ELECTRICAL CHARACTERISTICS OF THE SURFACE OF PRICE MOUNTAIN

by

Robert Alvin Whitehorne

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APPROVED:

Louis A. Pardue

Director of Graduate Studies

E. B. Norris

Dean of Engineering

APPROVED:

W. A. Murray

Head of Department

W. A. Murray

Major Professor

1951

Blacksburg, Virginia

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I. Introduction and Objectives

The establishment and maintenance of good electrical grounds is one of the most important problems that faces the commercial power companies today. Proper grounds are essential if continuity of service is to be maintained with varying weather conditions and also to insure the personal safety of company employees and customers. The problem of grounding is extremely important in regions such as we have in the vicinity of Blacksburg, Virginia, because the structure of the soil is such that it posesses a very high resistivity or specific resistance, hence good grounds are harder to locate. In this thesis the author will attempt to coordinate the results of geophysical prospecting (with electrical instruments) with the proper location and grounding scheme of a commercial power line.

A. Statement of the General Problem

The introduction to the importance of grounding can probably best be made by considering the effects of a lightning strike on or near an exposed transmission line. Naturally a direct strike is of greater hazard but induction voltages due to strikes near existing lines also account for transmission difficulties. A conservative method of estimating the voltage across the insulation at a given transmission tower is that the said voltage is equal to the product of the lightning current in the tower and the tower footing resistance. (20)* Hence the reduction of the tower footing resistance offers the most feasible method of controlling and reducing the voltage across the insulation. The natural tower footing resistance varies between wide limits, from a few ohms in some regions to several thousand ohms in other regions. The problem of reducing the tower footing resistance essentially becomes one of compromise between sustained system operation and system economy. The two most important methods of reducing footing resistance are by driving ground rods near the base of the towers and connecting them to the towers or by burying counterpoise wires in the earth between towers and connecting them to the towers. As a rule, the counterpoise is resorted to only when the desired value of footing resistance cannot be obtained by other means because the counterpoise system, though very effective, is very expensive. This paper will deal only with methods of reducing the footing resistance in a high resistance region when geophysical methods may be used to determine the approximate electrical characteristics of the surface strata of the region. These surface characteristics can be determined by a series of tests made by using a coordinated system of grounding arrangements with standard grounding rods.

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* The item, (20), refers to the number of the entry in the Bibliography given at the end of this paper.

B. Historical Background

1. Government Investigations

a. "Ground Connections for Electrical Systems", by O. S. Peters, Assistant Physicist, United States Bureau of Standards. (26)

This treatise on "Ground Connections for Electrical Systems" is probably the most widely distributed document of its type available today. Although written quite a few years ago, the research methods and the conclusions reached have not changed to a great extent. The purpose of the paper was to coordinate the methods used and the results obtained by the various commercial power companies in attempting to solve their individual grounding problems. This analysis was expected to reveal new solutions to the overall problems of system grounding and circuit protection. The author established various types of grounds in all parts of the country and conducted tests on them for periods of as long as one year in order that a relatively true picture of the effectiveness of the grounds could be obtained.

One of the most important facts that the author reveals in the paper is that the study of grounding principles does not allow an exact mathematical solution. For a person well acquainted with mathematical physics, it is relatively simple to arrive at an equation which under certain conditions will represent the true condition of the resistance between a metallic body in the earth and the earth itself. However, when an attempt is made to apply the equation practically to a large number of grounds, it becomes apparent that there are too many variables depending on such factors as the moisture content of the soil, the temperature of the soil, the lack of uniformity in the soil structure, and the effects of nearby electrical structures. The paper illustrates the many factors that have a direct bearing on the effectiveness of a ground connection and it is in this respect that the paper derives its wide acceptance by practicing engineers.

b. "Results of Electrical Resistivity and Induction Measurements at Abana Mine, Quebec, Canada", by E. V. Potter, United States Bureau of Mines. (27)

This paper was written as a result of one of the first efforts to use electrical instruments in geophysical prospecting. At the Abana Mine, the author laid out a system of coordinates and sought to determine by resistivity measurements whether there was any correlation between these measurements and the type and quality of the ore present. The author was unique in his arrangement of the measuring equipment, and although at the time his results were not very conclusive, a similar procedure today using modern instruments would no doubt reveal valuable information. In making the induction measurements, again the author was limited by the equipment available, but again the author was ahead of his time in technique.

c. "How to Compute Tables for Determining the Resistivity of Underlying Beds and their Application to Geophysical Problems", by Irvin Roman, United States Bureau of Mines. (310)

This paper was written in an attempt to illustrate the possibility of mathematical and statistical analysis of tests results being used to determine the resistivity in areas where it was difficult to conduct tests. The method is very useful when a considerable number of tests results are available and the surface geology of the region where the resistivity of the beds is desired is well known. The present day application of this type of statistical analysis is largely limited to the field of Petroleum Geology.

d. "Geology of the Appalachian Valley in Virginia", by Charles Butts, Virginia Geological Survey. (12)

This publication was issued by the Virginia Conservation Commission and represents the results of a lifetime of research and study by Doctor Butts. It is now a standard reference for geological study of the Appalachian Valley which is a tribute to its value. The publication is complete with plates illustrating the fossils found in the region, and numerous photographs of actual strata beds are included. The publication is very complete with respect to the regions near the town of Blacksburg, Virginia, especially the two most important geological landmarks, Brushy Mountain and Price Mountain. In each discussion of the different stratigraphy, the author gives each name by which the strata is known and the derivation of the name. The limits of the strata, the character, the distribution, the thickness, and the fossils and correlation are also included.

2. Industry Investigation

a. "Grounding Principles and Practices", by Reinhold Rudenberg, Claude Jensen, A. A. Johnson, W. R. Bullard, and Robin Beach. (4)

This paper represents a collection of lectures which were presented by the Power and Industrial group of the New York Section of the American Institute of Electrical Engineers. Each of the contributing lecturers was an established authority in the field on which they covered. The consolidated paper covers the subject thoroughly from the fundamental considerations on ground currents, the various methods of establishing grounds,, the various generator grounding devices, system grounding, and the effects of static electricity in industry and its relation to the overall grounding problem. The paper is very valuable because it presents not only the practical solutions but where a physical or mathematical approach would aid in understanding the authors have not hesitated in applying a more theoretical viewpoint.

b. "System Lightning Chart-Glyn Lynn-Claytor Section", American Gas and Electric Service Corporation. (5)

This chart presents a graphic picture of the outage history of this particular section of a typical high voltage transmission line where the line passes through a region in which the earth resistivity values are rather high. The chart shows at a glance the correlation between the number of outages due to lightning and the values of tower footing resistance. With only a few exceptions, the number of outages is in almost direct proportion to the value of the tower footing resistance. A chart such as this clearly illustrates the absolute necessity for maintaining as low a tower footing resistance as is possible if sustained electric service is to be maintained.

c. "A Manual on Ground Resistance Testing", by the James G. Biddle Company. (9)

This manual, while written primarily for the users of Biddle Instruments, contains a great amount of useful information on the technique of ground resistance testing. Of particular importance in the discussion of resistance testing is the selection of the reference grounds. A very useful appendix is included in the manual which gives a few of the reference formulas that are useful in ground resistance testing. Also the manual includes a cross-section of the latest industry findings with regard to improved methods of locating and measuring proper grounds.

d. "Grounding Electrical Circuits Effectively", by J. R. Eaton. (16)

This paper is one that has been prepared by an outstanding engineer after long experience in the power distribution field. The author covers three distinct topics in the paper: 1. Characteristics of Grounds; 2. Calculations and Installations; 3. Ground System Requirements. The area of the authors' investigation was in Michigan where a relatively wide range of earth resistivity values were encountered. The manual includes a number of curves drawn from data obtained under quite a few different conditions of soil moisture content and earth temperature. The paper is one of the few which contains illustrations of the effectiveness of multiple grounds as compared to single rod grounds.

C. Commercial Importance of Good Grounds

A previous reference was cited to reveal that the occurence of outages due to lightning was reflected directly to the value of the tower footing resistance.(5) In the sale of commercial power, the importance of service continuity cannot be overemphasized. In many large industrial comsumption contracts, the power company may be held financially responsible in case of a prolonged outage. Good grounds will lower the tower footing resistance and hence improve the possibility of a high rate of continuity. Of course, the public relations problem is involved because a power outage always makes the headlines of the local papers, and since the power distribution companies are public utilities, it is very good business for public sentiment to be on the side of the company. In this connection the safety problem appears because improper grounding may under certain circumstances endanger the lives of those working near the power facilities, whether these people be employees of the companies or consumers. It is the opinion of some well known engineers that in case of a death resulting from improper grounding facilities, a power distribution company could be legally charged with criminal neglect, and the responsible parties would be subject to prosecution.

II. Investigation

A. Selection of Testing Area

In selecting the test area for this problem, a number of factors had to be considered. Of course, the principal factor was that of finding a location that would be representative of the general problem, while at the same time being within easy access of Blacksburg. Also, it was desirable that the geology of the area be well known to serve as a basis of comparison with the results that would be obtained from the electrical measurements. The problem of obtaining the right to trespass on the test property and to leave buried rods was a minor one, but nevertheless essential to the proper conduct of the tests.

After a careful study of the region surrounding Blacksburg, Virginia, the site of Price Mountain was decided upon. Price Mountain is probably the most important geologic area in Montgomery County and one that has a very rich history. The Merrimac coal seam which lies in Price Mountain has been producing coal since the Civil War. Of greater importance at the present time is the fact that the California Oil Company had only recently drilled a test well nearly ten thousand feet deep in Price Mountain in search of oil, hence the geologic structure of the area is now very well known. The oil had constructed a road to the top of the mountain and the road was still open, thus making the site easily accessible by automobile from Blacksburg, which was about eight miles away. Permission was obtained from the owners of the property, the Brush Mountain Coal Corporation, to trespass and leave buried structure. Of relative importance to the conduct of the tests made in this study is the fact that a power transmission line passes over Price Mountain, hence an opportunity wasxafforded to study the history of the grounding problems on that particular line.

Geologically, the Price formation is generally a clastic formation composed of shale and sandstone, but in some places has two or more beds of coal which are most prominent in Pulaski and Montgomery counties. Price Mountain contains no limestone. Besides the sandstone mentioned above, the main constituents of the Price formation are thin-bedded sandstone, greenish clay, and sandy shale containing relatively thin layers of greenish, micaceous sandstone. (12)

The fact that the Price formation is composed of sandstone principally gives it a somewhat unique position so far as electrical conductivity is concerned. Research By the Bell Telephone System concludes that the resistivity of pure sandstone is about one billion meter-ohms, compared to the average earth resistivity of a large number of determinations of about one hundred meter-ohms. Of course, when the sandstone is not solid, the resistivity is somewhat less, however the presence of sandstone tells the praticing engineer to beware of grounding difficulties.

B. Selection of Testing Equipment

Before a suitable testing device was decided upon, it was necessary to review all of the conditions under which the tests were to be made, bearing in mind the determining factors of the expected range of the measurements, the required accuracy, the portability of the equipment, and the initial cost. After considering the above requirements, the choice became one selection between the Model W "Groundometer", manufactured by the Borden Engineering Company, and the "Megger" Ground Tester manyfactured by the James G. Biddle Company. The above factors were explored indiviidually and the following comparison made between the two instruments:

1. Expected range of measurements

   Since the soil was known to have a very high resistivity, a wide range meter was necessary. Both of the competing meters met the desired conditions of range but at a considerable difference in cost.

2. Required accuracy

The "Megger" had the higher accuracy rating without question, however, considering the type of measurement that was to be made and the range of values expected, a high degree of accuracy was not necessary. The "Groundometer" was sufficiently accurate under the circumstances. Here again, the difference in accuracy was not justified in view of the great difference in initial cost.

3. Portability and operation

Both of the instruments were readily portable and easily set up for measurements. In the case of the "Megger", however, it was necessary to crank a generator and read the deflection of an indicator on a scale. In the case of the "Groundometer", the power was furnished by dry cell batteries and the reading made by detecting a null in a telephone headset, hence both hands were free to adjust the instrument for maximum sensitivity and for recording the data.

