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NORTH STRADBROKE ISLAND GEOPHYSICAL SURVEY FOR UNDERGROUND WATER,

QUEENSLAND 1964

by

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ILLUSTRATIONS

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SUMMARY

A geophysical survey was made on North Stradbroke Island at the request of the Department of Mines, Queensland. The object of the survey was to investigate the underground water resources of the island with a view to using the water to supplement the Brisbane City water supply. Seismic refraction, gravity, and resistivity methods were used.

The seismic refraction method was used to determine the depth to the water table and to bedrock. From these data the thickness of the water-bearing rocks was calculated. The results show that the bedrock is under the present sea level for most parts of the area investigated. The greatest depth recorded was 314 feet. In some localities the existence of a perched water table was indicated.

The gravity results show a large regional gravity gradient, which may obscure smaller gravity features caused by the structure of the bedrock. The residual gravity values show some correlation with the bedrock structure as obtained by the seismic method.

The resistivity measurements indicate that sea water is found under the beaches only within 700 feet from the sea shore. In all other localities the water is fresh and of low salt content. The velocity of flow of ground water was measured using the 'single-well method' and the 'two-well method'. Close agreement was found between the results obtained by the two different methods. The velocity of flow obtained was two feet per day across the old land surface and up to eight feet per day in dune sand.

1. INTRODUCTION

The Geological Survey of Queensland is investigating the possibility of using the ground water of North Stradbroke Island to supplement the Brisbane City water supply. In this investigation five drill holes were put down to determine the depth to the water table and the depth to bedrock. A gauging station was also established on the outflow of the Eighteen Mile Swamp.

In response to a request from the Geological Survey of Queensland, the Bureau of Mineral Resources, Geology and Geophysics (B.M.R.) made a geophysical survey to determine the thickness of the water-bearing sands, the level of the top of the bedrock in relation to sea level, and the properties of the aquifer and water contained in it. Seismic refraction, resistivity, and gravity methods were used. The survey was done between 8th June and 10th October 1964 by a geophysical party consisting of E. J. Polak and L. Kevi, geophysicists; J. P. Pigott, geophysical assistant; P. Barr, technical officer; and five field assistants and a driller from 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 (NSW), and Titanium and Zirconium Industries Ltd of Dunwich.

As used in this Record, the term 'bedrock' refers to the deepest refractor with the highest recorded seismic wave velocity. The term 'overburden' refers to the soil and sand above the bedrock.

2. GENERAL INFORMATION

Location

North Stradbroke Island is located about 24 miles east of Brisbane. The island extends from latitude 27°20'S to 27°45'S and from longitude 153°20'E to 153°33'E (Plate 1), and is separated from the land by Moreton Bay.

Topography

The island is roughly triangular in shape with the apex towards the south. The base of the 'triangle' is about 7 miles long, and the length of the island is about 23 miles. The eastern shores are relatively smooth and straight but the western side is irregular, with several inlets.

A series of high transgressive dunes occupy the centre of the island, reaching a height of 720 feet at Mt. Hardgrave (Plate 2).

Plate 2 is based on the one-mile military map, but the contours have been modified in places according to the results of the topographical surveying carried out by the Department of Mines, Queensland, Cudgens "RZ" Mining Co., Titanium and Zirconium Industries Ltd, and by members of the geophysical party.

Rainfall

The rainfall in the area is high. In the ten years from 1954 to 1963 the average rainfall at Point Lookout was about 71 inches per year. The maximum rainfall in this period was 96 inches (in 1954) and the lowest (in 1960) was about 46 inches. Rains fall all the year round but generally the rainfall is much higher between October and May.

Surface hydrology

Some of the rain-water follows the valleys to the marginal fresh water swamps, from which the water drains to the sea. The main outflows are from the Eighteen Mile Swamp to Swan Bay (Plate 1) and from Amity Swamp to the north near Rocky Point beach and to the west near Amity Point (Plate 2). Some of the water finds its way to the perched inland lakes and swamps, where in places aeolian sands have blocked the valleys. This water slowly percolates through the sand to reach the permanent water table, but some evaporates during the dry months. Some of the inland lakes and swamps are permanent.

Subsurface hydrology

The rain-water percolates through the sand, reaching a water table. Two types of water table were found on the island. The upper one, the perched water table, is found in places where the old land surface material has slowed the downwards movement of the water. The water may follow the old land surface, feeding the present creeks where they cut through the old surface, or may penetrate deeper to the lower, main water table. The water below the main water table flows outwards from the centre of the island, reaching the sea through the marginal marshes, fresh water springs on the beaches, and through the sand below the beaches.

Geology

North Stradbroke Island is formed of sand dunes elongated in the north-north-west direction. The development of the island, as given by Hails (1964), occurred in six stages, all within the Pleistocene epoch:

1. Dunwich and Point Lookout exist as offshore islands.
2. Formation of barrier spits.
3. Building in an easterly direction by deposition or land emergence resulting from a fluctuating sea level.
4. Transgression of sand on the shallow water areas in the lee of the foredune barriers.
5. The growth of the second barrier spit from Point Lookout and the formation of the Eighteen Mile Swamp and Amity Swamp.
6. Foredune erosion and migration of the sand.

Outcrops of hard rocks cover a small area only (Plate 5). Mesozoic sandstone crops out at Dunwich, Mesozoic rhyolite at Point Lookout, and a small outcrop of Lower Palaeozoic greenstone is visible at low tide on the west coast about ten miles south of Dunwich. The limits of the extensions of the rhyolite, sandstone, or greenstone under the sand dunes are not known (Gardner, 1955).

3. METHODS AND EQUIPMENT

Gravity method

The gravity method is described by Heiland (1946). The gravity observations were made with Worden gravity meter, serial number 140. The instrument was calibrated on the Melbourne Calibration Range and the calibration factor obtained was 0.11115 milligal/division. The gravity interval of the Melbourne Calibration Range was taken as 53.04 milligals.

420 gravity stations were established in the area, making an average of seven gravity stations per square mile.

The absolute values of observed gravity were computed using BMR helicopter gravity station No. 9629 as base. The observed gravity adopted at this station is 979179.0 milligals. Station No. 9629 is based on pendulum station No. 47, which is located in the seismograph room of the Geology School, University of Queensland, and has an observed gravity value of 979169.8 milligals.

The gravity traverses were arranged so that they formed a closed network. The closing errors in the loops were computed and distributed. The greatest closing error was 0.17 milligal.

The elevations of 285 stations were obtained by topographic levelling carried out by the surveyor of the Department of Mines, Queensland, by the surveyors of Cudgens "RZ" Mining Company, and by the BMR party. 135 stations were levelled barometrically using "Mechanism" microbarometers Nos. 582/64 and 583/64.

Elevation correction

The observed gravity values were reduced to sea level. The combined 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 gm/cm^3 and the corresponding elevation correction constant (0.06854 milligal/foot) was used.

Latitude corrections

These were made to the international ellipsoid.

Seismic refraction method

The seismic refraction method depends upon the contrast in the elastic properties of different strata; it was used in the survey to determine the depth to the water table, the depth to the bedrock, and the velocities of the seismic wave in several layers of rocks.

During the survey on North Stradbroke Island geophones were placed in line, 50 and 100 feet apart, and shots were fired 25 and 1000 feet from the end geophones and in line with the geophone spreads. On some spreads a shot in the centre of the spread was also fired. For depth determination the 'method of differences' was used (Heiland, 1946). This method also allows the true velocity of the longitudinal wave to be established.

