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Some Shallow Earth-Resistivity Measurements in Iowa

By HOWARD R. DIXON AND THEODORE L. WELP[1]

INTRODUCTION

The Materials Department of the Iowa State Highway Commission has been experimenting with the electrical earth-resistivity method of geophysical exploration. During the summer of 1955 a full time crew ran extensive tests over various selected locations throughout the state of Iowa. The purpose of this investigation was to evaluate and demonstrate the use of earth-resistivity in preliminary subsurface reconnaissance by providing subsurface information useful in determining location, design, and construction of highways.

Experiments were made with both the depth profiling and the constant depth resistivity traverse methods of field operation. Three methods were used for analysing the field data: the Gish-Rooney (1925) or apparent resistivity curve, the cummulative resistivity technique developed by Moore (1945), and the individual layer or specific resistivity method devised by Barnes (1952). These methods will be described in the text.

The authors would like to point out that the following report is not a final analysis, but should be considered as a progress report of the initial years work.

APPARATUS

The equipment used in this investigation was built by the Ames Laboratory personnel of the Iowa State Highway Commission from plans supplied by the Physical Research Branch, Bureau of Public Roads (Shepard, 1935). As shown in the accompanying illustration (Figure 1), a milliammeter, potentiometer, and various current controlling devices are mounted in a hardwood box. The power supply unit consists of ten 22½ volt "B" batteries mounted in a wooden box that is equipped with the proper electrical connections and switches necessary to control the number of batteries to be used in the circuit. Four reels containing rubber insulated copper cable are mounted on a reel board in such a manner that they can be revolved without breaking contact in the circuit. The remaining equipment consists of two steel current electrodes, two porous pot potential electrodes filled with copper sulphate, and two specially marked cloth tapes.

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Figure 1. Portable electrical resistivity apparatus used by the Iowa State Highway Commission.

THEORY AND PROCEDURE

Figure 2 illustrates the component parts of an electrode arrangement that is usually referred to as Wenner's configuration. The four electrodes are placed in contact with the ground, equally distant apart, and in a straight line. After the instrument has been balanced a direct current (I), measured by the milliammeter, is passed between electrodes C_1 and C_2. At the same time the potential drop (E) between the two inner electrodes P_1 and P_2 is measured by the potentiometer. Two sets of measured current and potential readings are taken and the average recorded for each interval. The second set of the forementioned readings is taken with the current flow reversed to compensate for any stray currents present in the ground. Empirically, the above procedure will measure the resistivity of a mass of earth to a depth equal to the spacing "A" between the electrodes. Any electrode spacing can be used, but the authors have found three foot increments to be the most satisfactory for shallow depth—less than 100 feet—exploration. The electrodes are next moved to a second position which places them two "A" increments or six feet apart, and the total depth measured is equal to "2A" or six feet. The above procedure is repeated, increasing the spacing by "A" each time until the required depth to be measured is reached. This is what is called the depth profiling procedure.

