66/114

3.

COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

COPY 3

RECORD No. 1966/114

KOO-WEE-RUP RESISTIVITY SURVEY,

VICTORIA 1965

by

M. WAINWRIGHT

C O N T E N T S

I L L U S T R A T I O N S

S U M M A R Y

A resistivity survey was undertaken at Kooweerup to compare the performances of resistivity meters under varying geological conditions. A new power supply was tested, but in the absence of a suitably sensitive potential meter, did not yield reliable information. Curves obtained using the Wenner and Schlumberger electrode configurations provided fairly good correlation with available borehole information. Calibration and field tests of five resistivity meters have indicated their relative merits. Water quality and porosity studies have been made of the widespread aquifers lying beneath clay formations at a depth of 100 feet or more. No significant saltwater intrusion has been found in the survey area.

1. INTRODUCTION

A number of resistivity meters are commonly used by the Bureau of Mineral Resources, Geology and Geophysics, Geophysical Branch. These meters have been used on many geophysical surveys under a variety of field conditions. Experience has shown that there is usually a difference between field curves obtained by using different resistivity meters to make depth probes at the same site. The survey was designed to establish a comparison between five of these instruments under varying conditions, and so to relate the performance of each to particular geological and hydrological conditions. The survey also provided an opportunity for testing a more powerful d.c. supply unit, and for comparing different electrode configurations.

The survey was carried out over a small area in the vicinity of Koo-wee-rup, a small township roughly 44 miles south-east of Melbourne, and about two miles inland from Western Port Bay (see Plate 1).

It was carried out in conjunction with the State Rivers and Water Supply Commission, between 7th and 28th September, 1965. The party consisted of M. Wainwright, party leader, and three field hands provided by the Commission. A. Radeski, technical officer, assisted the party for four days. The State Rivers and Water Supply Commission provided assistance in many ways, and their help is gratefully acknowledged.

2. GEOLOGY

The geology and hydrogeology is described by Jenkin (1962). The survey was conducted over an area of about 12 sq. miles in the vicinity of the township of Koo-wee-rup, which is situated on an alluvial plain bounded by upland areas to the north and east. The Bunyip river flows into Western Port Bay about two miles south-west of the township through a system of drainage channels. At the time of the survey, the standing water table was generally only a few feet from the surface, and drainage channels were active. A number of boreholes in the vicinity of Koo-wee-rup demonstrate that clay formations extend from the surface to a depth of 100 feet or more, (see Appendix 1). Beneath are deposits of sands, gravels and clays, which overlie a similar succession of Pliocene to Eocene sediments. The Oligocene and Eocene beds contain marls, thin coal bands, and basaltic lava and tuffs. Deep bores have been drilled by the Department of Mines, Victoria, and extensive drilling of shallow boreholes for agricultural purposes by private contractors has added valuable stratigraphic information.

3. THEORY

The basic potential theory underlying the principle of resistivity work in layered media is well known and has been discussed in various publications and reports. (See Wiebenga, 1955; Dyson and Wiebenga, 1957; Dobrin, 1960; Andrew and Wiebenga, 1965; Polak, Wiebenga, Andrew, Wainwright and Kevi, in preparation). Briefly, current is introduced into the ground via metal electrodes. For a given applied current, the potential drop across two intermediate electrodes is a function of the resistivity of the ground formation. The greater the spacing of electrodes, the greater the depth penetration of the applied current. By expanding the electrodes about a central point and plotting the measured apparent resistivity against electrode spacing L/2 on a log diagram, a curve is obtained. Since the method depends on the measurement of a potential field, the curve could represent an infinite number of layered models (Andrew and Wiebenga, 1965).

The most widely used electrode arrangement is the Wenner system (Fig. 1(a)) where the four electrodes are arranged in line with equal spacing. In the Schlumberger arrangement, (Fig. 1(b)), the electrode spread is expanded about a fixed centre point, as in the Wenner case. However, for a constant spacing of b, the spacing L is expanded until the measured potential drops to such low values that the instrument readings are no longer accurate. The spacing b is then expanded to a new value, and the potential readings made as L is expanded further. Thus, b is kept small compared with L. Formerly, b was kept no greater than L/5. However, it has been found that b may be as great as L/3 (i.e. the Wenner spacing) without affecting the interpretation significantly.

A problem arising out of resistivity work on Stradbroke Island (Polak & Kevi, 1965) and in the Burdekin delta, North Queensland, (Wiebenga et al, in preparation) is that when highly conductive near-surface layers are present, penetration of current into the ground is limited. In an attempt to increase the penetration a higher amperage power supply system was constructed by the Bureau. This consists of a petrol-driven motor generator together with a rectifier unit, which is capable of supplying currents of up to 6 amps, and voltages of 230V; the potential difference was measured by a self-potential (S.P.) meter. It was expected that in or near the intertidal zone of Western Port bay, the presence of a near-surface saltwater wedge might resemble the conditions previously experienced in Stradbroke Island and in the Burdekin delta.

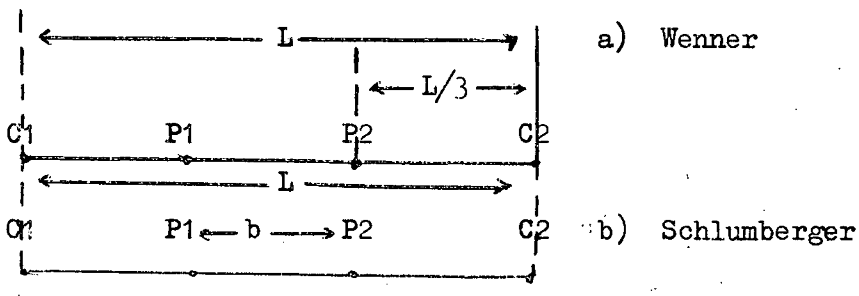


Fig. 1 Electrode configurations

It has been observed that the apparent resistivities computed from data collected using an a.c. resistivity meter were lower than those obtained using a d.c. instrument. This was investigated further on a resistivity survey in the Markham valley New Guinea in 1964. The report on this survey (Wainwright, in preparation) contains a discussion on the possible causes of the dc/ac discrepancies. One such possibility is the presence of clay particles adhering to sand grains, as is generally the case with most sand formations. When an alternating voltage is applied to a water-saturated medium such as this, a complex impedance is set-up, of which the real part is smaller than the purely resistive component measured when applying a direct current voltage. This is generally described as 'induced polarisation' and the clay particle theory is called 'membrane polarisation' by Marshall and Madden (1959). One of the practical uses of induced polarisation would be to relate the magnitude of the effect to clay content, frequency of the applied a.c. voltage, and level of water-table in the aquifer body. At Kooweerup, sediments containing a high percentage of clay extend to a depth of 100 feet or more, and areas saturated with saline water are present near the intertidal zones, on the southern edge of the survey area. It was not expected that the induced polarisation effect would be marked (Vacquier, Holmes, Kitzinger and Lavergne, 1957).

4. METHODS AND EQUIPMENT

The locations of depth probe sites in the survey area are shown in Plate 1. Wenner and Schlumberger configurations were used, the electrodes being expanded about a fixed centre point in each case.

At each site depth probes were repeated using alternative systems of electrodes, or repeated with the same electrode system but using different resistivity meters. Table 1 (below) gives a summary of work completed in the survey area.

TABLE 1

DATE	STATION	TYPE OF ELECTRODE ARRANGEMENT	INSTRUMENTS
9.9.1965	K.1	W	E, Y.
		S	E, G, T.
10.9.1965	K.2	S	E, G, Y, T.
13.9.1965	K.3	S	E, T.
		W	E, G, Y, T.
14.9.1965	K.4	W	E, G, Y, T.
17.9.1965		S	e.
20.9.1965		S	e.
15.9.1965	K.5	S	E, G.
15.9.1965	K. 6	S	E, G.
21.9.1965	K.7	S	E, G, Y.

Where W = Wenner spread.
S = Schlumberger spread.

E = ERR3.d.c. resistivity meter designed by the Bureau. (formerly designated Rm.1)

e = ERP d.c. resistivity system.

G = Geophysical megger, a.c. meter.

Y = 'Yew' a.c. resistivity meter.

T = ABEM Terrameter, a.c. resistivity meter.

Water samples were obtained in the vicinity of each depth probe site from boreholes and surface sources; the resistivity of each sample was measured in a standard mud-cell, using a Megger earth tester, and water quality was expressed in ohm-metres at 20°C, and in total dissolved salt content (p.p.m.) (Schlumberger, 1958).

Resistivity equipment used on the survey is listed below; the Megger Earth tester (0-1000 ohm) was not suitable for depth probe measurements, since the reading accuracy of the instrument in the range of 0 to 10 ohm is very poor.

