STATE OF SOUTH DAKOTA
Archie Gubbrud, Governor

STATE GEOLOGICAL SURVEY
Allen F. Agnew, State Geologist

REPORT OF INVESTIGATIONS
No. 89

THE RESISTIVITY METHOD APPLIED TO GROUND WATER STUDIES OF GLACIAL OUTWASH DEPOSITS IN EASTERN SOUTH DAKOTA

by
Daniel Lum, Geophysicist

Union Building
University of South Dakota
Vermillion, South Dakota
March, 1961

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figure

ABSTRACT

This report discusses the resistivity method in its application to problems of water-bearing glacial outwash deposits of sand and gravel in eastern South Dakota. The principles, field procedures, and methods of interpretation are discussed, particularly for the use of the Wenner configuration. The resistivity method for depth determinations of the glacial outwash deposits was limited by inaccuracy and unreliability of interpretations. The glacial deposits are believed to be too inhomogeneous and variable in lithology to permit correlation and interpretation of resistivity data except for very local and detailed investigations. Apparent resistivity field curves plotted on logarithmic graph paper with theoretical curve-matching interpretations and drill-hole control data from glacial deposits are presented for reference. The horizontal traverse method was found to be more useful than the depth-profile method in locating favorable sites for water test-wells by detecting and outlining outwash stream deposits and buried outwash channels in till.

THE RESISTIVITY METHOD APPLIED TO GROUND WATER STUDIES IN GLACIAL OUTWASH DEPOSITS

INTRODUCTION

Electrical resistivity exploration is a geophysical method which sometimes is used to determine the geology of the subsurface to depths of a few tens or hundreds of feet for problems of water supply, highway construction, and damsite location. In practice, this method is not intended to replace drilling, but rather to guide and supplement drilling operations which are expensive and which sometimes yield unrepresentative information from isolated points.

During the summers of 1957 and 1958 the writer carried out resistivity surveys in connection with geologic quadrangle mapping of the Big Sioux River area (fig. 1). The purpose of the surveys was to obtain subsurface information concerning the water-bearing glacial outwash sand and gravel deposits. In conjunction with drill-hole information, the resistivity <u>depth-profile</u> data were used to interpret thickness of the outwash deposits or the depth to the underlying glacial till. In the summer of 1959 the writer supervised resistivity surveys made in connection with studies of various city ground water problems. Instead of the depth-profile method previously used, the <u>traverse</u> method was employed in 1959.

It is hoped that this report will afford those engaged in the resistivity method of exploration, an opportunity to become acquainted with the principles, the field procedures and techniques, and the various limitations encountered, particularly with resistivity equipment utilizing low-frequency alternating current. It is not within the scope of this report to present a comprehensive discussion of the resistivity method but rather to provide a sufficient understanding of principles, operating techniques, and methods of interpretation to create an interest in and appreciation for this method.

ACKNOWLEDGMENTS

The writer wishes to express his sincere thanks to Dr. A. F. Agnew, State Geologist, whose aid and support made this work possible. The field assistance of P. D. Lidel, D. J. Buckmeier, and R. H. Benson in 1957 and 1958 is gratefully acknowledged. Clark Mulliner and Charles Mickel operated the resistivity surveys under the writer's supervision in 1959 at the towns of Ethan, Howard and Huron. The cooperation of local residents in the areas referred to in this report is also acknowledged.

PRINCIPLES OF THE RESISTIVITY METHOD

Electrical methods of exploration are based upon measuring the varying electrical properties of different rock materials in the subsurface, and interpreting the electrical measurements in terms of geologic information. The resistivity method is but one of several electrical methods in use, and is concerned with measuring the resistivity of subsurface materials. The resistivity of a material is defined as

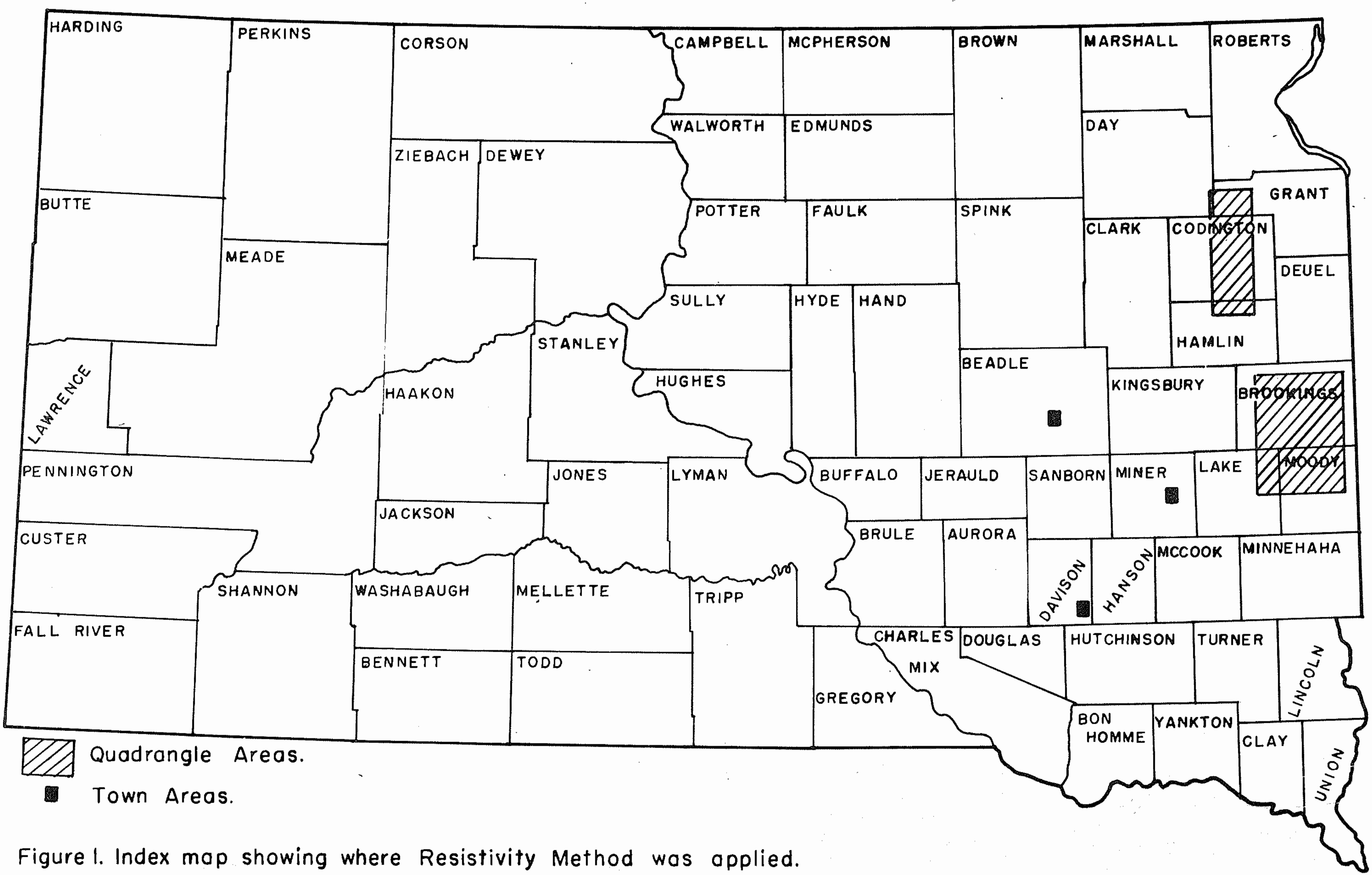


Figure I. Index map showing where Resistivity Method was applied.

the resistance of ohms between opposite faces of a unit cube of the material, and the units of resistivity commonly used are the ohm-centimeter and the ohm-meter.

The resistivity method consists of passing a measured amount of electric current through a segment of the earth and then measuring the potential difference associated with this current flow. To accomplish these measurements, four electrodes are placed in the ground. However, the electrodes must be placed in a special geometrical arrangement to permit an uncomplicated derivation of the mathematical relationship of the measured electric current, the measured potential difference prodiced by the current, and the resistivity of the subsurface material included within the zone of measurement.

Various configurations of the electrodes are used in electrical methods of explorations (fig. 2); however, the Wenner configuration is most commonly used. The Wenner configuration has four electrodes all placed in a straight line and all spaced an equal distance, a, apart; the mathematical formula relating the measured electrical quantities and resistivity of the material to which the current is applied, is one of the more simple derivations for the different configurations.

The derivation of the resistivity formula for the Wenner configuration is given below. Ohm's Law states:

$$R = \frac{V}{I} \qquad (1)$$

where I = current in amperes
V = potential in volts
R = resistance in ohms

For a conductor:

$$R = \rho \frac{L}{A} \qquad (2)$$

where, A = cross-sectional area
L = length
ρ = resistivity or the resistance of a cube of unit length

Combining these equations:

$$I = \frac{VA}{\rho L} \qquad (3)$$

Equation (3) is the starting point for determining the laws governing the current distribution in an infinite or semi-infinite conductor. From this equation the flow of current in a continuous medium can be expressed by LaPlace's equation shown below:

$$\frac{\partial^2 V}{\partial x^2} + \frac{\partial V}{\partial y^2} + \frac{\partial V}{\partial z^2} = 0 \qquad (4)$$

This equation does not determine the solution of any particular problem because there are certain boundary conditions to be satisfied.

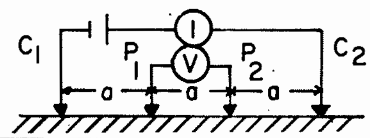
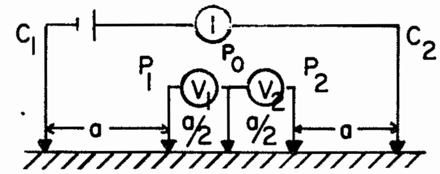
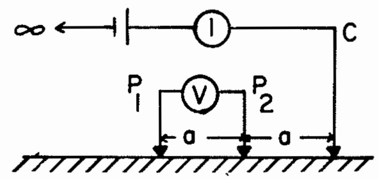
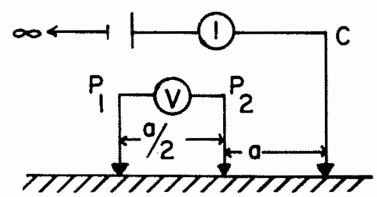
	Formula	Configuration
Wenner method	$\rho = 2\pi a \, V/I$	
Lee - Partitioning method	$\rho = 4\pi a \, V/I$	
Asymmetrical Wenner method	$\rho = 4\pi a \, V/I$	
Asymmetrical Lee method	$\rho = 6\pi a \, V/I$	

Figure 2. Electrode configurations used in electrical methods of exploration.

For the Wenner configuration, the ground is assumed to be a semi-infinite, electrically homogeneous and isotropic medium. These boundary conditions when applied to LaPlace's equation can be shown to yield the following expression:

$$V = \frac{I\rho}{2\pi r} \qquad (5)$$

where, $\underline{V}$, is the potential at any point at a distance, $\underline{r}$, from a small current source of intensity, $\underline{I}$, and, ρ, is the resistivity.

Referring to Figure 2, it can be seen that for the Wenner configuration the potential at P_1 due to current applied at C_1 and C_2 is:

$$V_1 = \frac{I\rho}{2\pi\left(\frac{1}{a} - \frac{1}{2a}\right)} \qquad (6)$$

and the potential at P_2 due to the current applies at C_1 and C_2 is:

$$V_2 = \frac{I\rho}{2\pi\left(\frac{1}{2a} - \frac{1}{a}\right)} \qquad (7)$$

Therefore the potential difference which is measured between P_1 and P_2 is:

$$V = V_1 - V_2 = \frac{I\rho}{2\pi\left(\frac{1}{a}\right)} \qquad (8)$$

or, the resistivity, ρ, is:

$$\rho = 2\pi a \frac{V}{I} \quad \text{(Wenner configuration)} \qquad (9)$$

However, the earth is seldom, if ever, either homogeneous or isotropic beyond very limited considerations, and consequently an "apparent" resistivity value--designated as $\underline{\rho a}$--of the subsurface material is actually measured. Because the subsurface generally is stratified in layers with different resistivity values, the measured resistivity value represents the sum-total effect of all layers involved, and does not represent the true resistivity value of any one layer. It is obvious, then, that an "apparent" resistivity value of the subsurface material is the quantity measured.

Finally, it is pointed out that the theory presented above applies to direct current. However, if equipment employing alternating current of low frequency (24 cycles or less) is used to eliminate interference caused by natural earth currents and polarization phenomena, the theory presented above can still be applied.

ELECTRICAL PROPERTIES OF ROCKS

Different rocks have different electrical properties and, generally, changes in the lithology of rocks result in changes of resistivity values. The flow of an electric current in non-metallic rocks is mainly electrolytic, that is to say, mainly electrochemical in nature. Practically all rocks have porosity, and thus contain moisture. It is the moisture content in rocks that makes them become good conductors, despite the fact that their constituent minerals (quartz, feldspar, etc.) may be poor conductors.

Laboratory studies of rocks have shown that for high values of moisture content, the conductivity of a rock approaches the conductivity value of its absorbed electrolyte. On the other hand, for very low values of moisture content the resistivity values are high and are governed by the properties of the rock material itself.

Listed below are some resistivity values from field and laboratory observations (Jakosky, 1950).

	Resistivity (ohm-cm)
Alluvium and silt	2500 - 150,000
Clay-shale	0.04 - 90,000
Clay	500 - 150,000
Glacial sediments	0.08 - 950,000
Conglomerate	2500 - 1,500,000
Sand	95 - 500,000

Because pure water is a poor conductor of electricity, it follows that it has a high resistivity, and therefore, an increase in conductivity of a rock must be attributed to contamination by electrolytes in solution. In general, water-bearing sand and gravel deposits have high resistivity values because: (1) there is only a small amount of electrolyte present in solution and, (2) there is a high permeability which permits movement of water, thereby diluting any concentration of electrolytes in solution. On the other hand, clay, glacial till, and to some extent silt, contain various soluble minerals and possess low permeability. The result is a greater abundance of soluble electrolytes. Thus, clays and clayey materials can be expected to have a much lower resistivity value than sands and gravels.

METHODS OF INTERPRETATION

There are two general schools of thought on the interpretation of resistivity data in terms of depths to various geologic layers within the subsurface. The mathematically-minded school relies upon a theoretical approach and the "practical-minded" school relies upon empirical methods. The former group argues that "rule of thumb" methods are not sufficiently precise, while the latter group argues that mathematical variables to justify assumptions that are necessary in theoretical interpretations cannot be applied to average field conditions. These two schools of thought are the subject of much controversy, but no theoretical approach or empirical approach has proved to be universally applicable.

Empirical Methods

Many empirical rules have been devised for interpreting resistivity measurements in order to simplify calculations necessary for theoretical methods. Many articles have been written illustrating the application of such rules to specific problems. Some of these rules are valid for the particular investigations discussed herein. However, one must be cautioned against the free and blind application of such rules to similar exploration problems in general. The conditions under which an empirical rule is developed may not be present in every area under investigation. The resistivity interpreter must always have some geologic control in order to develop, if possible, empirical rules for a given area.

The "potential bowl" theory is the basis for the "rule of thumb" assumption that the depth of investigation equals the electrode spacing of the Wenner configuration. The theory derives from the consideration that in an isotropic, perfectly homogeneous conducting medium, all points at an equal distance from the current electrode lie on an equipotential surface. Such a surface is a hemisphere whose center is the current electrode. The equipotential bowl is assumed to be a non-distorted surface and, if this were true, then the depth of investigation, d, would be equal to the distance, r (fig. 3).

For the ideal case the equipotential bowl is undistorted. Actually, however, there is distortion caused by the effect of the distant current electrode and also the effect of inhomogeneity and variable layering in the subsurface.

For the Wenner configuration, the effective depth of measurement is assumed to be equal to the electrode spacing, a, (fig. 4). The assumed condition for this "rule of thumb" is that the equipotential bowls of each current electrode are undistorted by each other. In actuality, the equipotential bowls are not hemispheres, but are asymmetrical about each current electrode (fig. 5).

In general, the depth of penetration is dependent upon many factors and the separation and configuration of the electrodes, together, is but one factor.

Empirical methods for determining the depth to bedrock, to water, and other geological discontinuities include (1) selecting some characteristic of the resistivity field curve (such as maximum, minimum, point of inflection, sharp break) and relating it to the depth of the geologic discontinuity, and (2) modifying the field curve before interpreting depths. Proponents of the first group include Gish and Rooney (1925)--maximum and minimum, and Lancaster-Jones (1930)--points of inflection. The widely-known and used method of Moore belongs in the second group. Moore's method involves the plotting of the sum of each resistivity reading plus all preceding readings, for each electrode separation (fig. 6). Arbitrary straight lines drawn through the resulting points produce intersections which are interpreted as depths to subsurface discontinuities. The Moore or cumulative method of interpretation illustrated in Figure 6 is an interpretation of the apparent resistivity curve R2 in the Appendix.

There is no simple proportionality factor between electrode separation and expected depth of penetration, which depends on such factors as the relative resistivities of the subsurface layers and the lateral variations in resistivity. Consequently, for a particular area of investigation with the resistivity method, geologic control from drill-holes should always be used to help determine, empirically, some rule relating the apparent resistivity field data to depths of various geologic discontinuities.

