A Correlation of Resistivity Variations in Saline and Non-saline Water Bearing Formations

by

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ABSTRACT

The paper is an outcome of the electrical resistivity measurement carried out by the Ground Water Development Organization on RTLH (Pirmahal-Chichawatni). An attempt is made to compare the true resistivity values and the trend of the apparent resistivity graph with water conductivity and to suggest a relationship between the two. It has been noticed that where formation is non-saline the true resistivity values are high and the apparent resistivity graph is rising, where the formation is saline the true resistivity values are low and the apparent resistivity graph is declining. Also there seems to be a correspondence between the resistivity magnitude and the degree of salinity.

1. Introduction

The electrical conductivity of geologic formations is generally controlled by the amount of water in their pore spaces and also by the salinity of water. The greater the water content or the higher the salinity the greater would be the formation conducting properties and therefore the lower the resistivity. It is, therefore possible in a saturated formation to discriminate between various areas of saline and non-saline water by measuring the electrical resistivity of the formation. However it must be acknowledged that the problem is not as simple as this and there are many limitations. For example electrical properties of geologic formations also depend on lithology, porosity, and the physical state such as compressibility etc,. The purpose of this paper is to compare the true resistivity values and the apparent resistivity graph with the data available for lithology and water quality of test line H in Rechna Doab and to suggest a relationship between the salinity of ground water at site and the true resistivity of the formation and the trend of the apparent resistivity graph.

The plains of Punjab are formed of material derived from the Himalayan Mountains as a result of weathering, erosion and subseqnent transportation and deposition by various natural agents such as stream, wind, glacier ect. The salts of sodium, calcium, aluminium and iron originally present in the Himalayas and adjacent hills together with acid radicals of chloride, sulphate and carbonate are therfore the basic chemical constituents of the sediments of the plains of Punjab. The length of time that water

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is in contact with these sediments governs, to a large degree the amount of material taken into solution by the water. In the Punjab plains the hydraulic gradients of the ground water generally are low and the movement of ground water is sluggish. Thus the ground water has ample opportunity to dissolve much soluble material. In areas where the hydraulic gradient is extremely low and or the availability of soluble material is relatively high, conditions are favourable for the salinization of the ground water.

The data analysed in this report is based on an electrical resistivity survey carried out along test line H (Pirmahal-Chichawatni) in Rechna Doab (Fig. 1). In addition to water quality determinations, lithologic logs (based upon drilling logs and electrical logs) of all test holes, drilled along this line are available, fig : 2 (a) — 2 (g). The water quality is based on conductivity test made in the water chemistry wing of the Ground Water Development Organization.

An approach to utilize the true resistivity values and apparent resistivisy graph for determining the salinity of a formation is made by a graphic presentation of the apparent resistivity in ohms-cm against water conductivity in micromhos at the same location. True resistivity values determined by applying the theoretical three layer curves of wetzel and Mc Murry are also given on the top of figs. 2(a)-2(g).

The term saline water used in the present paper means water having a conductivity of 1800 micromhos or more. The term non-saline or fresh water means water with a conductivity of less than 1800 micromhos. This method of defining the salinity of soil or water in terms of conductivity is based on experiments and is commonly used in the united States and other countries and has special advantage for us because of its known relationship to resistivity.

2. Discussion of the Problem

In this study a comparison of the true resistivity magnitude and the apparent resistivity graph with the existing lithologic and water quality data of the test line has been made in order to find a relationship between the true resistivity and trend of the apparent resistivity graph and water quality. In other words the problem is whether saline water zones can be delineated with resistivity measurements.

A resistivity curve represents a combined effect of the geologic formation including its water content and the quality of water. The geologic formation presents many variables such as mineral content, grain size, porosity, permeability, compressibility etc. Hence examining a resistivity curve and postulating that the rise and fall in the apparent resistivity graph or true resistivity is due to a variation in quality of water rather than a lithologic variation would perhaps appear irrational. Particularising, a resistivity drop may not only be due to saline water but might well be due to clay or silt layers or lenses which have low resistivity values. To eliminate such