TABLE 2

INSTRUMENT	MAKER	FREQUENCY	RANGE
ERR 3	B.M.R.	d.c.	0-10 K. ohm
Geophysical Megger	Evershed and Vignoles	8-10 c.p.s.	0-30 ohm
Megger Earth Tester	"	50-60 c.p.s.	0-3000 ohm
Terrameter	A.B.E.M.	4 c.p.s.	0-10 K. ohm
'Yew' Earth Resistance Tester	Yokagawa	65 c.p.s.	0-300 ohm
ERP.1/S.P. meter	B.M.R.	d.c.	0-1 Volt Potential difference

The ERP/S.P. Meter equipment consists of an 'Onan' petrol driven motor generator which supplies 115 volts to a Bureau constructed E.R.P.1. rectifier. From this up to 230 volts, and currents up to 6 amps, can be applied to the current electrodes. The potential difference across the potential electrodes was measured using a self-potential meter (Type D) constructed by the Bureau. The current was reversed, and the mean potential together with the mean current, were used to compute the mean apparent resistivity by application of Ohm's Law, and multiplication by a geometrical constant (See Plate 3, K.4). This is different from the method used in the other meters, which give a direct reading of resistance without determining the current or potential separately.

5. RESULTS

The results are discussed under the following four headings.

(i) Comparison of electrode arrangements.

(ii) Comparison of instruments.

(iii) Correlation of interpretations with geological information.

(iv) Water quality and porosity of formations.

(i) Comparison of Electrode Arrangements

For comparison the curves obtained using the Bureau constructed ERR3 d.c. resistivity meter at stations K1 and K3 are considered (See Plate 2). Clearly the curves are very similar; the measured resistance, which is a function of the potential difference between potential electrodes, is in the Wenner system greater than that for the Schlumberger for any given value of L/2. For example, at depth probe K3 for L/2 = 300 feet, the Wenner measured resistance is 0.043 ohm, whilst for the same value of L/2 the Schlumberger measured resistance is 0.0115 ohm. The accuracy of the ERR3 (discussed Part (ii) of this section see also Plate 6) deteriorates below 0.01 ohm, so that for measured resistances below 0.01 ohm the results will be increasingly less accurate; this will be of relatively greater importance in the Schlumberger electrode arrangement than in the Wenner for any given depth probe.

However, the Schlumberger method can be carried out much more rapidly, with less field labour, and there are theoretical grounds for suggesting that the system produces smoother curves. The basis of this is that the potential electrodes in the Schlumberger system are kept stationary for an expanding range of current spacings; this means that contact potential is constant over the same range. The two configurations on field evidence produce very similar curves, with the Schlumberger system to be preferred on practical grounds. The separate interpretations of the Wenner and Schlumberger curves for depth probes K1 and K3 are as follows :-

	Wenner	Schlumberger
K1	43-(3)-6-(30)-15-(120)-27	53-(3)-6-(29)-15-(127)-24
K3	105-(2)-34-(9)-12-(95)-19-(240)-70	105-(2)-34-(8.5)-12-(85)-20-(250)-36

where 1st and 3rd numbers etc. refer to resistivity of layer (ohm-metres) and 2nd and 4th numbers etc. (in brackets) refer to depth of interface (ft.).

(ii) Comparison of Instruments

Five resistivity meters were compared in the field, (two with direct current power supplies - d.c.; and three with alternating current power supplies - a.c.), and the field curves are shown in Plates 3 and 4. The three meters commonly used to make depth probes, namely ERR3, Geophysical Megger and Terrameter were calibrated against standard resistances in the range 0.001 ohm to 1000 ohm. (See Plate 6). The three instruments give results in close agreement in the range 0.5 ohm to 1000 ohm, but the Geophysical Megger is markedly less accurate than the other two instruments at 0.05 ohm and below. The mean error of each instrument at varying values of standard resistances is given. Note also that for each instrument there is a variation from the mean which in the case of the Geophysical Megger amounts to ± 20% of standard Resistance at 0.01 ohm.

Comparing the Terrameter and Geophysical Megger curves with the ERR3 curves (which from Plate 6 appears to be the most accurate), the field curves are similar, and lead to similar interpretations (e.g. K1, K2 and K4 Plate 3). At K3, the Geophysical Megger curve is similar to the ERR3 curve, but the Terrameter curve diverges for L/2 greater than 100 feet. This divergence cannot be attributed to an instrumental source, since at this value of L/2 the measured resistance is greater than 0.01 ohm (see Plate 6), and it may represent the induced polarisation effect noted in the Markham Valley survey, (Wainwright, in preparation). Similarly on Plate 3, at depth probes K5 and K7, (Plate 4), the Geophysical Megger curves diverge from the ERR3 curves. At K5, the divergence commences at L/2 = 150 ft, and at K7 the divergence commences for L/2 greater than 5 ft. In the latter case the measured resistances are very low and discrepancies between different instruments are to be expected. However, from Plate 6, one would expect the Geophysical Megger measured resistances to be greater than those of the ERR3 for particular values of L/2. This is not the case and also suggests that the induced polarisation effect is the reason for this.

Interpretation of the separate curves at K3 are given in histogram form in Plate 5, and the interpretations of all curves are given in Appendix 3. Of the remaining instruments the B.M.R. ERR1. high power d.c. resistivity instrument was tested at depth probe K4 on two separate occasions (see Plate 3). The curves were of poor quality with marked scatter, and differ considerably from the curves made at the same site with four other instruments. Whilst the power supply system operated well, the S.P. meter used to measure the potential and applied current separately for each value of L/2 is a sound one, since it enables the resulting data to be studied with respect to the magnitude of the applied current. It is possible to obtain readings of resistance with the other resistivity meters when the current is very small and the accuracy is correspondingly low, without any indication that this is the case.

The Yokagawa resistivity earth tester model L-10, or 'Yew' megger, has a low power output whose performance in depth probe work is typified by K2, Plate 3. For L/2 greater than 50 ft, the field curve diverges markedly from that of the ERR3. Because of the low power characteristics of the Yew megger, the applied currents are very small, and the resulting accuracy of the meter is low except where L/2 is small. The Geophysical megger and Terrameter might also be expected to demonstrate this effect of low applied current, although to a lesser degree. Because of its low power the 'Yew' megger is generally unsuitable for depth probe work.

In Appendix 3, the interpretations of field curves obtained using different instruments are generally similar. The region of field curves at L/2 greater than 200 ft is often not completely defined (see Plates 3 and 4), and matching with master curves may be based on extrapolation of field curves. This may lead to variation of the interpreted resistivity of the lowest layer.

(iii) Correlation of interpretations with geological information

The locations of boreholes are shown on Plate 1, as are depth probe sites and water sampling points. The logs of the boreholes are given in Appendix 1. Unless otherwise stated depth probes are discussed with reference to the ERR3 interpretations using the CGG master curves (see Plate 7).

Depth Probe K1

The rise in resistivity from 6 to 15 ohm-metres at a depth of 49 ft represents a clay formation saturated with saline or brackish water above, and better quality water below. The interface at 150 ft depth indicates the presence of a more sandy formation beneath the 15 ohm-metre layer. This is in broad agreement with the sparse data from bores (f), (g) and (h), although in bores (f) and (g) the fine sand commences at 95 ft. However, since the sand contains bands of lignite, it is possible that the upper part has a lower resistivity than one would normally expect for a sand formation.

Depth Probe K2

Fairly good agreement between resistivity interpretation and bore log (k). At 110 ft depth, the formation resistivity rises from 6 to 60 ohm metres, marking a change from clay to sand.

Depth Probe K3

The 12 ohm-metre layer in the depth range 9-150 ft probably indicates a clay or sandy clay saturated with brackish water; below this is a 28 ohm-metre layer of unconsolidated sand with fresh water, which overlies a 70 ohm-metre formation at 225 ft depth. This latter layer may be correlated with the limestone and silty sand zone (305-321 ft depth) proved by bore (k).

Depth Probe K4

The correlation of resistivity interpretation with bore logs (f), (g) and (j) is poor; this is not unexpected if the separation of K4 from these bores is considered (see Plate 1). The 3 ohm-metre layer extending to a depth of 60 feet probably represents a clay formation saturated with saline water. Below, the resistivity is greater than 13 ohm-metres, which may represent a change from clay to sand, or a marked decrease in salinity of the pore solution, or most likely a combination of both.

Depth Probe K5

The main resistivity layer of 12.5 ohm-metres extends from near the surface to 125 ft depth, and correlates with the gravel-with-clay (0-125 ft. depth) of bore (k). The 50 ohm-metre formation beneath represents a sandy formation, and also agrees with the lithological description from bore (k).

Depth Probe K6

This depth probe was made close to K5, and the interpretation is similar.

Depth Probe K7

Below 8 ft depth the resistivity of 2.7 ohm-metres probably represents a brackish or saline clay which overlies a more sandy formation at 50 ft depth. Whilst this does not correlate very closely with bores (f) and (g) one mile to the north-east, it is a reasonable interpretation.

