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TECHNICAL SERVICES SECTION

RESISTIVITY SURVEY, WARDANG ISLAND
JULY 1976

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and

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DEPARTMENT OF MINES - SOUTH AUSTRALIA

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PROTEROZOIC L

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BASEMENT DEPTH

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RESISTIVITY SURVEY METHOD.

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DEPARTMENT OF MINES
SOUTH AUSTRALIA

RESISTIVITY SURVEY, WARDANG ISLAND

JULY 1976

by

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Rept.Bk.No. 77/2
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D.M. No. 318/76

11th January 1977

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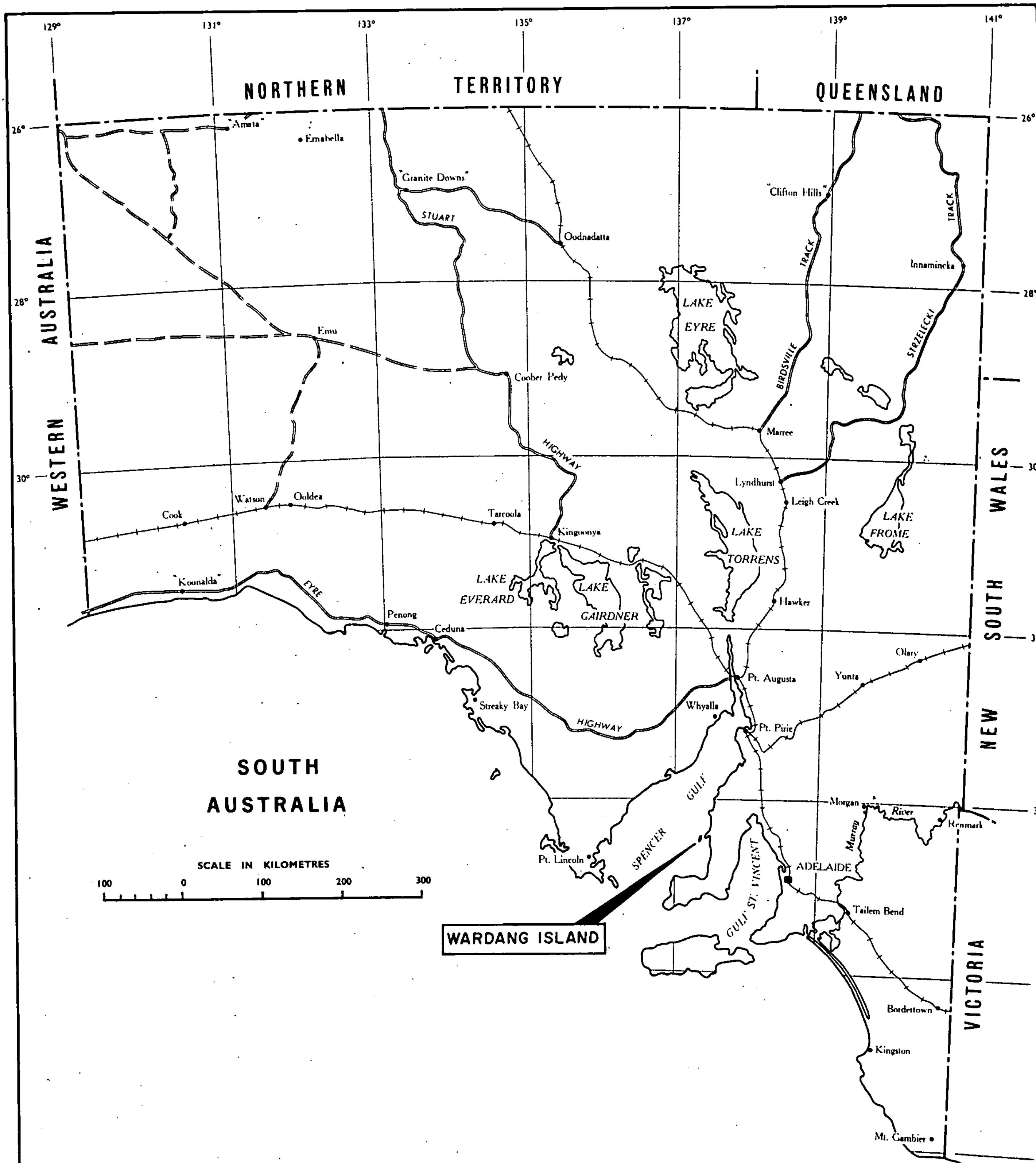

FIG. 1

DEPARTMENT OF MINES — SOUTH AUSTRALIA

Compiled.		WARDANG ISLAND LOCALITY MAP	Date:
Drn.	Ckd.		Drg. No. S12537

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DEPARTMENT OF MINES
SOUTH AUSTRALIA

Rept.Bk.No.77/2
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RESISTIVITY SURVEY, WARDANG ISLAND

ABSTRACT

Resistivity investigations were carried out on Wardang Island in an attempt to determine drilling sites favourable for fresh underground water. The thickness of the Bridgewater Formation (aeolianite) and basement elevations were mapped and contoured. Drilling sites were selected where thicker sections of aeolianite associated with basement depressions were found. Of the seven sites chosen five are within fully enclosed depressions while at the other two the depression is open to the sea. Overlying a low resistivity (2-5 ohm-m) saline near basement zone is a thinner intermediate resistivity (20-40ohm-m) zone which may indicate a fresh water zone. Only drilling can determine if the aeolianite contains water at these sites and if the overlying zone is fresh. However, the probability of a suitable supply from such localised saline environments is low and pumping rates would be strongly dependent on recharge from rainfall.

INTRODUCTION

Electrical soundings and traverses were carried out in July 1976 on Wardang Island at the request of the Department of Further Education. The purpose of this survey was to delineate the thickness of possible freshwater-bearing sediments and thus to site several test drill holes. The water was sought for domestic purposes and a supply of at least 1100 litres/hour was required. An earlier hydrogeological survey on the island by the South Australian Department of Mines (Shepherd, 1972) had indicated possible low yields of saline water.

Wardang Island is located 10 km west of Port Victoria on the west coast of Yorke Peninsula (Fig.1). The island has an area of 23km^2 and the topography, which is gently undulating, has a general eastward slope from a 30 m high near the lighthouse in the west to sea level along the eastern shore. In general the north, west and south coastlines have steep cliffs 9-12m high interspersed with short stretches of sandy beach while the eastern side contains a low lying saline swampy area about 1km wide and 4km long. Vegetation on the island is sparse as much of the original growth was cleared for mining and grazing purposes. Mining of the calcareous sand dunes and the underlying Bridgewater Formation for blast furnace flux has been carried out at various times.

Rainfall records have not been kept on the island but at Port Victoria the average is 385 mm per year and it is thought that the island would receive less than this, possibly 330 mm per year.

