage of 850 volts. The portable voltmeter is engineered to be very stable and sensitive and has excellent analogue filter and amplifier characteristics. The system will measure voltages of 1.0 millivolts with an accuracy of $\pm$ 0.5% and voltages of 100 microvolts with an accuracy of $\pm$ 5.0%, in the presence of most naturally occurring noise. Each of the electronic packages can be carried by one man; the motor-generator can be carried by one small vehicle.

The lowest standard operating frequency for the system is 0.125 Hz; however, a very simple modification lowers the frequency to 0.05 Hz. At these very low A.C. frequencies the effect of inductive coupling (skin-effect) will be significant only for measurements with very large electrode separations in areas of very low resistivity. It is only rarely that distortions for x = 2,000', N = 5 reach magnitudes of 10% to 20%. In these situations, corrections assuming a uniform earth or a two-layer earth are quite satisfactory to give the correct values. (See Notes).

In the past twelve months, McPhar has completed geothermal resistivity surveys in several areas of the world, including the very low resistivity environment of the Imperial Valley of California. The rate of progress of the surveys, the accuracy of the measurements and the interpretation of the results have confirmed our original assumptions.

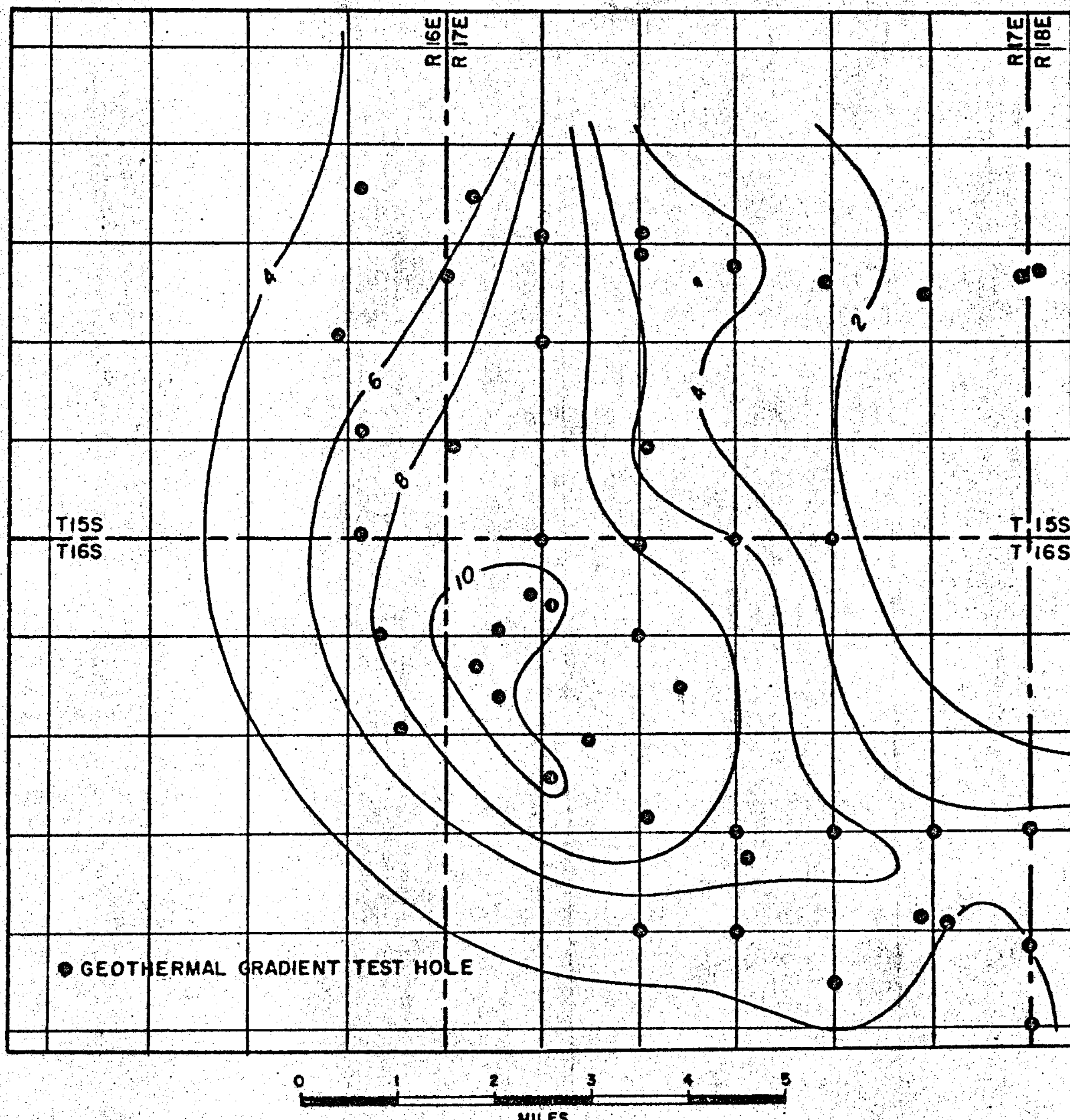
We can publish here some of the results from a survey completed over the East Mesa geothermal anomaly in Imperial County, California. It is centered about 35 miles southeast of the south end of the Salton Sea and about 18 miles due east of El Centro, California. The East Mesa Anomaly has been studied in detail by researchers from the University of California at Riverside and the results have been published [1.), 2.)] .

The center of the geothermal anomaly encloses about two square miles in the extreme north-west corner of T16S, R17E. The heat flow at the surface in this area is about five times that which is normal background in the Imperial Valley (Figure 1). The area of the heat flow high correlates quite closely with a gravity high and with a seismic ground noise high (Figure 2 and Figure 3).

A reconnaissance resistivity survey using the Schlumberger electrode configuration has also been completed in the Imperial Valley. Measurements were made at widely separated points using electrode separations up to 6,000 to 9,000 feet. This data (Figure 4) shows that a weak resistivity low exists at the East Mesa, at the contact between very low resistivity sediments to the west and slightly higher resistivity rocks to the east.

The resistivity anomaly at the East Mesa geothermal anomaly is not large in magnitude, due to the low background resistivity level. At East Mesa, the sediments are estimated to be at least 10,000 feet in thickness; the sands are highly porous and saturated with relatively saline waters.