On Plate 7 are cross-sections of the survey area :-

(i) K7-K1-K2-K3-K5-K6

(ii) K7-K4

Histograms of ERR3 interpretations and lithological logs of boreholes are correlated. Section (i) illustrates clearly the junction between predominantly clay formations and underlying sands and gravels. At depth probe K7, the 30 ohm-metre layer commences at 50 ft at K1. Probably the former represents an old sand-bar, inland from which developed a saltwater marsh. At K7, saltwater intrusion does not appear to have occurred in the 30 ohm-metre formation, but this would be a good point at which to repeat the depth probe at the end of a dry period. This method of delineating areas of salt water intrusion has been used with success in the Burdekin Delta, North Queensland. Depth probe K4 is situated in a somewhat similar position to the west of K7, but the basal layer has a resistivity of 13 ohm-metres; this probably represents a brackish sand or sandy clay (see resistivity classification below), due to minor saltwater intrusion.

Plate 8 illustrates the field resistivity curves, which are double logarithmic plots of apparent resistivity (ohm-metres) versus L/2 (ft). Note that the curves are broadly similar but that the apparent resistivity for any chosen value of L/2 in general increases with the distance inland of the depth probe site from the intertidal zone. This indicates that the water quality improves inland from the intertidal zone; the survey area was once a salt marsh which is seasonally flushed with fresh water running-off from the highland areas. Because of the low permeability, this process takes place slowly. From Plate 8, the sands and gravels have fairly high resistivities, and generally there is no evidence of a serious saltwater intrusion problem. Since the survey area is used mainly for stock-raising purposes, the amount of sub-surface water used is relatively small, and no problem of saltwater intrusion is likely to occur except in those areas very close to the intertidal margin.

(iv) Water quality, and porosity of formations

(a) Water Quality : the quality of water samples, determined in the manner described in Section 4, is expressed in ohm-metres at 20°C, and in terms of the total dissolved salts (p.p.m.) (see Appendix 2). The total dissolved content of salts is obtained approximately from the formula used by Guyod (1952).

$$Rw = 5000/C$$

Where C = Concentration of dissolved salts in p.p.m.

Rw = Water resistivity at 20°C, in ohm metres.

The resistivity of the "run-off" fraction of surface samples (e.g. these taken from active drainage channels) varies between 20 and 80 ohm-metres (250-62 p.p.m.). This contrasts sharply with the quality of samples pumped from sub-surface aquifers (2.5 to 6.3 ohm-metres, i.e. 2000-794 p.p.m.). Contours have been drawn on Plate 1, based on the resistivities of sub-surface samples; it is assumed that the water samples are derived from aquifers which are characterised by higher resistivities (see Plate 7). Formation resistivities have been classed into three broad divisions as given below, assuming a porosity of 30% for the formation (Wiebenga et al, in preparation).

Formation resistivity, R (ohm-metres)	Total dissolved salt content (p.p.m.)	Description
20	100	Fresh
20 - 6	1000 - 3000	Brackish
6	3000	Saline

(b) Porosity of Formations : the porosity of a formation can be computed from Archie's formula :-

$$\log R - \log Rw = -m \log P$$

Where R = Formation resistivity

Rw = Water resistivity

P = Porosity as a fraction

m = Cementation factor; for unconsolidated sediments m = 1.3.

Table 3 below gives the computed porosities of the higher resistivity formations based on the three-layer interpretations (see Plate 7).

TABLE 3

DEPTH PROBE	Rw (ohm metres)	Log Rw	R (ohm metres)	Log R	Porosity (%)	REMARKS
K1	3	0.477	36	1.556	18.5	
K2	5	0.699	60	1.778	18.5	
K3	4	0.602	(28 (70	(1.447 (1.845	15.7	Average taken
K4	3.2	0.505	14	1.146	32.1	Not used
K5	5±	0.700	50	1.70	17.1	
K6	5±	0.700	50	1.70	17.1	
K7	2.5	0.398	30	1.477	18.5	
					17.6	Mean Porosity

The mean porosity of 17.6% is rather low, being more typical of a medium gravel than sand, sandstone and shelly limestone as indicated by borehole data. Characteristics of rocks are discussed by Wiebenga and Jesson (1962); Plate 9, which relates characteristics of rocks as a function of grainsize, is taken from this report.

6. CONCLUSIONS

Resistivity depth probes made with both the Wenner and Schlumberger electrode systems show that the two produce very similar field curves; the latter is to be preferred on economic grounds.

The ERR3, Geophysical Megger and Terrameter give comparable performances in depth probing, except where the measured resistances fall below a certain value ascertained in calibration tests, and below which the ERR3 is to be preferred because of its better accuracy. The 'Yew' megger has limited application where the electrode spacing is such that the measured resistance is not less than 0.15 ohm. The power supply for the ERP.1 high power resistivity system was shown to operate well, but the potential meter used in conjunction gave rise to anomalous field curves.

Interpretations of depth probes agree quite well with stratigraphic information from boreholes. A junction between clay overlying sand at a depth of 90-130 ft is widespread over the survey area. Because of the clay zone extending from the surface, but also because the survey was conducted at a time when there was considerable rainfall "run-off" from the hills to the north and east, there is no evidence of significant saltwater intrusion in the area. It is suggested that resistivity measurements be repeated at the end of a dry period, so as to permit a comparison with current results, in order that zones of saltwater intrusion may be defined.

7. REFERENCES

ANDREW, J.T.G., and WIEBENGA, W.A. 1965 Two layer resistivity curves for the Wenner and Schlumberger electrode configurations. Bur. Min. Res. Rec. 1956/18

DOBRIN, M.B. 1960 GEOPHYSICAL PROSPECTING. McGRAW HILL

DYSON, D.F., and WIEBENGA, W.A. 1957 Geophysical investigations of underground water, Alice Springs, N.T. 1956. Bur. Min. Res. Rec. 1957/89

JENKIN, J.J. 1962 The geology and hydrogeology of the Western Port area Department of Mines, Victoria, Report No. 5

GUYOD, H. 1952 Electrical well logging fundamentals. Houston, Texas

MARSHALL, D.J., and MADDEN, T.R. 1959 Induced polarisation, a study of its causes Geophys. 24, No. 4 p. 790

SCHLUMBERGER 1958 INTRODUCTION TO SCHLUMBERGER WELL LOGGING, No. 8, p. 10. SCHLUMBERGER WELL SURVEYING CORP. U.S.A.

TODD, D.K. 1959 GROUNDWATER HYDROLOGY. McGRAW HILL

VACQUIER, V., HOLMES, C.R., KINTZINGER, P.R., and LAVERGNE, M. 1957 Prospecting for groundwater by induced electrical polarisation Geophys. 22, No. 3, p. 660.

WAINWRIGHT, M. Markham Valley resistivity survey T.P.N.G. 1964 Bur. Min. Res. Rec. (in preparation)

WIEBENGA, W.A. 1955 Geophysical investigations of water deposits, Western Australia Bur. Min. Res. Aust. Bull. 30

WIEBENGA, W.A., and JESSON, E.E. 1962 Geophysical exploration for underground water Bur. Min. Res. Rec. 93

WIEBENGA, W.A., POLAK, E.J., ANDREW, J.T.G., WAINWRIGHT, M., and KEVI, L. Underground water, Burdekin Delta, North Queensland Bur. Min. Res. Rec. (in preparation)

APPENDIX 1 - BOREHOLE DATA

The location of each bore is shown on Plate 1. Bores (a) to (h) were sunk by private contractors, mainly to obtain water supplies for irrigation and livestock purposes. Bores (j), (k) and (l) were sunk by the Department of Mines, Victoria.

Bore (a)	0-90 ft.	Clay
	90-240 ft.	Unknown
	240-250 ft.	Coarse sand
Bore (b)	5-60 ft.	Sandy clay
	60-85 ft.	Clay
	85-150 ft.	Mainly sand, but with some lignite bands
Bore (c)	0-48 ft.	Clay
	48-60 ft.	Sand
	60-78 ft.	Clay
	78-81 ft.	Sand (fairly saline i.e. 2000-4000 p.p.m.)
	81-170 ft.	Mainly clay, with some thin sand layers
	170-178 ft.	Lignite sand
	178-185 ft.	Lignite
	185-200 ft.	Fine sand, with fresh-water
	200-205 ft.	Coarse sand
Bore (d)	Similar to bore (b). Sea-shells at 225 ft. depth	
Bore (e)	0-32 ft.	Mainly clay
	32-81 ft.	Mainly sandy clay
	81-110 ft.	Black coal and wood
	110-130 ft.	Sand
	130-134 ft.	Clay
	134-163 ft.	Mainly sand
Bore (f) and (g)	0-95 ft.	Clay
	95 +	Fine sand with lignite - fresh water zone at 168 ft. depth
Bore (h)	0-128 ft.	Clay - saturated near surface with saltwater (2000- 4000 p.pm).
Bore (j)	(Department of Mines Bore 4, Tooradin, 1959)	
	0-17 ft.	Sand
	17-31 ft.	Clay
	31-36 ft.	Sand : fresh-water at base
	36-48 ft.	Clay
	48-218 ft.	Sand, with shells below 177 ft. depth
	218-304 ft.	Sandy clay
	304-318 ft.	Gravel with clay
	318-341 ft.	Basalt
	341-346 ft.	Clay

Bore (k)	(Department of Mines bore, alongside water tower N.E. of Kooweerup)	
	0-125 ft.	Mainly gravel with clay. Fresh-water at 41 ft depth
	125-185 ft.	Fine sand with some lignite
	185-225 ft.	Fine sandy clay
	225-305 ft.	Mainly sand with sandstone lenses, and shells below 258 ft.
	305-321 ft.	Limestone, silty sand with shells
	321-333 ft.	Clay
Bore (l)	(Department of Mines, Bore 3; located by road on Allotment 18, Section I, Kooweerup)	
	0-50 ft.	Unknown
	50-84 ft.	Clay
	84-100 ft.	Sandy clay. Fresh-water at 85 ft. standing at 13 ft. depth
	100-105 ft.	Coarse sand
	105-110 ft.	Clay

APPENDIX 2 - WATER RESISTIVITIES

Geophysical Branch,
Bureau of Mineral Resources,
Geology and Geophysics.