GEOLOGY

The general geology is described by Shepherd (1972) in a report on a groundwater survey carried out in 1972. The island is almost entirely covered by sheet calcrete (Rippon calcrete) which is hard and dense and ranges from 0.6 m to 1.5 m in thickness. Overlying this is a thin calcareous sandy soil (0.3-0.6m thick) which builds up in some areas into thick sand dunes. Underlying the Rippon Calcrete is the Bridgewater Formation, a calcareous aeolianite, which ranges in thickness from 3 m to 12 m. In the south of the island, Hallets Cove sandstone outcrops. This is a richly fossiliferous sandstone which forms large dense blocks, and is probably less than 6m thick. Underneath these flat lying Tertiary and Quaternary sediments are rocks of Lower Proterozoic age, consisting of dense gneiss, schist, amphibolite and possible equivalents to Moonta Porphyry (B.P. Thomson, Pers. Comm.). The upper boundary of the Lower Proterozoic basement rocks is an erosion surface and outcrops near sea level along the western coast.

An aquifer, if present, is likely to exist with an unconfined water table for both the aeolianite and the fractured Lower Proterozoic rocks. Ground water may occur in the aeolianite over the whole island but probably with high salinity in most areas. Limited supplies may occur in fractured basement. Thin lenses of fresh water resting on saline ground water may exist in some areas.

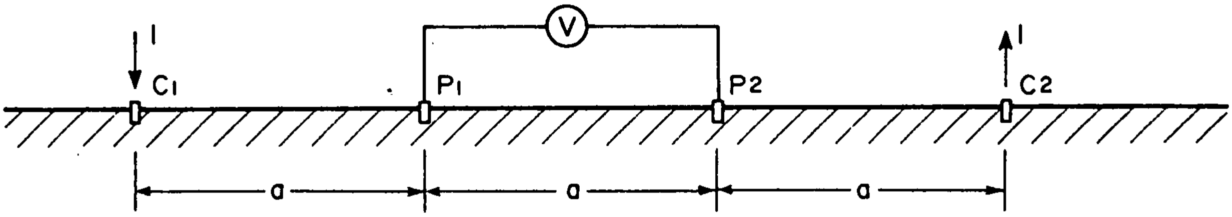
SURVEY PROCEDURE

1) Field work

A reconnaisance trip on the 1st July, 1976 was made to determine transport and other facilities on the island and to conduct experiments with seismic and electrical resistivity methods. The hammer seismic method proved to be ineffective due to the thick dense calcrete cover. Two trial vertical electrical soundings (VES 1 and VES 2) were successful in determining depth to the Lower Proterozoic basement. Control was obtained by locating a spread near an old well in the south of the island.

It was then decided to carry out a programme of combined depth soundings and resistivity profiling. A survey of ten days duration commenced on the 13th July, 1976. Twenty-eight vertical electrical soundings and 23 km of resistivity traversing were carried out. Transport on the island was by means of two Suzuki 185 cc. motor cycles hired for the survey, one of which towed a trailer carrying the equipment. A motor launch was chartered for trips to and from the island.

WENNER CONFIGURATION



$$\rho a = 2\pi a \frac{V}{I}$$

ρa - ohm - metres

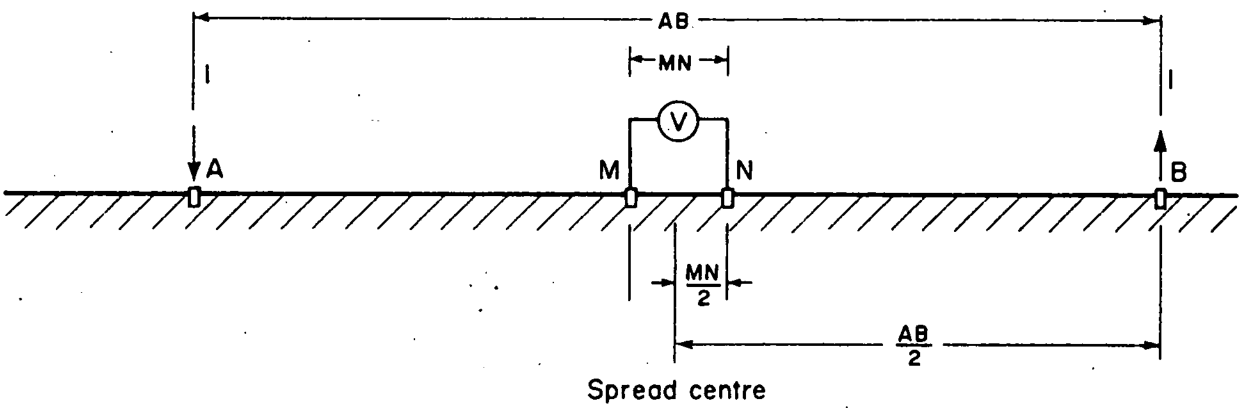
a - metres

V - volts

I - amperes

FIG. 2a

SCHLUMBERGER CONFIGURATION



$$\rho a = \pi \frac{V}{I} \frac{(AB/2 + MN/2)(AB/2 - MN/2)}{MN}$$

FIG. 2b

GEOPHYSICAL SERVICES SECTION		DEPARTMENT OF MINES–SOUTH AUSTRALIA	Scale: —
Compiled: B.J.T.		WENNER AND SCHLUMBERGER CONFIGURATIONS	Date: 12 · 1 · 77
Drn. A.F.	Ckd.		Drg. No. S 12301

