GEOLOGICAL SURVEY CIRCULAR 181

DEPARTMENT OF THE INTERIOR
March 3, 1849

ELECTRICAL RESISTIVITY STUDIES OF SUBSURFACE CONDITIONS NEAR ANTIGO, WISCONSIN

By H. Cecil Spicer

UNITED STATES DEPARTMENT OF THE INTERIOR
Oscar L. Chapman, Secretary

GEOLOGICAL SURVEY
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Washington, D. C., 1952

Free on application to the Geological Survey, Washington 25, D. C.

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ABSTRACT

Resistivity measurements are reported for the glaciated area near Antigo, Wis., to locate buried sand and gravel deposits in the glacial drift, which might be developed as aquifers, and to determine depths to the pre-Cambrian bedrock. The results of the resistivity study are presented both as cross sections and as contour maps. The apparent resistivity curves, their interpretation in terms of the thickness and character of the geological materials, as well logs of the area are given. On the basis of the study a number of sites were selected that would be suitable for drilling water-supply wells, no drilling has been done on the sites selected.

INTRODUCTION

The resistivity studies in the vicinity of Antigo, Wisc., were made at the request of the Office of the Ground Water Branch of the U. S. Geological Survey in Madison, Wisc., and in cooperation with Mr. Ernest F. Bean, State geologist of Wisconsin. Field measurements were taken during October 1948.

The writer was assisted in the field measurements by George J. Edwards, geophysicist of the Geological Survey, by members of the Madison office staff, and by men employed locally. Cooperation and assistance were also given by Ernest F. Bean, State geologist, Frank C. Foley, geologist in charge of the Ground Water Office of the Geological Survey at Madison, Wisc., and by Eugene Daniel and Wm. E. Price, Jr.

LOCATION AND GEOLOGY

The area in which the resistivity measurements were made is in Langlade County in the northeastern part of central Wisconsin. (See fig. 1.) The city of Antigo is located in the south-central part of this area, and it was partly in the interests of the city that the resistivity studies were undertaken.

A large part of the area is farm land under cultivation, but there are also scattered areas of marshy and tree-covered land. The soil covering the area varies, but it is mainly sandy clay or sandy loam. The other geological materials overlying the bedrock are glacial deposits consisting of sand, gravel, till, silt, and clay. The bedrock underlying the area is considered to be pre-Cambrian. An exposure of the crystalline rock in the southwest corner of the area (fig. 1) is weathered coarse-grained pink granite.

FIELD METHODS USED IN RESISTIVITY STUDIES

The resistivity measurements were all made with the Gish-Rooney type earth resistivity apparatus, which has been modified by the present writer from a commercially available instrument. Power for driving the commutator in the instrument was obtained from the truck storage battery, and power for the current circuit to energize the earth was supplied by a bank of super "B" batteries. Taps for various voltages were brought out to a control panel, and rheostats were included in the circuit to adjust the

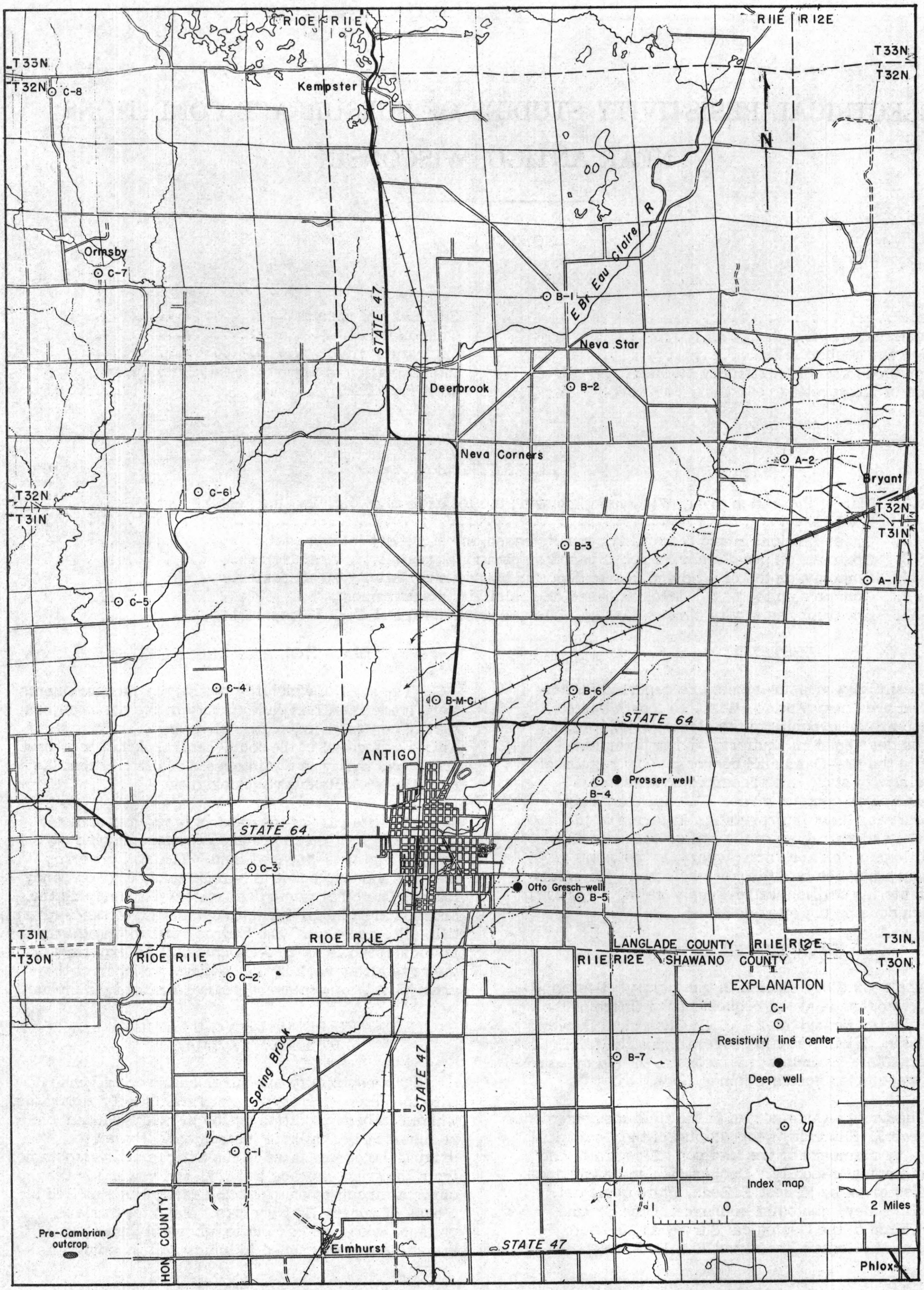

Figure 1.--Map of the Antigo area, Wisconsin, showing the location of resistivity line centers and deep wells.

amount of current flowing in the earth and through the current side of the instrument. The electrodes used for making contact with the earth for both the potential and current were copper-clad steel rods about 26 in. long with a hexagonal steel driving head on one end and a sharpened point on the other. Stranded bronze wire with synthetic rubber insulation was used for connecting the electrodes to the instrument and was carried on duralumin reels. Each electrode was carefully "mudded in" at each interval so as to maintain good contact with the earth.

Depth profiling was used throughout the study. Electrodes were set in the earth according to the modification of the Wenner arrangement as proposed by F. W. Lee. Measurements of potential were made by both the Wenner (1915) and Lee (1929) techniques thus giving three measurements at each interval. The apparent resistivity was computed by the Wenner (1915) formula $\rho_a = 2\pi a \frac{E}{I}$ for all the observations because it spreads the curves on the chart thus making them more accessible for interpretation; however, the curve form remains the same. The three resistivity curves thus obtained are shown (see figs. 6-23) and are termed Full, P-1, P-2, and are indicated by ⊙'s, △'s, and ×'s. Bearings for the depth profiles are referred to true north and are given for the P-1 direction. Altitudes are expressed as heights above mean sea level.

METHODS OF INTERPRETING RESISTIVITY CURVES

The resistivity curves obtained from this investigation (figs. 6-23) were interpreted by procedures explained in the literature on geophysics, and pertinent aspects will be pointed out for convenience to the reader. These methods of interpreting resistivity curves are based on theoretical and mathematical considerations, primarily the theory of images which is given by Jeans (1925) and others. These methods apply to two, three, and more layers, and in the writer's experience have been found to be more reliable than any of the empirical methods of interpretation that have been advanced.

The technique to be pointed out is not quick, nor is it easy, and it demands a knowledge of the theoretical aspects of apparent resistivity curves as will be found, for example, in Hummel (1931). Two-layer resistivity curves and two methods of interpreting them will be found in the papers by Roman (1931, 1934, and 1941). Three-layer resistivity curves will be found in an article by Wetzel and McMurry (1937), and the use of the Roman (1941) two-layer curves and the Wetzel and McMurry three-layer curves to aid in the interpretation of three and more layer curves is completely explained in Watson and Johnson (1938). Some aid in the understanding of their treatment of potential theory will be found in the article by Watson (1934).

The method of Tagg (1937) is useful at times for the interpretation of certain types of resistivity curves. Examples of its application will be found in the reference cited.

It has been demonstrated by both theory and model measurements that surface resistivity curves should be a series of smooth curves for two, three, four, and more layers and should be amenable to the interpretation procedures pointed out above. While the writer is cognizant of the fact that the earth is not so nicely bedded or layered as theory must assume, it has been his experience that this is a minor factor in comparison with the perversions of procedure that have entered into the taking of data for resistivity curves. If one does not get smooth curves then it is time to examine carefully the instruments in use, the techniques of measurement, and the site chosen for the observations. If the latter is at fault, select a better site to take the next line of observations, being sure that the measurements give a smooth apparent resistivity curve. If it is found that the instrumentation or techniques are at fault, try others or find the trouble and correct it. There are no doubt specific instances or certain localities where the generalization above will not hold, but an experienced operator will readily recognize such a geological condition.

SUMMARY OF RESULTS

Eighteen depth profiles were started in the Antigo area, but two were abandoned-one because of leakage in the wires, and the other because of the indicated presence of a buried conductor. The centers of the depth profiles were located (see fig. 1) so that the results would give information concerning the subsurface materials along three north-south profiles. These are indicated on the figures and in the text by the letters A, B, and C prefixed to the depth profile number.

