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DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD No. 1966/169

MARKHAM VALLEY RESISTIVITY SURVEY,

TERRITORY OF PAPUA AND NEW GUINEA 1964

by

M. WAINWRIGHT

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ILLUSTRATIONS

SUMMARY

A resistivity survey was made in the Markham Valley in the Territory of Papua and New Guinea using both direct current and alternating current instruments. A correlation was shown to exist between resistivity interpretations and borehole information, particularly in zones of high permeability on the Leron Plains. The thickness of outwash material was shown to reach a maximum of over 300 feet at Leron Plains, but was generally thinner at Erap, 25 miles to the east.

In both areas the comparison of direct current and alternatingcurrent resistivity curves consistently showed a difference between the two. This effect is known as induced polarisation. There is a correlation between this difference and moist or water-saturated clay, gravel, or sand formations. It was also shown that this induced polarisation effect is sufficiently large to be easily detected. Further research into the controls of induced polarisation in sediments is suggested.

1. INTRODUCTION

At the request of the Geological Branch of the Bureau of Mineral Resources, Geology and Geophysics (BMR), the Geophysical Branch made a resistivity survey in the deeply alluviated Markham Valley in the Territory of Papua and New Guinea (Plate 1). The object of the survey was partly to obtain further information on the aquifers in the area and partly to carry out research on the nature of anomalies arising between the comparison of resistivity curves obtained using direct current (d.c.) and alternating current (a.c.) instruments. The occurrence of such anomalies had been noticed on previous surveys made by the BMR in other areas. Theoretical studies on the phenomenom known as induced polarisation (IP) indicated that such anomalies may be expected under certain conditions. The Leron Plains and Erap areas were chosen for the survey because some borehole data were available there. A resistivity depth probe was also made in the Umi Bridge area.

The survey was made between the 3rd August and the 1st September 1964. The party consisted of J.T.G. Andrew (party leader), M. Wainwright (geophysicist), and W.A. Wiebenga (senior geophysicist). United Nations Fellow T. Sundararamayya was with the party for part of the survey. Field-hands were obtained from the Department of Lands, Surveys, and Mines of the Administration of TPNG and from local villages. Vehicles were provided by the Administration of TPNG, whose assistance is gratefully acknowledged.

2. GEOLOGY

The geology of the area has been described by Mackay (1955) and Best (1964). The Markham Valley is the eastern portion of the Ramu/Markham depression, a long, broad, flat-floored valley, flanked on the northern side by the Finisterre and Saruwaged Ranges, and on the southern side by the Kratke and Herzog Ranges. The valley contains thick alluvial deposits and the Markham River drains along the edge of the foothills on the southern side of the valley. The areas surveyed lie on the north side of the Markham River from the Umi River to the Erap River; the rivers on the north side drain from the foothills of the Finisterre and Saruwaged Ranges, which consist of Miocene slates, siltstones, and conglomerates (see Plate 1).

The floor of the Markham Valley is composed of flood-plain deposits, with piedmont sands, gravels, and silts bordering the mountain ranges on the northern side. Where tributary rivers such as the Leron and Erap Rivers flow southwards into the valley, separate outwash deposits of sands and gravels are developed that are generally more coarse than the Markham River alluvium. The Leron Plains station is established largely on the piedmont and river outwash deposits.

3. THEORY

The general theory for resistivity depth probe surveying is given by Parasnis (1962), who also discusses types of electrode arrangements and the interpretation of resistivity curves. The accuracy of interpretations is dependent on geological control in the form of borehole information, without which interpretations are ambiguous. Further useful control is afforded by knowledge of the depth to the local water table, and on the resistivity of the water saturating the formations. The resistivity of a formation is a function of its porosity; the resistivity of the pore solution saturating the formation is given by Archie's formula:

$$\log Rw/Ra = 1.30 \log V$$

where Ra = resistivity of saturated formation,
Rw = resistivity of pore solution,
V = porosity of formation, and
1.30 = cementation factor.

The resistivity of a pore solution is a function of the total dissolved salts, and varies with temperature. All water resistivity values are corrected to 20°C (see Plate 8).

An account of the drawing, interpretation, and evaluation of resistivity depth probe curves is given by Wiebenga, Polak, Andrew, Wainwright, and Kevi (1966); a further discussion on the interpretation of resistivity curves is given by Andrew and Wiebenga (1965).

It will be seen that differences arise in the resistivity curves derived using direct and alternating current instruments at the same site. The theory by which these differences may be explained is complex and, so far, incomplete. If an alternating voltage is applied across two electrodes in sand containing small amounts of clay, and is then interrupted, a small voltage that is set up across another pair of electrodes decays with time. This effect is called induced polarisation (henceforth referred to as the 'IP effect'), and has been used successfully in the exploration for disseminated metallic orebodies. Some early work was done by Schlumberger (1930), but its value in prospecting for groundwater was not generally realised until the work of Vacquier, Holmes, Kintzinger, and Lavergne (1957), who suggest that the effect is due to electrodialysis of clay within a saturated aquifer, which acts as a 'distributed electronegative membrane'; the magnitude of the effect depends on the kind of clay (kaolinite produces this effect, whereas montmorillonite does not), on the amount of clay present in the 'dirty' sand formation (high clay content mixtures do not give rise to the IP effect), and on the kinds of positive ions in the water. Vacquier <u>et al</u> also suggest that the IP effect is inversely proportional to the conductivity of the water and independent of the kind of negative ions dissolved therein. Marshall and Madden (1959) conclude that the IP effect is due to a number of factors, the most important of which are:

(1) Electromagnetic coupling
(2) Membrane polarisation
(3) Electrode polarisation

In prospecting for disseminated orebodies, factor (3) is the most important and is commonly accompanied by factor (1). Membrane polarisation, which is due to clay particles adhering to the surface of sand grains, should be the principal effect where the concentration of metalliferous disseminations is very low, as it is in most aquifers.

In terms of field measurements, membrane polarisation set up by an applied alternating voltage should give rise to a 'complex' impedance, the real component of which is smaller in magnitude than the ground resistance measured using an applied direct current voltage.

4. INSTRUMENTS

The resistivity depth probes were measured using an a.c. Geophysical Megger (0-30 ohms, frequency range 8-10 c/s) manufactured by Evershed and Vignoles; d.c. measurements were made with a type ERR3 resistivity meter designed and constructed by the BMR. The resistivity of the water samples was measured using a standard mud-cell in combination with a Megger Earth Tester (0-1000 ohms, frequency range 50-300 c/s), also manufactured by Evershed and Vignoles. The depth probe electrodes consisted of brass stakes 2 feet long and 1¼ inches in diameter.

5. METHODS

The survey was carried out by making resistivity depth probes adjacent to boreholes (for which geological information was available) and at intermediate sites. A symmetrical system of four electrodes (Wenner or Schlumberger configuration) is expanded about a fixed centre point and the resistivity of the ground is determined at different spacings of the electrodes. A curve is then plotted of resistivity against L/2 (where L is the distance between the outer electrodes) and from this the resistivity of formations beneath the ground surface, and their thickness, can be computed. For the purpose of computing the porosities of various formations in the manner described above (see Section 3), water samples were obtained from boreholes and their resistivity measured in a standard mud-cell in combination with a Megger Earth Tester. The temperature of each water sample was also taken, so as to correct the resistivity value to 20°C (see Plate 8).

6. RESULTS

Plate 2 shows the location of boreholes and depth probes at Leron Plains; Plates 9 and 10 show the interpretations of these depth probes as histograms. The results of the survey will be discussed in the following manner:

(1) Interpretation of D.C. resistivity curves to define the water table and the junction between Markham River alluvium and Leron River fan deposits.

(2) Water quality and porosity of formation.

(3) Comparison of d.c. and a.c. resistivity curves.

<u>Interpretation of d.c. resistivity curves</u> (Plates 9 and 10)

These curves have been interpreted with both the Type and Help curves (which is the repeated use of the two-layer method) and also with computed three-layer curves (Compagnie Generale de Geophysique, 1955). Correlation of both sets of interpretations with known water table data and with geological information from boreholes (Plate 6) clearly showed that the three-layer interpretations are more accurate in most cases. The depth to the water table is best indicated by the resistivity curves of highly permeable geological sections (e.g. L10 - Bore 12). This is because the resistivity contrast between the mainly dry formation above the water table and the saturated formation below the water table is high. In low permeability zones, the contrast between the two layers is small, since clayey formations tend to retain a large amount of moisture even when the water table has dropped. Plate 3 shows the contour map of the depth to water table at Leron Plains based on water levels recorded in boreholes. The figures underlined refer to the corresponding depths computed using three-layer curves. In general, the agreement between measured and computed water levels is good and in some cases (L12, L13, and L22) it has been possible to indicate the water table at locations intermediate between boreholes based on resistivity curves alone. The contours show that the water table is shallow near the western edge of the area (30 feet at Bore 9) but deepens eastwards to 147 feet depth at Bore 10. This is probably due to the increasing thickness of permeable fan deposits laid down in the channel of the Leron River, which runs approximately NNE/SSW along the eastern edge of the surveyed area.

The measured depth to water table at Bore 7 appears excessive (222 feet); gravel-and-clay extends to a depth of nearly 250 feet, which could explain this. However, a similar succession probably occurs at the nearby Bore 8, where the standing water table is at a depth of only 94 feet. The water table contours show a small embayment between Bore 4 and Bores 7 and 8, which may indicate a subsurface drainage channel in a NNW/SSE direction. It is possible that Bore 8 intersects an aquifer or aquifers of this subsurface channel, whereas Bore 7 does not.

The junction between the Markham River flood plain sediments and the coarser overlying fan deposits of the Leron River (including the mountain piedmont gravels, etc. that border the Finisterre and Saruwaged Ranges) should be indicated on the resistivity curves by a low resistivity-high resistivity discontinuity. The resistivity curves indicate either the depth to water table or the lithological discontinuity, but rarely both resistivity junctions; exceptions occur at L6 and L10 (also see E1 in the Erap area). The differentiation between the two types of discontinuities is based on correlation with known water-levels and borehole geological information. Plate 4 shows the depth to the interface between deposits of the Markham River and those of the Leron River (including the mountain piedmont deposits). It shows that the coarser material overlying the Markham River alluvium becomes markedly thicker from L5 (thickness 56 feet) eastwards towards L17 and L19 on the edge of the active drainage channels of the Leron River, where it is 320 feet thick.

At depth probe L23, the coarser material overlying the Markham River alluvium appears to be at least 250 feet thick; at L2 nearby it is 255 feet thick. This may represent an old channel of the Leron River as shown in the contour map (Plate 4). Further resistivity and borehole information would be needed to be sure of the location of such a channel.