4. Initial cost

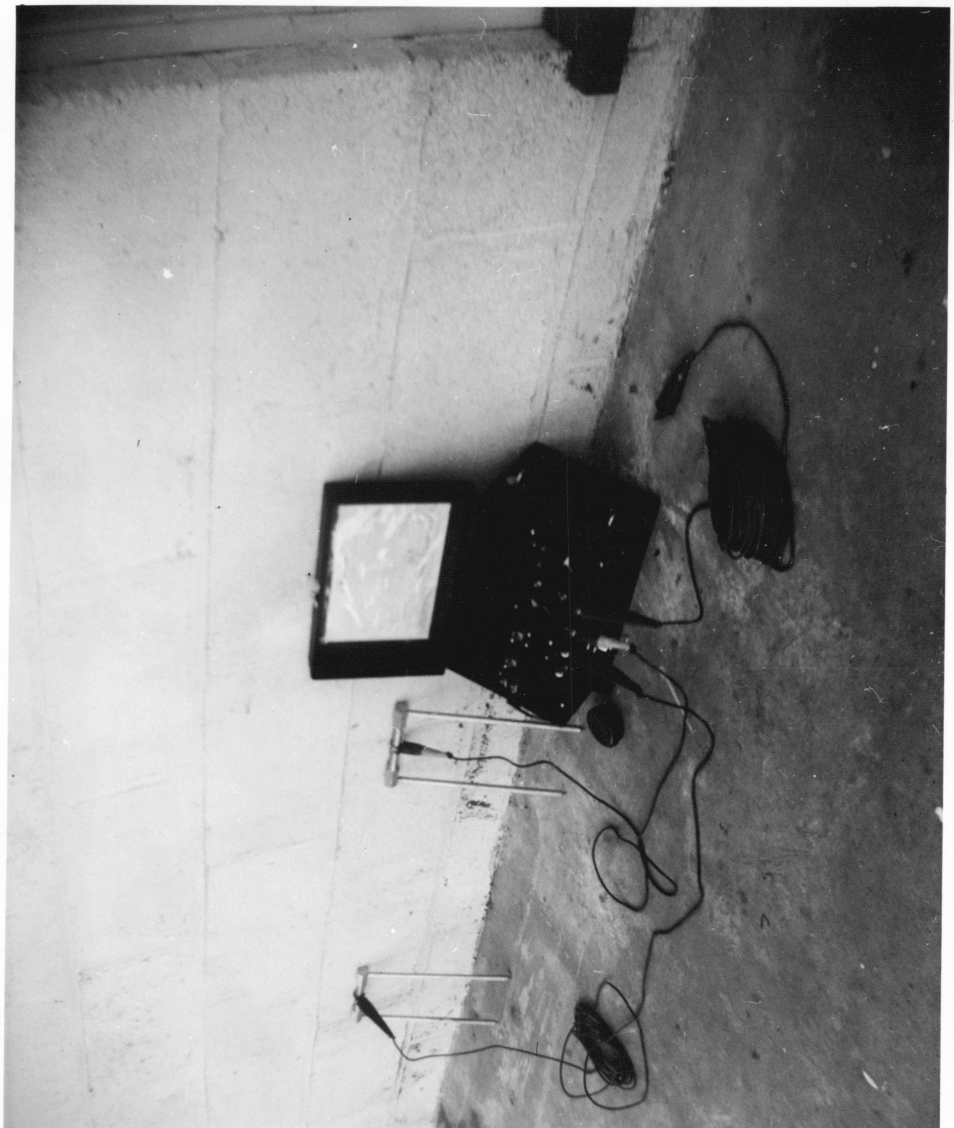
In view of the other factors, the initial cost was the item that determined the selection of the "Groundometer". The difference in cost was over one hundred dollars and since the appropiation came from the Virginia Polytechnic Institute Electrical

Engineering Department, economy had to be considered. The economy was well justified in this case in view of the type of measurement that was being made.

C. Principles and operation of the "Groundometer"

Basically, the type W "Groundometer", is a well designed Alternating Current Wheatstone Bridge. A small vibrator is incorporated within the instrument to develop the alternating current of the desired frequency. Being a bridge of the Wheatstone type, wherein balance is obtained by a null method, maximum sensitivity is attainable. The circuit and switching arrangements are so designed that when a minimum of sound is detected in the headset, the bridge becomes direct reading. This is made possible by really using two bridges, one to measure the resistance of one of the reference grounds, the other to measure the resistance of the ground connection under consideration.

A photograph of the type W "Groundometer" is shown on page 16, including two of the reference ground probes and their leads. The longer coiled lead connects to the ground rod at the test point and this lead should be at least twenty feet long. The earth distance of twenty feet becomes one leg of the bridge circuit and if this distance is too short, the bridge ratios will be distorted and it would be difficult to obtain a good indication of balance.



Type W "Groundometer" and Accessories

The operation of the type W "Groundometer" will be explained with reference to the circuit diagrams as given in Figures 1, 2, and 3 on pages 17 and 18 of this paper.

Figure 1: With the reference electrodes connected at "P" and "Y" and the ground to be tested at "X", the switch number 2 must be in the "B" or bridge position. At this time switch number 1 must be in the "Y" position with the "High-Low" switch on "low".

Figure 2: This figure represents the actual circuit with the switches in the positions given in figure 1. In Figure 2, only the part of the "Groundometer" which pertains to the bridge circuit are included. In this position, the "X" and "Y" electrodes are in series and the potential is applied directly to these electrodes. The "Y" rheostat is connected between "Xg" and "Yg" and its sliding contact is connected through the earphone to ground.* When the bridge is balanced, the rheostat will be divided into two portions, and these portions will be in proportion to one another as the "Xg" and "Yg" grounds.

Figure 3: This figure represents the instrument when the main switch is thrown in the "X" position, thus forming a Wheatstone bridge. One leg of the bridge consists of the "Xg" and "Yg" legs in series, and if the entire "Y" rheostat

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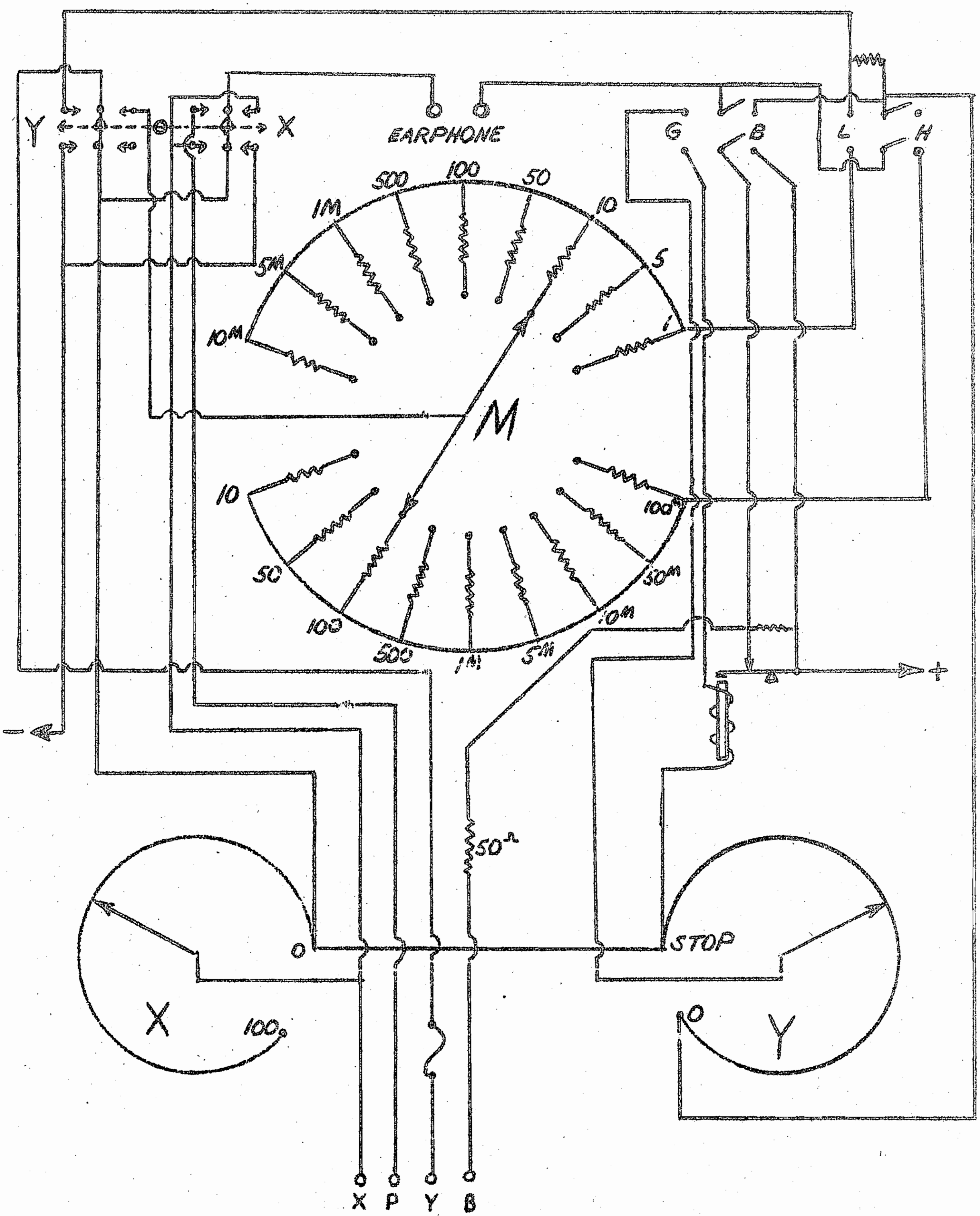
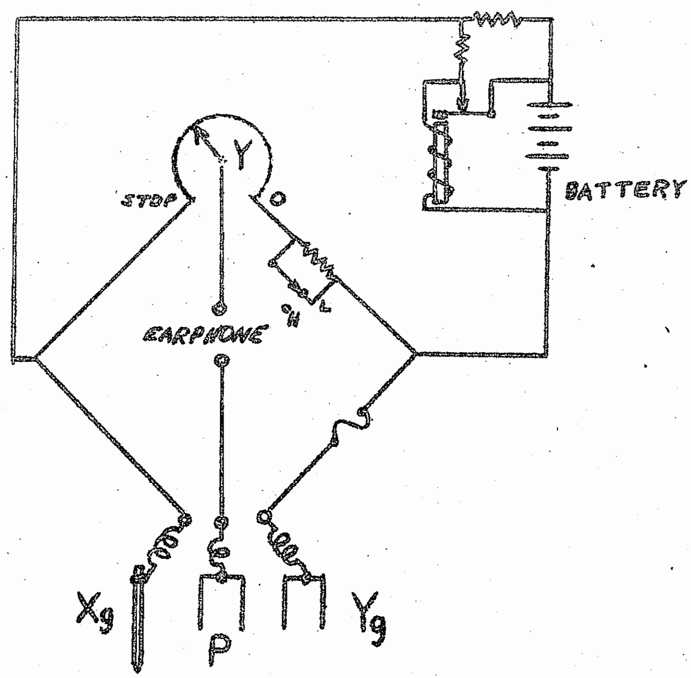
* "Xg" represents the resistance between probe "X" and earth.