Mud-Cell Constant = $\frac{6.38}{100}$ metres x Observed Resistances (Ohms)

AREA : KOO-WEE-RUP, VICTORIA
OBSERVER : M.W.
MEGGER TYPE : Earth-tester (0-3000 Ohms)
YEAR : 1965

M = Mud Cell
U = Underground
S = Surface
P = Probe (Constant ....)

DATE	LOCATION NUMBER	INSTMNT	DEPTH (feet)	TEMP. (°C)	OBSERVED READING (Ω)	CORRECTED READING	RESISTIVITY (Ohm-metres) at 20°C	SALINITY (p.p.m)	POROSITY (%)	REMARKS (Locations, Grid References, Pumping Data, pH values, Etc)
8-9	1	M	S	13.5	1050	67	59	85		Surface sample at centre K1
8-9	2	M	S	13.5	1450	92.5	81.5	61		From drain. Ditch adjacent K1
8-9	3	M	S	13.8	40	2.5	2.2	2480		Surface run-off, Sawtell's inlet
8-9	4	M	S	13.8	14	0.89	0.79	6330		From drainage channel, Sawtell's inlet
10-9	5	M	S	12.0	450	28.7	24.4	204		From settling tank. Water from drain. Adjacent water-tower, Kooweerup
10-9	6	M	S	10.0	1050	67	55	91		From drainage ditch at centre of K2
10-9	7	M	S	15.5	580	37	34	147		From Bunyip River drain, fast-flowing
10-9	8	M	S	16.0	350	22.3	20.8	240		From ancilliary drain parallel to Bunyip
13-9	9	M	S	14.0	380	24.2	21.7	230		From drain adjacent centre K3
13-9	10	M	U-n.a.	16.0	68	4.34	4.04	1230	37	From windmill pump, 100 yds. east of centre K3
14-9	11	M	U-n.a.	13.0	58	3.7	3.2	1560	24	Sample pumped from well 50 yds. south of centre K4 (Harewood House)
15-9	12	M	S	13.8	375	24	21.4	233		Sample from Bunyip River at Glovers Bridge - centre K5
15-9	13	M	S	15.0	530	33.8	30.8	162		From tank filled from drain - close to K6
21-9	14	M	S	17.1	41	2.6	2.5	2000		From small drain on north side of levee wall, 500 ft. south of centre of K7 (Dickensberg)
21-9	15	M	S	16.7	58	3.7	3.5	1430		From surface pond south of levee (see 14)
22-9	16	M	S	16.0	425	27.1	25.1	199		From active drain, west side Bunyip River
22-9	17	M	50	12.8	45	2.9	2.5	2000		Brackish - used only for cattle
22-9	18	M	45	16.0	75	4.8	4.4	1140	56	Sample from settling tank - probably polluted
22-9	19	M	S	14.5	400	25.5	23.9	209		From drain next to road
22-9	20	M	110	14.5	110	7.0	6.3	794	49	From settling tank

See Plate 1 for Locations

APPENDIX 3 - REPEATED TWO LAYER DEPTH PROBE INTERPRETATIONS

a) ERR3; b) Geophysical Megger; c) Terrameter; d) 'Yew' Megger.

1st, 3rd figures etc. refer to resistivities (ohm metres); figures in brackets refer to depths of interface (ft).

STATION	INSTRUMENT	INTERPRETATION
K1	a)	53 (3) 6 (29) 15 (127) 24
	b)	40 (3) 6 (35) 14 (130) 28
	c)	38 (3) 7 (24) 12 (135) 28
	d)	30 (3) 7 (40) 30 not complete
K2	a)	54 (1.4) 13 (9) 5 (35) 11 (135) 40
	b)	57 (1.2) 14 (7.5) 5.5 (41) 9 (130) 31
	c)	68 (1.1) 17 (6.3) 6.5 (45) 8.5 (125) 30
K3	a)	105 (2) 34 (8.5) 12 (85) 20 (250) 36
	b)	90 (2) 30 (9) 11 (85) 17 (270) 30
	c)	200 (8) 13 (80) 20 (300) 73
	d)	90 (2.2) 29 (9.5) 12 (85) 20
K4	a)	5 (5) 2 (70) 30 (450±) 15
	b)	5 (6) 2 (64) 30 (440) 11
	c)	5.5 (5.5) 2 (72) 22±
K5	a)	90 (3.5) 12.5 (130) 40
	b)	90 (3) 13 (120) 15
K6	a)	50 (3) 12 (130) 45
	b)	42 (3) 12 (132) 42
K7	a)	5 (1.5) 2.7 (4.6) 6 (8) 2.7(62) 23
	b)	3.8 (1.8) 2.5 (4.6) 4.3 (9.5) 2 (68) 18

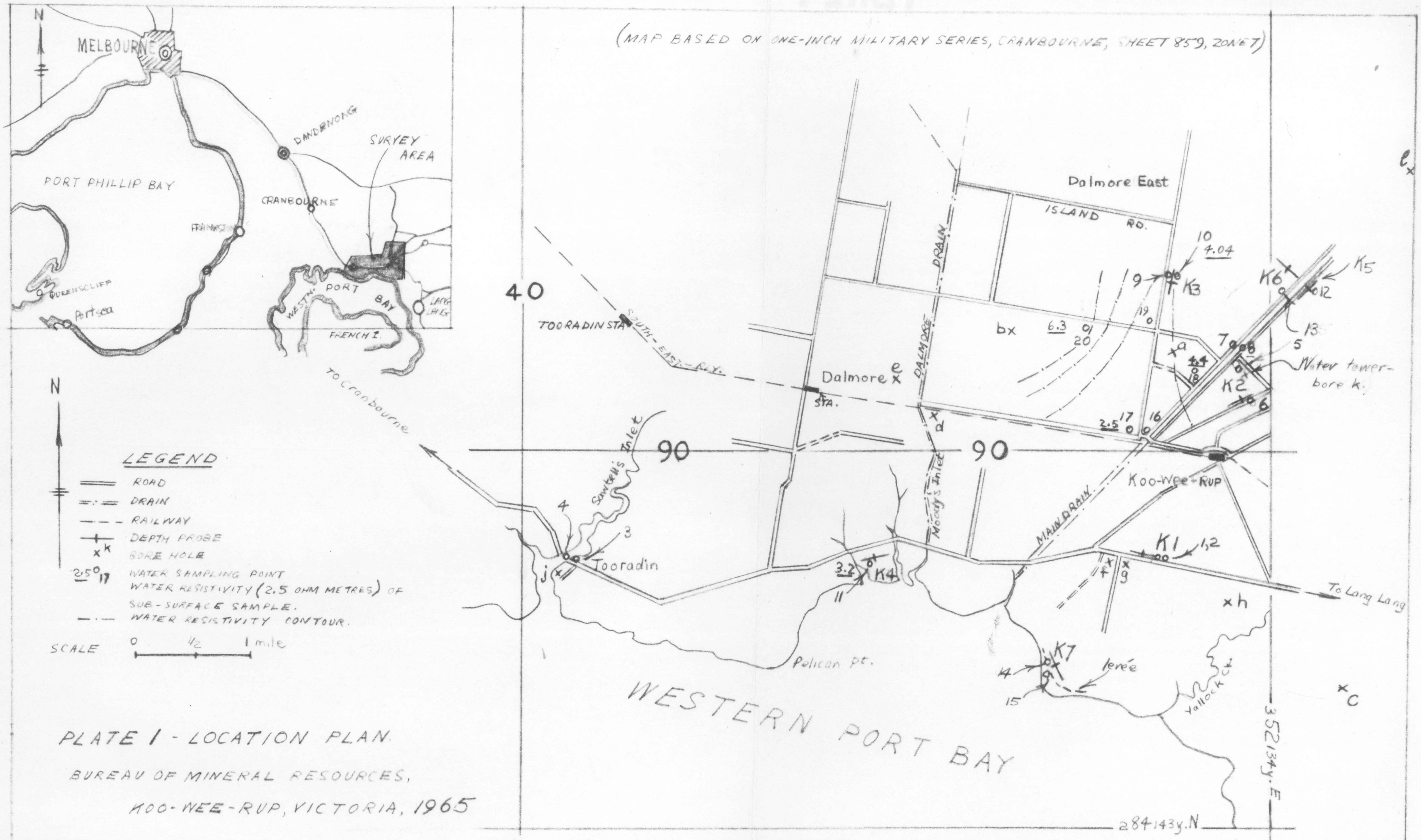


PLATE 1 - LOCATION PLAN.