At the time the geophysical measurements were made sample logs were available for only two wells in the area and neither well penetrated bedrock. Both wells are near the city limits of Antigo (fig. 1), and logs for them are given on p. 19. It is apparent from these logs that there is a considerable variation in the glacial materials over a relatively short distance.

A field test was made on the outcrop of pre-Cambrian rock to determine its resistivity. As expected, it was very high averaging 1.5×10^6 ohm centimeters (ohm cms). This value is higher than any of the resistivities computed from the apparent resistivity curves for the pre-Cambrian rocks, namely, 1.3×10^5 to 1.2×10^6 ohm cms. This is to be expected because of the dryness of the outcrop. The computed values of resistivity in ohm cms for the other materials are: soil or near-surface materials, 12.3×10^3 to 445.0×10^3; sand and gravel, 9.5×10^4 to 15.9×10^6; till, 6.8×10^3 to 21.8×10^3; clay, 2.8×10^3 to 6.1×10^3.

The interpretations from the apparent resistivity curves are presented diagrammatically in figures 2 to 5 inclusive. The numerical values are given in figures 6-23.

Figure 2 shows cross sections along the series of electrical depth profiles B and C, respectively, and are plotted with altitude above mean sea level in feet as the ordinate and distance in miles as the abscissa. It is apparent from these two figures that the pre-Cambrian rock surface rises to the west, and that the till becomes thinner in this direction. The sand and gravel deposit is, however, quite

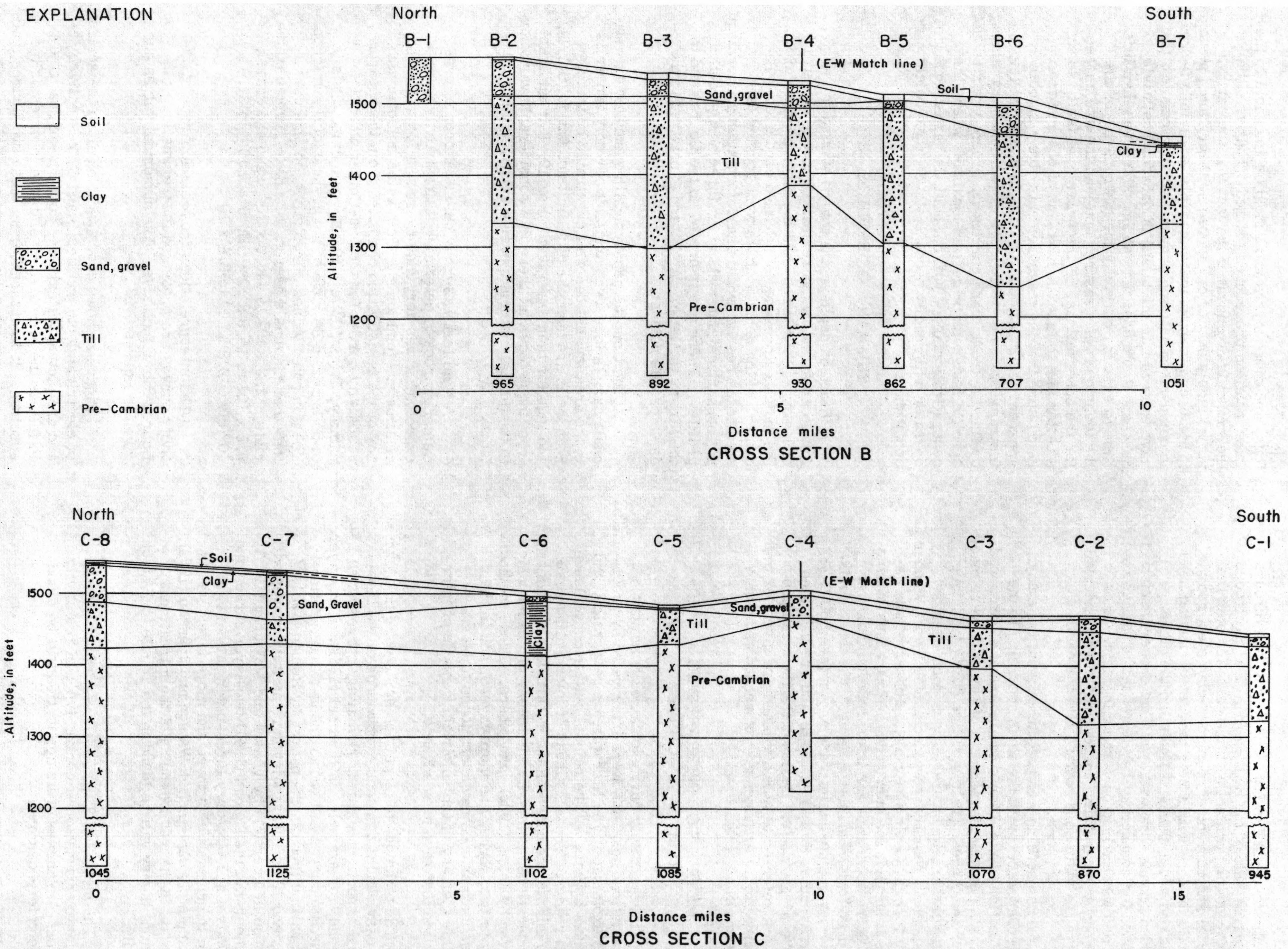

Figure 2.--Cross sections B and C showing deposits based on resistivity interpretations.

variable in thickness and does not show the definite trend to thin toward the west. At depth profile C-6, the till appears to be composed entirely of clay. At depth profiles C-8, C-7, and B-7 thin beds of clay are present near the surface of the ground.

The interpretations from the apparent resistivity curves are shown in a different manner in figures 3, 4, and 5. The area corresponds to that of figure 1 and shows the subsurface topography of the various deposits by means of contours drawn on their upper surfaces. No detail is included in these figures other than the data pertinent to the depth profiles. The altitudes on each of the subsurface deposits are obtained by subtracting from the altitude of each resistivity station the computed depths obtained from the interpretations to the several deposits. Both the surface and deposit altitudes are given in figure 3, and the surface altitude and deposit thickness are given in figures 4 and 5. Correct altitudes for the two wells shown in the figures were not available; so their altitudes were estimated.

Figure 3 indicates a ridge of pre-Cambrian rock more than 100 ft high across the central part of the area that is flanked by troughs. The random thickness of the sand and gravel will again be apparent in figure 4, and the tendency of the till to thin westward will also be seen. Little or no correlation seems to exist between the contours of the different deposits in this area, and as a result it would be nearly impossible to recognize high altitude bedrock from any surface or subsurface indications.

Most of the sand and gravel deposits in this area will probably yield water, and in many places it is sufficiently free of clay so that considerable water can be obtained from it. For shallow wells in sand and gravel at depths less than 60 ft, the following locations are selected: A-1, A-2, B-2, B-4, B-5, B-6, C-3, C-4, C-7, C-8, BMC. For medium depth wells in sandy till at depths less than 125 ft the selection is: A-2, B-2, B-4, B-5, B-7, C-3, BMC. For wells at depths greater than 125 ft, the sandy till or gravel at A-2, B-2, B-4, and B-7 appears to be the best of the locations studied. No drilling has been done on this selected group of sites.

Since this report was prepared, the city of Antigo has drilled two test wells in the NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 29, T. 31 N., R. 11 E. These wells are located in the city limits and are about 1$\frac{1}{2}$ miles south of resistivity depth profile BMC. Other information about them is given on p. 19.

Test well 1 did not reach bedrock at a depth of 73 ft where drilling stopped, but the driller reported bedrock at 72 ft in test well 2. According to the estimated contours on bedrock by geophysical measurements (fig. 3) the depth to bedrock in the vicinity of the drill holes should have been about 125 ft. If the reported bedrock of test well 2 is not a large boulder, then the high bedrock area indicated by depth profiles C-4, BMC, and B-6 must extend southward from BMC thus causing the bedrock in this direction to have a clifflike drop.

It is unfortunate, from the geophysical viewpoint, that drilling was discontinued before bedrock was reached in test well 1, and that a sample was not available for Mr. Thwaites, geologist of the Wisconsin Geological Survey, to examine to see if it was bedrock in test well 2. Such information would have eliminated any doubt about the correlation of geophysical measurements and drilling information.

CONCLUSION

The studies clearly indicate that it is possible to differentiate the glacial deposits in this area by means of electrical resistivity measurements and to determine the depths to and thicknesses of these materials, as well as the depth to the pre-Cambrian bedrock. It was also possible to evaluate the character of the glacial materials from their electrical resistivities and to recommend the most suitable sites for drilling water-supply wells.

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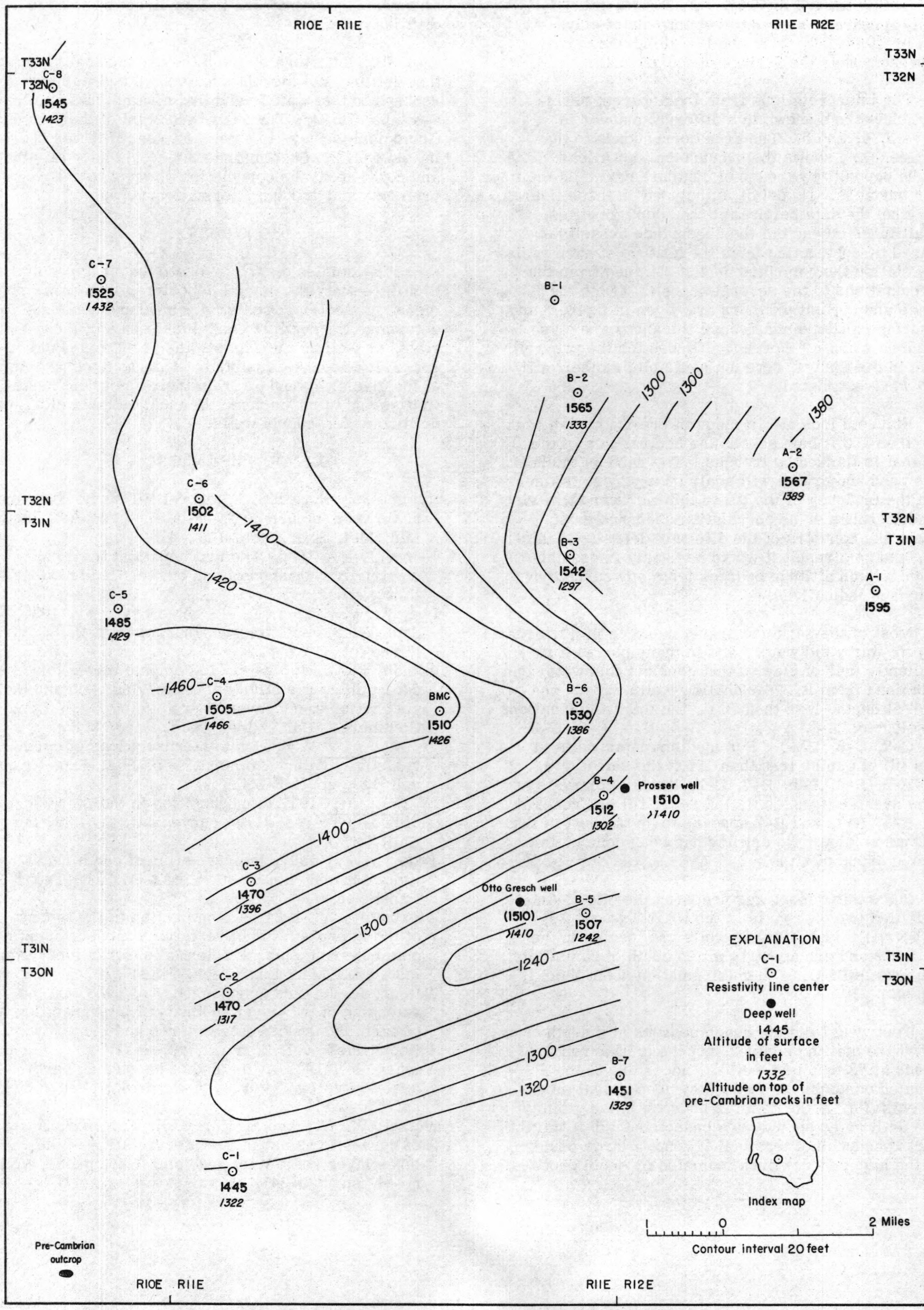