On occasion it has been found useful to run what is here called

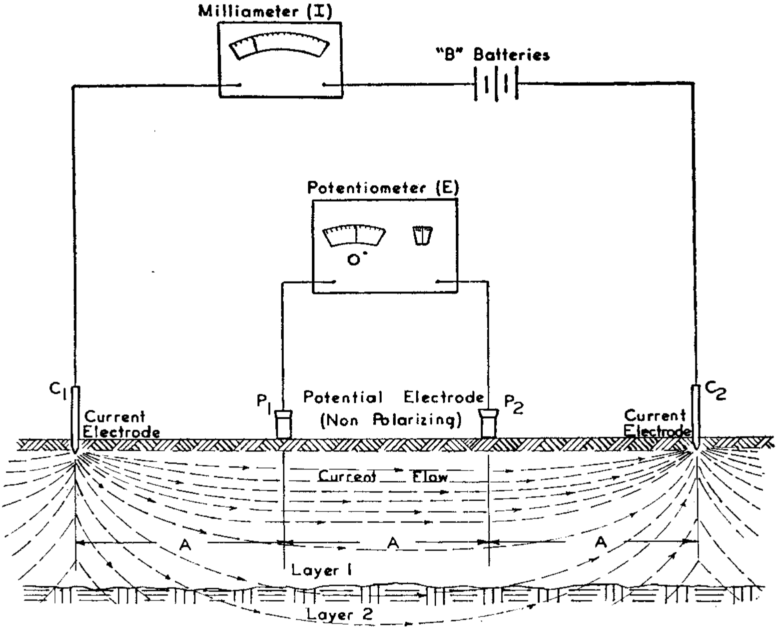


Figure 2. Schematic diagram showing fundamental principals of earth-resistivity.

the constant depth resistivity traverse. In this method of operation the electrode spacing is maintained at a constant increment and only one reading is taken at each station. From the resulting data a curve is plotted showing the apparent resistivity of the earth along the traverse for the fixed depth being investigated. This method is very useful when it is necessary to investigate wide areas in the shortest possible time as any high apparent resistivity reading will be indicative of possible changes in the strata below the surface being surveyed.

CALCULATIONS

All calculations in this report are based on Wenner's (1916) basic equation:

$$\rho a = 2 \pi A k \frac{E}{I} \qquad \text{(Equation 1)}$$

Where:

ρa=apparent resistivity in ohm-cm,
A =distance in feet between electrodes,
E =average potential drop in volts,
I =average current in milliamps,
k =a conversion constant for converting feet to centimeters.

The values of E and I obtained for each increment are substituted into equation 1 and the apparent resistivity calculated and plotted on graph paper as the ordinate, and the electrode increment "A" as the abscissa. The resulting curve will here be called the apparent resistivity curve, ρa, and is plotted as a dotted line in all the accompanying illustrations. Inflections shown by this curve indicate materials of different resistivity, but, because these inflections are smooth curves they seldom indicate the exact depth at which the changes in resistivity occur. This is the first method of analysis.

The second curve plotted is the cumulative resistivity curve, $\Sigma\rho$. On this curve the sum of all the apparent resistivities up to each corresponding "A" increment is plotted. Some of these plotted points can be connected by straight lines, and the point where the prolongation of any two such straight lines intersect has been found by Moore (1945) to empirically indicate the depth of the point of contact between two layers of different resistivity. The apparent and cumulative resistivity curves, when used in conjunction with one another, will locate with reasonable accuracy the position of the contacts between materials of different resistivities.

The third type of analysis is the individual layer or specific resistivity, ρ_S, curve. This method utilizes Equation 1 and has been modified by Barnes (1952) as follows:

$$\rho L_n = \pi A K \frac{E_n}{I_n - \dfrac{E_n}{\overline{R}_{n}\text{-}1}} \qquad \text{(Equation 2)}$$

Where:

ρ_l = resistivity in ohm-cm of any individual layer,
A = depth or thickness in feet of the layer interval,
I_n = current imput in amperes through the current electrodes,
E_n = potential difference in volts measured across the potential electrodes,
$\overline{R}_{n-1}$ = average resistance in ohms of the soil mass lying between the ground surface and the bottom of the layer just above the layer being investigated,
k = a conversion constant for converting feet to centimeters,
n = number of any individual layer.

The values determined by Equation 2 can be plotted as a bar graph for each increment, but the writers instead have used straight dashed lines to connect the midpoints of each bar at its extremity and have found that this greatly facilitates the plotting of the data (Figure 4). Each ρ_S value represents the resistivity of any individual layer of material of "A" thickness, and will be referred to as the specific resistivity. A detailed account of this method can be found in Barnes' (1954) publication.

This investigation has indicated that the specific resistivity curve is useful in predicting the lithologic types of materials below the ground surface at the point being tested. Figure 3 illustrates the specific resistivity ranges by percentage of the various lithologic material types from tests run over known exposures throughout Iowa during the summer of 1955. Twenty-five or more values were used in all the categories except quartzite, which is represented by only eight. It can readily be seen that about 70 to 80 percent of the values occur between definite specific resistivity limits. Experience has proven that in most cases the above mentioned limits are much more restricted in a small area during a limited time element. Many of the lithologic type specific resistivity values tend to overlap, but a basic knowledge of the geologic conditions present in the area under investigation will help in the interpretations. It will usually be necessary to run a calibration test over a known auger hole or exposure at the start or the finish of the project in order to facilitate the interpretations.