BUREAU OF MINERAL RESOURCES,

KOO-WEE-RUP, VICTORIA, 1965

J55/B5-26

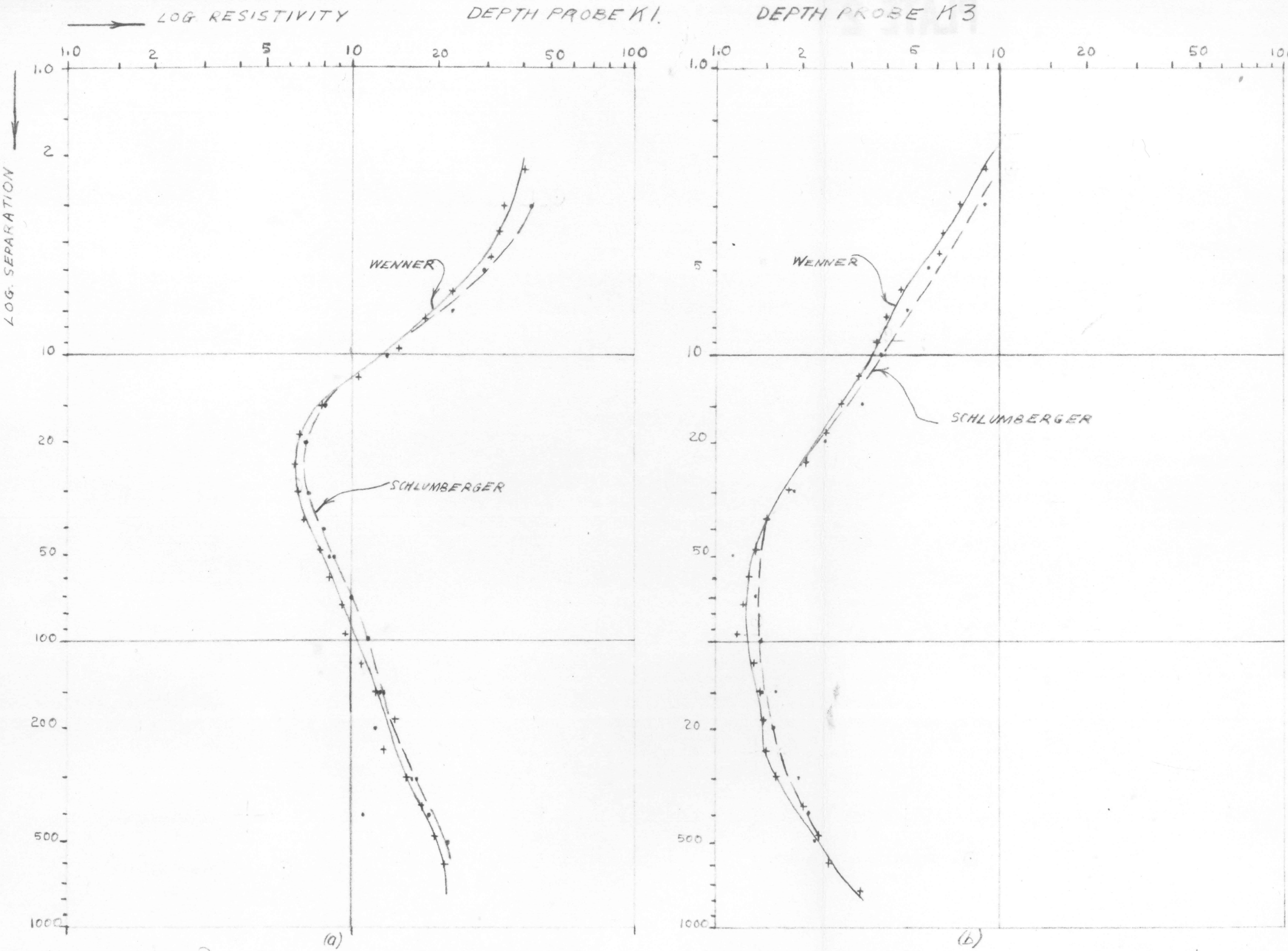
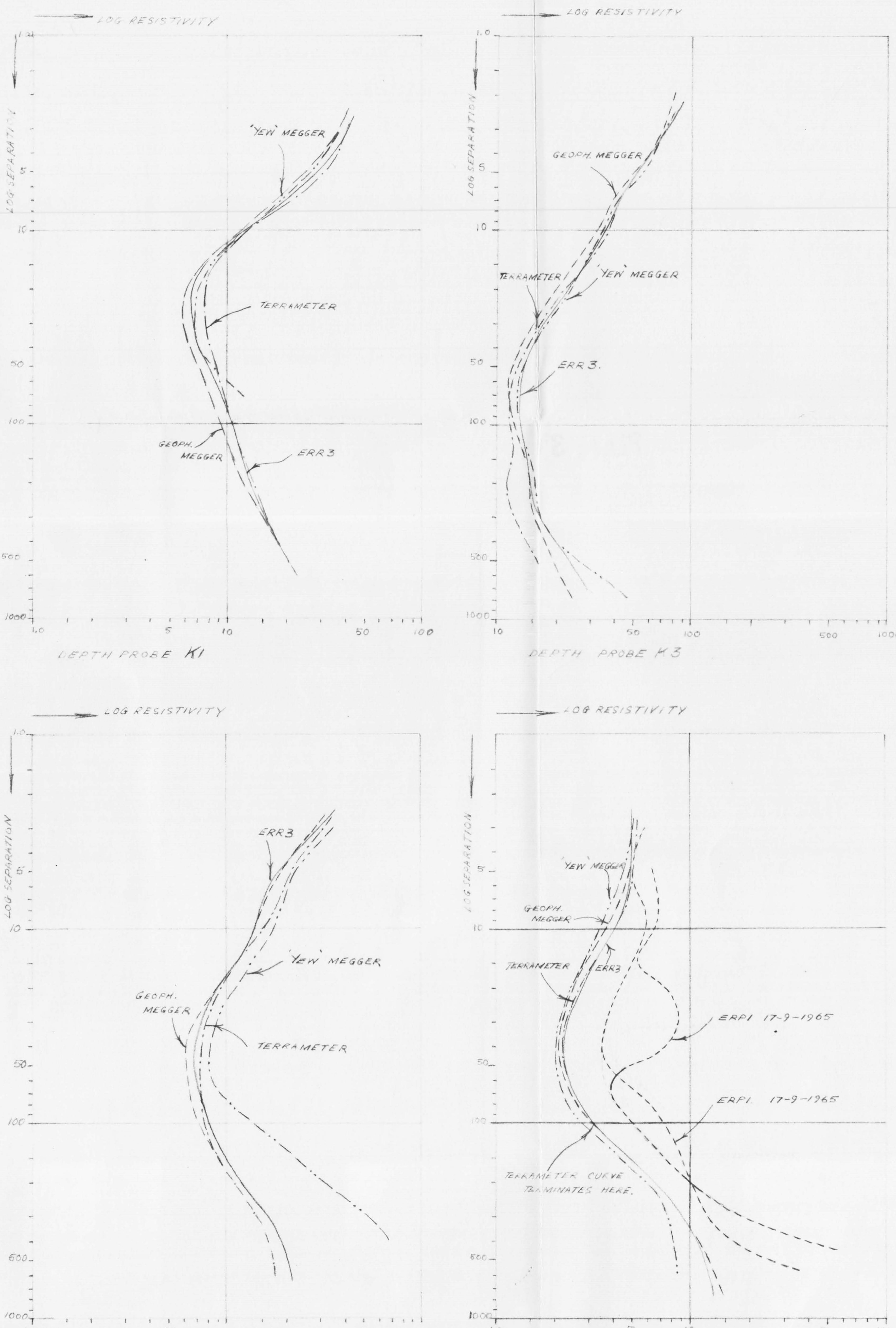


PLATE 2. COMPARISON OF WENNER AND SCHLUMBERGER (INSTRUMENT d.c. ERR3)