Figure 3.--Contours on pre-Cambrian rocks based on electrical resistivity measurements.

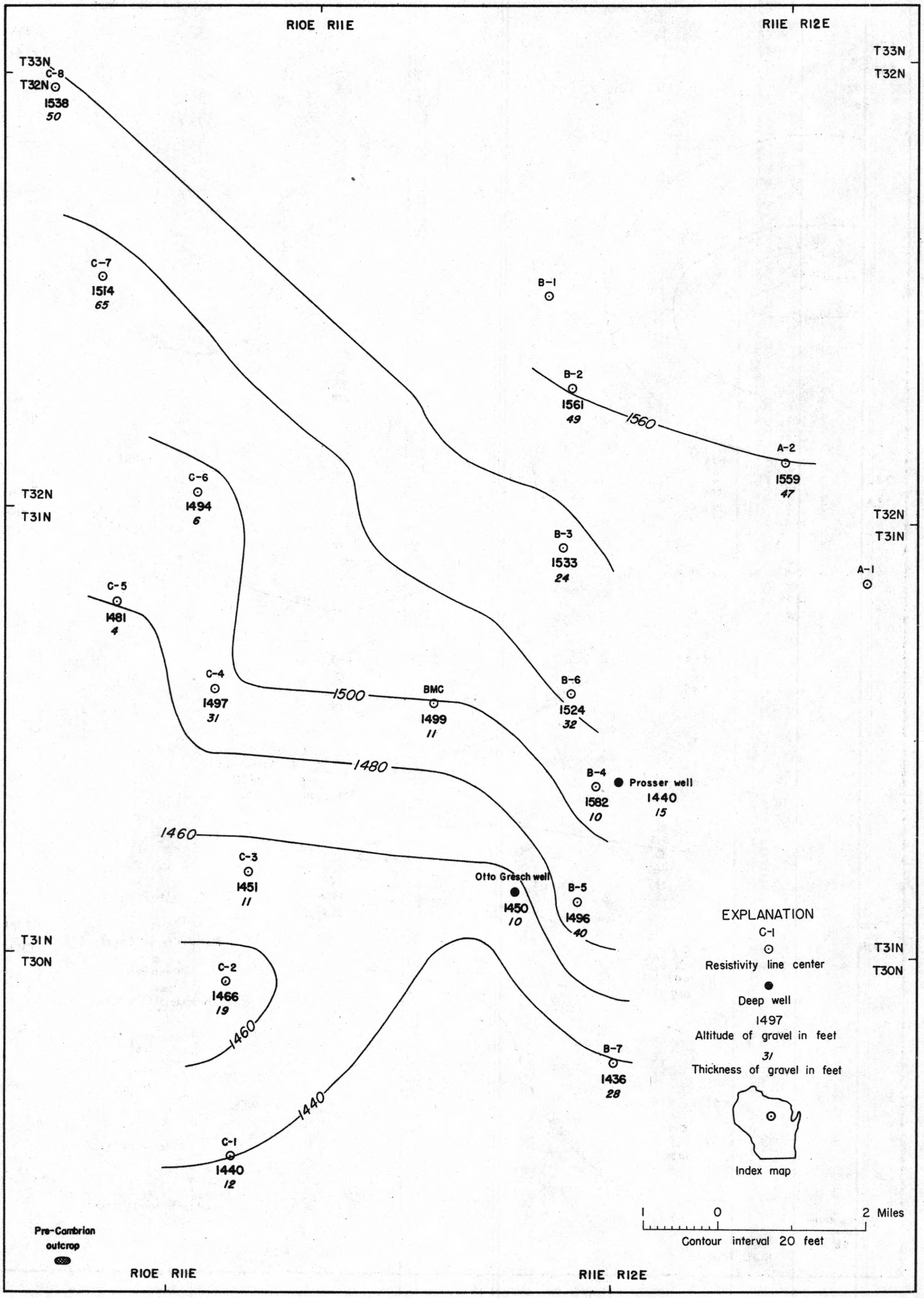

Figure 4.--Contours on top of sand and gravel deposits based on resistivity measurements.

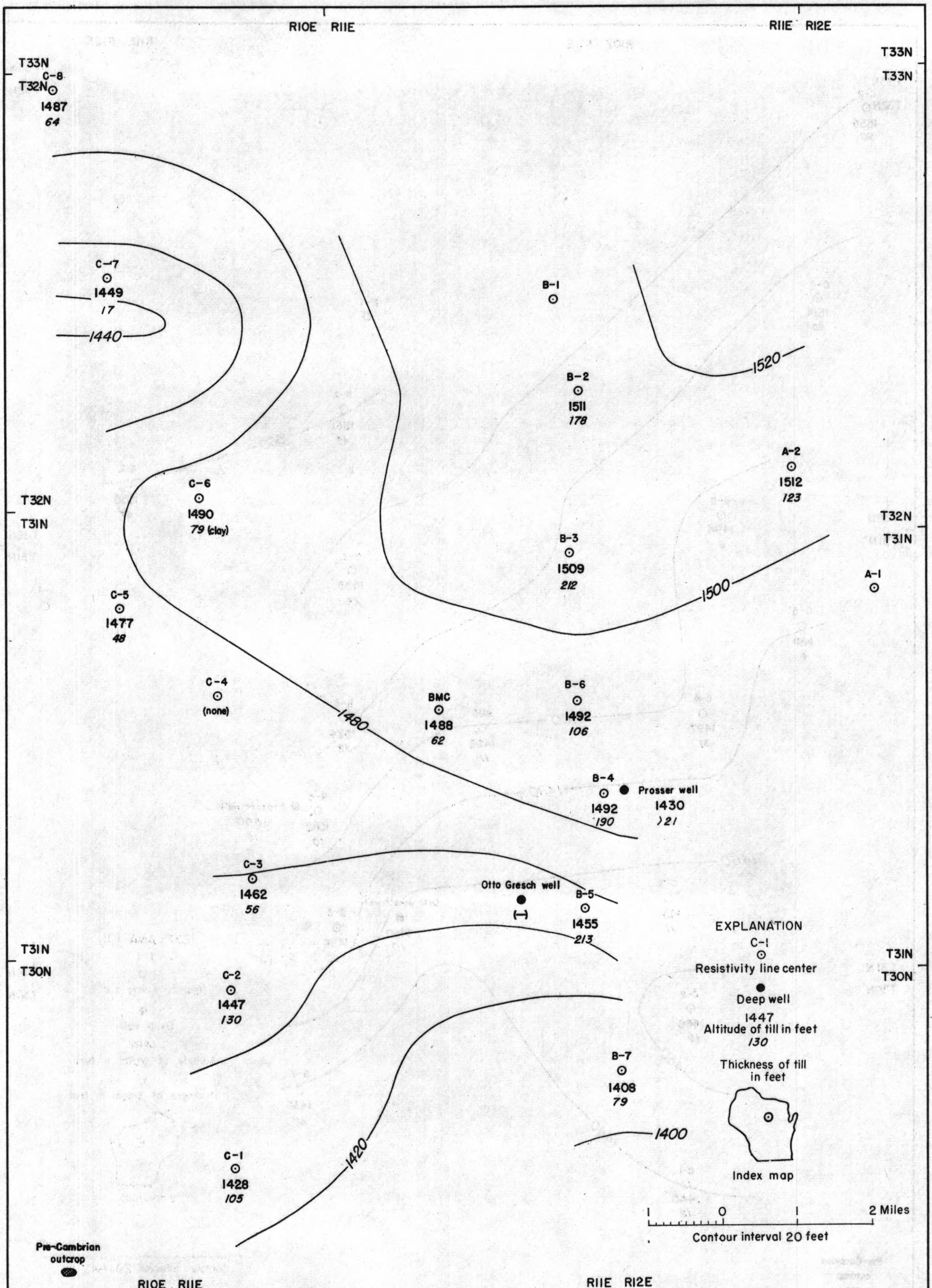

Figure 5.--Contours on top of till deposits based on resistivity measurements.