A 24-channel refraction seismograph manufactured by South-western Industrial Electronics Co. was used with Technical Instruments Co. geophones having a natural frequency of 20 c/s.

Resistivity method

In the resistivity method, current is supplied to the ground at two points and the potentail difference is measured between two additional points. The ratio of potential difference to current, multiplied by a spacing factor, gives what is known as the apparent resistivity.

The method of depth profiling uses a variable electrode spacing and therefore has a variable depth penetration, which makes it possible to determine the depth to different beds, as long as the boundaries have sufficiently high resistivity differences.

In the Schlumberger electrode arrangement (Compagnie Generale de Geophysique, 1963), the four electrodes are in line; the two inner electrodes (potential electrodes) are placed close together and the outside electrodes (current electrodes) are separated by more than five times the potential electrode spacing. The logarithm of the apparent resistivity is plotted against the logarithm of half the current electrode spacing. The plotted field curves are compared with pre-computed theoretical curves (Compagnie Generale de Geophysique, 1965).

Non-porous rocks have a high resistivity. The resistivity of porous rocks such as sands and sandstones depends on their porosity and on the resistivity of the water contained in the pores. The following formulae are used for calculation:

$$R = FR_w = P^{-m}R_w \qquad \ldots\ldots\ldots\ldots(1)$$

where R = resistivity of rock in ohm-metres

F = formation factor

R_w = resistivity of pore solution in ohm-metres

P = porosity as a fraction

and m = cementation factor

The cementation factor ranges between 1.25 and 2.2; in near-surface dune sands it is about 1.25.

The resistivity of the pore solution can be found approximately from the formula

$$R_w = \frac{5000}{C} \text{ ohm metres} \qquad \ldots\ldots\ldots\ldots(2)$$

where C is the salt concentration in p.p.m. Resistivity of the pore solution must be corrected to 20°C.

Three instruments were used in the survey: a Geophysical Megger (0 - 30 ohm) and a Megger Earth Tester (0 - 3000 ohm), both manufactured by Evershed and Vignoles, and a Tellohmeter manufactured by Nash and Thompson.

To measure the resistivity of water, a mud cell constructed by the BMR was used.

Velocity of flow, porosity, and permeability

To determine the velocity of flow of water in the aquifer, several wells were dug to reach the water table. A plastic rod with four electrodes four inches apart was inserted into the sand at the water table. The electrodes were connected to an instrument on the surface (Plate 10) and the resistivity of the sand saturated with the groundwater was read. A solution of common salt in water was then poured into the hole. Subsequently the resistivity of the assembly was read every few hours till the readings increased to the original groundwater value. The change in resistivity of the assembly is related to the dissipation of the salt introduced into the hole, and thus to the velocity Vo of groundwater flow. The resistivity of the assembly is inversely proportional to the salt concentration and the formula generally used for velocity of flow determination using the fluorescein dye can be applied here. If the resistivity R min of the assembly immediately after the salt water was introduced in a bore of radius a, rises to a value of R after time t, the velocity of the groundwater flow is given by:

$$V_o = \frac{\Pi a}{2t} \ln \frac{R_t}{R_{min}} \qquad \ldots\ldots\ldots\ldots(3)$$

A general formula based on the concentration of dye or salt is derived in Plate 10. The full derivation is given because in some publications (e.g. Chapman, 1962), the formula differs by a factor of $\frac{1}{2}$, giving the velocity of flow only half the actual value.

To support these measurements, control holes were drilled ten feet away from the observation pit that was fitted with the resistivity probe. The control holes were filled with salt water. Readings of resistivity were taken every six hours approximately. The decrease in resistivity indicated the time of arrival of salt water at the observation pit, and the velocity of underground flow was then calculated from the distance and the time. The six-hour period between readings limited the accuracy.

The levels of the groundwater table in all holes were measured to obtain the gradient of the water table i. The permeability k can then be calculated from the formula:

$$k = Vo/i \qquad \ldots\ldots\ldots\ldots(4)$$

With a very short spacing of drill holes and with the small differences in level, the calculated gradient in the water table may not be accurate.

Permeability of the sand can also be calculated from the results of a sieve analysis. Some calculations were carried out for comparison with the values obtained from velocity of flow and gradient. Hazen's and Kozeny's formulae (Loudon, 1952) were used.

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 consisting of an increase in gravity towards the east. The large regional gravity gradient obscures the smaller gravity features that may be produced by the structure of the bedrock.

To remove the masking effect of the regional gravity the 'profile method' described in Jakosky (1950, p. 421-424) was used. Three profiles were drawn in the direction of the regional gradient (85°). 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:

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

where Gr = a regional gravity in milligals,

x = distance in 85° direction from an arbitrary zero line (located at 2.19 miles from BMR helicopter station No. 9629 in 265° direction)

and A, B, and C are constants.

The constants A, B, and C were found from the average of the three profiles. Thus the equation representing the regional gravity was obtained as:

$$Gr = 0.35x^2 + 0.10x + 35$$

The regional gravity value was evaluated at each gravity station by use of this equation. 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 taking a random selection of fifty stations, the correlation coefficient between the residual gravity and the elevation of the bedrock, as given by the seismic results, was computed. The correlation coefficient obtained was + 0.60, which is significant at the one percent level. Thus there is a definite correlation between the residual gravity and the elevation of the bedrock.

The correlation coefficient between the Bouguer anomalies and the elevation of the bedrock was also computed using the same randomly selected fifty stations. The correlation coefficient obtained was + 0.47. Thus the correlation between the Bouguer anomalies and bedrock elevation is not so good as the correlation between residual gravity values and bedrock elevation, but is still significant.

Seismic results

The seismic velocities may be arranged in five groups, corresponding to the following layers:

Top layer. This is interpreted as soil with a velocity of 1000 to 1800 ft/s. The layer consists of sandy soil with roots of trees, shrubs, and grasses.

Second layer. This layer, with a velocity of 2000 to 3500 ft/s, is interpreted as sand above the water table. The difference in the velocities may be the results of different moisture content, different soil content, age, and history. At several localities a thin layer of higher velocity (about 5000 ft/s) has been indicated by the time/distance curvebetween the lower velocity beds (reversal of velocities). This layer was interpreted as an old land surface with a perched water table.

Third layer. This is interpreted as sand fully saturated with water. It shows seismic velocities from 4900 to 6000 ft/s.

Fourth layer. A layer with seismic velocities of 8000 to 9400 ft/s was identified on several traverses. It was interpreted as weathered bedrock. This layer may extend over the whole of the island, but if so it is too thin to be recorded on all time/distance curves. A maximum thickness of 15 feet was recorded.

Fifth layer. The highest velocity refractor is interpreted as a slightly weathered or unweathered bedrock. Its seismic velocity is between 10,000 and 20,000 ft/s.

The depths to the interfaces of separate layers were calculated using the above velocities. The error in depth determinations is considered to be less than ± 15 percent. This estimate is based on experience of results in other areas with similar geological conditions.

The seismic results are shown in Plates 5 to 8.

Plate 5 shows the contours of the bedrock (top of the fourth or fifth layer). The plan indicates two major uplifts of rocks - one near Point Lookout and the second near Dunwich. These two uplifts were instrumental in building up the island as described above. Several other smaller 'islands' covered by dunes project slightly above the present sea level.