FIG. I

LOCATION MAP SHOWING POSITION OF TEST HOLES AND RESISTIVIT

Scale :- 1 inch = 1 mile

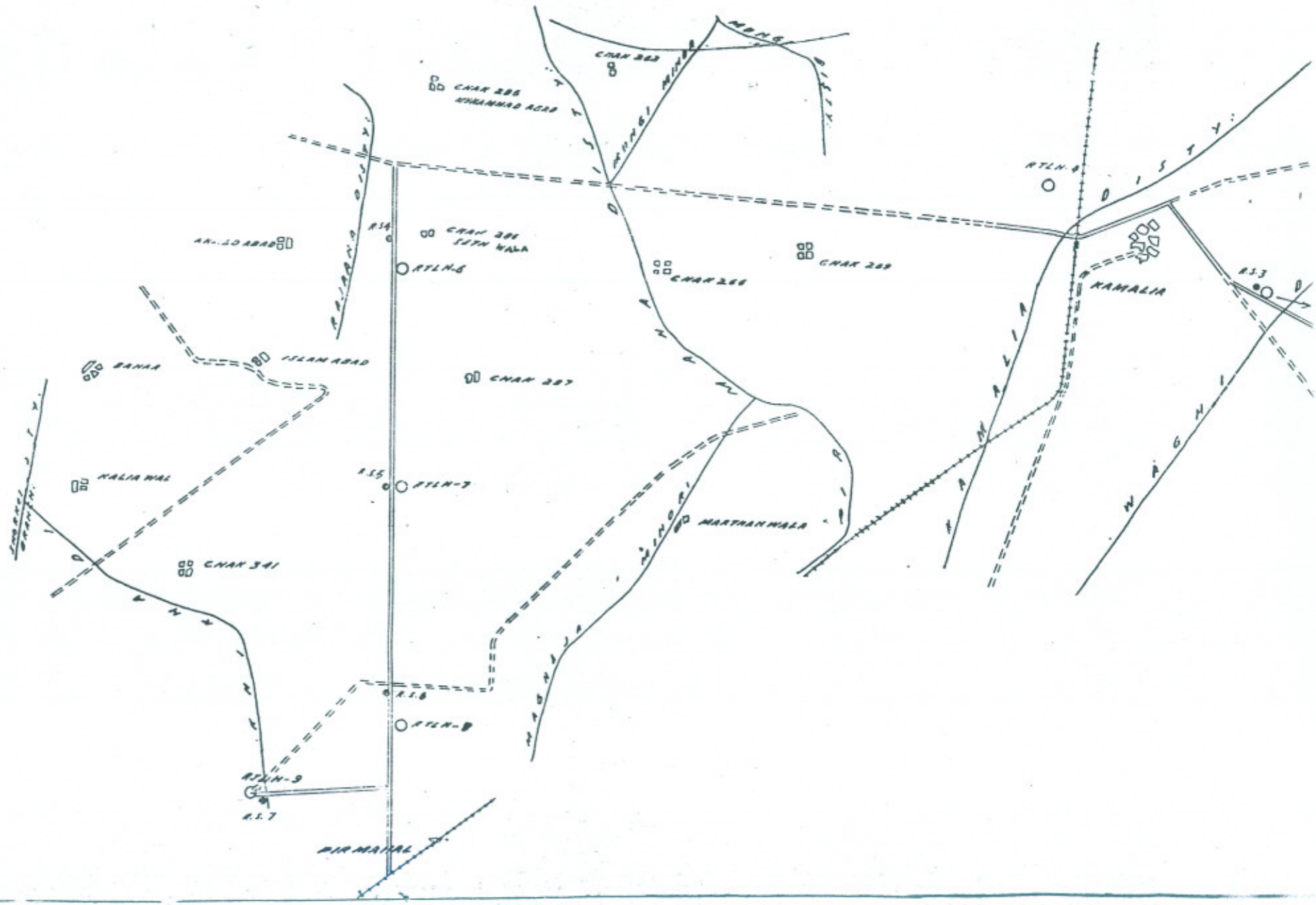
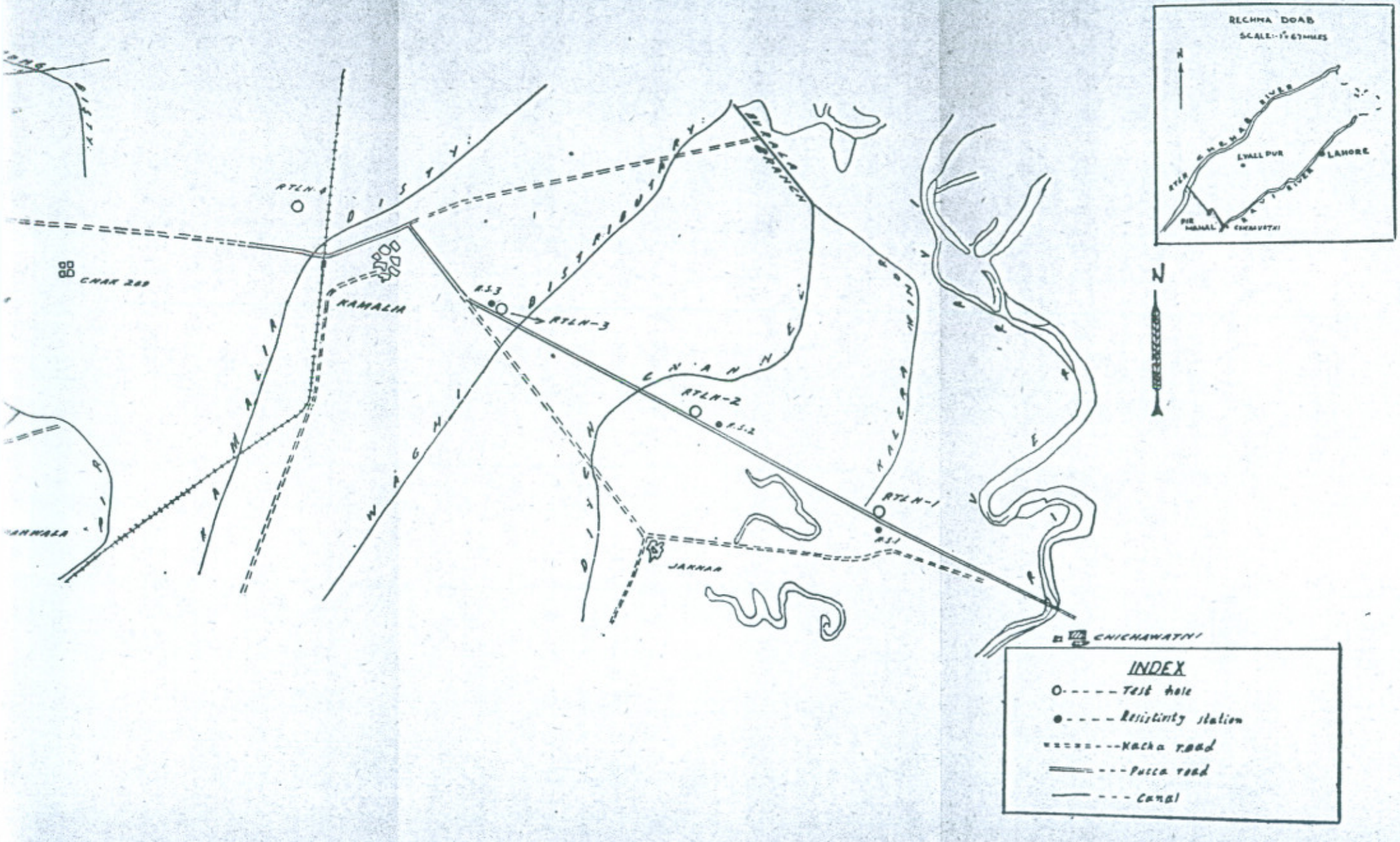