500—6.76 G6584 O

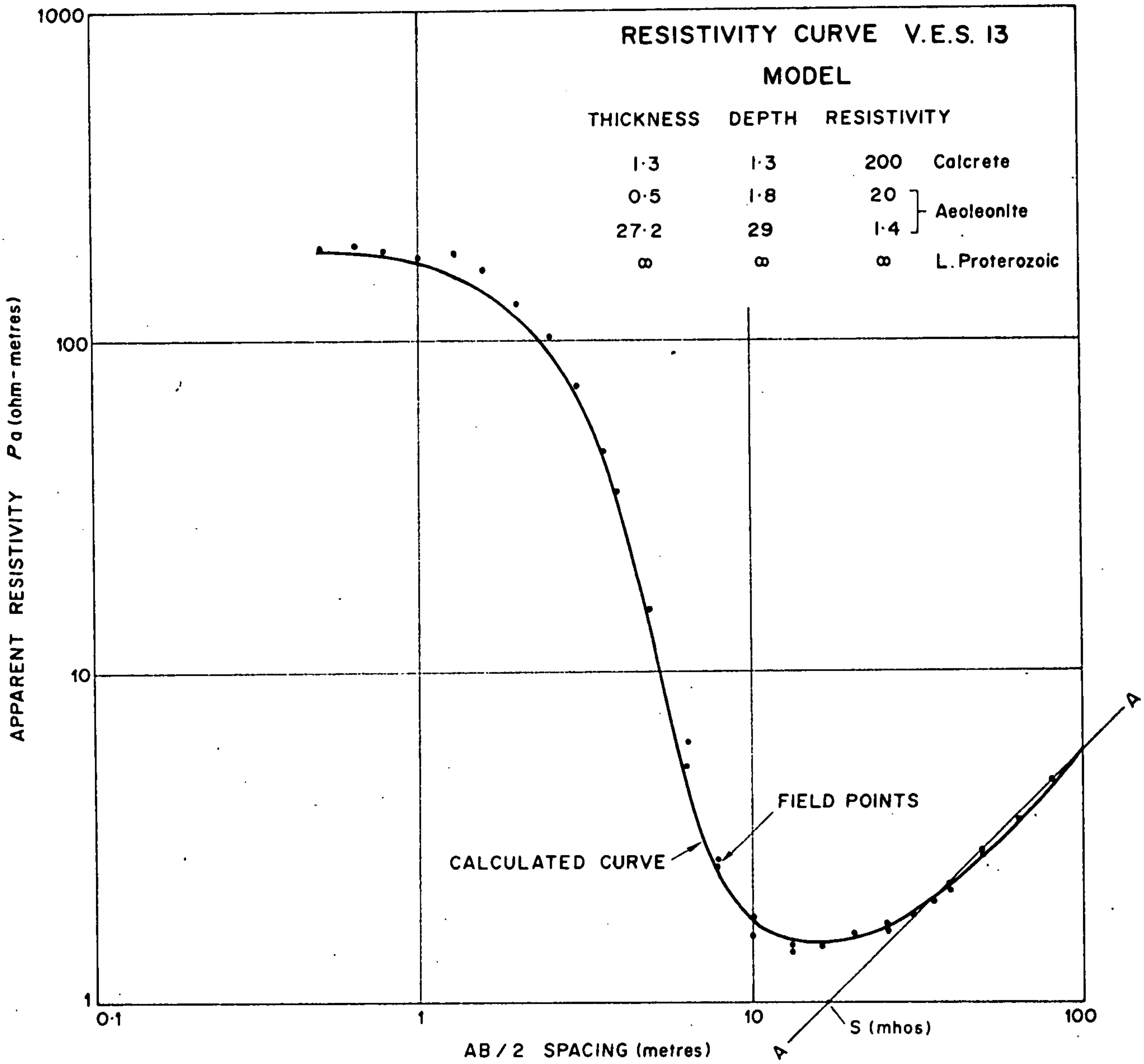


FIG. 3

GEOPHYSICAL SERVICES SECTION	DEPARTMENT OF MINES–SOUTH AUSTRALIA	Scale: —
Compiled: D. R.	WARDANG ISLAND RESISTIVITY SURVEY	Date: 12·1·77
Drn. A.F. Ckd.	RESISTIVITY CURVE V.E.S. 13	Drg. No. S 12538

500—6.76 G6584 O

2) Equipment

Resistivity measurements were made by using a Geoscience low-power Induced Polarization transmitter to introduce a regulated current into the ground. Power to it was supplied from a 12 volt lead-acid battery via a dc-ac inverter. A McPhar P660 receiver was used to measure voltages generated between potential electrodes. The transmitted current was usually 0.065 amps at a frequency of 3 Hz with checks for inductive coupling at 0.3 Hz. Steel pegs were used as electrodes.

3) Vertical Electrical Soundings

Soundings using an expanding Schlumberger array (Fig.2B) were made at sites selected to give broad coverage of the island and to determine the typical vertical section. Further soundings were made on anomalies discovered during resistivity profiling. This array used potential electrodes (M,N) inside of and in line with the outer current electrodes (A,B). The distance between the outer electrodes (AB) was increased in steps keeping symmetry about the spread centre with readings being taken of current and voltage for each step until the voltage became too small to be read accurately. The potential electrode spacing (MN) was then increased (keeping the ratio MN/AB less than 0.2) before continuing expansion of the current electrode spacing. From the measurement of potential (V) and the known transmitted current (I) the apparent resistivity was calculated using the relationship shown on figure 2B.

The apparent resistivity was plotted against corresponding AB/2 values on log-log paper for later interpretation (Fig.3). For this survey the minimum AB/2 was 0.5m and the maximum was 100m.

4) Resistivity Profiling

Resistivity profiling using the Wenner array (Fig.2A) was carried out over 23 line km on the island. The electrode spacing (a) used was 50m based on results from the initial series of Schlumberger depth soundings. At this spacing the measured apparent resistivity was inversely proportional to the depth to high resistive basement (see Interpretation). Thus the profiling method, calibrated by using vertical electrical soundings, enabled a detailed basement map to be drawn (Figs.4A and 4B).

In the Wenner configuration four electrodes were driven into the ground at equal spacings (a) along a straight line. Between the outer pair of electrodes (C1, C2) a current (I) was transmitted and the potential (V) between the inner pair of electrodes (P1,P2) measured. Using the relationship shown on figure 2A the apparent resistivity was calculated. After each set of readings, the total spread was shifted along one unit of spacing (a) and new readings were taken. Thus a profile of apparent resistivity was obtained with resistivity values being plotted at the midpoint of each successive spread location.

INTERPRETATION

1) Vertical Electrical Soundings

Interpretation was carried out firstly by using Orellana and Mooney (1966) 3-layer curves together with auxiliary curves to determine resistivities and thicknesses of multiple layers. These curves were calculated on the basis of horizontal layering which seemed justified in this case. Results were then tested with a computer program GHOSH (Ghosh, 1971) which calculates theoretical model curves when parameters of thickness and resistivity for the assumed number of layers are entered.

After comparison of calculated and field curves the models were adjusted until a good fit was obtained (Fig.3). The interpreted models are listed in Appendix II.

2) Resistivity Profiling

The profiles shown in Appendix III were obtained by plotting the logarithm of the apparent resistivity, against the distance along the traverse. After the profiling was completed, additional vertical electric soundings were carried out at locations which had given low apparent resistivities, thus suggesting possible thicker sections of aeolianite.