Plate 6 shows the contours of the main water table (the top of the third layer). The areas where the time/distance curves indicate a perched water table are shown. In some places the thickness of the sand at the perched water table may have been too thin in relation to the overlying dry sands to be recorded on the time/distance curve; therefore the areas shaded may not represent all the areas of the perched water table on the island.

Plate 7 shows the isopachyte plan of the sand formation saturated with water. The plan indicates that the thickness of the saturated sand is up to 400 feet near Mount Corrie, and that a large area of the island contains water-saturated sand 200 to 300 feet thick.

Plate 8 shows profiles across the area along the lines of section indicated in Plates 3 to 7. The directions of the lines were especially chosen so that they cut the Bouguer anomaly contours as close to right angles as possible. The sections show the distribution of the five layers; section FF contains in addition the positions of the perched water table.

Resistivity results

Resistivity of water. The resistivities of several samples of water were measured and corrected to a standard temperature of 20°C. The values obtained are given in Table 1. The salt content in p.p.m., as calculated from equation 2 is included in the table (Note: C4D, etc indicates location in relation to the seismic spread shown in Plates 5 to 8)

Samples 1 to 24 are of surface waters. The water is of good quality with a low salt content. The resistivity of the surface water will not be constant throughout the year - it will be higher after heavy rain; and the character of water may change depending on the type of material over which the creek is flowing. Therefore, although the values included in Table 1 should be considered as approximate only, the differences will be small, e.g. the measured values at the Lake Kaboora varied within 10 percent over a period of three months.

Samples 25 to 29 are of sea water. The salt content varies between 18,500 and 25,000 p.p.m. This concentration is lower than the mean concentration of salt in the sea, which is 30,000 p.p.m.

Samples 30 to 37 are of water from below the water table, obtained from shallow pits. The depth to the water table is also given.

TABLE 1
Resistivities of water samples

Sample No.	Location	Resistivity (ohm-m)	Salt content (p.p.m.)	Depth to water table (feet)
1	Point Lookout Road (C1DD)	25	199	
2	Amity Road Marsh (D1E)	79	63	
3	Yerrol Creek, Dunwich	102	49	
4	Old Tazi Road (C4D)	166	30	
5	Rocky Point Lagoon (CO)	24	210	
6	Cooroonpah Creek (D4D)	105	48	
7	Cooroonpah Creek Bridge	156	32	
8	Cooroonpah Creek, Old Rd	136	37	
9	Capenbah Creek, Myora	118	42	
10	Lake Karboora (D5DD)	123	41	
11	Creek near D6	128	39	
12	Tazi Village Marsh	57	88	
13	Old Tazi-Dunwich Rd	106	47	
14	Aranaval Creek	108	46	
15	Myora Spring	96	52	
16	One Mile Creek, Dunwich	104	48	
17	Dunwich Cemetery Creek	106	47	
18	Dunwich Swamp	81	61	
19	Yarram Rd (A4)	57	87	
20	Yarram Rd (A4B)	75	67	
21	Yarram Rd (B4)	84	59	
22	Tortoise Lagoon	96	52	
23	Blue Lagoon	107	47	
24	Point Lookout Hotel Creek	41	122	
25	Sea water, Rocky Point	0.22	23800	
26	Sea water, Fisherman Bay	0.20	25000	
27	Sea water, Amity Point	0.27	18500	
28	Sea water, Lifesaving Club	0.20	25000	
29	Sea water, off Old Tazi Rd	0.21	23800	
30	Point Lookout, Shaft (COC)	59	85	5
31	Point Lookout, Shaft (C1DD)	39	130	11
32	Amity Road Shaft (D1E)	60	83	6
33	Cooroonpah Creek Shaft (D4D)	69	72	9
34	Lake Karboora (D5DD)	98	51	8
35	Old Yarram (B4)	86	56	11
36	Rocky Point, drillhole	78	64	26
37	Dunwich refuse heap	38	132	12

The results of several resistivity measurements of ground water on the beach near Rocky Point are shown in Plate 9. The curve 'resistivity of ground water' shows an increase of water resistivity with distance from the sea. Table 2 gives the details of resistivity and salt content of these samples (temperatures corrected to 20°C).

TABLE 2

Water samples, Rocky Point beach

Distance from sea (feet)	Resistivity (ohm-m)	Salt content (p.p.m.)
0	0.3	16,700
50	0.9	5,500
150	2.5	2,000
200	4.5	1,100
350	8.5	590
450	12.0	420
650	28.0	178
750	47.0	107

When the logarithm of resistivity is plotted against the distance from the sea edge, the points are on a straight line for distances between 200 and 750 feet. The equation of the line is

$$\log R_w = 1.88 \times 10^{-3} + 0.268$$

where R_w = resistivity of water and L = distance in feet.

The points on the section 0 to 200 feet lie below the line, indicating excessive mixing of the water during the advance of the tide over the beach.

Resistivity depth probes. Eleven resistivity depth probes were made during the survey; their positions are shown in Plate 3. The results of five of the probes are shown in Plate 9.

Depth probes A to D indicate a gradual increase in the resistivity of underground water from A to D. The near-surface resistivity, which is only 5 ohm-metres at probe A, increases to 600 ohm-metres at probe D. The apparent increase in resistivity shown on the lower portion of probe A is due to the power of the instrument being too low to saturate the ground with electric current. Probes B to D indicate a lower resistivity bed at the bottom; at probe D the depth to the low resistivity bed obtained by the use of theoretically calculated curves coincides with the depth to bedrock indicated by the seismic method. These two facts suggest that the bedrock is of a porous rhyolite saturated with salt water.

At depth probe F, the low resistivity bed between 6 and 9 feet coincides with a layer of peat found there in a pit. The high resistivity below 9 feet indicates that there is fresh water in the sand and that the bedrock is of a low porosity rock or, if porous, it is saturated with fresh water.

At depth probe E, the second bed with a resistivity of 400 ohm-metres indicates fresh water. A lower resistivity bed 600 feet below the surface may indicate mudstone.

At depth probe G, there was a resistivity of 450 ohm-metres below a depth of 10 feet.

At depth probe H, there was a resistivity of 480 ohm-metres below a depth of 15 feet.

At depth probe I, there was a resistivity of 650 ohm-metres below a depth of 6 feet.

At depth probe J, there was a resistivity of 500 ohm-metres below a depth of 12 feet.

At depth probe K, there was a resistivity of 600 ohm-metres below a depth of 18 feet.

Resistivity depth probes taken inland from the beaches indicate that there is no intrusion of salt water into the aquifer.

Velocity of flow, porosity, and permeability

The determination of the velocity of flow of the underground water was carried out in the following stages :

(a) A pit was dug to the water table.

(b) A sample of water was taken and the resistivity R_w measured.

(c) A four-electrode sonde was inserted and resistivity R of the ground was measured.

(d) Porosity of the sand was calculated from equation 1.

(e) Saltwater was added to the pit, readings of resistivity were taken for several days, and the apparent resistivity was plotted against time (Plate 10).

(f) Velocity of flow was calculated from equation 3.

(g) A second pit, ten feet away, was drilled to the water table and salt water was added to the pit.

(h) Resistivity readings in the first pit were taken for several days. The drop in resistivity indicated arrival of salt water at this pit.