BUREAU OF MINERAL RESOURCES. KOO-WEE-RUP, VICTORIA, 1965

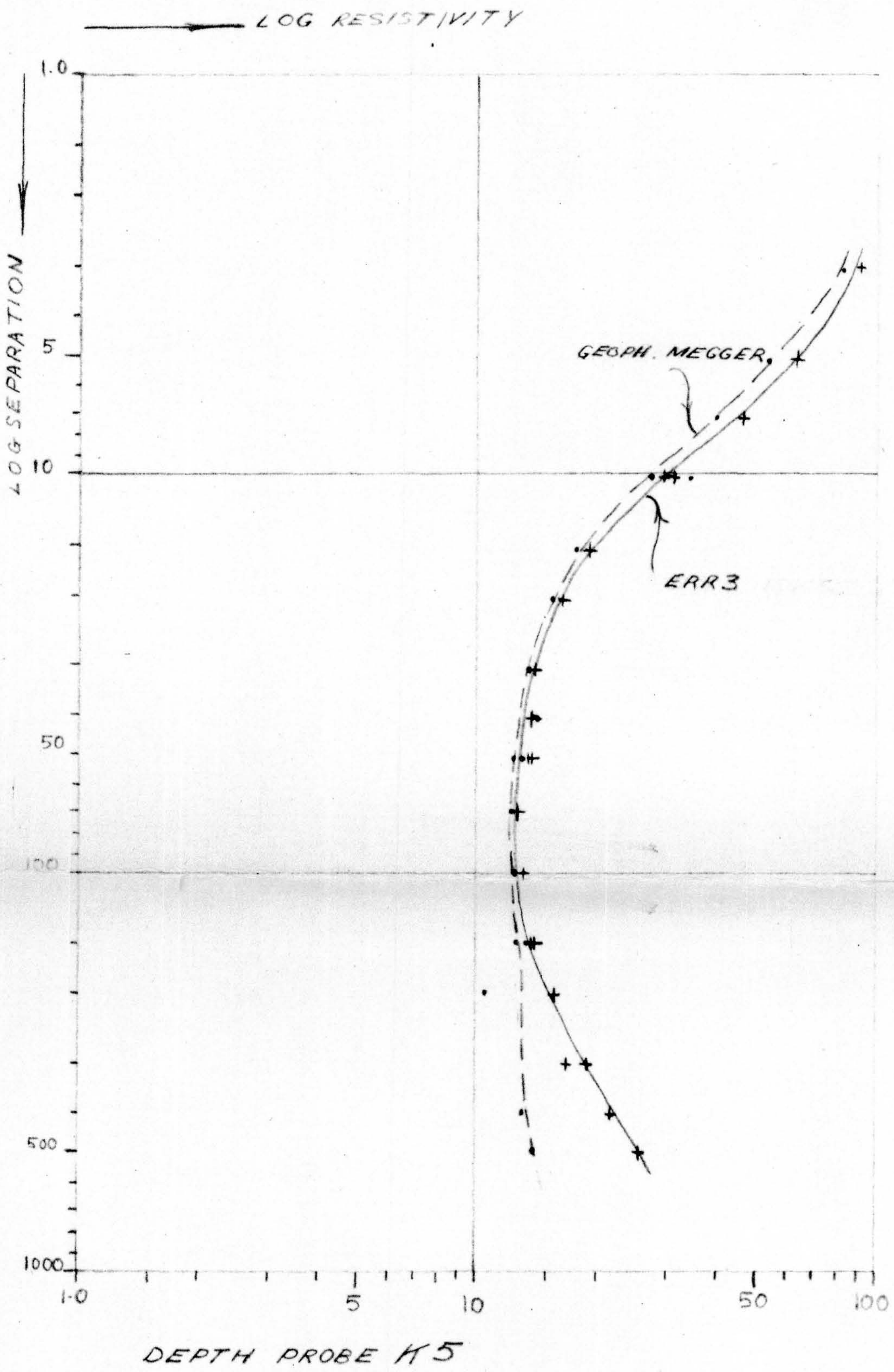
J55/B5-27

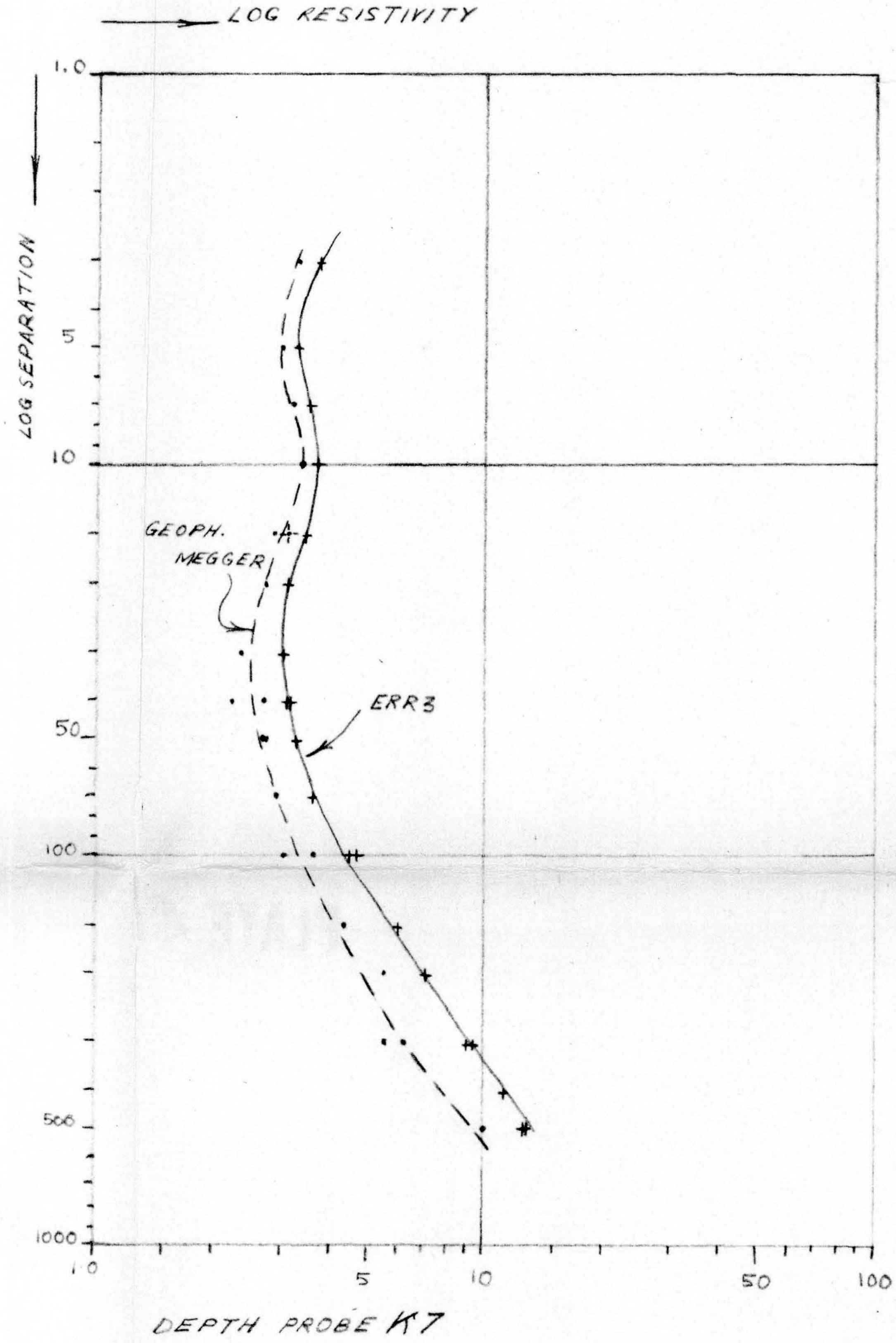


J55/B5-28

PLATE 3 COMPARISON OF RESISTIVITY METERS

BUREAU OF MINERAL RESOURCES, KOO-WEE-RUP, VICTORIA 1965.