RESULTS OF TESTS

The descriptions of the following ten tests will demonstrate the versatility and reliability of the earth-resistivity method of subsurface exploration. In studying the tests it should be noted that the zero points of the scales have been placed to affect a separation of the curves on the graphs.

Test R 106 (*Figure 4*). Here is illustrated the method of presentation used for all tests. This test is one of a series that was run in Henry County where the bedrock is Mississippian limestone overlain by a thickness of about 20 feet of silty and sandy clay. The apparent resistivity curve shows a relatively low but increasing resistivity in the clay, followed by a more rapidly increasing resistivity once the limestone has been reached. Regardless of the lack of any sharp inflections on the apparent resistivity curve, the cummulative curve locates the contacts within a foot of their actual positions as logged in a test hole. The reason for the break at 28 feet could not be determined because the test hole did not go below the top of the bedrock. The derivation of the dashed line method of plotting the specific resistivity, as previously described, is illustrated here. In all the following figures the bars have been omitted and only the dashed lines drawn. The contact between the unconsolidated materials and the bedrock, in this test, is somewhat masked—probably due to the irregularity of the upper surface of the rock. The deeper unweathered rock

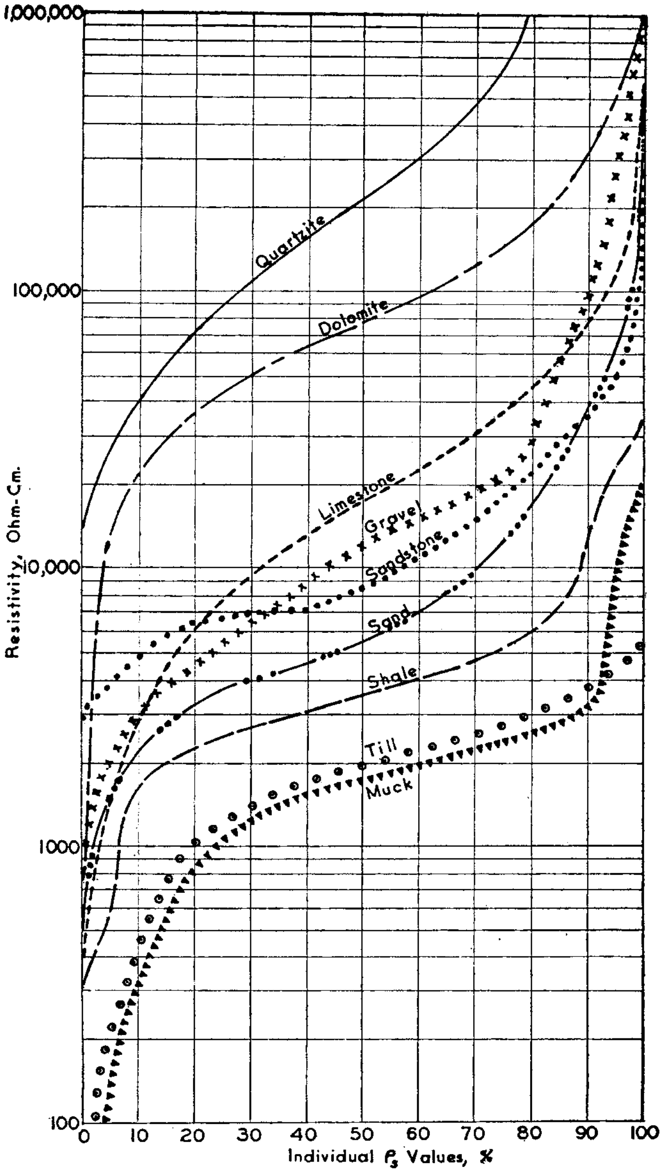


Figure 3. Cummulative-frequency curve showing specific resistivity, ρ_s, values of some earth materials.