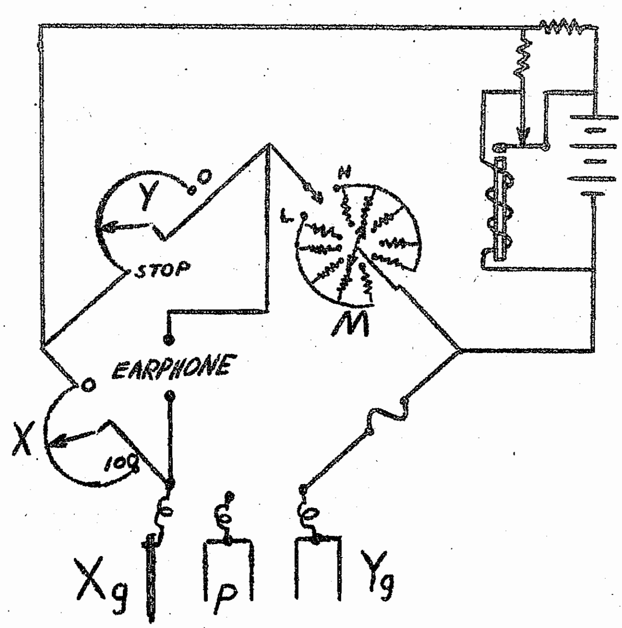


CIRCUIT DIAGRAM – TYPE W GROUNDOMETER

FIGURE 1



TYPE W GROUNDOMETER - Y POSITION
FIGURE 2



TYPE W GROUNDOMETER - X POSITION
FIGURE 3

were in the circuit, the bridge would measure the total resistance of "Xg" and "Yg". However, when the bridge was in the "Y" position, the "Y" rheostat was adjusted so that the portion of "Y" remaining in the circuit in Figure 3 is proportional to the total resistance of "Y" as the resistance of "X" rheostat is to the total of "Xg" and "Yg". As a result, the bridge actually measures "Xg" plus "Yg" times the ratio of the "Y" rheostat, which means that the bridge reading will be the resistance of "Xg" only. *

D. Method of attack

Since the principal purpose of the measurements taken in these tests was to determine the electrical characteristics of the strata at the surface of Price Mountain, it was important that the methods used would not lead to erronous conclusions. As a result, a method of variable references was decided upon.

Consider the case where the instrument would be placed at the center of a circular area with a fixed reference ground at that point, and the test rods moved around the circumference in a regular manner with readings being taken every twenty-five or thirty degrees. This method would reveal the characteristic of the earth on the

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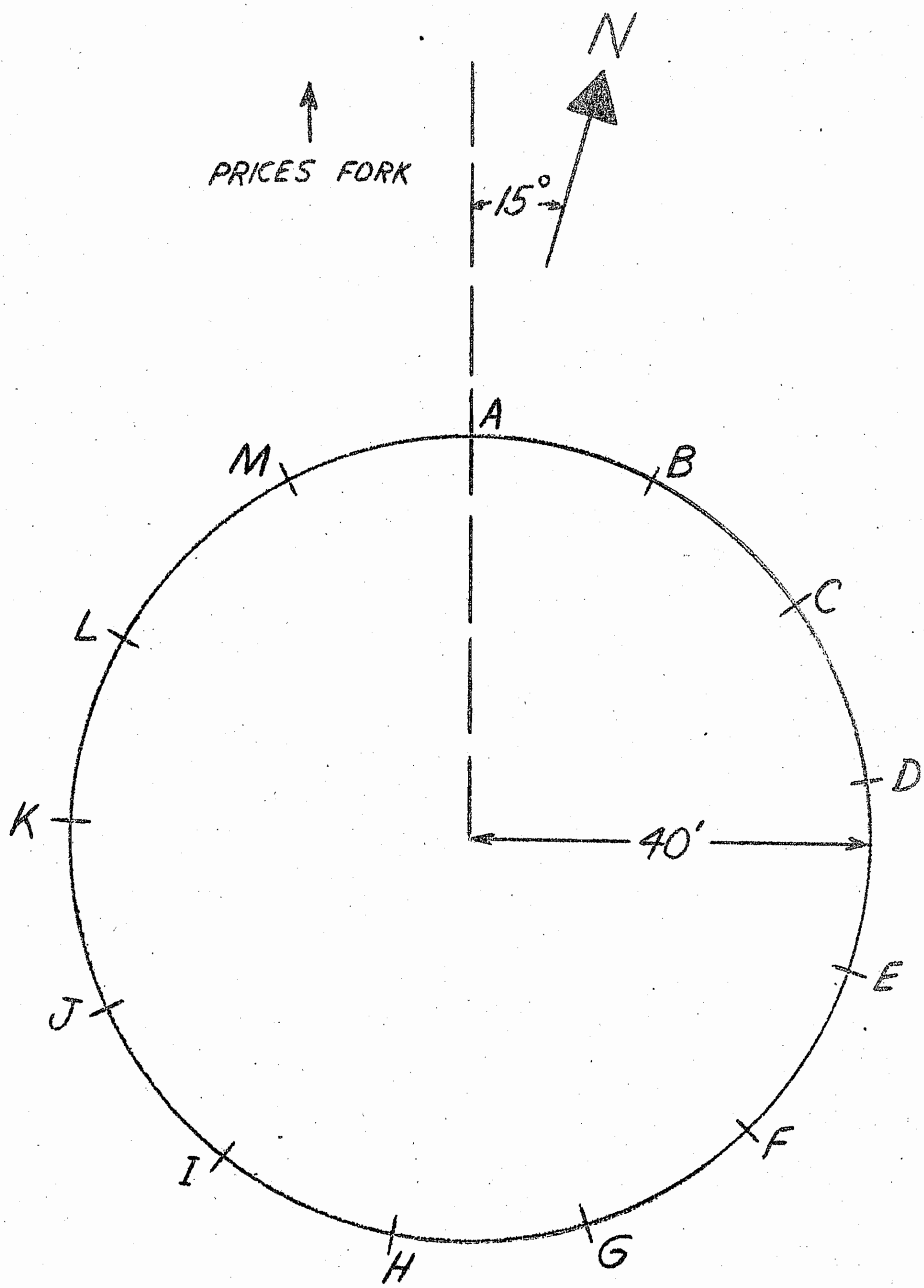
* "Groundometer" Operation Manual, Borden Engineering Co.

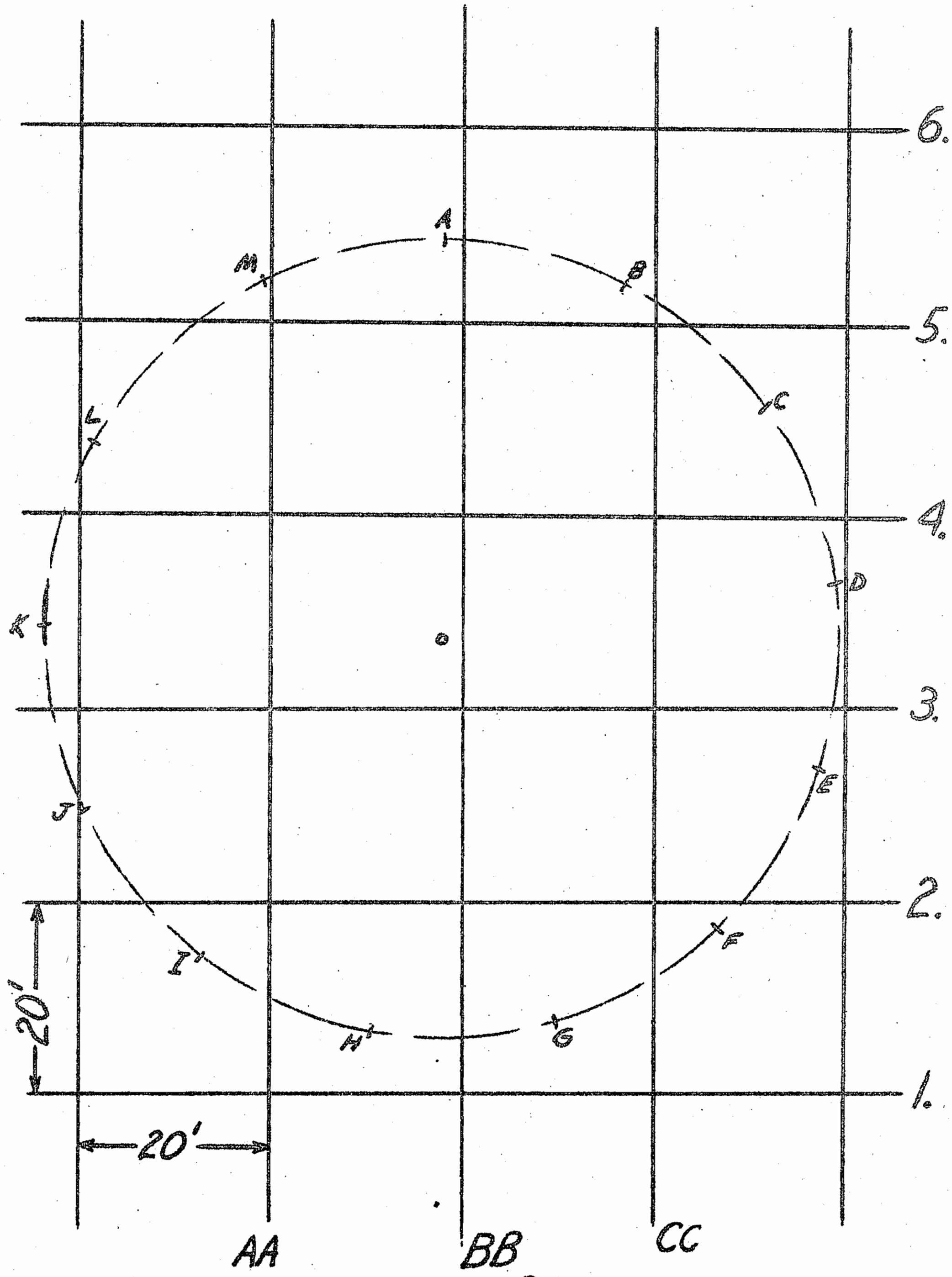


PHASE I
LOCATION OF READING STATIONS
PLATE I

boundary of the circle, but would reveal nothing about the strata within the circular area. This method was used as Phase 1 of the investigation and the geometric layout is illustrated as Plate 1, page 20. In order to determine the surface characteristic of the area lying within the circle, it was decided to superimpose upon the circle a system of rectangular grids with a series of measurements being taken at selected points of the grid system, and with the reference ground moving. The combination of the two systems of measurement would have the advantages of both the methods, namely, by well defining the boundary characteristic and charting the interior of the area simultaneously. By combining the results of the two systems, it would be possible to construct graphically the approximate levels of surface strata, either into levels of uniform resistivity or into levels of similar geologic structure.

The problem of selecting suitable reference grounds was eliminated by using the rectangular grid system and interchanging test rod locations with the locations of the reference ground probes. The correlation of the circular and rectangular systems is illustrated as Phase 2 of the investigation and is given on Plate 2 on page 22.

The accuracy of the "Groundometer" was sufficient



PHASE 2
LOCATION OF READING STATIONS
PLATE 2

so long as the resistance of the reference electrode is less than twenty times the resistance of the ground to be tested when the instrument was used on the low scale. When used on the high scale, the reference resistance should be less than three hundred times the resistance of the tested ground. Of course, as the magnitude of the reference resistance rises, it becomes more difficult to get a true balance on the bridge and the sensitivity is decreased because the low currents which would flow as a result of the high resistance would not produce a very loud tone in the headset. The standard reference probes supplied with the instrument were used except in the cases where the reference resistance became excessive with respect to the test resistance, then Copperweld ground rods were used and driven deeper than the reference probes. The reference probes could be driven only nine inches and should not be used in extremely high resistant soils.

The method of geophysical prospecting with electrical instruments is not new, however, it is the belief of the author that this type of application to the field of electrical distribution is new. In 1931, a series of tests were made at Abana Mine in Quebec, Canada, to see if the presence or absence of certain minerals could be detected by electrical measurements, both by resistivity and induction measurements. The results of these tests were published in 1931 by the United States Bureau of Mines. (27) In these tests, only the system of grids was used in the resistivity determinations.

The use of multiple ground rods is practiced by a large number of commercial power companies as a means of reducing the ground resistance of their electrical structures. If the resistance of one rod in certain soil is known or can be measured, it is possible to predict mathematically how much the resistance can be lowered by multiple rods in a certain configuration if the soil is assumed to be uniform in structure. In this paper, the author uses multiple rods more as a check on the degree of soil uniformity in particular regions than as a means of lowering the resistance.

E. Recording of test data

Since there are a very great number of factors that contribute to the resistivity of the soil in a given location, as many of these factors as is possible should be duly recorded along with the actual resistance readings. As a result, the form for recording test data had the provision for the soil temperature, the approximate moisture content, the weather conditions on the date of the tests, the type and depth of reference electrode used, and of course the location and depth of the test ground.