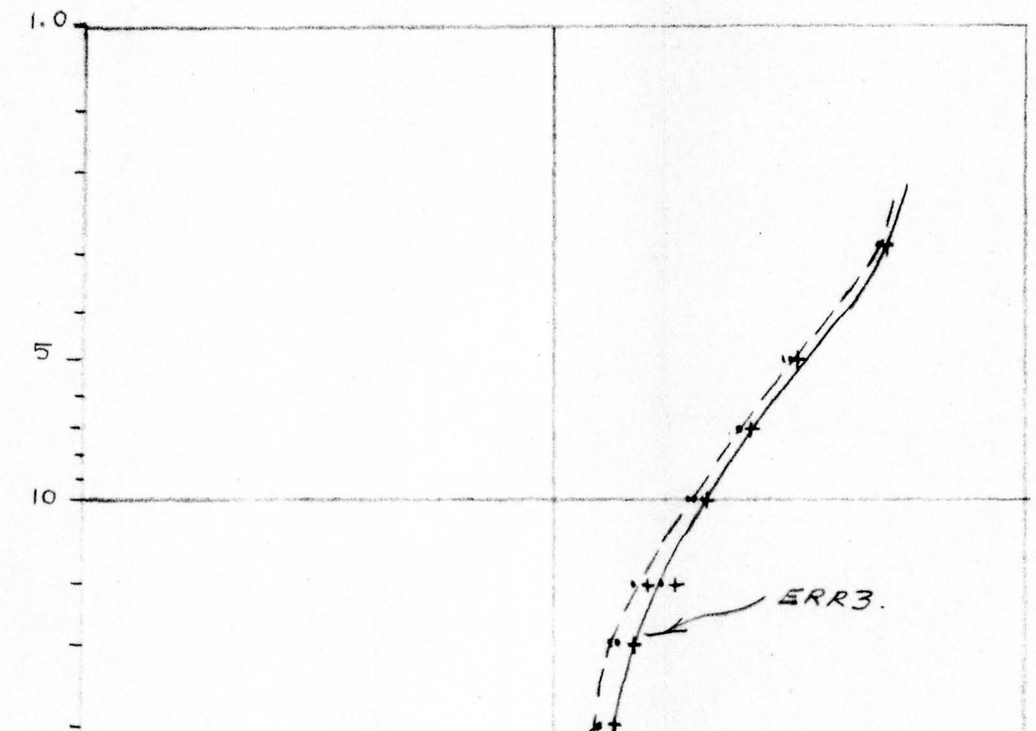


PLATE 4 COMPARISON OF RESISTIVITY METERS.

BUREAU OF MINERAL RESOURCES - KOO-WEE-RUP, VICTORIA. 1965.