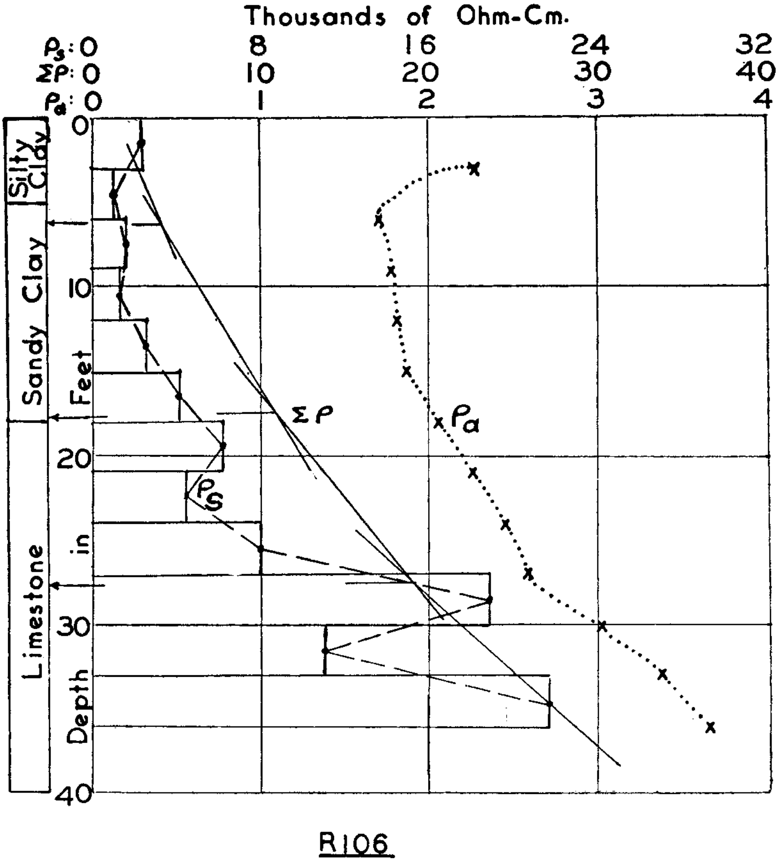


Figure 4. Earth-resistivity test showing method of presentation of apparent, summation, and specific resistivity curves.

shows the high specific resistivity values characteristic of limestone.

Test R 154 (*Figure 5*). This test was run 4500 feet west of Test R 106 and was included here for comparison because of the similar geologic conditions encountered. These two sets of curves, because of their similar trends (and with all of their local anomalies) are indicative of the reliability of the three-fold method of interpretation. The pronounced fluctuations in the apparent and specific resistivity curves may be due to groundwater conditions or to variations within the rock. This is one of the tests used in Figure 9.

Tests RT 8, RT 1, and RT 6 (*Figure 6*). Tests RT 8, RT 1 and RT 6 were run on exposures along State Highway 340 between the town of McGregor and Pikes Peak State Park. Test RT 8 was