Two depth probes were made at the Erap agricultural station and the resistivities of water samples were measured at nine bores. Plate 11 shows a contour map of water levels for the area. The three-layer interpretations for both depth probes agree reasonably well with known water levels. At depth probe E1 the resistivity interpretation suggests a lithological change at a depth of about 70 feet. This agrees well with drill hole information at Bore 3 (see Plate 6). It seems likely that the Erap agricultural station is established on outwash deposits of the Erap River, which thicken towards the north.

Water quality and porosity of formations

Samples of water were obtained directly from boreholes where possible; in some cases samples were taken from surface storage facilities and these may not be truly representative of water quality at depth. Thus since the computed porosity of formations is based on water quality data, some anomalous porosity values may be expected. Table 1 shows the computed porosity of formations. Only those depth probes adjacent to boreholes have been used, i.e. at points where the quality of the subsurface water has been measured. The porosity of the water-bearing formation computed for L10 is high; probably the second layer resistivity was interpreted too low. An alternative interpretation, consistent with the field measurements, is shown in Plate 9. The porosity at L11 is also high, but since the curve interpretation is reasonable Rw is probably too high. At L16 the curve is difficult to interpret, and the formation resistivities may not be accurate; the porosity of formation at L18 is also very high, and this is probably due to an anomalous Rw value, since the curve interpretation is reasonable.

TABLE 1

Computed porosities of formations at Leron Plains

Depth probe station	Bore No.	Depth range of saturated formation (d.c. solution) (ft)	Resist. of formation (d.c. solution) (ohm-metres)	Resist. of pore solution (ohm-metres)	Depth to water table 't' (measured) (ft)	Porosity %	Lithology of formation
L1	6	44-115	245	28	85	18	Clay or clay gravel
L2	7/8	75-255	175	38	80-110	28	" " "
L3	7/8	7-∞	100	38	95-130	45	" " "
L4	5	15-240	100	32	73	40	Not known
L5	Hstd	28-56	136	26	30	26	" "
L6	1	26-78	69	26	30	43	" "
L7	2	13-130	97	18	60	26	Gravel, clay, or clay-gravel
L10	12	60-240	43	21	73	< 54	Mainly gravel
L11	11	95-∞	47	23	95	< 56	Clayey gravel
L14	13	6-110	110	17	34	24	Gravel or gravel-sand
L16	14	78-∞	60	25	96	49	Clay-gravel
L17	Govt	9-320	145	32	140	25	Not known
L18	10	180-∞	55	30	150	<60	" "
L20	3	9-51	236	15	40	12	Gravel and clay
L21	4	14-203	102	23	80	30	Gravel to 100 ft - not known below

Comparison of d.c. and a.c. resistivity curves

The resistivity data obtained at Umi Bridge and Erap is similar to that obtained at Leron Plains, the latter data forming the basis of this discussion. Plate 13 shows a typical example of the difference between d.c. and a.c. resistivity curves at L18. These curves have been interpreted separately, but where the thickness of the middle layer in the a.c. curve differs markedly from that of the equivalent d.c. layer, then it has been adjusted to the d.c. thickness. This can be computed using either the Maillet or Hummel relation, depending on the configuration of the interpretation (Andrew & Wiebenga, 1965).

Both curves have been interpreted on the basis of the Compagnie Generale de Geophysique (C.G.G.) master curve CH58S.

For the d.c. resistivity curve the interpretation obtained is:

55 ohm-metres	0 - 30 ft depth
126 ohm-metres	30 - 180 ft depth
55 ohm-metres	> 180 ft depth

For the a.c. resistivity curve the interpretation is:

52 ohm-metres	0 - 36 ft depth
121 ohm-metres	36 - 144 ft depth
52 ohm-metres	> 144 ft depth

In this instance the resistivity of the middle layer is greater than the resistivity of the first and third layers, and the relationship given below is used:

$$R1 \times h1 = R2 \times h2$$

where R1 = Initial value of resistivity of a layer; h1 = Initial thickness of the layer; R2 = Adjusted resistivity of the layer; h2 = Adjusted thickness of the layer.

For the case of the second layer in the interpretation of the a.c. curve at L18 we have:

$$121 \times (144-36) = R2 \times (180-30)$$

where R2 is the adjusted resistivity of the layer and 180-30 = h2 is the thickness of the equivalent d.c. layer.

Thus we have: $R2 = \frac{121 \times 108}{150} = 87$ ohm-metres

The adjusted configuration of the a.c. interpretation is:

52 ohm-metres	0 - 30 ft depth
87 ohm-metres	30 - 180 ft depth
52 ohm-metres	> 180 ft depth

The d.c. and a.c. interpretations for L18 are shown in histogram form in Plate 13. Similar interpretations were carried out for those depth probes adjacent to boreholes; some curves were difficult to interpret using the C.C.G. three-layer master curves, and two-layer Type and Help curves were used.

Plates 9 and 10 show the interpretation results for d.c. and a.c. (about 9c/s) methods. Plate 6 shows the depth ranges where these differences occur plotted side by side with the bore logs.

Following Vacquier et al (1957) there should be no variation due to IP effect in dry formations or in saturated formations that contain no clay. Hence it may be concluded that no IP effect would be observed above the water table. However, Plate 6 shows that there is an IP effect above the water table at many places, e.g. at L7 (Bore 2), L20 (Bore 3), L1 (Bore 6), L2/3 (Bore 7), L18 (Bore 10), L11 (Bore 11), L10 (Bore 12) and L16 (Bore 14).

The geology suggests that most of the subsurface formations consist of a mixture of gravel, sand, and clay. Because of its low permeability and the yearly rainfall, the clay never becomes completely dry and the moist formations apparently contain sufficient water to cause an IP effect. It may also be observed that most pronounced IP effects take place in gravel-and-clay formations, moist or water saturated.

7. CONCLUSIONS

The resistivity survey has provided information on the depth to the water table and the porosity of material at Leron Plains; it has given some indication of the depth to the Markham Valley flood plain sediments, which are overlain by a variable thickness of outwash deposits of the Leron River; it suggests that the Markham River sediments contain a large amount of clay. The survey has also provided information on an interesting research object, namely the application of induced polarisation theory to the exploration for water.

The use of direct current and alternating current instruments to make resistivity depth probes at the same site shows that measurable differences occur, even when corrected for instrumental discrepancies.

This investigation should be followed up by a more complete research into the possible factors controlling induced polarisation in sediments, namely: lithology, salinity of the pore solutions, the amount and types of clay in sediments, and the optimum frequency range of the applied a.c. current. A suitable area for such research would be a delta.

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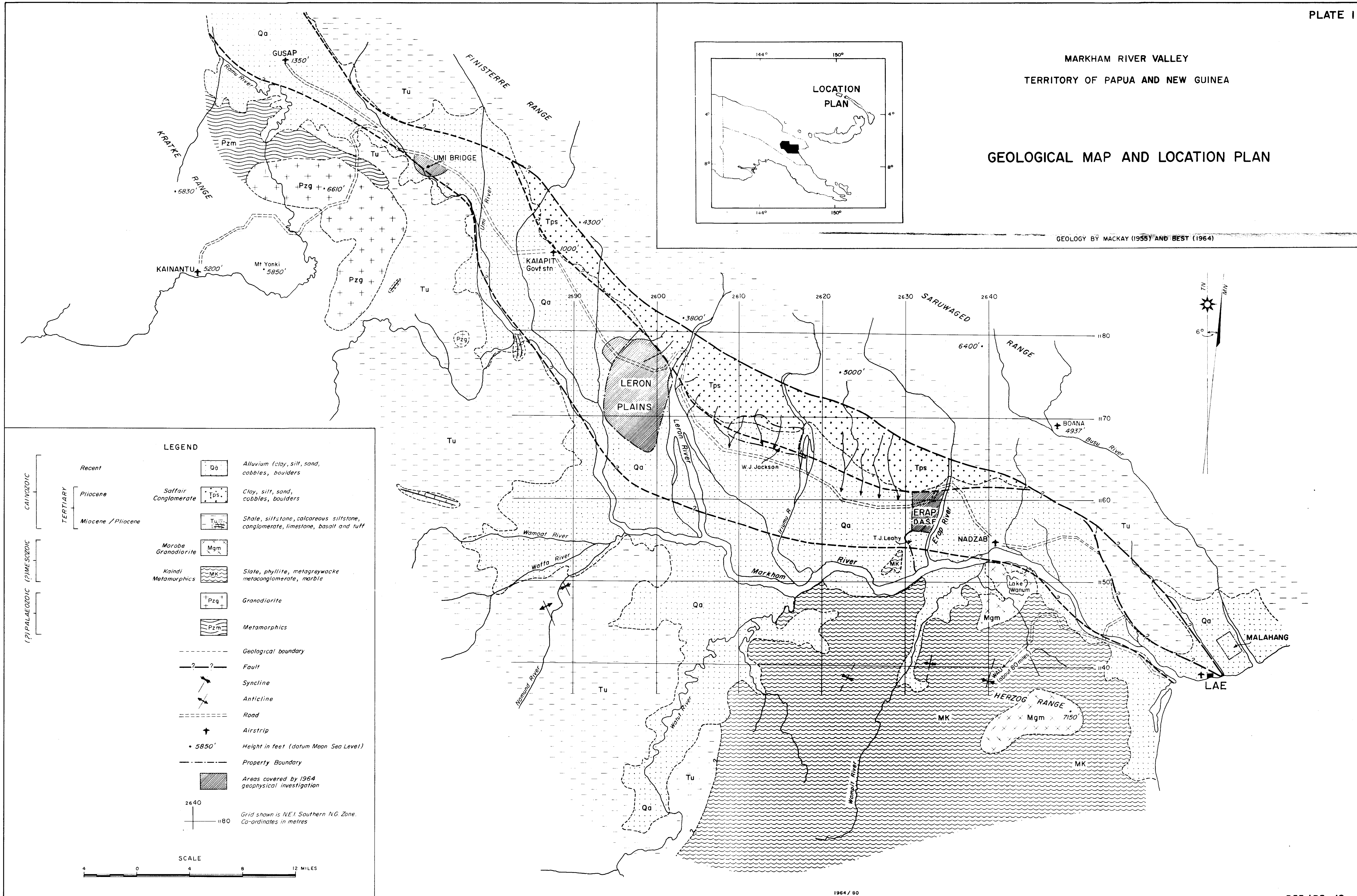
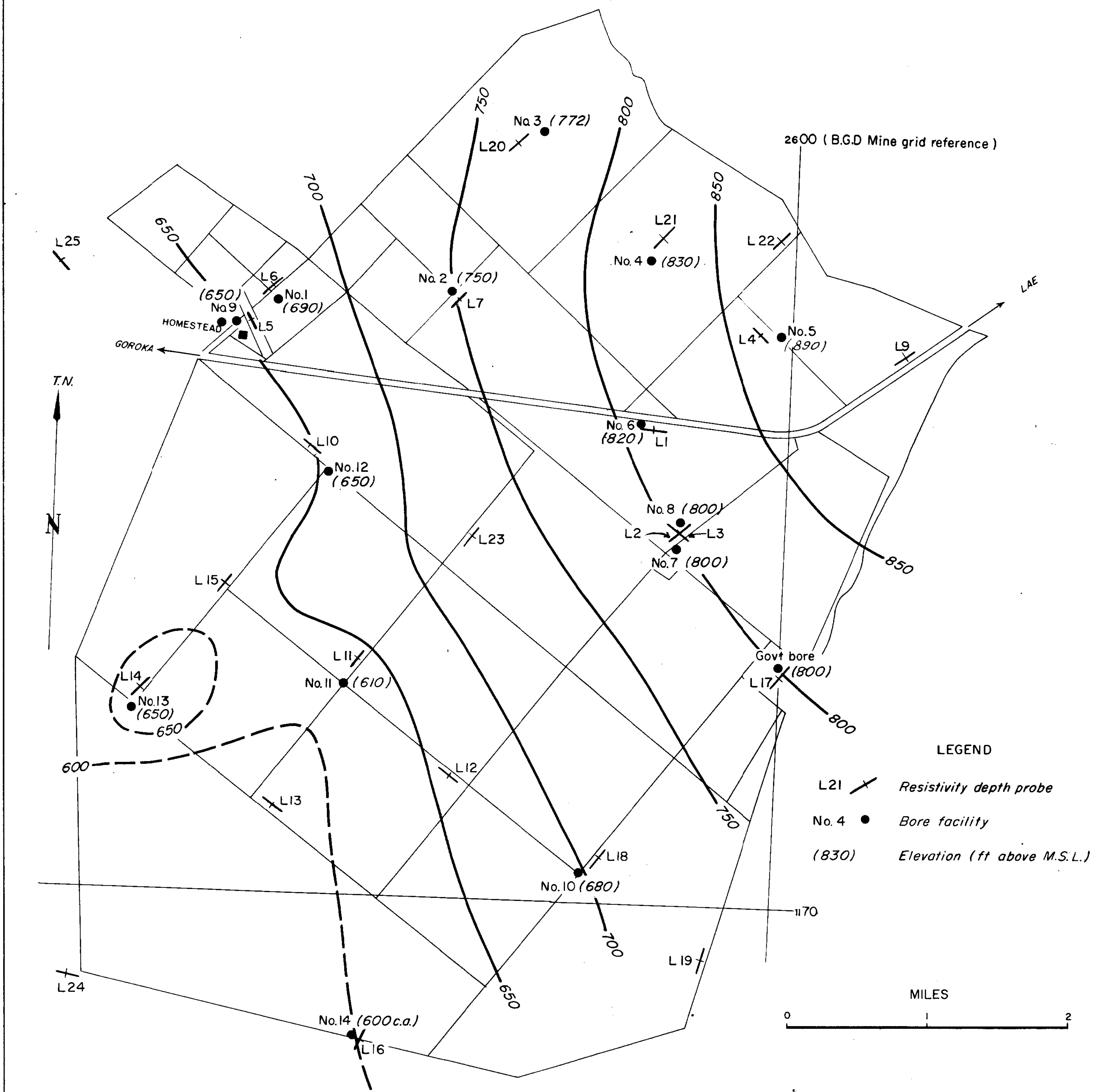