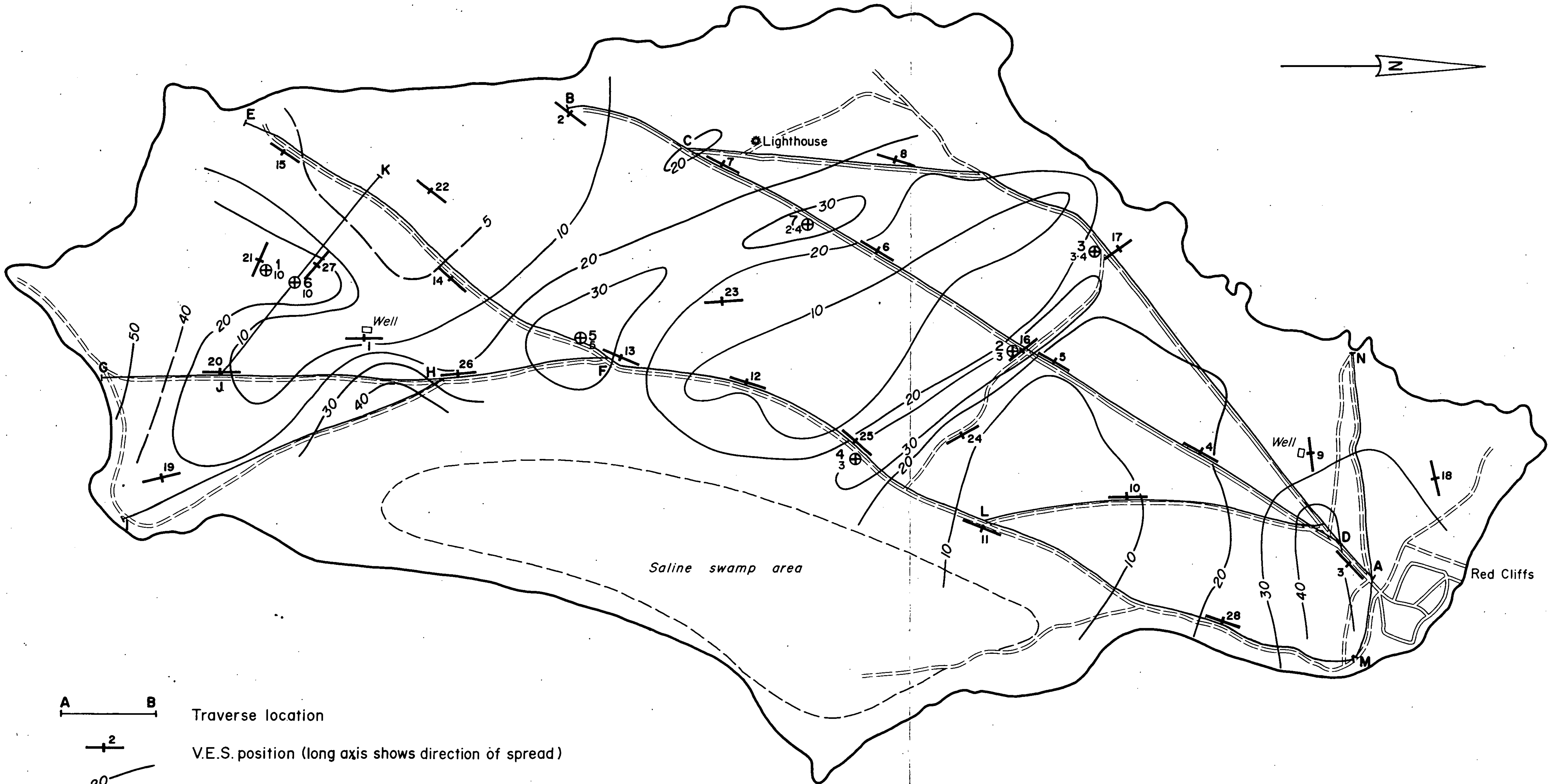
Results of vertical electrical soundings at intervals along the traverse lines were used in obtaining the apparent resistivity-depth correlations. The procedure used for obtaining basement depths is described in Appendix I. Discrepancies between adjacent soundings were generally small and were smoothed out.

RESULTS

The results of the investigation are summarized on the two contoured plans (Figs. 4A and 4B). The basic interpreted models for the soundings are listed in Appendix II. The resistivity profiles are in Appendix III.

1) Vertical Electrical Sounding results

A generalized vertical section of the resistivity is shown in the table. The various geological horizons are correlated where possible on the basis of outcrop and exposures in wells on the islands.



A — B Traverse location

V.E.S. position (long axis shows direction of spread)

Contour showing thickness of aeoleanite and calcrete in metres.

Drilling site
Priority
Depth to saline level in metres

METRES 400 0 400 800 1200 1600 2000 METRES

FIG. 4a

GEOPHYSICAL SERVICES SECTION	DEPARTMENT OF MINES – SOUTH AUSTRALIA	SCALE 1 : 20 000
COMPILED : D. Roberts, B. Taylor	WARDANG ISLAND RESISTIVITY SURVEY	DATE 12 · 1 · 77
DRN. A.F. CKD	SEDIMENT THICKNESS	PLAN NUMBER 77–29