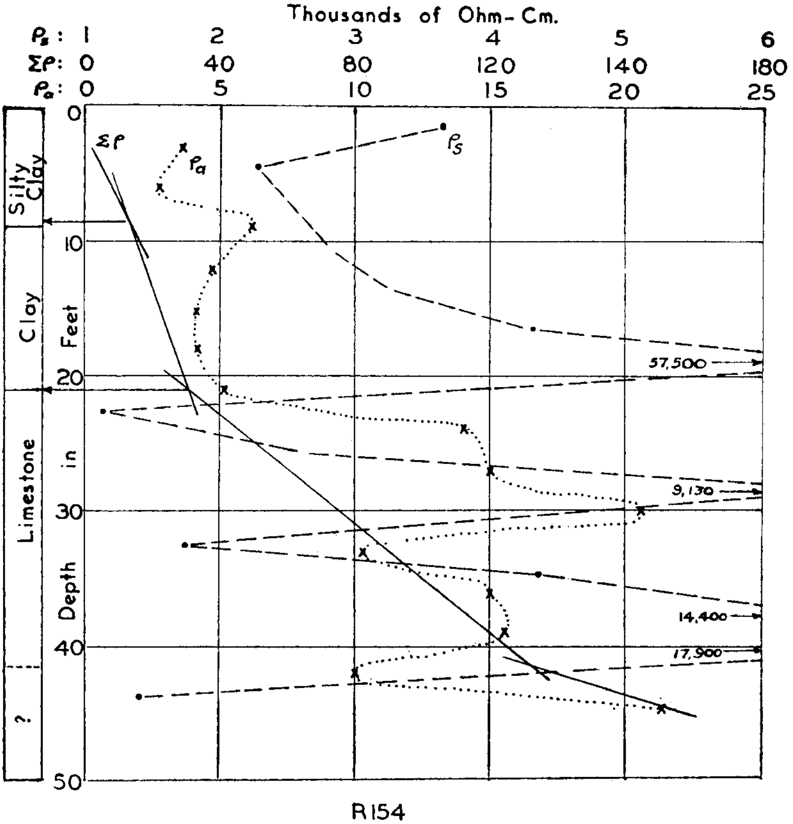


Figure 5. An earth-resistivity depth profile test on a highway relocation in Henry County.

run on the following geologic section in descending order: residual soil, Spechts Ferry shale, McGregor limestone, Pecatonica dolomite, Glenwood shale, and the St. Peter sandstone. This test illustrates the ability of the earth-resistivity method to point out the contacts of numerous lithologic changes in a given rock sequence. The intraformational break in the McGregor limestone is the transition zone between the upper massive and the lower thin-bedded rock. Tests RT 1 and RT 6 are simple two layer sequences and show the differences between apparent resistivity curves of a poorly cemented sandstone and a dolomite. Test RT 1, which was run over the St. Peter sandstone, shows a markedly decreasing resistivity once bedrock was reached, while Test RT 6 shows a sharp increase in both the apparent and specific resistivity in the Prosser dolomite.

Test R 184 (*Figure 6*). This test was run along "the bluff line" in the northern part of Harrison County on a silt-volcanic ash-