FIG. 1
TEST HOLES AND RESISTIVITY STATION ON TEST LINE H RECHNA DOAB

Scale :- 1 inch = 1 mile



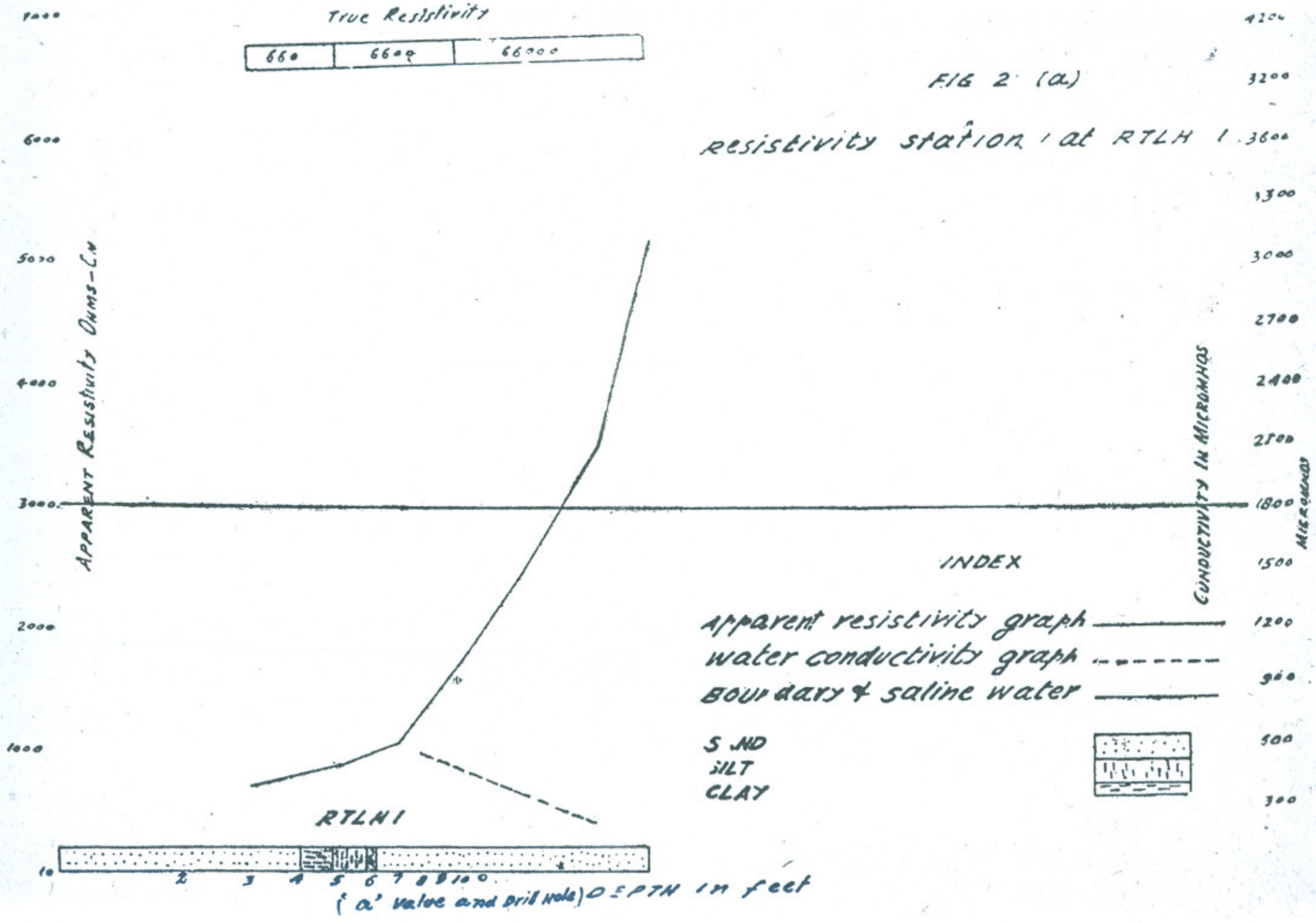
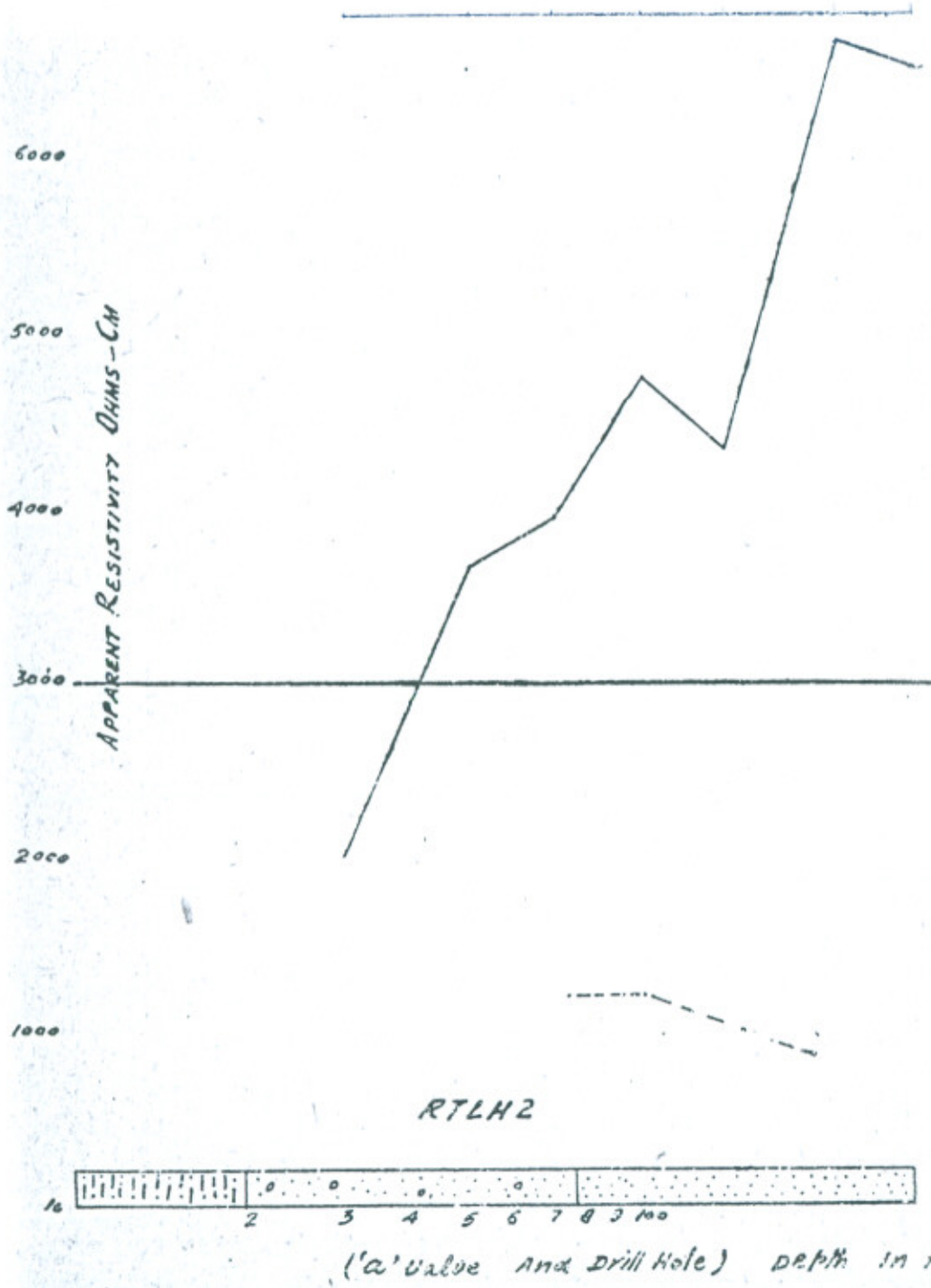

True Resistivity
660
6600
66000
FIG 2 (a)
resistivity station 1 at RTLH 1
APPARENT RESISTIVITY OHMS-CM
CONDUCTIVITY IN MICROMHOS
MICROMHOS
INDEX
apparent resistivity graph
water conductivity graph
Boundary of saline water
SAND
SILT
CLAY
RTLH1
1 2 3 4 5 6 7 8 9 10
('a' value and drill hole) DEPTH IN feet

FIG 2 (B)