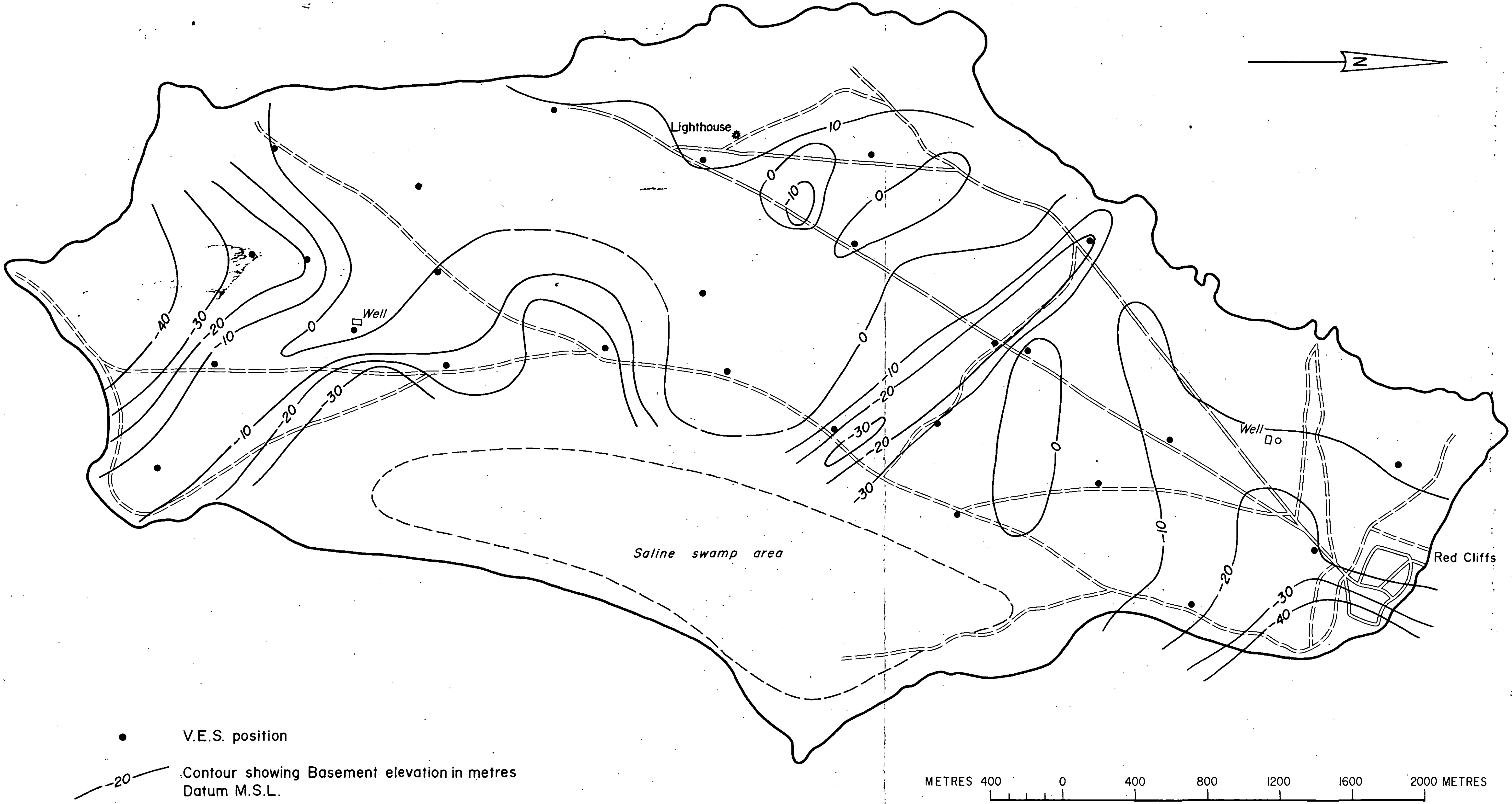


FIG. 4b

GEOPHYSICAL SERVICES SECTION	DEPARTMENT OF MINES – SOUTH AUSTRALIA	SCALE 1 : 20 000
COMPILED : D. Roberts, B. Taylor	WARDANG ISLAND RESISTIVITY SURVEY	DATE 12 · 1 · 77
DRN . A.F. / CKD .	INTERPRETED ELEVATION OF PROTEROZOIC BASEMENT	PLAN NUMBER 77-30

Table

Resistivity section from Soundings

Layer	Resistivity(ohm-m) Range	Mean	Thickness(m)	Geological Log
1	30-60	40	0-1	Calcareous Soil
2	100-250	173	0.5-2	Rippon Calcrete
3	20-40	29	1.2-5	Aeolianite
4	2-5	3.5	8-30	(Bridgewater Formation)
5	50 - ∞	-	∞	Crystalline Basement (Lower Proterozoic)

The top layer was sometimes absent and surveying was carried out on calcrete outcrop. The resistivity of basement was variable probably due to variations in weathering. Longer spreads may have detected infinitely resistive basement in several cases. The rise from the lowest resistivity was correlated with the basement-aeolianite interface. In most soundings the aeolianite was subdivided into thick saline and thinner less saline zones.

2) Resistivity profiling results

The resistivity profiling results were converted to thicknesses (see Interpretation section) which were plotted on a plan and contoured (Fig. 4A). This plan indicates the variation in thickness of sediments overlying basement. Since the calcrete and soil are thin the map is an indicator of the variation in thickness of the aeoleanite. A basement elevation map (Fig. 4B) was obtained by subtracting the thickness data from the elevation at each point. The published topographic map with a contour interval of 7.62m (25 ft.) was used and thus control is poor. However, the topography is gentle and the approximation should be reasonable.

3) General

Sites of interest for groundwater search are enclosed basement lows, thick aeoleanite sections and thicker sections of the intermediate resistivity material above the saline zone.

The main possibility for fresh groundwater on the island is within thin lenses of fresher water overlying the saline portion of aeolianite. The resistivity results indicate two resistivity zones within the aeolianite, the main one being saline (3.5 ohm-m) and the upper thinner zone being of intermediate resistivity (30 ohm-m). The saline zone is not necessarily saturated with water, but may be due to a highly clay matrix or merely moist saline conditions.

In some areas there is evidence that the saline zone is dry as in the well near VES 9. In another well near VES 2 the aeolianite is damp and the fractured basement contains seeping water. Wells within the Red Cliffs settlement intersect highly saline water within the aeolianite. However, in the sites marked on the contour plan (Fig.4A) there is no way of predicting the availability of water except by drilling.

Basement lows and thick aeolianite (Figs.4A and 4B) occur together. These locations are often open to the sea which could allow saltwater intrusion. In some places there are isolated enclosed basins which are small in area but which may be free from saltwater intrusion (sites 2, 5 and 7 on Fig.4A). In these sites there is a thick section of low resistivity overlain by a 2-4m intermediate zone. Site 1 appears open to the sea but a thicker section (10 m) of the intermediate zone indicates the possibility of an overlying freshwater zone. This again can only be tested by drilling.

CONCLUSIONS

Resistivity depth soundings and profiling have enabled contoured sediment thickness and basement elevation plans to be drawn. The main unit above basement is the Bridgewater Formation - an aeolianite which may be subdivided by resistivity into two zones. The lower thicker zone has a low resistivity (3.5 ohm-m) and if saturated with water would most likely be saline. The upper zone has an intermediate resistivity (30 ohm-m) and if saturated should contain fresher water than below. There is, however, no guarantee that the aeolianite contains water as it is dry in two control sites and saturated at another.

To avoid sea water intrusion and enclosed basin and a thicker section of aeolianite are required. This requirement is satisfied at sites 2, 5 and 7 on figure 4. However, the lower zone is still saline and the upper zone is relatively thin (2-5m). At site 1 which is open to the sea there is a better prospect for freshwater. Thin zones of freshwater sitting on saline water would need to be pumped slowly to avoid saltwater contamination.

Seven drilling sites are marked on figure 4A together with priority and interpreted depth to saline horizon. Until these sites are drilled, there is no way of knowing if the aeolianite contains water at those sites and if there is a fresh zone above the saline. Drilling of these sites should be carried out carefully with frequent sampling of any water cut so as not to penetrate the underlying saline zone.

The probability of a freshwater supply from such a localised saline environment is low.

Recharge of such small basins would be slow and thus pumping rates would need to vary according to rainfall conditions.

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DCR:BJT:JL
11th January 1977

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APPENDIX I

Procedure for determining basement depths from resistivity profiling

Firstly, Schlumberger apparent resistivity curves coincident with the resistivity profiles are examined. For the proposed procedure to be most reliable, the section should consist of a low resistivity formation underlain by highly resistive basement. The conductance S of a section is determined by drawing a straight line angled at 45° to the horizontal along the upward sloping part of the curve (Line AA on Fig.3). The value of S in ohms is obtained from the intersection of this line with the one ohm-metre fiducial line. It is made up from contributions of all layers above the resistive basement viz.

(1) $$S = \sum_{i=1}^{N} \frac{E_i}{\rho_i}$$

N = layers above basement

Ei = thickness of layer i

ρi = resistivity of layer i

S = total conductance

When a thick low resistivity layer underlies thin higher resistivity layers most of the conductance ($>$90%) may be within the low resistivity layer. Thus the measured conductance is related approximately to total thickness T (in m) of the section by the relation

(2) $T \simeq S \times \rho$

where ρ is resistivity of the low resistivity layer in ohm-m. If there is not a dominant low resistivity layer an average resistivity is used for ρ.