MARKHAM VALLEY RESISTIVITY SURVEY 1964

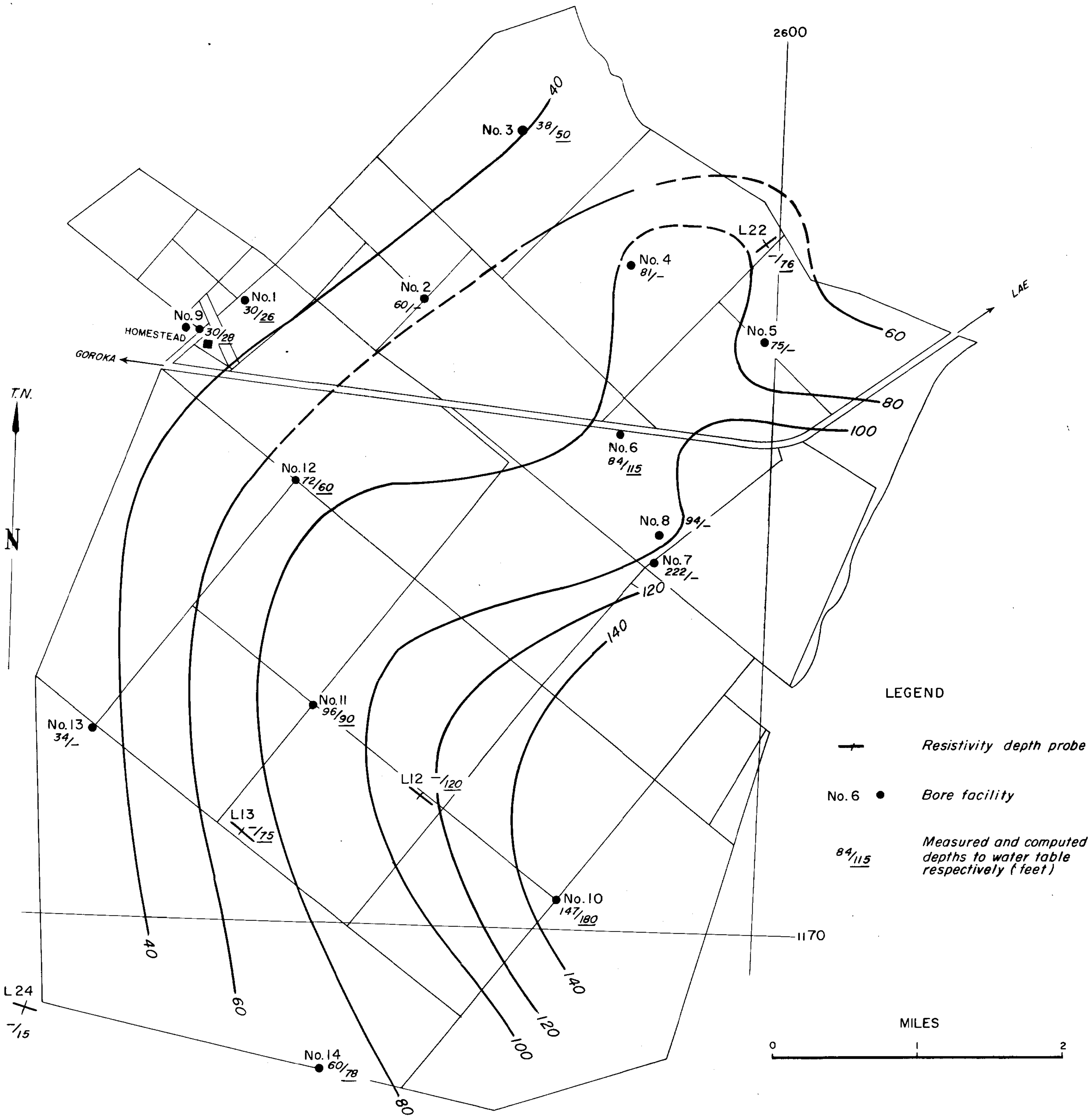
PLATE 2



LERON PLAINS ESTATE - MARKHAM VALLEY, NEW GUINEA, 1964

BORE HOLE AND RESISTIVITY DEPTH PROBE LOCATION PLAN AND ELEVATION CONTOURS

(BASED ON BULOLO GOLD DREDGING CO. LTD (B.G.D.) DRAWING No. L-8) TO ACCOMPANY RECORD No. 1966/169 *Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics.* B55/B5-13-2



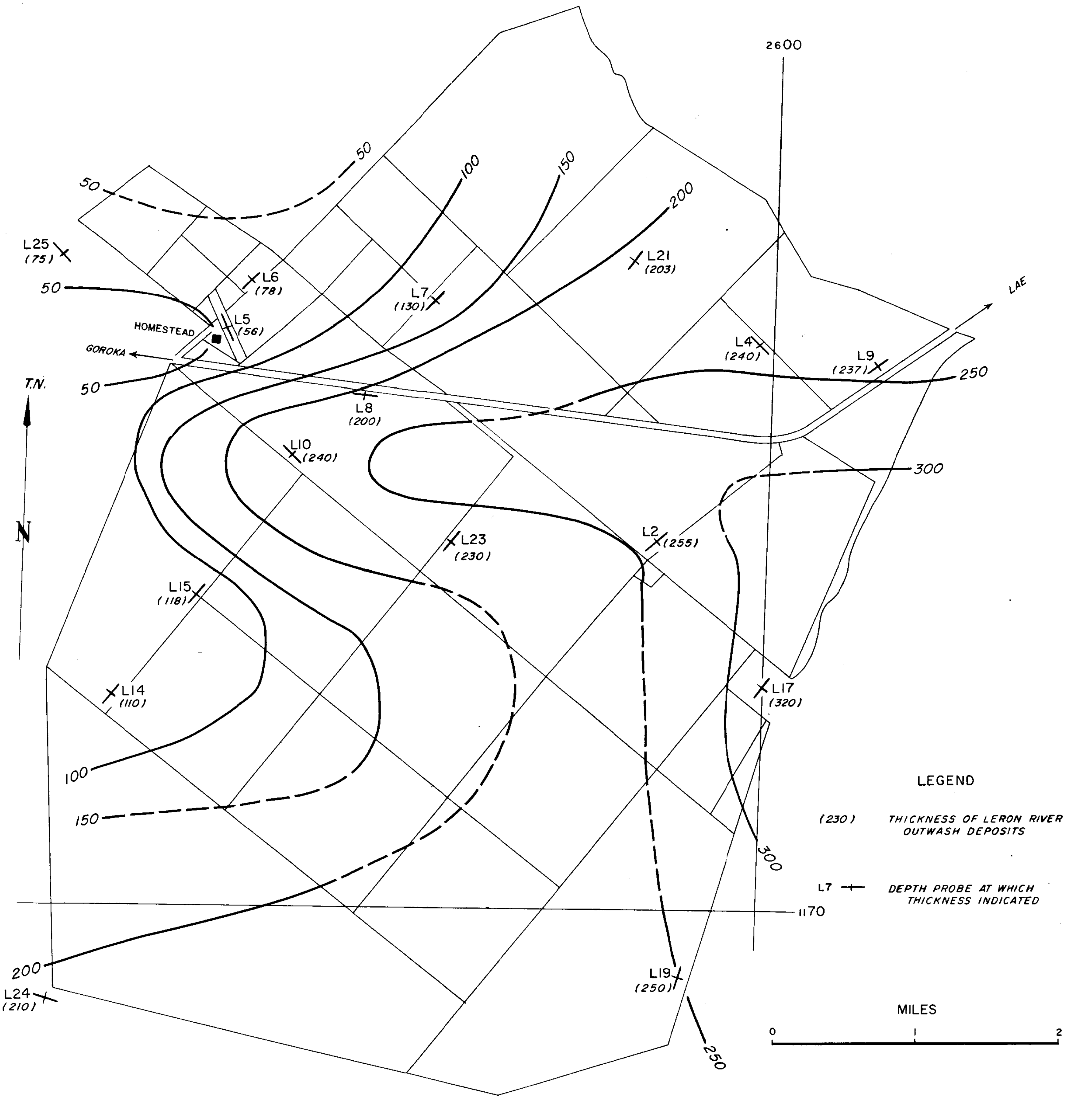
LERON PLAINS ESTATE - MARKHAM VALLEY, NEW GUINEA, 1964

WATER TABLE CONTOURS

(CONTOURS BASED ON MEASURED WATER LEVELS)