Resistivity station 2 of RTLH - 2



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Apprant resistivity graph ——————

water conductivity graph - - - - - -

Boundary of saline water ——————

SAND

SILT

CLAY

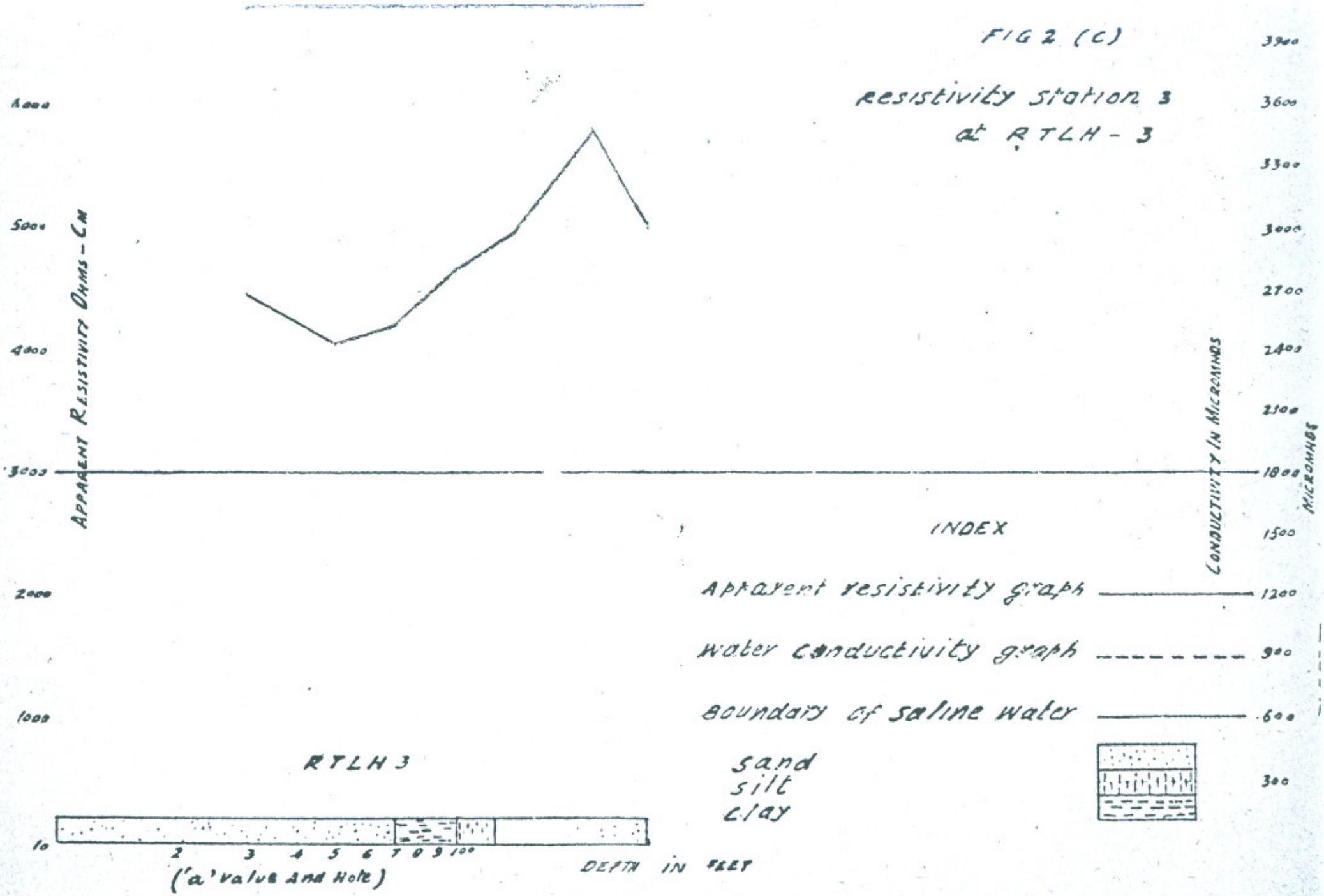


RTLH2

('a' Valve And Drill Hole) Depth in feet

FIG 2 (C)

Resistivity station 3
at RTLH - 3



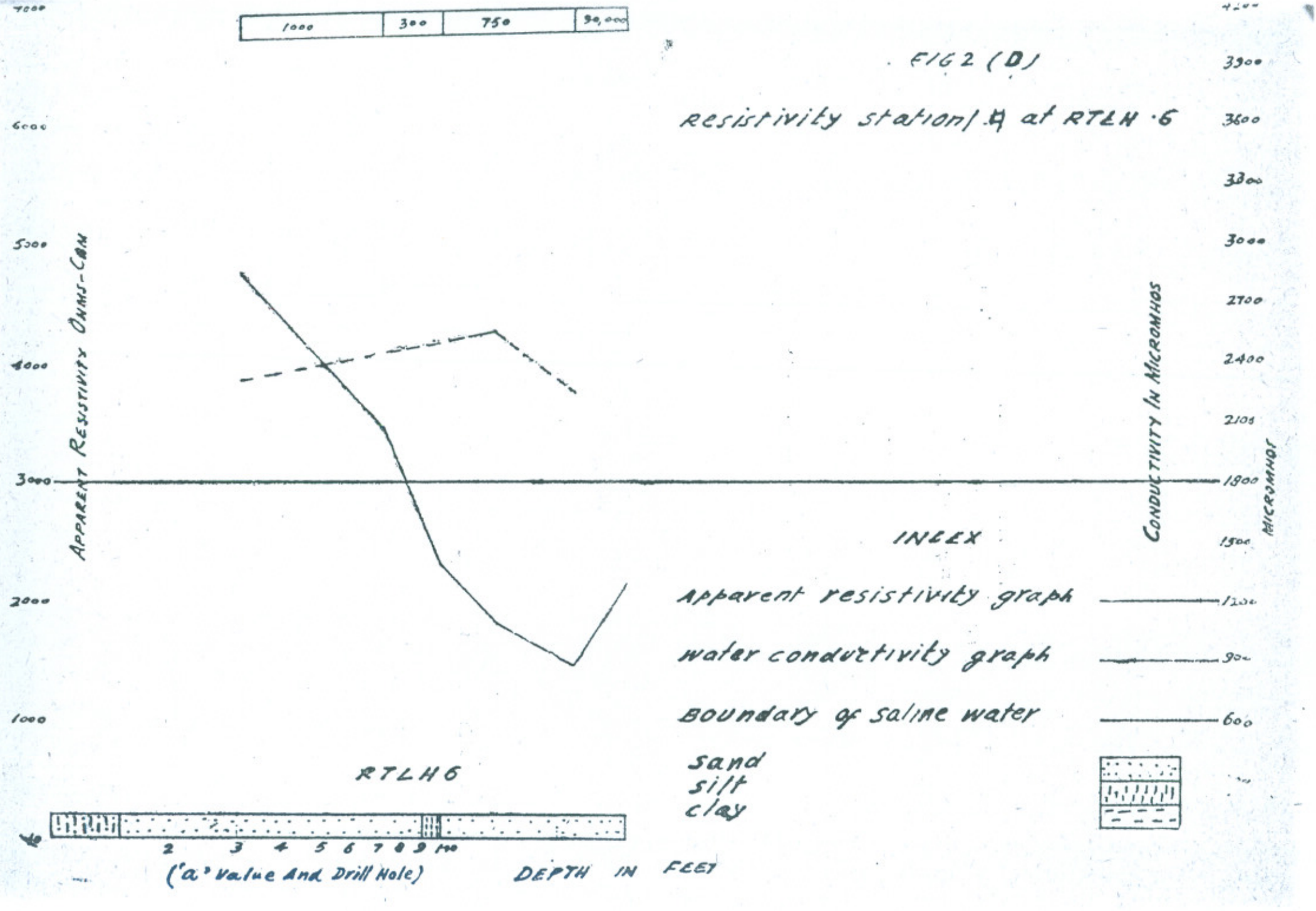

1000
300
750
30,000
FIG 2 (D)
resistivity station 4 at RTLH 6
APPARENT RESISTIVITY OHMS-CM
CONDUCTIVITY IN MICROMHOS
MICROMHOS
7000
6000
5000
4000
3000
2000
1000
4200
3900
3600
3300
3000
2700
2400
2100
1800
1500
1200
900
600
INDEX
Apparent resistivity graph
water conductivity graph
Boundary of saline water
Sand
silt
clay
RTLH6
2 3 4 5 6 7 8 9 100
('a' Value And Drill Hole)
DEPTH IN FEET