When the basement is infinitely resistive, points on the Schlumberger or Wenner resistivity curves plotted on the usual logarithmic system fall on a straight line at 45° to the axes for large electrode spacings; ie. for D $>$ an optimum spacing,

(3) $\text{Log } \rho a = \text{Log } D - \text{Log } S + \text{Log } k$

or $\rho a = \frac{kD}{S}$

ρa = apparent resistivity(ohm-m)

D = spacing parameter (m)

= a for Wenner array

= $\frac{AB}{2}$ for Schlumberger array

S = total conductance (mhos)

k = constant for given array

At the point where $\rho a = 1$,

(4) $S = kD$

For the Schlumberger system (where $k = 1$ and $D = \frac{AB}{2}$) if a point is known to lie on the straight line $S = \frac{AB}{2\rho a}$, then values of S can be determined and using equation (2) values of thickness T obtained. A value of k for the Wenner system may be established wherever values of ρa have been obtained for both systems using the conductance determined from the Schlumberger system.

(5) $k = \frac{S\rho a}{a}$

a = apparent resistivity on Wenner array

a = 50 m for this survey

Using the relationship of equation (3) the total conductance can then be found for the adjacent Wenner station and hence using equation (2) values of thickness T.

APPENDIX II

Interpreted Results for VES 1 - 28 WARDANG ISLAND

T = Thickness(metres) D = Depth(metres) R = Resistivity(ohm-metres)

VES 1

T	D	R
1.2		230
2.8	1.2	30
∞	4	140

VES 2

T	D	R
.1		120
.85	.1	300
.71	.95	675
14.3	1.7	19.5
∞	16	115

VES 3

T	D	R
2.7		49
27	2.7	4.9
∞	29.7	∞

VES 4

T	D	R
.42		76
1.9	.42	114
20	2.3	4.9
∞	22.3	112

VES 5

T	D	R
.49		40
1.9	.49	26
13.6	2.4	5.3
∞	16	62

VES 6

T	D	R
2.2		145
2.4	2.2	29
19.4	4.6	3.9
∞	24	∞

VES 7

T	D	R
.62		430
1.74	.62	21.5
15.3	2.3	4.7
∞	17.6	208

VES 8

T	D	R
.1		74
.23	.1	1480
2.1	.3	184
16.2	2.4	5
∞	18.6	120

VES 9

T	D	R
.32		13.5
1	.32	34
16	1.3	5.2
∞	17.3	136

VES 10

T	D	R
1.3		32
1	1.3	80
2.1	2.3	14.8
9.5	4.4	1.8
∞	14	92

VES 11

T	D	R
2.2		29
11	2.2	2.9
∞	13.2	29

VES 12

T	D	R
.65		150
1.6	.65	60
10.5	2.2	6.4
∞	12.7	∞

APPENDIX II (cont)

VES 13

T	D	R
1.3	[illegible]	200
.5	1.3	20
27.2	1.8	1.4
∞	29	∞

VES 14

T	D	R
.55		130
1.4	.55	52
5.8	2	5.9
∞	7.8	152

VES 15

T	D	R
.76		58
2.5	.76	23.2
3.5	3.3	2.1
∞	6.8	174

VES 16

T	D	R
.46		26
.12	.46	5.2
.06	.58	280
1.7	.6	16.3
8.7	2.3	3.6
37	11	2.67
∞	48	∞

VES 17

T	D	R
1.2		140
3.4	1.2	14
21.5	4.6	3.1
∞	26	∞

VES 18

T	D	R
.23		140
1.8	.23	28
6.5	2	2.9
∞	8.5	57

VES 19

T	D	R
.55		225
.06	.55	5.6
.03	.6	2600
2.5	.6	43
19.8	3.1	4.8
∞	23	19.6

VES 20

T	D	R
.4		27
.4	.4	14.8
11.6	.8	3.6
∞	12.4	75

VES 21

T	D	R
.05		29
.7	.05	145
9.9	.8	18
20	11	1.85
∞	31	∞

VES 22

T	D	R
1.7		350
3.6	1.7	17.5
9.5	5.3	2.1
∞	15	∞

VES 23

T	D	R
1.8		150
3.2	1.8	15
10	5	3.4
∞	15	24

VES 24

T	D	R
.7		31
.9	.7	77
1.4	1.6	20.4
12.4	3	1.45
∞	15.4	72

APPENDIX II (cont)

VES 25

T	D	R
.6		88
1.3	.6	35
8	1.9	3.5
19.6	10	1.64
∞	30	40

VES 26

T	D	R
1.1		210
1.7	1.1	21
14	2.8	2
∞	17	34

VES 27

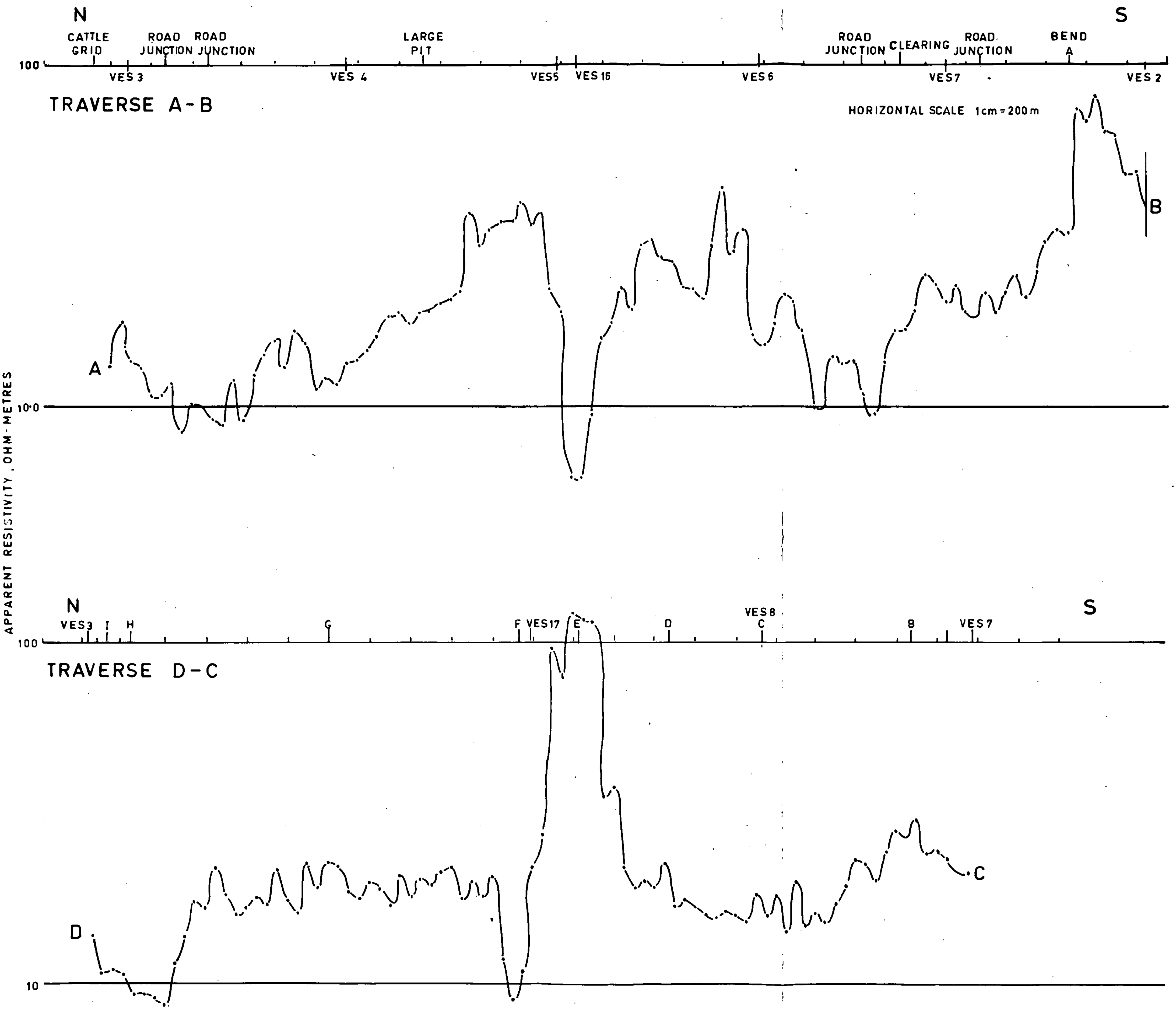
T	D	R
1.6		170
9.6	1.6	10.2
17	11.2	4
∞	28.2	∞