TABLE 3

Porosity of sand and velocity of flow of ground water

Location	Single-pit method			Double-pit method		Difference
	R_W (ohm-m)	Porosity %	Vo (ft/day)	Vo Range (ft/day)	Vo mean (ft/day)	%
A Amity Rd (C1DD)	84	24	1.2	1.8-2.0	1.9	58
B Amity Rd (D1E)	60	42	8.5	7.0-11.0	9.0	6
C Lake Karboora	106	30	6.9	5.0-8.0	6.5	6
D Point Lookout Rd (COC)	59	25	2.0	2.0-2.5	2.2	9
E Old Tazi Rd	80	31	6.3	-	-	-
F Beach outlet of Yarram Rd	96	40	7.1	6.3-6.8	6.6	7
G Telephone line (H1H)	81	38	7.3	-	-	-
H Blue Lagoon (A7)	96	29	3.2	4.0-5.2	4.6	44
I Cooroonpah Creek (D4D)	69	26	4.2	-	-	-

At locations A, D, H, and I the sonde was located in a bed that was considered to be an old land surface. The sand there was stained with black plant material. The porosity calculated from the resistivity data is between 24 and 29 percent; the velocity of the ground water flow calculated from the single-pit method is between 1.2 and 4.2 ft/day. The markedly lower porosities and velocities in these beds are taken as further evidencefor the existence of perched water tables above the old land surfaces.

Porosities at locations B,C, E, F, and G are between 30 and 42 percent, with a mean of 37 percent from the five determinations. This value of 37 percent agrees with the results of Kolbuszewski (1953); therefore, this value will be accepted as a mean porosity for all the dune sand on the island.

The velocities obtained with the double-pit method are higher than those obtained with the single-pit method. This is to be expected, as water in the double-pit method will flow along the line of least resistance, whereas in the single-pit method the measurements are limited to the volume of sand close to the inserted sonde. The difference between results obtained by the two methods is less than 10 percent.

The velocity of flow in sand outside the old land surface varies between 6.3 and 8.5 ft/day with an average of 7.3 ft/day (single-pit method).

To calculate the permeability of the sand from data from Table 3 the following investigations were carried out (Table 4):

a) The elevation of the water table at both pits was measured and the gradient of the water table was computed.

b) Permeability k was calculated from equation 4. The permeability is expressed in centimetres per second per unit of hydraulic gradient.

c) Permeability was calculated from Hazen's and Kozeny's formulae. In the Kozeny formula the porosity from Table 3 was used for the calculation.

TABLE 4

Permeability of sand calculated from data obtained in the pit

Location of sample (see Table 3)	B	C	E
Velocity ($x\ 10^{-3}$ cm/s)	3.0	2.4	2.2
Porosity (percent)	42	30	31
Gradient	0.10	0.18	0.20
Permeability ($x\ 10^{-3}$ cm/s), equation 4	30.0	15.4	11.0
Hazen's formula	26.0	25.0	22.0
Kozeny's formula	28.0	10.0	10.0

The Geological Survey of Queensland has determined the permeability of the sample from location E using the Falling Head Method (Todd, 1959) and obtained the value of 9.0×10^{-3} cm/s. The value is very close to the value obtained during measurements in the field and to the value calculated using Kozeny's formula.

To obtain further information on the permeability of the sand, Hazen's and Kozeny's formulae have been applied to several results of sieve analyses of sand from Stradbroke Island, carried out by the Department of Mines, Queensland. The average porosity of 37 percent was used in Kozeny's formula. The results are given in Table 5.

TABLE 5

Permeability of sand (x 10^{-3} cm/s) from sieve analysis

Sample	Hazen (H)	Kozeny (K)	Ratio (H/K)	Sample	Hazen (H)	Kozeny (K)	Ratio (H/K)
S31	24.4	12.4	1.9	S321	32.4	19.4	1.6
S176	3.6	4.0	0.9	S322	84.0	47.4	1.8
S310	73.0	29.8	2.4	S323	25.6	16.0	1.6
S311	25.6	19.9	1.3	S324	25.6	17.3	1.5
S317	19.0	31.0	0.6	S325	32.5	19.5	1.7
S318	2.5	2.6	1.0	S326	32.0	19.4	1.6
S319	90.0	84.6	1.1	S328	74.0	18.0	4.1

Loudon (1952) in the conclusions of his theoretical and empirical investigation states : "It is shown that Kozeny's formula agreed better than other published formulae with a series of careful measurements of permeability . . . and is more accurate than Hazen's formula, which, though useful, may lead to an error of a factor of two either way". This conclusion seems to be supported by the results included in Table 4.

Two very high ratios between values obtained from the two formulae (shown in Table 5) for samples S310 and S328 are the results of a very high content of fine particles in the British Standard Sieve Range 25 to 100. In conditions like this Hazen's formula would give a very high value.

A very low ratio shown by sample S317 results from the lack of information of fine sizes in the sieve analysis.

The average permeability for samples included in Tables 4 and 5 calculated from Kozeny's formula is 24 x 10^{-3} cm/s, based on 17 determinations.

Todd (1959, p. 24) gives a graph from which the specific yield and the specific retention can be calculated. For sand with porosity of 37 percent, the specific yield will be 30 percent and the specific retention will be 7 percent.

Quantities of water

Using the values obtained in the preceding sections the following quantities of water were calculated:

Total rainfall. The area of the island north of the ropeway is 61 square miles, and has an average rainfall of six feet per year. The average rain intake per year is thus 10 x 10^9 ft^3, or 6.25 x 10^{10} gallons.

Total water in the sand below the water table. The volume of sand between the water table and the bedrock was calculated as 3.8 x 10^{11} ft^3. The total volume of water in sand of average porosity of 37 percent is 1.4 x 10^{11} ft^3, or 8.7 x 10^{11} gallons.

The total volume of water available for pumping (specific yield 30 percent) is 1.13 x 10^{11} ft^3, or 7.1 x 10^{11} gallons.

Total water in sand above sea level. The volume of sand is 1.9×10^{11} ft^3. The total volume of water is 0.71×10^{11} ft^3, or 4.42×10^{11} gallons. The total volume available for pumping is 0.57×10^{11} ft^3, or 3.55×10^{11} gallons.

5. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The volume of the sand below the water table and above the bedrock in the northern part of the island is 3.8×10^{11} ft^3.

The sand has an average porosity of 37 percent, a specific yield of 30 percent, and a specific retention of 7 percent. The average permeability calculated from Kozeny's formula is 24×10^{-3} cm/s.

The volume of water in the sand below the water table is 1.4×10^{11} ft^3, of which 1.13×10^{11} ft^3 is available for pumping, leaving 0.27×10^{11} ft^3 of water absorbed in the bed. The water below the water table is fresh and of low salinity, but its salt content may increase during flow through the sand. The average velocity of flow is 7.3 ft/day.

At several places, a perched water table has been located. The perched water table is the result of the old land surface slowing down the rate of percolation of water towards the main water table.

The water in the main and perched water tables is flowing downwards, feeding creeks, lakes, marshes, and springs on the beaches and escaping to the sea below the sea level. The intrusion of salt-water is limited to a distance not exceeding 700 feet from the mean-sea-level shoreline.

The resistivity of water measured just offshore is higher than the resistivity of the sea water further away, indicating a flow of fresh water through the sand.

Recommendations

Some of the seismic survey spreads should be repeated to check the location of velocity interfaces, especially those between dry and wet sand.

Measurements of water resistivity should be repeated in places to find whether they have changed significantly since 1964.