McPHAR GEOPHYSICS



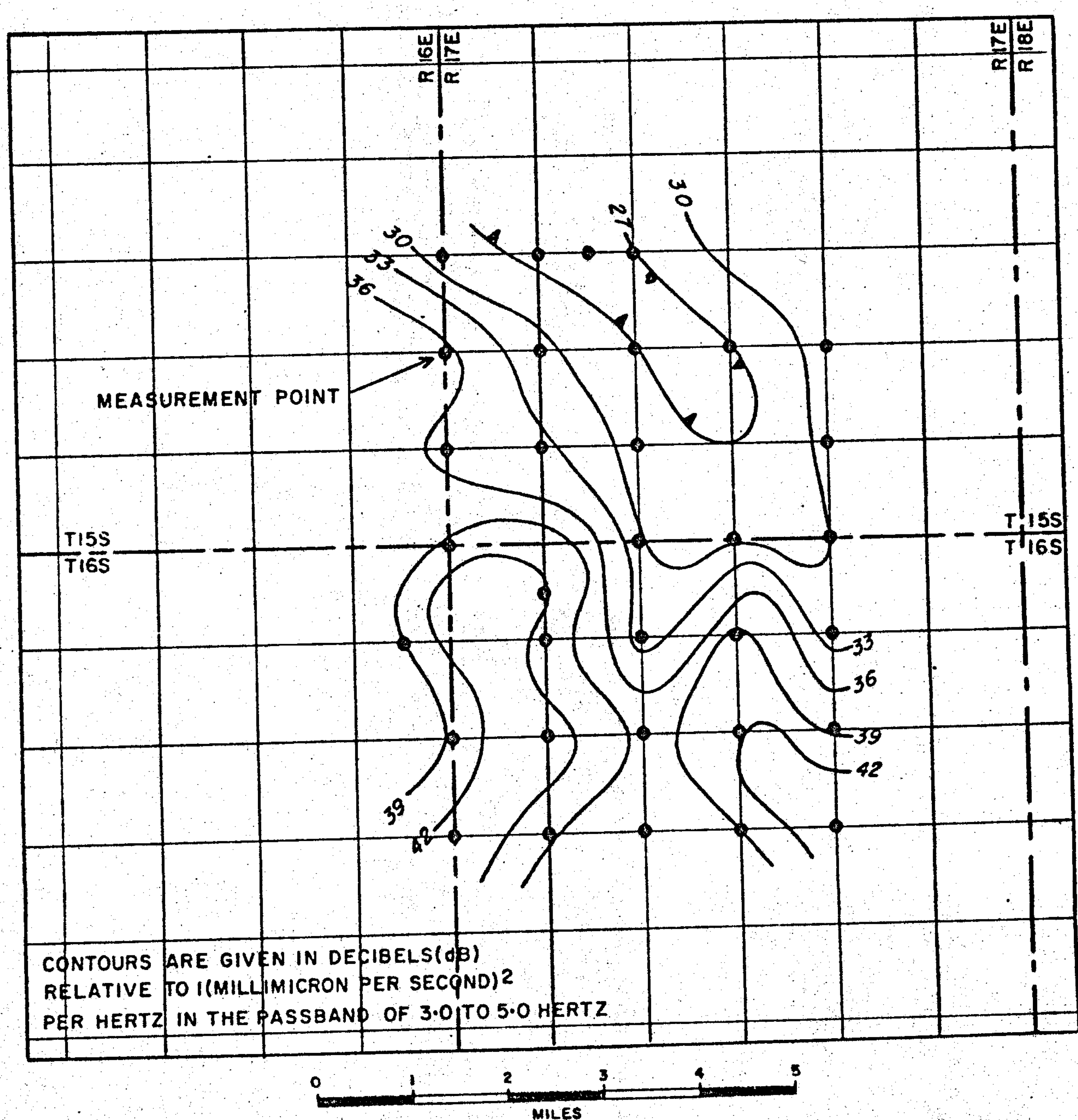
MESA AREA, IMPERIAL COUNTY-CALIFORNIA.

GEOTHERMAL GRADIENTS (°F/100 FEET)

(data from Rex et al 1971)

FIG.

McPHAR GEOPHYSICS



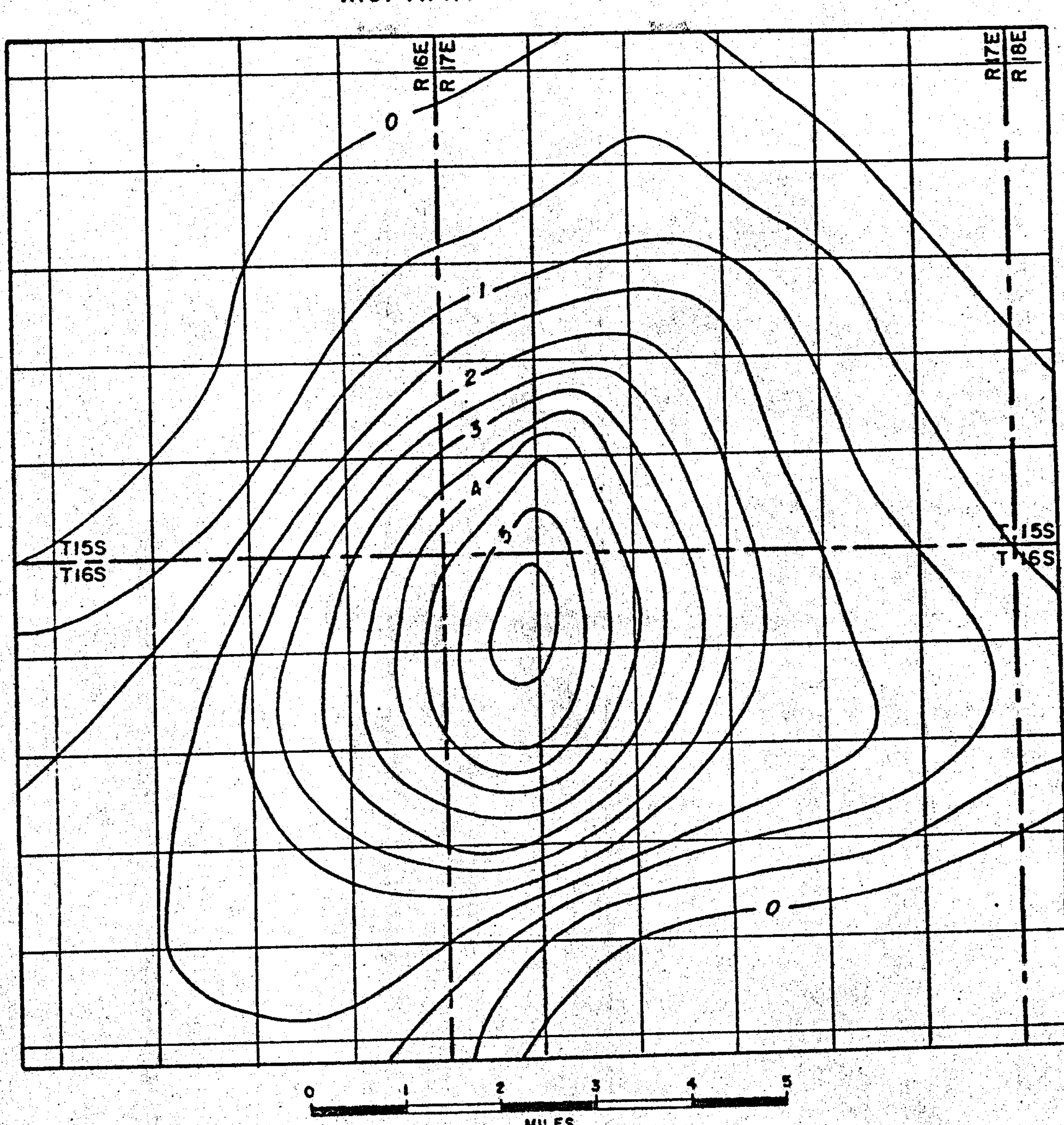
MESA AREA, IMPERIAL COUNTY-CALIFORNIA.