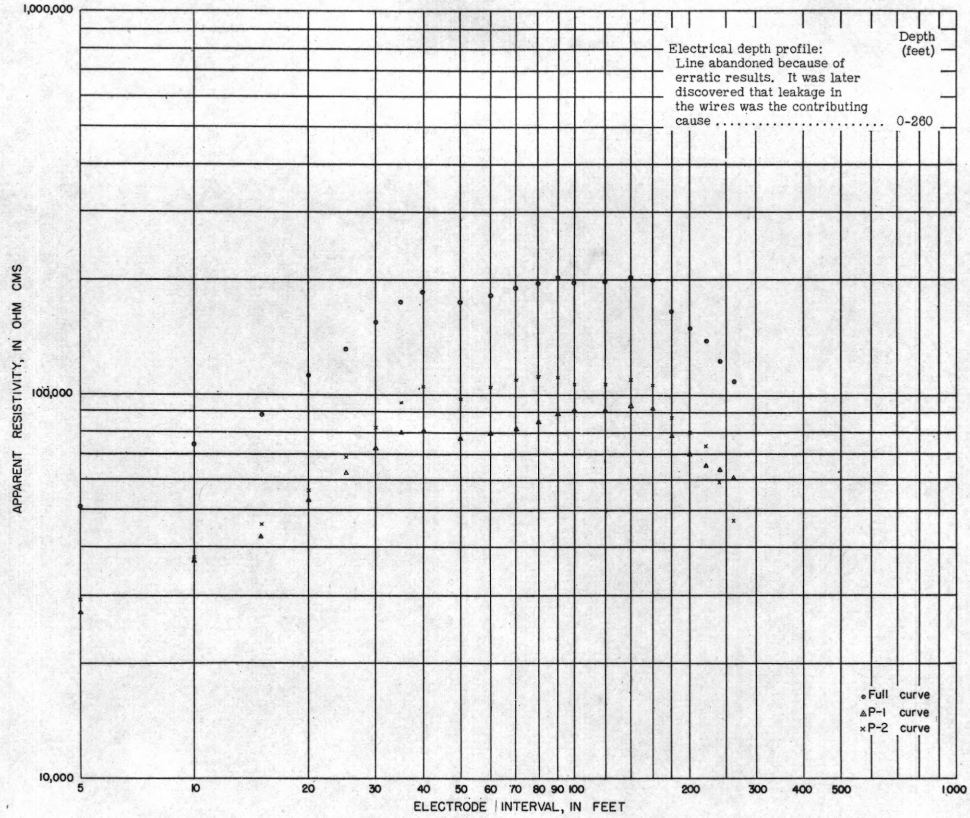

Figure 6.--Line A-1, SW¼SW¼ sec. 5, T. 31 N., R. 12 E. P-1 N. 1° E. Altitude, 1,595 ft.

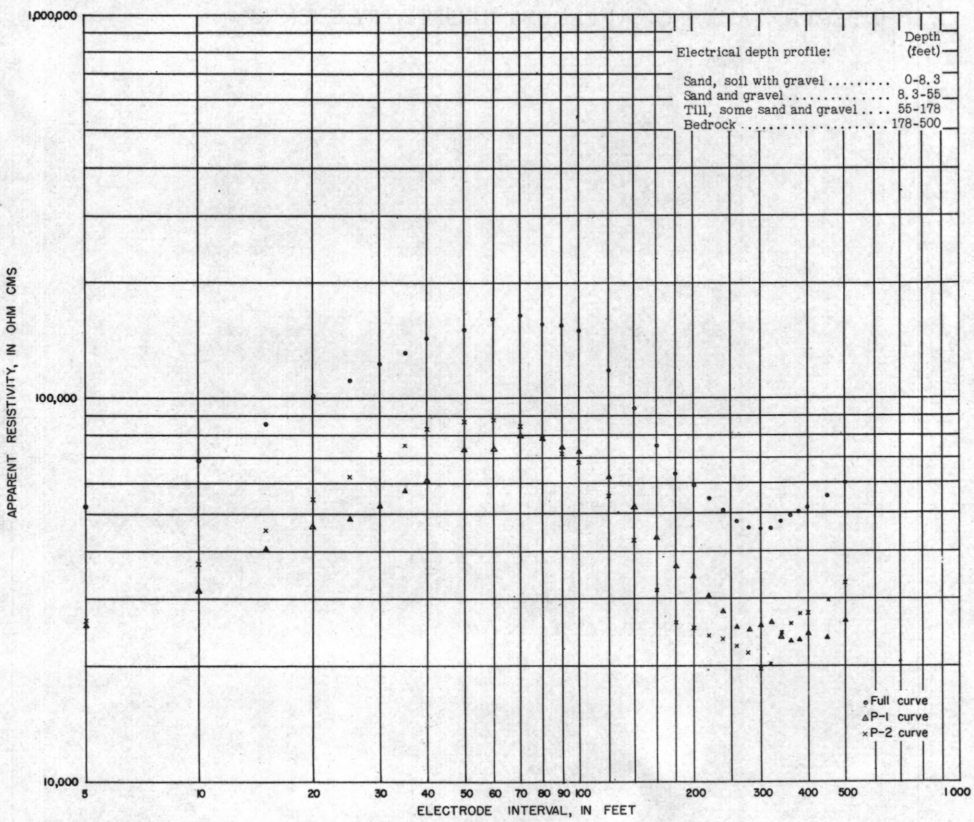

Figure 7.--Line A-2, NE¼NE¼ sec. 36, T. 32 N., R. 11 E. P-1 N. 2° W. Altitude, 1,567 ft. The interpreted depths or thicknesses of beds given in this section are not to be considered accurate to tenths of a foot. These values are given primarily to assist those interested in following through the interpretation procedure as outlined in the text, because by using the method described, the values can easily be interpreted in tenths of a foot to depths of approximately 15 to 20 ft.

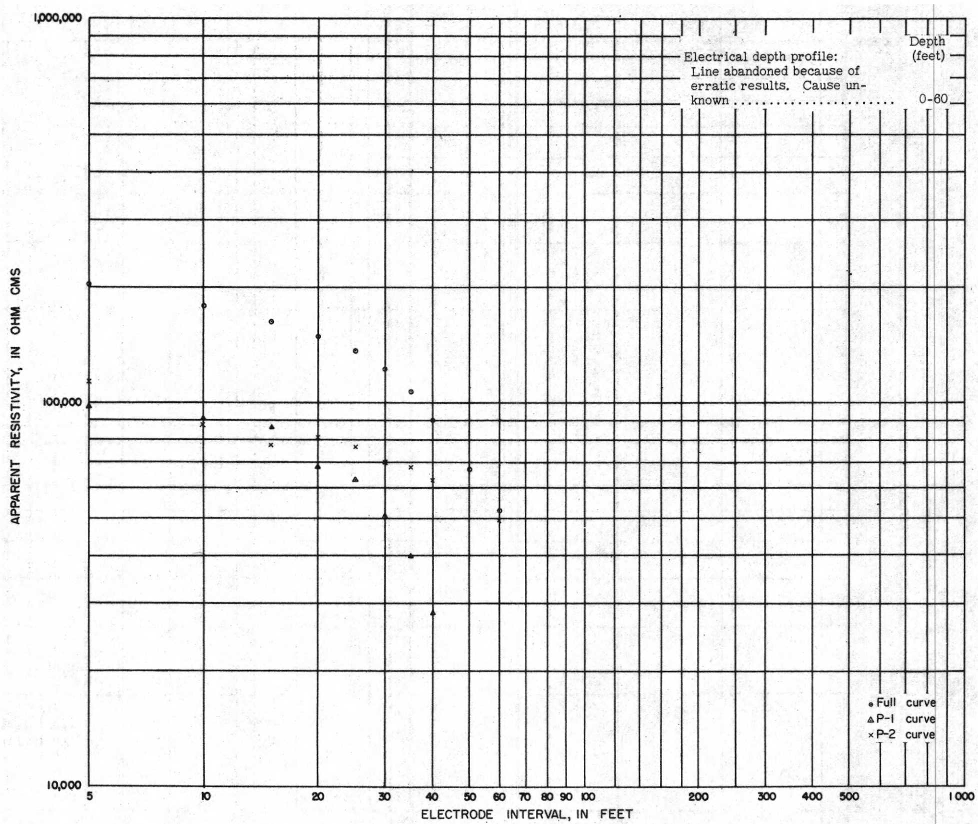

Figure 8.--Line B-1, SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 16, T. 32 N., R. 11 E. P-1 N. 90° E. Altitude not taken.

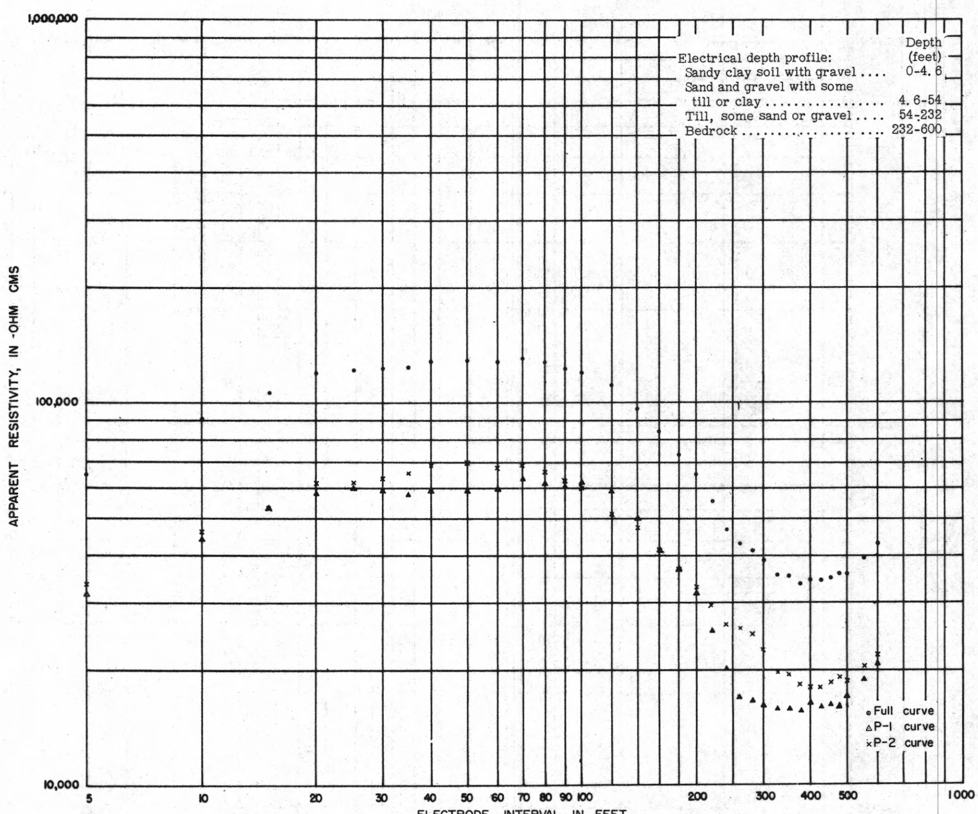

Figure 9.--Line B-2, NW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 28, T. 32 N., R. 11 E. P-1 N. 5° W. Altitude, 1,565 ft.