Investigations should be conducted to determine corrosive and other properties of water.

All the flowing creeks should be examined, and the seepage from the perched and main water tables should be mapped. Seepage from the perched water table may reveal the old land surfaces.

Some trenching near the seepage from the perched water table may indicate whether a simple trench breaking through the old land surface could introduce larger quantities of water into sands beneath, resulting in reduced flow of the creeks.

A continuous salinity profile, run offshore, could reveal where fresh water runs into the sea. The same results could be obtained from infra-red air photography.

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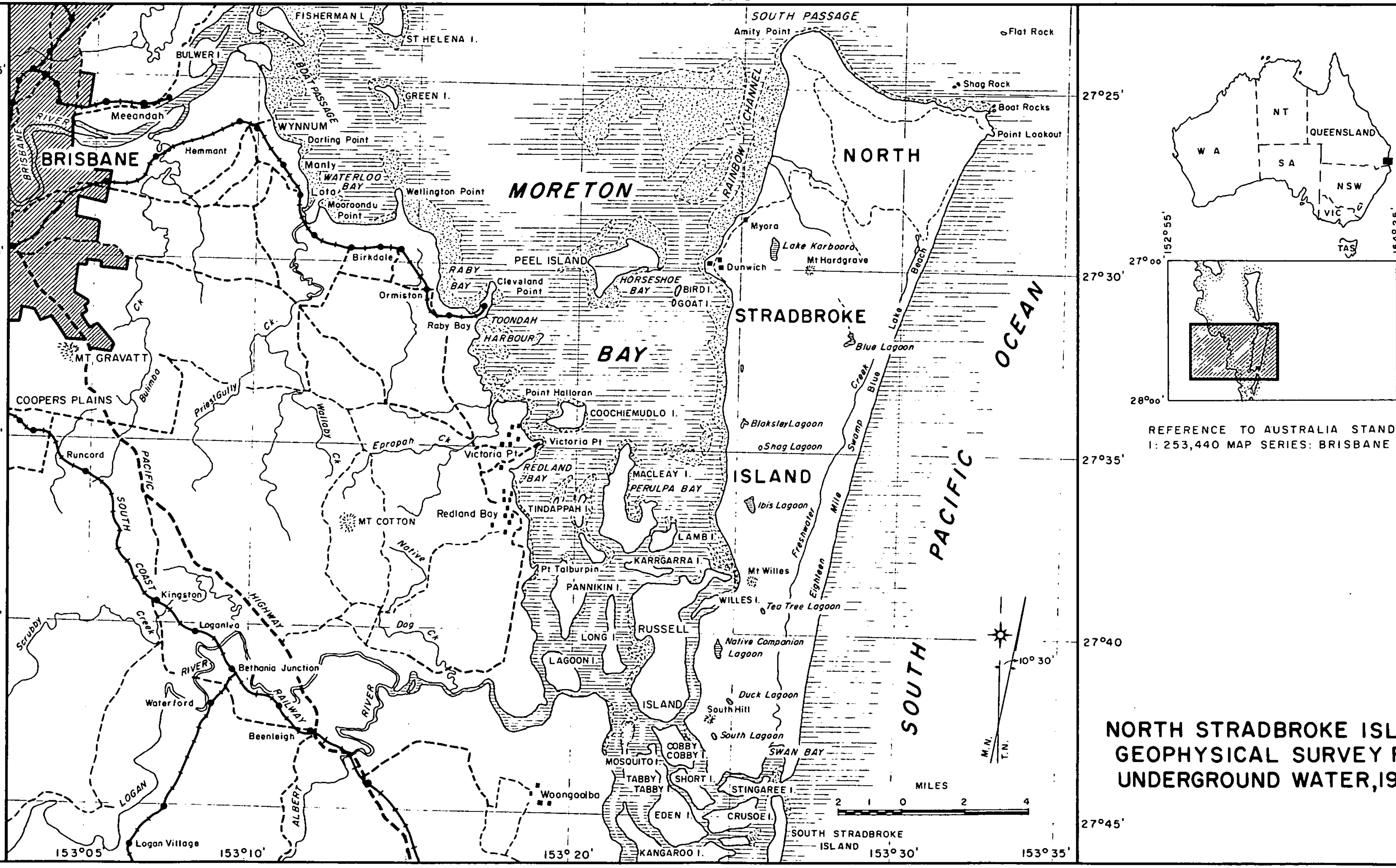


REFERENCE TO AUSTRALIA STANDARD
1: 253,440 MAP SERIES: BRISBANE

NORTH STRADBROKE ISLAND GEOPHYSICAL SURVEY FOR UNDERGROUND WATER, 1964

PLATE 1

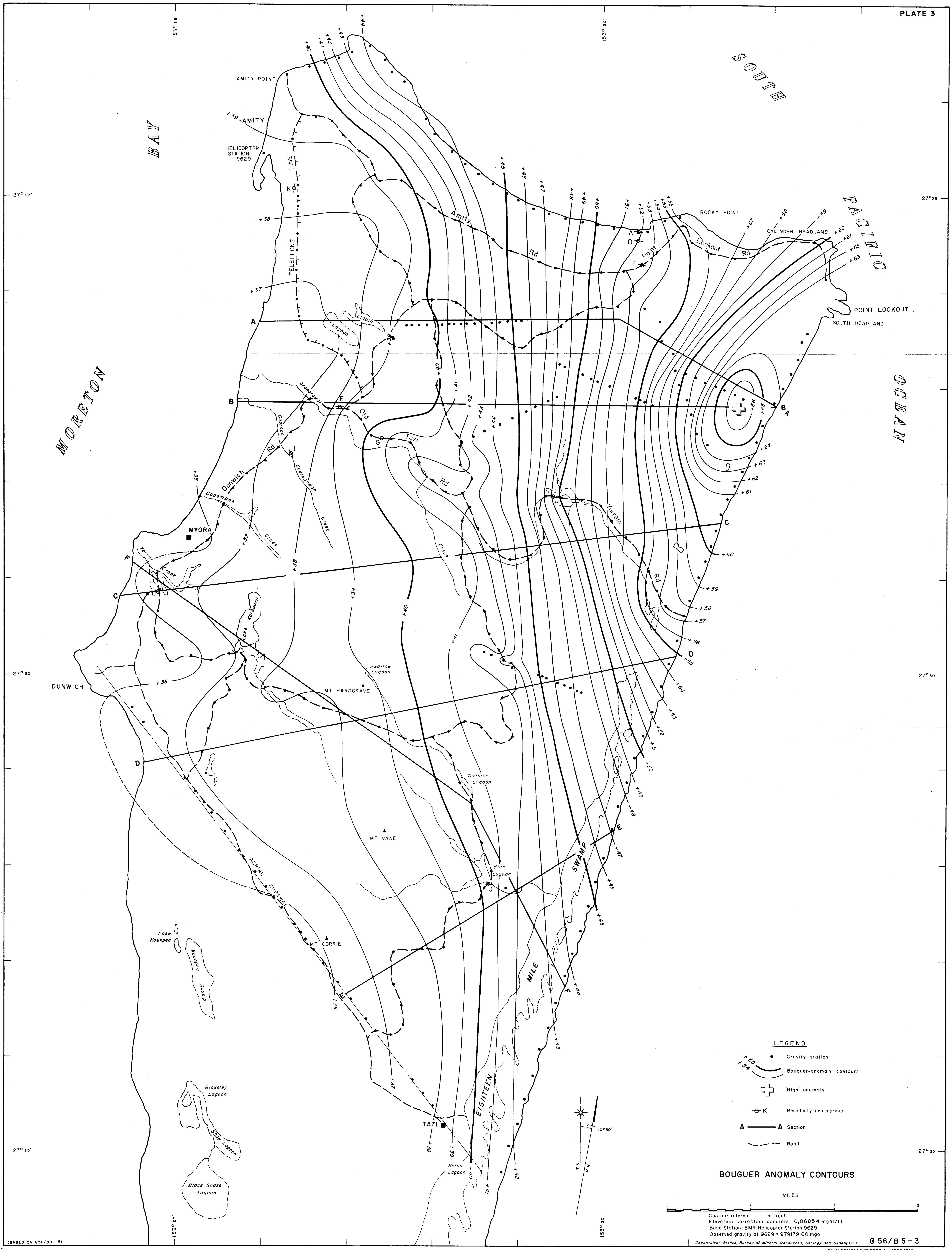
Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics.