FIG 2 (e)

Resistivity stations at RTLH 7

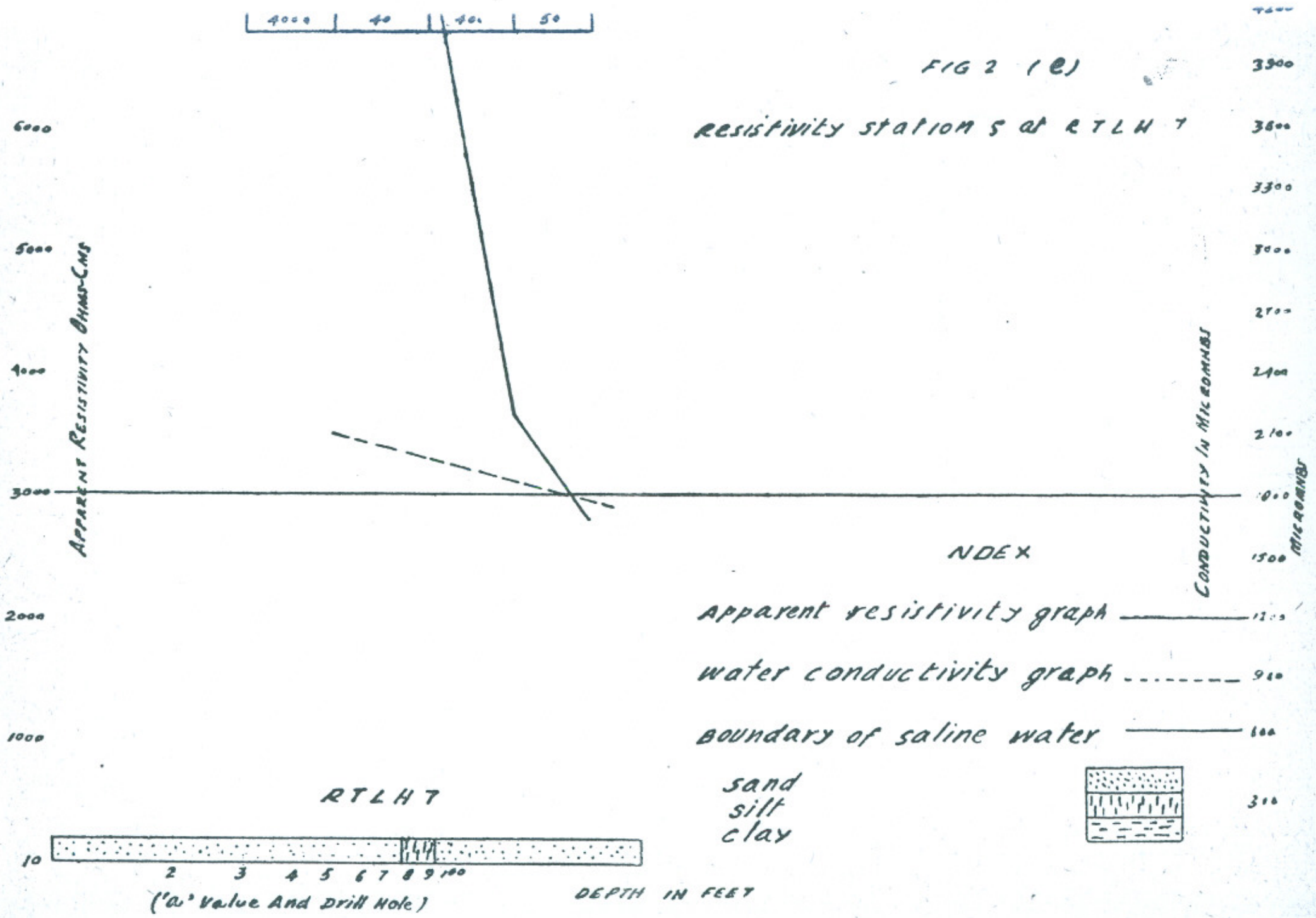


Fig. 2 (f)