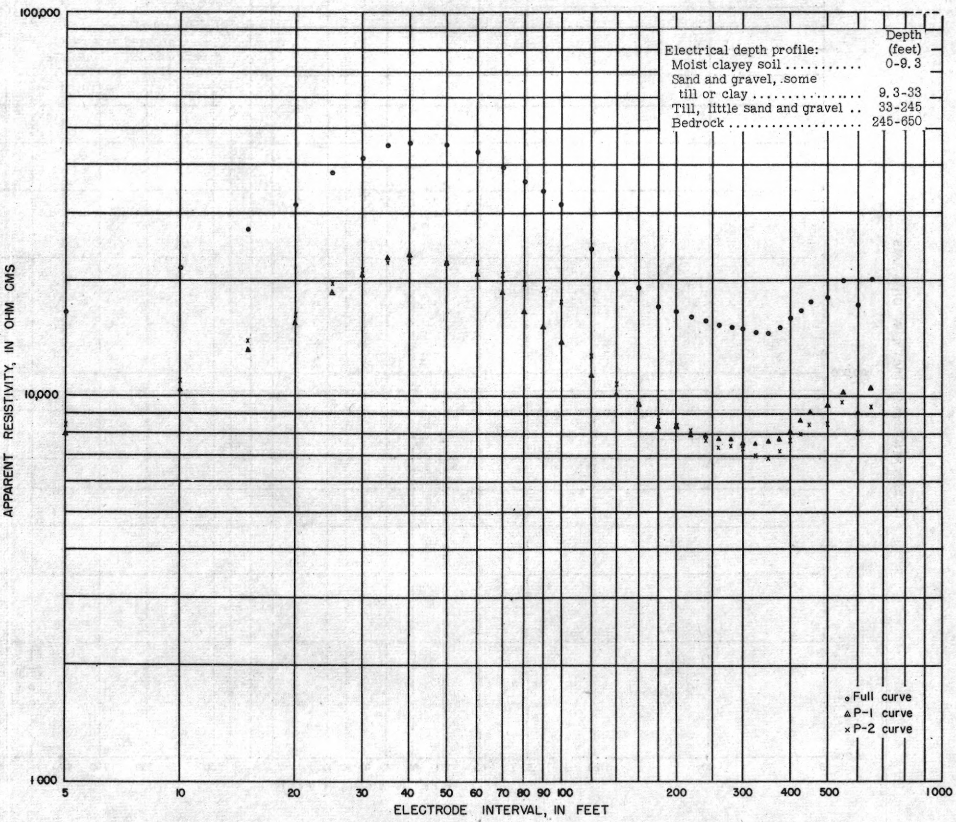

Figure 10.--Line B-3, SE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 4, T. 31 N., R. 11 E. P-1 N. 5° W. Altitude, 1,542 ft.

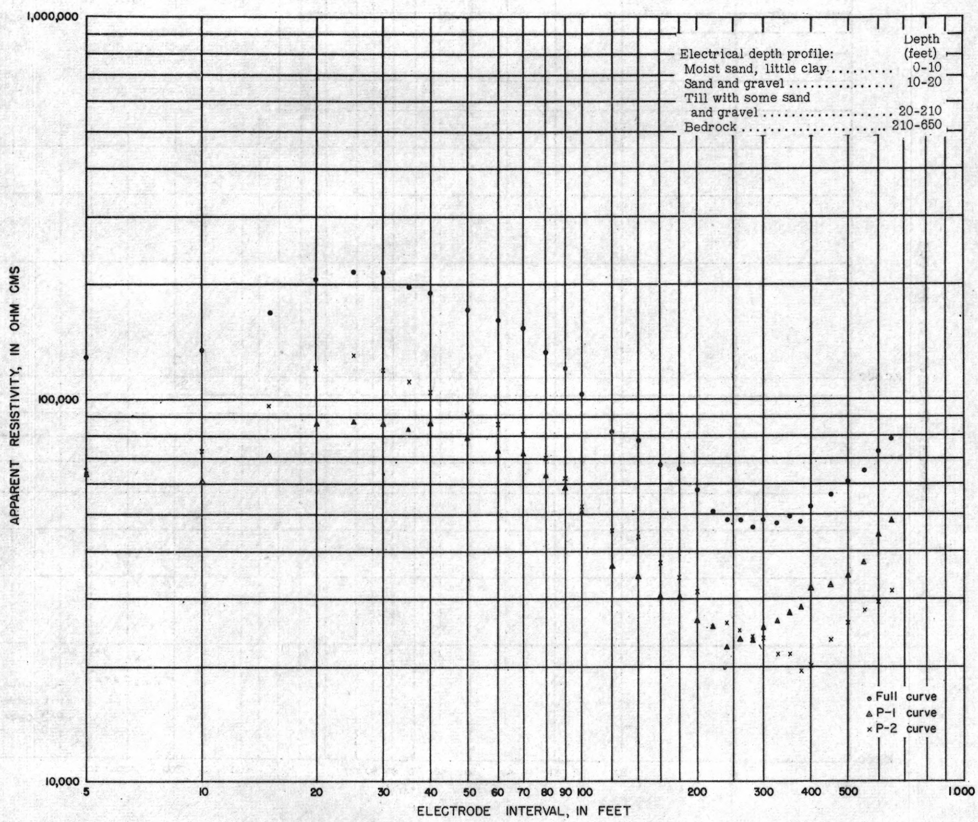

Figure 11.--Line B-4, NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 22, T. 31 N., R. 11 E. P-1 N. 0° E. Altitude, 1,512 ft.

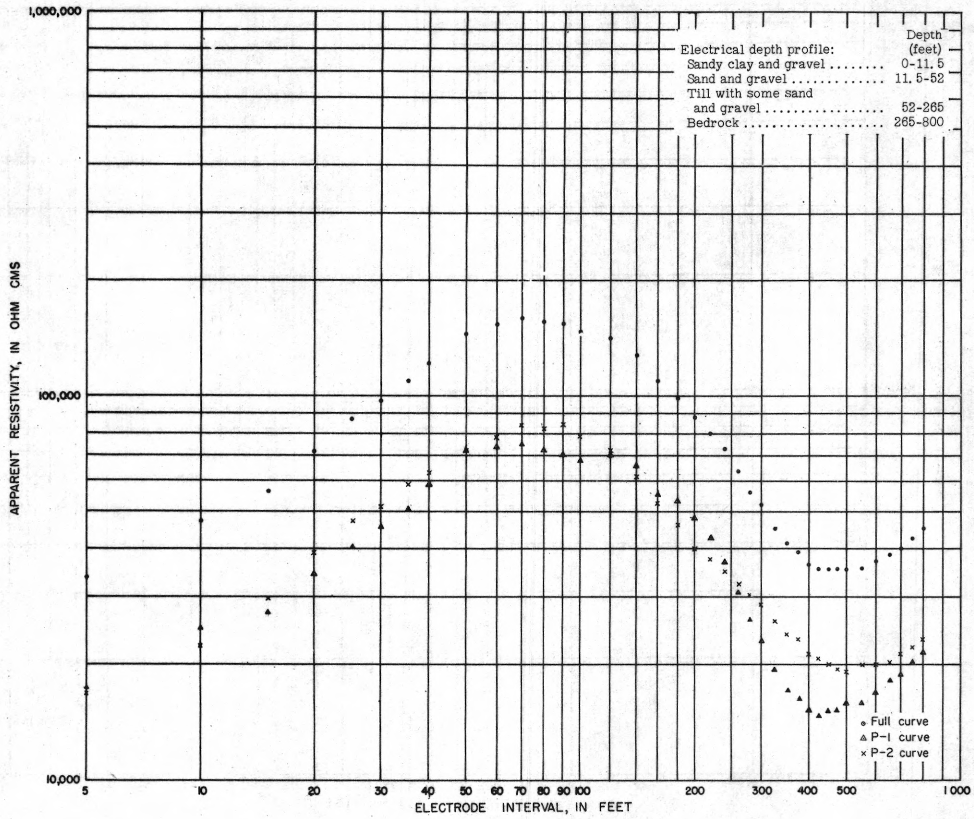

Figure 12.--Line B-5, Center NW¼ sec. 34, T. 31 N., R. 11 E. P-1 N. 4° W. Altitude, 1,507 ft.

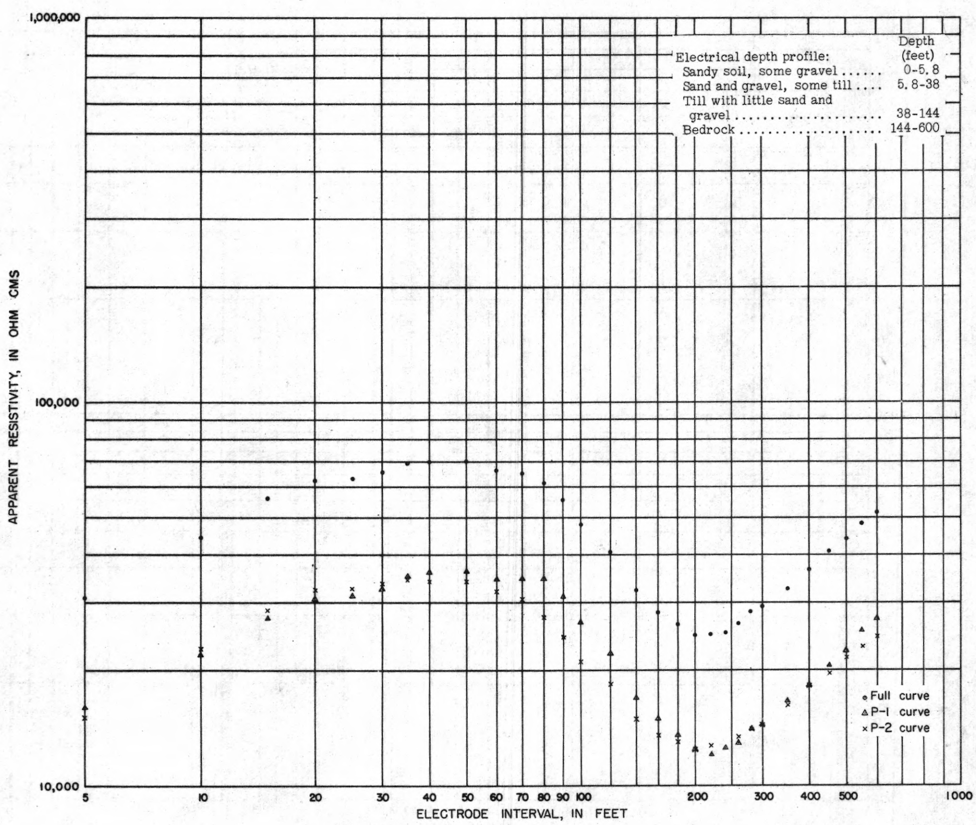

Figure 13.--Line B-6, NW¼SW¼ sec. 15, T. 31 N., R. 11 E. P-1 N. 13° E. Altitude, 1,530 ft.