VES 28

T	D	R
.49		280
.27	.49	56
.45	.76	600
2.8	1.2	84
23	4	2.55
∞	27	∞

APPENDIX III

Resistivity Profiles



WARDANG ISLAND RESISTIVITY SURVEY
RESISTIVITY PROFILES
TRAVERSES A-B, D-C

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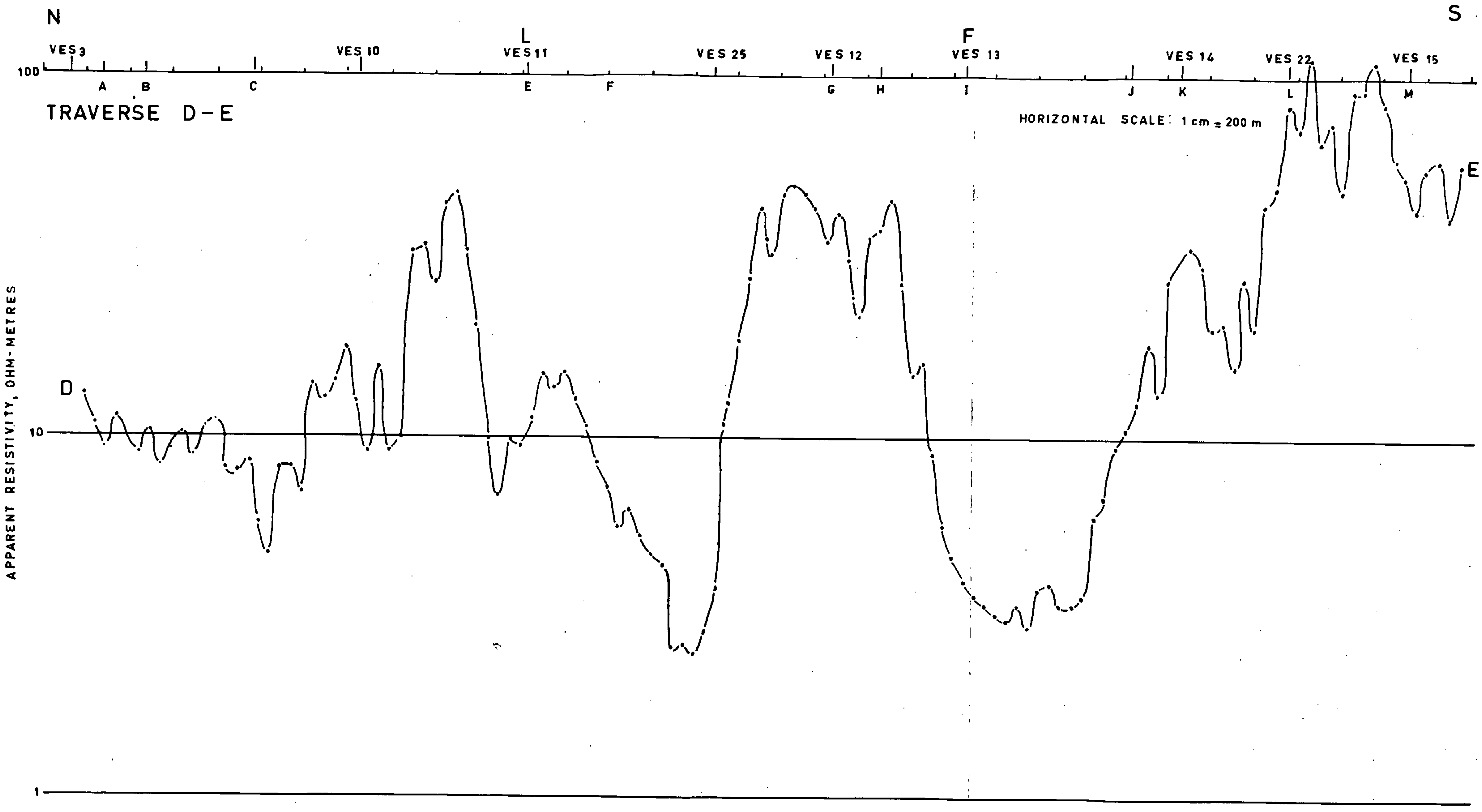