SEISMIC GROUND NOISE

(data from Coombs 1972)

FIG. 2

McPHAR GEOPHYSICS



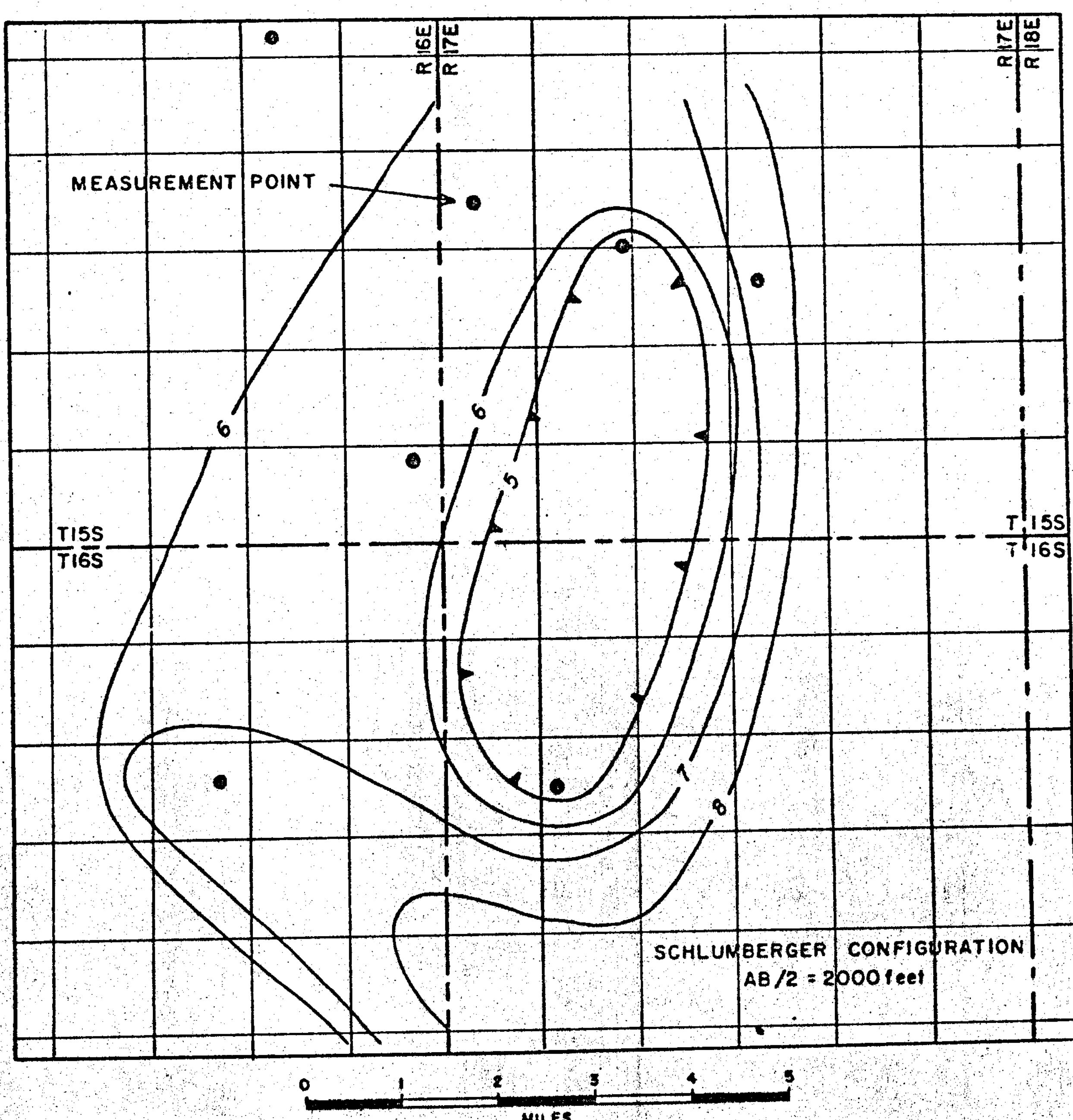
MESA AREA, IMPERIAL COUNTY-CALIFORNIA.

REGIONAL GRAVITY ANOMALY— CONTOUR INTERVAL 0·5 MILLIGALS.

(data from Rex et al 1971)

FIG. 3

McPHAR GEOPHYSICS



MESA AREA, IMPERIAL COUNTY-CALIFORNIA.

APPARENT RESISTIVITY IN OHM-METRES

(data from Rex et al 1971)

Fig 4?

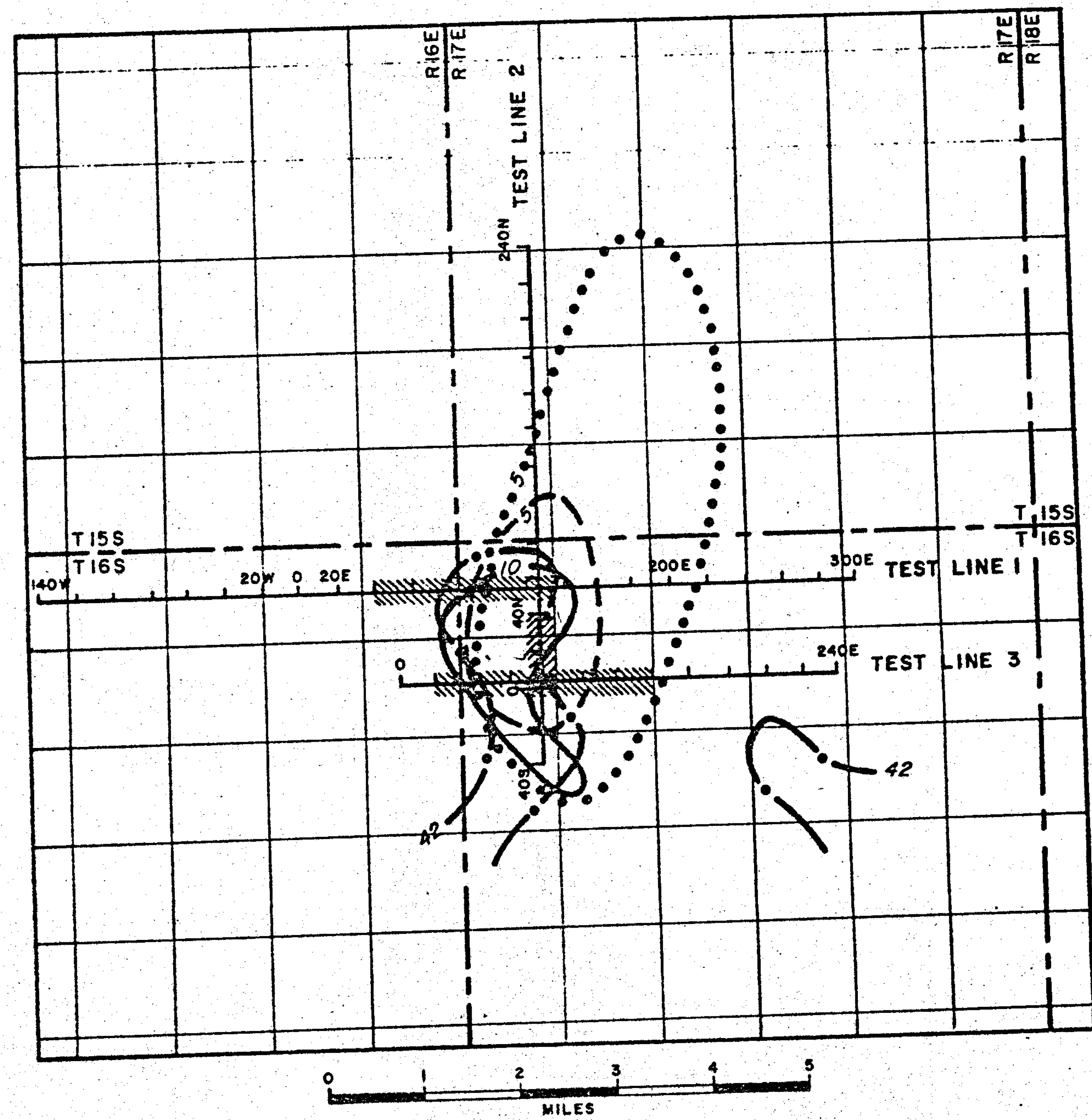
Two deep wells (in excess of 5,000 feet) have been drilled in this area. The well near the center of the heat flow high has temperatures at depths that are approximately 100°F higher than those in a well about two miles to the west.

