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RECORD No. 1963/163

GRAVITY SURVEYS OF THE GREAT BARRIER REEF AND ADJACENT COAST, NORTH QUEENSLAND 1954-60

by

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CONTENTS

ILLUSTRATIONS

SUMMARY

A gravity survey was made in the Great Barrier Reef area in 1954, readings being taken at landing places on islands and reefs. In 1958-59 further work was done using an underwater gravity meter. The results are combined with those of adjacent land surveys and are presented as anomaly maps and a series of profiles, approximately perpendicular to the coast, showing topography, geology, and gravity anomalies. The predominant feature is a rise in gravity oceanwards, presumably associated with the thinning of the Earth's crust. With suitable assumptions as to the cause of this rise, residual anomalies corresponding to shallower geological features can be estimated. The absence of large anomalies associated with the main topographical changes suggests that these changes are not, as some authors have supposed, expressions of major vertical faults. Alternative explanations are considered, but the correct solution must await further information. The residuals generally are small, and do not suggest any large quantity of near-surface material with a marked density contrast.

1. INTRODUCTION

This Record describes gravity surveys in an area of North Queensland, comprising a coastal strip extending about 40 to 70 miles inland, and the offshore area to the outer limits of the Great Barrier Reef, between latitudes about 14°S and 19°S; i.e. from the vicinity of Cape Melville to Townsville.

The initial survey in the area was carried out by the writer during August to October 1954. The land portion was surveyed between about 15°S and 18°S, and readings were made on islands and reefs in the corresponding offshore area. In addition, a traverse was run along the coast southwards to Townsville.

The work was done as the result of a request by the Great Barrier Reef Committee for geophysical work to help in solving some of the structural problems associated with the formation of the Great Barrier Reef and the continental shelf.

The survey was planned as a reconnaissance survey with the object of exploring the broader structural features of the area. It was also regarded in some measure as a test to assess the value and practicability of gravity work in these areas, with a view to possible future extensions of the survey.

The land portion of the area was covered by vehicle using existing roads. In the offshore portion, a normal land gravity meter was carried by motor launch and readings were taken on reefs and islands where it was possible to land.

In 1958 further work was done in the offshore area using an underwater gravity meter (Goodspeed & Williams, 1959). This work was part of a regional gravity survey extending from Thursday Island to Maryborough along the Inner Steamer Channel of the Great Barrier Reef. Stations were read at about 20-mile intervals along the channel, and in addition several cross traverses were run from the coast to near the outer reef with a nominal station interval of five miles. Further work was done on land in this area in 1960 as part of a regional network survey with stations at five-mile intervals (Flavelle, 1963). Some results of Marshall and Narain (1954) have also been incorporated in the gravity maps and profiles.

2. OPERATIONS

1954 Survey

An Atlas gravity meter (No. F-21) was used throughout the 1954 survey. This meter has been described by Aquilina (1950).

At the time of the survey the reading-point for normal sensitivity had drifted close to one end of the range of movement of the indicator between the stops. This made it awkward to take readings quickly. Adjustment of the reading-point to a position nearer the centre of the range of movement gave a decreased sensitivity in setting of the null position; this corresponded to a decrease in accuracy of the readings and an increase in stability of the meter. The former feature was not a serious drawback in a survey of this nature, where extreme accuracy was not required. The latter feature was a distinct advantage in many cases as readings had to be taken on rather unstable 'niggerheads' on the coral reefs.

Transport on land was by Land-Rover, with a trailer for moving equipment between bases. Traverses were set out along existing roads for the most part. Bases were set up at Cairns, Mossman, Mount Carbine, Cooktown, Atherton, and Innisfail, and the main part of the area was covered by traverses radiating from these points.

For the 1954 island readings a 39-ft motor launch, M.V. Possum, was used. Much of this work would not have been possible without the excellent knowledge of the reefs and passages possessed by the owner-captain, Mr Hector Macdonald. The maximum speed of the vessel was about eight knots. This part of the survey was limited in several ways by the operating conditions. It was virtually impossible to arrange for drift control by repeating stations, because of the distance between suitable anchoring points. Exigencies of tides and weather prevented readings from being repeated at overnight stops in many cases. Thus the only control was by ties to land stations at Cairns, Cooktown, and Mourilyan Harbour (near Innisfail). Many reefs have no permanent projections above sea level and emerge only at low spring tide. This applies particularly on the outer reefs. Wharfs or jetties were available only at the three base stations and at Green Island. At other places meter and operator had to be rowed ashore in a flat-bottom boat; such landings were of course only possible if the weather was suitable.

The survey took place during the season of south-east trade winds. During this season a breeze of about 15 to 20 knots blows almost continuously. Cloud cover and rain were frequent. Many of the reefs are uncharted and navigation in such areas depended on good visibility and the local knowledge of the crew. Favourable conditions are with the sun shining, but not against the direction of travel, and the surface of the sea slightly disturbed, but not too rough. An excellent description of navigation among reefs was given by Steers (1929).

There are few points where fresh water can be obtained in the area and, except at Cairns, it must be carried a considerable distance by bucket. Cooktown and Lizard Island were the only two supply points. At Lizard Island, water had to be carried about half a mile and then rowed out to the vessel. Thus the range of the survey could be limited by the capacity of the ship's water tanks.

The sea-going survey took place in three trips, the first a one-day cruise to Fitzroy Island and Green Island and return to Cairns. The second cruise occupied thirteen days from 6th to 18th August, travelling northward from Cairns. Low spring tides occurred during the daytime about 14th August. Therefore the first part of the survey was chosen as travelling along the inner line of reefs and islands, many of which are permanently exposed; when the lowest tides were expected, the return journey southwards was made so as to obtain readings at as many of the outer reefs as possible. The third trip, southwards from Cairns, occupied five days from 27th to 31st August. This was timed to coincide with the next spring tides; however, tides and weather were not so favourable, and several possible landing points had to be missed.

Throughout this part of the survey only two stations per day were occupied, on the average.

1958 Survey

The underwater gravity meter used was a North American gravity meter UW-2R-7. This is similar to a North American land gravity meter, but is modified so that the position of the beam and the tilt of the meter can be detected electrically as well as optically. The external controls (clamping and resetting mechanisms and reading dial) can be operated electrically by means of servo-motors on a panel fitted to the top of the gravity meter. Gravity meter and panel are enclosed in a watertight bell. The bell is mounted in gimbal rings attached to a rigid circular base, and its attitude can be controlled by two servo-motors in response to signals originating from the level detectors on the gravity meter. All control and power-supply circuits enter the bell from a neoprene-covered cable through a watertight connector. The other end of the cable is attached to the control unit on the boat.

The control unit consists of a power supply, level-signal amplifiers, an amplifier for signals from beam-position detector or depth indicator, and an operating console. The latter has controls and indicators for levelling the gravity meter, clamping or unclamping the beam, and adjusting to the null position; it also has indicators for operation of the thermostatic control of the temperature of the gravity meter.

The bell enclosing the gravity meter is fitted with a pressure-sensitive device, which is used to indicate depth. Depth readings are also made at the operating console.

Power for the control and reading equipment was provided by a 1500-watt, 115-volt, 60-c/s generator driven by a petrol engine.

For taking a reading at sea the bell with the gravity meter enclosed was lowered from the boat to the sea bottom on a steel wire cable attached to a hydraulic winch. The winch was mounted on rails running athwartships; the bell with its supporting frame and the winch could be carried amidships for extended travelling, or projecting over one side ready for lowering during operations.

The equipment was mounted on M.V. Kano, a 60-ft motor launch chartered from Mines Administration Pty Ltd. Part of the work was carried out on the Queensland Authority to Prospect for Oil No. 53P, which at that time was held by Humber Barrier Reef Oils Pty Ltd, which shared in the charter of the boat.

Field work was carried out during October to December 1958, with M.J. Goodspeed as party leader.

No stations were repeated for long-term drift control. Gravity-meter drift was calculated from observations at ports where gravity values had previously been established, viz. at Thursday Island, Cairns, Townsville, and Rockhampton. A Worden gravity meter was used for tying from the wharfs to established gravity stations. Measurements with this meter were made as near as possible to the positions of the underwater gravity readings; corrections were made for difference in elevation and in the attraction of water and land above or below the two stations.

Short-term drift control for the cross traverses was obtained by re-occupation of stations located close to islands.

The results of this survey between latitudes 14°S and 19°S have been included in this Record; i.e. between Princess Charlotte Bay and Cape Bowling Green and including cross traverses No. 1, 2, and 3.

1960 Land Survey

This was carried out by J.R.H. van Son between February and June 1960. Worden gravity meter No. 260 was used. All stations were read twice for drift control. The survey followed main roads for the greater part.

Surveying - horizontal control

Positions of the land stations were determined mostly by identification of features on the military 4-mile or 1-mile series of maps. Queensland Lands Department 4-mile and 2-mile series maps were also used. However, some roads were not very accurately plotted, and some had been remade and their course altered since the maps were drawn; consequently the positions of a few stations are probably uncertain to within one or two miles. This applies particularly to the Mulligan Highway between Mount Carbine and Cooktown, for which apparently no accurate maps existed.

Positions for the island stations were taken from the Admiralty Charts. Some of the 'niggerheads' and reefs exposed at low tide were not shown on these, but had been located and plotted on the Admiralty Charts by Mr Macdonald on the basis of sailing times and directions of travel on many previous trips. Positions of these stations may be out by about two miles or so.

For the underwater gravity meter work, stations were located by use of the horizontal sextant and station pointer. This involved measuring the angles between three prominent landmarks which were shown on the charts. Under good conditions an accuracy of a few minutes of arc could be obtained in the angles; this was better than plotting accuracy on the scale of the charts used (approximately 1:300,000).

Where landmarks could not be seen, dead-reckoning methods were used. Distance was measured by a patent log, and heading was maintained by magnetic compass. Sometimes this could be supplemented by compass bearings on one or two features. It was generally possible to fix the end of a traverse in relation to an island or reef shown on the charts, and to distribute errors accrued in dead-reckoning. Nevertheless, errors of one or two miles may be present in some station locations.

Elevations

The land survey stations were located, wherever possible, near railway stations, level crossings, or Main Roads bench-marks. The difference in elevation from these points was measured or estimated to the nearest foot; the information for the reference points was very kindly supplied by the Queensland Main Roads Department and the Queensland Government Railways.

In the 1954 survey, barometric methods were used for stations that could not be referred to a point of known level. An Askania recording microbarograph and an Askania field microbarometer were used. The microbarometer is very light, quick and easy to read, sensitive to pressures corresponding to about 0.3 ft of elevation, and unaffected by normal transport with reasonable care. The microbarograph is not so satisfactory - its sensitivity is not so great; the recorded deflection is proportional to the current through a photo-electric cell, which depends not only upon pressure changes but also on the intensity of the light-source, and hence varies substantially with small changes in battery voltage. Moreover the microbarograph has a substantial temperature coefficient, but this model had no means of recording the temperature.

Because of the difficulties in finding suitable bases to set up the microbarograph and leave it running, some of the field stations are a considerable distance from the base (in some cases as much as 50 miles). The microbarometer was read in conjunction with the gravity meter, and repeat readings were made wherever practicable. Whenever possible, tie stations were also made at points of known elevation such as railway stations and sea level, and in only a few places where the distances from such tie points considerable. In reducing the barometric data, barometer readings at meteorological stations were obtained from the Commonwealth Bureau of Meteorology, and the synoptic weather charts were studied. This information was used to supplement the microbarograph recordings and to establish regional pressure gradients.