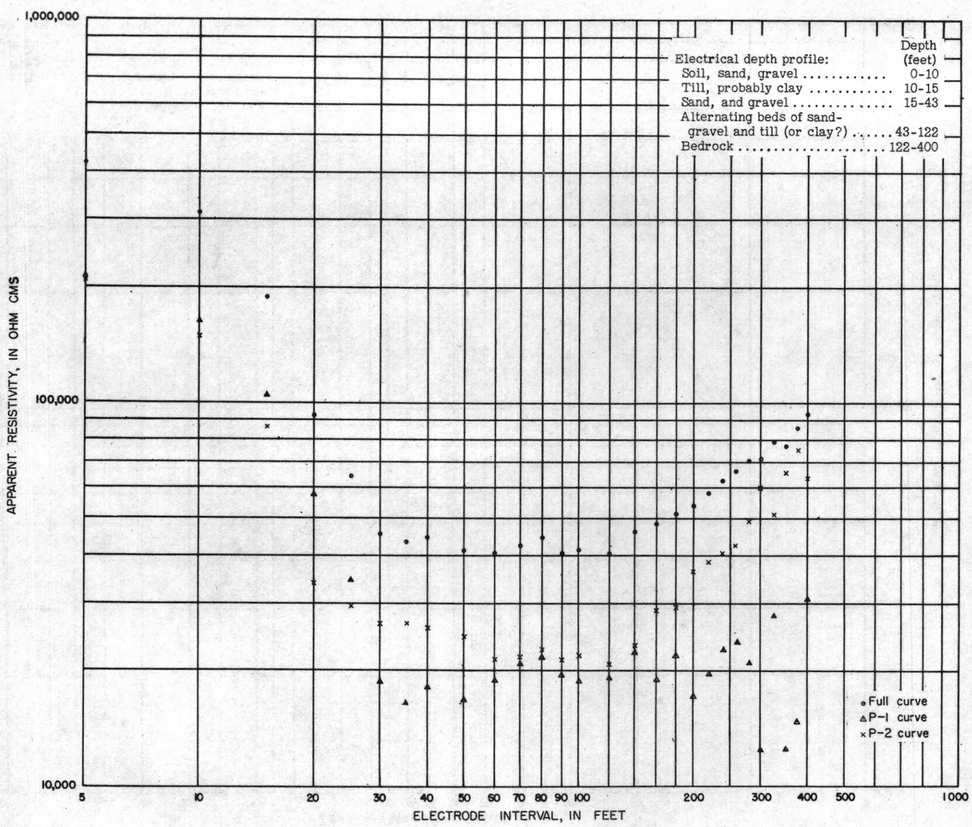

Figure 14.--Line B-7, SW¼NW¼ sec. 7, T. 30 N., R. 12 E. P-1 N. 2° W. Altitude, 1,451 ft.

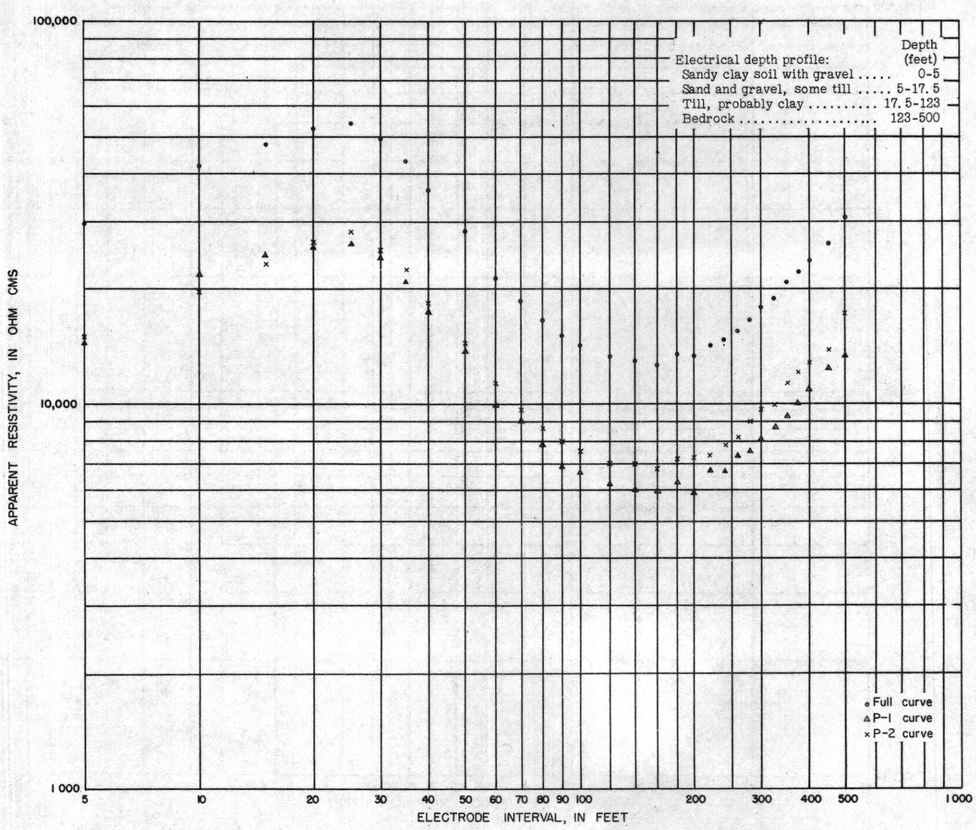

Figure 15.--Line C-1, NE¼SE¼ sec. 16, T. 30 N., R. 11 E. P-1 N. 55° E. Altitude, 1,445 ft.

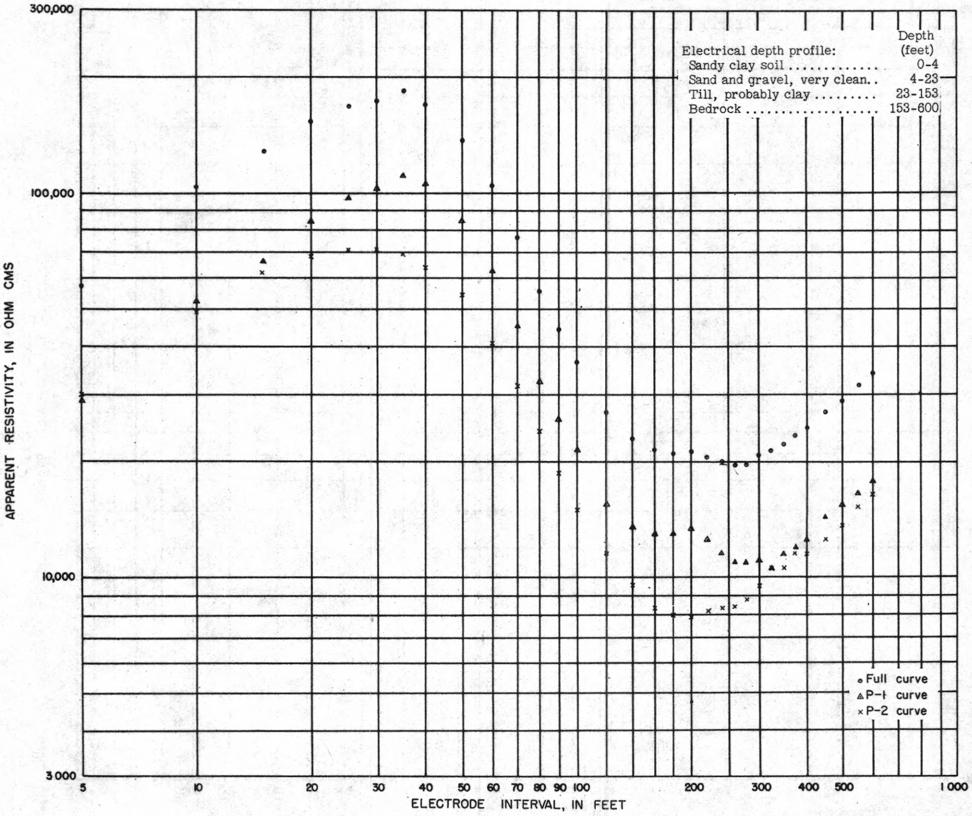

Figure 16.--Line C-2, SE¼NE¼ sec. 6, T. 30 N., R. 11 E. P-1 N. 5° W. Altitude, 1,470 ft. There is an appreciable difference in depths to bedrock on the P-1 and P-2 halves of the measurements. This is interpreted as indicating that the center of the line lies near the edge of an old lake, which is now filled. The depth to bedrock increases to the north.