III. Results and Conclusions

A. Tabulation of Results

The information given below is pertinent to the analysis of the test resul$s, however, since the data contained in Tables 1, 2, and 3 was accumulated on the same day, the information below is common to the above indicated tables and will not be repeated until there is a change in the test conditions.

Date: October 30, 1950 Stations: A, B, C

Weather: Clear Temperature; 60 F. Soil: Dry

Test Rod: Standard Five Foot Copperweld, ½" diameter

Depth of Reference Electrodes: 6 inches.

Table 1: Resistance Measurements at Station A.*

Depth	Y	Multiplier	X	Ohms
12"	9.0	5	30	150
18"	9.1	5	28	140
24"	13.3	5	23	115
30"	15.5	5	20	100
36"	17.0	5	17	85
42"	19.0	5	16	80
48"	19.0	5	16	80

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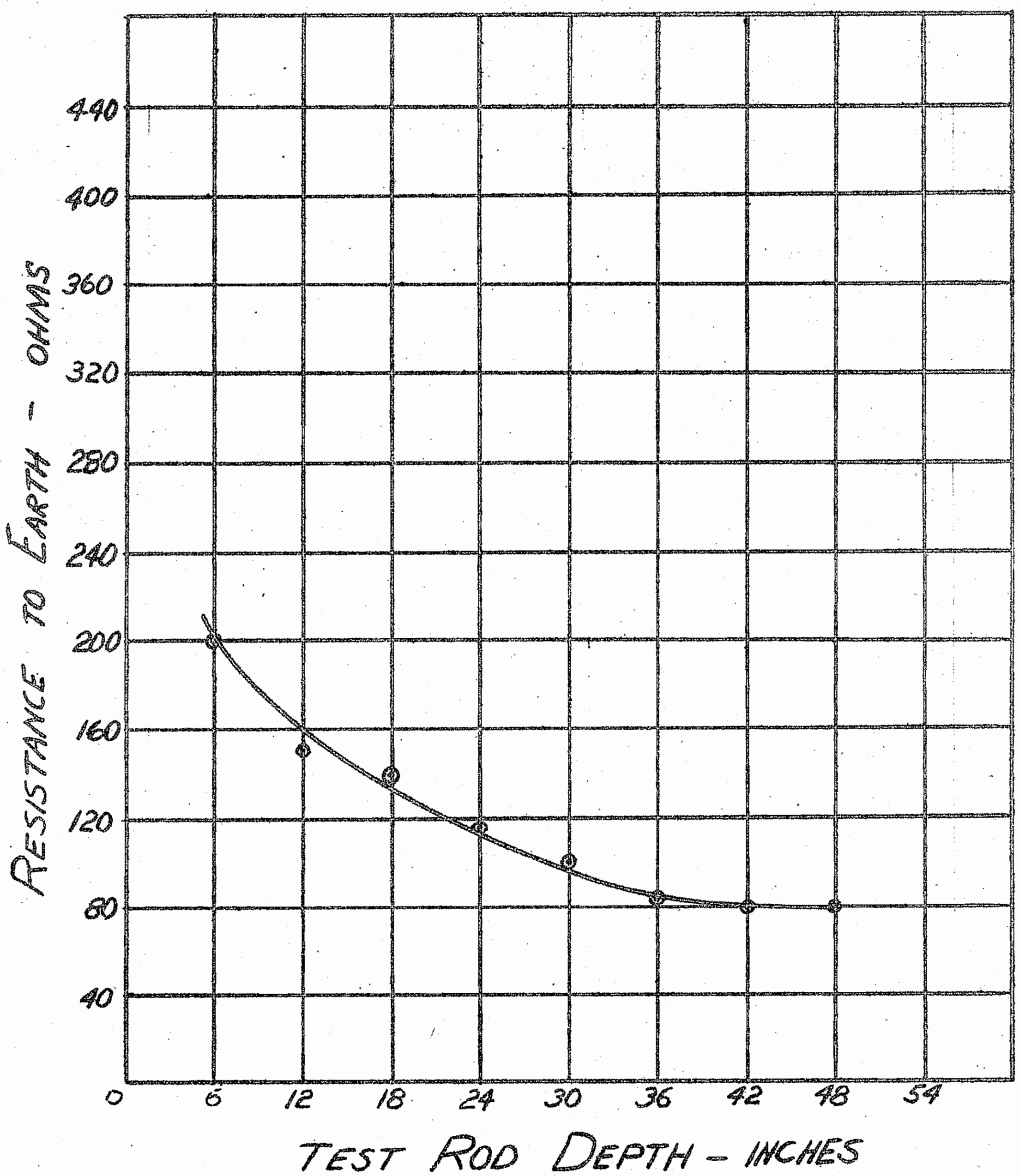
* Explanation of Table Symbols:
Depth: The driven depth of the ground rod under test.
Y: The ratio reading from the "Y" rheostat.
Multiplier: The multiplication factor of the scale.
X: The resistance reading from the "X" rheostat.
Ohms; The calculated resistance (X times Multiplier).



RESULTS AT STATION A - PHASE I
PLATE 3

Table 2: Resistance Measurements at Station B.

Depth	Y	Multiplier	X	Ohms
6"	4.0	5	72	360
12"	8.0	5	38	190
18"	11.8	5	28	140
24"	1313	5	22	110
30"	15.5	5	19	95
36"	16.0	5	18	90
36½"	16.0	5	18	90

Table 3: Resistance Measurements at Station C.

Depth	Y	Multiplier	X	Ohms
6"	2.3	10	60	600
12"	6.0	10	25	250
18"	7.0	5	41	205
24"	9.5	5	33	165
30"	11.5	5	25	125
33"	11.5	5	25	125

Date: November 5, 1950 Stations: D through M

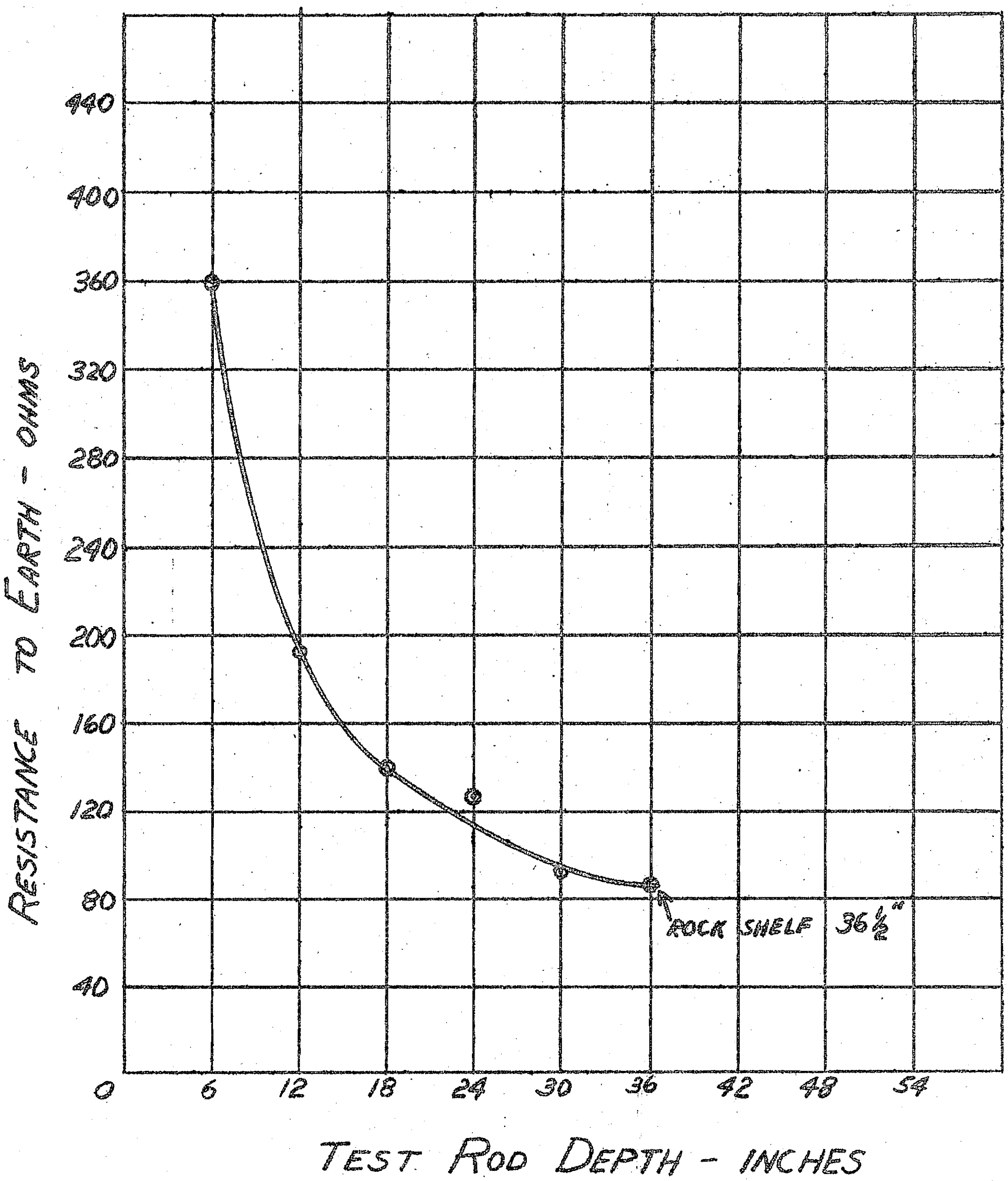
Weather: Clear Temperature; 40 F. Soil: Very Damp

Test Rod: Standard Five Foot Copperweld, ½" diameter

Depth of Reference Electrodes: 6 inches

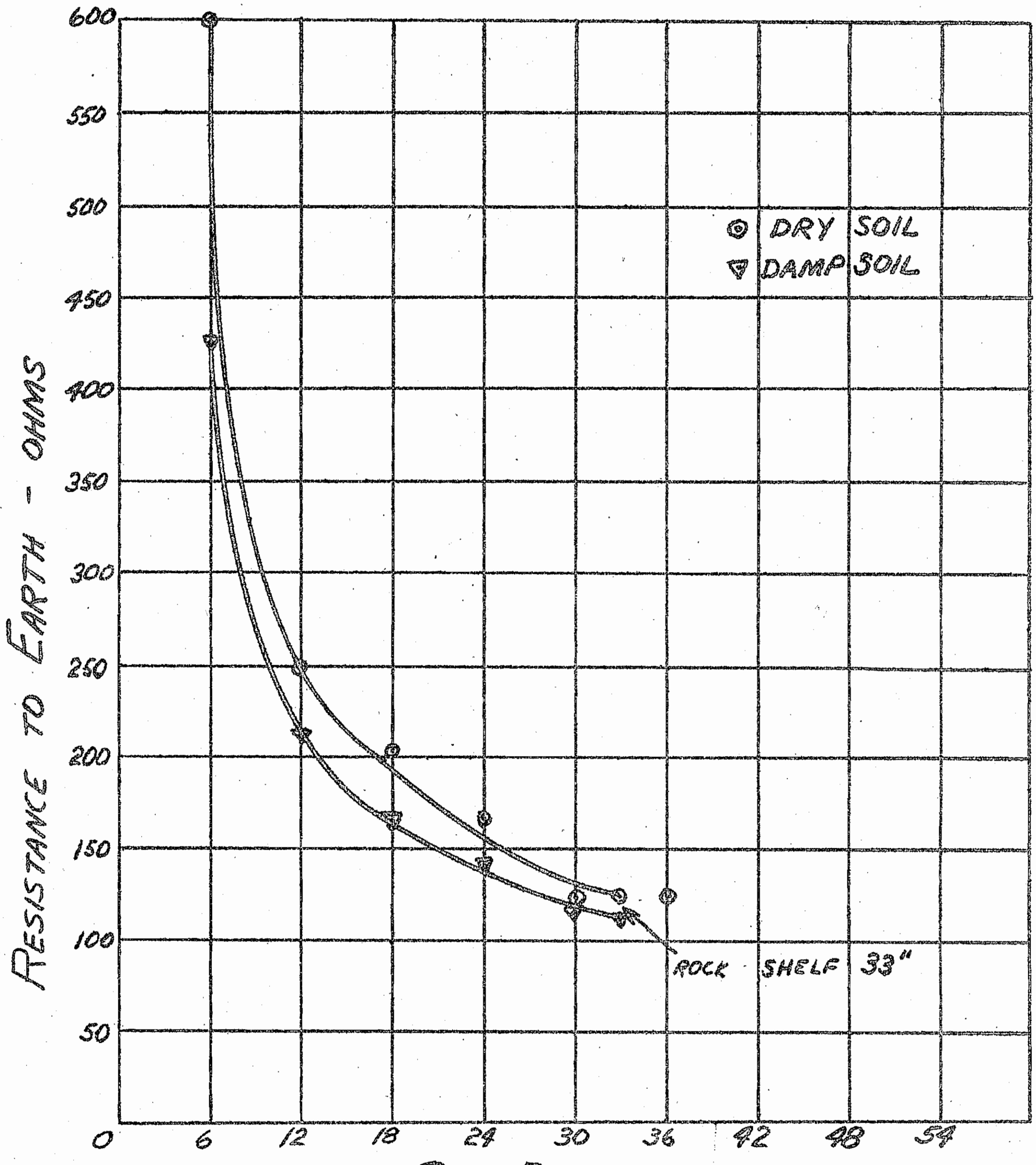
Table 4: Resistance Measurements at Station D.