WARDANG ISLAND RESISTIVITY SURVEY
RESISTIVITY PROFILES
TRAVERSE D-E

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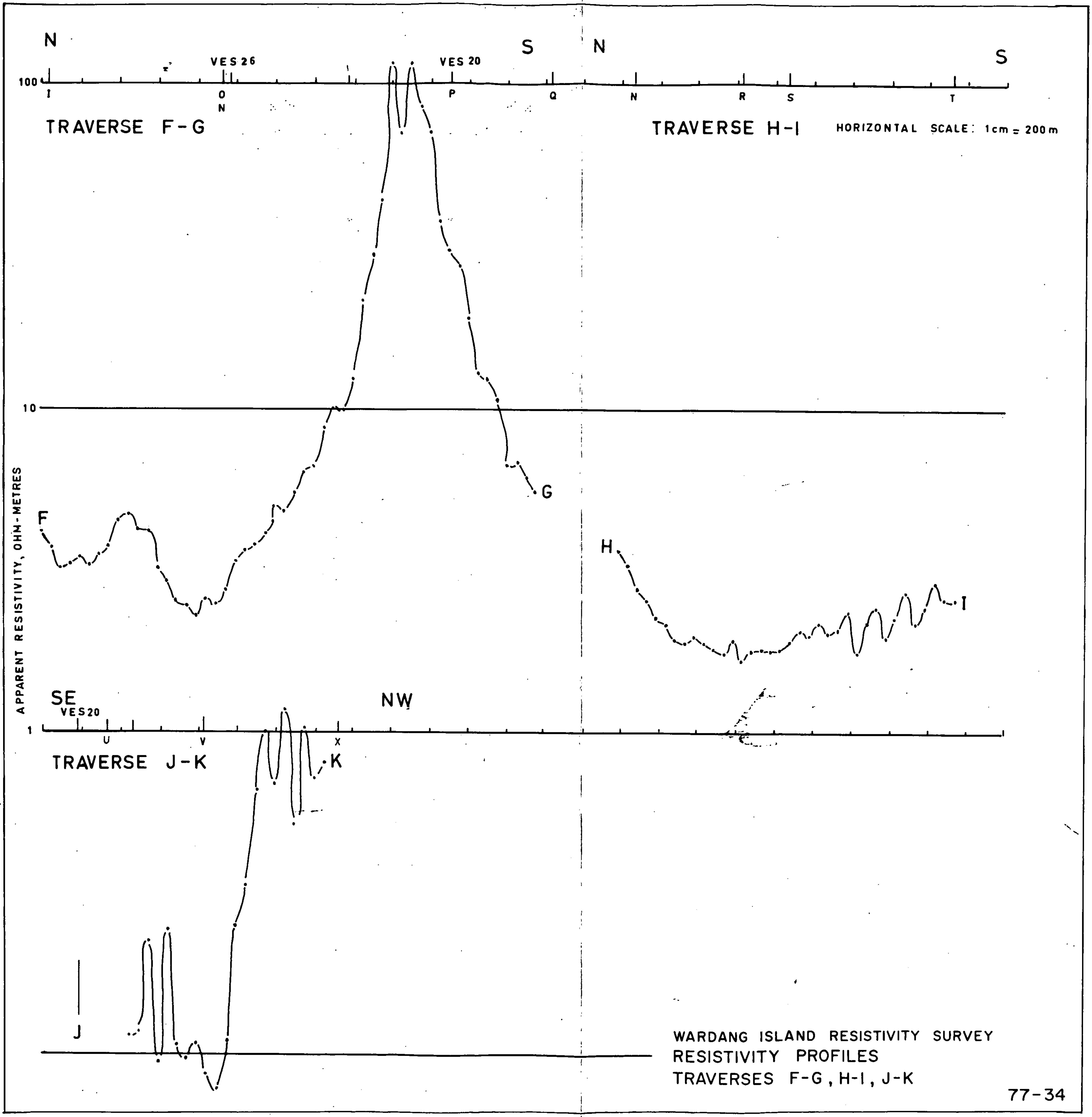

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RESISTIVITY PROFILES
TRAVERSES F-G, H-I, J-K

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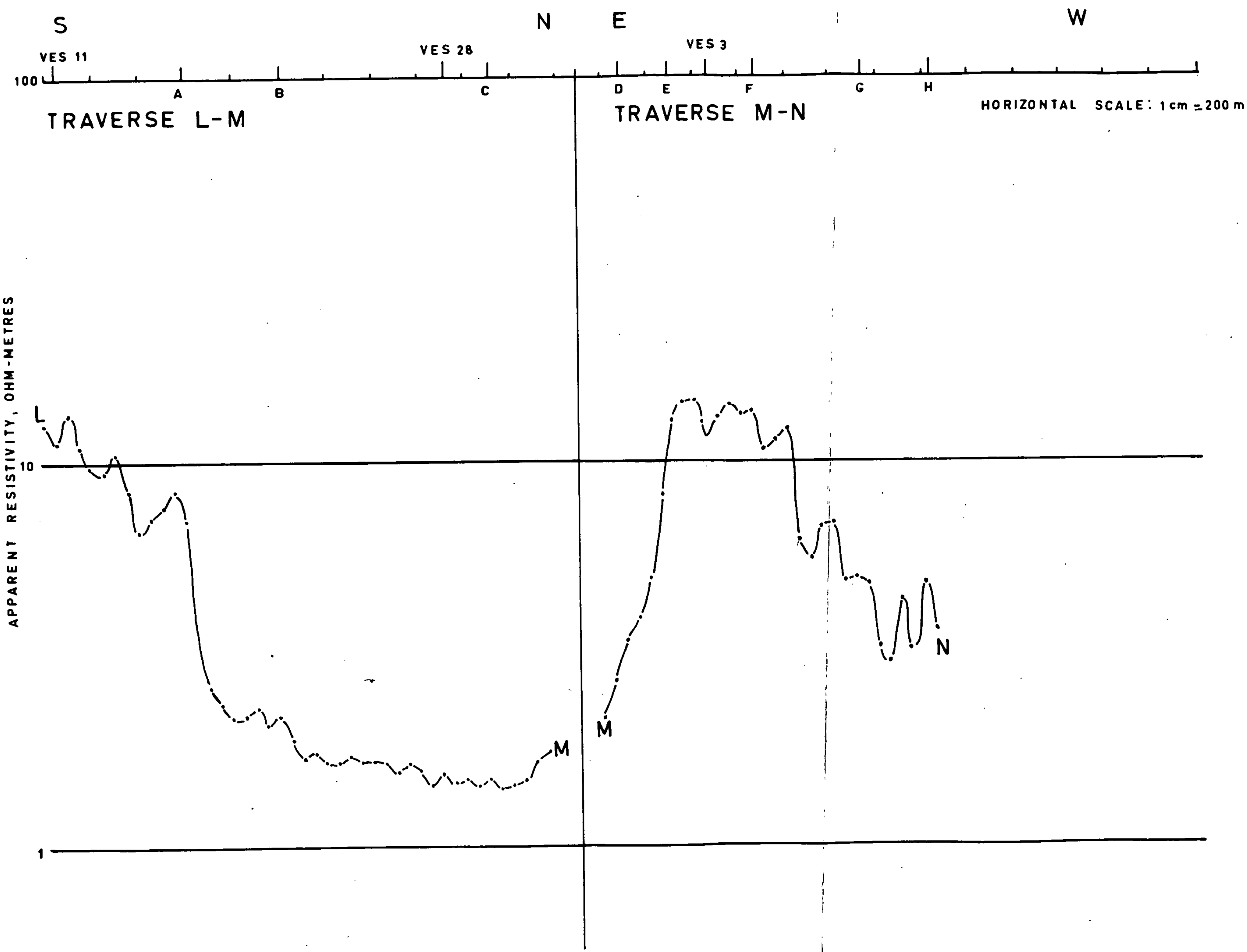

WARDANG ISLAND RESISTIVITY SURVEY
RESISTIVITY PROFILES
TRAVERSES L-M, M-N

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