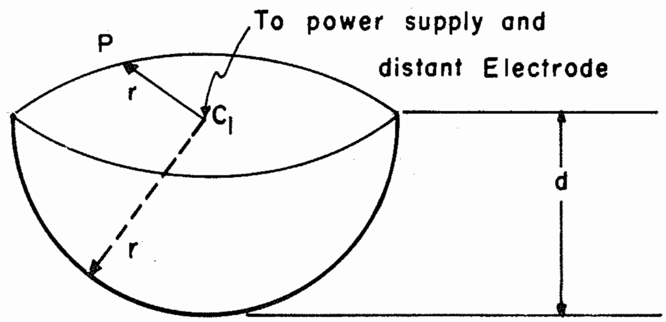


Figure 3. Assumed equipotential bowl surrounding electrode C_1.

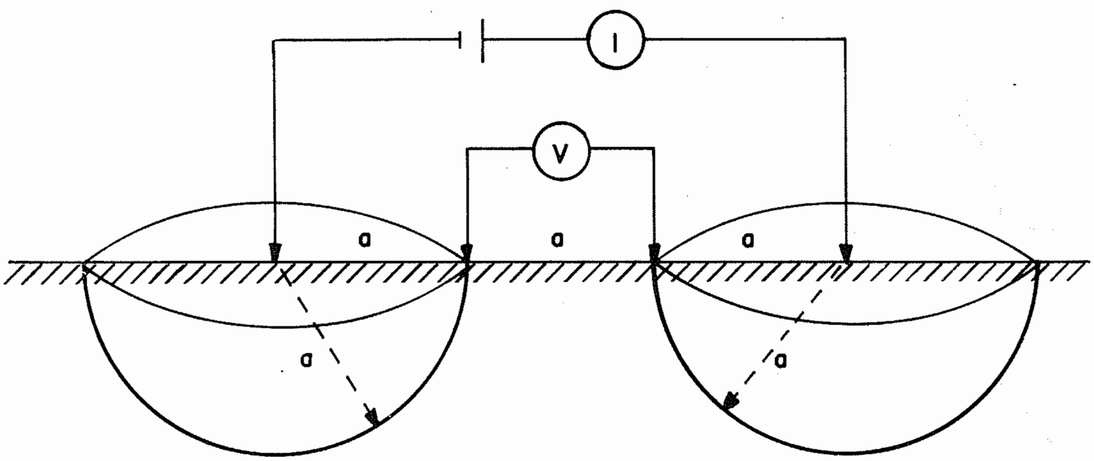


Figure 4. Equipotential bowl theory for the Wenner configuration.

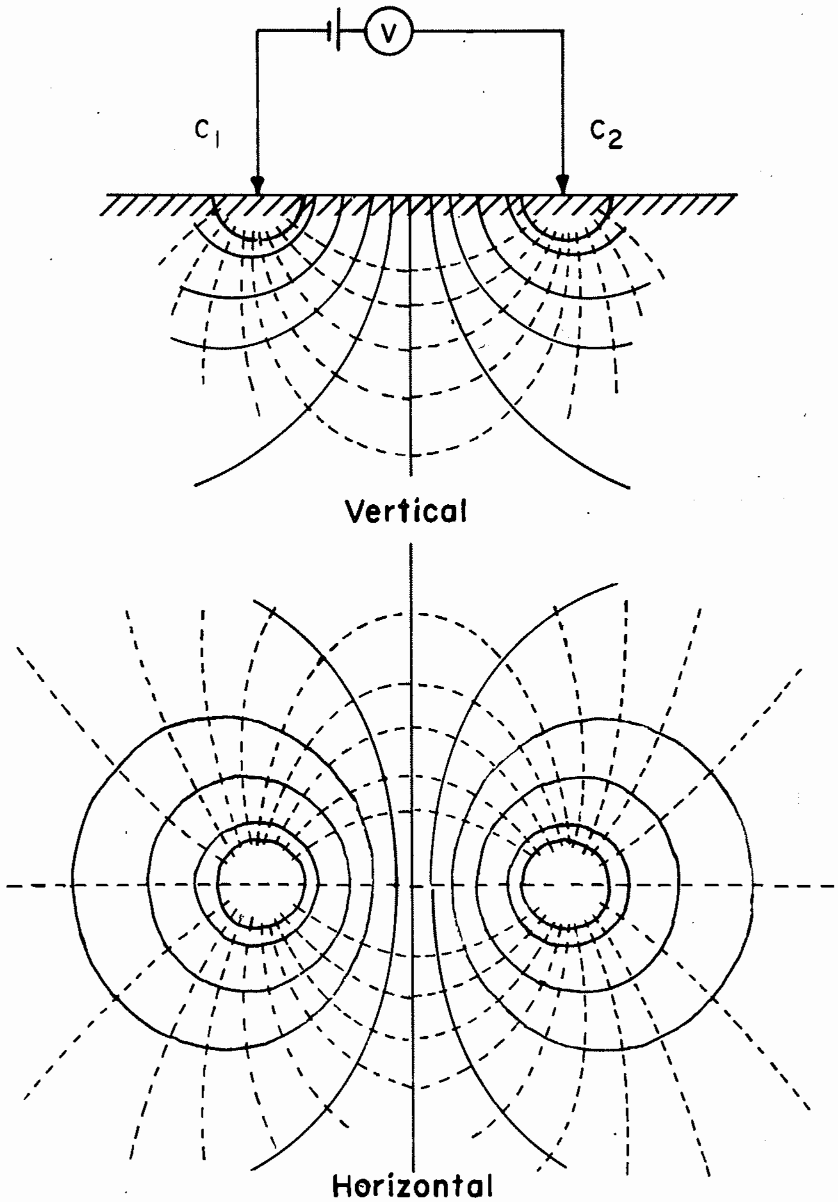


Figure 5. Potential and current distribution in Vertical and Horizontal planes. After Heiland, 1940)

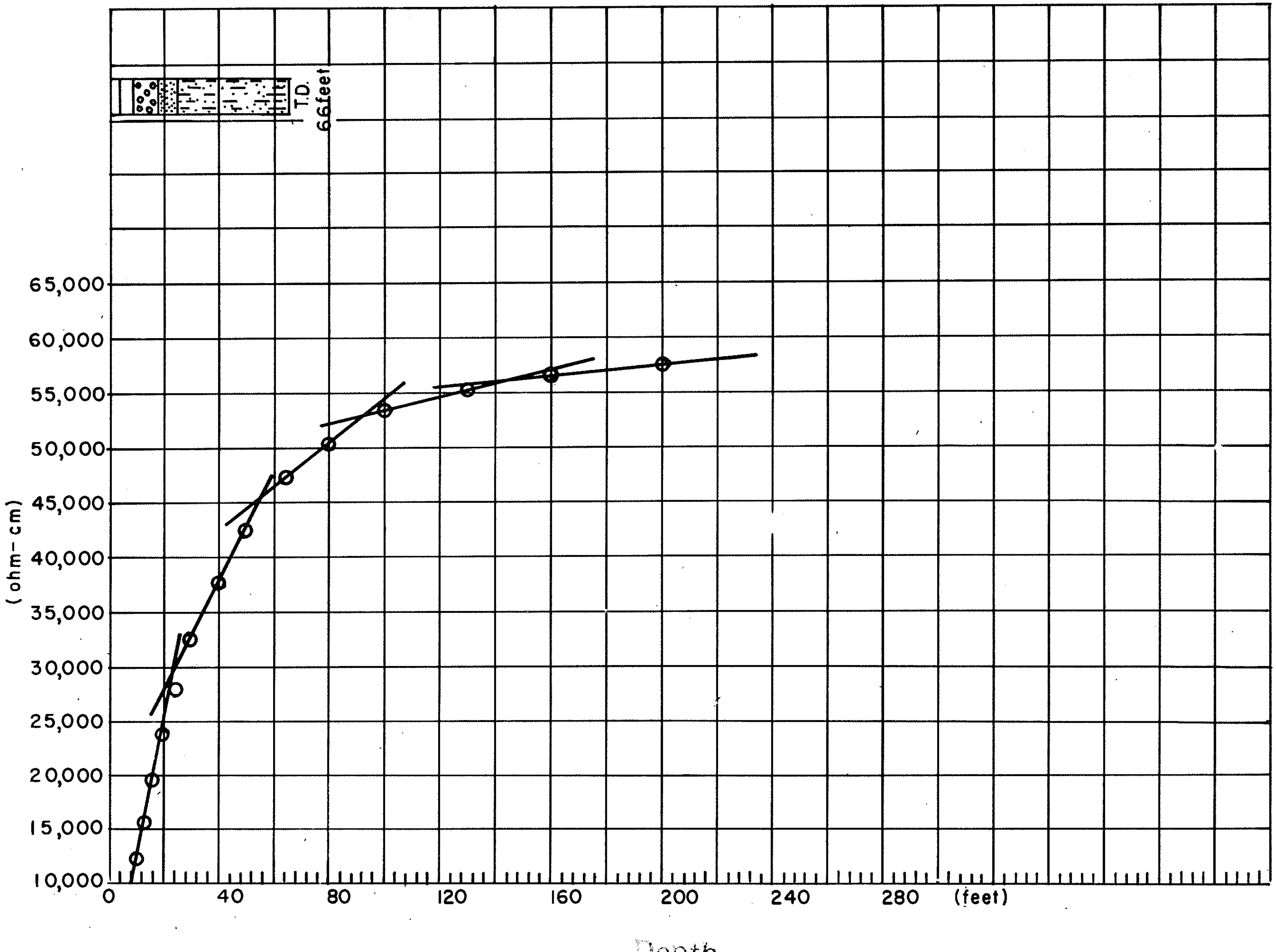


Figure 6. The Moore or cumulative method of interpreting apparent resistivity curves. (Lithologic symbols in Appendix.)

Theoretical Method

Theoretical curves (electrode separation vs apparent resistivity) have been computed for a number of different combinations of relative resistivity values for horizontal two-, three-, and four-layered subsurface (Mooney and Wetzel, 1956). These curves are drawn on logarithmic graph paper to make their shape, and thus their interpretation, independent of the units of measurement used in the field work. By comparing and matching field curves to one of the theoretical curves, a complete interpretation can be made for depths to one, two, or three essentially horizontal discontinuities, and for the true resistivities of the materials between them. The interpretation procedure is given by the authors mentioned above, and, therefore, no discussion concerning it need be given here.

FIELD PRECAUTIONS

There are certain precautions which must be taken in the field when using the resistivity method. The principles which have been discussed above are based upon ideal conditions, which are seldom, if ever, the actual geologic situations in the subsurface. The "potential bowl" which is assumed to be undistorted, is under actual field conditions disturbed by inhomogeneity of the subsurface, by natural earth currents, by polarization phenomena, by uneven topography, and by man-made interferences such as fences and underground iron pipes.

Every effort should be made to select the best location for a resistivity station by using whatever subsurface geology is known or can be surmised. Obviously, when field conditions approach the ideal conditions required by the resistivity method, better and more reliable interpretations can be made from apparent resistivity field curves. The effects of natural earth currents or telluric currents and polarization phenomena can be minimized by applying low-frequency alternating current instead of direct current. Attention must be given to avoid buried iron pipes, wire fences with iron fence posts, power lines, and any other electrical conductor. Other situations which should be avoided are stagnant water-filled ditches and swampy areas. If not avoidable, their distance from the resistivity station should be at least equal the largest electrode separation used.

FIELD OBSERVATIONS

From the equation (9) for the Wenner configuration it can be seen that by determining, V, I, and a, the apparent resistivity, ρa, can be obtained. Further, if the current, I, is made equal to, a, the electrode separation, then, ρa, is directly proportional to, V, the potential difference measured between P_1 and P_2. Thus, by using a calibrated potentiometer, the apparent resistivity value can be read directly in units of ohm-centimeters. The Bays instrument which the writer has used, is read directly in ohm-centimeters.

The two most widely-used methods of field observation are depth profiles and horizontal traverses. In depth profiling, apparent resistivity readings are obtained for a series of different electrode spacings at each station. A typical page of field notes is illustrated in Figure 7, and it shows recorded readings for electrode spacings varying from 3 to 160 feet. As mentioned in the above paragraph, the applied current (milliamperes) is made equal to the electrode spacing. However, for the small spacings 3 to 10 feet, the ammeter (current meter) scale cannot be read accurately for such small values of current. To obtain the apparent resistivity reading for an electrode spacing of 3 feet, 12 milliamperes of current is applied and the resistivity reading is recorded. Because 12 divided by 4 gives a current value of 3 milliamperes, it follows that the recorded resistivity value must also be divided by 4 to give the apparent resistivity value for 3 milliamperes. Beyond a current value of 10 milliamperes, the ammeter scale of the Bays instrument can be read accurately.

The horizontal traverse method with the Wenner configuration is used to investigate lateral variations and discontinuities in the subsurface geology, such as outwash sand and gravel deposits in glacial till or buried outwash channels in glacial till. At each station, resistivity readings are obtained for several different electrode spacings in order to obtain data for horizontal investigations at various depths. A typical page of field notes is shown in Figure 8. By obtaining a grid network of resistivity stations, contours of equal values of apparent resistivity can be drawn to produce an iso-resistivity map.

FIELD PROCEDURES

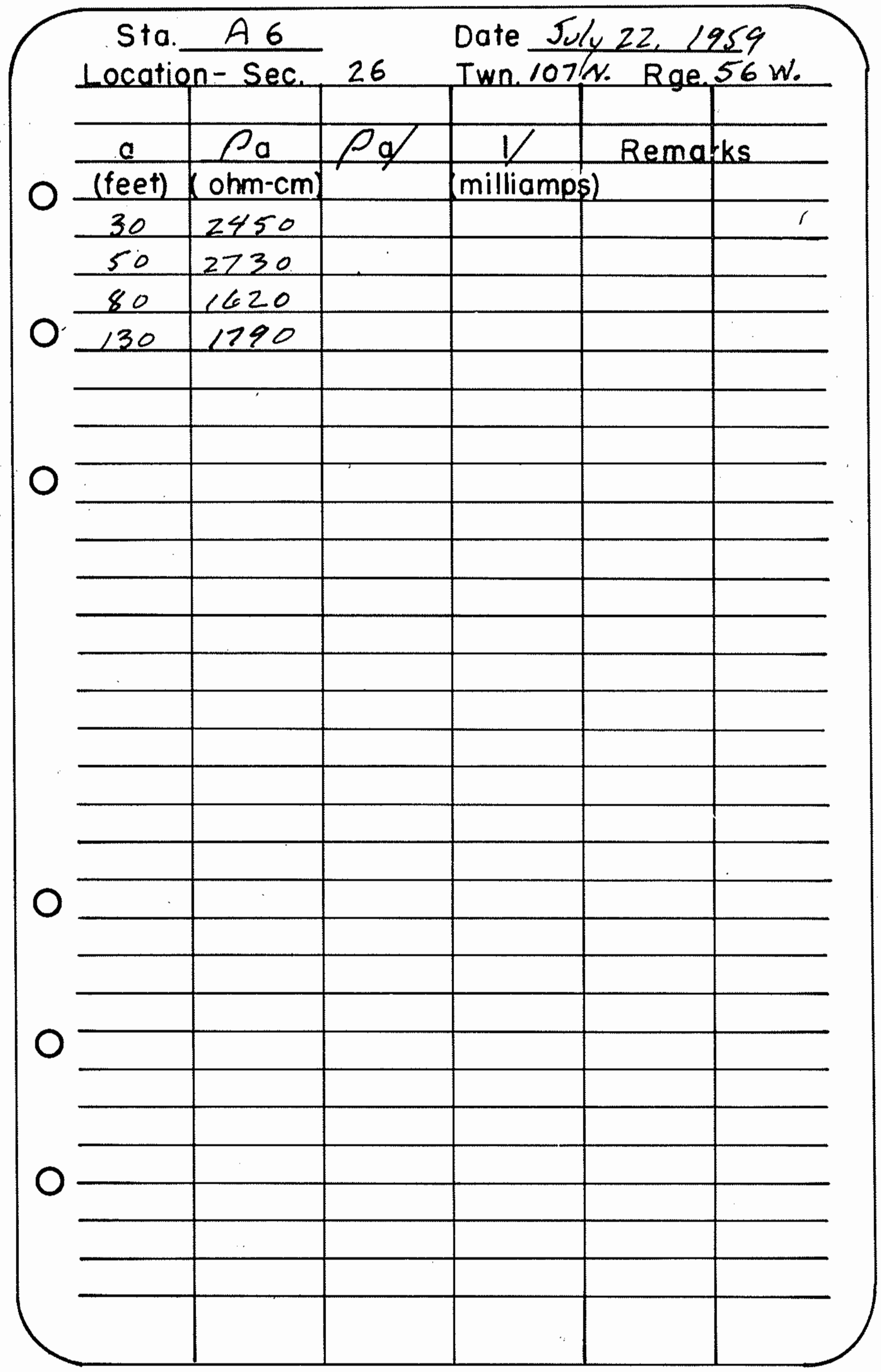
Figure 9 shows the Wenner configuration in schematic diagram and also the actual field arrangement with the Bays instrument. The instrument shown in the center of Figure 9 is connected electrically to electrodes C_1 and C_2 (steel stakes) and P_1 and P_2 (copper-tipped stakes) with cable reels and jumper wires. To facilitate obtaining the correct electrode spacings for each value of, a, all distances are measured and marked with colored tape on the current cables from the center line to the electrodes. In the figure it can be seen that the distance from the center point to P_1 or P_2 is always, $\frac{a}{2}$, and to C_1 or C_2 is always, $\frac{3a}{2}$. The distances required for the potential electrodes (inside stakes) are marked on the current cables with red tape, and the distances required for the current electrodes (outside stakes) are marked with yellow tape. The values for electrode separations used for depth profiling are given below: (all values are in feet)

Sta. R 28 Date Aug 2. 1957

Location.—Sec. 10 Twn. 10 N. Rge. 51 W.

a (feet)	ρa (ohm-cm)	ρa/	1/ (milliamps)	Remarks	
3	4520	18,100	12/4 = 3		
4	4030	12,100	12/3 = 4		
5	4370	13,100	15/3 = 5		
6.5	4700	9400	13/2 = 6.5		
8	5550	11100	16/2 = 8		
10	6750	13,500	20/2 = 10		
13	7600		13		
16	8600		16		
20	9800		20	Minor Fluct.	
25	10,600		25		
30	11,300		30		
40	12,900		40	distance Ok.	
50	13,000		50		
65	10,600		65		
80	9,300		80		
100	6,000		100		
130	2600		130		
160	1400		160		
200			200		
250			250		
300			300		

Figure 7. A typical page of field notes, Wenner configuration, depth profile method.