G 56/B5 – 22

TO ACCOMPANY RECORD No 1965/248

MORETON
BAY
SOUTH
PACIFIC
OCEAN
Dunwich
Myora
Amity Point
Rocky Point
Point Lookout
EIGHTEEN
MILE
SWAMP
AMITY
SWAMP
LAKE KARBOORA
Flying Fox
Creek
MT HARDGRAVE
MT CORRIE
Blue Lagoon
NORTH STRADBROKE ISLAND — ELEVATION CONTOURS
MILES
Contour Interval 50 feet
G56/B5-9-1
PLATE 2

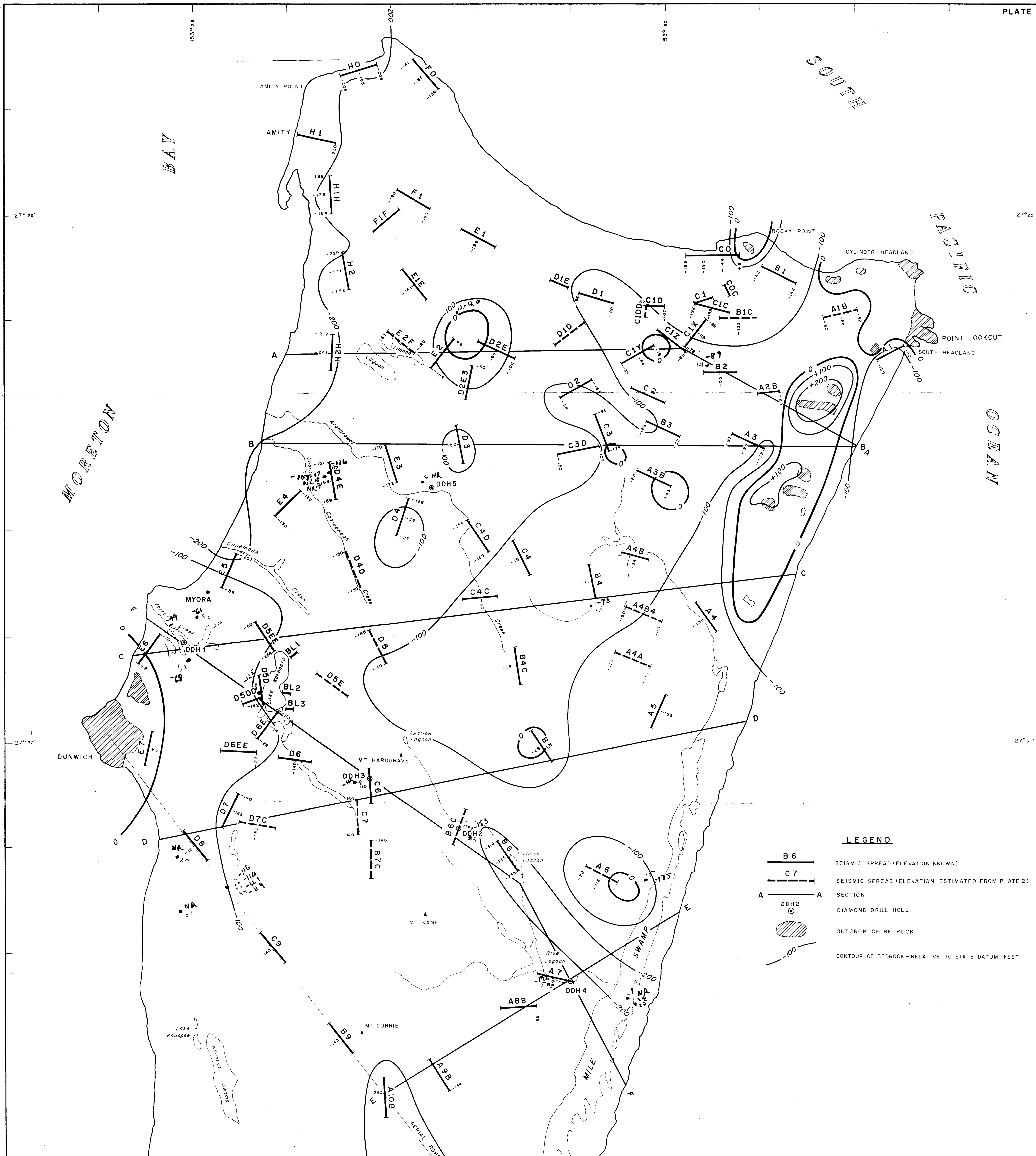
PLATE 3



TO ACCOMPANY RECORD No. 1965/248


PLATE 4
153° 25'
153° 30'
27° 25'
27° 30'
27° 35'
MORETON
BAY
SOUTH
PACIFIC
OCEAN
AMITY POINT
AMITY
ROCKY POINT
CYLINDER HEADLAND
POINT LOOKOUT
SOUTH HEADLAND
MYORA
DUNWICH
MT HARDGRAVE
MT VANE
MT CORRIE
TAZI
Swallow Lagoon
Tortoise Lagoon
Blue Lagoon
Heron Lagoon
Lake Kounpee
Kounpee Swamp
Blaksley Lagoon
Black Snake Lagoon
Lake Karboora
Capembah Creek
Yarrol Creek
Cooroon Cooroonpah Creek
AERIAL ROPEWAY
EIGHTEEN MILE SWAMP
LEGEND
Gravity station
Residual gravity contour
'High' anomaly
'Low' anomaly
A —— A Section
RESIDUAL GRAVITY CONTOURS
MILES
Contours interval 1 Mgal
(BASED ON G56/80-15)
Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics
G56/B5-10
TO ACCOMPANY RECORD No. 1965/248

PLATE 5



CONTOURS OF BEDROCK ELEVATION

(BASED ON G56/80-15)