The very low resistivity level in the Imperial Valley makes the East Mesa geothermal anomaly an excellent location to check the practicality and usefulness of Dipole-Dipole resistivity measurements using standard A.C. resistivity equipment. Test lines were surveyed through the center of the heat-flow high (See Figure 5).

The measurements were made using x = 2,000', N = 1,2,3,4,5 along lines about five miles long. The results have been plotted in our normal "pseudo-section" manner (see Notes) and are shown in Figures 6 - 8. The results have been corrected for inductive coupling effects at 0.125Hz; the corrections range from 1.0% for N = 1 to 35% for N = 5. These corrections are the largest that we have ever had to make; they are a direct result of the extremely low resistivity level. The results shown in Figures 6 - 8 indicate a distinct resistivity low, at depth, that correlates with the East Mesa geothermal high. The details of the resistivity low can be seen much more clearly in the Dipole-Dipole data than from the reconnaissance survey.

Even in the low resistivity environment of the Imperial Valley, Dipole-Dipole resistivity measurements can be accurately made. The low resistivity zone, with a contrast of about four to one relative to background, is quite distinct. Under these ideal conditions of easy access, flat topography and excellent ground contacts for current electrodes, survey progress of five to six miles per day can be expected. This type of resistivity survey will therefore be of assistance in geothermal exploration.

McPHAR GEOPHYSICS



MESA AREA, IMPERIAL COUNTY - CALIFORNIA

TEMPERATURE GRADIENT HIGH (FIG. 1)

SEISMIC NOISE ACTIVITY (FIG. 2)

APP. RESISTIVITY LOW (FIG. 4)

GRAVITY HIGH (FIG. 3)

LATERAL EXTENT OF RESISTIVITY LOW AT DEPTH

FIG.