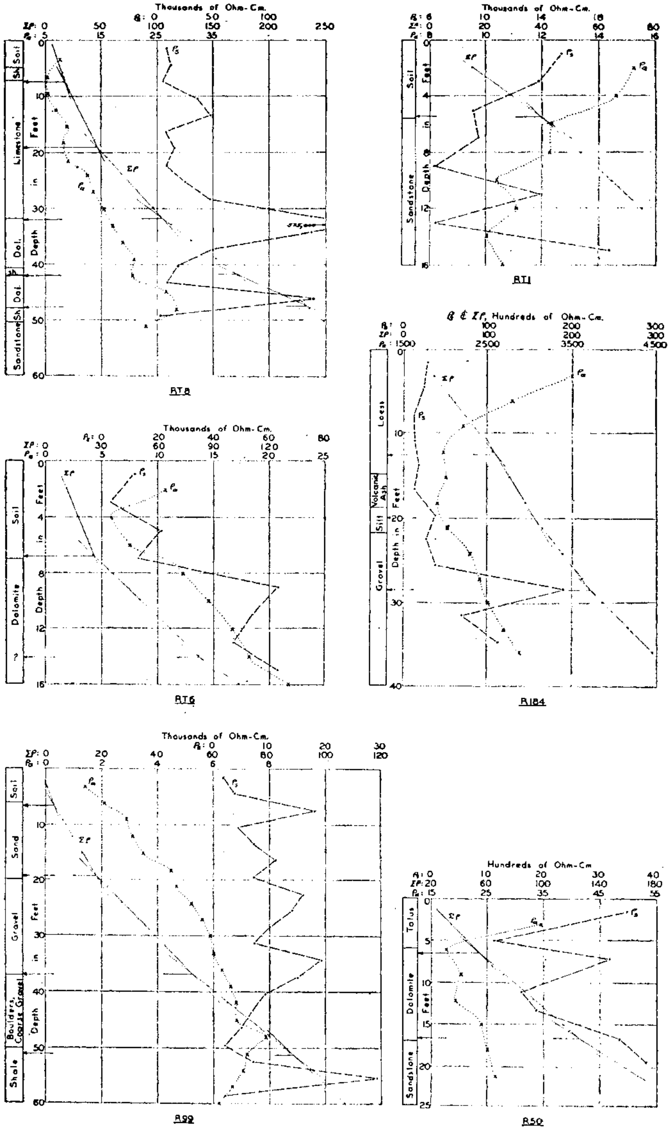


Figure 6. Shallow depth profile tests over various subsurface conditions in Iowa.

gravel deposit. A 2 foot cobble layer in the gravel between 27 and 29 feet accounts for the high specific resistivity at this layer and the resistivity changes at 28 feet. The cummulative curve shows one break for each change of material only, and does not distinctly mark the upper and lower boundaries of each. This may be due to the thinness of the layers or the similarity in resistivity of the layers.

Test R 99 (Figure 6). Here is a calibration test run over a known gravel deposit at Colfax, in Jasper Countery, and used in evaluating tests taken over gravel prospect sites (See Figure 8). In general the grain size of the material increased with depth to the contact with the Pennsylvanian shale. This increase in grain size is reflected in the apparent resistivity curve, which shows an increasing resistivity to the top of the shale.

Test R 50 (Figure 6). This test was one of a series run on a proposed relocation of a bridge approach to the Mississippi River at Marquette, Iowa. The bedrock, Madison dolomite, was overlain by a talus of limestone and dolomite boulders. This test was included to show the applicability of this method for determining the contact between talus and bedrock.

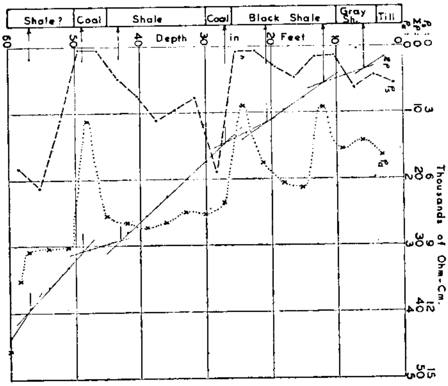
Test R 172 (Figure 7). This test was run on Pennsylvanian coal beds in a strip mine in Mahaska County. The coal beds, marked by extremely low resistivity, stand out quite clearly from the shale beds in both the apparent and specific resistivity curves. The contacts are somewhat obscured, which is due (possibly) to the high carbon content of the coals and black shales, the relative thinness of the coal beds, or the ionization of the ground water.

Test R 195 (Figure 7). Test R 195 was run over a peat and muck deposit in Cerro Gordo County. The apparent resistivity curve, after an initially high resistivity in the fill and peat, decreased abruptly, leveled off, and remained constant until the sand was reached. This profile typifies the curves of all tests run over muck deposits.

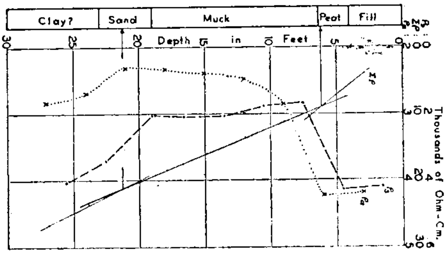
APPLICATIONS

Figure 8 shows how a calibration curve, R 99 (Figure 6), can be used for correlating and evaluating unknown curves. Curves R 101 and R 102 represent tests run over unknown deposits during a sand and gravel prospect in Jasper County. On the basis of the curves, it was predicted that only sand would be found at the two locations; this prediction was verified when the sites were drilled.