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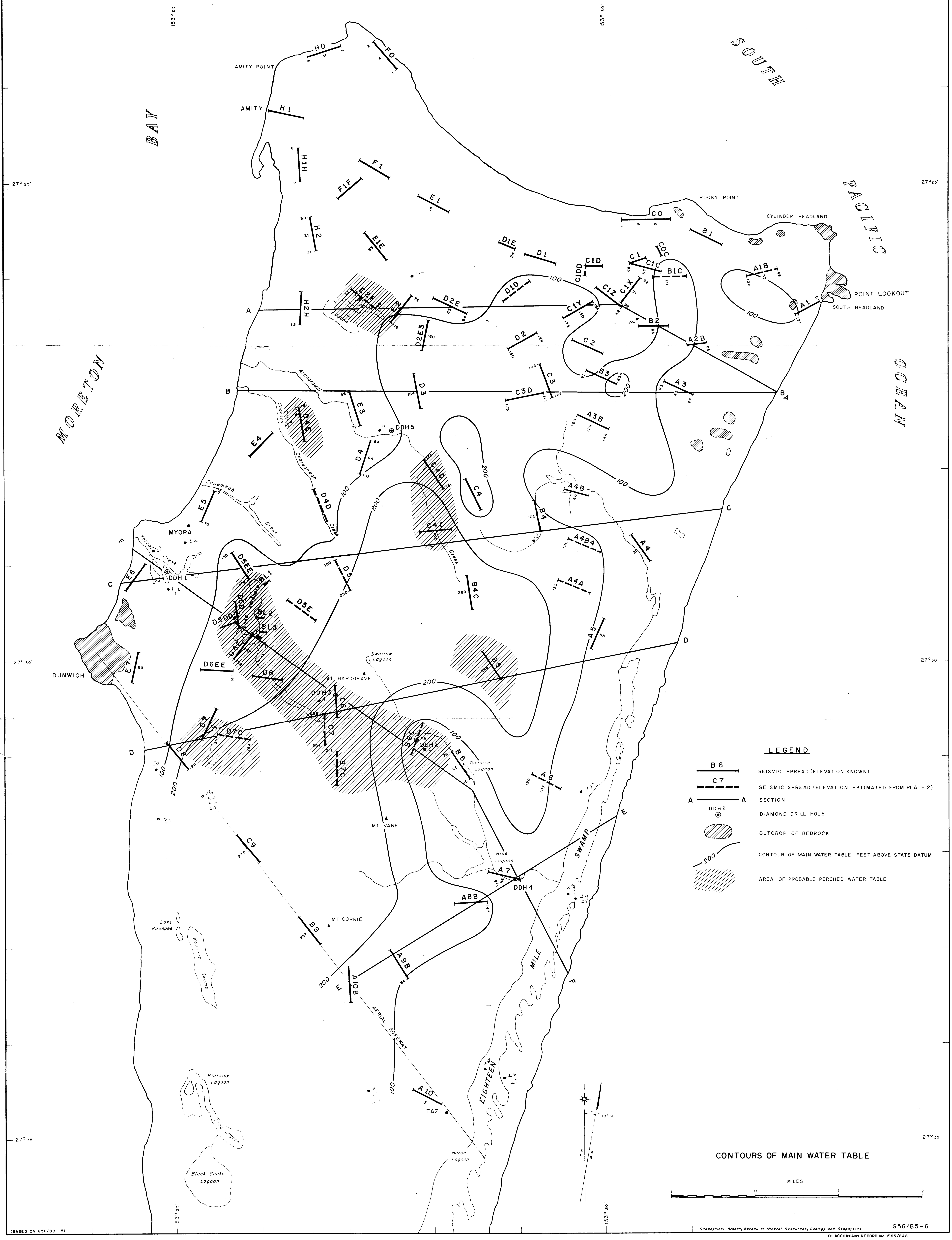
PLATE 6