In spite of this, several barometric elevations differed considerably from elevations known from other sources, and some large discrepancies occurred between repeated readings at the same station, particularly where the surrounding topography was steep or where the elevation differed greatly from that at the base station. The traverse from Mount Carbine to Cooktown involved the longest distance between points of known elevations. The misclosure error on this traverse over 100 miles was only three feet; this is of course not an indication of high accuracy at all intermediate points.

In the 1960 survey a few of the stations that could not be located near bench-marks were levelled by means of Western Elevation Meter No. 204. This meter consists of a highly damped pendulum mounted on the floor of a car. By means of a photo-electric detector, a D.C. amplifier, and a servo-motor, an integrating wheel is displaced along its axis by a distance proportional to the sine of the slope of the car floor. This wheel runs on a disc connected to the front wheel of the car by a flexible drive; thus rotation of the disc is proportional to distance travelled. The combination of integrating wheel and disc thus gives rotations of the wheel proportional to elevation changes. The wheel is geared to a counter whose reading can be converted to feet, reading to the nearest 0.1 ft. Distance travelled is also recorded in feet.

The angle between the floor and the pendulum is affected by vehicle acceleration. Compensation is provided for this by a small D.C. generator attached to the front wheel. The output of this is fed to coils near the pendulum. When the speed of the vehicle changes, the change in current in the coils acts so as to counter the mechanical acceleration of the pendulum. This compensation is effective provided vehicle speed and accelerations are not too large, but careful driving is essential.

Elevation readings were taken at all stations on a forward, reverse, and another forward run. From these readings instrumental drift was eliminated and a check on performance could be made.

The accuracy obtainable over short distances on good roads could be better than $\pm$ 1 ft. For the five-mile intervals in the 1960 survey the standard error was estimated as about $\pm$ 4 ft.

For the underwater gravity meter, depths of observation points were obtained from the depth-measuring device attached to the bell. This could be read to 0.1 ft. No systematic check on the accuracy of the depth measurements could be made, but it is believed that these were accurate to within about $\pm$ 1 ft. Measured depths were corrected to mean sea level with the aid of tide tables.

3. GEOLOGY

The geology of the area has been described by Hill (1951), Fairbridge (1950), and White (1961) amongst others. The land survey was conducted in the region of the Tasman Geosyncline, whose extent seawards is not known.

A predominant feature is the alignment of mountain ranges, valleys, coastline, chains of reefs, and edge of the continental shelf, as well as structural trends, in approximately a north-north-westerly direction. Occasionally the coastline cuts across this trend, truncating some of the physiographical and structural features. Farther south (e.g. south of Townsville) this parallelism is not so obvious and the outer reefs and the mountain ranges diverge from the coastline in opposite directions.

In the coastal strip the exposed rocks are predominantly Lower Palaeozoic Barron River Metamorphics, with granitic intrusions. The Hodgkinson Basin (Devonian-Carboniferous) lies inland northwards from Cairns and is overlain by Mesozoic sediments west of Cooktown. South-west of Cairns are the Atherton Tablelands (elevation about 2500 ft) comprising granite and Tertiary basalt. These are flanked on the east by the Bellenden Ker Range, which rises to over 5000 ft in places and contains the highest mountains in Queensland.

The islands in the Great Barrier Reef area include both high islands, rising to several hundred (in some cases over 1000) feet, and low islands, at the most a few feet above sea level. High islands are generally nearer to the coast and consist of continental-type rocks, granitic or metamorphic, generally similar to those on the adjacent mainland. Jones and Jones (1956) have indicated the presence of Barnard Metamorphics of Precambrian age in the islands and in some headlands between 17°S and 18°S latitude. The low islands are sand cays on the north-western edges of coral reefs. Some have been stabilised by vegetation. There are also reefs and cays which are submerged, or which only emerge at low tides. High islands commonly have fringing coral reefs.

The reefs and reef islands occur mainly in two belts - the outer or barrier reef and a chain of inner reefs. The 'steamer channel' is about 90 to 150 ft deep between the inner reefs and the coast. There is another channel, with about the same depth, between outer and inner reefs, but this zone is not well mapped, and reefs occur in places within the channel.

The character of the outer reefs is different north and south of Trinity Opening (east of Mossman). Northwards, the edge of the continental shelf coincides with the edge of the barrier reef. The outer reefs have a clearly marked outer edge, and form a series of arcuate structures. Outside the reefs the ocean bottom falls with a slope of seven or eight degrees to the Queensland Trench, whose depth is 6000 to 7200 ft.

South of Trinity Opening the lines of outer and inner reefs are less clearly marked and the 600-ft depth line lies some distance outside the outer reefs. The slope of the continental shelf is smaller and the depth of the ocean is less. The reefs are farther from the coast.

A bore was put down at Michaelmas Cay by the Great Barrier Reef Committee in 1926 (Richards & Hill, 1942). Reef material was found to a depth of 378 ft, and quartz-foraminiferal sand to bottom of hole at 600 ft. No basement was encountered. Other bores have been put down farther south, outside the area under discussion: one at Heron Island (23°26'S, 151°57'E) which gave coral to 506 ft depth and sand to 732 ft, no basement (op. cit.); and one at Wreck Island (23°20'S, 151°58'E) which reached basement at 1795 ft (Mott, 1960).

As coral does not grow at great depths (150 to 180 ft at the most), either subsidence of the land or rise in sea level is required to account for the thickness of coral. Post-glacial eustatic rise could account for 200 ft of this, but subsidence must have occurred to account for the rest. The presence of sand in the bores makes it probable that further subsidence has occurred. As the deposits are post-Pleistocene this must have occurred fairly rapidly. Raised benches and oyster beds however, indicate that emergence of a few feet has occurred very recently.

The growth of the coral reef is generally supposed to have started on a basement ridge or similar feature, and to have grown on top of dead reefs at or near sea level as subsidence occurred. Theories differ as to the cause of the subsidence. It is generally supposed that faulting controls the edge of the continental shelf, at least in the northern part of the area.

Parallel faulting has been invoked by many authors to account for the physiographic features of the adjacent mainland, such as the parallel trends of river valleys, mountain ranges, and coastline and the rather abrupt changes in level between these features. This theory, however, has been criticised on the grounds that no detailed mapping has been carried out to support it and that differential erosion could equally well account for the features.

No earthquakes have been recorded from the Coral Sea area, suggesting that faulting is not active at present.

The Palaeozoic rocks of the Tasman Geosyncline in this area presumably continue under the continental shelf. They have been considerably affected by intrusion, metamorphism, and diastrophism and could be regarded as basement when considering any possibilities of oil accumulation. It is not known whether any substantial thickness of Mesozoic or Tertiary sediments might overlie them, but this is considered unlikely in the vicinity of Cairns.

Recent work has been carried out by BMR geologists in an area including the Mossman, Atherton, and Einasleigh 1:250,000 sheets (White, 1961). The western part of the area covered by the gravity survey overlaps the eastern part of these. This work has shown that the present apparent eastern margin of the geosyncline is controlled by tectonic movements subsequent to deposition, and that the central axis of deposition probably coincides approximately with the apparent eastern margin. Igneous intrusive activity occurred both in Permian and in Recent times. Tectonic movements were predominant during the Mesozoic, and basalt flows occurred during the Tertiary.

Marshall and Narain (1954) carried out gravity work that included traverses inland from Cairns, Townsville, and Rockhampton and a traverse along the coast from Brisbane to Cairns. In their analysis of the results they calculated residual anomalies by removing a smooth regional anomaly drawn through the lower points of the Bouguer anomaly curve, so that the residuals are predominantly positive. Zones were designated as high or low according to whether the residual anomalies were greater or less than 5 mgal. In this way they found a correlation between the low zones and sedimentary basins as indicated by Hill (1951). However, the distance between the traverses was so great that correlations of such small anomalies should not be regarded as definite. In the area of the present survey, Marshall and Narain's regions 8 (high), 9 (low), and 10 (high) correspond with the North Coastal High, the Hodgkinson and Star Basins, and the Chillagoe Shelf of Hill (1951) respectively.

4. REDUCTION OF RESULTS

Gravity observations

The gravity observations on land were corrected for drift and for loop misclosures by the method of Smith (1951). Ties were made to the BMR pendulum stations No. 52 at Cairns and No. 51 at Townsville (Dooley et al., 1961). The values used for these stations were the then-adopted values of 978,499.4 mgal for Cairns, and 978,622.3 mgal for Townsville. The most recent adopted values (Dooley, 1962) are 978,500.7 mgal for the Cairns pendulum station, and 978,624.0 mgal for Townsville. Thus a correction of about 1.5 mgal should be added to bring these values into line with the 1962 Australian Network values. The calibration factor used was 0.112 mgal/scale div., based on measurements over the Ferntree Gully/Kallista calibration range near Melbourne. Latest information on the correct value for this range indicates that the correct calibration factor for Atlas gravity meter F21 in 1954 should be 0.11175 mgal/scale div. As the total range of observed gravity for the survey is about 370 mgal, this implies a systematic error amounting to about 0.8 mgal. This is not likely to affect the map contours or profiles visibly, nor the interpretation of the gravity results; however, these figures are recorded here for future reference.

With the original calculation the gravity-meter difference between Cairns and Townsville pendulum stations was 123.84 mgal, compared with a pendulum difference of 122.9 mgal. With the revised calibration factor and the adjusted values for Cairns and Townsville, the differences are 123.56 and 123.3 mgal respectively, showing much better agreement.

From the misclosure adjustments the accuracy of the gravity difference between two points of the land survey is estimated as about $0.06n^{\frac{1}{2}}$ where n is the number of intervals between the two points.

In order to assist with the drift corrections for the island stations, readings were taken with the gravity meter stationary at base stations on a few days before, between, and after the cruises. These base readings were corrected for tidal gravity variations (Goguel, 1954), and from the residual readings an average curve of diurnal variation was constructed. This variation is presumably due mainly to temperature effects.

The island stations were corrected for tidal gravity variation and then a diurnal correction was applied from the empirical curve described above. Residual drift was distributed in proportion to time for each of the three cruises. The rates determined for the three cruises were in reasonable agreement, the gravity-meter reading increasing at a rate of 1.9, 1.6, and 1.7 mgal per day respectively.

In addition to the base station at Cairns, ties were made to stations at Cooktown (S15) and Mourilyan Harbour (168), which were connected to the land survey. In adjusting for misclosures these stations established by the land survey were regarded as of fixed value, as the accuracy of the land survey is considered to be much higher than that of the island survey. Stations S6, S7, S8, and S15 were observed on both the outward and return legs of the second cruise, and station S3 was observed on both the first and third cruises. These repeat readings were also used in adjusting misclosures.

An estimate of the accuracy of the island stations can be made from the discrepancies at the ties to land stations and the repeat stations. For seven such differences the r.m.s. difference is 0.96 mgal. Repeat readings were made at some stations where overnight stops or other stays of a few hours duration occurred. These were averaged to obtain station values. The r.m.s. difference for 13 such readings is 0.65 mgal.

The former estimate should represent the error to be expected between stations a few days' cruise apart; the latter estimate should apply to adjacent stations. A mean standard error for the difference between stations may be taken as about 0.8 mgal.

For the underwater gravity meter survey the gravity readings were first corrected for the difference between sea level at the time of observation and mean sea level, as determined from the tide tables. These corrections were small (0.013 mgal/ft with a maximum tide variation of 4ft above or below MSL). Next, corrections were applied for the variation in tidal force (Goguel, 1957). These corrections were also fairly small, reaching a maximum of 0.26 mgal.

After these corrections had been applied the mean rate of drift between the pendulum station observations was applied as a correction to the intervening readings. For the cross traverses extra drift corrections were derived from repeated readings at control stations. The drift rates were consistent and low (about +0.3 mgal per day).