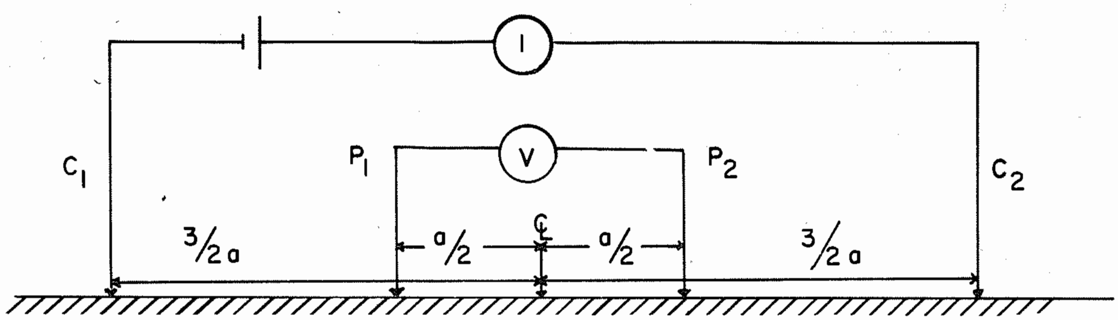


Sta. A 6　　Date July 22, 1959

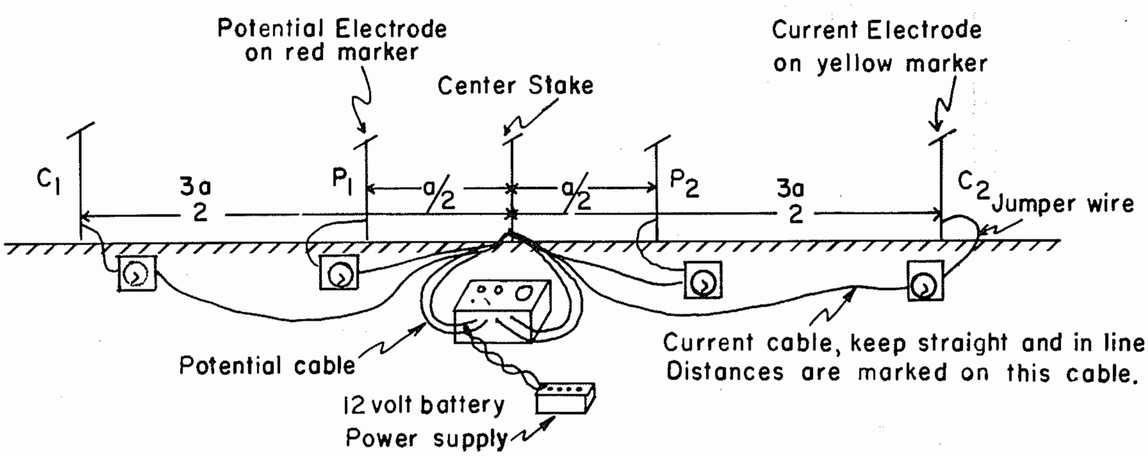
Location- Sec. 26　Twn. 107 N.　Rge. 56 W.

a (feet)	ρa (ohm-cm)	ρa/	I/ (milliamps)	Remarks
30	2450			
50	2730			
80	1620			
130	1790			

Figure 8. A typical page of field notes, Wenner configuration, horizontal traverse method.



(a) Schematic Diagram



(b) Field Arrangement

Figure 9. The Wenner configuration, using Bays Instrument.

Electrode Separation	Potential Electrode (red tape)	Current Electrode (yellow tape)
3	1.5	4.5
4	2	6
5	2.5	7.5
6.5	3.2	9.8
8	4	12
10	5	15
13	6.5	19.5
16	8	24
20	10	30
25	12.5	37.5
30	15	45
40	20	60
50	25	75
65	32.5	97.5
80	40	120
100	50	150
130	65	195
160	80	240
200	100	300

Experience has shown that a two-man crew is satisfactory for efficient field work. Once the equipment is set up, one man is at the instrument to obtain and record the apparent resistivity value read from the calibrated dial. The second man stands at one of the outer (current) electrodes. When an observation has been made, the first man signals the second man who then moves out the outer stake to the next yellow marker on the current cable, and next moves out the inner stake (potential electrode) to the next red marker, after which he proceeds to make the next observation at the instrument. In the meantime the first man has proceeded to move the other inner and outer stakes to the next colored markers in the same manner, and remains at the outer electrode until the second observation has been made. Afterwards, the procedure is repeated.

Field experience has shown that errors in observations occur most frequently in the placing of the electrodes at the correct distances for each electrode separation. If the apparent resistivity field curve contains "breaks" in the curve, it is more likely to be caused by error in the field work rather than by geologic discontinuities in the subsurface.

In general, readings should be obtained for values of electrode separations several tens or even a hundred feet greater than the desired depth of investigation.

FIELD MAINTENANCE

At the beginning of an exploration program, the following items should be checked. First, a 12-volt battery in good condition should be obtained; next, the distances of the red and yellow markers should be checked, corrected and replaced with new tape.

Despite careful handling of the reels and cables, a certain amount of operative breakdown is to be expected. Experience indicates that the majority of the instrument failures are due to poor or broken electrical connections in the jumper wires (fig. 9). Electrical continuity in the cable connections can be checked by using an ohmmeter. It is recommended that frequent inspection of blue jumper wires be made. Usually there is an internal break of the wire near the jumper-wire clips. If the probes, clips, or other exposed connections are rusted, fine sandpaper should be used to remove the rust and prevent failures due to poor connections.

RESULTS OF THE RESISTIVITY DATA

Apparent Resistivity Curves

During the summers of 1957 and 1958, the depth-profile method was used to supplement drill-hole data in evaluating depths to the base of water-bearing glacial outwash sand and gravel deposits. Different empirical methods of interpretation were used, including the Moore or cumulative method. Also, the theoretical curve-matching method was applied to the apparent resistivity field curves. In the Appendix, the apparent resistivity curve obtained for the glacial outwash deposits of the Big Sioux River at each locality is presented on the log-log scale, and the interpretations of depths to and the true resistivities of the subsurface layers are plotted against the drill-hole log. There are two reasons for presenting the field data and interpretations: (1) they will serve as a reference for the type of apparent resistivity curves obtained in some of the glacial deposits in Eastern South Dakota; (2) with drill-hole information for geologic control, it is evident that the depth-profile method has met with little success in giving accurate and reliable results except when used to investigate very limited areas.

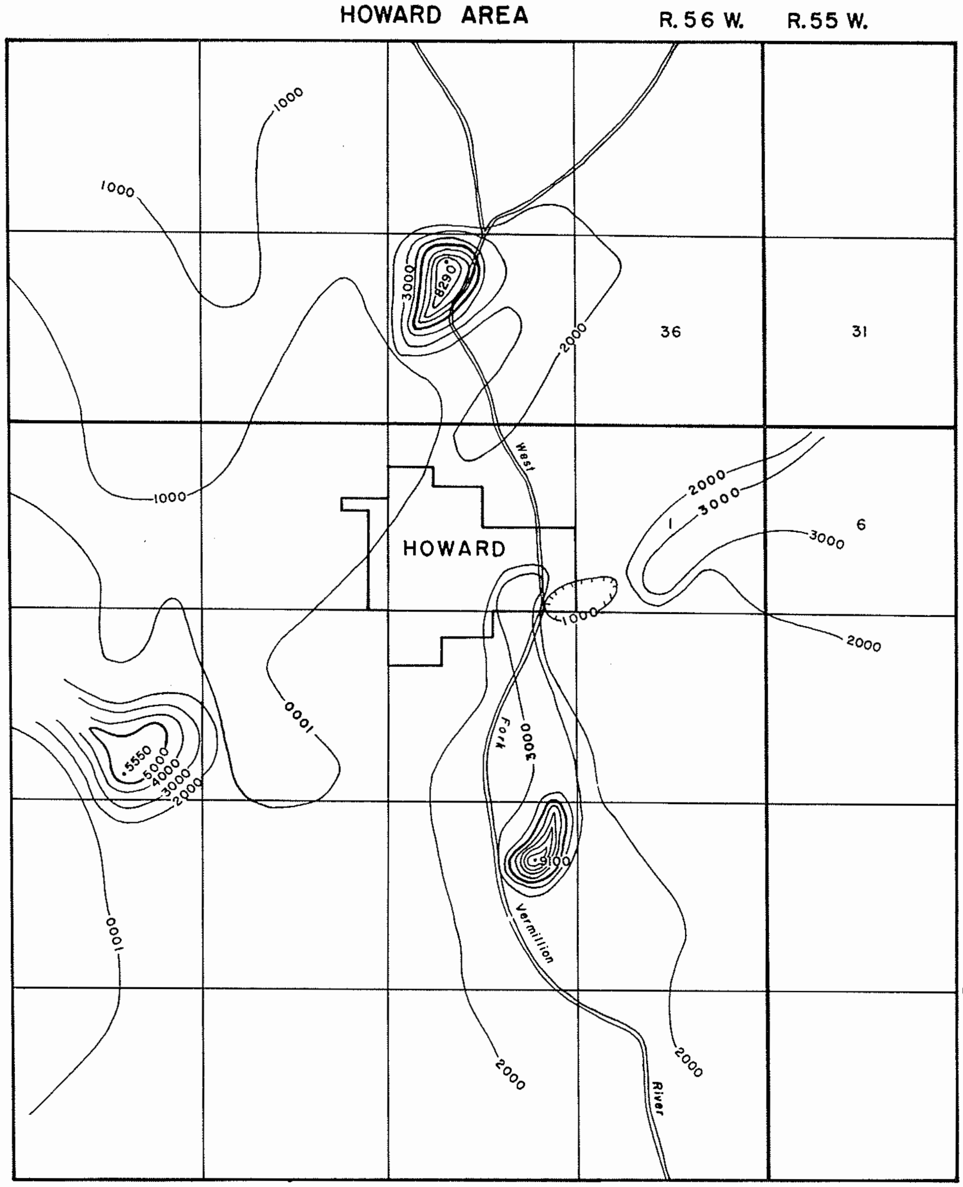
Limited success in interpretation also was obtained with empirical methods. It is believed that the geology of glacial deposits is so unpredictably variable, even over very short distances, that the resistivity data cannot be correlated or interpreted successfully except for very detailed surveys.

Iso-Resistivity Contour Maps

In the summer of 1959 the horizontal traverse method was applied to town water-supply problems. The purpose of the resistivity method was to help locate favorable sites for shallow test wells. The contours, it was hoped, would be successful in outlining water-bearing sand and gravel outwash deposits in till. Areas of high resistivity values were expected to show these deposits.

In the Howard area, the resistivity contours (for an electrode separation of 50 feet) show three small anomalous highs in Sections 9, 35, and 14 (fig. 10). These anomalies were tested with a jeep-mounted drill but no corresponding geologic change was observed from the till, which covers the entire area. Possibly, the anomalies reflect a local sand and pebble concentration in the till. It is pointed out that the contours have low values, in the range of 500-2000 ohm-cm, which is a reliable

ISO-RESISTIVITY CONTOUR MAP
of the
HOWARD AREA



EXPLANATION

Contour Interval= 1000 ohm-cm.

Effective Depth (electrode spacing) = 50 feet.

Scale in Miles
0 1 2

FIGURE 10

indication that no sizeable sand and gravel deposits are present in the area at a depth of 50 feet or less.

In the Ethan area the resistivity contour map (for an electrode separation of 30 feet), successfully outlined the glacial outwash deposits (fig. 11). Figure 12 shows the geology of the area, and its correlation with the resistivity map is striking. In Sections 2 and 3, resistivity highs of 35,600 and 62,800 ohm-cm reflect the sand and gravel deposits whose boundaries were difficult to determine by surface geologic mapping (Donald Jorgensen, personal communication, 1960). In the till areas the resistivity values are low--only several thousand ohm-cm--which generally indicates till in eastern South Dakota. In Sections 7 and 18 where drill-hole information shows that the Cretaceous Niobrara chalk is locally high structurally, there is a resistivity high of approximately 6000 ohm-cm which reflects the bedrock surface of the Niobrara overlain by a thin deposit of glacial till at a depth of about 30 feet (Donald Jorgensen, personal communication, 1960).

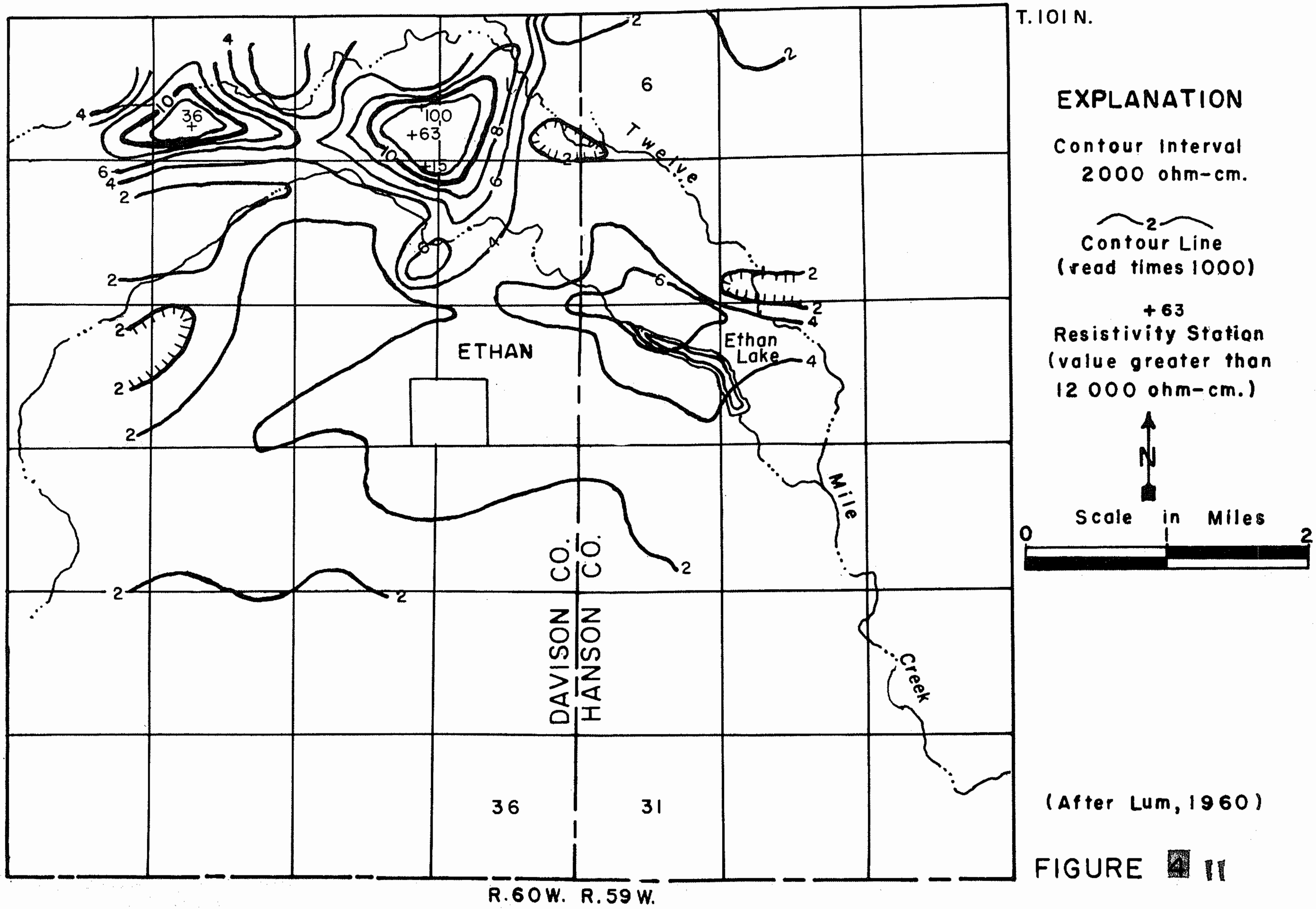
In the Huron area a buried glacial stream channel was thought to exist, from a study of information from water wells in the area. The horizontal traverse method was applied in an attempt to outline the buried channel and thereby to locate favorable sites for shallow test wells. Figure 13 shows an iso-resistivity contour map (for an electrode separation of 30 feet) in an area east of Huron. The contours trend generally north-south, outlining successfully the buried channel. Several resistivity highs of 10,000 ohm-cm or more occur within the channel outline. These highs probably reflect very local lateral changes in lithology, and possibly changes in thickness of the buried outwash deposits. The high resistivity values of 10,000 ohm-cm indicate the presence of sand and gravel deposits within the till; the till is characterized by low values of resistivity (2000 ohm-cm). Drill-hole information shows the lithology of buried channel material to be highly variable even locally. Several shallow test wells indicated that a good supply of shallow water could be obtained from the area.

