1966/190

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COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD No. 1966/190

NORTH STRADBROKE ISLAND GEOPHYSICAL SURVEY FOR UNDERGROUND WATER,

QUEENSLAND 1965

by

L. KEVI and J.S. MILSOM

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SUMMARY

A geophysical survey was made on the southern half of North Stradbroke Island, Queensland, in 1965. The survey was the continuation of a previous survey done in 1964, which covered the northern half of the island. The object was to gain information about the underground water resources of the area.

Seismic, gravity, and resistivity methods were used.

For most parts of the area investigated, bedrock was found to be between 0 and 200 ft deep relative to mean sea level. The seismic data indicate some localities where a perched water table is present. From the seismic data the total amount of water stored in the aquifers was computed at between 3.5×10^{10} to 7×10^{10} ft^3. The resistivity data suggest that the amount of fresh water stored within the aquifer is about 5×10^{10} ft^3.

1. INTRODUCTION

The Geological Survey of Queensland is investigating the underground water resources of North Stradbroke Island (see Plate 1 for location) and in response to their request, the Bureau of Mineral Resources, Geology and Geophysics, carried out geophysical surveys in the island in 1964 and 1965 to determine the elevation of the top of the bedrock and the thickness of the water-bearing sand. The results of the 1964 survey, which was restricted to the northern half of the island, are described by Polak and Kevi (1965).

This Record describes the survey done in 1965, which covered the southern half of the island. Seismic refraction, resistivity, and gravity methods were used. The geophysical party consisted of L. Kevi (party leader), J. S. Milsom (geophysicist), and four field-hands supplied by the Department of Mines, Queensland.

It is desired to acknowledge the assistance given by the Department of Mines, Queensland, Cudgens "RZ" Mining Company of Kingscliff (N.S.W.) and Titanium and Zirconium Industries Ltd. of Dunwich, Queensland.

2. GEOLOGY

The following description of the geology of the area is based on Gardner (1955).

Most of the island is covered by sand dunes elongated in the north-north-west direction. The dunes are stabilized by vegetation. Carbonaceous and ferruginous cementing material indurates the sand at several localities.

There are only a few outcrops of hard rocks. In the northern part of the island a Mesozoic sandstone outcrop is found on the west coast at Dunwich and several rhyolite outcrops occur in the north-east near Point Lookout. In the southern half of the island the only hard rock outcrop is the lower Palaeozoic greenstone, which is visible at low tide at Canaipa Passage (Plate 2).

3. METHODS AND EQUIPMENT

Gravity method

The object of the gravity survey was to gain information about the nature and topography of the bedrock under the sand. (The term 'bedrock' as used in this report refers to the deepest refractor found by the seismic method having a seismic velocity of 11,000 to 20,000 ft/s).

The gravity observations were made with Worden gravity meter No. W61. The instrument was calibrated on the Melbourne Calibration Range on the 7th May 1965. The instrument constant was 0.09047 mgal/scale division using a gravity interval of 53.04 mgal for the Melbourne Calibration Range. The instrument was calibrated again after the completion of the survey on the 22nd November 1965 on the Canberra Calibration Range. The instrument constant was then 0.09043 mgal/scale division using a gravity interval of 54.72 mgal for the Canberra Calibration Range. The instrument constant of 0.09047 mgal/scale division was used to compute the observed gravity values.

The absolute values of observed gravities were computed using the Brisbane pendulum station PS47 as a base. The observed gravity at PS47 used was 979,169.8 mgal (Dooley, 1965).

Altogether, 245 gravity stations were established in the area, making an average of about 5 gravity stations per square mile. Of these, 174 gravity stations were established at survey pegs of the Cudgens "RZ" Mining Co., the elevations being obtained from the company. The elevations of 20 gravity stations were obtained by topographic levelling done by the party using a "Watts Microptic" level; 51 gravity stations were levelled barometrically using "Mechanism" microbarometers.

Elevation corrections. The observed gravity values were reduced to mean sea level (State datum). The elevation correction factor is a combination of the free air correction factor and the Bouguer correction factor. The latter is directly proportional to the density of near-surface rocks. This density was taken as 2.0 g/cm^3 and the corresponding elevation correction factor (0.06854 mgal/ft) was used.

Latitude corrections. Corrections were made to the international ellipsoid and were calculated from the formula: $g = 978{,}049\ (1+0.0052884 \sin^2\theta - 0.0000059 \sin^2 2\theta$, where θ is the latitude.

Seismic refraction method

The seismic refraction method is described in reports of previous engineering surveys in Queensland (e.g. Polak & Kevi, 1965).

An SIE 24-channel seismograph was used with TIC geophones having a natural frequency of 20 c/s. The geophone spacing used was 100 ft. Two shots were fired at each end of each geophone spread, one at 10 ft and one at 600 ft from the end geophones. One shot was also fired at the centre of the spread. In addition to the normal spreads with geophones at 100-ft spacing, weathering spreads with geophones at 10-ft spacing were used to obtain the velocities of the upper layers. The total length of seismic traverses was 25 miles.

Resistivity method

The method used is described by Polak and Kevi (1965).

Twenty-eight resistivity depth soundings (see Plate 2) were made using Geophysical Megger serial number 929333 and the Schlumberger electrode arrangements (Compagnie General de Geophysique, 1963). The resistivity of water samples was measured using a Megger Earth Tester serial number 1171138 and a mud cell constructed by the Bureau of Mineral Resources.

4. RESULTS

Gravity results

The contour map of Bouguer anomalies (gravity values corrected for elevation and latitude) is shown in Plate 3. The Bouguer anomalies show a regional trend increasing in gravity towards the east.