The observed gravity values obtained as above were corrected to mean sea level. In addition to the normal free-air correction (-0.094 mgal/ft), allowance was made for the attraction of a horizontal 'slab' of water equal in thickness to the depth below mean sea level. This attraction is upwards at the point of observation but downwards at mean sea level. The resulting combined 'free-air' correction is -0.0678 mgal/ft. With the usual correction for latitude the resulting anomaly is regarded as the free-air anomaly at mean sea level.

A simple Bouguer correction was then applied, equivalent to replacing the sea-water (density 1.03 g/cm^3) by rock of the standard density (2.67 g/cm^3). This correction is +0.0209 mgal/ft.

Elevations of stations

Elevations of the island stations and some shore stations were referred to sea level. The height of these above sea level was estimated at the time of the reading. The state of the tide at this time was determined from the tide tables supplied by the Queensland Department of Harbours and Marine and the elevations were corrected to mean sea level. The estimated standard error for these stations is about $\pm$ 1 ft.

All elevations supplied by Main Roads Department, Queensland Government Railways, and others were referred to mean sea level.

The microbarometer pressure readings were converted to the equivalent altitude in feet by special tables constructed for that purpose, and were corrected for instrument temperature. The microbarograph charts were similarly converted, instrument temperature being estimated from occasional readings of a nearby thermometer. Information was obtained from the Commonwealth Bureau of Meteorology about barometer readings at a number of their stations including Cairns, Mount Surprise, Palmerville, Port Douglas, Cooktown, Coen, and Cardwell. These were also converted to equivalent altitudes in feet and were used to supplement the microbarograph readings. The method of interpolating for equivalent sea-level pressure at the field station in time and space using several base stations is the same as that described by Dooley (1963). Isobaric charts were also studied.

The difference in barometric altitude between base station and field station was corrected for air temperature and humidity by means of a nomogram constructed for that purpose. Readings of wet and dry-bulb thermometers were taken in conjunction with the microbarograph recording; these were used for the humidity correction and also to estimate the mean air temperature.

During those parts of the survey where barometric elevations were used, microbarometer readings were made wherever possible at points of known elevation, and corrections were made to the readings at other stations accordingly. Microbarometer readings were repeated at most stations occupied, and average values were obtained. The differences in elevation obtained from repeat readings give an estimate of the accuracy to be expected. Table 1(A) shows the r.m.s. difference e for groups of stations selected according to the time interval T between repeat readings; n is the number of measurements in each group.

TABLE 1. r.m.s. DEVIATION OF BAROMETRIC ELEVATIONS

	T (hr)	n	e(ft)
(A) Differences between repeat readings	less than 1.5	32	8
	1.5 - 2.5	18	13
	2.5 - 3.5	23	19
	more than 3.5	23	17
(B) Differences from true elevations	2 - 4	24	13
	4 - 5	33	12
	5 - 6	22	17
	more than 8	32	17

T = time interval between repeat readings

n = number of measurements in each group

e = r.m.s. difference for group of stations

Figure 2 shows the difference between barometric elevation and true elevation at points where the latter is known. The barometric elevations have been corrected as described above. The resulting differences can also be used to estimate the errors for unknown stations. The r.m.s. differences are given in Table 1(B), where T represents the time between base readings. The data for 24th and 27th September, where deviations of more than 100 ft occur, have been omitted from these calculations. These figures may give a better estimate of the actual error than the repeat stations as it is possible that systematic effects due to incorrect pressure gradients, or associated with local topography, may affect both readings at the same station in the same way. However, it is seen that the estimates are about the same for equivalent values of T.

For almost all barometrically levelled stations, observations were made at stations of known elevation within one or two hours before and after the observations at the station of unknown elevation, except for stations on the northern sheet (Plate 1) and on the Mount Molloy/ Cooktown road. From Tables 1(A) and (B) a standard error of about ± 13 ft may be estimated for single readings, or ± 9 ft where repeat measurements were made. However, the possibility of large deviations like those on 24th and 27th September should be borne in mind. It is believed that these are most likely to occur under the following conditions:

(a) Where large distances are involved and there is either an error in the horizontal pressure gradient used in the corrections, or travelling barometric disturbances reach the base and field stations at substantially different times.

(b) Where large elevation changes are involved and there is an error in the temperature-humidity correction; the error in resultant elevation is comparatively large, as it is proportional to the product of these two quantities.

(c) In areas of uneven topography, which influences local air movements, particularly where vertical air currents occur.

Estimates of levels of stations relative to road and railway bench-marks or other features were made to the nearest foot. It is believed that the errors in these surveys would not exceed one or two feet. In some cases it was hard to identify the gravity station on the road plans supplied later by the Main Roads Department; here the error may be about ± 5 ft. A few stations were tentatively located on the plans, but the difference between barometric and true elevations showed a substantial departure from the curves of Figure 2. These were about 30 to 50 ft and were consistent for repeated readings on otherwise smooth curves. It was concluded that the tentative locations were erroneous, and the barometric elevations were used instead of those derived from the Main Roads plans.

Barometric elevations were used at the following 61 stations: 10, 34, 35, 37, 43-59, 71-80, 82-91, 103, 108-111, 115, 116, 126-132, 135, 136, 154, 156, 158, 160.

The following stations were not accurately located on the Main Roads Department plans. An estimate of the possible errors is given in brackets afterthe station numbers : 18(± 5 ft), 155 (± 5 ft), 123 (± 3 ft), 158 (± 2 ft), 193 (± 5 ft).

Locations of stations

Inaccurate locations could lead to errors in the gravity latitude corrections.

The accuracy of location of the stations on the 1-mile maps is probably 0.2 miles or better, corresponding to about 0.15 mgal. On the 4-mile maps the error may be about 0.5 miles, corresponding to 0.4 mgal. The errors are possibly more than this in the Cooktown area (Plates 1 and 2) and on the Mulligan Highway (stations 46-58 and 91 on Plates 3 and 4). For these stations and the stations at sea the standard error in location may be taken as about 2 miles, corresponding to 1.6 mgal.

Calculation of anomalies

Free-air anomalies were calculated by the standard methods (Heiland, 1946, p136). The density used for calculating Bouguer corrections was 2.67 g/cm^3, which has been adopted as a standard for regional work. This is not necessarily the best density to use for any part of the area nor for the area as a whole. However, as no one density is likely to be the most suitable for all parts of the area it is best to adopt a standard density and to regard any departures from this density as sources of anomalies.

Terrain corrections were estimated by an approximate method that involved much less labour than the usual 'spider-web' chart methods. The method makes use of the two-dimensional nature of the major topographic features and applies appropriate modifications where this is not a good enough approximation. The method was developed from that of Hubbert (1948). Corrections were calculated only where they exceeded about 0.1 mgal.

The terrain corrections were largest near the edge of the plateau and on the outer reefs, and reached about 4 mgal. For most stations they were much less than this. The standard error of the estimated corrections would probably be about 0.1 of the correction, with a minimum standard error of 0.1 mgal.

Isostatic anomalies have been calculated for a few stations in the area, firstly on the Pratt-Hayford theory, with a depth of compensation 113.7 km; and secondly on Vening Meinesz's (1941) theory of regional compensation T = 20, 30, and 40 km, and for various radii of compensation R = 0, 29.05, 58.10, 116.2, and 174.3 and 232.4 km. In this theory it is assumed that the Earth's crust bends under the load like an elastic plate; thus the compensation for any topographical feature is spread over a considerable area surrounding it. The degree of spreading is indicated by the value of R, and the limiting case R = 0 corresponds to local compensation on the Airy-Heiskanen system. The various isostatic anomalies are given in Table 2.

TABLE 2. ISOSTATIC ANOMALIES

Station No.	Latitude (South)	Longitude (East)	Elevation (ft)	Free-air	Bouguer	Hayford H=113.7 km	VENING MEINESZ REGIONAL ANOMALIES																
							T = 20 km						T = 30 km						T = 40 km				
							r=0	1	2	4	6	8	0	1	2	4	6	8	0	2	4	6	8
92	17°16.0'	145°28.6'	2469	+44.6	-39.0	-9.8	+18.4	+13.8	+10.8	-0.6	-9.2	-17.2	+4.3	+3.4	+0.8	-7.5	-16.8	-21.2	-4.3	-7.1	-13.7	-20.2	-25.2
1	16°53.0'	145°45.0'	9	+17.5	+18.2	+15.1	+33.0	+33.5	+33.7	+29.2	+22.3	+17.3	+28.5	+28.2	+27.9	+23.9	+18.3	+13.5	+23.5	+22.5	+19.2	+14.5	+10.5
S4	16°45.6'	145°58.3'	15	+54.8	+55.3	+42.4	+55.0	+55.2	+55.4	+52.9	+50.6	+47.7	+52.7	+52.8	+52.8	+50.4	+48.3	+46.4	+49.1	+48.9	+47.0	+45.2	+43.6
S40	15°47.4'	146°16.1'	0	+65.7	+66.5	+35.4	+44.6	+42.7	+38.0	+35.5	+37.0	+38.7	+39.3	+38.3	+36.4	+34.1	+35.9	+37.3	+37.0	+35.4	+35.3	+35.8	+36.3
145	17°30.7'	145°37.0'	2693	+63.3	-27.9	+2.6																	
148	17°31.6'	146°01.3'	29	+13.4	+12.8	+16.9																	

All anomalies are given in milligals

T is mean thickness of Earth's crust

R = radius of regionality of compensation = r x 29.05 km

Summary of errors

Table 3 gives a summary of the estimated errors from various sources and the resulting errors in the Bouguer anomalies, for some typical stations.

As some of the errors apparently do not accumulate according to the square root law, estimates have been made for stations separated by about six station (i.e. $n^{\frac{1}{2}}$ = approx. 2.5).

The resulting errors in the gravity anomalies range from 0.25 to 1.8 mgal.

TABLE 3. ESTIMATED ERRORS IN GRAVITY ANOMALIES

Type of Station	Errors (mgal) due to gravity	elevation	location	terrain	Combined error (mgal)
Land, 1-mile maps, rail or MRD levels	0.15	0.12	0.15	0.10	0.25
Land, 4-mile maps, MRD or rail level.	0.15	0.12	0.40	0.10	0.45
Land, 4-mile maps, repeated barometric levels, large terrain correction.	0.15	0.55	0.40	0.40	0.8
Cooktown area, Mulligan Highway.	0.15	0.80	1.60	0.10	1.8
Island stations near shore.	0.80	0.12	0.80	0.10	1.15
Island stations, outer reef.	0.80	0.12	1.60	0.40	1.8
Underwater gravity meter stations near shore.	0.20	0.12	0.10	0.10	0.27
Underwater gravity meter stations, outer reef.	0.20	0.12	1.60	0.40	1.7

5. DISCUSSION OF RESULTS

The results of the survey are presented as Bouguer anomalies on Plates 1, 3, 5, and 7, and as free-air anomalies on Plates 2, 4, and 6. The free-air anomaly maps were prepared after the 1954 survey, and have not been revised to include later data included in the Bouguer anomaly maps.

The main feature apparent is the general rise in Bouguer gravity values from landward to seaward, from -40 mgal in the Atherton-Herberton region, to + 80 mgal on the outer reef east of Cooktown. This is to be expected because of the rise in the Mohorovicic Discontinuity from the continent to the ocean.

Free-air anomalies generally average fairly close to zero over large areas where the elevation or depth are fairly constant. This is a result of isostasy. However, near continental margins, mountain ranges, or ocean deeps the free-air anomalies may depart considerably from zero, because isostatic compensation is unlikely to be exact and because the anomalies due to features at the base of the crust are more widely spread than those due to surface features.

In the land part of the area surveyed, free-air anomalies are positive - about 40 mgal in the mountainous area - and show a correlation with details of topography. In the sea areas they are almost coincident with the Bouguer anomalies. This follows from the definition of the anomalies, because the observations were made on islands near sea level, or in shallow water.