Figure 9 is a cross section of a proposed cut showing the practical application of earth-resistivity to a highway relocation project in Henry County. This cross section was compiled from a series of tests of which R 154 (Figure 5) is an example. It should be noted that the boundary between the silty clay and the clay



R172



R195

Figure 7. Depth profiles over carbonaceous material. Test R 172 taken along a strip mine exposure in Mahaska County. Test R 195 run over a peat and muck deposit in Cerro Gordo County.

was indicated in all the tests and that the data as plotted is in very close agreement with that obtained by drilling. The only exception to the apparent over-all agreement of data is Test R 34, where the top of the clay was indicated to be 4 feet below the projected contacts found by drilling. Because R 34 was run at a point between two holes drilled 100 feet apart it is difficult to verify the reliability of this prediction.

The application of the constant depth resistivity traverse to a highway relocation problem is demonstrated in Figure 10. Two constant electrode spacings, of 15 and 30 feet, were used in this illustration in order to better display the changes that occur in the apparent resistivity profiles for different depths to the limestone bedrock. Along most of the traverse the bedrock and resistivity profiles are in confirmation: that is, when the depth to the bedrock increases, the resistivity decreases. Usually, the overburden consists of silty clay underlain by clay, but in places the occurrence of a

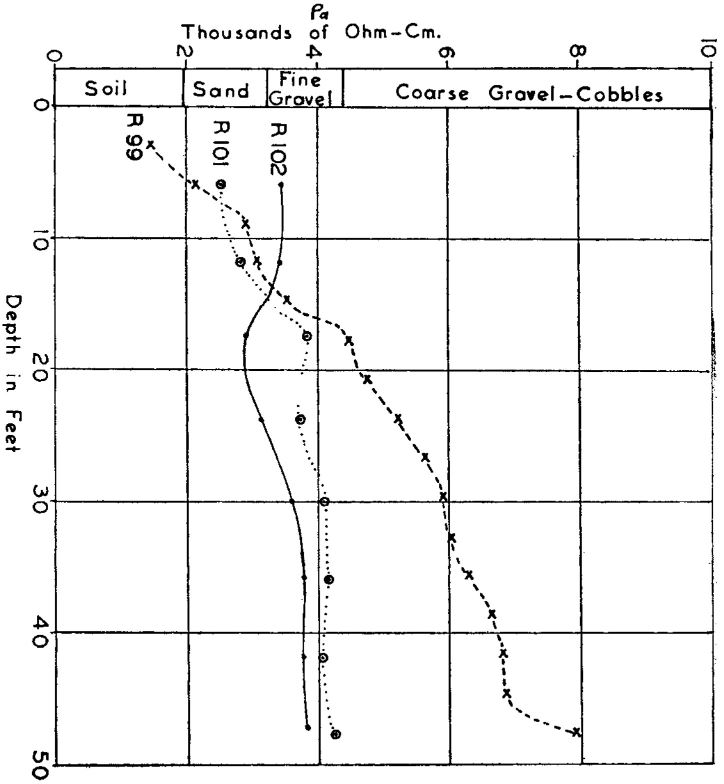


Figure 8. A graph showing the application of a calibration curve.

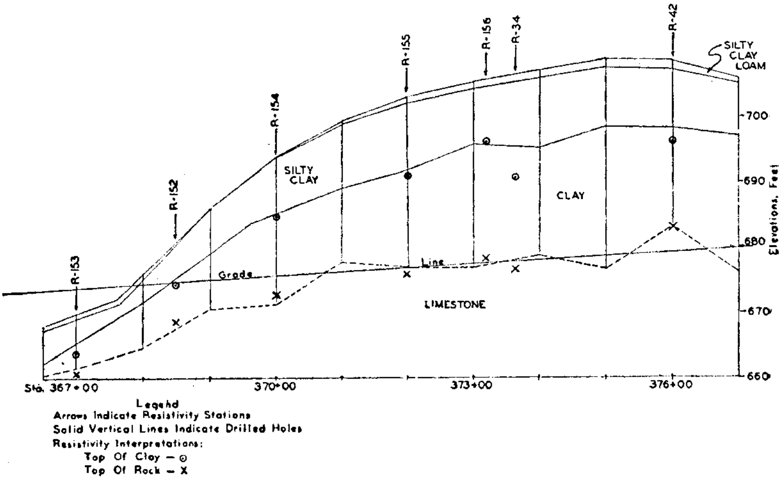


Figure 9. Cross section of a proposed cut along a highway relocation in Henry County, comparing resistivity data with subsurface data obtained by drilling.