The largest gravity feature disturbing this regional trend is the gravity 'high' surrounded by the +39-mgal contour north of Canaipa Passage. This gravity 'high' does not correspond to high bedrock elevation as obtained from the seismic results but approximately coincides with an area showing high bedrock velocities (Plate 5). A smaller gravity feature disturbing the regional trend is in the north-western part of the area near Lake Kounpee. Here the Bouguer anomalies increase towards the west opposing the regional easterly trend.

Selecting fifty gravity stations from places where seismic depth determinations were also made, the correlation coefficient between the Bouguer anomalies and the elevation of the bedrock was computed. The value obtained was -0.18, which is not significant. The correlation coefficient between the Bouguer anomalies and the bedrock velocities was also computed and was obtained as +0.36. This is significant at the 0.02 level (Weatherburn, 1957).

To remove the masking effect of the regional trend from the Bouguer anomaly map the 'profile method' described by Jakosky (1950, pp. 421-424) was used. Five profiles were drawn in the direction of the regional gradient (110° from true north). The profiles suggested that the regional increase of gravity was not linear. It was assumed that the regional gravity could be represented by the equation:

$$G = Ax^2 + Bx + C$$

where G = regional gravity (mgal),

A, B, and C are constants, and

x = distance from an arbitrary zero line in miles.

The constants A, B, and C were found using the points on the five profiles and applying the method of least squares. Thus the equation representing the regional gravity was obtained as:

$$G = 0.67\,(x - 1.37)^2 + 34.45$$

The x = 0 line passed through the intersection point of latitude 27°45' and longitude 153°20'. The direction of the x = 0 line is 20° from true north.

Using the above equation, the value of regional gravity was evaluated at each gravity station. The residual gravity was obtained by subtracting the regional value from the Bouguer anomaly. The contour map of residual gravities is shown in Plate 4.

By comparing this map with the map showing bedrock contours and velocities (Plate 5), the correlation between the residual gravity and bedrock velocities was found to be greater than the correlation between residual gravity and bedrock elevation. Using the sample of fifty stations mentioned above the correlation coefficient between the residual gravities and bedrock velocities was found to be +0.58, which is signigicant at the 0.001 level. The correlation coefficient between the residual gravities and the bedrock elevations was obtained as +0.32, which is significant at the 0.02 level.

Thus the gravity features appear to reflect intra-bedrock density variations rather than the topography of the bedrock.

Seismic results

The seismic velocities observed can be arranged in groups as shown in Table 1.

TABLE 1

Observed seismic velocities

Layer	Longitudinal wave velocity (ft/s)	Probable rock type
Top	1000 - 1500	Soil
Second	2000 - 3000	Sand above the water table
Third	4500 - 6000	Sand saturated with water
Fourth	7000 - 9000	Weathered bedrock
Fifth	11,000 - 20,000	Slightly weathered to fresh bedrock

The fourth layer was indicated on a few spreads only. In most localities it was absent or was too thin to be recorded.

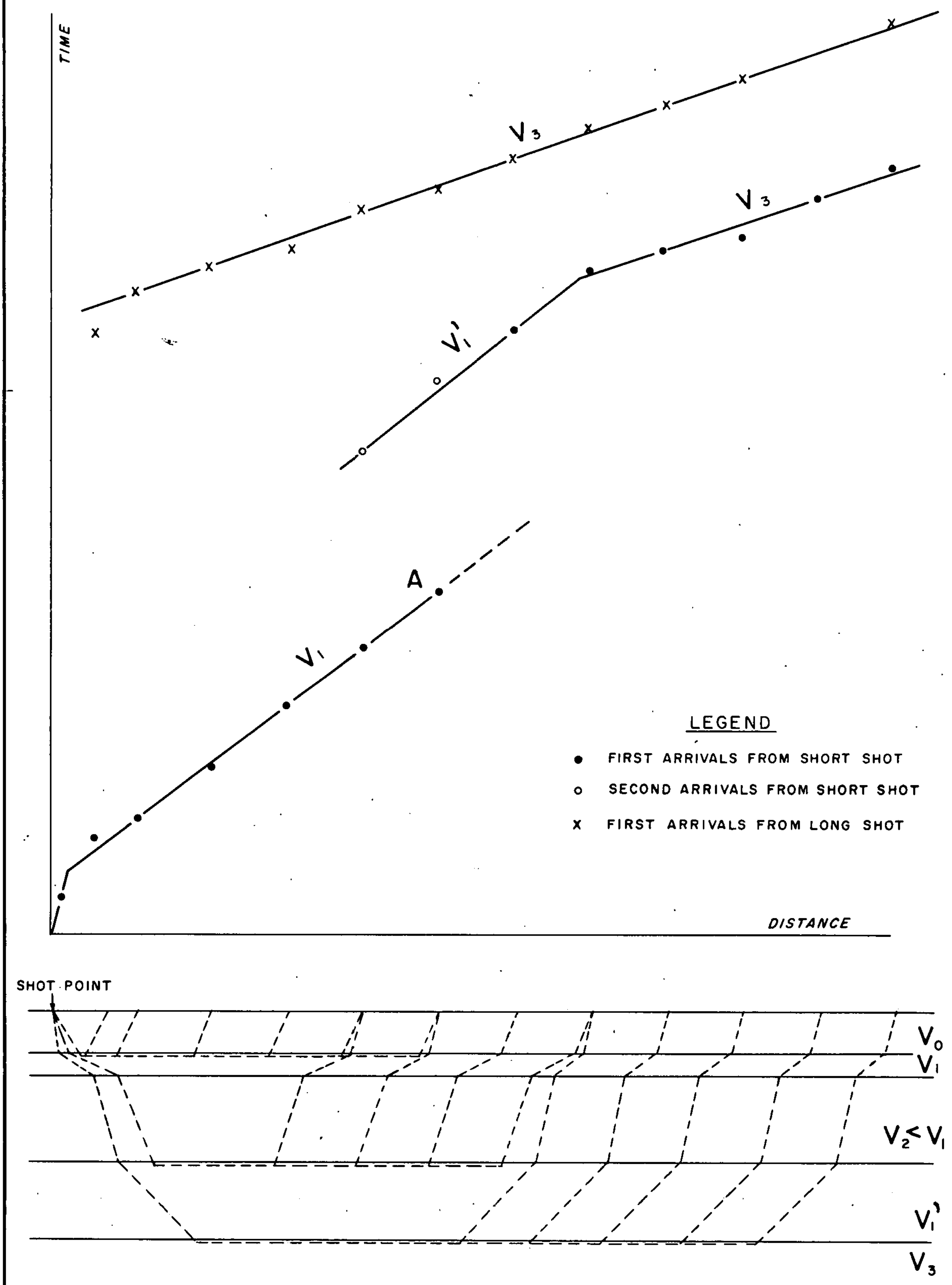
The time-distance curves suggested velocity reversals at several localities. Under a layer of about 5000-ft/s velocity, a lower velocity layer was indicated and under this another layer with a velocity of 5000 ft/s was shown. Similar cases have been described for the northern section of the island by Polak and Kevi (1965). The upper 5000-ft/s velocity probably indicates a perched water table. The localities where velocity reversal was indicated are shown in Plate 6 (at seismic spreads A17, A20, and AB24).