EAST MESA GEOTHERMAL ANOMALY

IMPERIAL COUNTY, CALIFORNIA

TEST LINE 1

Frequency – 0·125 Hz. Values corrected for inductive coupling

$\rho / 2\pi$ in ohm-feet = (ρ in ohm-metres) x 0·52

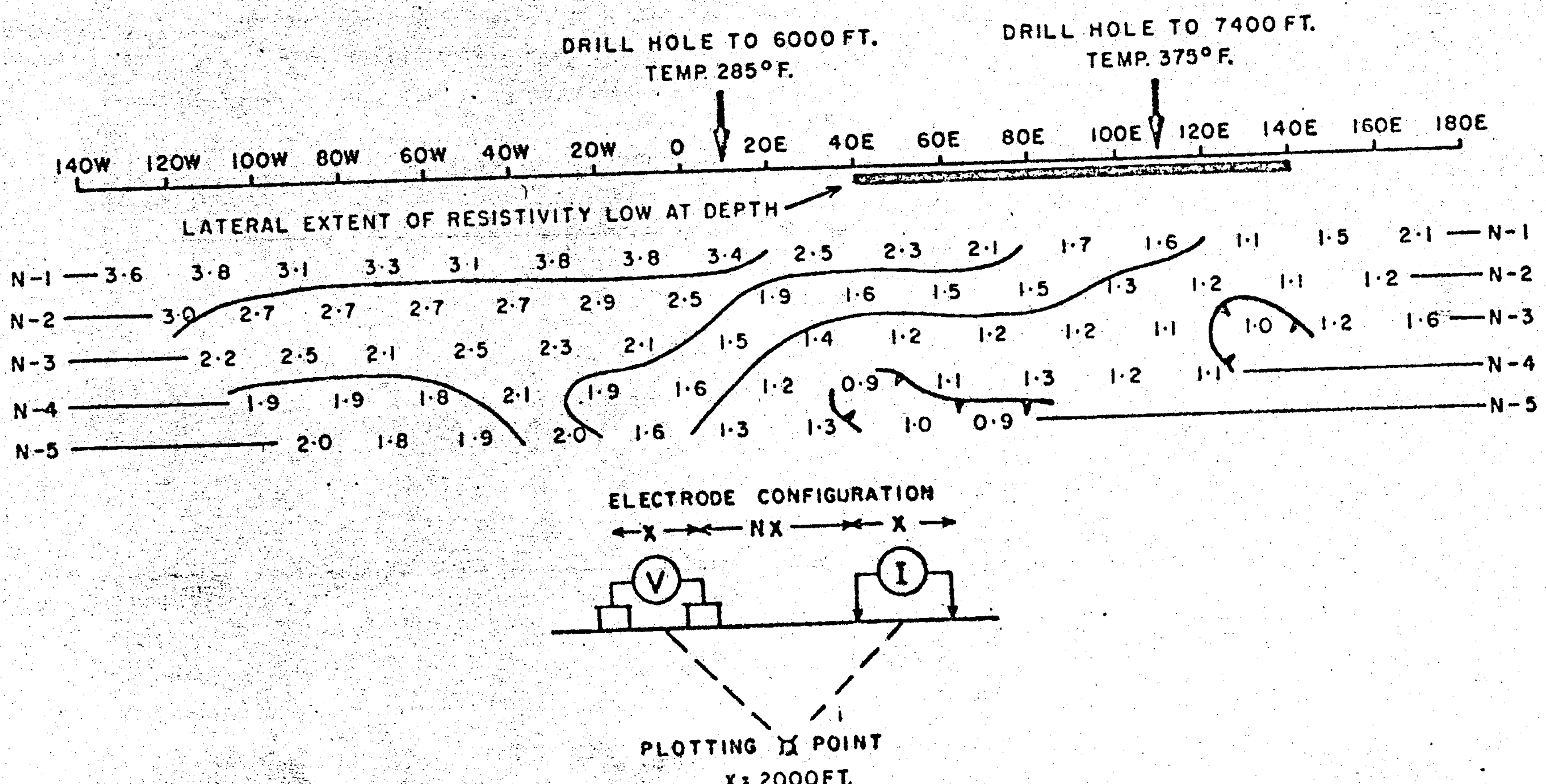


FIG. 6

EAST MESA GEOTHERMAL ANOMALY

IMPERIAL COUNTY, CALIFORNIA

TEST LINE 2

Frequency - 0·125 Hz. Values corrected for inductive coupling

$\rho / 2\pi$ in ohm-feet = (ρ in ohm-metres) x 0·52

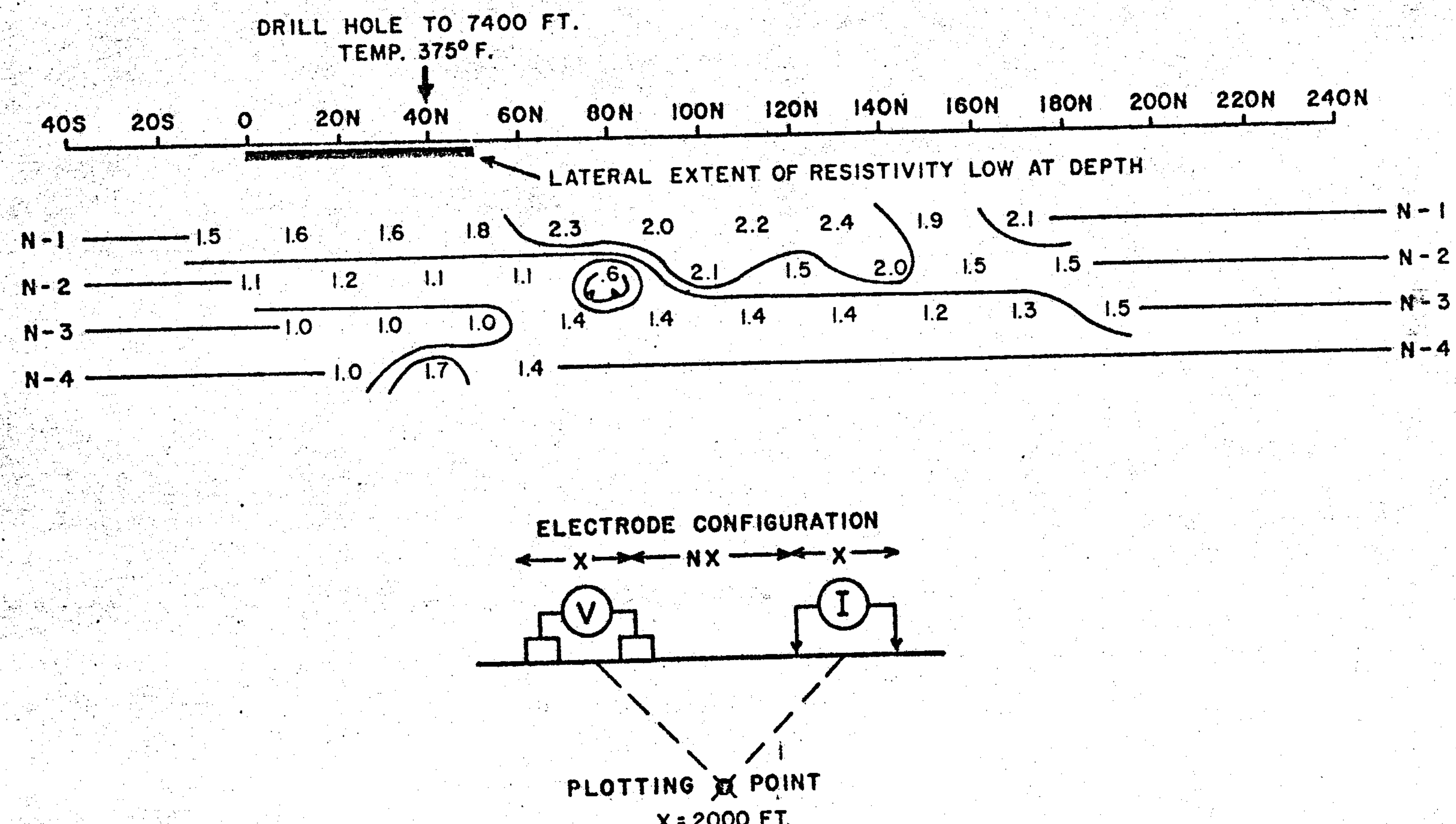


FIG. 7

EAST MESA GEOTHERMAL ANOMALY

IMPERIAL COUNTY, CALIFORNIA

TEST LINE 3

Frequency – 0·125 Hz.   Values corrected for inductive coupling

$\rho / 2\pi$ in ohm-feet = (ρ in ohm-metres) x 0·52

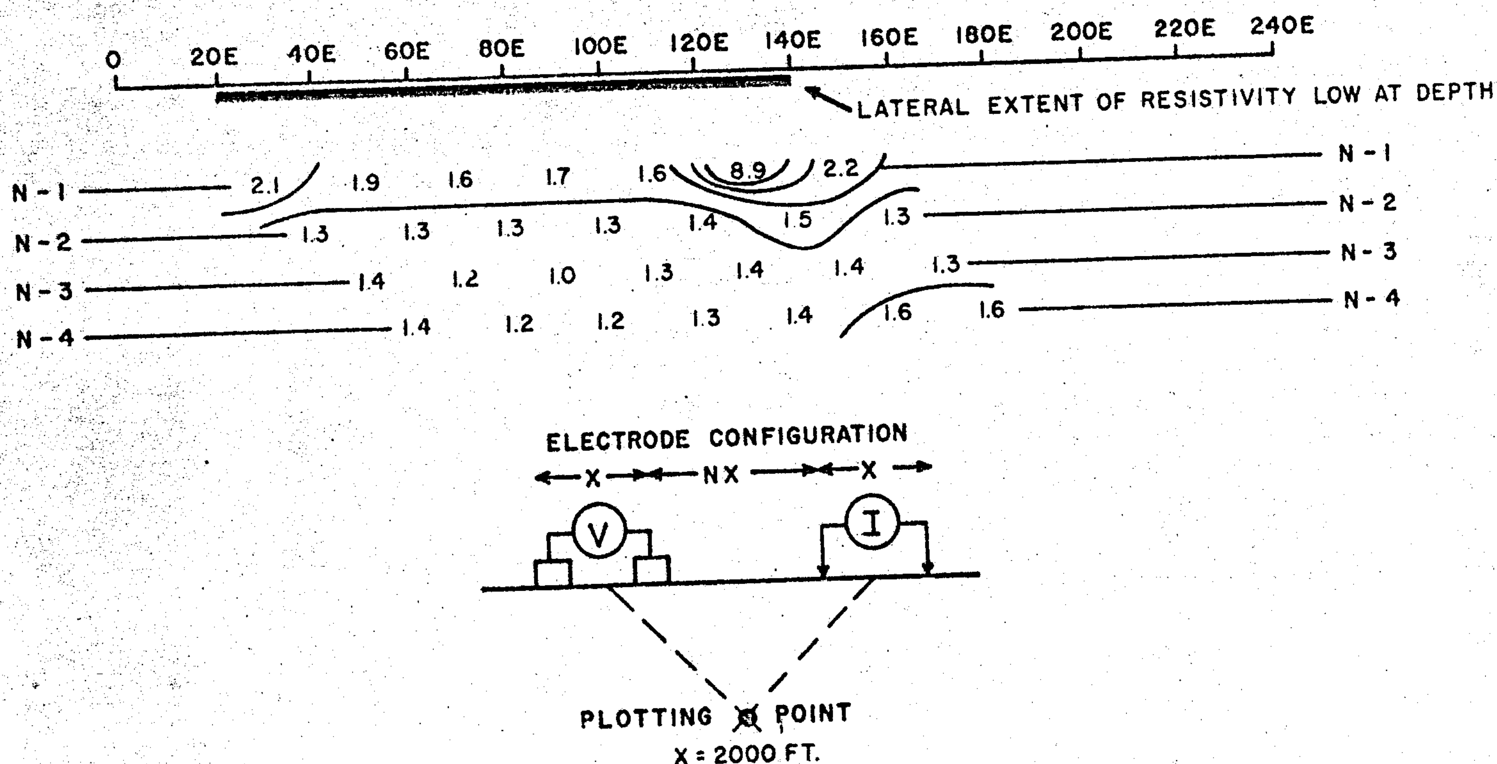


FIG. 8

References:

1.) Rex, R.W. (Principal Investigator); Babcock, E.A.; Beihler,S.; Combs, J.; Coplen, T.C.; Aders, W.A.; Furgerson, R.B.; Garfunkel, Z.; Meidev, T.; and Robinson, P.T. of University of California, Riverside, July 1, 1971.

"Co-operative Geological-Geophysical-Geochemical Investigations of Georesources in the Imperial Valley of California"

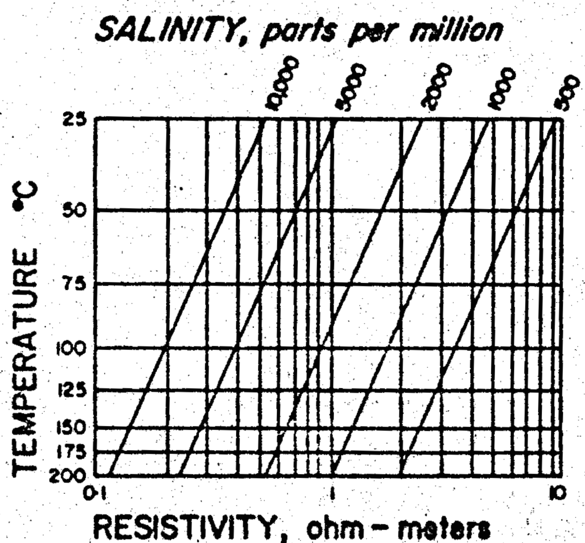
2.) Combs, Jim; "Review and Discussion of Geothermal Exploration Techniques" (1972) First Conference of the Geothermal Resources Council.

NOTES ON GEOTHERMAL EXPLORATION

USING THE RESISTIVITY METHOD

Many geophysical methods have been tried in the exploration for geothermally "hot" areas in the upper regions of the earth's crust. The only method that has been consistently found to be successful has been the resistivity technique. In this geophysical method, the specific resistivity (or its reciprocal, the specific conductivity) of the earth's subsurface is measured during traverses over the surface.