CONCLUSIONS

The resistivity method used for depth (thickness) determinations of glacial outwash deposits in the Big Sioux River area has met with only limited success. The resistivity results are generally unreliable. This fact is believed to be caused by the unfavorable geologic inhomogeneity and variability of the glacial deposits even over short distances. Any accurate and reliable depth interpretations from apparent resistivity curves, whether empirical or theoretical, must be accompanied by sufficient drill-hole information to provide geologic correlation and control of the resistivity data.

The horizontal traverse method, which is used to make an iso-resistivity contour map, has been applied with some success in locating favorable sites for shallow water wells, thereby reducing the amount of expensive drilling which would otherwise have been required. The resistivity maps have shown favorable results in areas (1) entirely of till, (2) of till and surface glacial outwash deposits, and (3) of a buried outwash channel in till.

ISO-RESISTIVITY CONTOUR MAP
of the
ETHAN AREA



(After Lum, 1960)

FIGURE 4 11

SOUTH DAKOTA GEOLOGICAL SURVEY
ALLEN F. AGNEW, STATE GEOLOGIST

GEOLOGIC MAP OF THE ETHAN AREA

STATE OF SOUTH DAKOTA
RALPH HERSETH, GOVERNOR

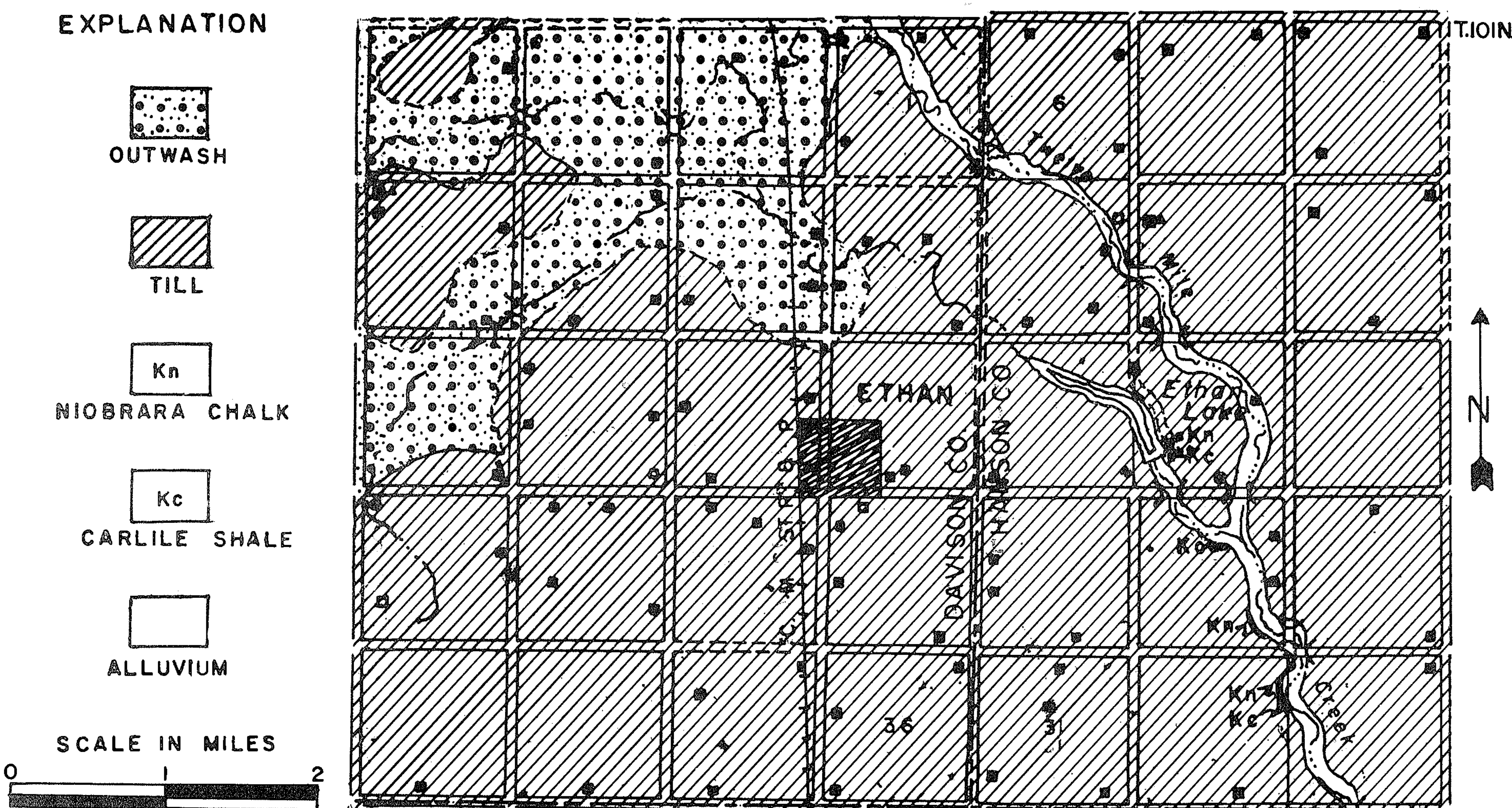


FIGURE 12

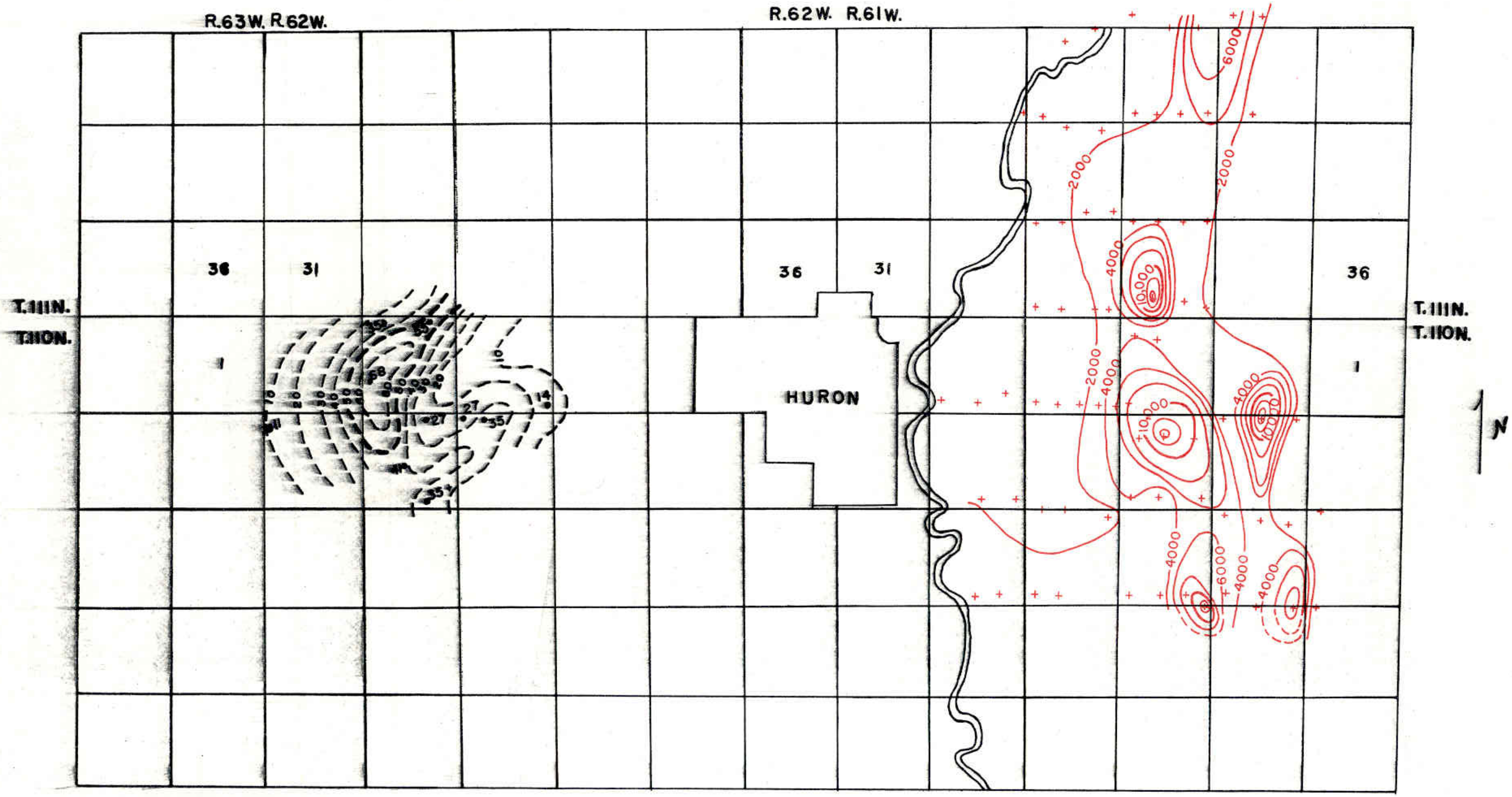
Figure 13

[redacted]

ISOPACH AND ISO-RESISTIVITY MAP
OF OUTWASH DEPOSITS
NEAR HURON

SOUTH DAKOTA GEOLOGICAL SURVEY
ALLEN F. AGNEW, STATE GEOLOGIST

STATE OF SOUTH DAKOTA
RALPH HERSETH, GOVERNOR



•58 DRILL HOLE (giving sand thickness)

THICKNESS CONTOUR (interval 10 feet)

SCALE 0 1 2 3 MILES

by
M. J. TIPTON
NOV., 1959

\+ RESISTIVITY STATION (sta. no. given on plate 3)

4000 ISO-RESISTIVITY CONTOURS
INTERVAL = 2000 OHM-CM.

Survey by C. Mulliner, C. Mickel; supervised by D. Lum

REFERENCES CITED

Gish, O. H., and Rooney, W. J., 1925, Measurement of resistivity of large masses of undisturbed Earth: Territorial Magnetism and Atmospheric Electricity, p. 261.

Heiland, C. A., 1940, Geophysical Exploration: Prentice Hall, Inc., New York.

Jakosky, J. J., 1950, Exploration Geophysics: Trija Publishing Co., Los Angeles.

Lancaster-Jones, E., 1930, The Earth-Resistivity Method of geophysical prospecting: Mining Magazine, v. 42, p. 352.

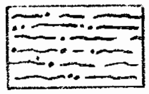
Mooney, H. M., and Wetzel, W. W., 1956, The potentials about a point electrode and apparent resistivity curves for a two-, three-, and four-layered earth: University of Minnesota Press, Minneapolis.

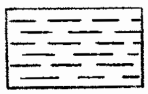
APPENDIX

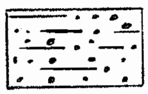
Apparent resistivity field curves with drill-hole information and depth interpretation by the theoretical-curve matching method.

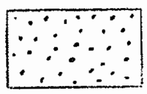
Three-layer Interpretations R1 to R7
Four-layer Interpretations R8 to R19

Legend

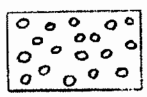

topsoil

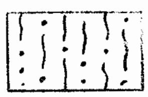

clay


silty sand


sand


sand and gravel


clean gravel


till

Explanation

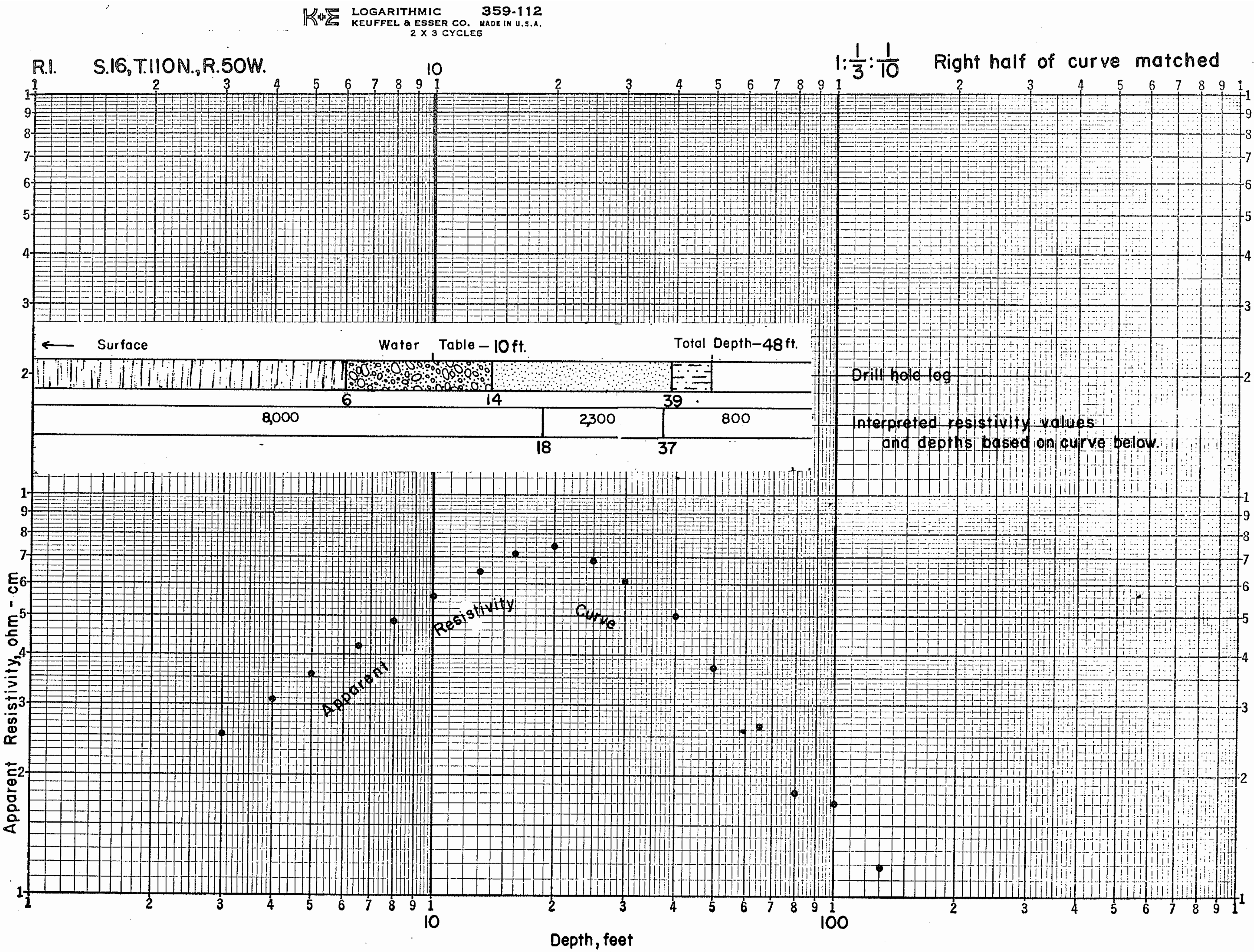
(1) Log cycle: 1, 10, 100 feet (Abscissa) and 1000 and 10,000 ohm-cm.

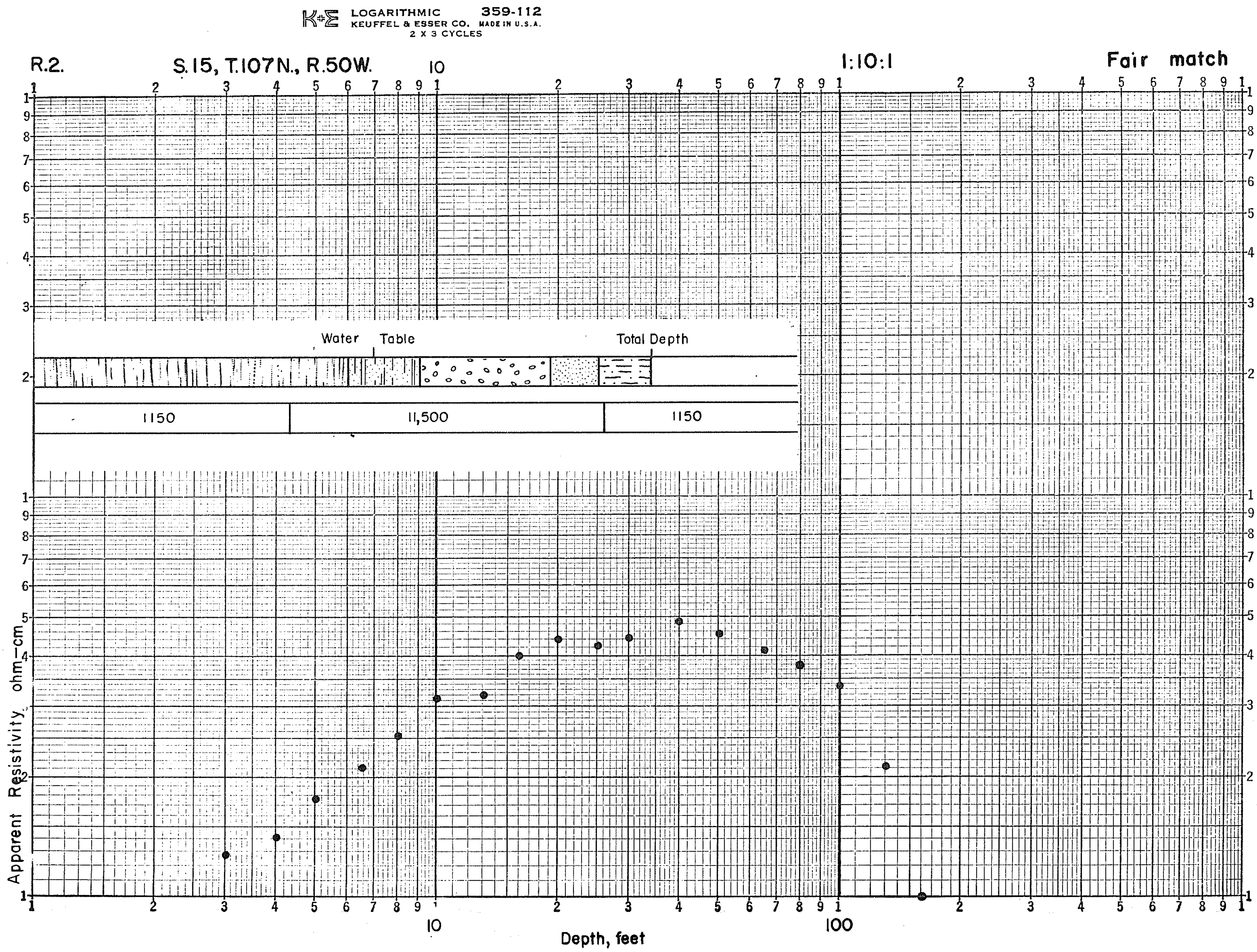
(2) Geologic section is shown horizontally in the insert: Interpreted depths of subsurface layers with true resistivity values of these layers is shown in lower part of this insert.