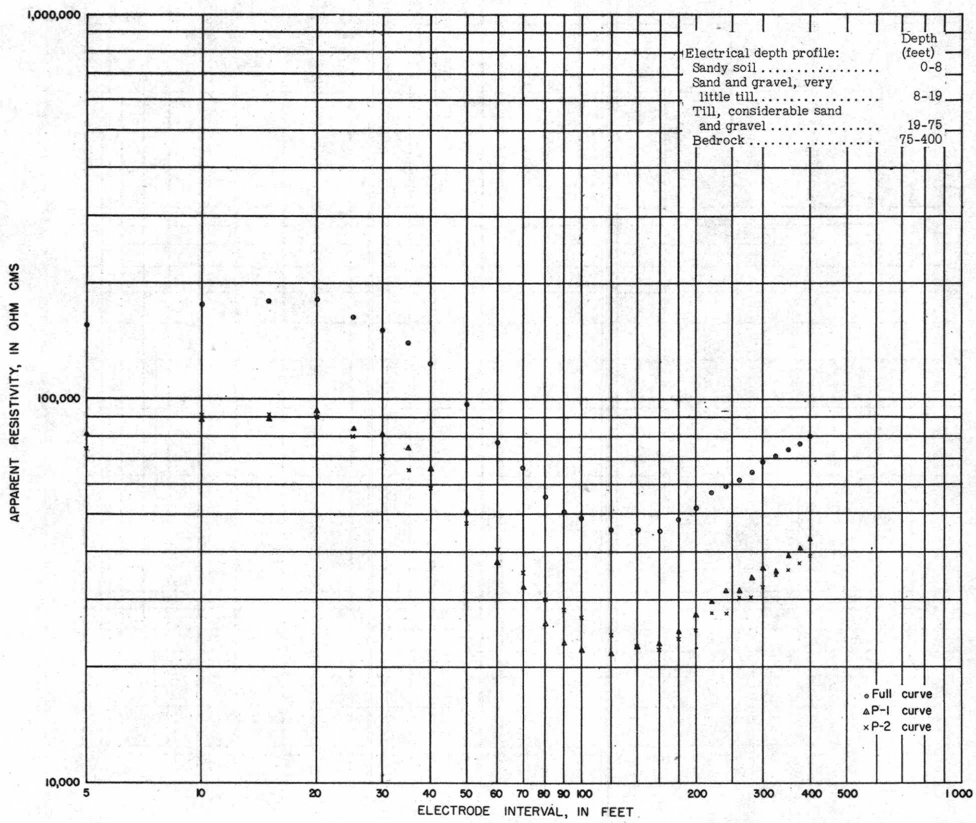

Figure 17.--Line C-3, SW¼NE¼ sec. 26, T. 30 N., R. 10 E. P-1 N. 3° W. Altitude, 1,470 ft.

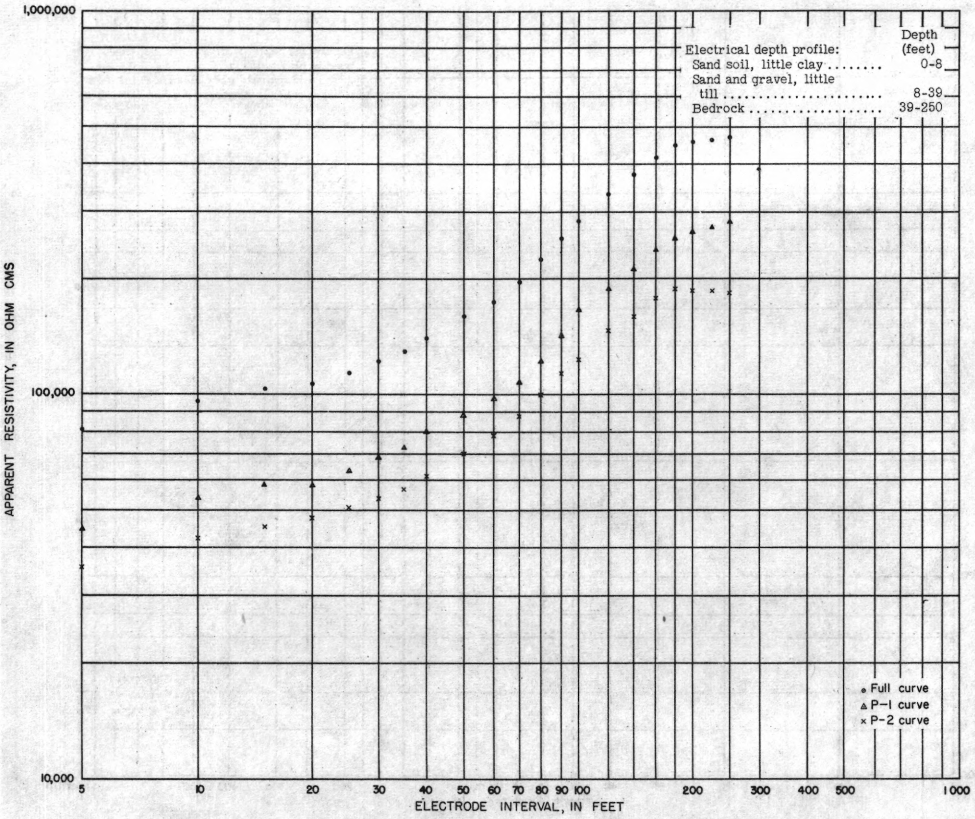

Figure 18.--Line C-4, SE¼NW¼ sec. 14, T. 31 N., R. 10 E. P-1 N. 4° W. Altitude, 1,505 ft.

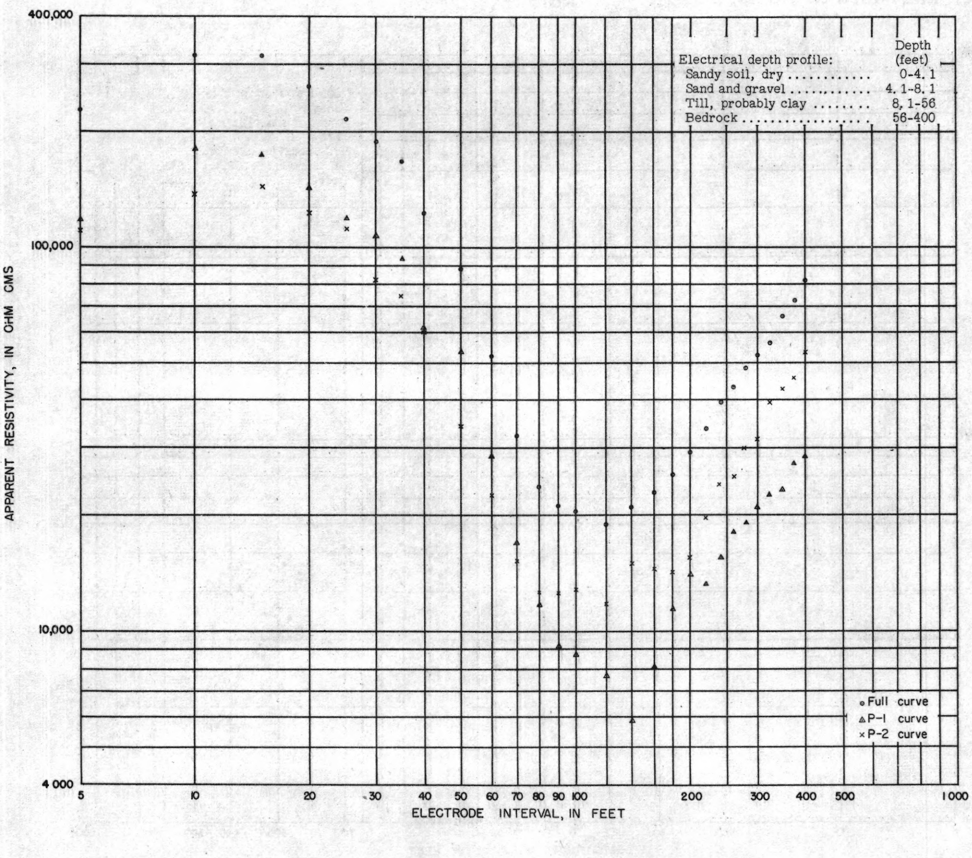

Figure 19.--Line C-5, NW¼NW¼ sec. 10, T. 31 N., R. 10 E. P-1 N. 1° W. Altitude, 1,485 ft.

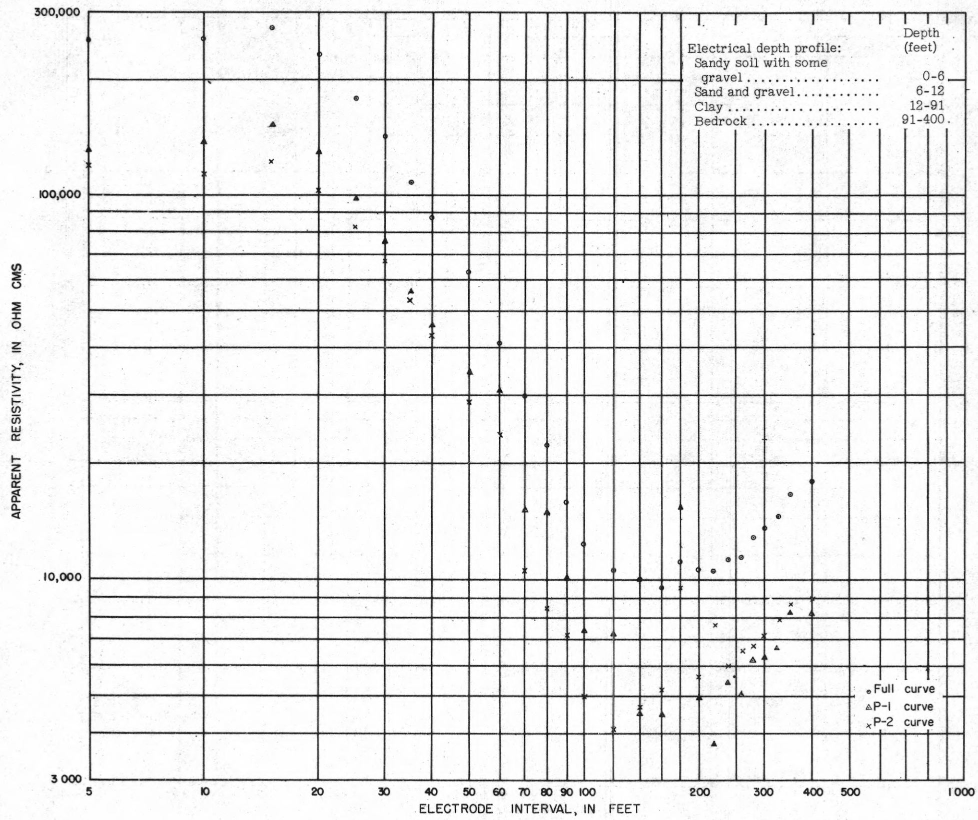

Figure 20.--Line C-6, SW¼SW¼ sec. 35, T. 32 N., R. 10 E. P-1 N. 85° E. Altitude, 1,502 ft.