The principle of the technique is based on the fact that the resistivity of solution-saturated rocks will decrease as the salinity of the solutions is increased and/or the temperature of the system is increased (see Figure 1). Therefore, volumes of the earth's crust that contain abnormally hot and saline solutions can often be detected as regions of low resistivity.



VARIATIONS OF SOLUTION RESISTIVITY WITH TEMPERATURE AND SALINITY

FIG. 1

The resistivity measurements are usually made using grounded current and potential electrodes, but some useful data can sometimes be obtained using electromagnetic techniques. The field data shown on plan maps in Figure 2 are from the Broadlands Area in New Zealand; in this area there are substantial flows of hot water and steam at the surface.

The results show resistivity lows measured with a Wenner Configuration Resistivity Survey and a loop-loop electromagnetic survey. The anomalous pattern is much the same in both cases and the regions of low resistivity correlate well with the areas of increased rock temperature.

If the rock volume saturated with hot solutions does not extend to the surface it will be necessary to use large electrode intervals to detect the resistivity lows. The resistivity data shown in "pseudo-section" form in Figure 3 is from Java. Along this line there are two deep regions of low resistivity detected for the larger electrode intervals used. Zone A is associated with surface manifestations of geothermal activity. The source of the resistivity low at Zone B is unknown.

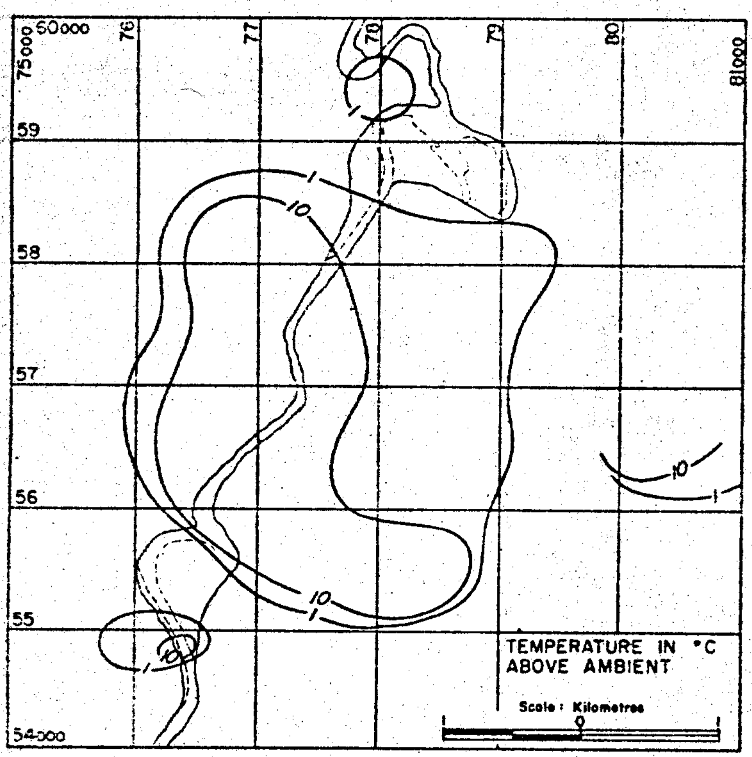
If the abnormally hot region occurs in a sedimentary basin, the general resistivity level can be quite low, due to the high porosity in normal sediments. This is the case in the Imperial Valley of California. The resistivities shown in Figure 4 are from an area near El Centro, California. The largest electrode separation used was 12,000 feet.