(3) In upper right hand corner, the resistivity ratio of theoretical curve used for interpretation is presented, with a brief remark on curve matched.

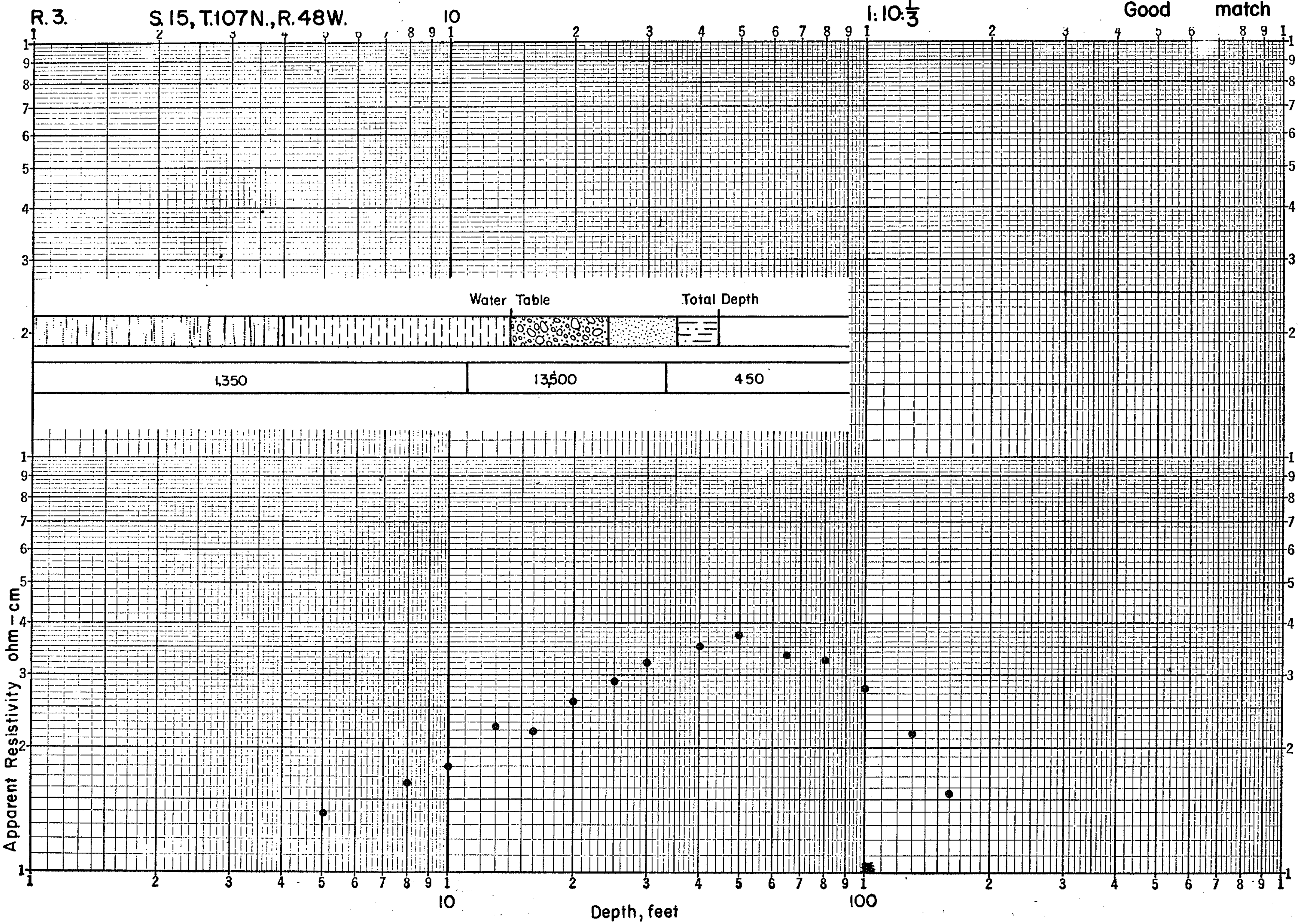
R.I. S.16, T.110N., R.50W.

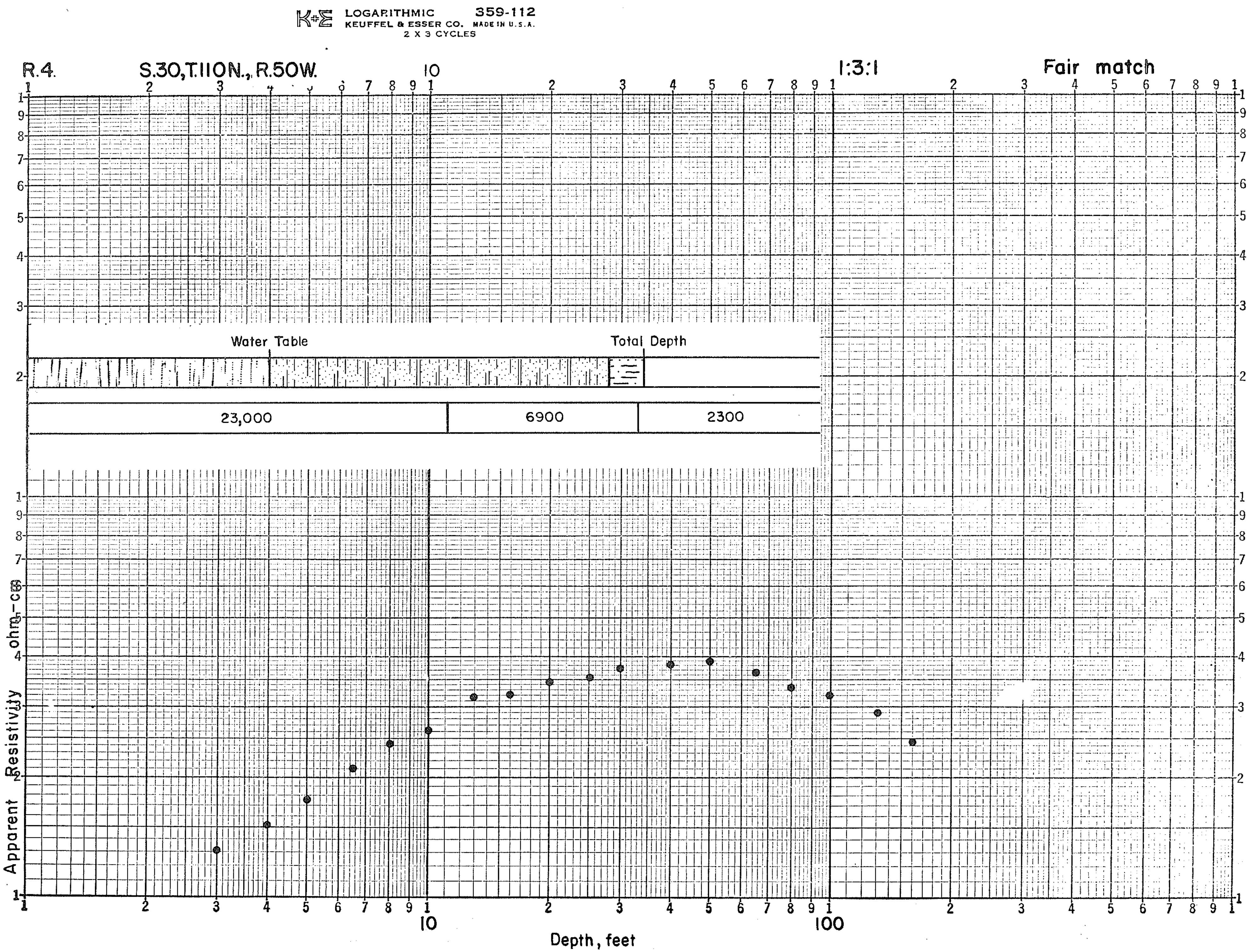
$1 : \frac{1}{3} : \frac{1}{10}$ Right half of curve matched

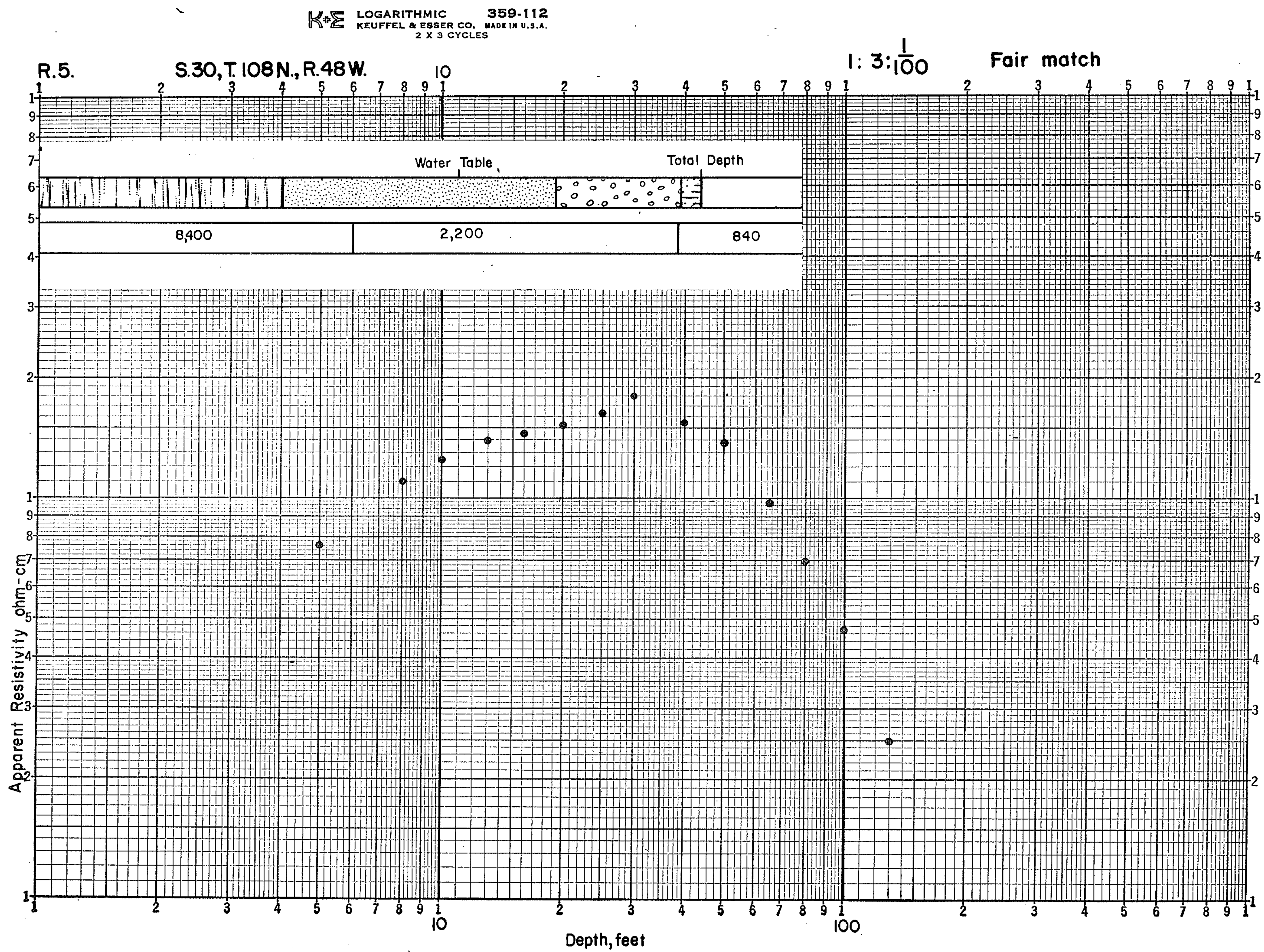



K+E LOGARITHMIC 359-112
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 X 3 CYCLES
R.2.
S.15, T.107N., R.50W.
1:10:1
Fair match
Water Table
Total Depth
1150
11,500
1150
Apparent Resistivity, ohm-cm
Depth, feet
10
100

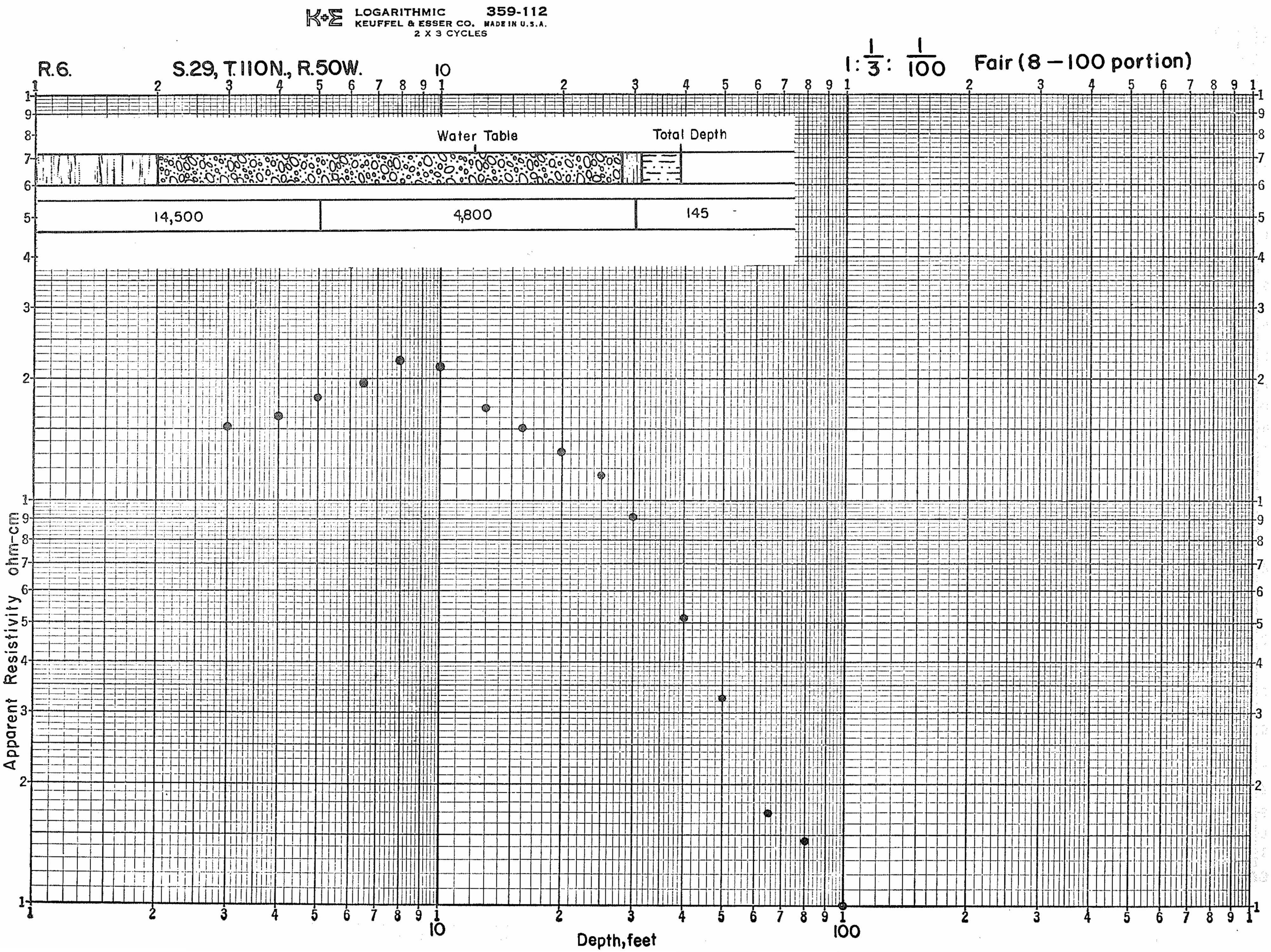
K+E LOGARITHMIC 359-112
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 X 3 CYCLES