The generality of positive free-air anomalies indicates that the area surveyed, considered alone, is not isostatically compensated. However, compensation may occur over a wider area, with this area indicating local deviations.

Regional anomalies

The regional trends are most readily studied on Plate 7, which shows Bouguer anomalies on a scale of 40 miles to an inch (the same scale as the BMR Tectonic Map of Australia).

The Bouguer anomalies are generally higher in the northern part of the area, both on land and at sea. On land the minimum anomaly ranges from about +20 mgal inland from Cooktown to about -40 mgal inland from Innisfail. This corresponds to a general rise in topography, from a few hundred feet elevation in the north to the mountainous and tableland areas with elevations from 2500 to 5000 ft. The maximum observed seaward anomalies range from about +80 mgal in the north to about +40 mgal towards the edge of the continental shelf near Innisfail (farther south the observations do not approach the edge of the shelf). The gravity gradients are also higher in the north. This corresponds to the submarine topographic features of the Queensland Trench, which has a depth of about 7200 ft (2.2km) off Cooktown, and about 4500 ft (1.3 km) off Innisfail. The continental slope is steeper in the north, being about seven or eight degrees off Cooktown and only about two degrees off Innisfail.

The general trend of negative correlation between Bouguer anomaly and topography from north to south is in accordance with the principle of isostasy although, as we have seen, compensation does not appear to be complete.

There are some marked deviations from the general parallel trend of the Bouguer anomaly contours. In the north near Cape Melville the contours change direction in conformity with the general outline of the coast. They also trend east-west inland from Cooktown. There is no strong directional trend over the tablelands, where the gradients are lower.

Near Low Isles, there is a change of direction, which appears to be due to a feature striking approximately east-west. The change of direction of the seaward contours depends largely on the single reading at station S38; however, the trend also appears in the contours on the land to the west of this. It is suggestive that this cross-trend is close to Trinity Opening, which forms a roughly east-west line separating two characteristic types of shelf and reef topography. The gravity evidence available is not enough to make any reliable interpretation of this trend. It could be associated with a structural feature such as a fault or scarp striking east-west and down-thrown to the south.

Plate 8 shows profiles for a few selected isostatic anomalies from those given in Table 2 for a section through four typical stations: Atherton in the mountains, Cairns on the coast, Green Island near the middle of the continental shelf, and Milln Reef at the edge of the shelf. For all isostatic hypotheses the anomalies are positive at Green Island and Milln Reef. Further, the anomalies are higher at Green Island than at Milln Reef. This is partly because of a high local anomaly at Green Island as shown by the westward bow in the 50-mgal contour on Plate 3. Although the isostatic anomalies are lower than the free-air and Bouguer anomalies at these places, they are still about +40 to +50 mgal, confirming the conclusion that this area is not isostatically compensated. Cairns also has a positive isostatic anomaly for all hypotheses, ranging from about +10 to +30 mgal.

The isostatic anomalies at Atherton range from about -20 to +20 mgal, and some hypotheses give anomalies close to zero. However, there is no justification for the supposition that these hypotheses may be better than the others for the area, as they do not give low values for the other stations.

The subterranean profile of the Mohorovicic Discontinuity has been plotted to natural scale on Plate 8, on the basis of the Airy hypothesis with sea-level thickness of the crust 30 km. Also plotted is a possible course of the boundary departing from the Airy boundary in a way that would account for the gravity anomalies. This shows the boundary rising to the under-sea level considerably west of the continental shelf edge. It is not intended to put this forward as the only possible explanation of the anomalies, nor even as the most probable explanation, but merely to indicate the sort of departure, from the Airy boundary, that would explain the isostatic anomalies. It is very probable that density contrasts occur at depths less than the Mohorovicic Discontinuity and that part of the anomalies can be explained by variations in these. In particular, the high value at Green Island very probably results partly from a shallower feature. Full interpretation is in any case difficult without extension of the survey beyond the shelf.

Plates 9 to 15 show profiles of the Bouguer anomaly over the sections shown on Plate 7. The topography is shown on these plates with a vertical exaggeration of about 20:1. The geology shown has been taken from the Geological Map of Queensland and the BMR Tectonic Map of Australia. A smooth regional anomaly is drawn through the Bouguer anomaly profile on each plate.

We will consider the regional anomalies first. The smoothness of these is such that they are most likely to represent deep-seated features. As there is no evidence to suggest the presence of any substantial thickness of light sediments on land, the rise in gravity cannot very well be attributed to the thinning-out of a sedimentary sequence. If there is a substantial thickness of sediments on the shelf, this would contribute a negative gravity anomaly. There could possibly be a sedimentary sequence thickening towards the edge of the shelf;

this would result in the diminution of the gravity gradient over the shelf. The gravity gradients are fairly high, however, and lend no support to this. The gradients on profiles E, F, and G are lower than those on B, C, and D; the difference could be attributed to sediments. However, we shall assume for the present that there are no sediments and that the regional anomaly is associated with deep-seated features (In this connexion a few hundred feet of sediments, as in the bore at Michaelmas Cay, would give an anomaly of only a few milligals, which would not offset the argument seriously).

These deep-seated features are likely to be the wedging-out of a continental granitic layer and its replacement by an oceanic basaltic layer, and the rise of the Mohorovicic Discontinuity in accordance with isostasy.

A reliable interpretation of the regional profiles would require the extension of the survey beyond the outer reef. The eastern ends of most of the profiles do not show much decrease in gradient such as would be expected if gravity is approaching a maximum. Even if the extension of the profile had been observed, no interpretation of a gravity anomaly is unique. The possible presence of more than one surface of density contrast, or of continuous density variations, would contribute further to the ambiguity.

The following discussion therefore is merely an attempt to examine some of the possibilities and estimate some limits to the features that might cause the anomalies. In view of the ambiguities, the attempted interpretation will be confined to the simplest case, viz. that the gravity anomalies arise from a single surface representing a boundary between two materials of constant density. It is assumed that the gravity profiles and the features in the surface are two-dimensional - i.e. that the cross-sections along the profiles are representative of features of extended length at right angles to the profiles; this approximation appears to be near enough for our present purposes. The profiles are not all perpendicular to the gravity contours; this means that horizontal distances shown on the profiles should be reduced by the sine of the angle between the section line and the contours. For the very approximate estimates being made, this will not be a serious factor.

The interpretation will aim at finding surfaces of density contrast whose profiles consist of two horizontal lines joined by a central line of constant slope. The corresponding anomaly should approach a horizontal line at both ends of the profile; this occurs at the western end of the profiles, but observations in general have not been carried far enough for this to be observed at the eastern end. Methods of interpretation of this type of profile make use of the total change in anomaly as one parameter. Thus we will attempt to estimate the maximum anomaly.

An estimate is possible by assuming that the Queensland Trench is isostatically compensated. If this is so, and if the Trench is wide compared with the depth of compensation, then the free-air anomaly should approach zero as the profile is extended over the Trench. The Bouguer anomaly can then be calculated from the depth of water. The value so obtained is independent of the depth of compensation or of the density contrast involved; it will probably be high because of the finite width of the Trench and because such features are in general not completely compensated.

During the Scripps Oceanographic Institution's 'Expedition Monsoon' in 1960 (Helfer, Caputo, & Harrison, 1962) a gravity profile was run by a surface-ship gravity meter on board the Argo across the Coral Sea while approaching Cairns. This gave free-air anomalies of about -20 mgal over the Trench, confirming that in this area (about $16^{\circ}20'$S, $146^{\circ}50'$E) the Trench is slightly undercompensated.

Table 4 gives some details of the observed anomalies and topography of the profiles, and also the maximum Bouguer anomalies calculated by the above method. The estimated total change in anomaly from land to sea is also given.

TABLE 4. INTERPRETATION OF GRAVITY PROFILES

		Profile					
		B	C	D	E	F	G
Continental slope (deg.)		7	8	4	6	4	2
Min. Obs. g (mgal)		+20	+8	-20	-35	-38	-35
Max. Obs. g (mgal)		+84	+70	+56	+70	+46	+34
Max. depth of Trench (km)		2.2	1.9	1.65	1.5	1.5	1.3
Calc. max. g (mgal)		150	130	110	100	100	90
Est. Δg (mgal)		130	122	130	135	138	125
(km)		6.1	5.0	5.3	5.5	5.6	5.1
Quarter width (km)		23	32	31	35	40	40
Max. gradient (mgal/km)		1.3	1.4	1.5	0.93	0.85	0.77
H_o (km)		32	28	28	46	51	51
x = 40 km	i (deg.)	8.7	7.1	7.5	7.9	8.0	7.3
	H (km)	26	23	23	43	50	50
x = 60 km	i (deg.)	5.9	(4.8)	(5.0)	5.2	5.3	4.9
	H (km)	22	(17)	(17)	40	44	44
x = 80 km	i (deg.)	4.4			3.9	4.0	3.6
	H (km)	13			34	40	40
x = 100 km	i (deg.)				3.1	3.2	2.9
	H (km)				27	34	34

Other parameters required are the maximum gradient of the anomaly profile, and the 'quarter-width' (x_1). The latter is the distance between the point where the anomaly is half way between maximum and minimum and the point where it is one-quarter (see Fig. 2). These have been measured from the profiles and are listed in Table 4.

Two possible subterranean profiles are shown in Figure 2 which would give almost the same gravity profile. In the following it is assumed that the density above the profile is 2.67 g/cm^3 and below it 3.27 g/cm^3. h will be the same for either interpretation and can be obtained from

$$h = \Delta g / 2\pi k(d_2 - d_1) = 0.0397 \, \Delta g \quad ---- (1)$$

where k is the gravitational constant and using the notation of Figure 3. h is in kilometres and Δg in milligals. Estimates of h are given in Table 4.

The case of the vertical step ($i = 90^\circ$) gives the maximum possible value H_o for H. (It is assumed that h is small compared with H; for the present approximate interpretation h/H could be as much as 0.3 without affecting the estimates seriously).

One method of estimating H_o is to take $H_o = x_1$ (Nettleton, 1942). Another method is given by Bancroft (1960):

$$H_o = (\Delta g / \pi)/(dg/dx)_{max} \quad ---- (2)$$

The maximum depth estimates from this formula are listed in Table 4 for comparison with the quarter-width. These agree fairly well for profiles C and D, but are somewhat deeper for profiles B, E, F, and G.

Another approximate interpretation can be made for the case where the angle i is small (Fig. 3c). Heiland (1946, p260) gives the formula for the gravity gradient over a slope. In terms of Figure 3, this can be written :

$$dg/dx = 2k(d_2 - d_1) \sin i \left[\sin i \log_e (r_2/r_1) + a \cos i \right] \quad ---- (3)$$

If h is small compared with H, then we may take $r_2 \simeq r_1$ and $X/2H \simeq \tan a/z$ near the point of maximum gradient, which is nearly above the centre of the slope in this case.

Putting $\cos i \simeq 1$ and $\sin i \simeq i \simeq h/X$, we get then

$$(dg/dx)_{max} = 2k(d_2 - d_1) \; ah/X \quad ---- (4)$$

Substituting for h from (1) we get

$$X/a = (\Delta g/\pi)/(dg/dx)_{max} = H_o \quad ---- (5)$$

from (2). Therefore

$$X/2H = \tan \tfrac{1}{2}a = \tan (X/2H_o)$$

whence

$$H = X/2 \cot (X/2H_o)$$

Thus H can be calculated for assumed values of X. Some values of H and i for selected values of X are given in Table 4. It will be seen that as X increases, i and H both decrease. For large values of X the assumption that h/H is small may no longer hold and the interpretation is not valid. Some doubtful values have been enclosed in brackets and other have been omitted from the table.