Figure 1 shows an example of a time-distance curve and ray paths suggesting velocity reversal (spread AB24). After point A no more arrivals were recorded from the V_0/V_1 interface. This is probably due to the attenuation of energy travelling in a thin V_1 layer.

Time-distance curves similar to that of Figure 1 are often shown by text books as examples of curves produced by refraction across a fault (Dobrin, 1960). Second arrivals recorded in some cases, however, produced a portion of the curve which is consistent with the velocity reversal interpretation but not with the fault interpretation, as the break in the curve is related to distance from the shot-point and is not restricted to a particular location on the geophone spread. Resistivity depth probing at seismic spread A20 suggested the presence of a perched water table, which is consistent with the seismic velocity reversal (see histogram of resistivity depth probe 10 in Plate 9).

(Facing page 4)

FIGURE I



TIME - DISTANCE CURVE AND RAY PATHS
SUGGESTING VELOCITY REVERSAL
SPREAD AB 24

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics. G56/B5-43

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The depths to the interfaces separating the different layers were computed at the two ends and at the centre of each seismic spread.

The error in the seismic depth determination depends on the following factors:

(a) The error involved in fitting straight lines to the points of the time-distance curves to determine the velocity of the various layers.

(b) The error due to the extrapolation necessary to determine the intercept time.

(c) The possible presence of a 'hidden layer' that cannot be detected by recording the first arrivals of seismic waves.

The errors due to (a) and (b) were estimated by computing several depths for the same point using different possible extrapolations and different possible velocities. The standard percentage error in seismic depth determination due to (a) and (b) was found to be ±12%.

The thickness of a possible 'hidden layer' can have any value from zero to a maximum that depends on the velocities and thicknesses of the layers above and below, and on the velocity of the 'hidden layer' itself. The velocity of the 'hidden layer', however, is unknown (Leet, 1950).

A layer with a velocity of from 7000 to 9000 ft/s was found on a few seismic spreads on the island but in most localities it was not detected by the first arrivals. Assuming that it was present as a 'hidden layer' between the layer of velocity 4500 to 6000 ft/s and bedrock, its maximum possible thickness was computed in several cases. It was found that a maximum error of -30% in the depth to bedrock and a maximum error of +50% in the thickness of the 4500-to 6000-ft/s layer. could result. The root mean square of the computed maximum errors for the various cases due to the possible 'hidden layer' was 21% in the depth to bedrock and 36% in the thickness of the 4500-to-6000-ft/s layer.

The contour map of the top of the bedrock is in Plate 5. Over most of the area the bedrock is between 0 and -200 ft relative to mean sea level. The highest bedrock elevation was +71 ft (at seismic spread BC17), and the lowest -390 ft (at seismic spread AB13).

The contour map of the top of the third layer (4500 to 6000 ft/s velocity) is shown in Plate 6. This interface probably represents the water table. At some localities, however, it appears to be exceptionally high and it is doubtful whether it represents the main water table (i.e. at spreads BC8, B9, C9, BC12, AB16, NW end of A14, and A16). It is possible that at these localities it represents an indurated sand or clay, strongly weathered bedrock, or a perched water table.

Probably, a perched water table was indicated at several localities by velocity reversal (Plate 6). Perched water table, however, can be present at other places without being indicated by velocity reversal. Disregarding the possible presence of an intermediate layer between sands and bedrock, an isopachyte plan of the 4500-to-6000-ft/s layer was drawn (see Plate 7). This layer probably represents water-saturated sand. The isopachyte plan was used to compute the volume of the 4500 - 6000 ft/s velocity layer, and hence to estimate the amount of water stored in the sand. An estimate of the quantities of water stored in the northern section of the island, i.e. north of the aerial ropeway (Plate 5) is given by Polak and Kevi (1965). The results for the area south of the aerial ropeway are given below.