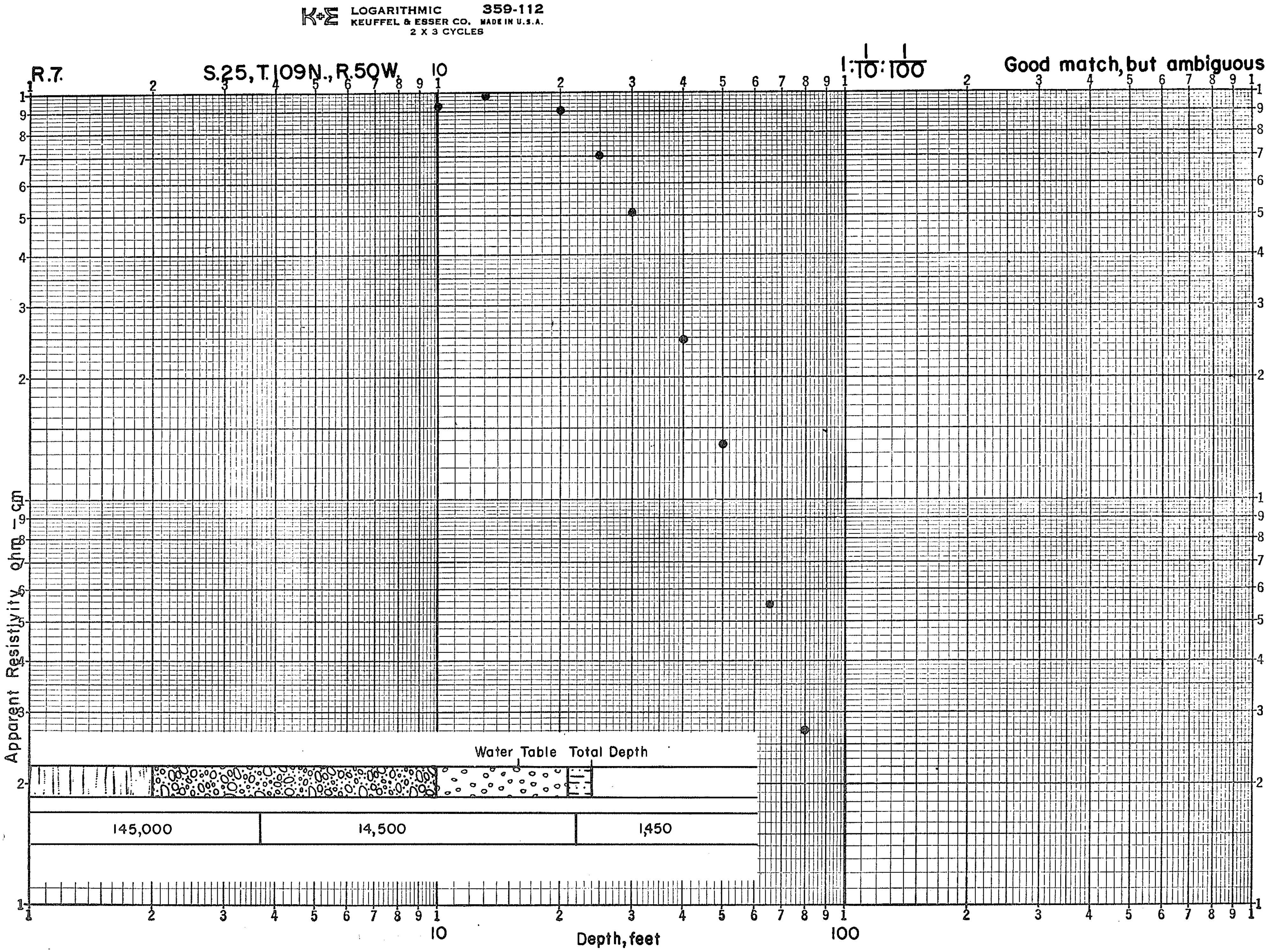



K+E LOGARITHMIC 359-112
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 X 3 CYCLES
R.4.
S.30,T.110N.,R.50W.
1:3:1
Fair match
Water Table
Total Depth
23,000
6900
2300
Apparent Resistivity ohm-cm
Depth, feet
10
100

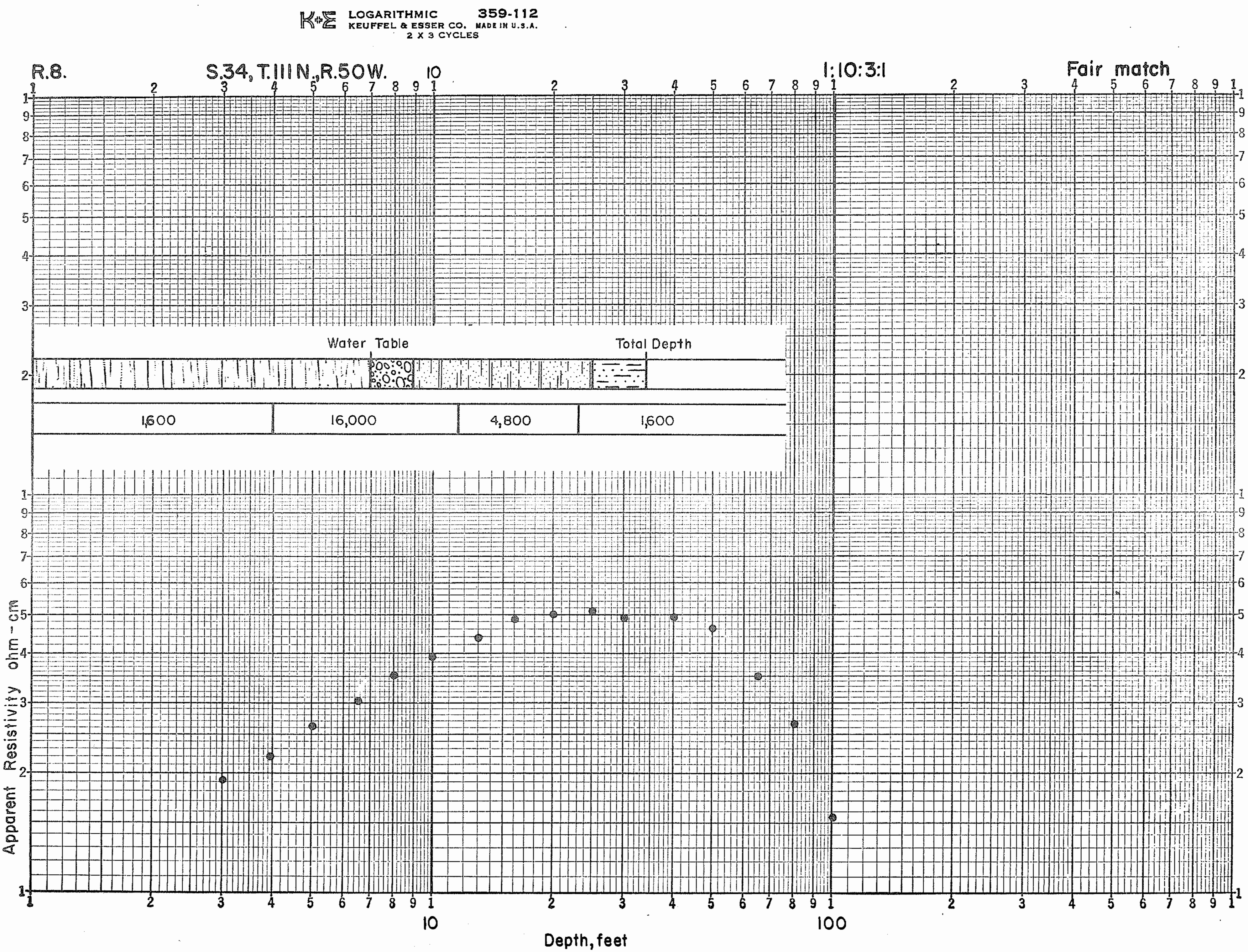


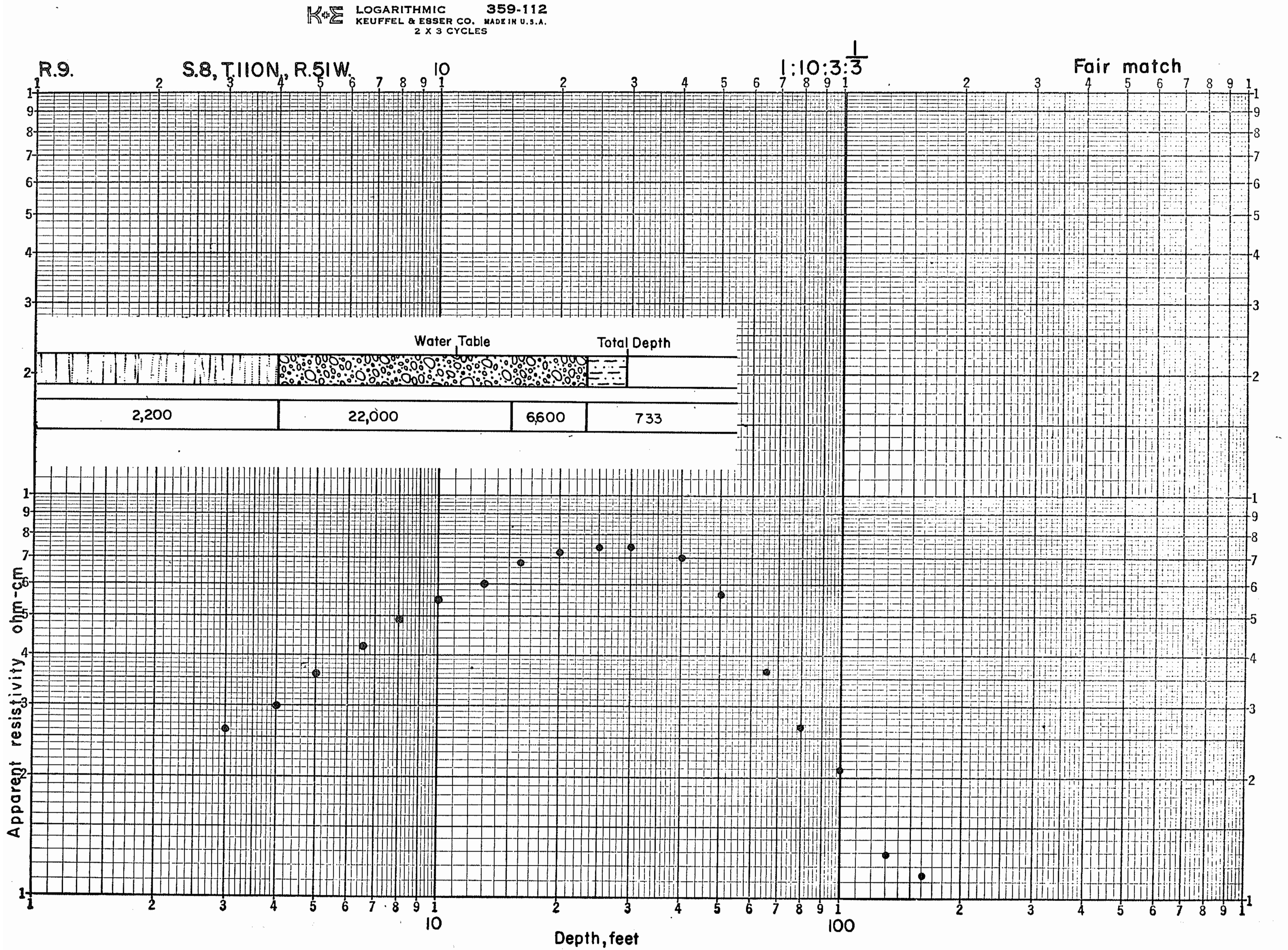
K+E LOGARITHMIC 359-112
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 X 3 CYCLES
R.5.
S.30, T.108N., R.48W.
1: 3: $\frac{1}{100}$
Fair match
Water Table
Total Depth
8,400
2,200
840
Apparent Resistivity ohm-cm
Depth, feet
10
100

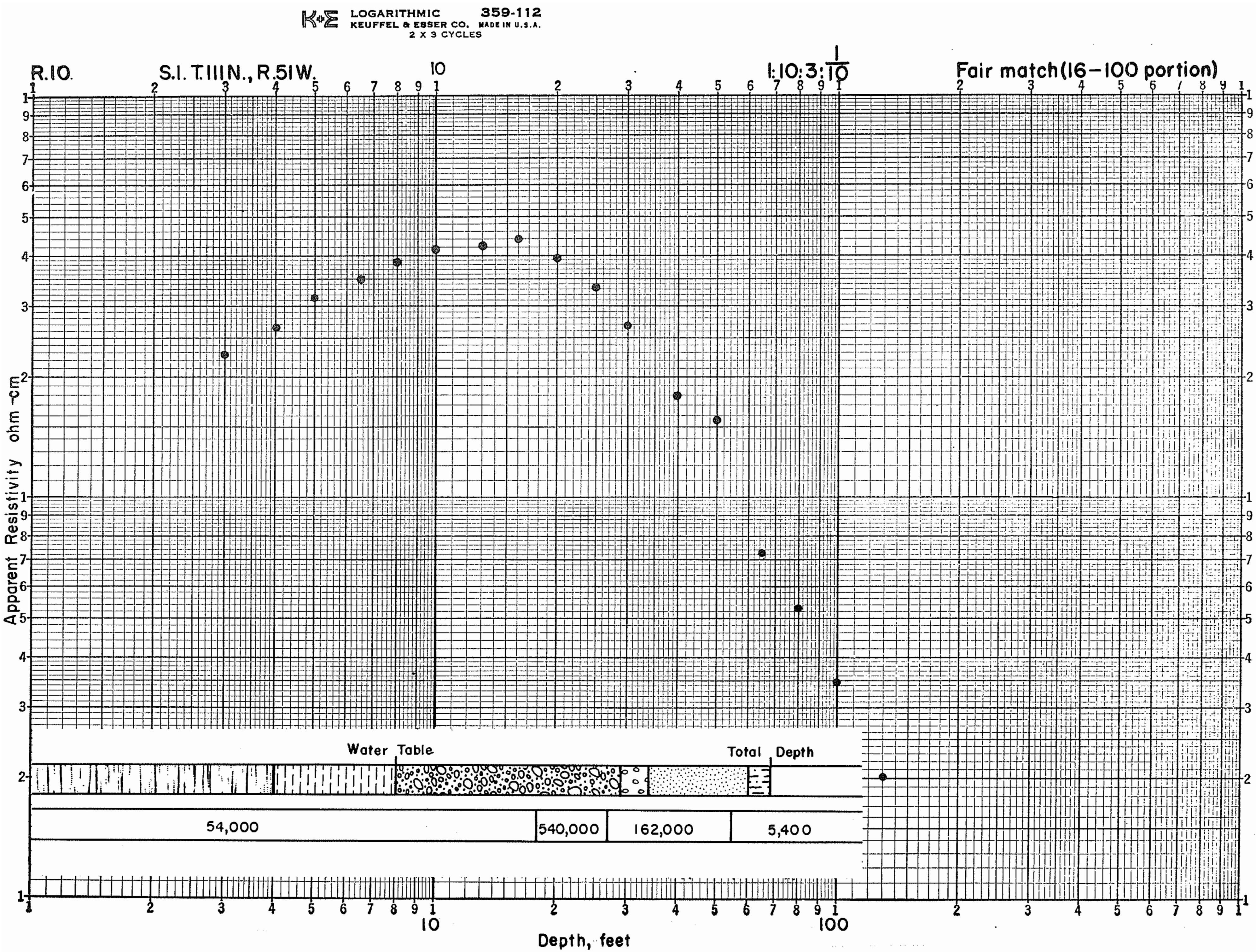

K+E LOGARITHMIC 359-112
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 X 3 CYCLES
R.6.
S.29, T.110N., R.50W.
1 : 1/3 : 1/100
Fair (8 — 100 portion)
Water Table
Total Depth
14,500
4,800
145
Apparent Resistivity ohm-cm
10
100
Depth, feet



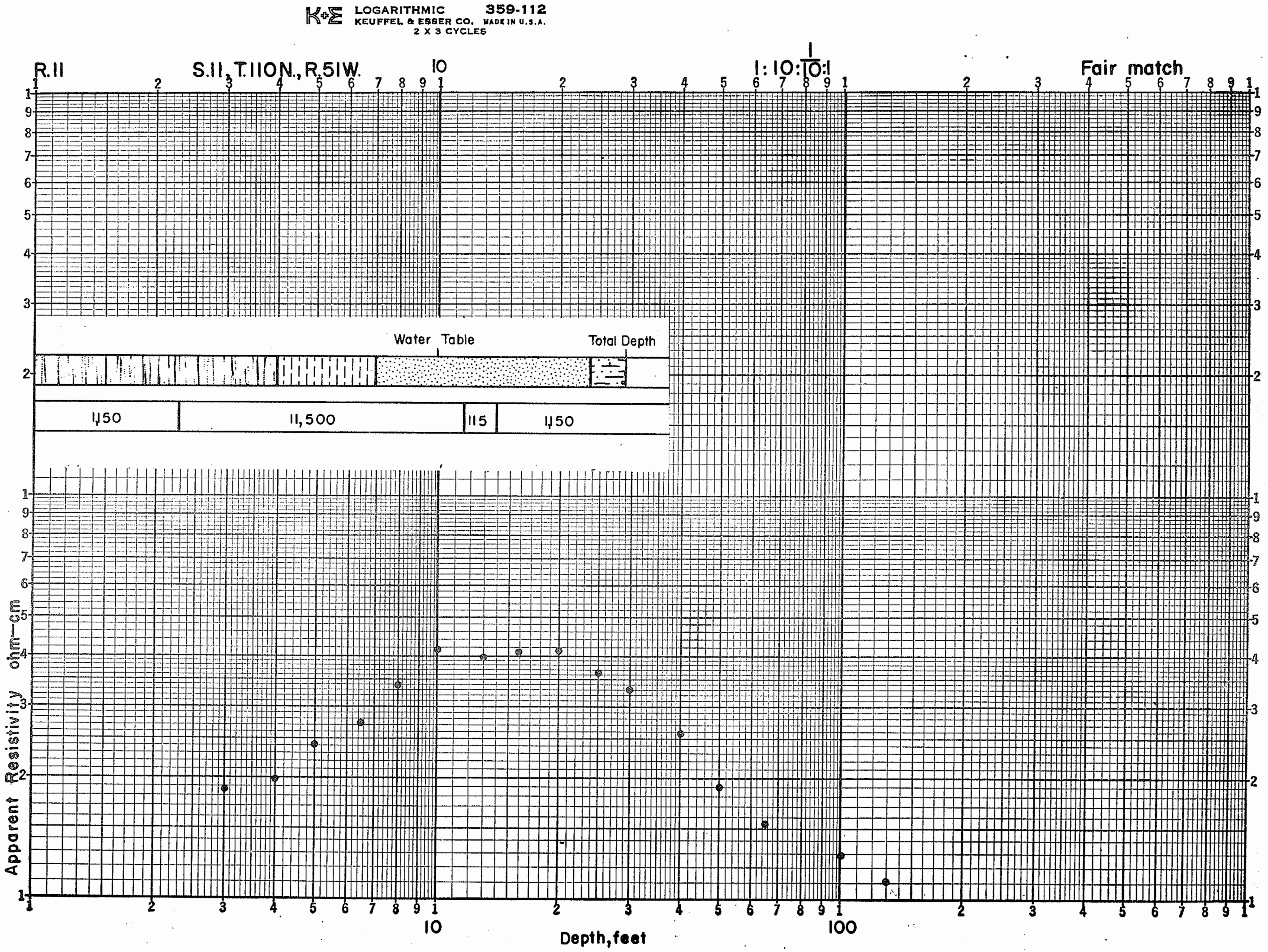
K+E LOGARITHMIC 359-112
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 X 3 CYCLES
R.7.
S.25, T.109N., R.50W.
1 : 1/10 : 1/100
Good match, but ambiguous
Water Table
Total Depth
145,000
14,500
1,450
Apparent Resistivity, ohm - cm
Depth, feet
10
100