Depth	Y	Multiplier	X	Ohms
6"	2.3	10	31	310
12"	4.1	10	20	200
18"	5.0	5	35	175
24"	6.0	5	30	150
30"	6.2	5	26	130
31½"	6.2	5	26	130



RESULTS AT STATION B- PHASE I

PLATE 4



COMPARATIVE RESULTS AT STATION C

PLATE 5

Table 5: Resistance Measurements at Station E.

Depth	Y	Multiplier	X	Ohms
6"	1.5	10	60	600
12"	1.7	10	55	550
14"	1.7	10	54	540

Table 6: Resistance Measurements at Station F.

Depth	Y	Multiplier	X	Ohms
4½"	0.4	50	40	2000

Table 7: Resistance Measurements at Station G.

Depth	Y	Multiplier	X	Ohms
6"	1.0	10	90	900
11"	1.1	10	90	900

Table 8: Resistance Measurements at Station H.

Depth	Y	Multiplier	X	Ohms
6"	0.9	50	20	1000
12"	1.0	10	85	850
13"	1.1	10	80	800

Table 9: Resistance Measurements at Station I.

Depth	Y	Multiplier	X	Ohms
6"	1.5	10	55	550
8"	2.0	10	40	400

Table 10: Resistance Measurements at Station J.

Depth	Y	Multiplier	X	Ohms
6"	2.0	10	40	400
12"	3.0	10	28	280
16"	3.0	5	56	280

Table 11: Resistance Measurements at Station K.

Depth	Y	Multiplier	X	Ohms
6"	0.11	10	70	700
12"	0.13	10	50	500

Table 12: Resistance Measurements at Station L.

Depth	Y	Multiplier	X	Ohms
6"	1.4	10	65	650
12"	1.5	10	60	600
18"	1.5	10	56	560

Table 13: Resistance Measurements at Station M-1.

Depth	Y	Multiplier	X	Ohms
6"	1.6	10	55	550
12"	2.5	5	70	350

Table 14: Resistance Measurements at Station M-2.

Station M-2 approximately 4 feet from Station M-1.

Depth	Y	Multiplier	X	Ohms
6"	2.2	10	80	800
12"	6.0	10	25	250
18"	9.0	5	29	145
19"	9.1	5	25	125

Table 15: Resistance Measurements at Station N.

Depth	Y	Multiplier	X	Ohms
6"	2.0	10	50	500
12"	4.5	5	38	190
18"	6.0	5	25	125
24"	7.0	5	24	120
30"	8.0	5	20	100
36"	9.0	1	80	80
42"	10.0	1	70	70

Date: November 12, 1950 Table 16 Grid Line: AA

Weather: Clear Temperature: 50 F. Soil: Dry

Test Rod: Standard Five Foot Copperweld, ½" diameter.

Depth of Reference Electrodes: 7 inches.

Meter Station	Depth	Y	Multiplier	X	Ohms
1	7"	1.4	50	38	1900
2	7"	.17	50	50	2500
3	7"	3.0	10	34	340
4	7"	9.0	5	35	175
5	7"	8.0	5	27	135
5	12"	8.0	5	13	65
5	24"	4.0	1	63	63

Date: November 18, 1950 Table 17 Grid Line: BB

Weather: Clear Temperature: 50 F Soil: Dry

Test Rod: Standard Five Foot Copperweld, ½" diameter.

Depth of Reference Electrodes: 6"

Meter Station	Depth	Y	Multiplier	X	Ohms
1	6"	3.0	50	30	1500
2	6"	0.5	50	30	1500
3	6"	1.2	10	52	520

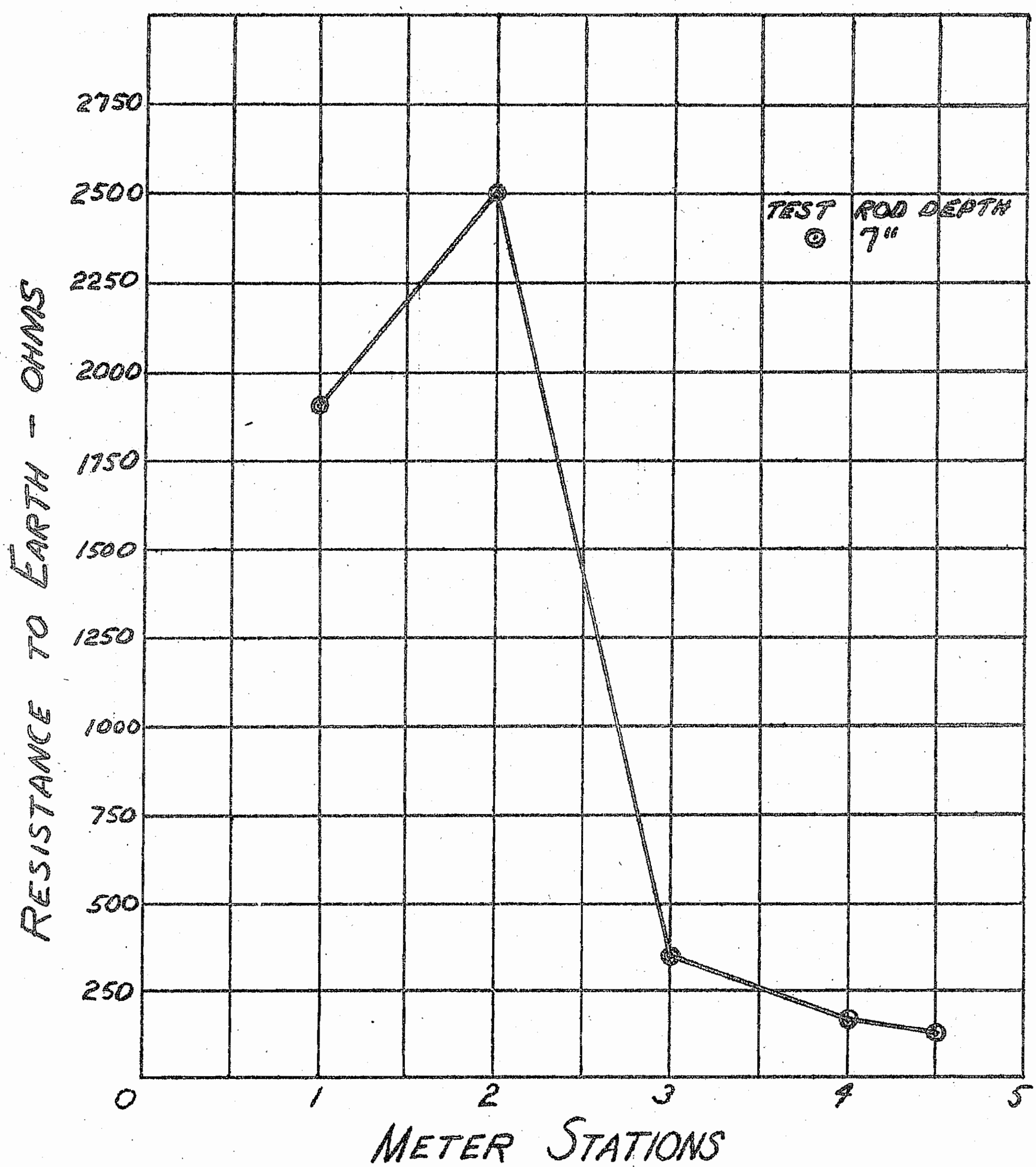
Grid Line: BB (Continued)

Meter Station	Depth	Y	Multiplier	X	Ohms
4	6"	4.1	10	30	300
5	6"	6.0	10	25	250
5	12"	8.0	5	35	175
5	24"	21.0	1	85	85
5	32"	32.0	1	52	52
4	12"	5.0	5	40	200
4	24"	9.0	5	23	115
4	36"	13.0	1	91	91
3	12"	1.8	5	70	350
3	18"	3.0	5	45	225
3	24"	3.5	5	37	185
3	30"	4.0	5	31	155
3	31"	4.0	5	31	155

Table 18: Effects of Multiple Rods, Station 5, Grid Line BB

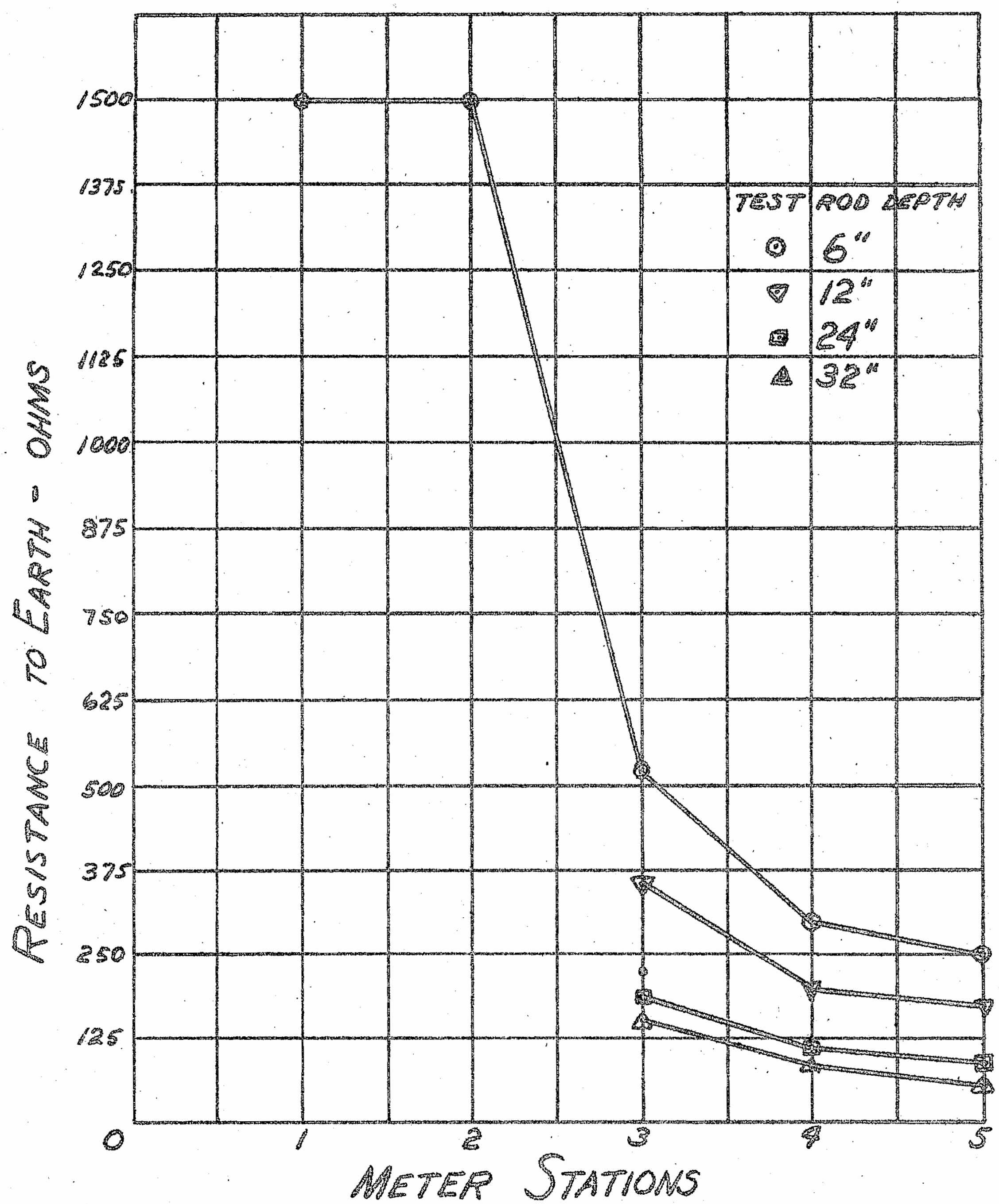
The readings below were taken with the "Groundometer" located at Station 3, Grid line BB, and for arrangement of the multiple rods, refer to plate 10, page 37.