Rainfall. The area of the island south of the aerial ropeway is 46 square miles. The average rainfall per year is 73 inches. Thus the average volume of rain is about 0.8×10^{10} ft^3.

Amount of water stored in the sand. The volume of the material between the water table and bedrock is 24×10^{10} ft^3. Assuming 30% porosity and considering the possible presence of an intermediate layer, the volume of water stored in the sand is larger than 3.5×10^{10} ft^3 and smaller than 7×10^{10} ft^3.

Amount of water stored above the sea level. The volume of water-saturated sand above sea level is 10×10^{10} ft^3 or slightly less if the hidden layer between sands and bedrock reaches above sea level. Assuming 30% porosity, the amount of water stored above sea level would not exceed 3×10^{10} ft^3.

Resistivity results

Resistivity of water samples. Water samples were taken from several swamps and lakes. The resistivity of the water samples was measured using a Megger Earth Tester and a mud cell. The results, corrected to the standard temperature of 20°C, are shown in Table 2.

TABLE 2

Resistivity of water samples (corrected to 20°C temperature)

Sample No.	Locality	Resistivity (ohm-metres)	Approximate salt content (p.p.m.)
1	Lake Kounpee	119	42
2	Kounpee Swamp	100	50
3	Blakesley Lagoon	113	44
4	Shag Lagoon	53	94
5	Ibis Lagoon	106	47
6	Tea Tree Lagoon	76	66
7	Horseshoe Lagoon	84	60
8	Duck Lagoon	82	61

The approximate salt content was computed using the formula:

$$C = 5000/R$$

where C = salt content in p.p.m. and

R = resistivity of water in ohm-metres.

The results in Table 2 indicate fresh water with low salt content.

Resistivity depth probes. The resistivity depth probes were interpreted by comparing the resistivity curves obtained by the field measurements with a collection of theoretical curves calculated for assumed resistivity models. The set of theoretical curves used contained 480 three-layer curves (Compagnie Generale de Geophysique, 1963). Interpolation between the theoretical curves was often necessary when matching the measured curve to ~~the~~ theoretical curve. In cases where the measured curves indicated more than three layers, Hummel's and Maillet's principles were used to replace the first two layers by an equivalent single layer (Andrew & Wiebenga, 1965).

The interpretation of some of the curves was checked by using several interpretations as models and computing the resistivity curves produced by the models using a computer. Comparison of field curves with computed curves is shown in Plate 10. The method of computing the resistivity curves produced by assumed models is described by van Dam (1964). The computer programme was written by B. G. Cook of the Bureau of Mineral Resources.

The results of the resistivity interpretations are shown in Plate 8 in the form of histograms. The results of the seismic depth determinations in the neighbourhood of the resistivity depth probes are shown in the same plate.

The resistivity of water-saturated unconsolidated rocks can be used to estimate the salinity of the ground water. Table 3 compares the resistivity of saturated material with salinity of the pore solution (Wiebenga, et al, 1966).

TABLE 3

Resistivity versus salinity of pore solution

Resistivity of material (ohm-metres)	Total dissolved salts in pore solution (p.p.m.)	Classification of water
less than 6	more than 3000	Saline
6 to 20	3000 to 1000	Brackish
more than 20	less than 1000	Fresh

The figures in Table 3 are based on an assumed porosity of between 30% and 35% and are therefore approximate values.

The depth probes along the eastern coast of the island (Plate 8, Section F) show the presence of a low resistivity layer, probably indicating salt or brackish water at comparatively shallow depth. Depth probe No. 28 indicates a low resistivity layer at about 2 ft below mean sea level. Most of the other depth probes along the eastern coast show the presence of a low resistivity layer at about 30 to 100 ft below mean sea level.

Results of resistivity depth probes further inland are shown on sections G, H, J, and K (Plates 8 and 9). Resistivities smaller than 20 ohm-metres are indicated at several places. Thus depth probes Nos. 2, 7, and 12 show the presence of the low resistivity layer at 45 to 70 ft below mean sea level. Depth probes Nos. 9, 14, and 16 indicate the low resistivity layer at a depth greater than 100 ft below mean sea level.

At depth probe No. 7 the interpretation indicates the top of a low resistivity layer (7 ohm-metres) at 5 ft below sea level. The seismic depth determination gave the position of the top of the bedrock with 18,000-ft/s velocity at about the same level. These results suggest the presence of a layer of weathered bedrock, which was not detected by the seismic method.

Depth probe No. 10 suggests a perched water table, which was also indicated by velocity reversal on the seismic spread in the same locality.

The seismic data give an estimate of the total amount of water in the aquifers, whereas the resistivity data indicate the distribution of salt or brackish and fresh water. By comparison of the resistivity and seismic results along sections H, J, and K, an estimate can be made of the ratio between fresh and total amount of water (Plates 8 and 9). For sections H and J this is about 0.69 and for K about 0.66, i.e. an average of about 0.68. This gives the maximum amount of fresh water available as $0.68 \times 7 \times 10^{10}$ ft^3, or about 5×10^{10} ft^3.

5. CONCLUSIONS

Over most of the area investigated the bedrock is between 0 and -200 ft relative to mean sea level. The volume of water stored in the sand was computed as between 3.5×10^{10} ft^3 and 7×10^{10} ft^3.

The resistivity results indicate the presence of salt or brackish water at various depths below the sea level. Comparing resistivity and seismic results, the volume of fresh water stored in the sand was estimated at about 5×10^{10} ft^3.