K+E LOGARITHMIC 359-112
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 X 3 CYCLES
R.8.
S.34, T.111 N., R.50 W.
1:10:3:1
Fair match
Water Table
Total Depth
1,600
16,000
4,800
1,600
Apparent Resistivity ohm - cm
Depth, feet
10
100

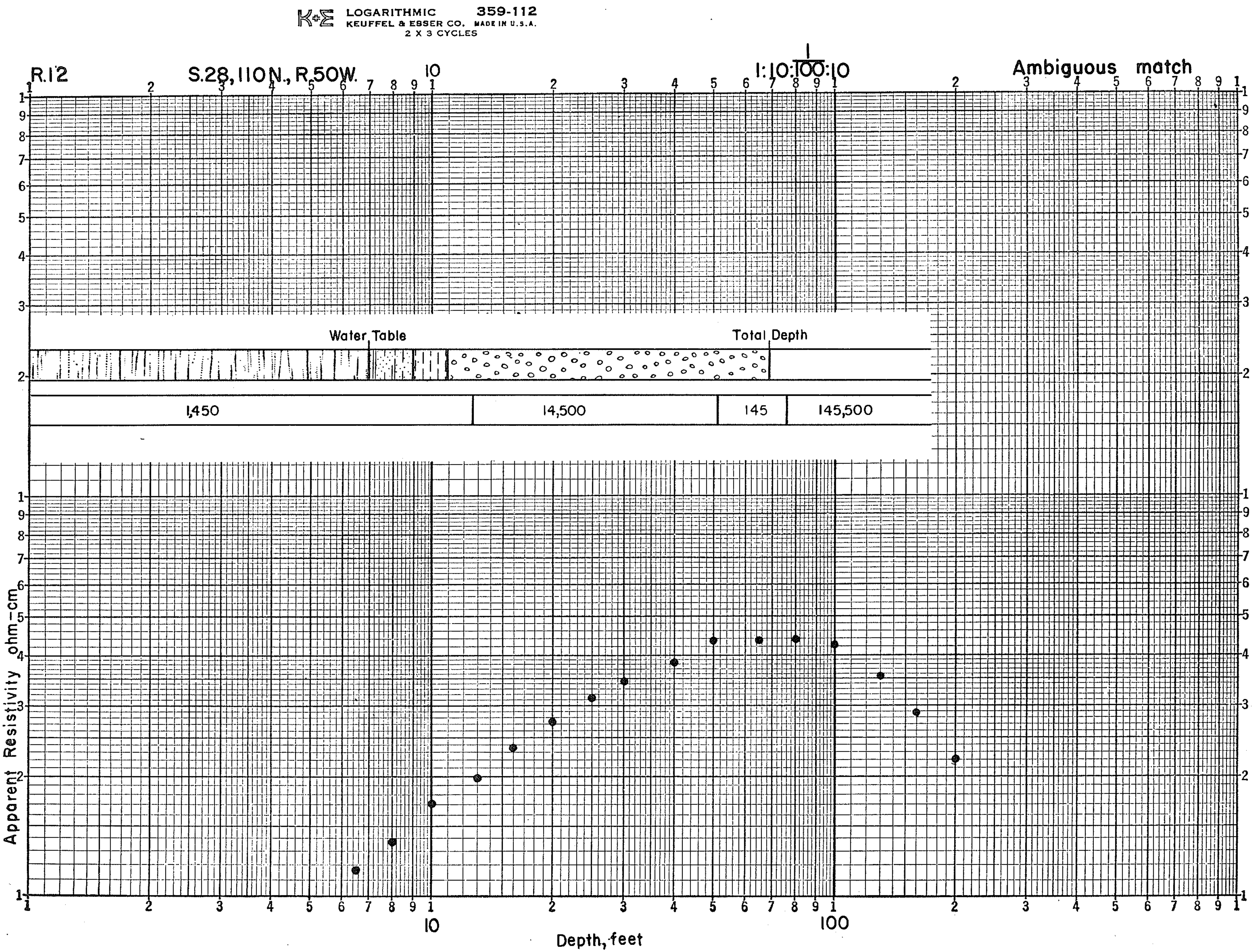

K+E LOGARITHMIC 359-112
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 X 3 CYCLES
R.9.
S.8, T.110N, R.51W.
1:10:3:$\frac{1}{3.3}$
Fair match
Water Table
Total Depth
2,200
22,000
6,600
733
Apparent resistivity ohm-cm
Depth, feet
10
100

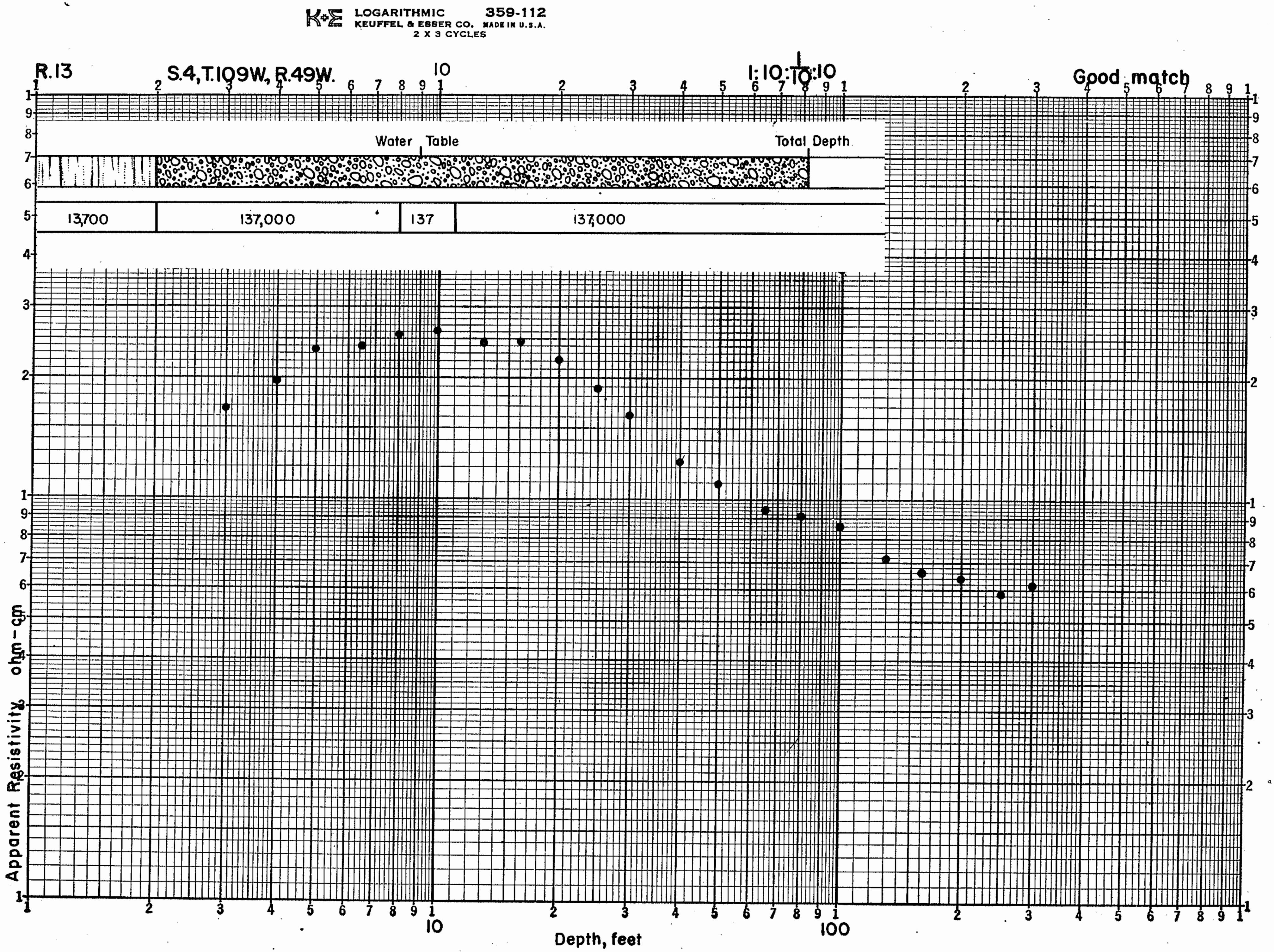


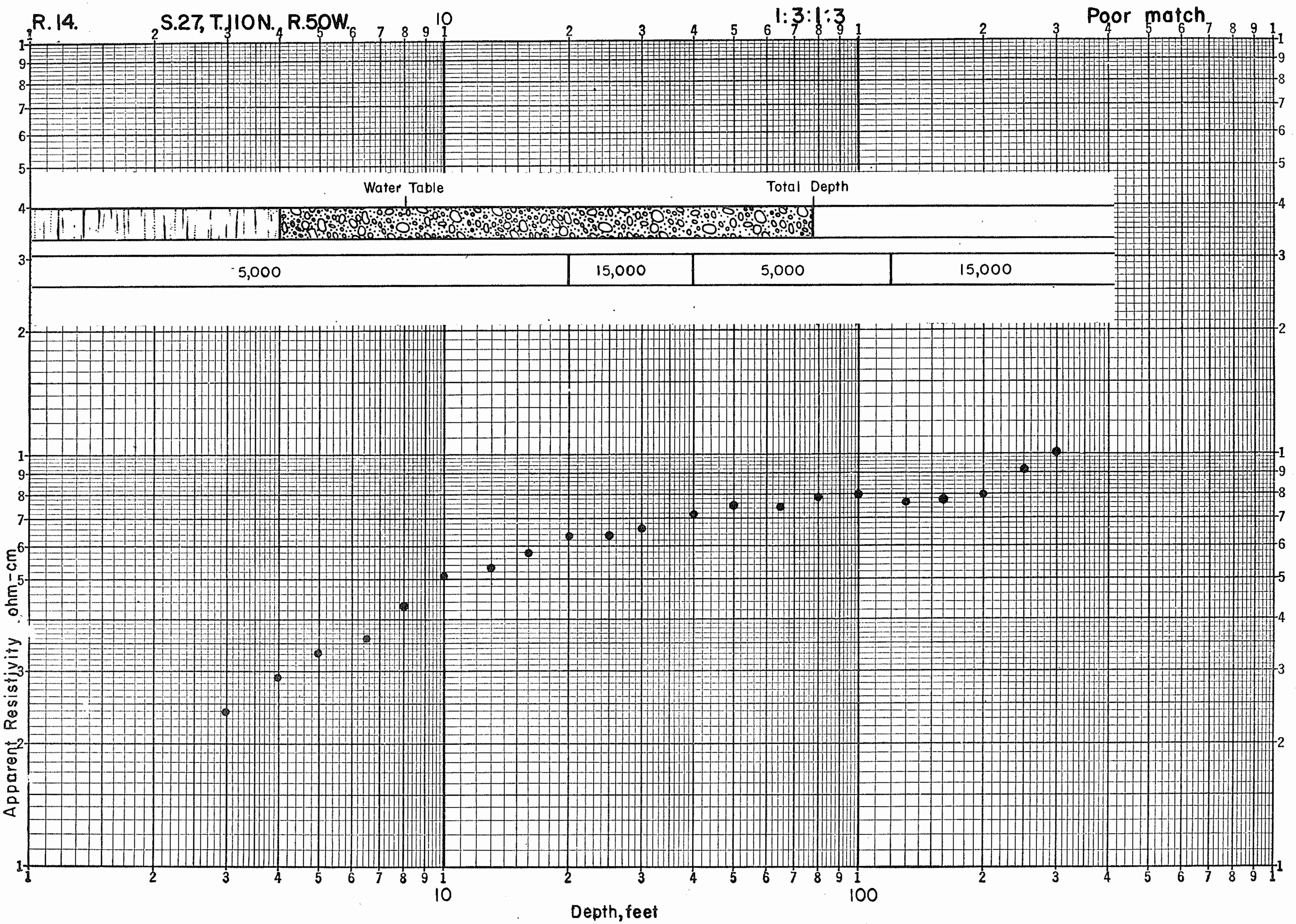
K+E LOGARITHMIC 359-112
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 X 3 CYCLES
R.10.
S.I. T.111N., R.51W.
1:10:3:1/10
Fair match(16–100 portion)
Apparent Resistivity ohm-cm
Water Table
Total Depth
54,000
540,000
162,000
5,400
10
100
Depth, feet