Plate 10 Figure	Depth	Y	Multiplier	X	Ohms
A	30"	8.5	1	90	90
B	30"	8.0	1	72	72
C	30"	7.0	1	90	90
D	30"	6.0	5	20	100
E	30"	5.0	5	20	100



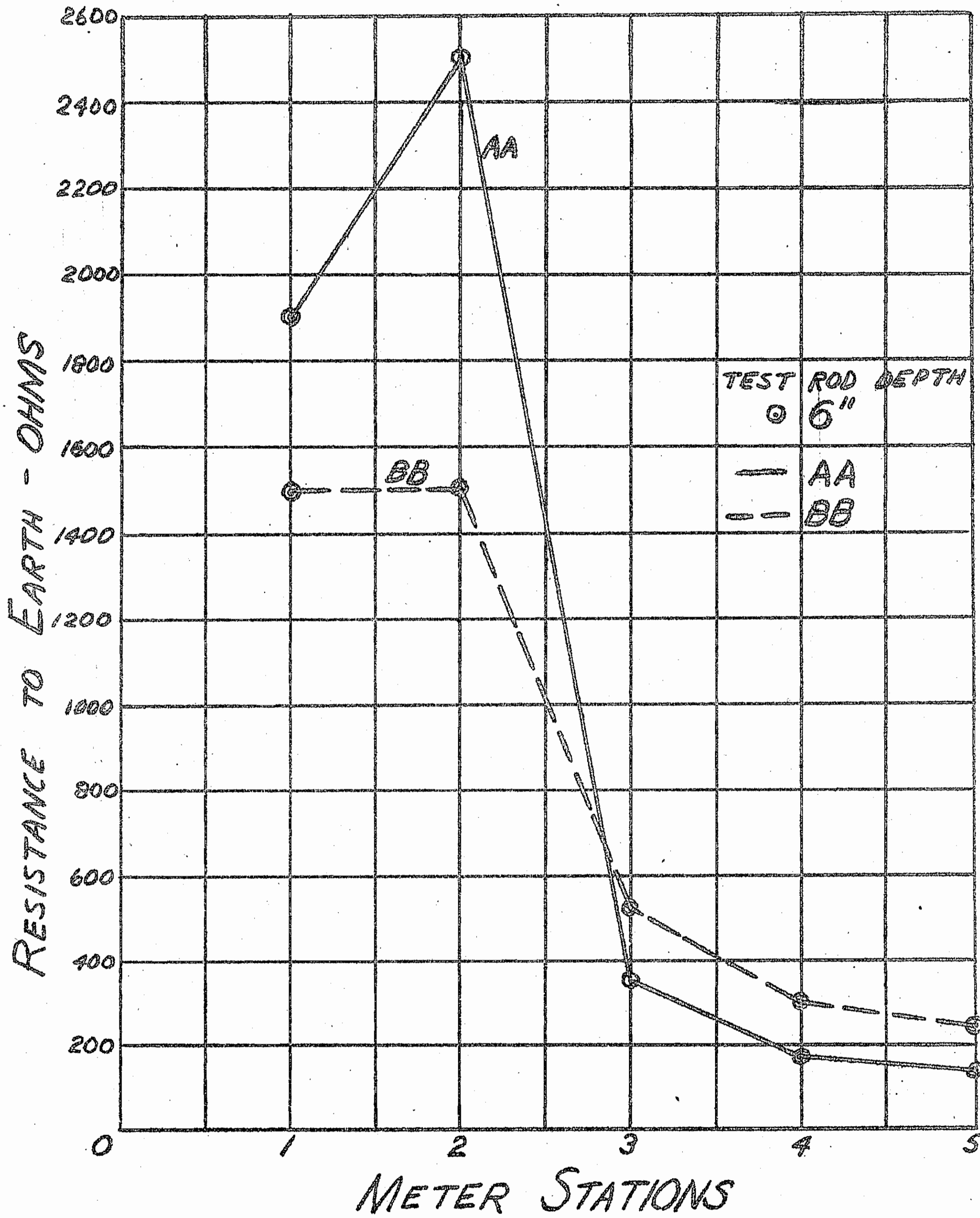
RESULTS ALONG LINE AA - PHASE 2

PLATE 6



RESULTS ALONG LINE BB - PHASE 2

PLATE 7



COMPARATIVE PROFILE - LINE AA AND BB

PLATE 8

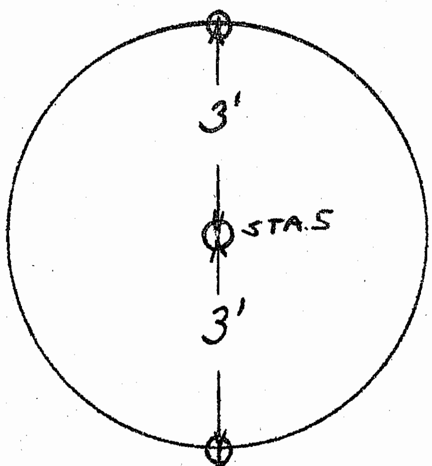


FIG. A.

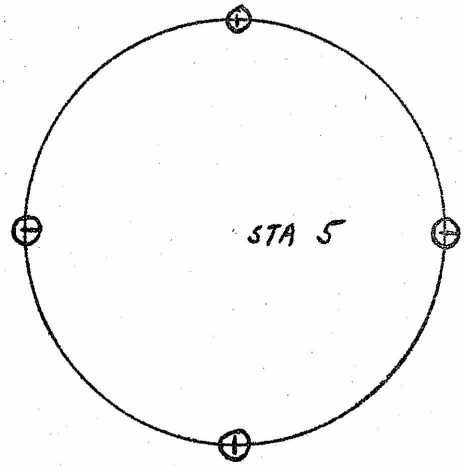


FIG. B

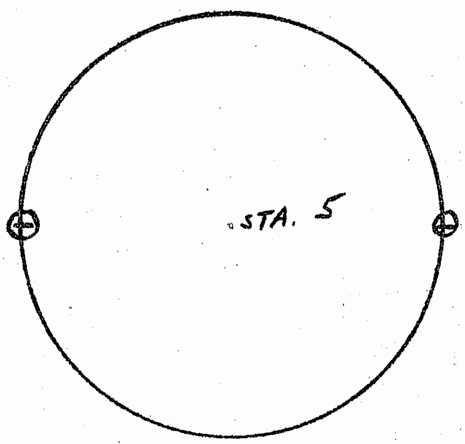


FIG. C

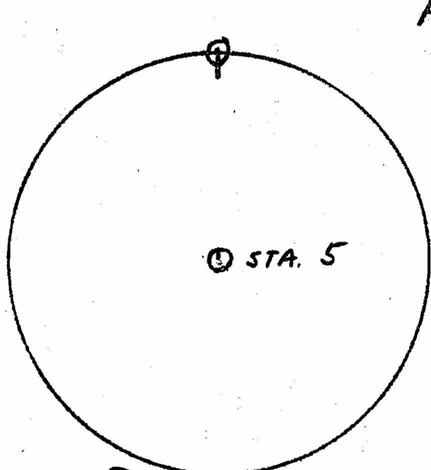


FIG. D.

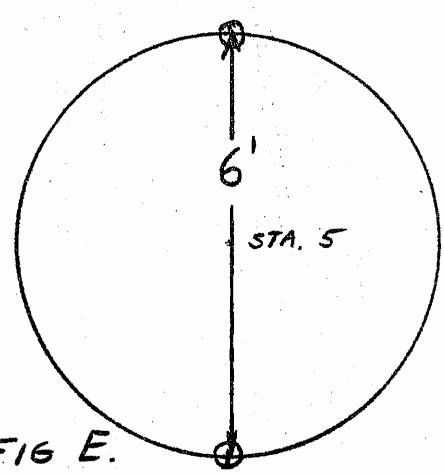
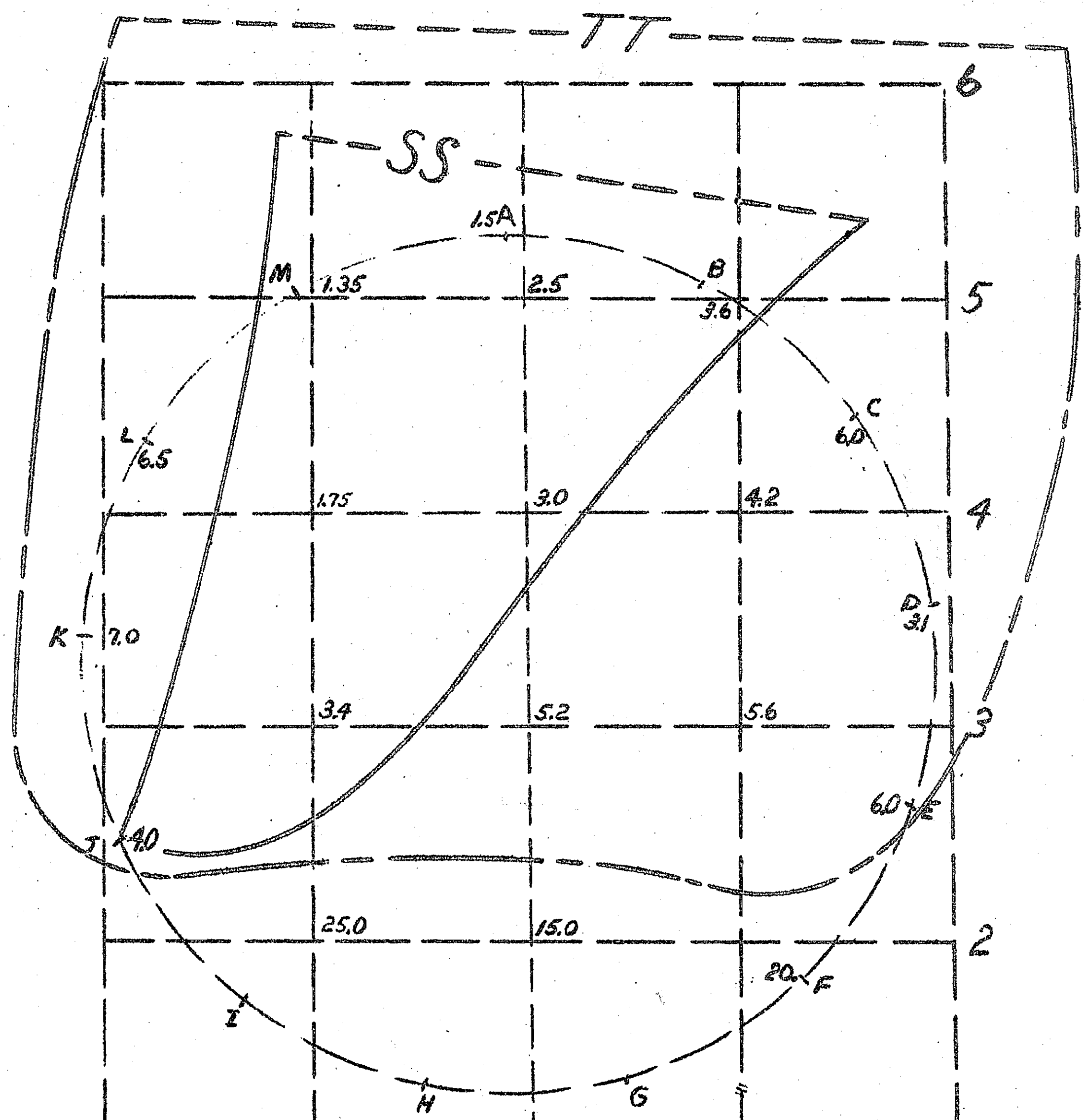


FIG E.