$5 \cdot 0 \times 10^{7}$

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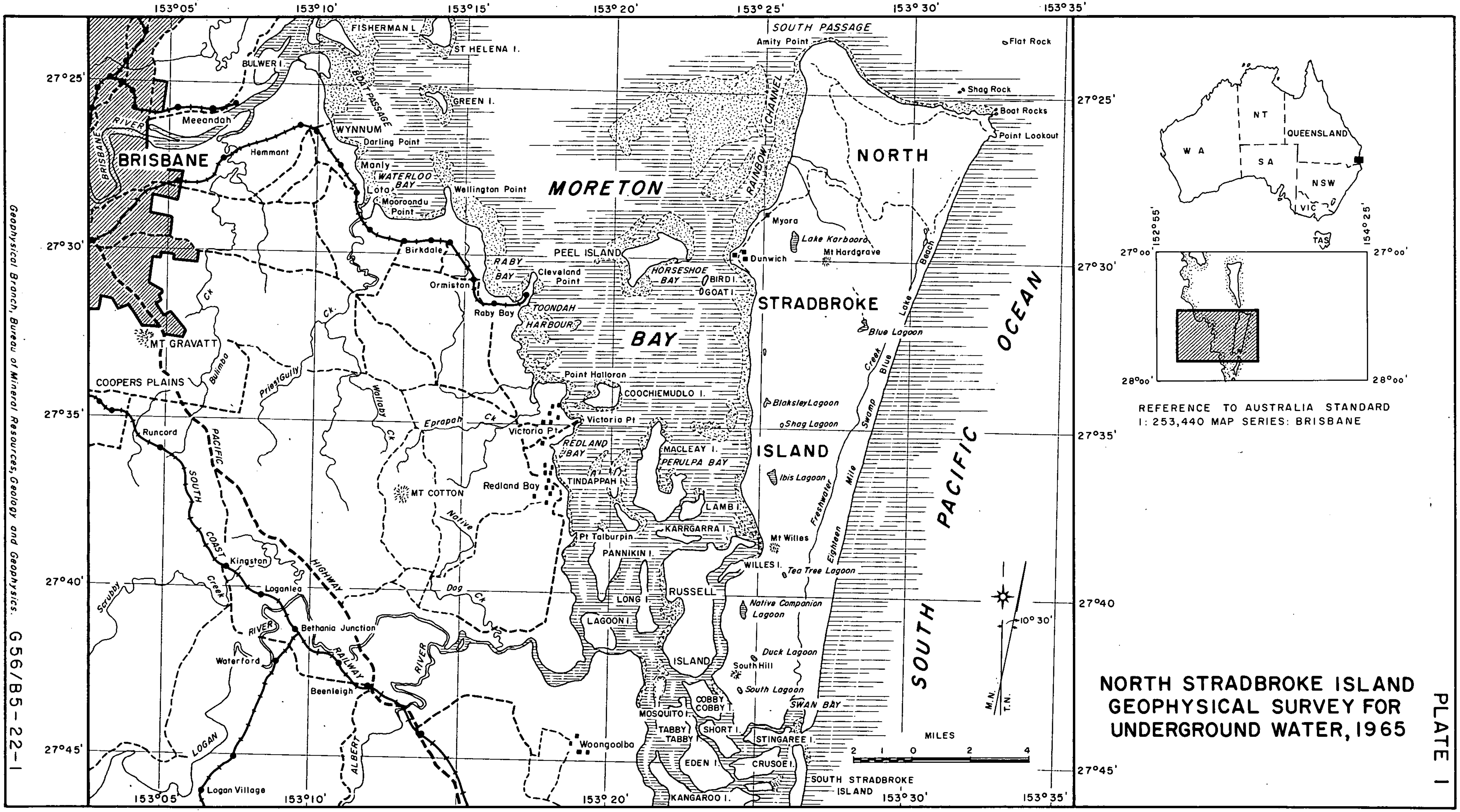
APPENDIX

Data for Dunwich Sub-base gravity station, Queensland

Station:	Dunwich Sub-base
Location:	Centre of concrete slab covering the PMG man-hole outside Dunwich Post Office
Latitude:	27° 30' 3"
Longitude:	153° 24' 16"
Reduced level:	48 ft relative to State datum
Observed gravity:	979,181.35 mgal

The observed gravity at Dunwich Sub-base was obtained by measuring the gravity interval between pendulum station PS47 (Brisbane) and Dunwich Sub-base. The observed gravity at PS47 was taken as 979,169.8 mgal.



NORTH STRADBROKE ISLAND GEOPHYSICAL SURVEY FOR UNDERGROUND WATER, 1965

PLATE I

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G56/B5-22-1

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TOPOGRAPHICAL MAP AND LOCATION
OF RESISTIVITY DEPTH PROBES

LEGEND

+40 BOUGUER ANOMALY CONTOURS (milligals)

GRAVITY STATION

"HIGH" ANOMALY

"LOW" ANOMALY

Elevation correction constant = 0·06854 mgal / ft

BOUGUER ANOMALY CONTOURS

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PLATE 4

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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PLATE 5

CONTOURS OF TOP OF BEDROCK

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G56/B5-36

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G56/B5-36

CONTOURS OF THE TOP OF THE 4500-TO-6000-FT/S VELOCITY LAYER

LEGEND

- A19 — SEISMIC SPREAD – FIGURES INDICATE ELEVATION OF TOP OF 4500-TO-6000-FT/S VELOCITY LAYER RELATIVE TO STATE DATUM – (FEET)
- 100 — CONTOUR OF WATER TABLE – RELATIVE TO STATE DATUM – (FEET)
- AREA OF OBSERVED SEISMIC VELOCITY REVERSAL INTERPRETED AS PERCHED WATER TABLE
- -30 — TOP OF THE SALT OR BRACKISH WATER FROM RESISTIVITY RESULTS RELATIVE TO STATE DATUM (FEET)