CONTOURS OF MAIN WATER TABLE

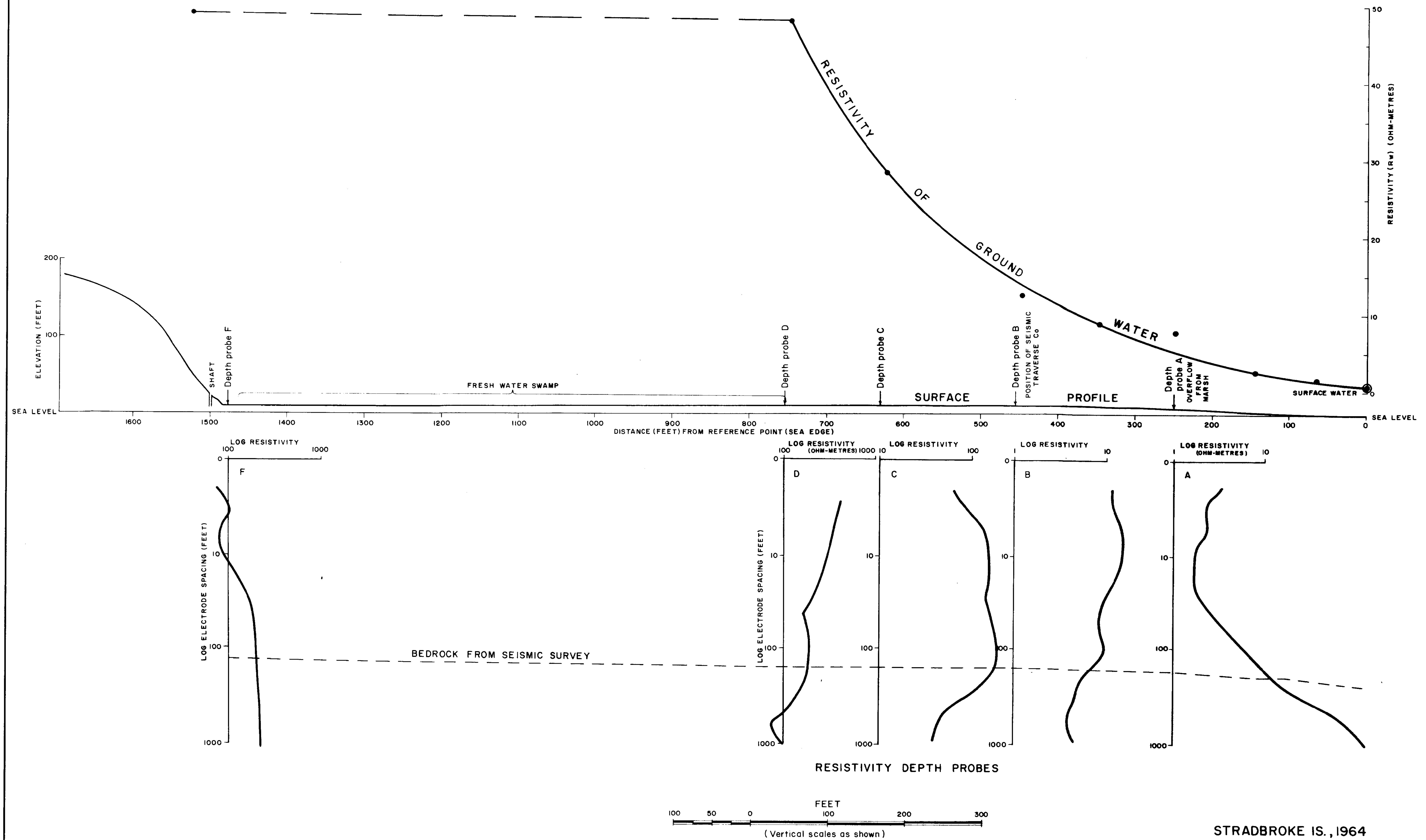
TO ACCOMPANY RECORD No. 1965/248

PLATE 7

TO ACCOMPANY RECORD No. 1965/248

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics G56/B5-14

TO ACCOMPANY RECORD No. 1965/248



STRADBROKE IS., 1964
ROCKY POINT BEACH

RESISTIVITY MEASUREMENTS

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS G56/B5-11
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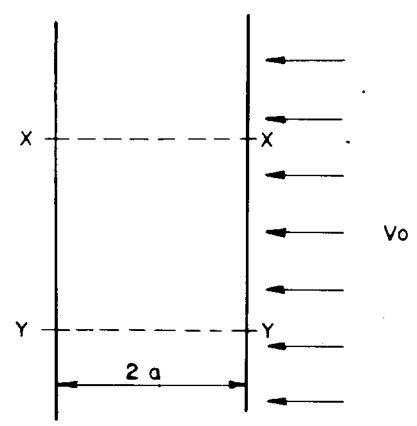
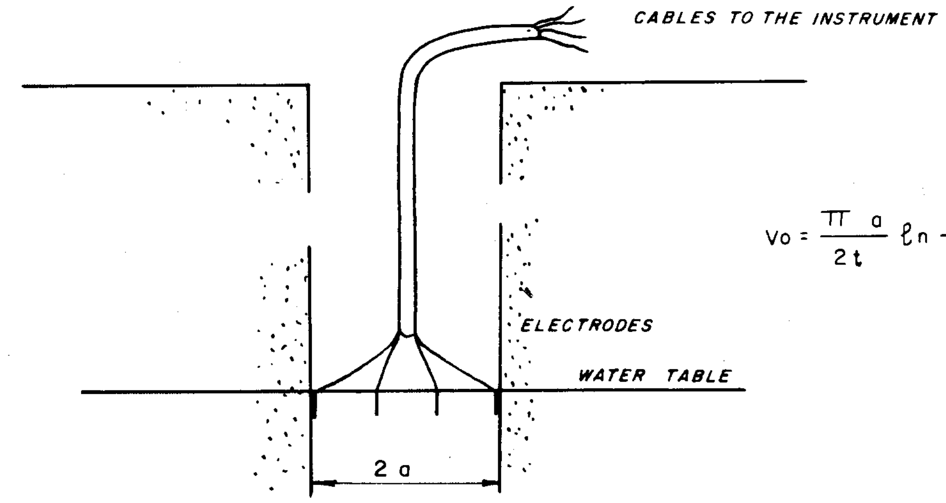
NORTH STRADBROKE IS.





$$V_o = \frac{\pi a}{2t} \ln \frac{R_{min}}{R_t}$$

Volume of fluid ΔQ flowing through unit depth of the well in time Δt is

$$\Delta Q = 2a V_o \Delta t$$

Volume of fluid Q in unit cylinder

$$Q = \pi a^2$$

Change in mass of salt Δm in time Δt is

$$\Delta m = -2a V_o \Delta t\, C$$

Change in salt concentration is

$$\Delta C = \frac{\Delta m}{Q} = -\frac{2a V_o \Delta t\, C}{\pi a^2}$$

Let $\Delta t \longrightarrow 0$

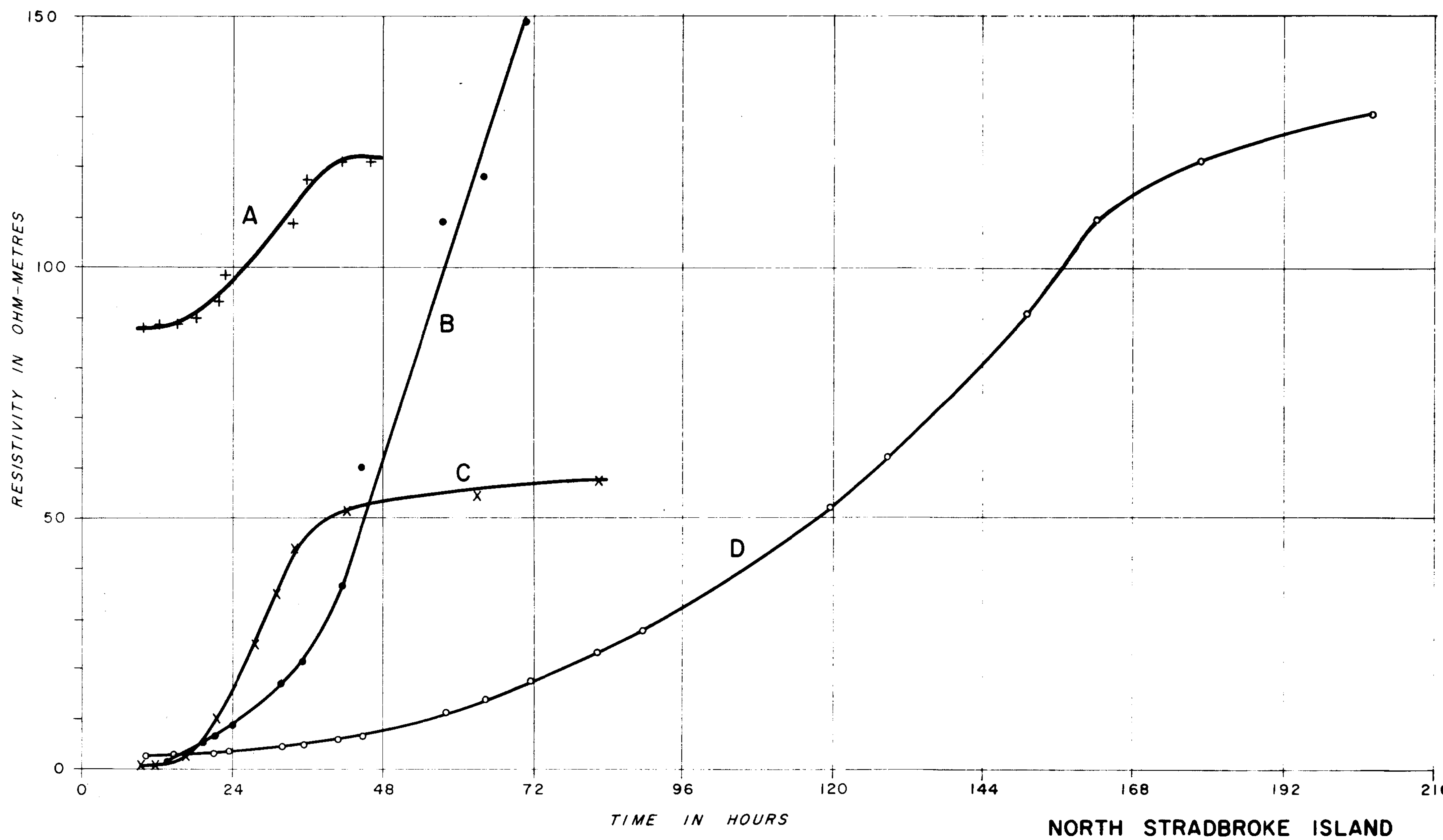
$$\frac{dC}{C} = -\frac{2 V_o dt}{\pi a}$$

Integrating,

$$\int_{C_o}^{C_t} \frac{dC}{C} = -\frac{2V_o}{\pi a} \int_o^t dt$$

$$\ln C_t - \ln C_o = -\frac{2 V_o t}{\pi a}$$

$$V_o = \frac{\pi a}{2t} \ln \frac{C_o}{C_t}$$



NORTH STRADBROKE ISLAND

DETERMINATION OF VELOCITY OF FLOW OF UNDERGROUND WATER

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS. G56/B5-30
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