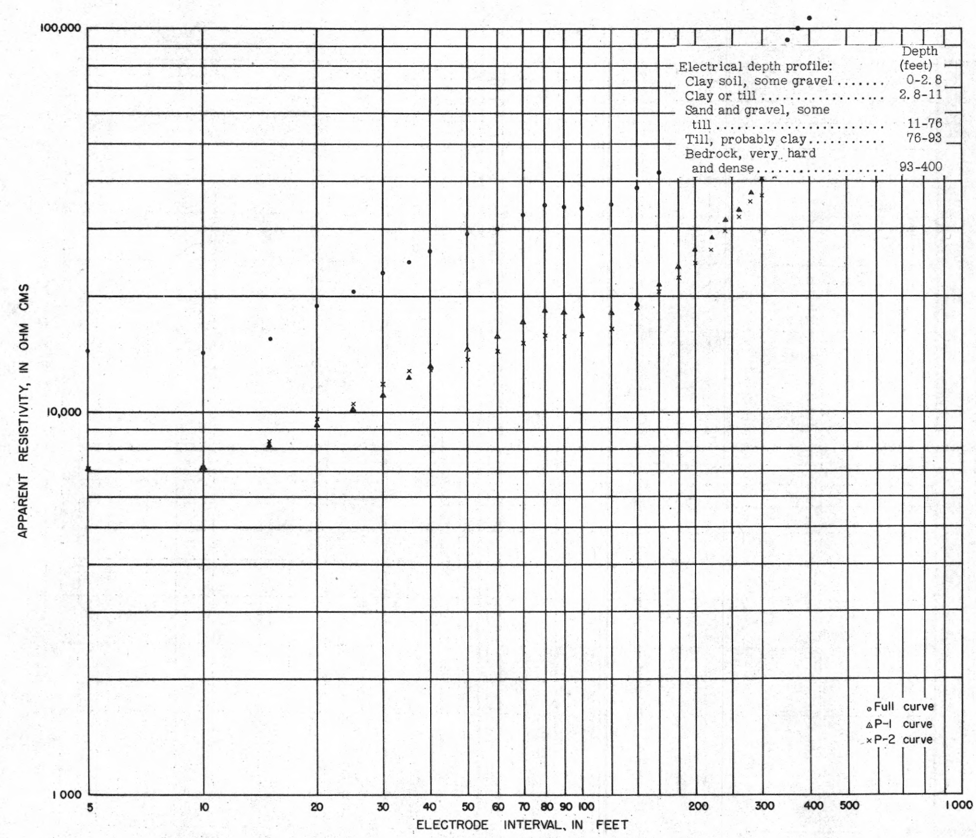

Figure 21.--Line C-7, SE¼SE¼ sec. 16, T. 32 N., R. 10 E. P-1 N. 5° W. Altitude, 1,525 ft. At some place between Lines C-6 and C-7, the till layer begins to thin so that at C-7 it is only about one-seventh as thick as at C-6.

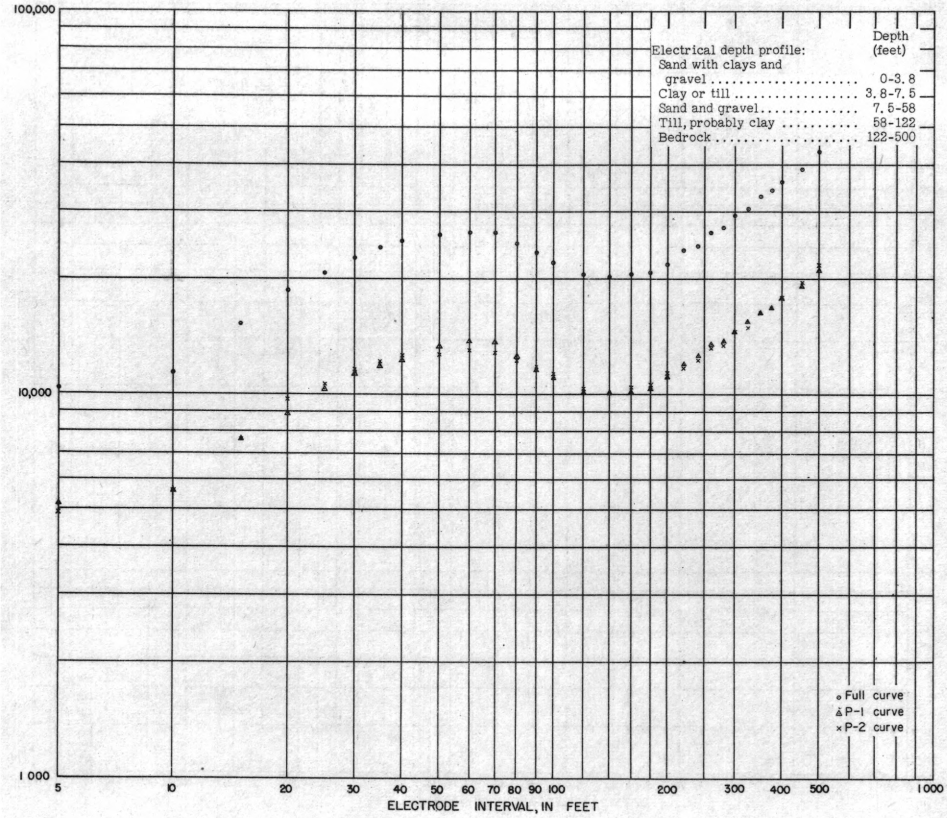

Figure 22.--Line C-8, NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 4, T. 32 N., R. 10 E. P-1 N. 12° W. Altitude, 1,545 ft.

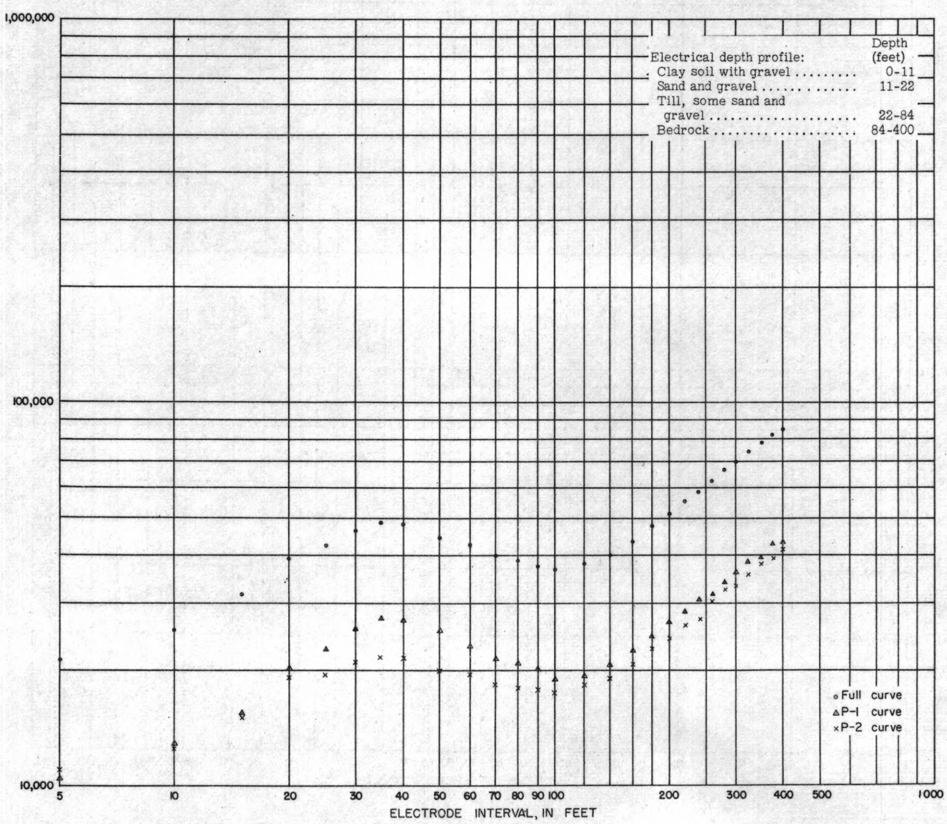

Figure 23.--Line BMC, NW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 17, T. 31 N., R. 11 E. P-1 N. 4° W. Altitude, 1,510 ft.

WELL LOGS

[Samples examined by F. T. Thwaites]

Otto Gresch farm well, Antigo, Wis., E$\frac{1}{4}$NW$\frac{1}{4}$, W$\frac{1}{2}$NE$\frac{1}{4}$ sec. 33, T. 31 N., R. 11 E. Altitude, 1,510 ft (estimated)

	Depth (feet)
Sand, fine, silty	0-5
Sand, medium; some pebbles	5-35
Sand, fine to coarse	35-50
Sand, medium to coarse	50-60
Sand, medium; some pebbles	60-69

Prosser farm well, Antigo, Wis., SE$\frac{1}{4}$ sec. 22, T. 31 N., R. 11 E.. Altitude, 1,510 ft (estimated)

Gravel, sandy	0-5
Sand, coarse; some pebbles	5-20
Sand, medium to very coarse	20-30
Gravel, sandy, coarse	30-35
Sand, fine to coarse	35-60
Gravel, sandy, coarse	60-65
Sand, medium to pebbly	65-80
Till, very sandy	80-87
Gravel, fine, stony	87-92
Till, sandy	92-101

Antigo test well 1. Near corner of Graham Avenue and Fulton Street. NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 29, T. 31 N., R. 11 E. Altitude, 1,500 ft

Silt, some sand, brownish-gray	1-5
Sand, fine to coarse, much silt, brownish-gray	5-10
Sand, medium to very coarse, light-gray	10-15
Sand, medium to very coarse	15-20
Sand, medium, light-gray	20-30

Antigo test well 1.--Continued

	Depth (feet)
Sand, medium, light-gray	30-40
Sand, medium, light-gray; some small pebbles	40-45
Sand, medium to coarse, light-gray; some small pebbles	45-52
Sand, medium to coarse, light-gray	52-58$\frac{1}{2}$
Sand, medium to very coarse, much silt, yellowish-gray	58$\frac{1}{2}$-73

Antigo test well 2. Near corner of Arctic Street and Graham Avenue. NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 29, T. 31 N., R. 11 E. Altitude, 1,500 ft

Silt, some sand, light brownish-gray	1-5
Sand, fine to medium, much silt, light brownish-gray	5-10
Sand, medium to coarse; some silt, light-gray	10-15
Sand, medium to coarse, light-gray	15-18
Sand, medium to very coarse, small pebbles, light-gray	18-30
Sand, medium, light-gray, very little coarse material	30-32
Sand, medium to coarse; pebbles to $\frac{1}{2}$ in	32-35
Sand, medium, light-gray	35-47
Sand, medium to coarse, some pebbles, light-gray	47-54
Sand, fine to coarse, light-gray	54-57
Sand, medium to coarse, brown-gray; some silt	57-61
Sand, medium to coarse; small pebbles	61-71
Gravel, fine, sandy, light-gray; stones to $\frac{1}{2}$ in	71-72
Bedrock, no samples, driller's report	72

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