Resistivity station 6 at RTLH-8

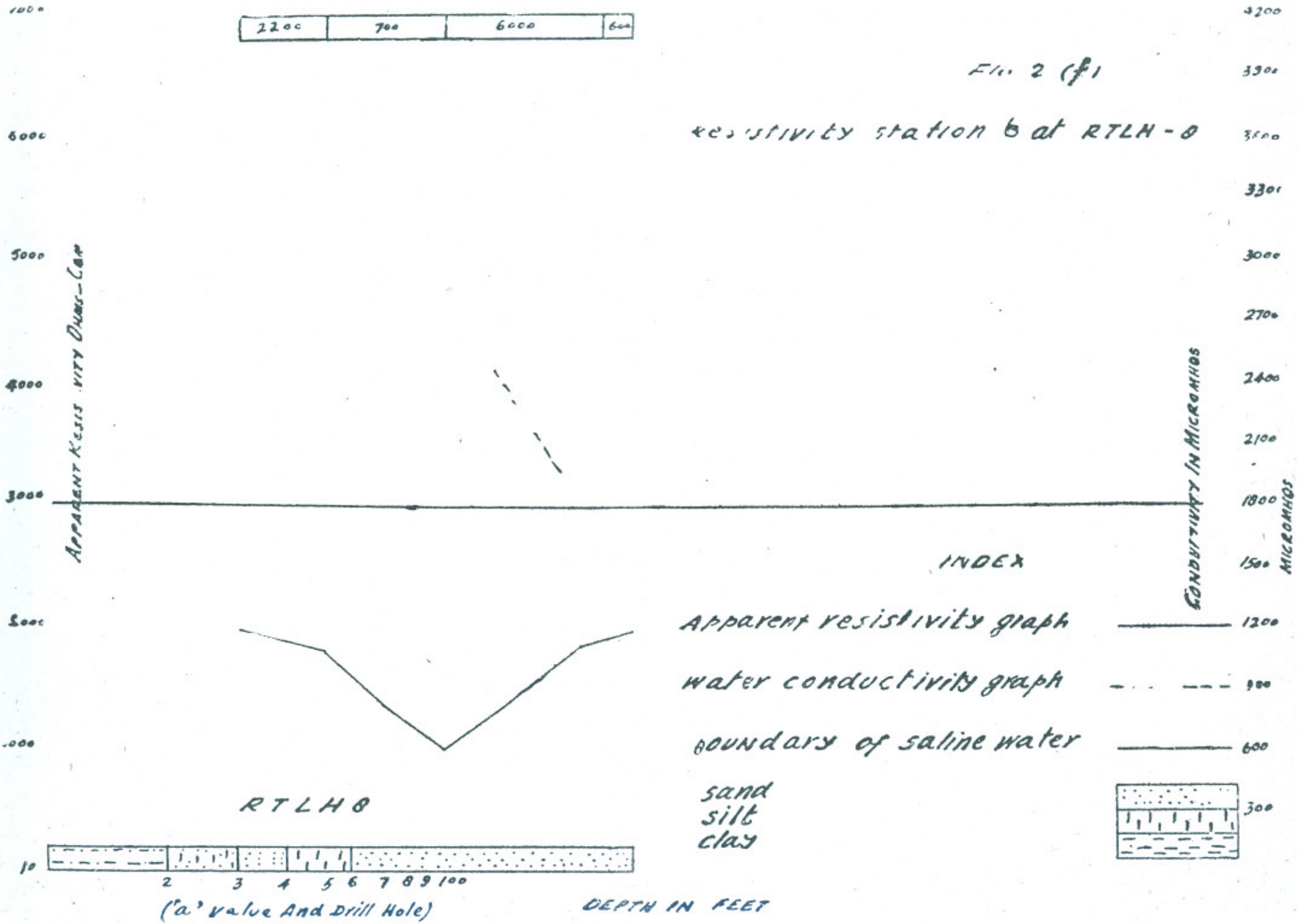
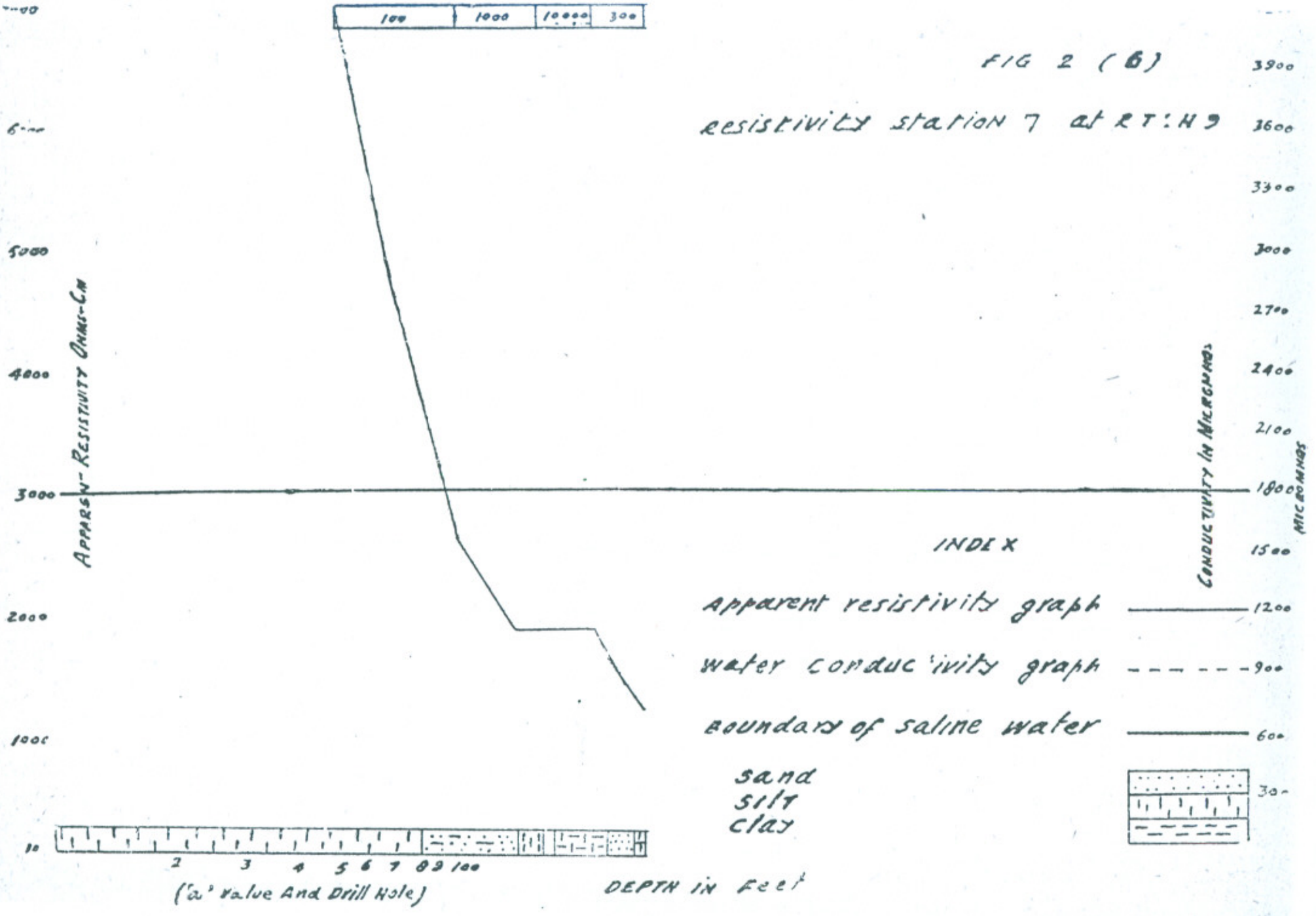


FIG 2 (6)

resistivity station 7 at RT: H 9



INDEX

apparent resistivity graph ——————

water conduc'ivity graph - - - - - -

boundary of saline water ——————

sand

silt

clay

a possibility lithologic logs of the holes are given in the same figure with the apprent resistivity graph and water conductivity graph. Further, experience has taught that a resitivity curve has a characteristic shape when typical materials such as bedrock, gravels, medium and coarse sands, clay and silts are encountered. The curve also has a characteristic shape when a saline water zone is encountered. There is no denying the fact that saline zone saturated with water has a high electrolytic conduction. The resistivity tends to become low and therefore the apparent resistivity curve shows a sharp decline from the normal shape. In fig 3 a few typical resistivity curves actually obtained in the field by the staff of Ground Water Development Organization are shown to substantiate what has been postulated. In certain cases such as saline water or a low resistivity clay formation ambiguity may arise since both indicate low resistivty values. However it should be noted that the gradient of the curve in the fresh water zone of the clay is not as steep as is observed in the saline water zone, where the resistivity values approach zero. All of these cases are possible and have been confirmed by lithologic log and water quality data. It therefore seems relevant that with the lithological control and equipped with experience gained by general observation of resistivity curves it is possible to correlate the trend of the resistivity graph and the resistivity magnitudes with saline and non-saline water zones as long as the limitations are realized.