NOTE: THE TOP OF THE 4500-TO-6000-FT/S VELOCITY LAYER IS INTERPRETED AS THE WATER TABLE

PLATE 7

THICKNESS OF 4500-TO-6000 FT/S VELOCITY LAYER

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SEISMIC AND RESISTIVITY PROFILES FOR SECTIONS F AND G

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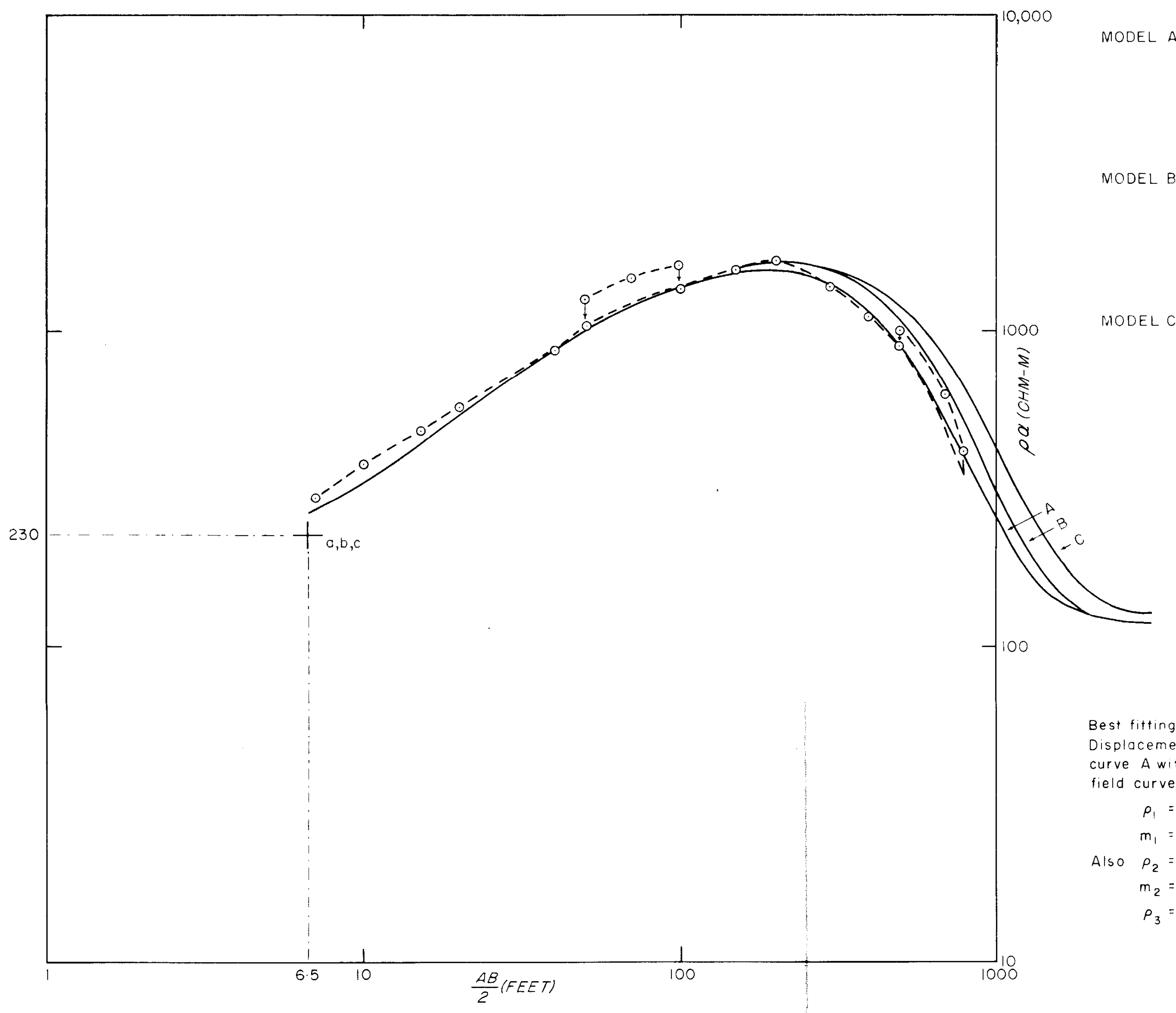
SEISMIC AND RESISTIVITY PROFILES FOR SECTIONS H, K, AND J

DEPTH PROBE No. 1



MODEL A

$\rho_1 = 1{\cdot}0$ — $m_1 = 1{\cdot}0$
$\rho_2 = 9{\cdot}0$ — $m_2 = 30{\cdot}0$
$\rho_3 = 0{\cdot}5$

MODEL B

$\rho_1 = 1{\cdot}0$ — $m_1 = 1{\cdot}0$
$\rho_2 = 9{\cdot}0$ — $m_2 = 35{\cdot}0$
$\rho_3 = 0{\cdot}5$