(BASED ON B.G.D. DRAWING No L-8) TO ACCOMPANY RECORD No. 1966/169 *Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics.* B55/B5-13-3

PLATE 4



LERON PLAINS ESTATE – MARKHAM VALLEY, NEW GUINEA, 1964

THICKNESS OF OUTWASH DEPOSITS (DEPTH TO MARKHAM RIVER ALLUVIUM)

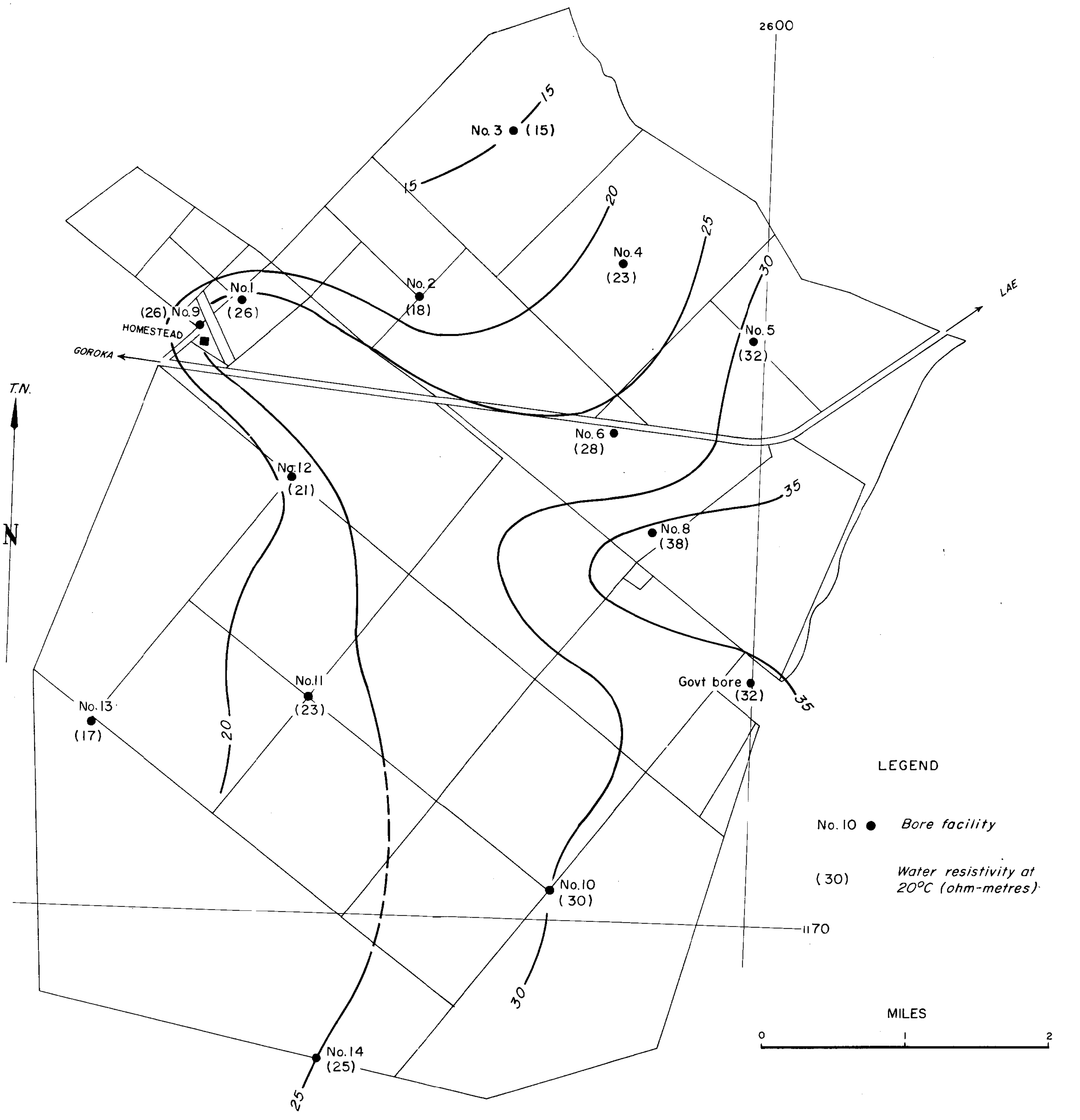
(BASED ON B.G.D. DRAWING No L–8)

TO ACCOMPANY RECORD 1966/169

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics. B55/B5–13–4

PLATE 5

PLATE 5

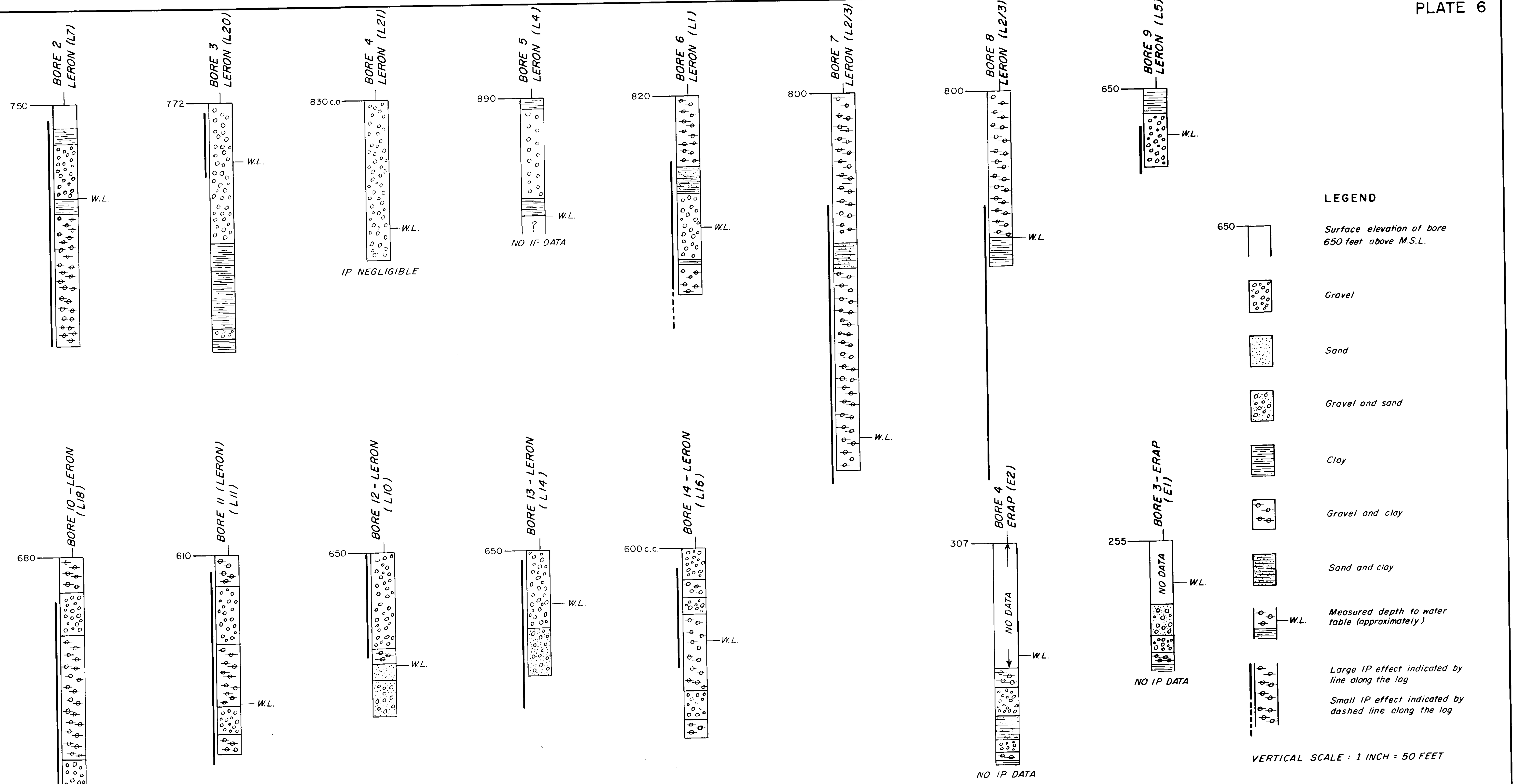


LERON PLAINS ESTATE - MARKHAM VALLEY, NEW GUINEA, 1964

WATER RESISTIVITY CONTOURS

(BASED ON B.G.D. DRAWING No L-8) TO ACCOMPANY RECORD No. 1966/169 Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics. B55/B5-13-1