J55/65-29

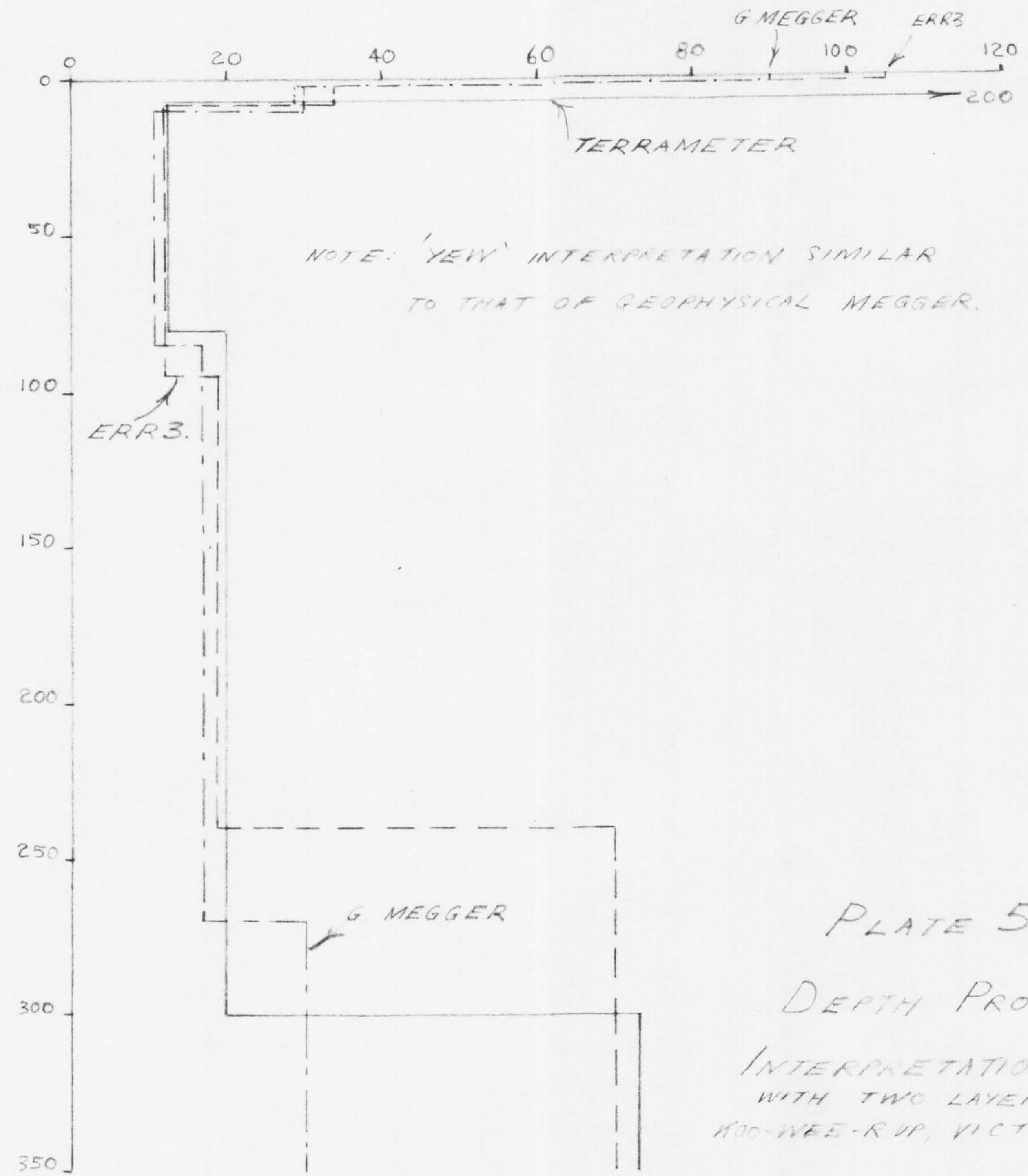


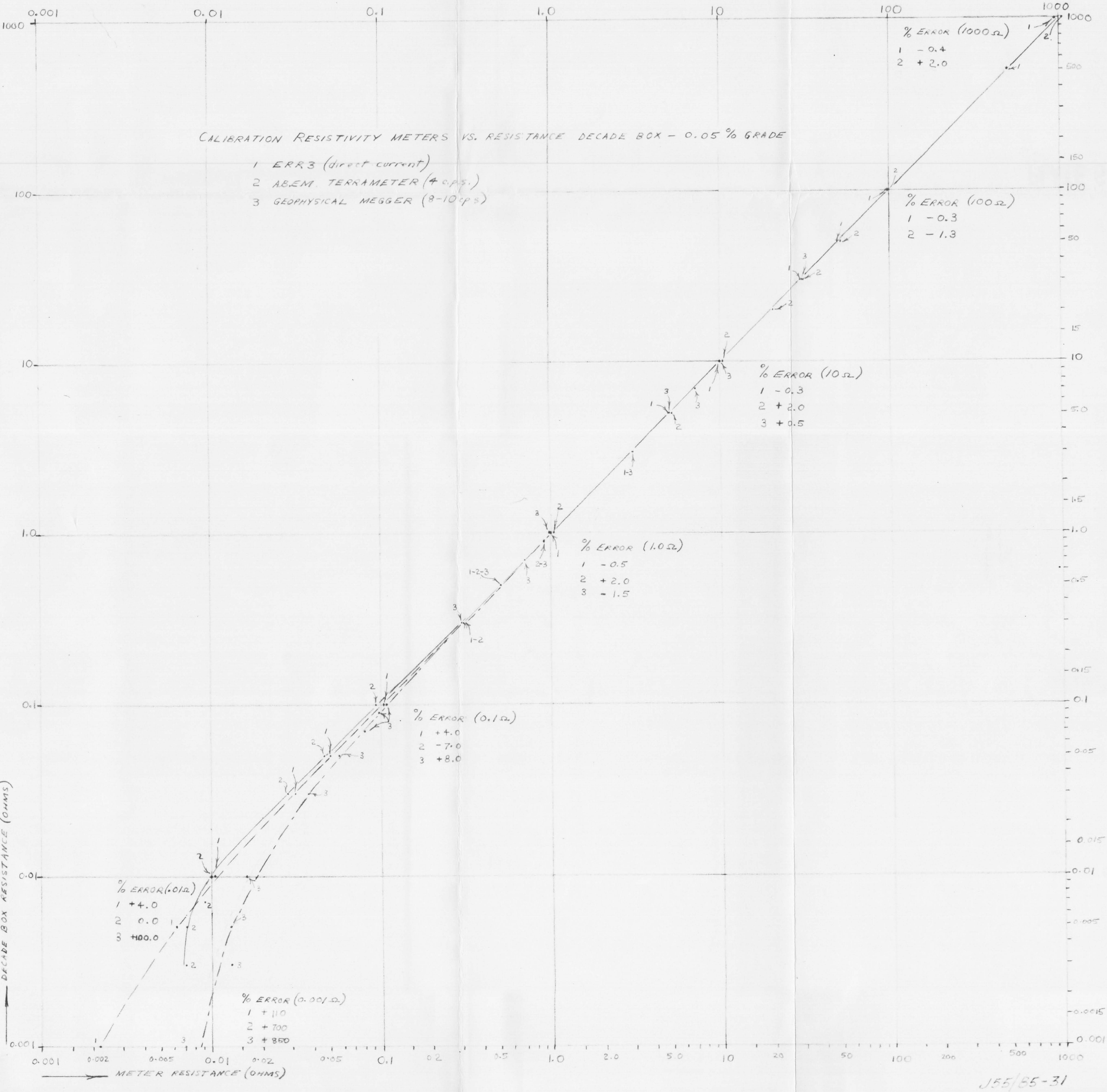
PLATE 5

DEPTH PROBE K3

INTERPRETATION HISTOGRAM.
WITH TWO LAYER CURVES
KOO-WEE-RUP, VICTORIA, 1965

J55/B5-30

PLATE 6



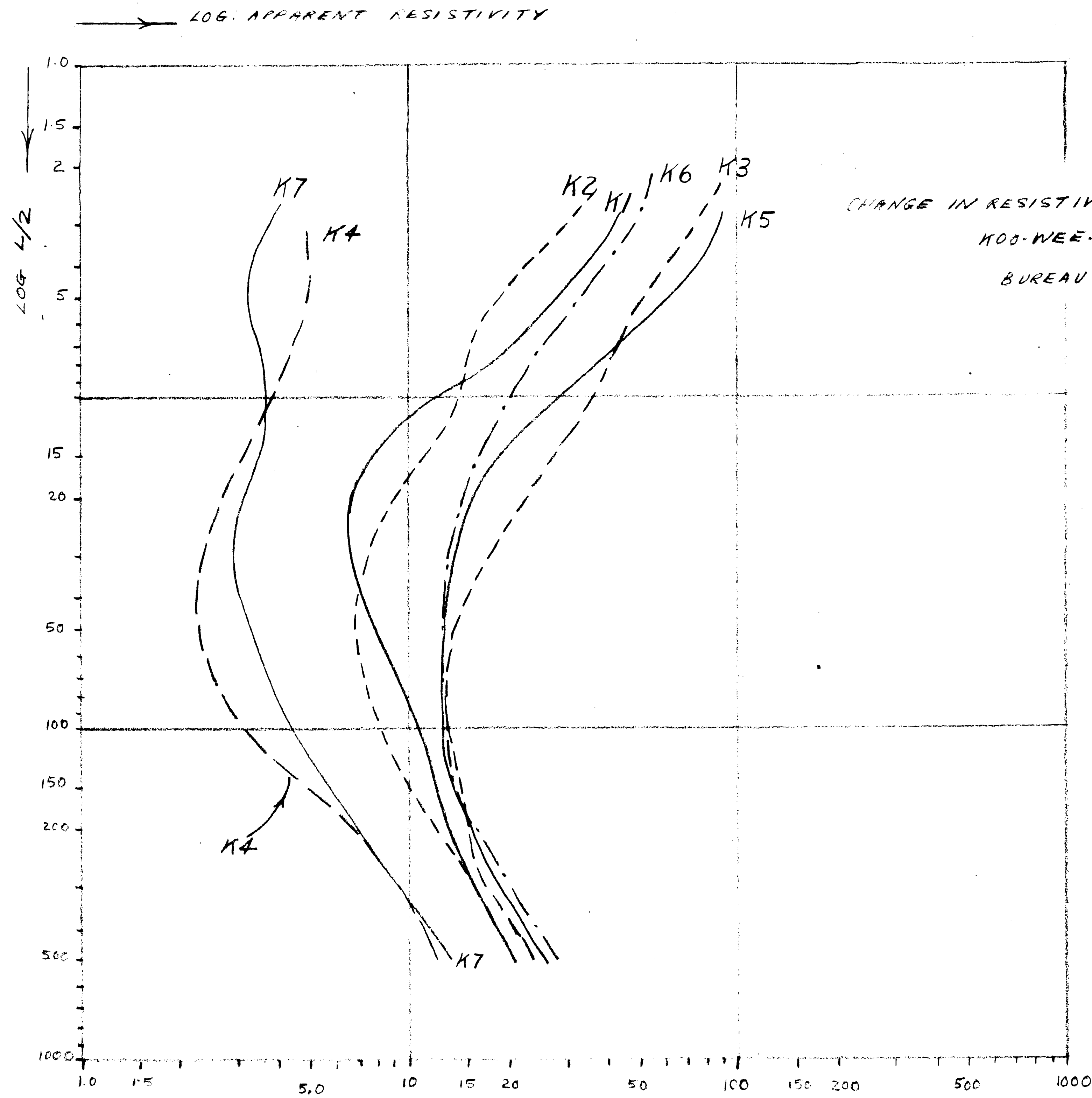
J55/85-31

PLATE 7 CROSS-SECTIONS K7 TO K6 AND K7 TO K4

KOO-WEE-RUP, VICTORIA, 1965

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

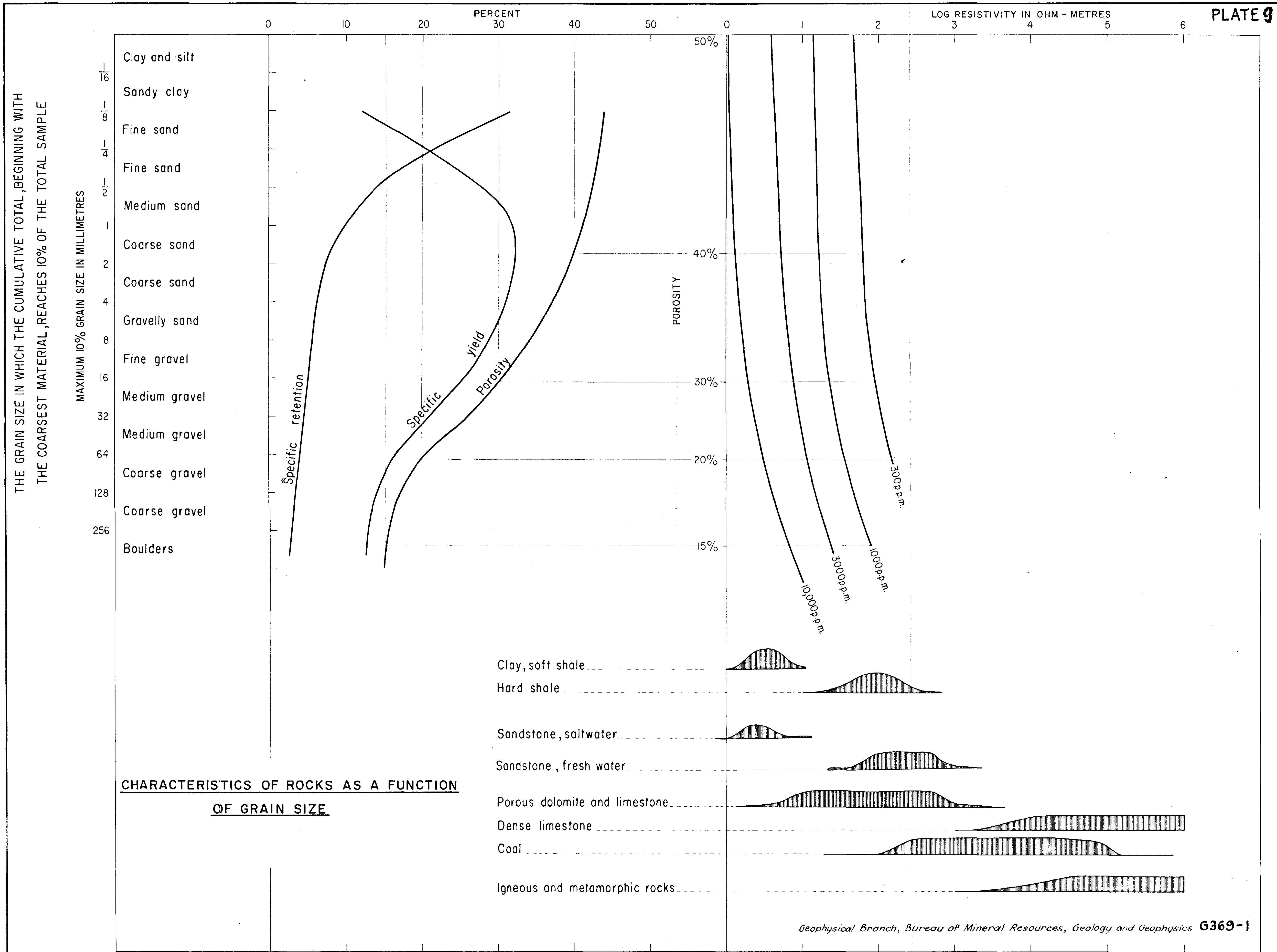
PLATE 8



CHANGE IN RESISTIVITY INLAND FROM INTERTIDAL ZONE
KOO-WEE-RUP, VICTORIA, 1965
BUREAU OF MINERAL RESOURCES.

J55/R5-32

PLATE 9



CHARACTERISTICS OF ROCKS AS A FUNCTION OF GRAIN SIZE

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics G369-1

TO ACCOMPANY RECORD No [redacted]