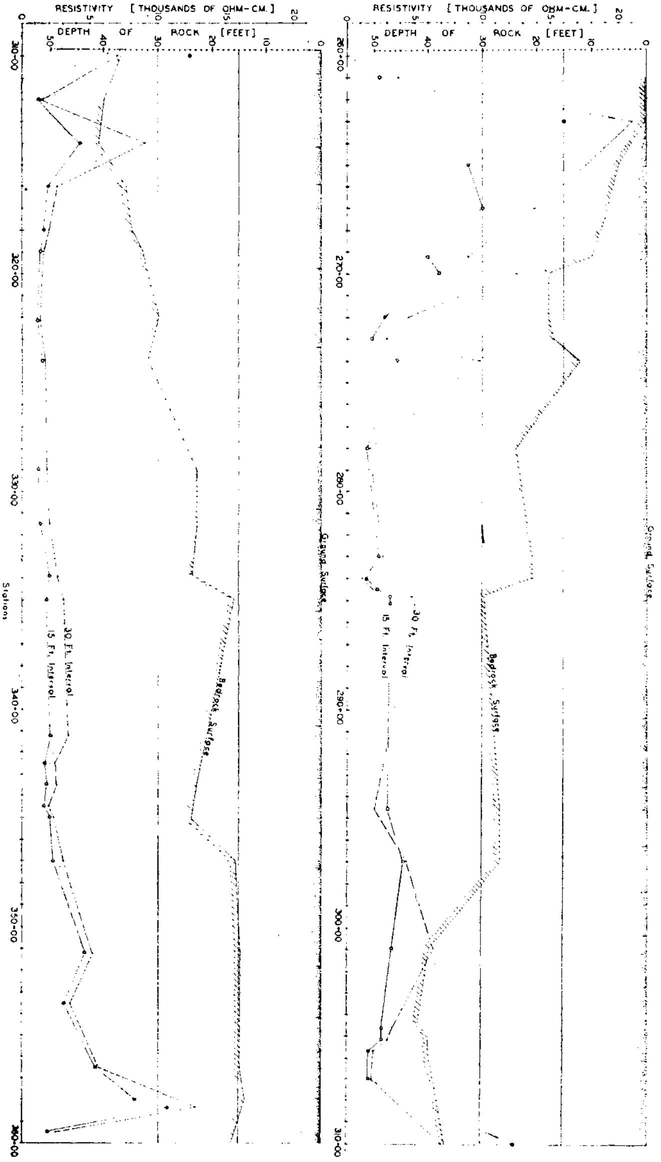


Figure 10. A constant depth resistivity profile showing relation of bedrock to 15 and 30 ft. interval fixed depth traverses.

gumbotil or shale between the limestone and the surface will cause abrupt anomalies in the resistivity curves without the corresponding change in the bedrock profile. This traverse would greatly facilitate the spacing of drill holes in any situation where it is desired to obtain the most information from the least number of holes.

CONCLUSIONS

This study has demonstrated that earth-resistivity definitely has a place in the field of highway engineering-geology. The following conclusions were drawn from this study:

1. The empirical methods used, as explained in this paper, are fast, inexpensive, and accurate when used by experienced personnel.
2. The field work can be handled by operators with only the minimum amount of training, but the interpretation of the data should be done by experienced personnel with an adequate knowledge of the geology of the area being studied.
3. The nature of the investigation determines the type of field curves and methods of analysis to be applied.
4. There are some situations, as in any other geophysical method, where earth-resistivity can not be advantageously used.
5. It is possible, under most conditions, to differentiate between two different types of material within two feet of their contact.
6. The "A" spacings of the electrodes determine the resolving power of the instrument relative to thickness of strata.
7. It is apparently possible to identify materials by their specific resistivity ranges.

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