PLATE 6

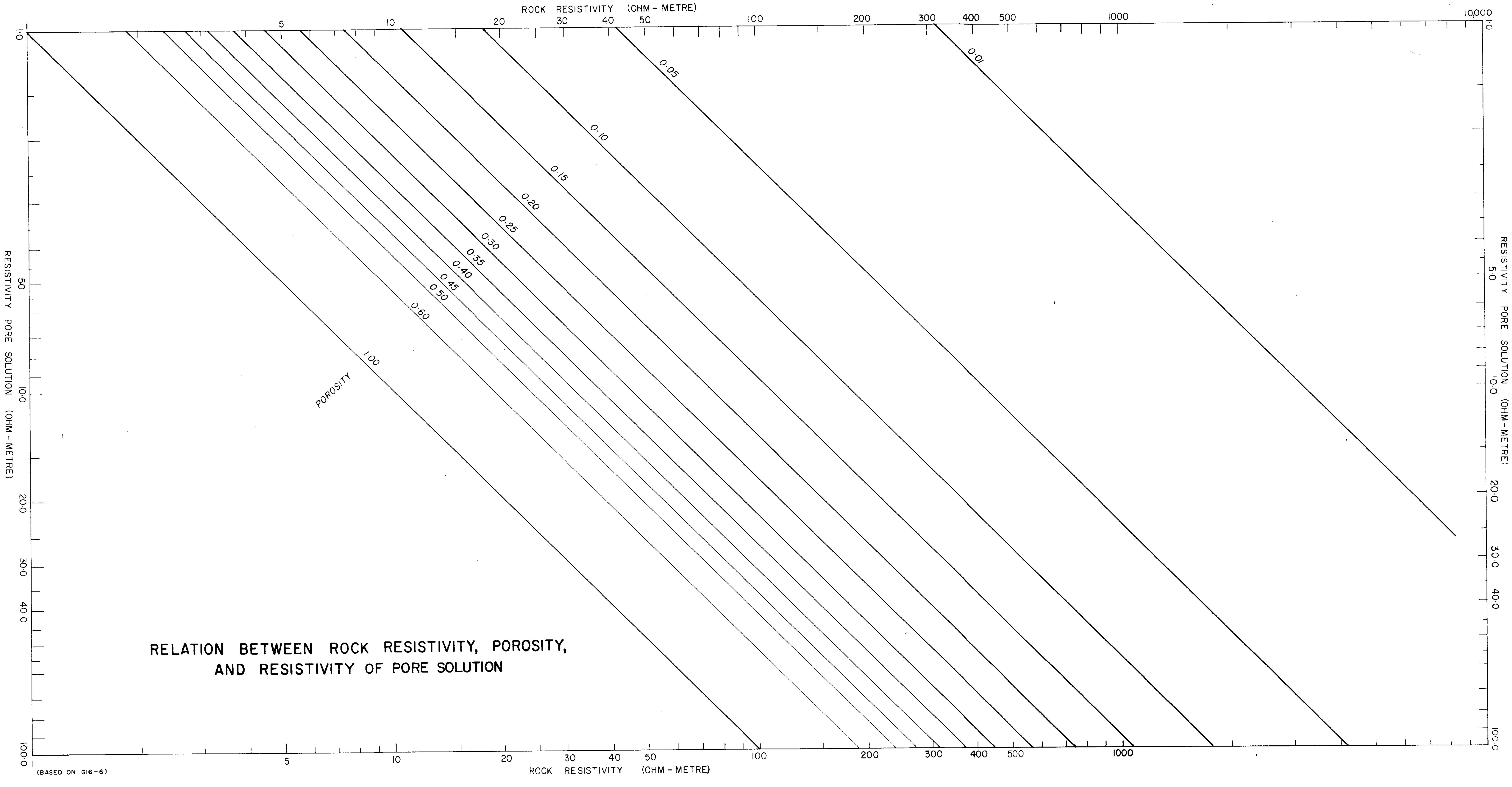


MARKHAM VALLEY RESISTIVITY SURVEY, TPNG 1964

BORE HOLE LOGS WITH INDICATED INDUCED POLARISATION EFFECT

LERON PLAINS AND ERAP D.A.S.F.

TO ACCOMPANY RECORD No. 1966/169 Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics B55/B5-23

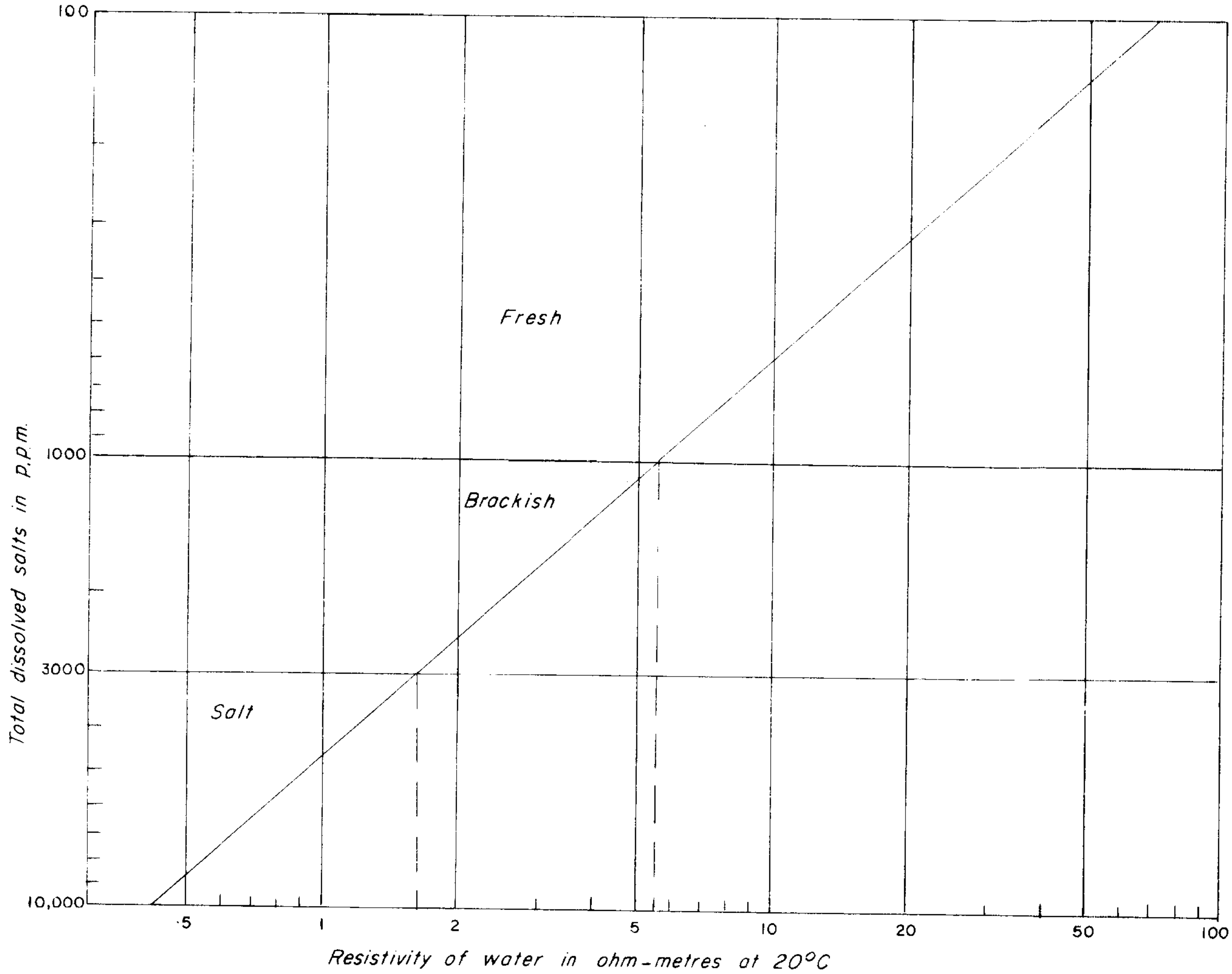


RELATION BETWEEN ROCK RESISTIVITY, POROSITY, AND RESISTIVITY OF PORE SOLUTION

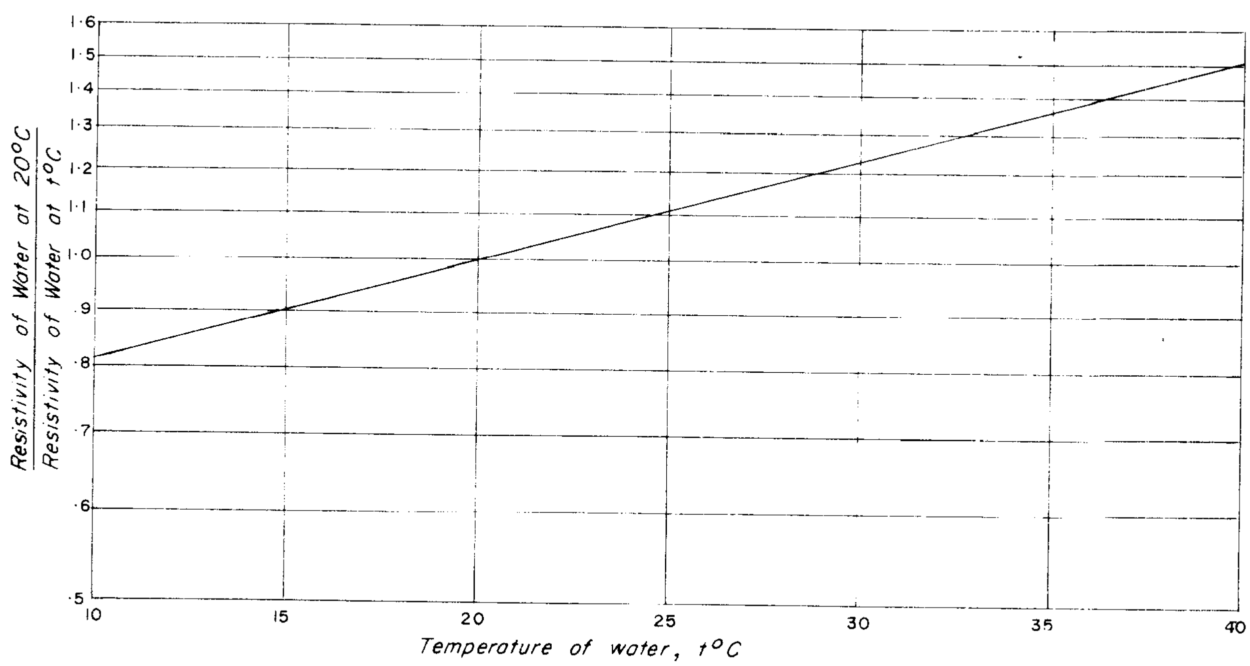
To Accompany Record No 1964/111 and No. 1966/169