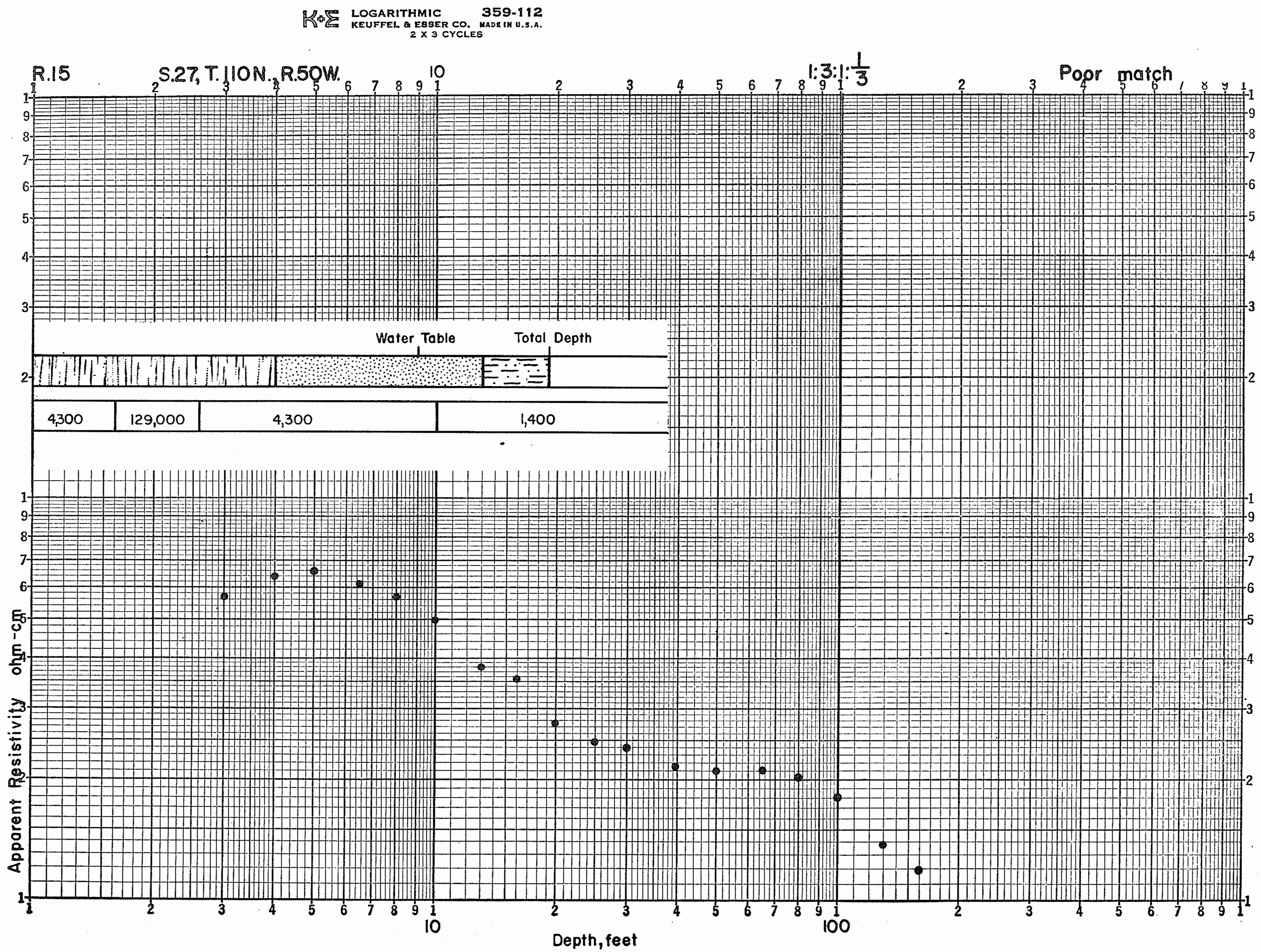


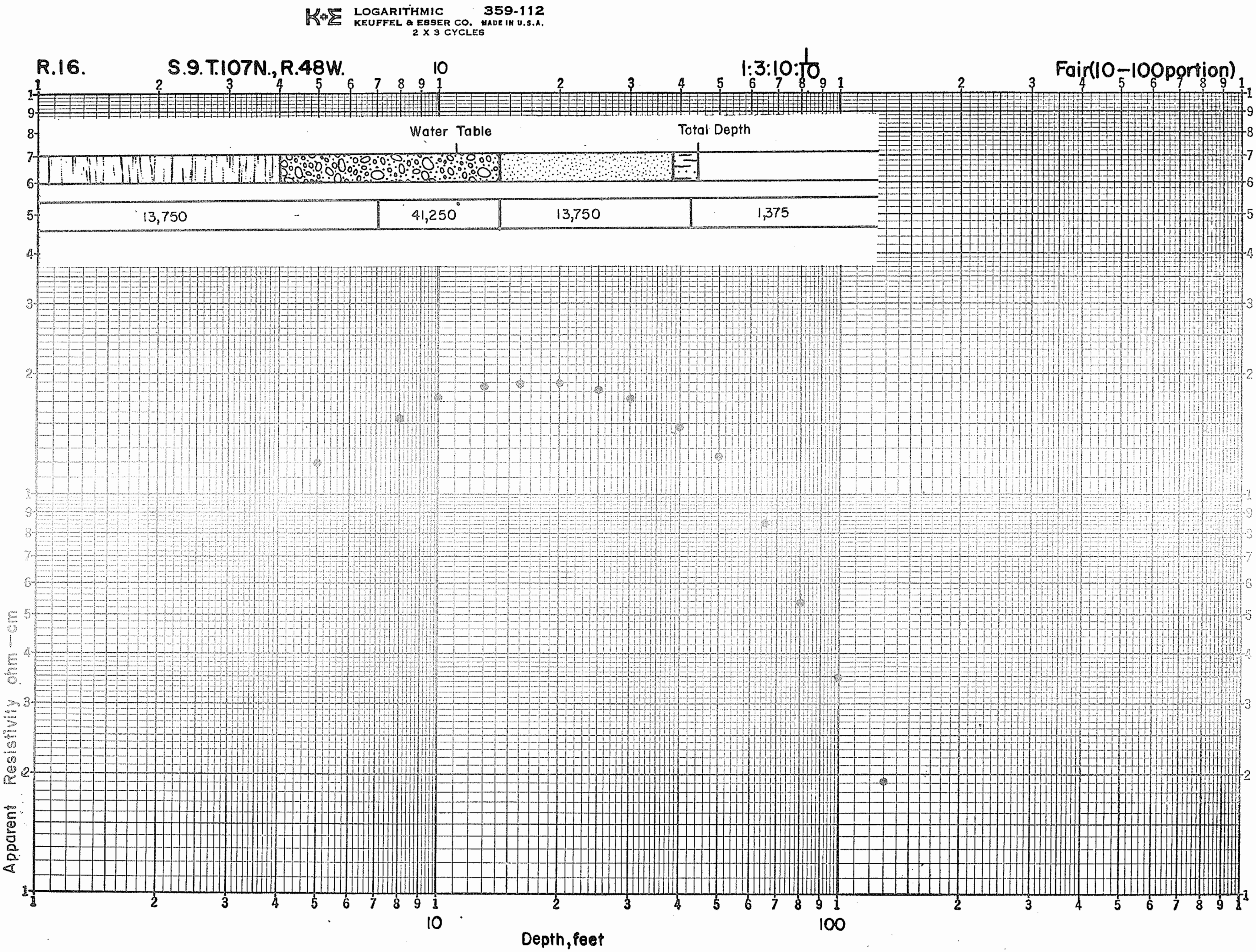
K+E LOGARITHMIC 359-112
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 X 3 CYCLES
R.11
S.11, T.110N., R.51W.
1:10:1/10:1
Fair match
Water Table
Total Depth
1150
11,500
115
1150
Apparent Resistivity ohm-cm
Depth, feet
10
100


K+E LOGARITHMIC 359-112
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 X 3 CYCLES
R.12
S.28, 110N., R.50W.
1:10:100:10
Ambiguous match
Water Table
Total Depth
1,450
14,500
145
145,500
Apparent Resistivity ohm-cm
Depth, feet
10
100

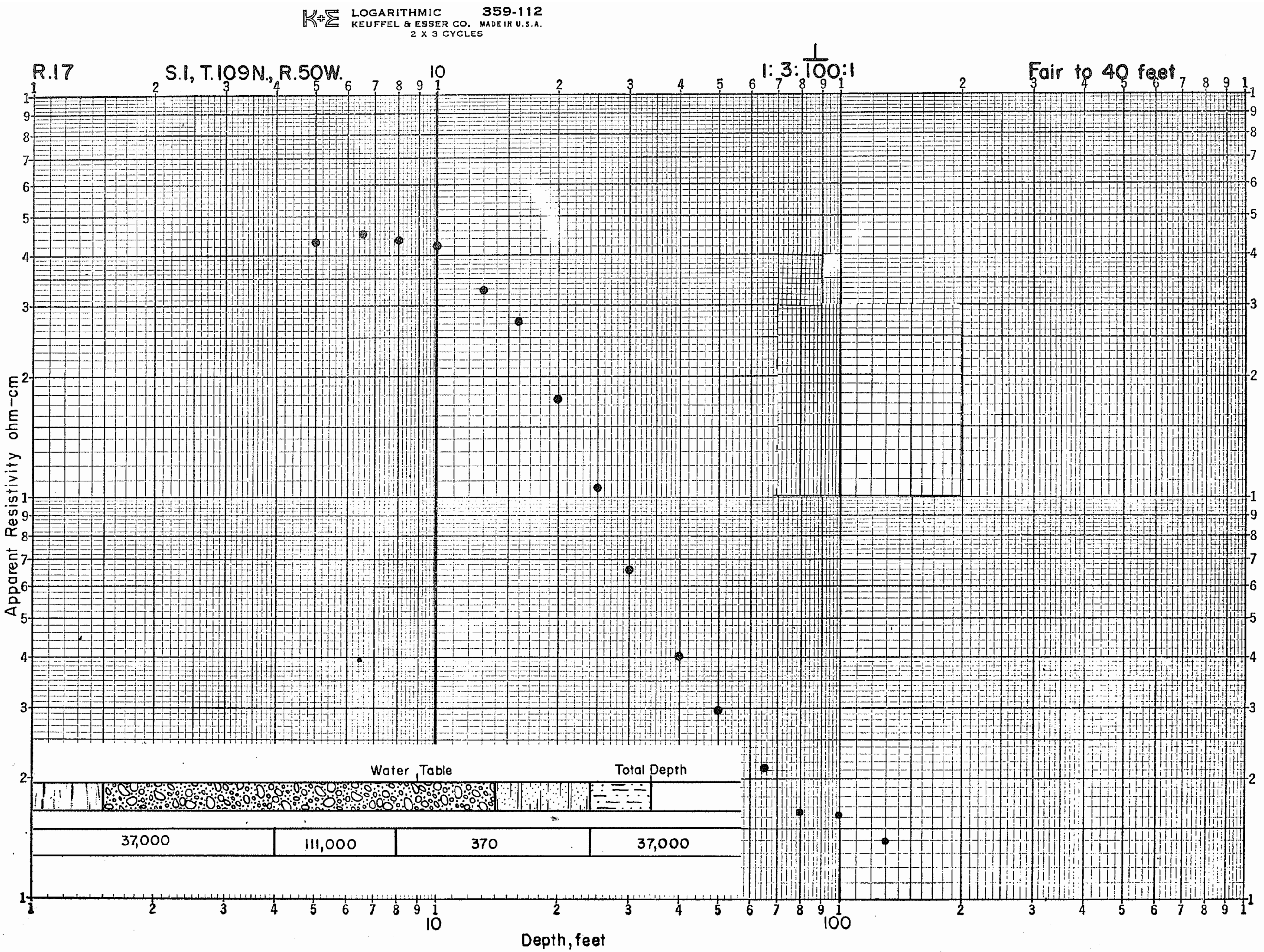

K+E LOGARITHMIC 359-112
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 X 3 CYCLES
R.13
S.4,T.109W, R.49W.
1:10:10:10
Good match
Water Table
Total Depth
13,700
137,000
137
137,000
Apparent Resistivity ohm-cm
Depth, feet
10
100

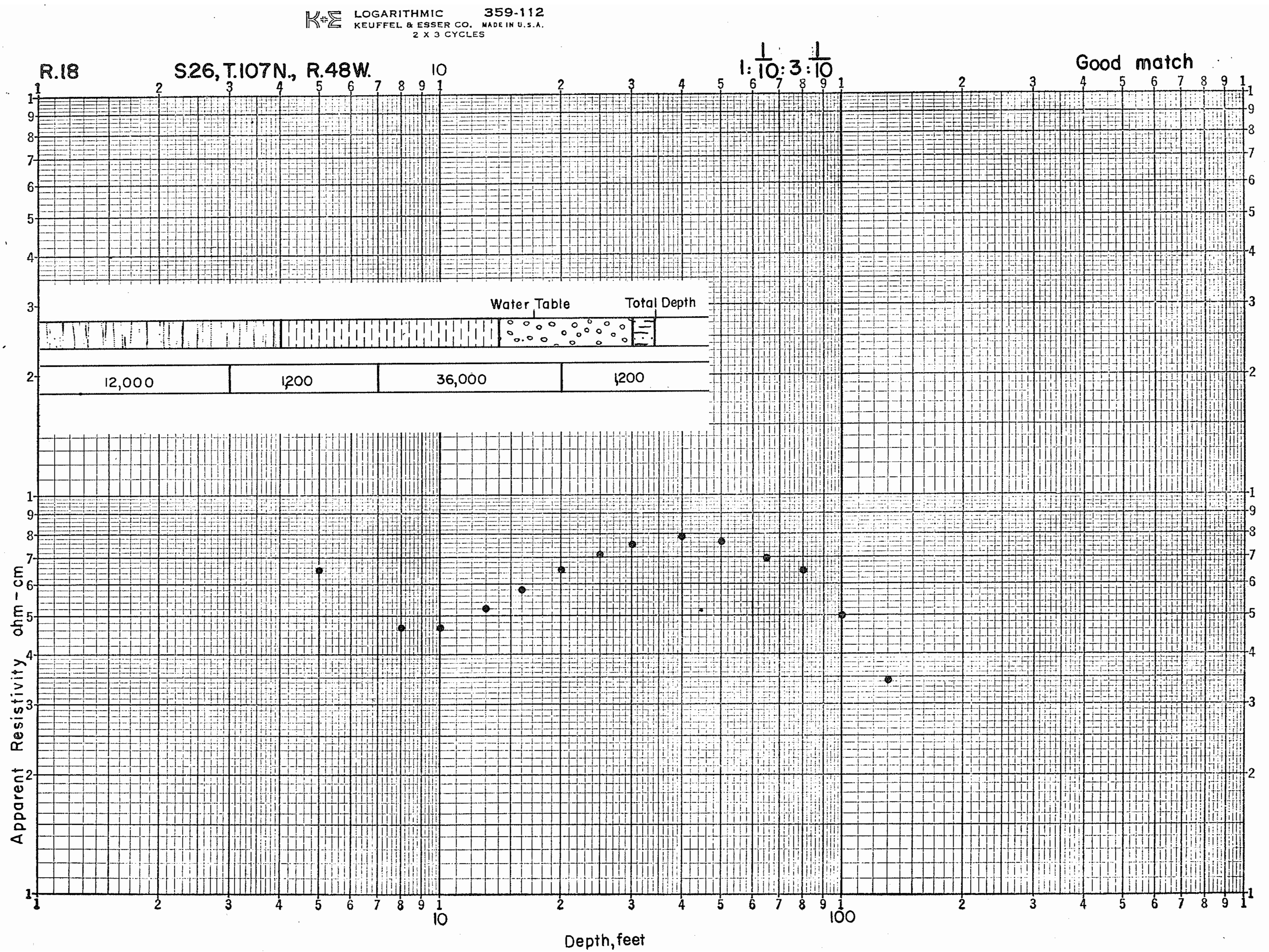

R. 14.
S.27, T.110N. R.50W.
1:3:1:3
Poor match
Water Table
Total Depth
5,000
15,000
5,000
15,000
Apparent Resistivity ohm-cm
Depth, feet
10
100

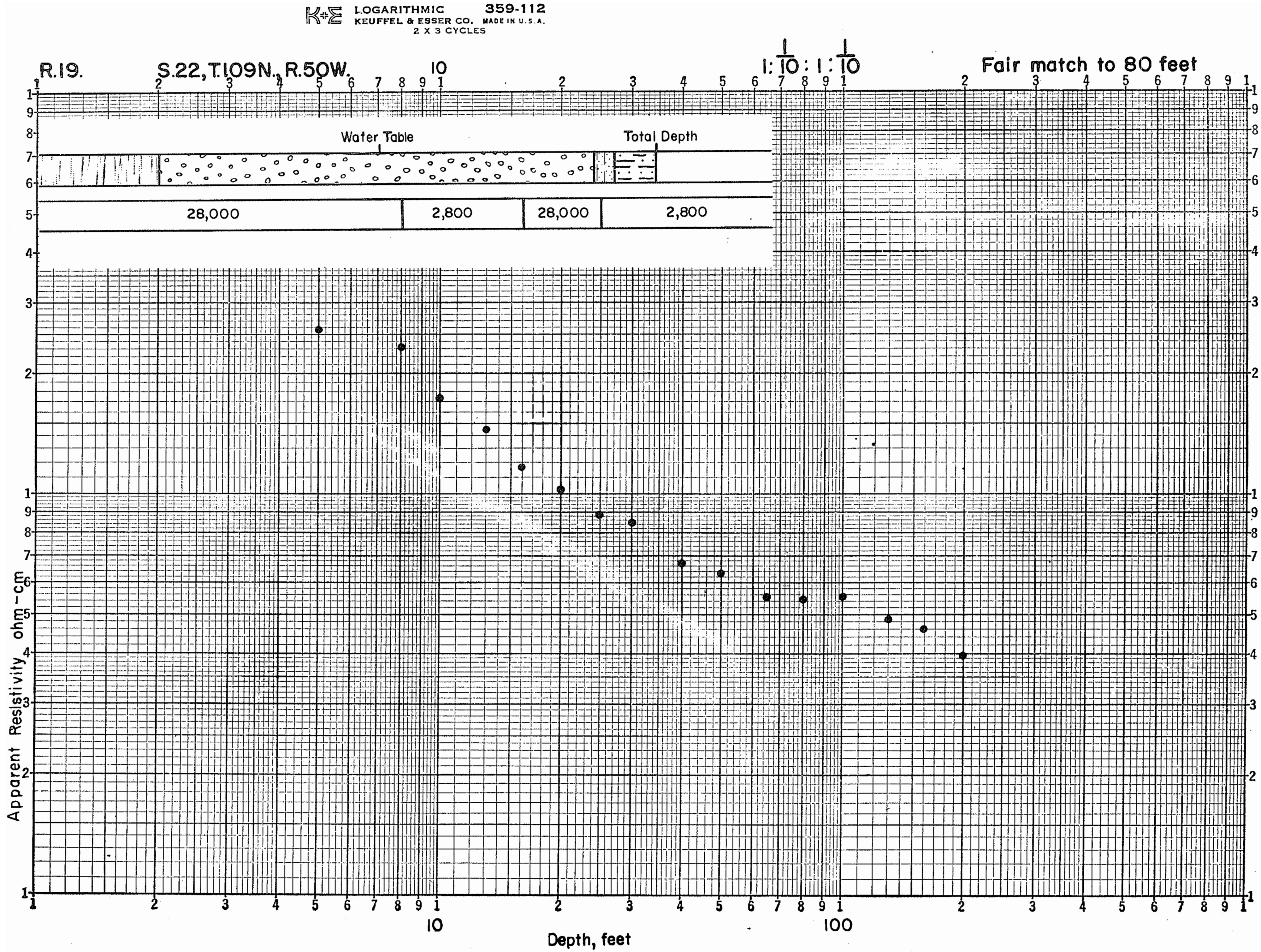

K+E LOGARITHMIC 359-112
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 X 3 CYCLES
R.15
S.27, T.110N., R.50W.
1:3:1:1/3
Poor match
Water Table
Total Depth
4,300
129,000
4,300
1,400
Apparent Resistivity ohm-cm
Depth, feet



K+E LOGARITHMIC 359-112
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 X 3 CYCLES
R.16.
S.9.T.107N.,R.48W.
1:3:10:10
Fair(10-100portion)
Water Table
Total Depth
13,750
41,250
13,750
1,375
10
100
Depth, feet
Apparent Resistivity ohm-cm


K+E LOGARITHMIC 359-112
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 X 3 CYCLES
R.17
S.I, T.109N., R.50W.
1:3:100:1
Fair to 40 feet
Apparent Resistivity ohm-cm
Water Table
Total Depth
37,000
111,000
370
37,000
10
100
Depth, feet


K+E LOGARITHMIC 359-112
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 X 3 CYCLES
R.18
S26, T.107N., R.48W.
1: 1/10 : 3 : 1/10
Good match
Water Table
Total Depth
12,000
1200
36,000
1200
10
100
Depth, feet
Apparent Resistivity ohm-cm



K+E LOGARITHMIC 359-112
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 X 3 CYCLES
R.19.
S.22, T.109N., R.50W.
1: 1/10 : 1: 1/10
Fair match to 80 feet
Water Table
Total Depth
28,000
2,800
28,000
2,800
Apparent Resistivity, ohm-cm
10
100
Depth, feet