Small values of H imply that the high-density surface approaches sea level to the east. This would result in asymmetrical profiles, with the curvature of the 'shoulder' of the anomaly greater than that of the 'heel'. Without extending the profile seawards, of course, it cannot be decided whether this occurs.

The above interpretation indicates that the regional profiles could be explained by a rise of about 6 km in the Mohorovicic Discontinuity at a mean depth of about 25 to 40 km. To the south, either the Discontinuity would be deeper than in the north, or the slope of its surface less steep. The difference in general level of the profiles (50 to 60 mgal) could be explained by the discontinuity being about 2 to 3 km deeper, which would be of the order of magnitude required to compensate for the topography. Thus the interpretation of a gentler slope (three degrees or less) of the surface to the south (profiles E, F, and G) than in the north (seven to eight degrees or steeper - possibly much steeper) seems more likely.

It should be emphasised, however, that this is only one possible interpretation. Density contrasts at shallower depths probably also occur, and the picture could be much more complex. Seismic refraction and aeromagnetic measurements could help to establish the possible sources of the gravity anomalies. Without some outside control it is impossible to arrive at a unique interpretation of the gravity results.

If the maximum anomalies over the Queensland Trench are less than those assumed, the resulting estimated depths to the density contrast surface would be less than those in Table 4.

Residual anomalies

Residual anomalies have not been plotted separately on Plates 9 to 15, but their nature may be judged from the departure of the Bouguer anomaly curve from the regional anomaly. Anything more definite than this is hardly justified, because of the arbitrary method of drawing the regional curves and the wide spacing of observations in some parts of the area, particularly at sea. Therefore the following correlations with geological features are mainly qualitative rather than quantitative.

On profile $B-B_1$ the residual anomaly is low over the Cretaceous outcrops of the Laura Basin. The amplitude of the anomaly is only a few milligals, and does not suggest any great thickness of sediments. There does not appear to be any anomaly associated with the Jurassic sediments.

There is a definite 'high' where the Barron Metamorphics crop out near Cooktown and another one offshore to the east. Again, these are only a few milligals.

Profile $C-C_1$ shows a high residual anomaly near the outcrop of the Barron Metamorphics and extending westwards over the Hodgkinson Formation outcrop. If the latter is taken as consisting of rocks of lower density than the Barron Metamorphics, the gravity profile suggests that these are very thin east of station 85. However, as White (1961) claims that these two formations are conformable it is probable that each contains rock-types with a range of densities, and these ranges may overlap. Thus the interpretation may not be quite so simple. A marked 'low' is associated with the granite outcrop near station 80.

On profile $D-D_1$ there is a low residual anomaly near the granite outcrop, but lack of stations towards the centre of the outcrop prevents its full development being shown. The lack of any significant anomaly associated with the abrupt drop in topography to the coastal plain is a noteworthy feature on this and the following profiles E to H.

The Bouguer anomaly minimum over the highlands becomes more negative with increasing height and reaches its lowest values on profiles E, F, and G.

The small oscillations in anomalies near the edge of the plateau on profiles E, F, and H could be due either to assuming the wrong density in correcting for elevation or to inaccurate terrain corrections. However, the maximum terrain corrections calculated by the approximate method were about 4 mgal; the oscillations are about 5 mgal, which seems too large to be attributed to errors in the terrain correction. On profile E the Bouguer anomaly tends to follow the topography, which suggests that the rock density is higher than the figure of 2.67 used; a density difference of about 0.2 to 0.3 g/cm^3 would be enough to account for the magnitude of the effect. A density of 2.85 to 3.0 g/cm^3 would be consistent with known densities of Lower Palaeozoic metamorphic rocks in other areas.

Profiles F and H, and possibly also D, show the Bouguer anomaly trending in the reverse direction to the topographic change; this suggests a lower rock density than 2.67 g/cm^3. The density differences needed to account for these effects would be about 0.3 to 0.5. The resulting rock density would be lower than expected for the main rock-types in the area. Thus there may be other factors contributing to these gradients. On profile G the topographic slope is too gentle to enable an effect of this nature to be isolated.

On profiles C and E two branches of the Bouguer anomaly curve are shown over the seaward part of the traverse. These correspond to stations lying somewhat north and south of the sections on Plate 8. On profile E the difference between the two branches is noticeable; the southern branch corresponds to the area where continental rocks occur in the capes and high islands (e.g. Fitzroy Island), while the northern branch passes through Green Island, a low island. The general relation of Bouguer anomaly 'highs' with low islands is presumably due to the fact that the latter are farther out to sea and therefore in a region of thinner crust. The small residuals over the plateau on profiles F and G may be associated with individual volcanic flows, but there is not enough detail to be sure of this.

The residual 'high' associated with the Barnard Metamorphics is apparent on profiles F and G. This suggests that they are denser than the neighbouring Barron Metamorphics and is consistent with the supposed Precambrian age assigned to them by Jones and Jones (1956).

Profile $H\text{-}H_1$ is not at right angles to the topographic features or to the gravity contour lines. The edge of the Paluma Range is part of a marked linear feature, apparent on the aerial photographs, which follows the coast north-west from Townsville and maintains this direction inland when the coast veers to the north. Once again there is no marked gravity anomaly such as would be expected from a major fault.

The absence of substantial gravity anomalies associated with the abrupt topographical changes suggests that these are not expressions of faults with large vertical throw. Faulting in a material of uniform density, e.g. granite, would perhaps not produce any substantial gravity anomaly; however, this explanation would require that the down-thrown block would stop falling with its upper surface very close to sea-level. Over an extent of some hundreds of miles it seems likely that the level of the original down-thrown surface would vary considerably, and some parts would be well below sea-level; this would lead to valleys, which would fill with sediments lighter than the parent rock, giving rise to negative gravity anomalies.

Differential erosion is another hypothesis that has been put forward to explain the topography in this area. It is possible that this may have been associated with faulting that involves horizontal rather than vertical movement.

Extension of the gravity traverses beyond the outer reefs would be needed to determine whether there is faulting associated with the outer reef. If the position of this is controlled by faulting, a decrease in gravity, or at least a decrease in gradient, would be expected as the reef-line was crossed. The profiles presented in this Record do not show much evidence of a decrease in gradient as the outer reef is approached, except perhaps on profiles $D\text{-}D_1$ and $F\text{-}F_1$.

A Bouguer profile prepared from the data of Helfer et al. (1962) shows a gravity drop oceanwards over the continental slope just outside Grafton Passage. However, this is only for one interval near the end of the traverse, and is only 3 mgal, which is within the probable error estimated for the surface-ship measurements. This measurement is therefore suggestive of faulting, but far from conclusive.

Farther south, near Wreck Island, it was possible to extend two underwater gravity-meter traverses into the shallow water beyond the outer reefs (Dooley & Goodspeed, 1959). A decrease in gravity was found, suggesting a basement high feature or scarp under the reefs in that area. The comparatively shallow depth at which basement was struck in the Wreck Island bore (1795 ft) supports this interpretation. The gravity gradients in this area are much lower and suggest a trough filled with sediments between the mainland and the outer reef, with the negative anomaly due to the sediments counteracting the normal rise of gravity oceanwards. The steep gradients in the northern area, however, suggest that there is no great thickness of sediments on the continental shelf; nevertheless, residual anomalies may indicate local accumulations in places.

6. CONCLUSIONS

The regional gravity anomalies are consistent with the Mohorovicic Discontinuity rising from land to ocean by about 5 to 6 km at a depth of about 30 to 40 km, the rise being somewhat steeper under the northern part of the area. However, this interpretation is by no means unique and is probably complicated by density variations at shallower levels. Lack of gravity information outside the continental shelf makes reliable interpretation impossible.

An east-west trend of the gravity contours near Trinity Opening may be associated with the difference in reef and shelf topography north and south of the opening. Not enough detail is available to decide what sort of structural feature may be associated with this.

Low residual anomalies are generally associated with granite, and with Cretaceous sediments of the Laura Basin. High residual anomalies are associated with the Barnard Metamorphics. These residuals in general are only a few milligals, and if the regional anomaly is due to deep-seated causes, this implies that there is no great thickness of rocks of marked density contrast near the surface. In particular the gravity results do not suggest that there is a large accumulation of light sediments on the continental shelf, and do not imply the existence of faults of large vertical throw associated with the major changes in topography.

Improvements in the interpretation would result from geological mapping (which is already in progress), seismic refraction work (particularly on the continental shelf area), aeromagnetic surveys to determine depth to basement and hence near-surface density variations, and extension of the gravity survey beyond the continental shelf by surface-ship gravity meter or by submarine pendulums.

Measurements of densities of samples of the various rock-types in the area would of course also assist interpretation. However, these would need to be unweathered samples from drill cores or quarries.

7. GRAVITY DATA FILES

The BMR gravity data used in this Record are stored in the Gravity Group of the Geophysical Branch of the BMR under the following reference numbers:

1954 Survey

54-101 Gravity anomaly computations

54-102 Field note books - gravity meter and barometer, including station descriptions

58-517 Gravity drift sheets

58-518 Microbarograph records

58-519 Wet and dry bulb thermometer

58-521 Tidal corrections

58-522 Corrections to gravity readings (drift and tidal)

58-523 Barometric elevation calculations

58-524 Survey data

58-528 Gravity loop misclosures

Underwater gravity survey

58-512 All data and calculations

Regional network survey

60-501 Gravity field notes

60-502 Station descriptions

60-503 Elevation information

60-504 Gravity anomaly computations

60-505 Station descriptions

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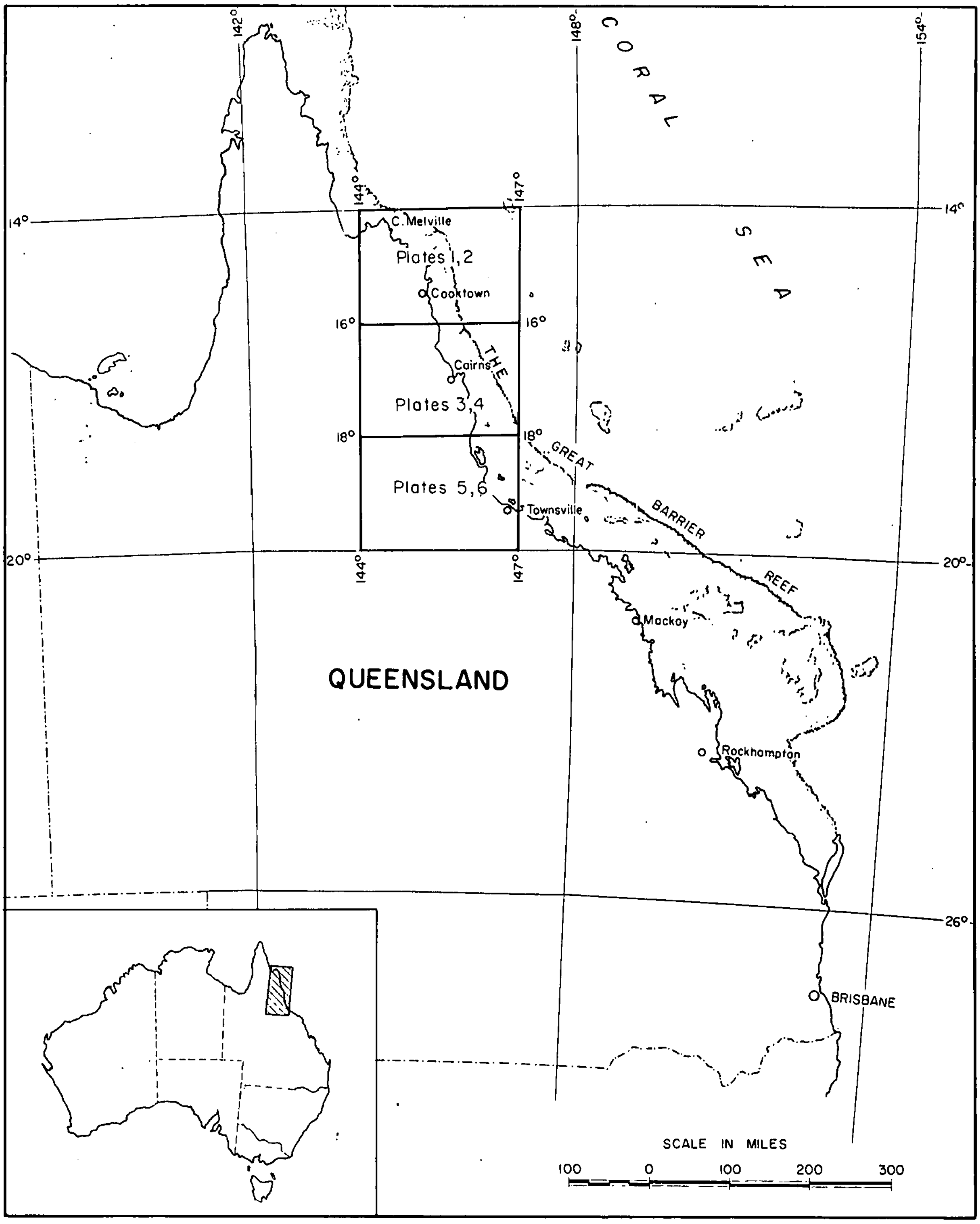