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics. E55/B5-83

PLATE 8



1. WATER RESISTIVITY TO SALINITY CONVERSION DIAGRAM

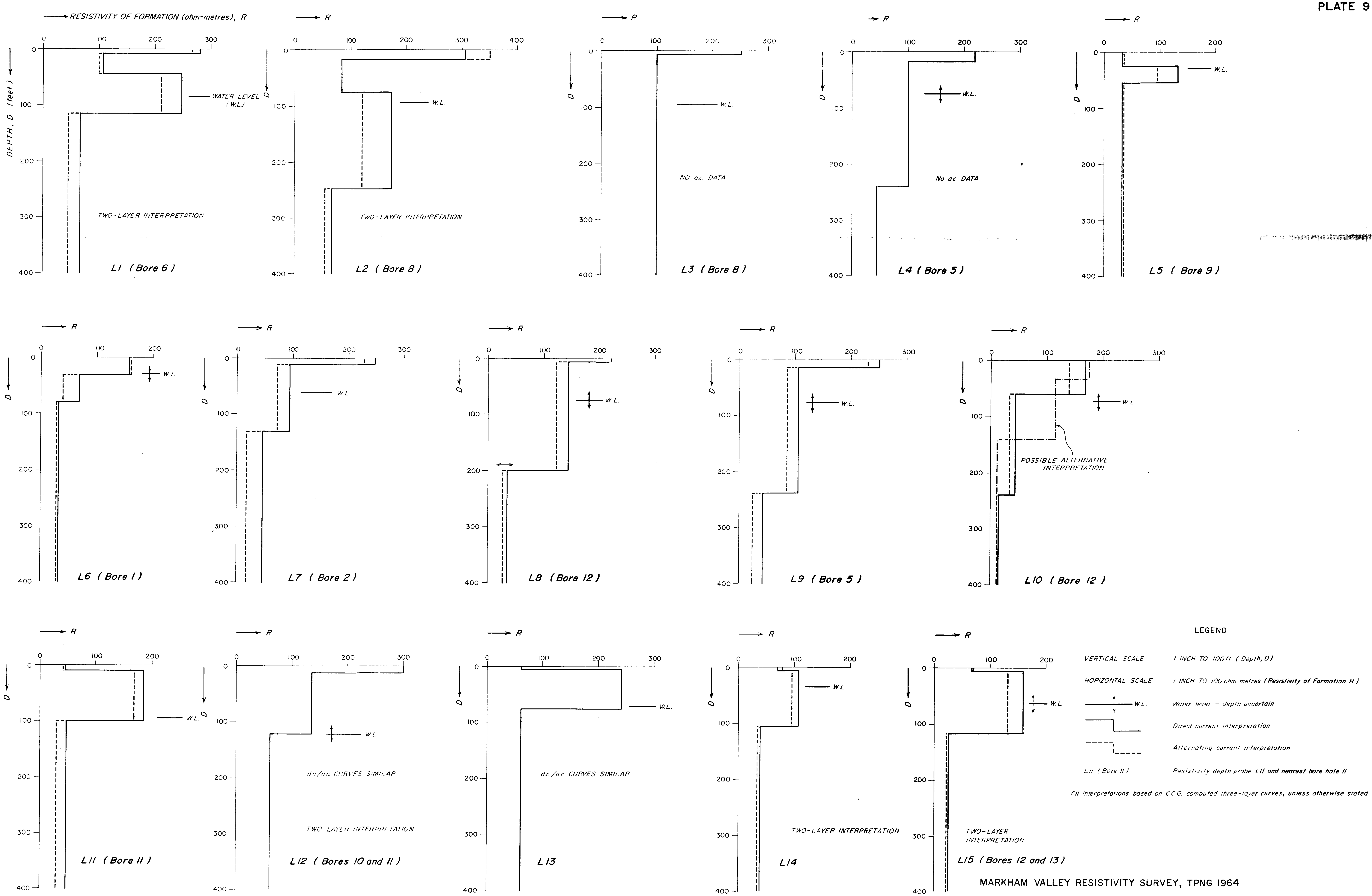


2. TEMPERATURE CORRECTION DIAGRAM FOR RESISTIVITY

G/RU QLD 1963 UNDERGROUND WATER

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS E55/B5-84

To accompany Record No. 1964/111 and 1966/169



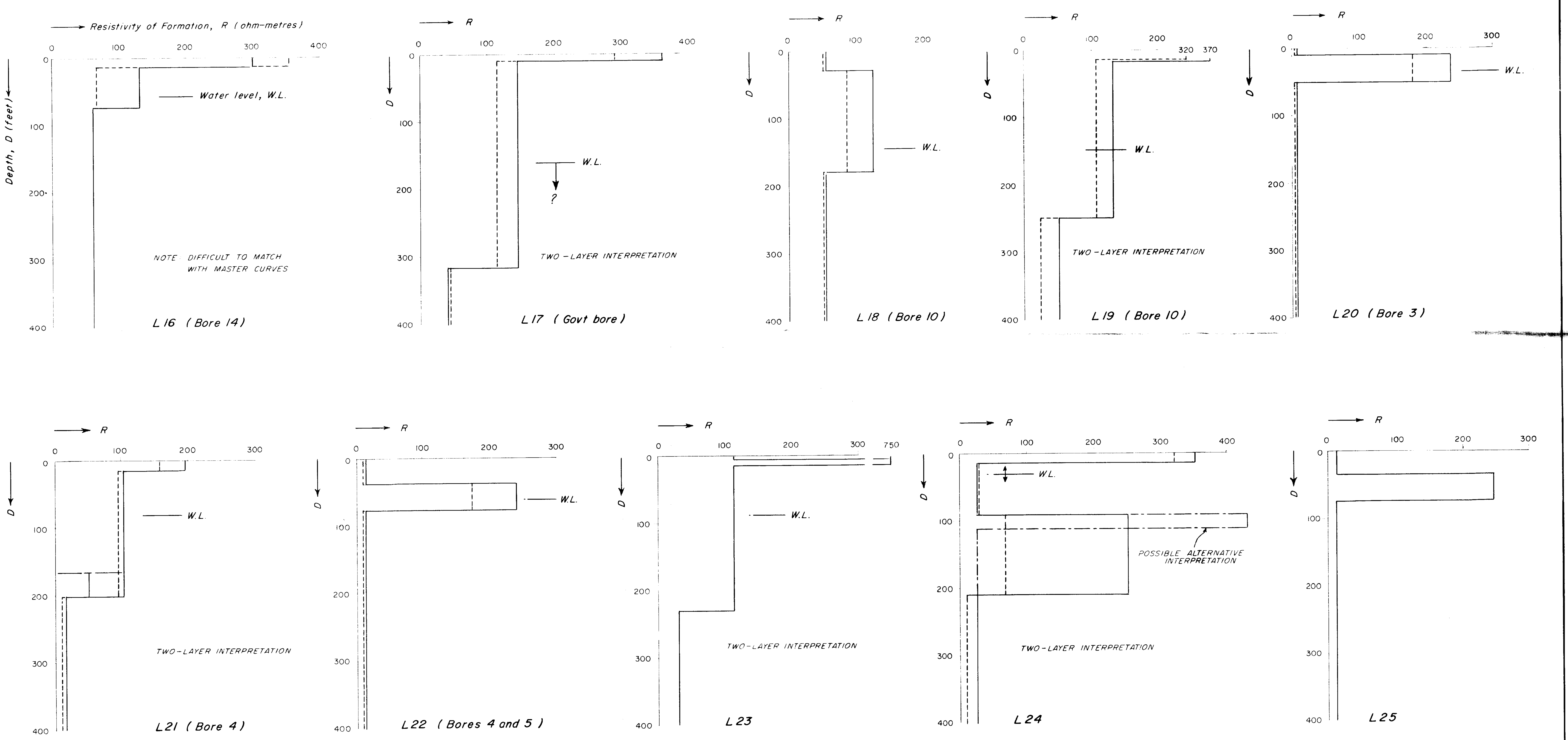
MARKHAM VALLEY RESISTIVITY SURVEY, TPNG 1964

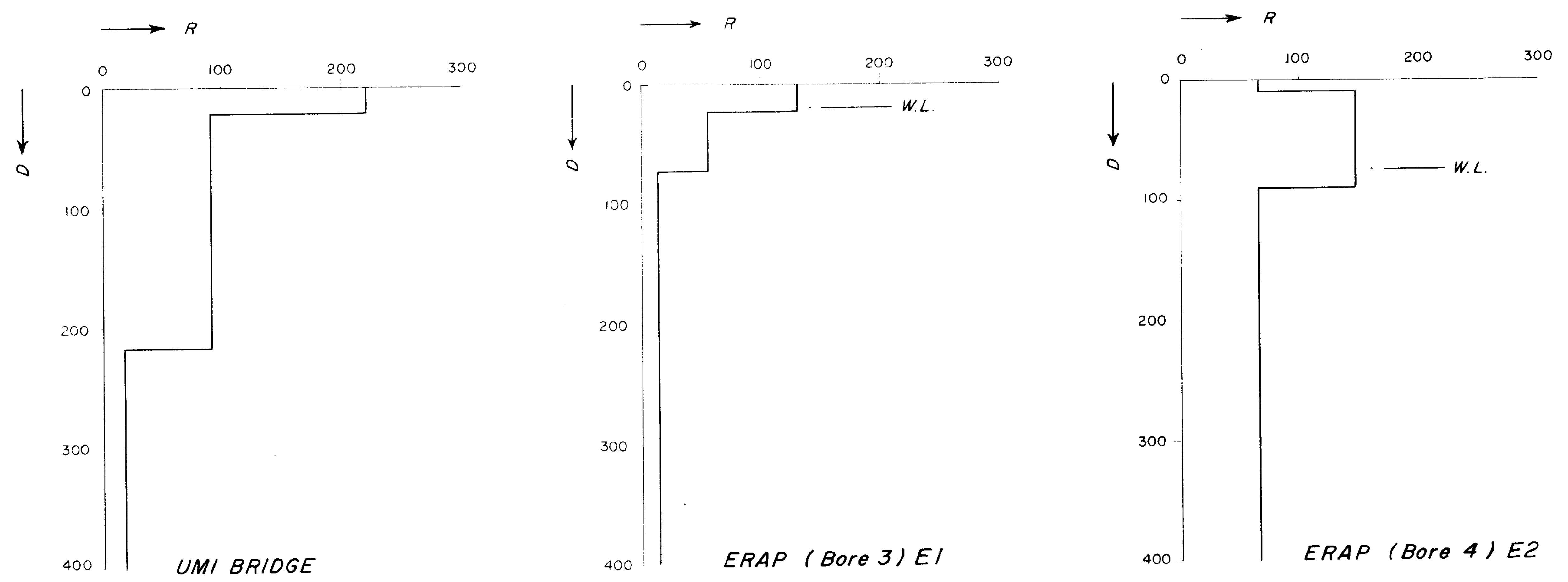
INTERPRETATION HISTOGRAMS OF RESISTIVITY DEPTH PROBES, LERON PLAINS

TO ACCOMPANY RECORD No. 1966/169

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics

B55/B5-20





LEGEND

VERTICAL SCALE	1 INCH TO 100 ft (Depth, D)
HORIZONTAL SCALE	1 INCH TO 100 ohm-metres (Resistivity of Formation, R)
W.L.	Water level - depth uncertain
	Direct current interpretation
	Alternating current interpretation
L19 (Bore 10)	Resistivity depth probe L19 and nearest bore hole 10