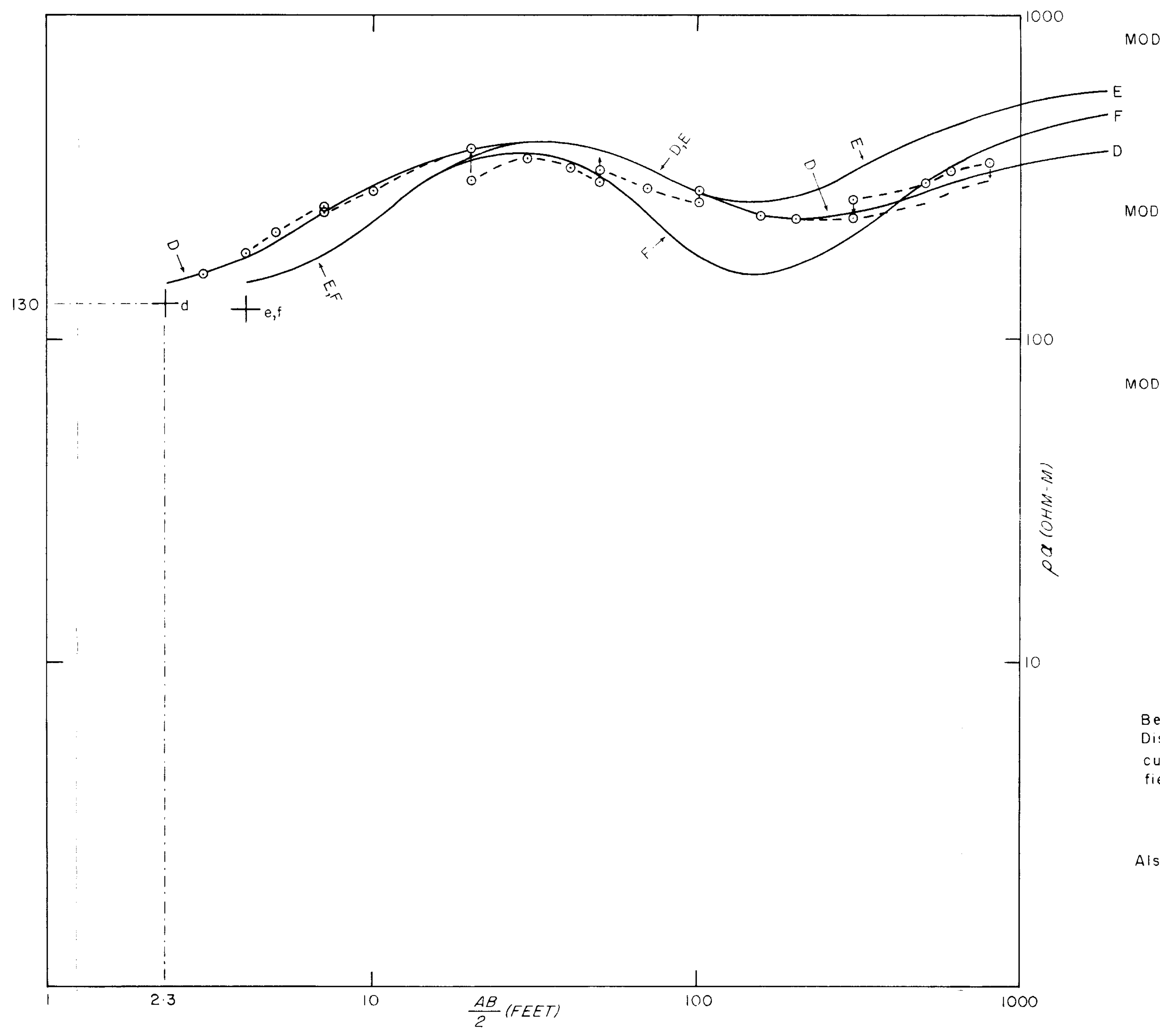
MODEL C

$\rho_1 = 1{\cdot}0$ — $m_1 = 1{\cdot}0$
$\rho_2 = 9{\cdot}0$ — $m_2 = 40{\cdot}0$
$\rho_3 = 0{\cdot}5$

Best fitting computed curve: A
Displacement of origin of computed curve A with respect to the origin of field curve gives –

ρ_1 = 230 ohm-metres
m_1 = 6·5 feet
Also $\rho_2 = 9\rho_1$ = 2070 ohm-metres
$m_2 = 30 m_1$ = 195 feet
$\rho_3 = 0{\cdot}5\rho_1$ = 115 ohm-metres

DEPTH PROBE No. 8



MODEL D

$\rho_1 = 1{\cdot}0$ — $m_1 = 1{\cdot}0$
$\rho_2 = 4{\cdot}0$ — $m_2 = 11{\cdot}0$
$\rho_3 = 1{\cdot}6$ — $m_3 = 87{\cdot}5$
$\rho_4 = 3{\cdot}2$

MODEL E

$\rho_1 = 1{\cdot}0$ — $m_1 = 1{\cdot}0$
$\rho_2 = 9{\cdot}6$ — $m_2 = 3{\cdot}0$
$\rho_3 = 1{\cdot}6$ — $m_3 = 35{\cdot}0$
$\rho_4 = 6{\cdot}4$