Fig.1. LOCALITY MAP

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS G231-23

TO ACCOMPANY RECORD No 1963/163

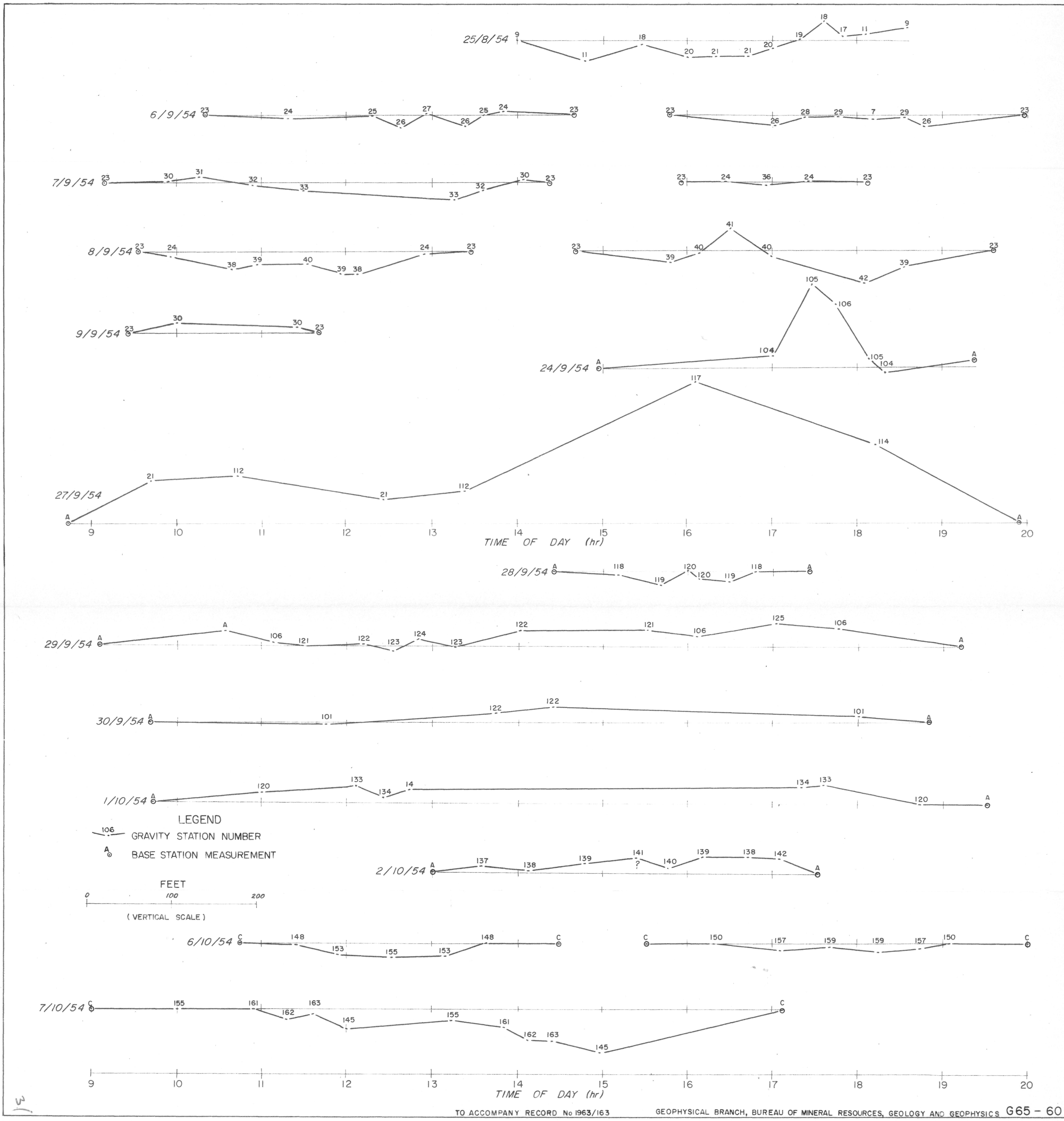
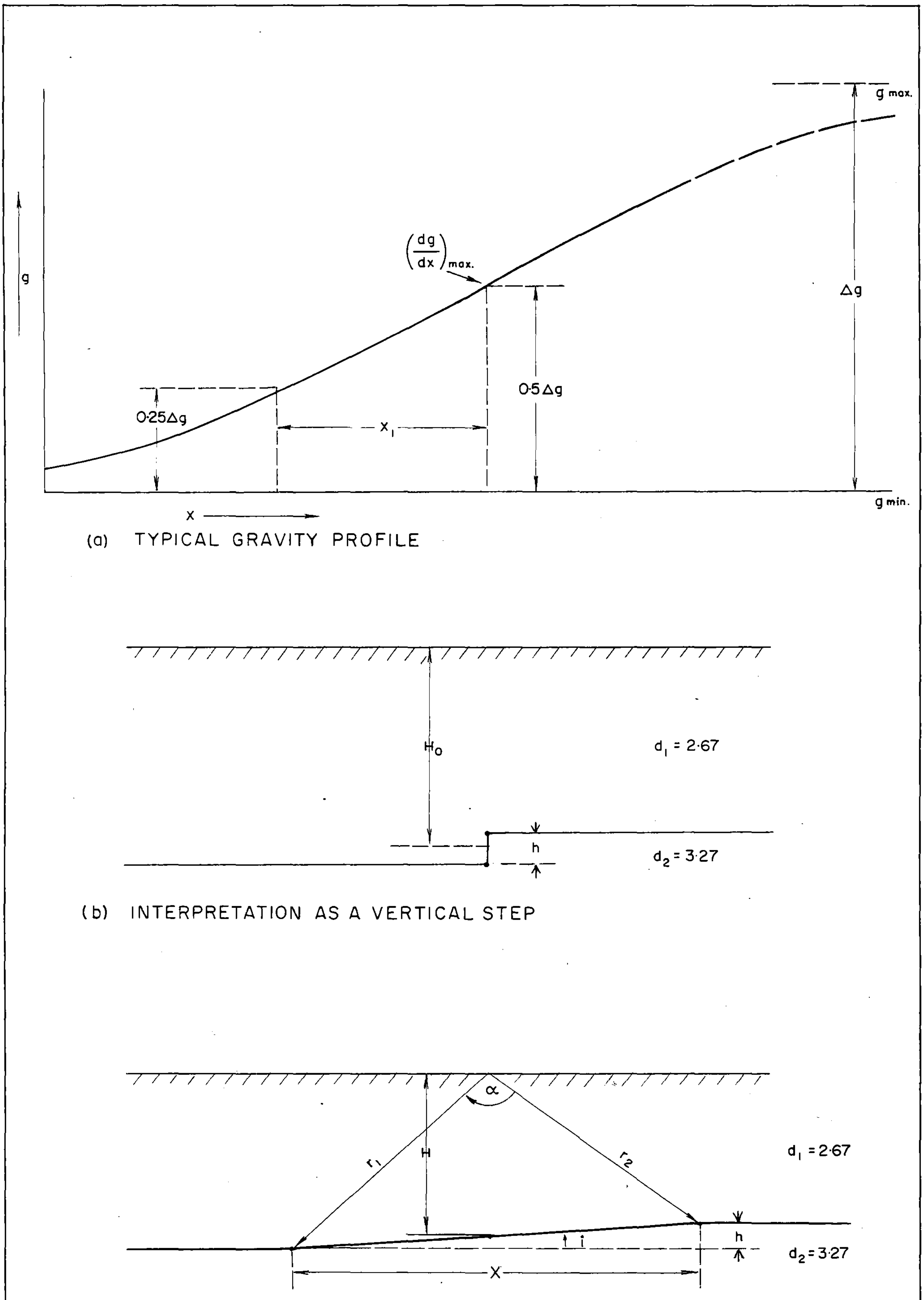