The results show a two-layer geometry with the upper layer having a thickness of approximately one-half electrode interval (i.e. 1,000 feet). The resistivity in the upper layer is 3.0 ohm-meters; the resistivity of the lower layer is 1.5 ohm-meters. Due to the small resistivity contrast, additional measurements would be necessary to determine the possible geothermal importance of the lower resistivity layer at depth.

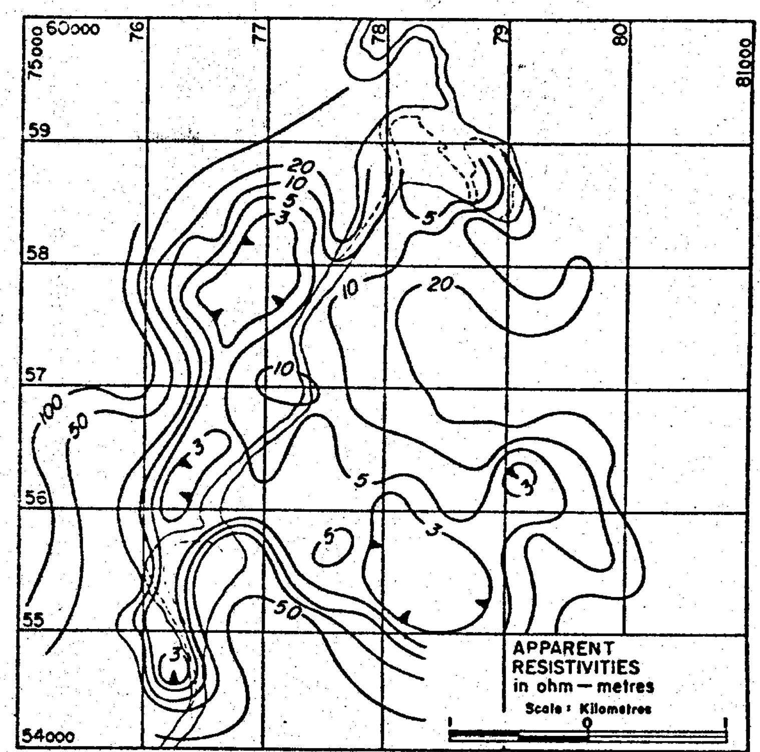
The results shown in Figure 4 are from a dipole-dipole electrode configuration survey. Our dipole-dipole data is plotted as a "pseudo-section" for several values of n; the separation between the current electrodes and potential electrodes, as well as the location of the electrodes along the survey line, determine the position of the plotting point. The two-dimensional array of data is then contoured (see below). The contour plots <u>are not</u> sections of the electrical properties of the earth; they are convenient