ARRANGEMENT OF MULTIPLE GROUNDS

PLATE 10



INSIDE REGION SS, SHELF 24" TO 32"
INSIDE REGION TT, SHELF 14" TO 24"
OUTSIDE REGION TT, SHELF UNDER 14"

RESISTANCE CONTOURS - TEST ROD 7"

PLATE 9

Arrangement of "Groundometer" and Test Rods for Measurement Along a Grid Line.

Arrangement of a Multiple Ground at Station 5, Grid Line BB.

I. Determination of Resistivity

The resistivity of the soil in question can be determined if the resistance measurements, the depth of the rod, and the geometrical shape of the rod are known. The following equation is taken from the Bureau of Standards Publication 108 (26). No attempt will be made to derive the equation since several approximations must be made in its derivation. For a rod driven vertically into the earth, there is no precise method for calculating its exact value of electrostatic capacity.

In general:

$$R = \frac{p}{2\pi C}$$

where R = Resistance to earth in ohms

p = Resistivity in ohms per centimeter cubed

C = Combined electrostatic capacity of the electrode and its image.

For a vertical rod, the following approximation is made for the electrostatic capacity:

$$C = \frac{L}{2 \log_e \frac{2L}{d}}$$

where L = twice the distance (l) in centimeters to which the rod is driven

d = diameter of rod in centimeters.

Consider a set of readings at Station A at a depth of 30".

then R = 100 ohms

L = 2 x 30 = 60" = 152.4 cm

d

$$d = \tfrac{1}{2}'' = 1.27 \text{ cm}$$

$$p = R\ (\ 2\ \Pi\ )\ C$$

$$p = 200\ \Pi \quad \frac{152.4}{2 \log_e \frac{305}{127}}$$

$$p = 200\ \Pi\ \frac{(\ 152.4)}{2(5.48)} = 8770.$$

This figure is not far from the value of 10^4 ohms per centimeter cubed which is given in reference material for similar regions where sanstone is found. (39)

This figure is about one hundred times the average resistivity of soils in relatively low resistance regions where there is little rock. (39)

Examination of the tables for values of resistance at a test rod depth of thirty inches reveals that the values range from 95 to 125 ohms, test rod to earth. These values would correspond to soil resistivities ranging from a low os 8300 to 14,000 ohms per centimeter cubed. Considering the type measurements being made and the inherent sources of error such as driven effect on the rod, that is not allowing it to remain in the soil some time before taking measurements.

According to authorities, when making resistivity determinations in high resistant soild by this method, the expected error is on the order of 20%. (9). The principle source of error is the inability to secure good reference grounds and the low currents that flow from the measuring equipment because of the extreme resistance of the soil.

B. Discussion of Curves

The general shape of Plate 3 and Plate 4 indicate the exponential variation of the resistance to earth with the test rod depth. It is interesting to note that the leveling-off portion of the curves is at about the same point, in the vicinity of eighty ohms, however, it is significant that at a depth of 6 inches, there is a difference of 160 ohms in the values. This clearly indicates the necessity for piercing the surface crust, even with shallow ground rods. The results in the first foot may be entirely misleading and lead to serious and totally incorrect conclusions.

The two curves on Plate 5 indicate the effect of moisture on the resistivity of the surface strata. The comparison illustrates that the difference will be from about five to fifteen per cent, depending to a large extent on the porosity of the soil and, of course, the amount of moisture.

Plate 6 illustrates a profile along grid line AA from point to point. The meter stations are twenty feet apart. This profile again displays the inadequacy of using the shallow surface for determining the true characteristic. The profile also illustrates the resistance gradient near the surface and can be used to determine depth of uniform resistance layers if a sufficient number of points are tested at varying depths.

Plate 7 illustrates in a profile the same type of result as Plates 3 and4. This plate clearly points out that definite resistance layers exist because the values follow the same tread at different depths. An exhaustive research on this type of measurement could possibly reveal something about the character of any metallic ores that might be present. (27).

Plate 8 enables a three dimensional interpretation of the structure because the grid lines were separated by twenty feet. By utilizing the results of such profiles as this plate and others, plate 9 was constructed as an evidence of the three dimensional visualization. Plate 9 represents a resistance contour of the test area. The enclosed contours represent two distinct layers of surface structure, at least as far as electrical conductivity is concerned. It is the belief of the author that considerable research could be engaged in along the lines of Plate 9 from both and electrical and a geologic standpoint. It would be interesting to see how close the actual geologic surface strata corresponds to the equivalent electrical layers as evidenced by the measurements. Since a well ten thousand feet deep was recently drilled on Price Mountain, and geologic samples periodically examined, in all probability some correlation between the electrical and the geologic structure could be found and put to some practical use.

C. Derivation of Resistance of Vertical Rod in Earth

With reference to Figure A, Plate 11, page 46, consider dividing the rod into "n" spherical elements which over the length "l" of the rod in the ground have the mutual distance:

$$dl = \frac{l}{n} \qquad (1)$$

each feeding a current $\frac{I}{n}$ into the earth.

With reference to Figure B, Plate 11, if "y" is the distance from any element to a point "V" on the surface of the earth, then:

$$\sin\alpha = \frac{y\,d\alpha}{dl} \qquad (2)$$

Now the potential of a spherical source of current in space is:

$$V = \rho\frac{I}{4\pi y} \qquad (3)$$

since $V = RI$ and $R = \rho\frac{l}{A}$

for sphere of radius "y", $l = y$, $A = 4\pi y^2$

Therefore, from equation (3) above, the incremental potential is:

$$dV = \rho\frac{I}{n}\,\frac{}{4\pi y} \qquad (4)$$

considering the incremental currents $\frac{I}{n}$.

Substituting equation (2) in (4) we have:

$$dV = \rho\frac{In\,d\alpha}{4\pi n\,l\sin\alpha} \qquad (5)$$

From Figure A, Plate 11, the limiting value of the angle α is β .

Integrating equation (5):

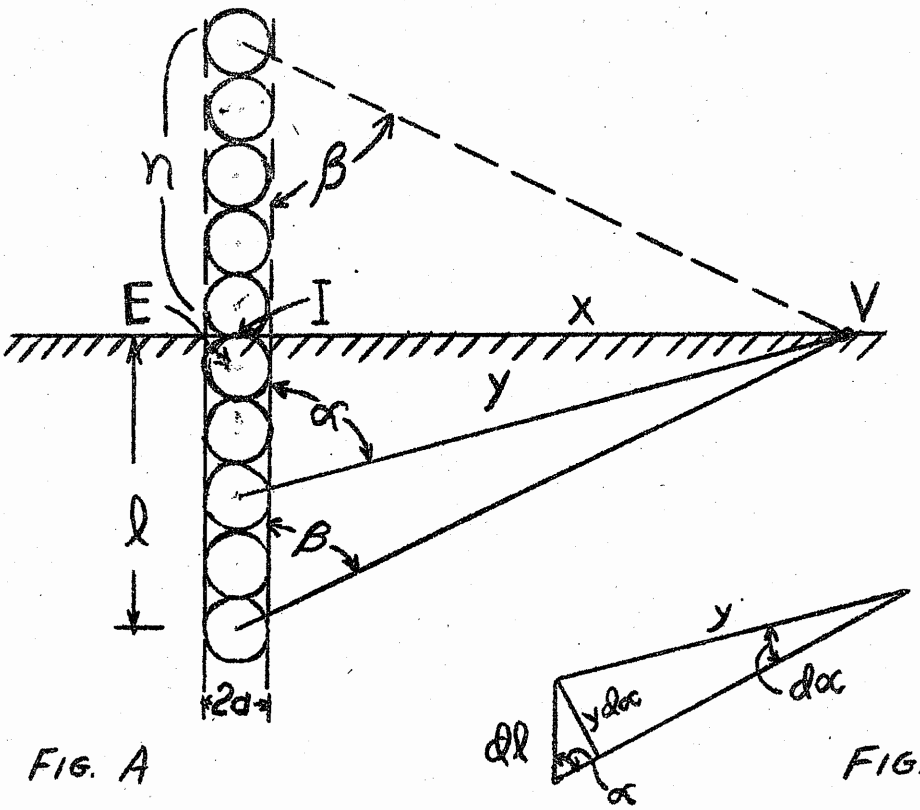


FIG. A

FIG. B

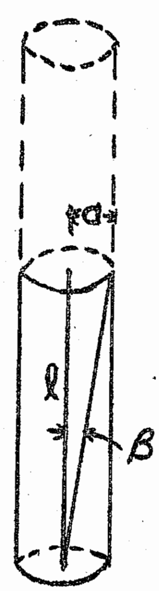


FIG. C

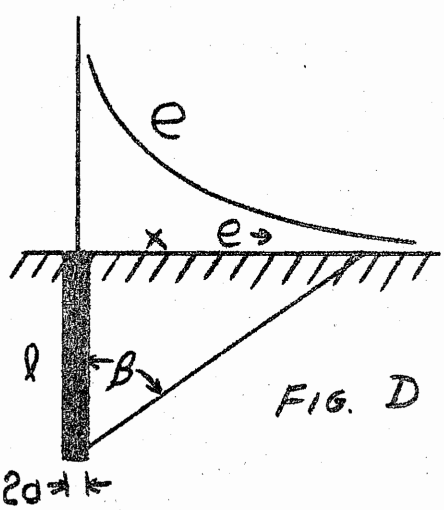


FIG. D

MATHEMATICAL CONSIDERATION OF A DRIVEN ROD

PLATE 11

$$V = \frac{\rho I}{4\pi l}\int_{-\beta}^{+\beta}\frac{d\alpha}{\sin\alpha} = \frac{\rho I}{2\pi l}\log_\epsilon \cot\frac{\beta}{2} \tag{6}$$

But from Trigonometry: $\cot\frac{\beta}{2} = \frac{1+\cos\beta}{\sin\beta}$ (7)

and considering the distance "x" to be very great, the angle β will approach zero.