3. *Method of presentation*

Apparent resistivities in ohm-cm obtained at 'a' values of 30′, 50′, 70′, 140′, 220′, 300′ are plotted on ordinate against depth on abscissa on a semilograthmic graph paper. The resistivity values upto an 'a' value of 300' were taken because water samples only to that depth were available. Only those test holes are selected where resistivity measurements are made directly at or nearby and where sample data are available. Lithologic logs based on drilling logs and electric logs are presented in the same figures. Water samples collected at the test holes and corrected at 25°C of temperature for their conductivities are also presented in figures 2(a)-2(g). The conductivity graph of water in micromhos is plotted for each water sample collected at a specified depth. The conductivity values are given on the ordinate while the depths in feet are given on the abscissa.

The four types of data i.e. the true resistivity values the apparent resistivity graph, lithologic logs and water quality are presented in figures 2(a)-2(g) for purposes of comparision and can be considered as the basic data upon which this paper is presented.

4. *Discussion of results*

We will discuss lithology, resistivity and water quality of each test hole to provide a systematic approach to comparision and therefore a rational approach to any conclusion.

At resistivity station No. 1 fig: 2(a) located near RTLH 1 the curve starts with an initial true resistivity value of 660 ohms-cm and attains

a maximum true resistivity value of 66000 ohms-cm at a depth of 100′-300′ maintaining all through a rising gradient. The conductivity of water obtained from a depth of 80′ and 220′ is 275 and 625 micromhos respectively which is well within the limit of fresh water. Lithologic log shows predominance of clay and silt upto a depth of 60′ which corresponds very well with the low true resistivity of 660 ohm–cm at depth of 30′-50′. This is then followed by a thick layer of fine to medium sand to a depth of 300′. High true resistivity values, rising gradient of the Curve would indicate a non-saline saturated formation.

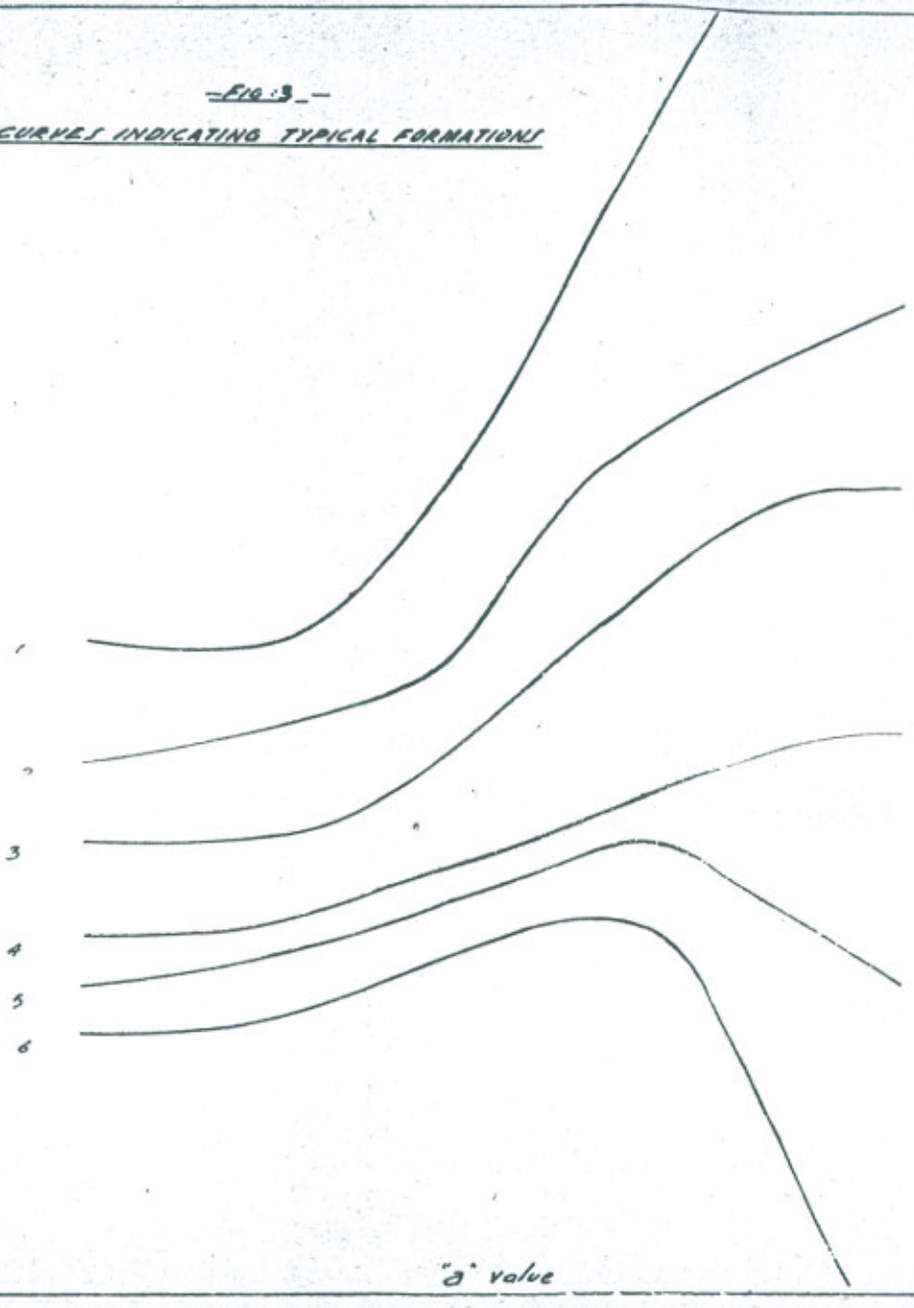
At resistivity station No. 2 fig. 2 (b) the curve starts with an initial true resistivity value of 200,000 ohm-cm. A minimum true resistivity value of 2000 ohm-cm is obtained at a depth of 100′-140′. The curve maintains all through a rising gradient. The conductivity of water obtained from a depth of 75', 100' and 200' is 710, 725 and 525 micromhos respectively, which is within the conductivity range of fresh water. Lithologic log of RTLH 2 shows sandy clay material upto a depth of 20' underlain by fine to medium sand with occasional gravels to a depth of 300'. The resistivity values higher than 2000 ohm–cm with a steady rising apparent resistivity gtadient are an indication of a non-saline satured zone.

At resistivity station 3 fig. 2(c) an initial true resistivity value of 1700 ohm-cm and a maximum true resistivity value of 6000 ohm-cm is recorded at a depth of 30'-60' and 100'-220' respectively. The curve has a rising gradient from 50' to 220'. The curve falls from 30'-50' and 220'-300' probably due to some near surface inhomogeniety or the effect of thick overburden of clay and silt at a depth of 70'-125'. The lithology remains fine to medium sand throughout except at depth of 70'-125' where silt and clay are mixed in a varying percentage with sand. The conductivity of water obtained at a depth of 100' is 1200' micromhos which remains within the limit of fresh water. True resistivity values higher then 1700 ohm-cm with a rising gradient of the apparent resistivity curve suggests a non-saline formatian. However low true resistivity value of 600 ohm-cm recorded at a depth of 220'-300' may suggest a change in quality of water at that depth.