All interpretations based on CCG computed three-layer curves, unless otherwise stated

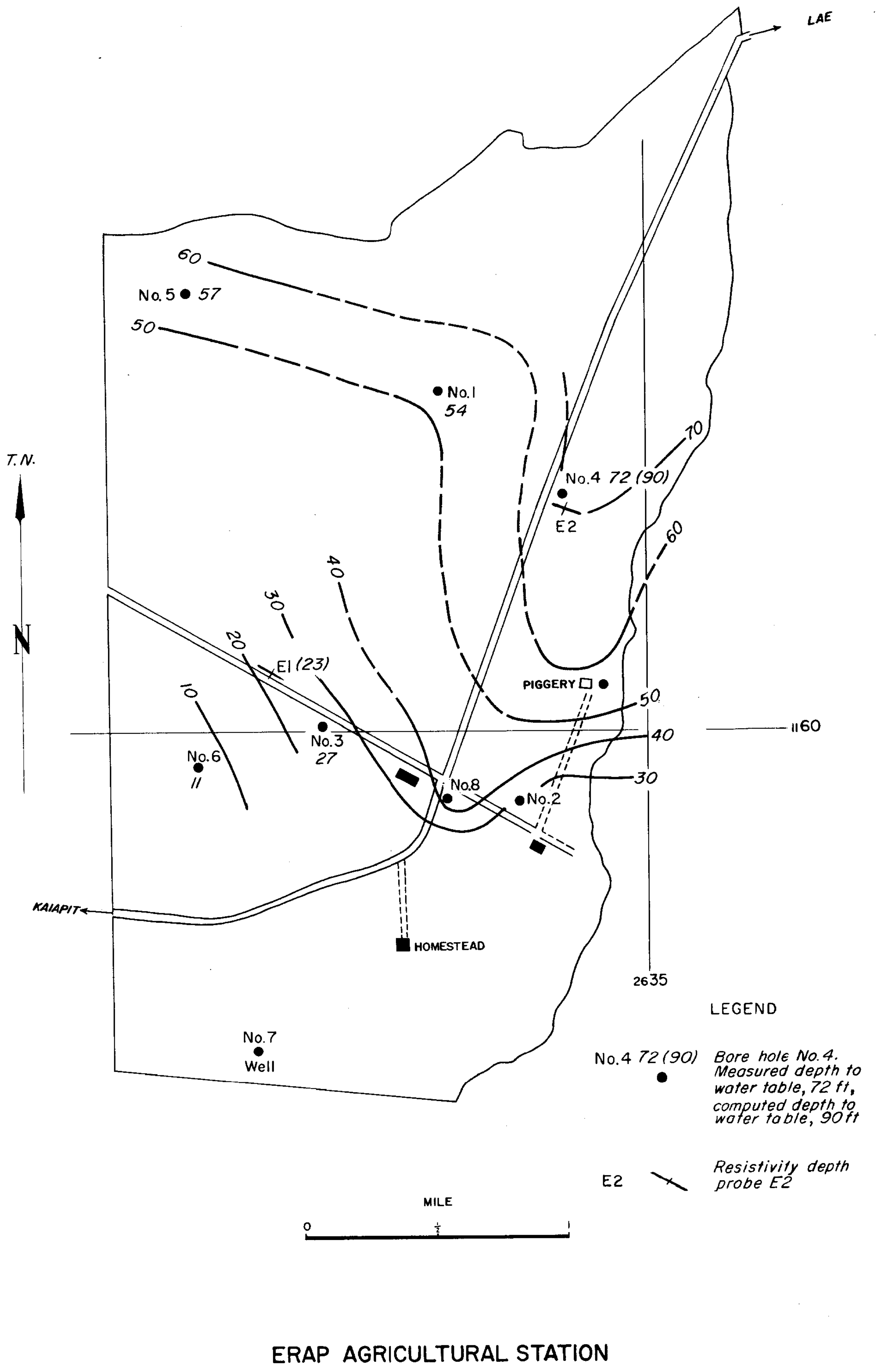
MARKHAM VALLEY RESISTIVITY SURVEY, TPNG 1964

INTERPRETATION HISTOGRAMS OF RESISTIVITY DEPTH PROBES

LERON PLAINS, UMI BRIDGE AND ERAP D.A.S.F

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics

PLATE II

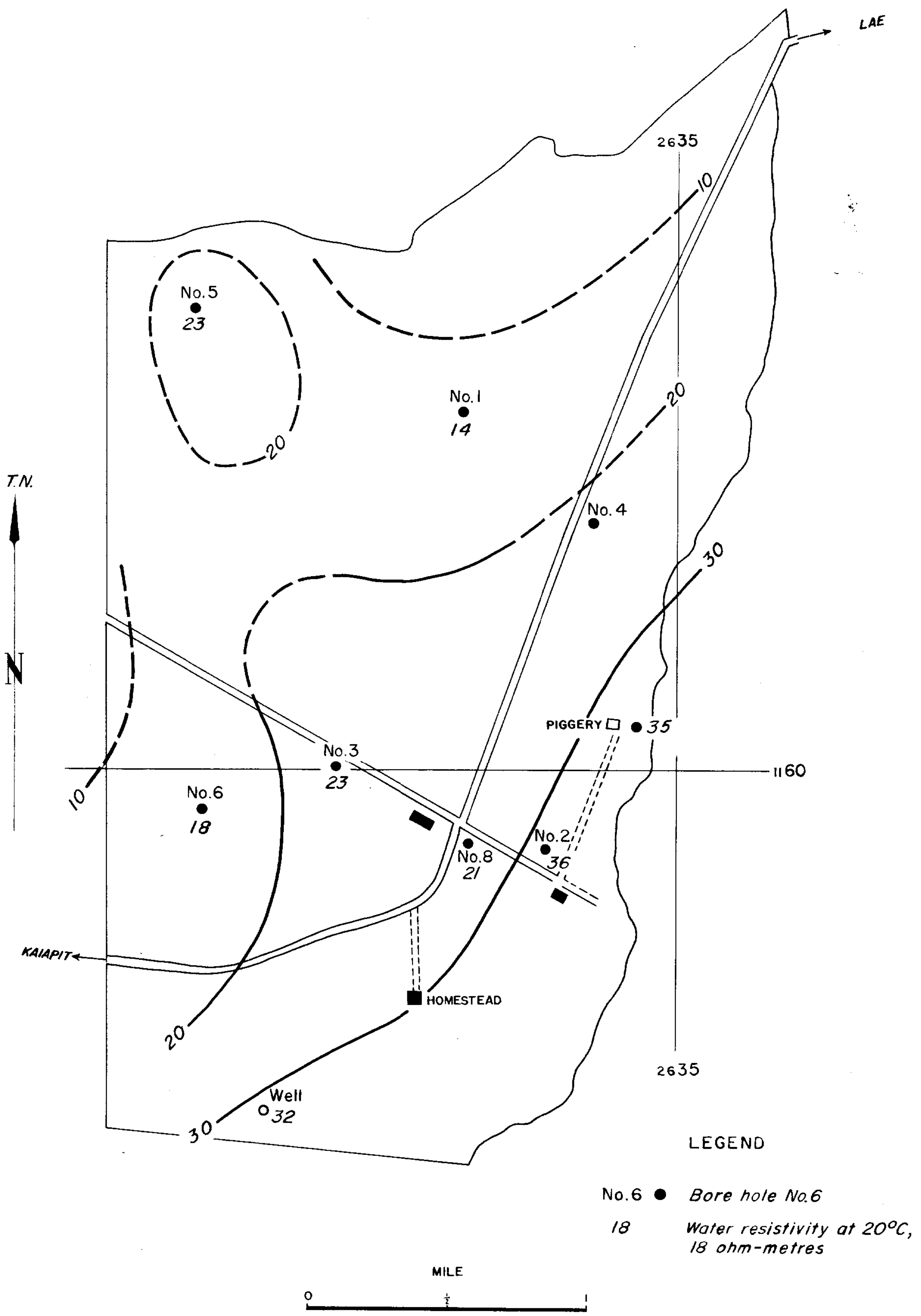


ERAP AGRICULTURAL STATION
MARKHAM VALLEY, NEW GUINEA
1964

WATER TABLE CONTOURS

(BASED ON PNGB55-10-6) *Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics.* B55/B5-18-1