GEOPHYSICAL SURVEY

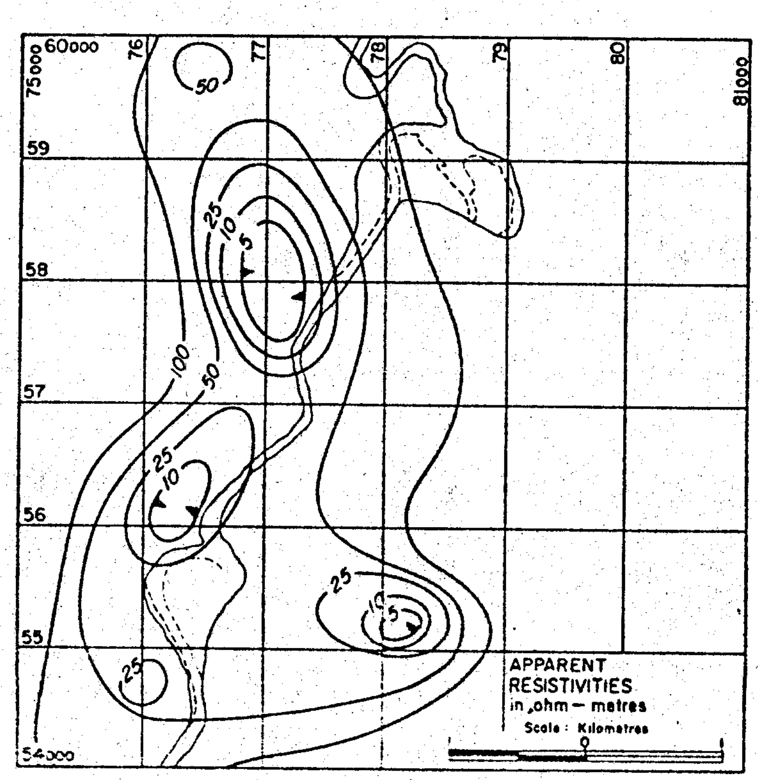
BROADLANDS AREA, NEW ZEALAND



A. TEMPERATURE AT 15m DEPTH



B. APPARENT RESISTIVITY SURVEY USING WENNER CONFIGURATION A = 180m.



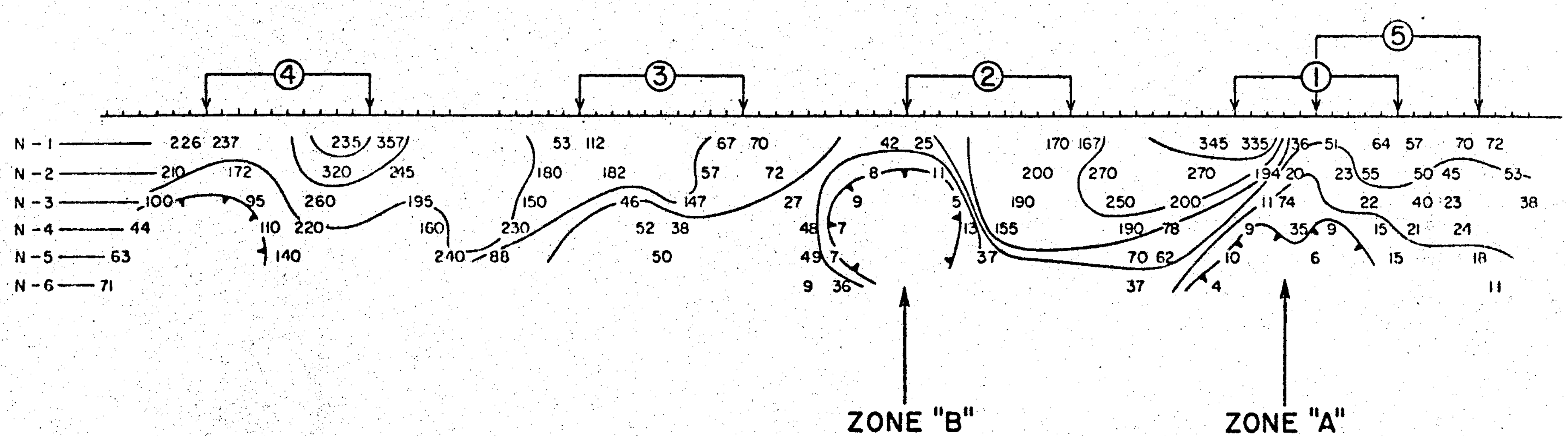
C. APPARENT RESISTIVITY SURVEY USING LOOP TO LOOP ELECTROMAGNETIC METHOD

COIL SEPARATION = 65metres FREQUENCY = 440 Hz

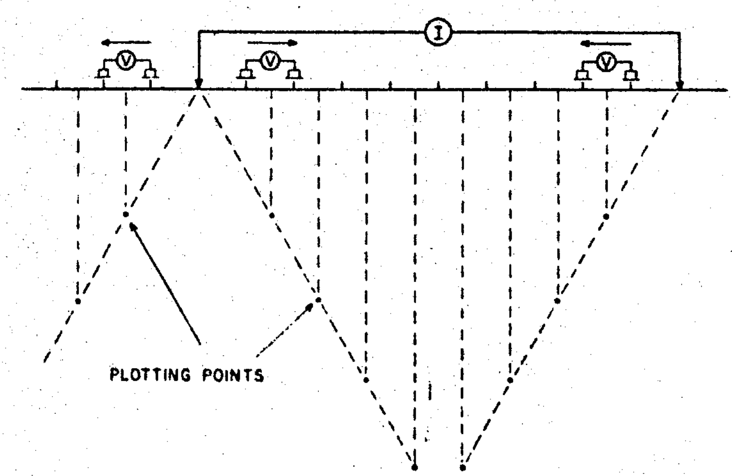
FIG. 2

APPARENT RESISTIVITY SURVEY, DIENG PLATEAU AREA, JAVA, INDONESIA

Pseudo Section Plotting Method Along Dieng–Bator Road



ELECTRODE CONFIGURATION AND PLOTTING POINTS



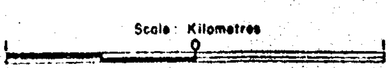


FIG. 3

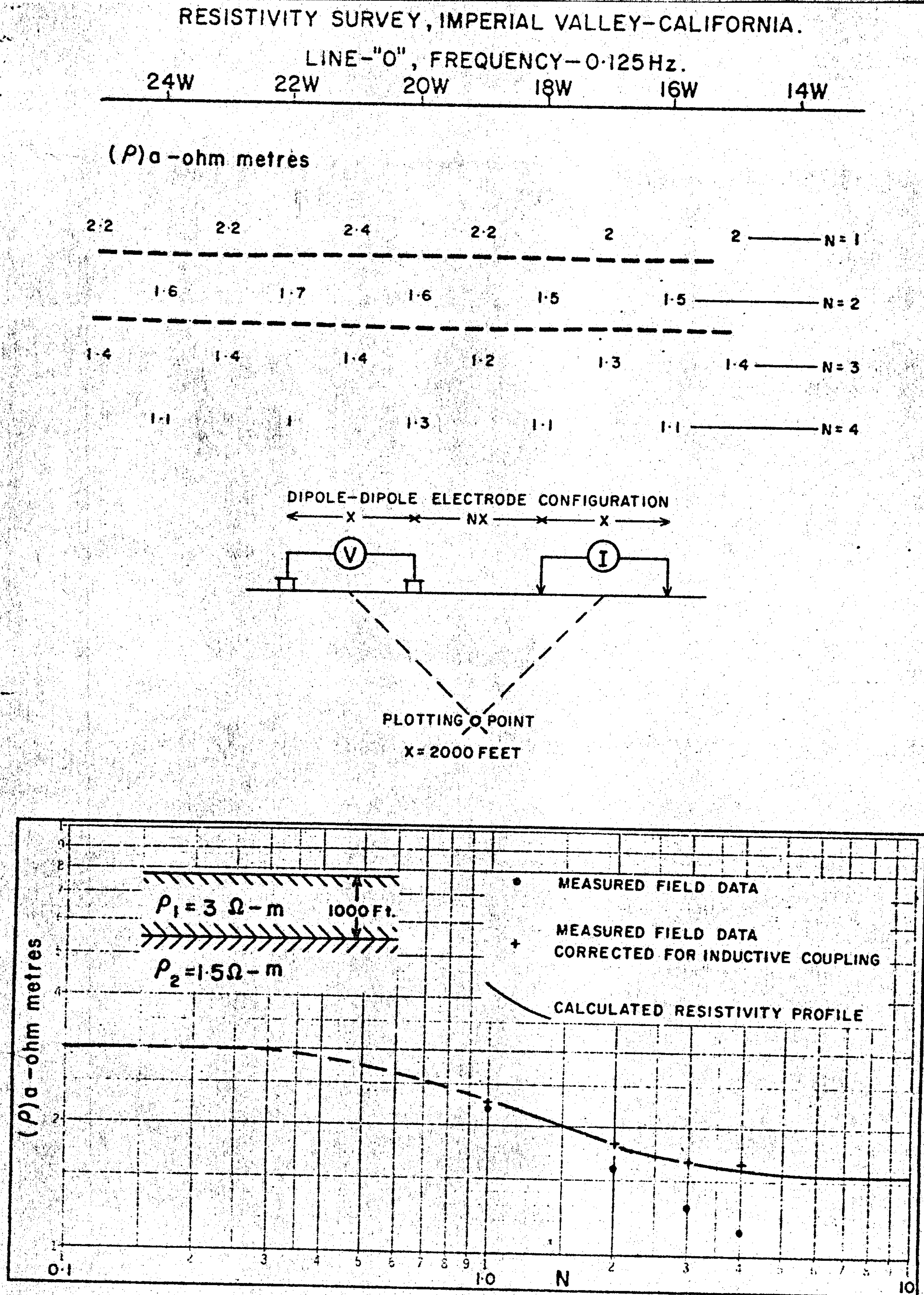

RESISTIVITY SURVEY, IMPERIAL VALLEY-CALIFORNIA.
LINE-"O", FREQUENCY-0·125 Hz.
24W 22W 20W 18W 16W 14W
(ρ)a -ohm metres
2·2 2·2 2·4 2·2 2 2 N = 1
1·6 1·7 1·6 1·5 1·5 N = 2
1·4 1·4 1·4 1·2 1·3 1·4 N = 3
1·1 1 1·3 1·1 1·1 N = 4
DIPOLE-DIPOLE ELECTRODE CONFIGURATION
X NX X
V
I
PLOTTING POINT
X = 2000 FEET
ρ1 = 3 Ω-m
1000 Ft.
ρ2 = 1·5 Ω-m
MEASURED FIELD DATA
MEASURED FIELD DATA CORRECTED FOR INDUCTIVE COUPLING
CALCULATED RESISTIVITY PROFILE
(ρ)a-ohm metres
0·1
1·0
N
10

FIG. 4

graphical representations of the measurements made. However, with experience the contour patterns can be interpreted to give some information about the source of the anomaly.

If the contour patterns indicate very simple geometries, more quantitative interpretations can often be made. For instance, if the contours are horizontal for a lateral distance of four to six electrode intervals, a horizontally layered geometry is indicated. In this situation, theoretical type-curves for dipole-dipole measurements in a layered geometry can be used in "curve fitting" techniques to give the true resistivities and depths for the earth.

DIPOLE-DIPOLE PLOTTING METHOD