At resistivity station 4 fig. 2 (d) the curve has an initial true resistivity value of 1000 ohm-cm and a minimum true resistivity of 300 ohm-cm at a depth of 70′-100′ with a falling gradient all through except at a depth of 220′ to 300′ where it rises, perhaps due to a fresh wate zone as suggested by the conductivity curve. The lithologic log shows fine to medium sand throughout the depth of the test hole except at depth of 0—15′ where sandy clay is encountered and at 90′—100′ where a lens of clay is present. The conductivity of water obtained at depths of 30′,135′,220′ is 2300, 2525, 2240 micromhos respectively which is the conductivity range of saline water. Low true resistivity values and a falling gradient of the apparent resistivity graph would suggest a saline formation. It is at this station that the reversal of the gradient of the apparent resistivity curve takes place, resulting in low true resistivity values. At stations 1,2 and 3 the gradient of the apparent resistivity was rising, true resistivity higher, water was observed to be fresh but at this station the gradient is falling true resistivity is low the water is observed to be saline, lithology, showing no significant change.

-Fig: 3-

CURVES INDICATING TYPICAL FORMATIONS



-INDEX-

1. BEDROCK OVERLAIN BY CLAY
2. GRAVAL FOLLOWED BY COARSE SAND
3. MEDIUM TO COARSE SAND. OVERLAIN & UNDERLAIN BY F. SAND
4. FINE TO MEDIUM SAND.
5. FINE SAND FOLLOWED BY CLAY
6. FINE SAND CONTAINING SALINE WATER

Traced by:-

At resistivity station 5 fig 2 (e) at RTLH 7 an initial true resistivity value of 4000 ohm-cm is recorded with a minimum resistivity of 40 ohm-cm at a depth of 40′—85′, with a steep consistently falling gradient. The lithologic log shows fine to medium sand throughout the hole except at depth of 70′—90′ a clay layer is encountered. The conductivity of water obtained from depths of 50′, 250′ is 2700 and 1700 micromhos which is the conductivity range of saline water. Low true resistivity value and a steep falling gradient of the curve indicate a saline saturated formation.

At resistivity station 6 fig. 2 (f) located near RTLH 8 the curve starts with an initial true resistivity of 2200 ohm-cm and a minimum true resistivity of 600 ohm-cm at a depth of 250′—300′. Also a low true resistivity value of 700 ohm-cm is recorded at a depth of 50′—100′. The curve has a falling gradient up to 100′ depth and then a rising gradient upto 220′. The water conductivity obtained at a depth of 105′ and 185′ is 2820 and 2040 micromhos respectively which is the conductivity of saline water. A low apparent resistivity gradient with low true resistivity values indicate a saturated saline zone.

At resistivity station 7 fig.2 (g) the gradient of the curve shows a steep decline with a minimum true resistivity of 100 ohm-em at a depth of 50′—100′ and a maximum true resistivity of 10,000 ohm-cm at a depth of 160′-220′. Also low true resistivity values of 300 ohm-cm and 1000 ohm-cm are obtained at depths of 220′—300′ and 100′—160′. The lithologic log shows concentration of clayey material with pockets of sand interspersed at various depths. The conductivity of water obtained at a depth of 200′ is 4100 micromhos which is the conductivity of saline water. A falling apparent resistivity gradient with low true resistivity values does indicate the effect of saline saturated zone in addition to the possible effect of clay material which at this station is profound.

5. Conclusion.

In the present work an attempt is made to compare the true resistivity variation with lithologic log and water conductivity data in the area extending from Pir-Mahal to Chichavatni (RTLH) and to find a relationship between true resistivity values or gradient of apparent resistivity values and saline or fresh saturated zones. It has been noticed that where true resistivity values are higher than 1700 ohm-cm and the gradients of the curves are rising as at stations 1, 2 and 3″ non-saline saturated zone is indicated. At stations 4,5,6 and 7 where resistivity values are lower than 1000 ohm-cm and the gradients of the curves are declining saline saturated formations are indicated. However the method to determine saline and non-saline formations through resistivity measurement has certain limitations as at resistivity station 7 located near RTLH 9 though the falling gradient suggests a saline formation yet thick overburden of clay has an equally lowering effect on resistivity values and consequently on the gradient of the curves. This limitation should be realised and given due consideration prior to making any positive correlation between true resistivity values, apparent resistivity graph and the water quality.

The results of this study have been achieved as a by-product of routine resistivity measurement programme carried out for sub-surface geologic investigations. The work has proved to be of good value and it hoped to continue and enlarge upon it. It is also hoped to take up a self potential survey along the same line and see if high self potential might not be associated with the saline areas. This would help to confirm the present resistivity studies. The applicability of the work at this stage seems to be very wide and may prove of fundamental importance in survey of saline and non-saline areas throughout West Pakistan.

Table 1 showing values of apparent resistivity at various resistivity stations.

Resistivity Station.	Values in ohm-cm against electrode separation in feet.						
	30′	50′	70′	100′	140′	220′	300′
Res. Station 1 at $RTLH_1$	674	860	1145	1700	2420	3540	5200
Res. Station 2 at $RTLH_2$	1975	3640	3920	4750	4340	6650	6500
Res. Station 3 at $RTLH_3$	4450	4030	4220	4670	4960	5810	5050
Res. $Station_4$ at $RTLH_6$	4760	760	3440	2300	1830	1455	2160
Res. Station 5 at $RTLH_7$	39300	22290	12800	6260	3670	2810	—
Res. Station 6 at $RTLH_8$	2020	1790	1375	1089	1325	1825	1970
Res. Station 7 at $RTLH_9$	16990	7000	4600	2585	2030	1876	1060

The above readings were taken by employing a Gish. Rooney type of instrument having a double commutator. The wenner configuration of electrodes was employed in which four electrodes are equally spaced 'a' feet-

apart in a straight line along the surface. The value of 'a' is increased after each measurement and as the configuration is expanded the current penetrates deeper into the earth. A current I is applied to the two outer electrodes and the drop in voltage V between the two inner electrodes is read on a potentiometer. The apparent resistivity Pa of the ground is then calculated from the formula.

$$Pa = 2\pi a \frac{v}{I}$$

REFERENCES

1. A set of curves to assist in the interpretation of the three layer resistivity problem, by W.W. Wetzel and Howard V. McMurry.

2. Resistivity Survey along RTLH (Pir-Mahal—Chichavatni) by S. Hashim Raza.

3. Resistivity Survey in Shahkot Sangla area, by Irshad Mufti.

4. Resistivity Survey along test line E in Chaj Doab (Sargodha-Chiniot), by R. A. Shamsi.

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