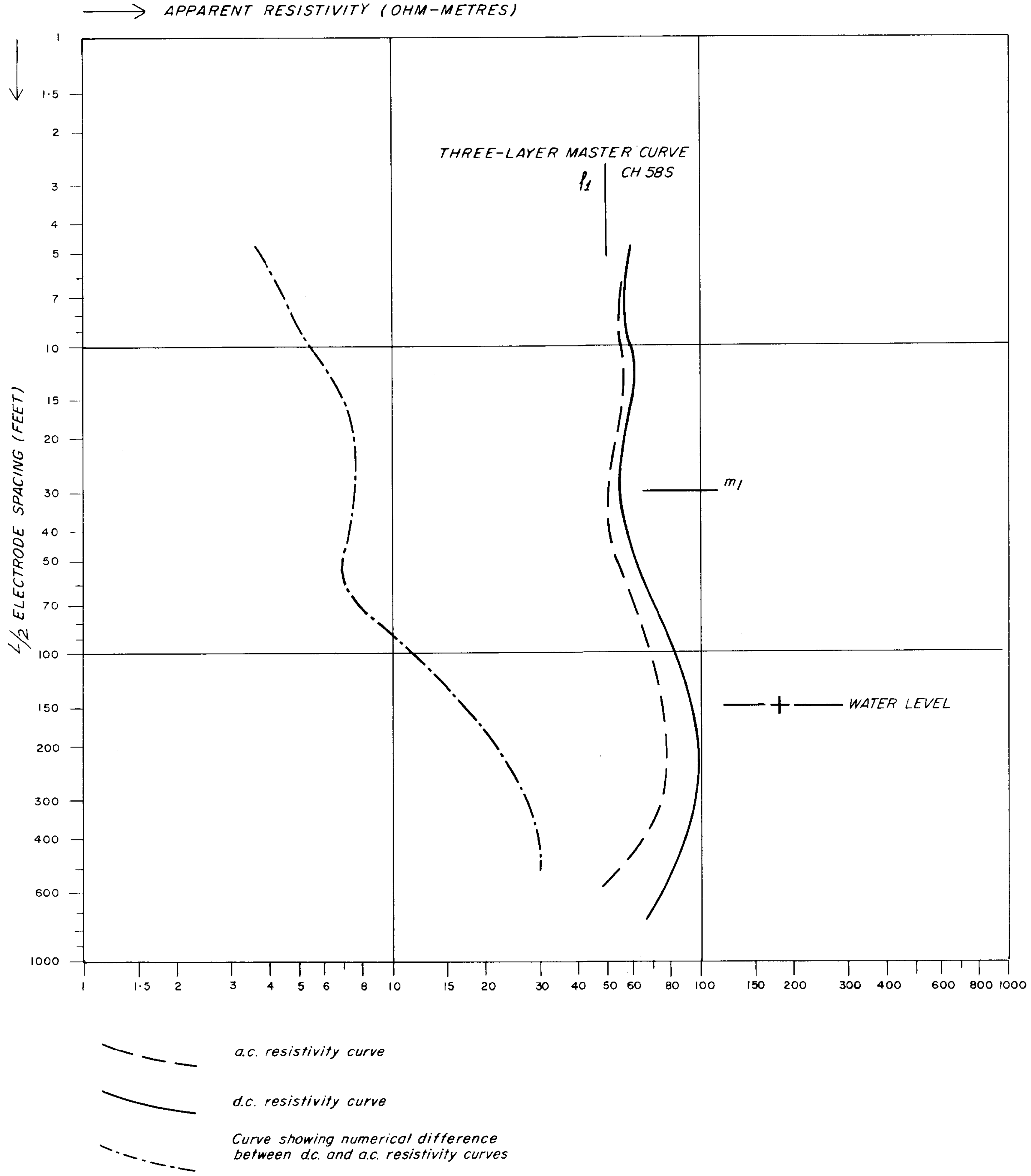
TO ACCOMPANY RECORD No. 1966/169



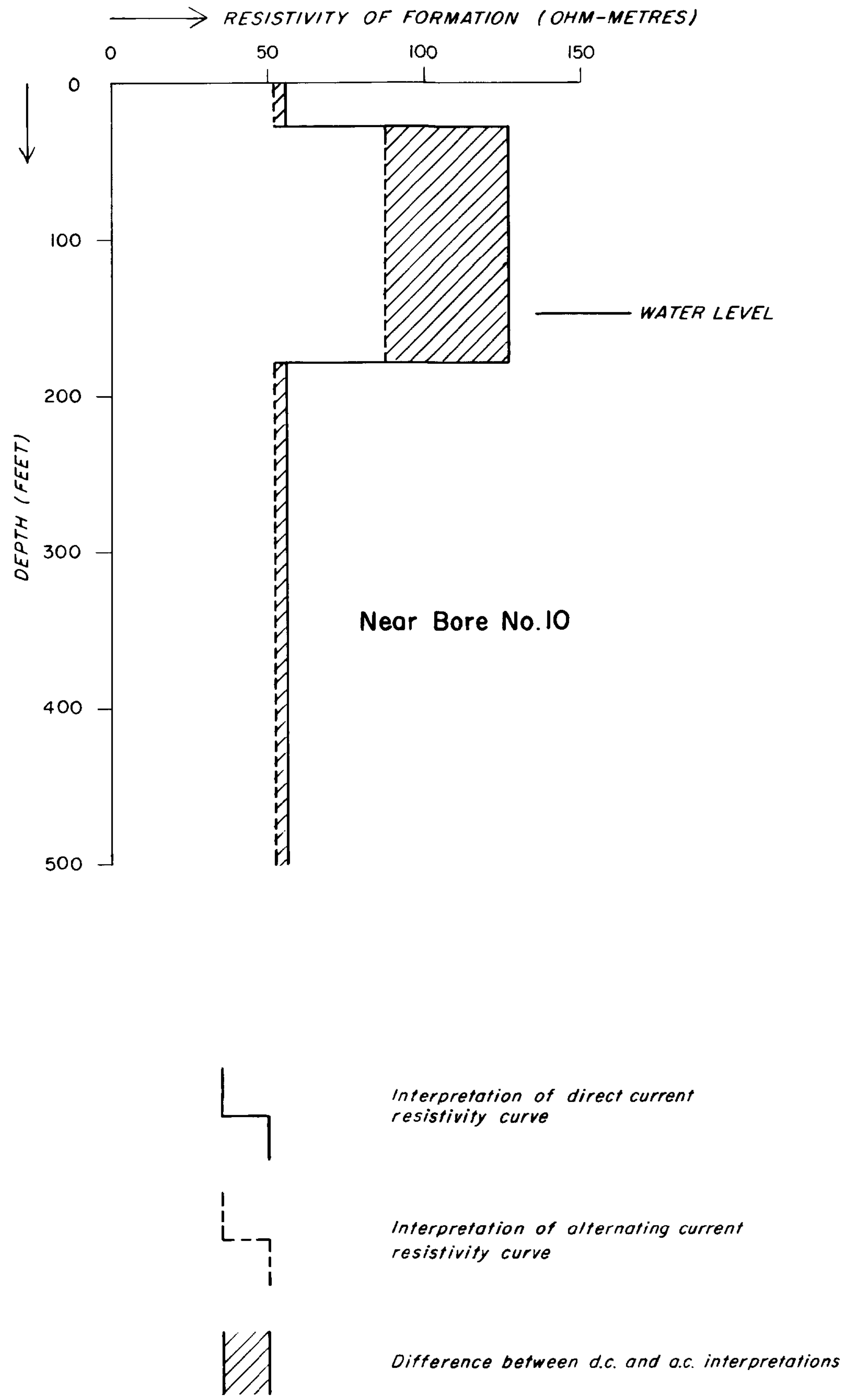
ERAP AGRICULTURAL STATION
MARKHAM VALLEY, NEW GUINEA, 1964

WATER RESISTIVITY CONTOURS

RESISTIVITY DEPTH PROBE L18 – LERON PLAINS

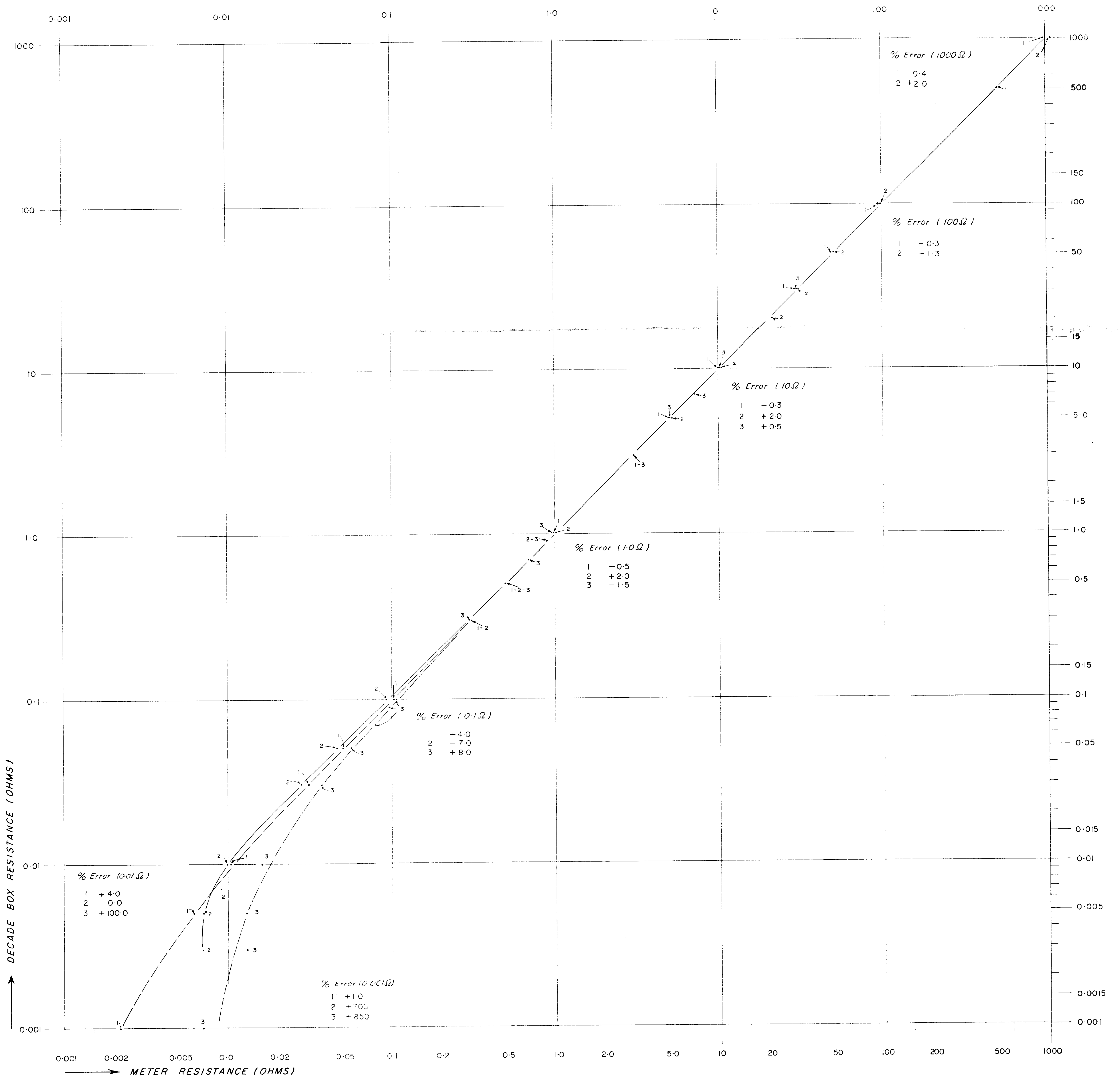


INTERPRETATION HISTOGRAM L18



TYPICAL d.c, a.c. AND DIFFERENCE CURVES

PLATE 14



LEGEND

1 ERR3 (direct current)
2 ABEM Terrameter (4 c/s)
3 Geophysical Megger (8-10 c/s)

CALIBRATION OF RESISTIVITY METERS USING A RESISTANCE DECADE BOX (0·05% GRADE)

MARKHAM VALLEY RESISTIVITY SURVEY 1964

TO ACCOMPANY RECORD No 1966/169

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics

B55/B5-25