Fig. 2 BAROMETRIC ELEVATION CORRECTIONS



G 65-62

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics

TO ACCOMPANY RECORD No 1963/163

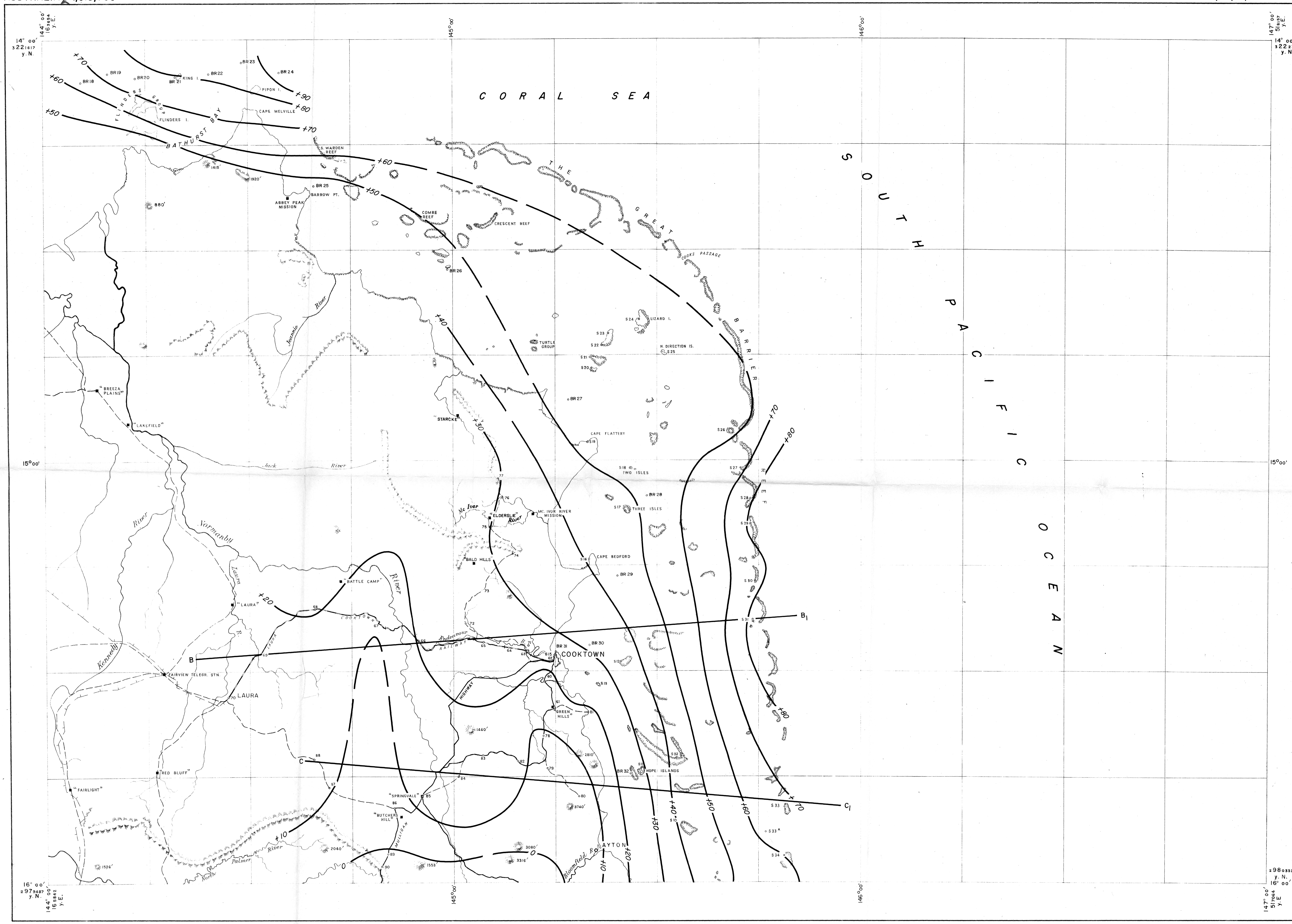
Fig. 3

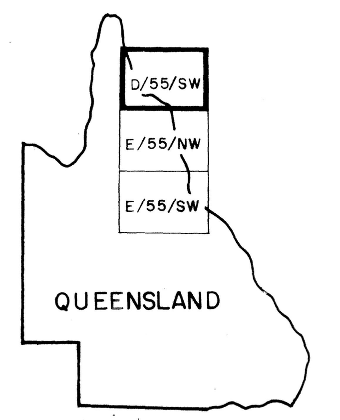
32

AUSTRALIA 1:1,013,760

D/55/S.W.
QUEENSLAND

D55/9,10,13,14 ZONE 7





MAP DATA

PROJECTION: *TRANSVERSE MERCATOR, AUSTRALIAN SERIES*

CONTROL: *4 MILE MILITARY MAPS AND QLD. DEPT. OF LANDS 4 MILE MAPS*

DETAIL: *GRID AND GRATICULE COMPUTED AND COMPILED BY THE GEOPHYSICAL DRAWING OFFICE*

PLANIMETRIC DETAIL FROM 4 MILE MILITARY MAPS, QLD. DEPT. OF LANDS 4 MILE MAPS, I.C.A.O. CHARTS AND ADMIRALTY CHARTS

GEOPHYSICAL DATA FROM B.M.R. SURVEYS

RELIABILITY: *(A) PLANIMETRIC – RELIABLE SKETCH*

(B) GEOPHYSICAL – REGIONAL GRAVITY

REGIONAL GRAVITY SURVEYS (1954-60)
NORTH COASTAL AREA, QLD.
BOUGUER ANOMALIES

SCALE IN MILES

8 4 0 8 16 24 32

LEGEND

TOPOGRAPHY

WATERCOURSE — ROAD

HOMESTEAD — TRACK

GRAVITY

GRAVITY STATION

S 24 STATION NUMBER

1553 ALTITUDE IN FEET

GRAVITY CONTOURS IN MILLIGALS

GRAVITY HIGH ANOMALY

" LOW "

EXPLANATION

GRAVITY DATUM – CAIRNS PENDULUM STATION EQUALS 978,499·4 MILLIGALS

ELEVATION DATUM – M.S.L. CAIRNS

AVERAGE ROCK DENSITY OF 2·67 g/cm³ HAS BEEN USED FOR THE CALCULATION OF BOUGUER ANOMALIES.

TO ACCOMPANY RECORD No 1963/163

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

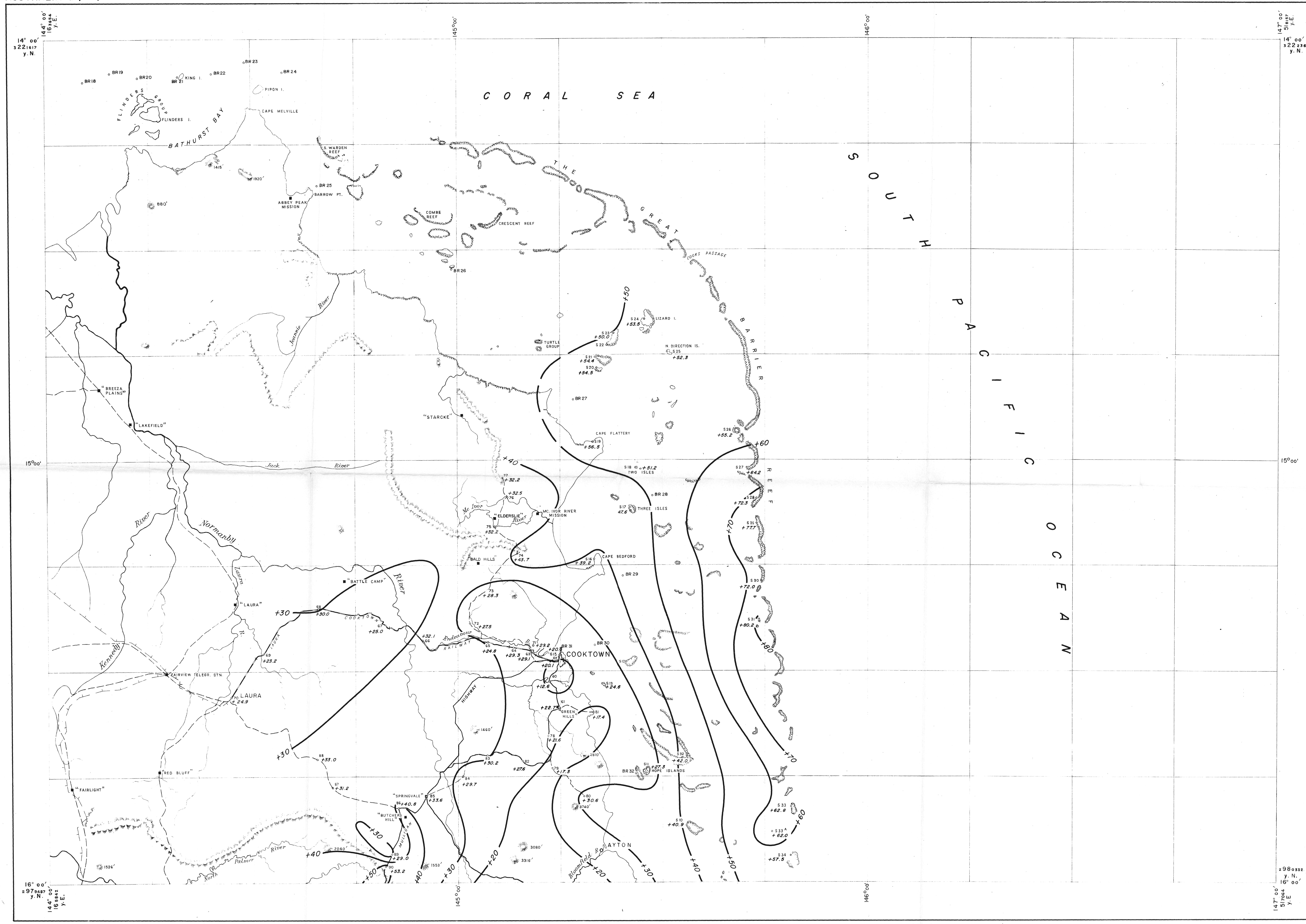
G 69-307-1

AUSTRALIA 1:1,013,760

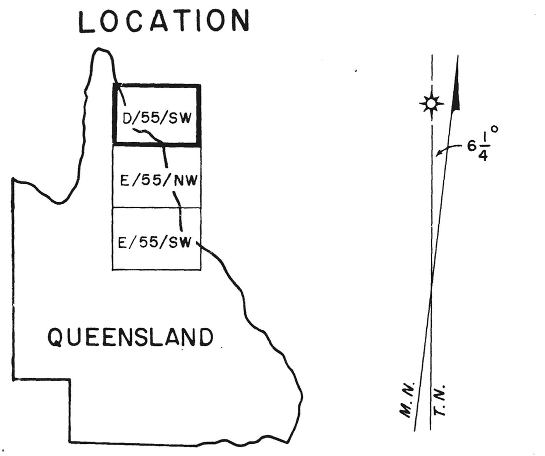
D/55/S.W.
QUEENSLAND

PLATE 2

D 55/9,10,13,14 ZONE 7



LOCATION



MAP DATA

PROJECTION: TRANSVERSE MERCATOR, AUSTRALIAN SERIES

CONTROL: 4 MILE MILITARY MAPS AND QLD. DEPT. OF LANDS 4 MILE MAPS

DETAIL: GRID AND GRATICULE COMPUTED AND COMPILED BY THE GEOPHYSICAL DRAWING OFFICE

PLANIMETRIC DETAIL FROM 4 MILE MILITARY MAPS, QLD. DEPT. OF LANDS 4 MILE MAPS, I.C.A.O. CHARTS AND ADMIRALTY CHARTS

GEOPHYSICAL DATA FROM B.M.R. SURVEYS

RELIABILITY: (A) PLANIMETRIC – RELIABLE SKETCH

(B) GEOPHYSICAL – REGIONAL GRAVITY

REGIONAL GRAVITY SURVEYS (1954-60)
NORTH COASTAL AREA, QLD.
FREE-AIR ANOMALY MAP

SCALE IN MILES

8 4 0 8 16 24 32

LEGEND

TOPOGRAPHY

WATERCOURSE

HOMESTEAD

ROAD

TRACK

GRAVITY

GRAVITY STATION

S 24 STATION NUMBER

1553 ALTITUDE IN FEET

GRAVITY CONTOURS IN MILLIGALS

GRAVITY HIGH ANOMALY

" LOW "