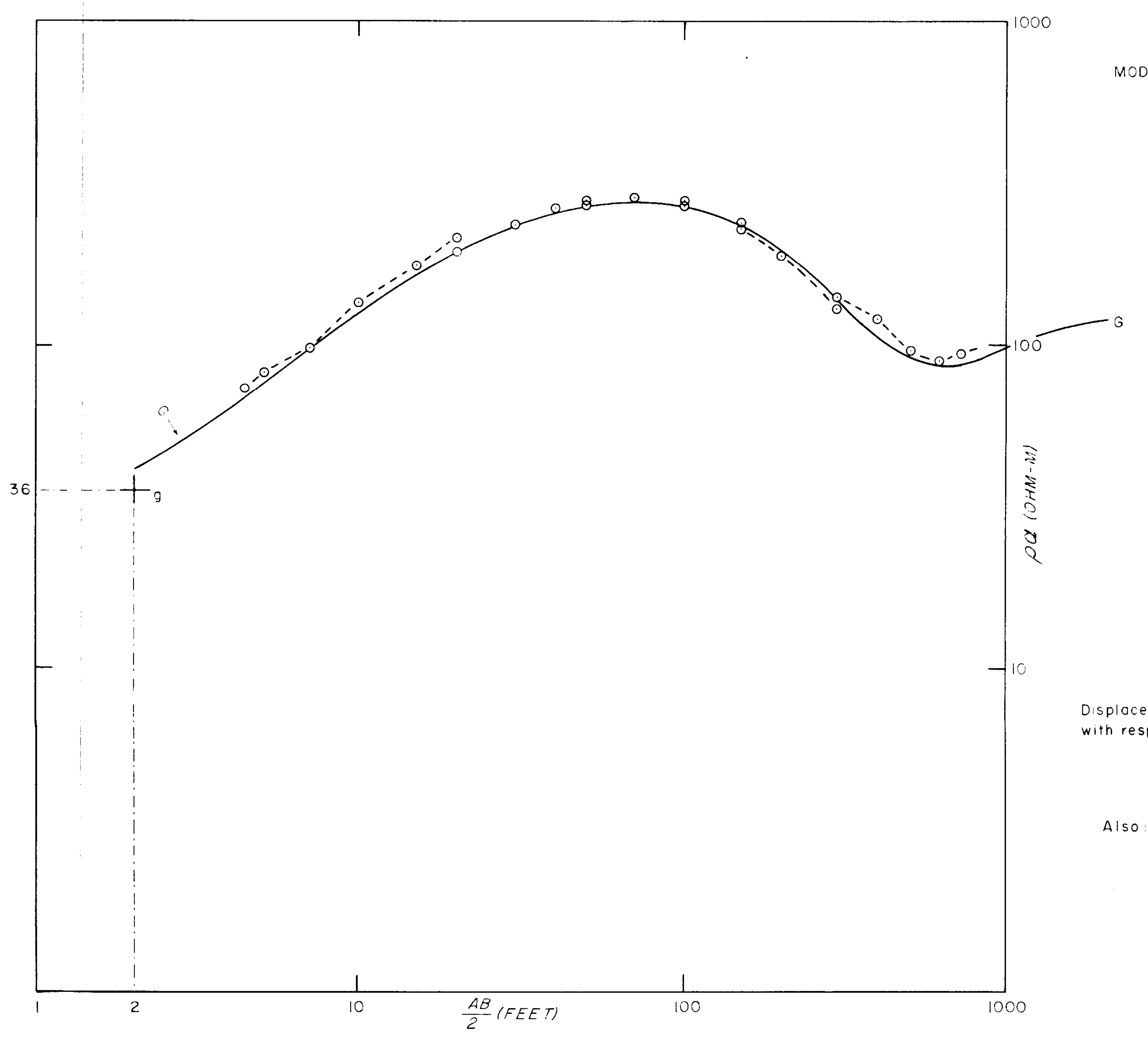
MODEL F

$\rho_1 = 1{\cdot}0$ — $m_1 = 1{\cdot}0$
$\rho_2 = 9{\cdot}6$ — $m_2 = 3{\cdot}0$
$\rho_3 = 0{\cdot}8$ — $m_3 = 35{\cdot}0$
$\rho_4 = 6{\cdot}4$

Best fitting computed curve: D
Displacement of origin of computed curve D with respect to the origin of field curve gives –

ρ_1 = 130 ohm-metres
m_1 = 2·3 feet
Also: $\rho_2 = 4\rho_1$ = 520 ohm-metres
$m_2 = 11 m_1$ = 25 feet
$\rho_3 = 1{\cdot}6\rho_1$ = 208 ohm-metres
$m_3 = 87{\cdot}5 m_1$ = 201 feet
$\rho_4 = 3{\cdot}2\rho_1$ = 416 ohm-metres

DEPTH PROBE No. 4



MODEL G

$\rho_1 = 1{\cdot}0$ — $m_1 = 1{\cdot}00$
$\rho_2 = 10{\cdot}0$ — $m_2 = 82{\cdot}00$
$\rho_3 = 0{\cdot}2$ — $m_3 = 103{\cdot}33$
$\rho_4 = 9{\cdot}0$

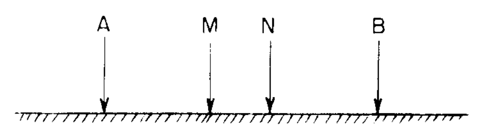
Displacement of origin of computed curve G with respect to the origin of field curve gives –

ρ_1 = 36 ohm-metres
m_1 = 2 feet
Also: $\rho_2 = 10\rho_1$ = 360 ohm-metres
$m_2 = 82 m_1$ = 164 feet
$\rho_3 = 0{\cdot}2\rho_1$ = 7 ohm-metres
$m_3 = 103{\cdot}33 m_1$ = 207 feet
$\rho_4 = 9\rho_1$ = 324 ohm-metres

LEGEND

ρ_α — Apparent resistivity
AB — Distance between current electrodes
Field curve
Computed curve of model A
+a — Origin of curve A
ρ_n — Resistivity of the n^{th} layer
m_n — Depth from surface to interface between the n^{th} and $(n+1)^{th}$ layer

ELECTRODE CONFIGURATION USED



A, B — Current electrodes
M, N — Potential electrodes

Change in potential electrode spacing. Arrow indicates displacement necessary to produce continuous curve

COMPARISON OF FIELD CURVES WITH COMPUTED CURVES DUE TO ASSUMED RESISTIVITY MODELS

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