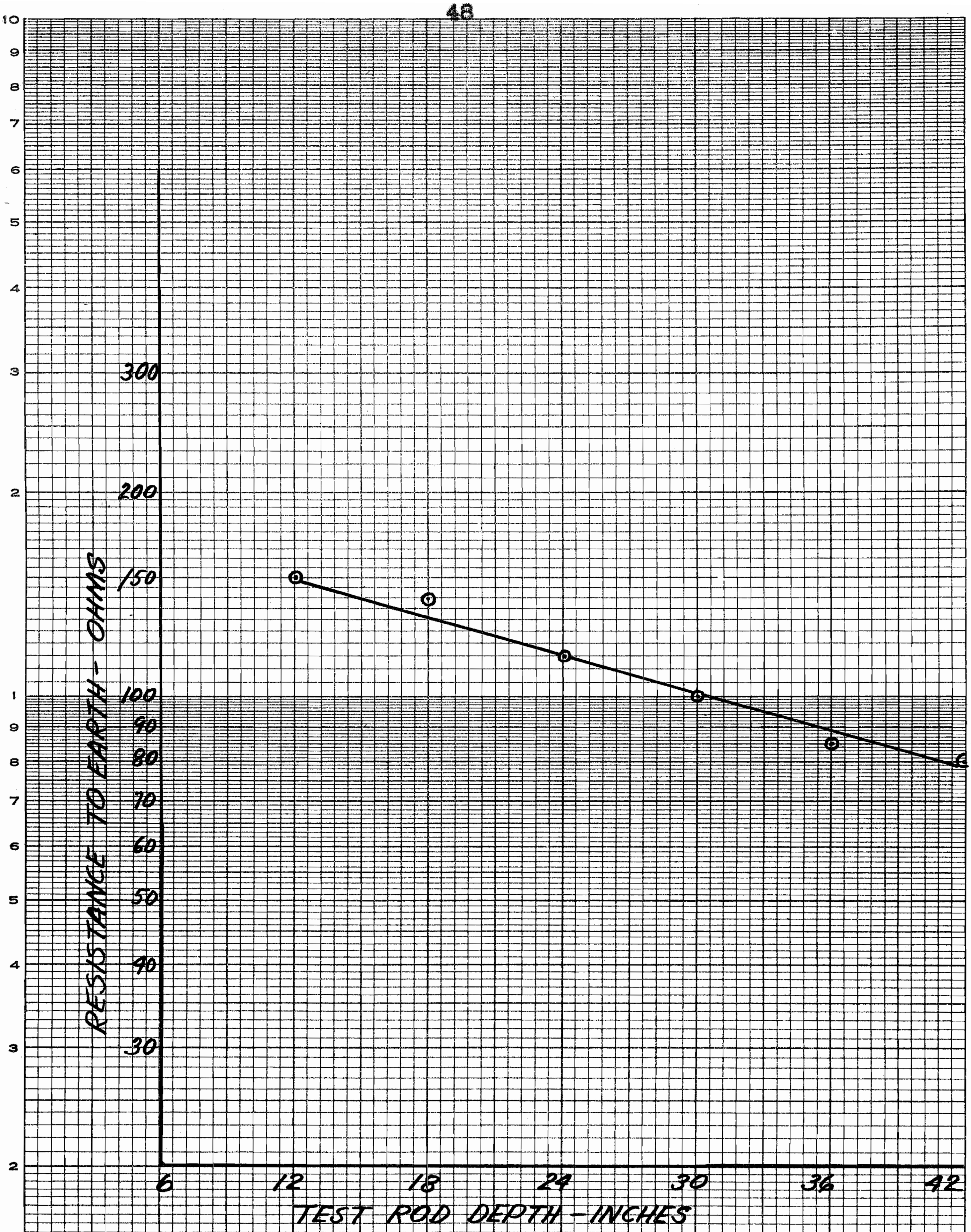
Hence:
$$\log_\epsilon\left(\frac{1+\cos\beta}{\sin\beta}\right) \approx \cos\beta \approx \frac{l}{x}$$

$$V_\infty = \frac{\rho I}{2\pi x} \tag{8}$$

However, on the surface of the rod, if "a" is small compared to "l", then:
$$\cot\frac{\beta}{2} \approx \frac{2l}{a} \tag{9}$$

Hence:
$$V = \frac{\rho I}{2\pi l}\log_\epsilon \cot\frac{\beta}{2} \tag{10}$$

and:
$$R = \frac{V}{I} = \frac{\rho}{2\pi l}\log_\epsilon\left(\frac{2l}{a}\right) \tag{11}$$



LOGARITHMIC PLOT - STATION A

PLATE 12

With reference to plate 12, page 48, it is noted that when the resistance to earth is plotted on semi-logarithmic paper with respect to the depth of the test electrode, a straight line results. This line indicates that the resistance decreases with increased rod depth, but at a logarithmic rate. This result agrees with the theoretical conclusion shown on page 47.

D. Statement of Conclusions

1. Characteristics of Driven Rods

a. Effect of Moisture on Earth Resistance

Moisture content is usually expressed in per cent by weight of the dry soil. Perfectly dry soil, 0% moisture, would have practically infinite resistance. The critical range for moisture content is between 0% and 20%. Tremendous changes take place in this region. According to Lewis (20), the normal variation in moisture content is from ten percent in dry seasons to about thirty-five percent in wet seasons, the average being about 16%-18%. It must not be concluded, however, that the moisture alone is the predominant factor in the low resistivity of soils. In some locations, ground electrodes driven directly in river beds or mountain streams present high resistance to earth. The critical factor is the purity of the water and the presence of natural elements in the soil because it is the solubility of the natural elements in the water that lowers the resistance, not the mere presence of water.

b. Temperature effect

The principal effect of the temperature of the soil in changing the resistivity is in what way it affects the moisture in the soil. Below freezing, the soil resistance increases rapidly, hence, particular care must be taken that ground rods are driven below the frost line. For best results the previous weather history should be studied to determine a safe depth. Another factor is that if the soil freezes, the effective length of the rod is decreased, causing a still further reduction in resistance.

c. Depth effect

As the curves included in this report indicate, the depth to which a rod is driven determines to a great extent the effectiveness of an electrode as a ground rod. It is apparent that increased depth increases the contact surface between the electrode and the earth. In general, the soil resistivity decreases with depth by virtue of the fact that the moisture content increases with depth. The effects of temperature changes on the surface will have less effect on the buried electrode if the depth is great. The limiting factors are usually economic or geologic, rock, etc.

2. Economic Considerations

Of course, a power company is a business, and as such it must make a profit so the stockholders can be rewarded for their investment. As a result, companies do not spend excessive sums for grounding. They must satisfy a perpetual compromise between safety, system stability of service, and cost. They should make every effort to safeguard their employees and customers and also to protect their installed equipment, such as transformers, transmission lines, ans sub-stations. The entire purpose of a shallow ground such as tested in this paper is to provide adequate protection at a minimum of cost.

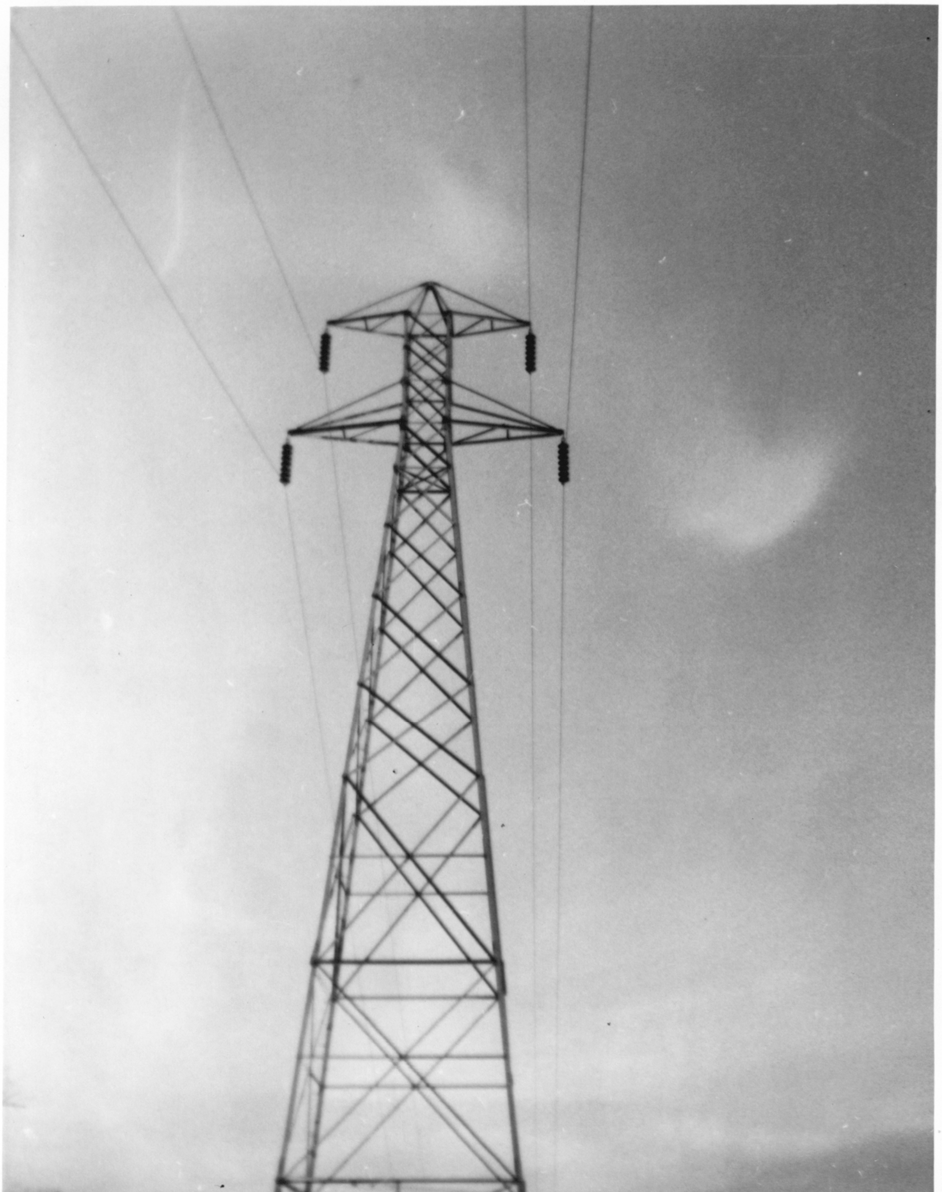
It is the belief of the author that the making of a series of ground tests at the time a line is being proposed would facilitate its later operation being more successful. Outages can be very expensive and it is never good reasoning to take a chance and save a penny where one sustained outage would be more than enough to pay for all system grounds.

In regions such as that investigated in this paper where the resistivity is very high, line location should be thoroughly investigated with ground problems in mind.

The results of this investigation reveal that a line could be built across Price Mountain and operate normally from a ground standpoint, but the grounding could not be hap-hazard. A photograph of a transmission line passing over a portion of the mountain is found on page 53. This particular line has a ground wire, strung on insulators, and can serve as a spare conductor in case of a single line to ground fault. This method is effective but very expensive, there again, the constant compromise of cost and sustained operation.

3. Geologic Correlation

The results of this investigation indicate that there is a very close tie between the electrical and geologic characteristic of Price Mountain. It is the hope of the author that a further investigation may be made into the surface and interior of Price Mountain by resistivity and induction measurements, especially since the interior is well classified by the work of the California Oil Company.



Transmission Line Crossing Price Mountain

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VITA

Robert Alvin Whitehorne

I was born on June 20, 1925 in Portsmouht, Virginia. I attended the Public Schools there and was graduated from Woodrow Wilson High School in Portsmouth on June 16, 1942. On June 15, 1942 I enrolled as a student of Engineering at Virginia Polytechnic Institute and remained there until called into the service in May 1944. From May, 1944 until August 1946 I served in the United States Marine Corps as a Radio-Radar Technician and also as a Recruiter. In October of 1946 I returned to Virginia Polytechnic Institute and graduated with a Bachelor of Science Degree in Electrical Engineering in March, 1948.

While a student I was a member of the V.P.I. Cotillian Club, Eta Kappa Nu, and served as a student assistant in Electrical Engineering.

Upon graduation I worked as a Transmission Engineer for the American Telephone and Telegraph Company for six months. In September, 1948, I returned to V.P.I. as as Instructor in Electrical Engineering and as a part-time Graduate Student. I resigned from the faculty of V.P.I. in October 1950 to accept a position as as engineer with International Business Machines Incorporated and am currently located at their branch office in Roanoke, Virginia

I am married to the former Margaret Langley Kirby of Portsmouth, Virginia, and have two children, Lynn Elizabeth Whitehorne and Robert Alvin Whitehorne, Jr.

My present address is: 1532 Maiden Lane, Apt. 2
Roanoke, Virginia

Robert Alvin Whitehorne

ABSTRACT

Electrical Characteristics of the Surface of Price Mountain

by

Robert Alvin Whitehorne

The establishment and maintenance of good electrical grounds is one of the most important problems that faces the commerical power companies today. The problem of grounding is extremely important in regions such as Blacksburg, Virginia, because the structure of the soil is such that it posesses a very high resistivity of specific resistance. Since there is nothing that can be done about the earth's surface itself, our efforts can be concentrated on some means of improving the type of connections that are made between the earth and an electrical system.

By correlating the results of geophysical prospecting with electrical instruments and the knowledge of the importance of good grounds to the maintenance of a commerical power system, this paper seeks out the answer by improving the method of selecting the proper grounding points in a given area.