EXPLANATION

GRAVITY DATUM – CAIRNS PENDULUM STATION EQUALS 978,499·4 MILLIGALS

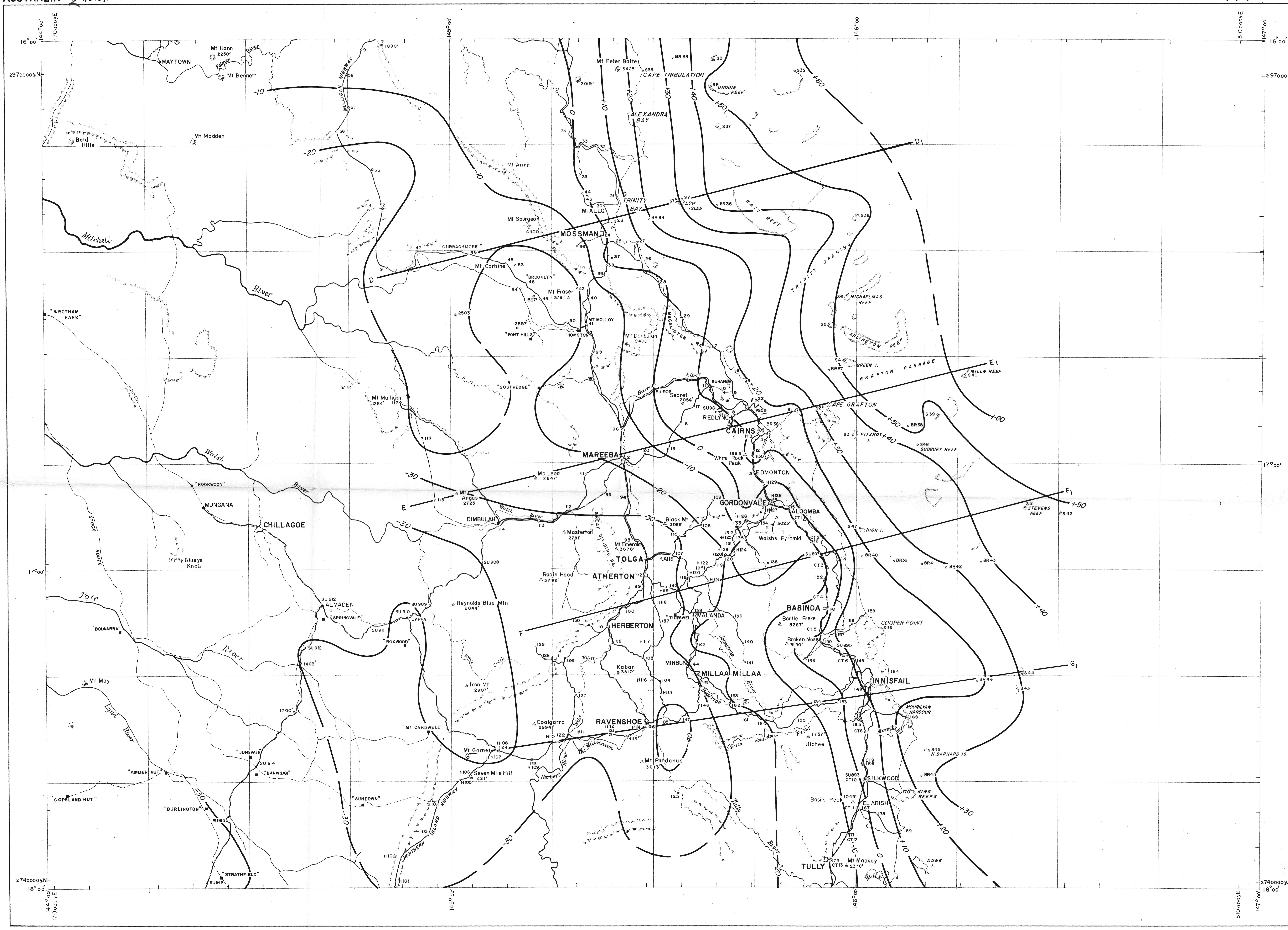
ELEVATION DATUM – M.S.L. CAIRNS

AVERAGE ROCK DENSITY OF 2·67 g/cm^3 HAS BEEN USED FOR THE CALCULATION OF BOUGUER ANOMALIES.

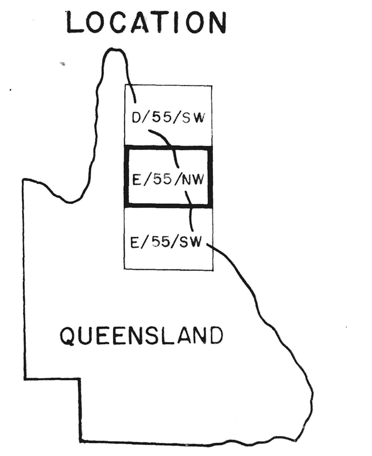
TO ACCOMPANY RECORD No 1963/163

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

G 69-312



LOCATION



MAP DATA

PROJECTION: TRANSVERSE MERCATOR, AUSTRALIAN SERIES.
CONTROL: EXISTING 1 AND 4 MILE MILITARY MAPS.
DETAIL: GRID AND GRATICULE COMPUTED AND COMPILED BY THE GEOPHYSICAL DRAWING OFFICE.
PLANIMETRIC DETAIL FROM 1 AND 4 MILE MILITARY MAPS AND ADMIRALTY CHARTS.
GEOPHYSICAL DATA FROM SYDNEY UNIVERSITY AND B.M.R. SURVEYS.
RELIABILITY: (A) PLANIMETRIC — RELIABLE SKETCH.
(B) GEOPHYSICAL — REGIONAL GRAVITY.

REGIONAL GRAVITY SURVEYS (1954-60)
NORTH COASTAL AREA, QLD
BOUGUER ANOMALIES

SCALE IN MILES
8 4 0 8 16 24 32

LEGEND

TOPOGRAPHY

WATERCOURSE — ROAD
HOMESTEAD — TRACK

GRAVITY

GRAVITY ST-N (B.M.R.)
" " (SYDNEY UNIV.) — GRAVITY CONTOURS IN MILLIGALS
173 STATION NUMBER
GRAVITY HIGH ANOMALY
420.3' ALTITUDE IN FEET — GRAVITY LOW ANOMALY

EXPLANATION

GRAVITY DATUM — CAIRNS PENDULUM STATION EQUALS 978,499.4 MILLIGALS.

ELEVATION DATUM — M.S.L. CAIRNS.

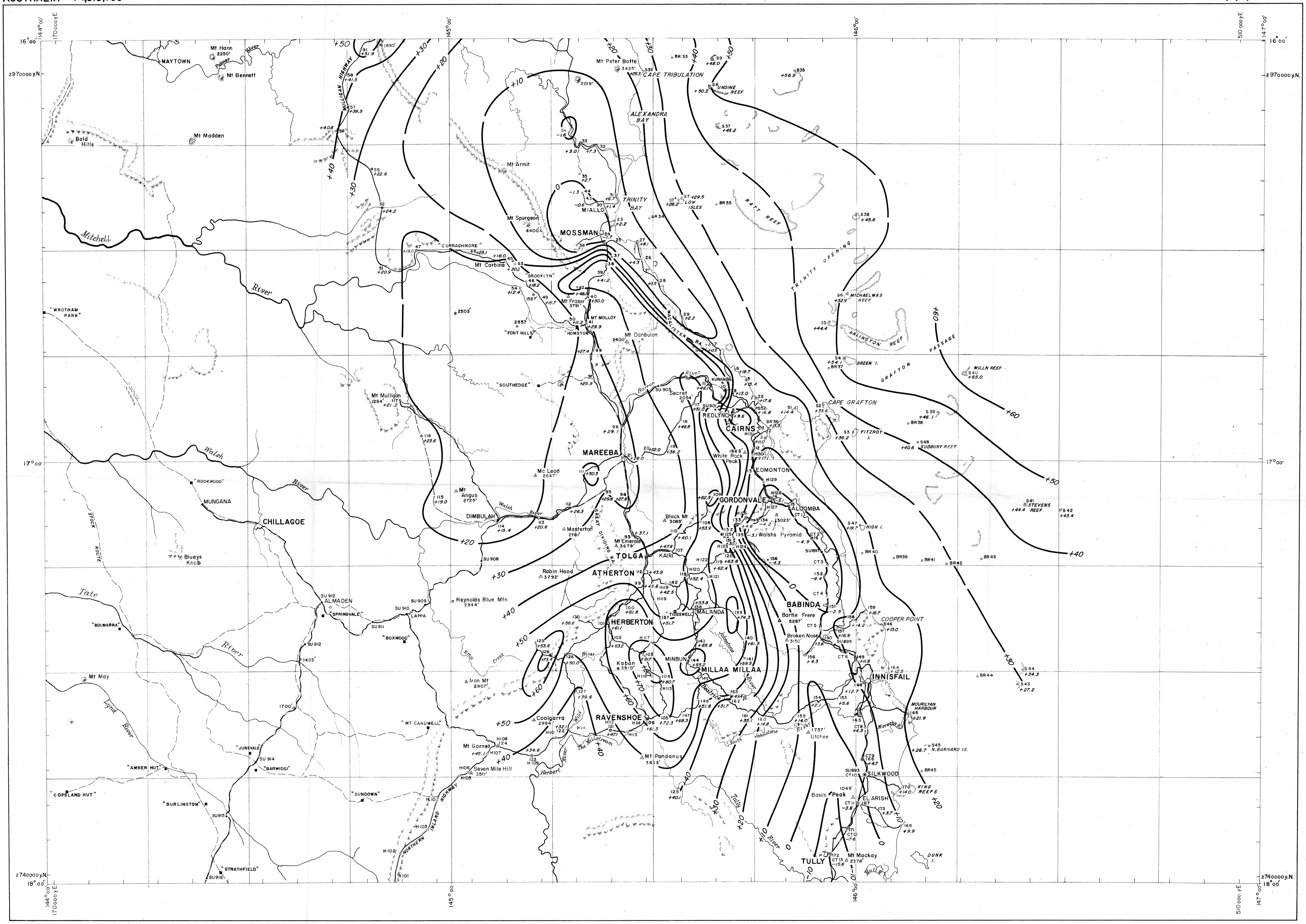
AVERAGE ROCK DENSITY OF 2·67 g/cm^3 HAS BEEN USED FOR THE CALCULATION OF BOUGUER ANOMALIES.

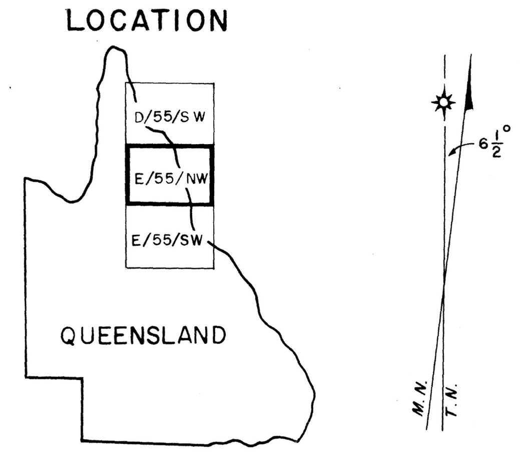
2
AUSTRALIA 1:1,013,760

E/55/N.W.
QUEENSLAND

PLATE 4

E55/1,2,5,6 ZONE 7





MAP DATA

PROJECTION: TRANSVERSE MERCATOR, AUSTRALIAN SERIES.
CONTROL: EXISTING 1 AND 4 MILE MILITARY MAPS.
DETAIL: GRID AND GRATICULE COMPUTED AND COMPILED BY THE GEOPHYSICAL DRAWING OFFICE.
PLANIMETRIC DETAIL FROM 1 AND 4 MILE MILITARY MAPS AND ADMIRALTY CHARTS.
GEOPHYSICAL DATA FROM SYDNEY UNIVERSITY AND B.M.R. SURVEYS.
RELIABILITY: (A) PLANIMETRIC — RELIABLE SKETCH.
(B) GEOPHYSICAL — REGIONAL GRAVITY.

REGIONAL GRAVITY SURVEYS (1954-60)
NORTH COASTAL AREA, QLD

FREE-AIR ANOMALY MAP

SCALE IN MILES
8 4 0 8 16 24 32

LEGEND

TOPOGRAPHY
WATERCOURSE — ROAD
HOMESTEAD — TRACK

GRAVITY
GRAVITY ST-N (B.M.R.) (SYDNEY UNIV) — GRAVITY CONTOURS IN MILLIGALS
173 STATION NUMBER — GRAVITY HIGH ANOMALY
420.3' ALTITUDE IN FEET — GRAVITY LOW ANOMALY

EXPLANATION

GRAVITY DATUM — CAIRNS PENDULUM STATION EQUALS 978,499.4 MILLIGALS.
ELEVATION DATUM — M.S.L. CAIRNS.
AVERAGE ROCK DENSITY OF 2·67 g/cm^3 HAS BEEN USED FOR THE CALCULATION OF BOUGUER ANOMALIES.

TO ACCOMPANY RECORD No 1963/163

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

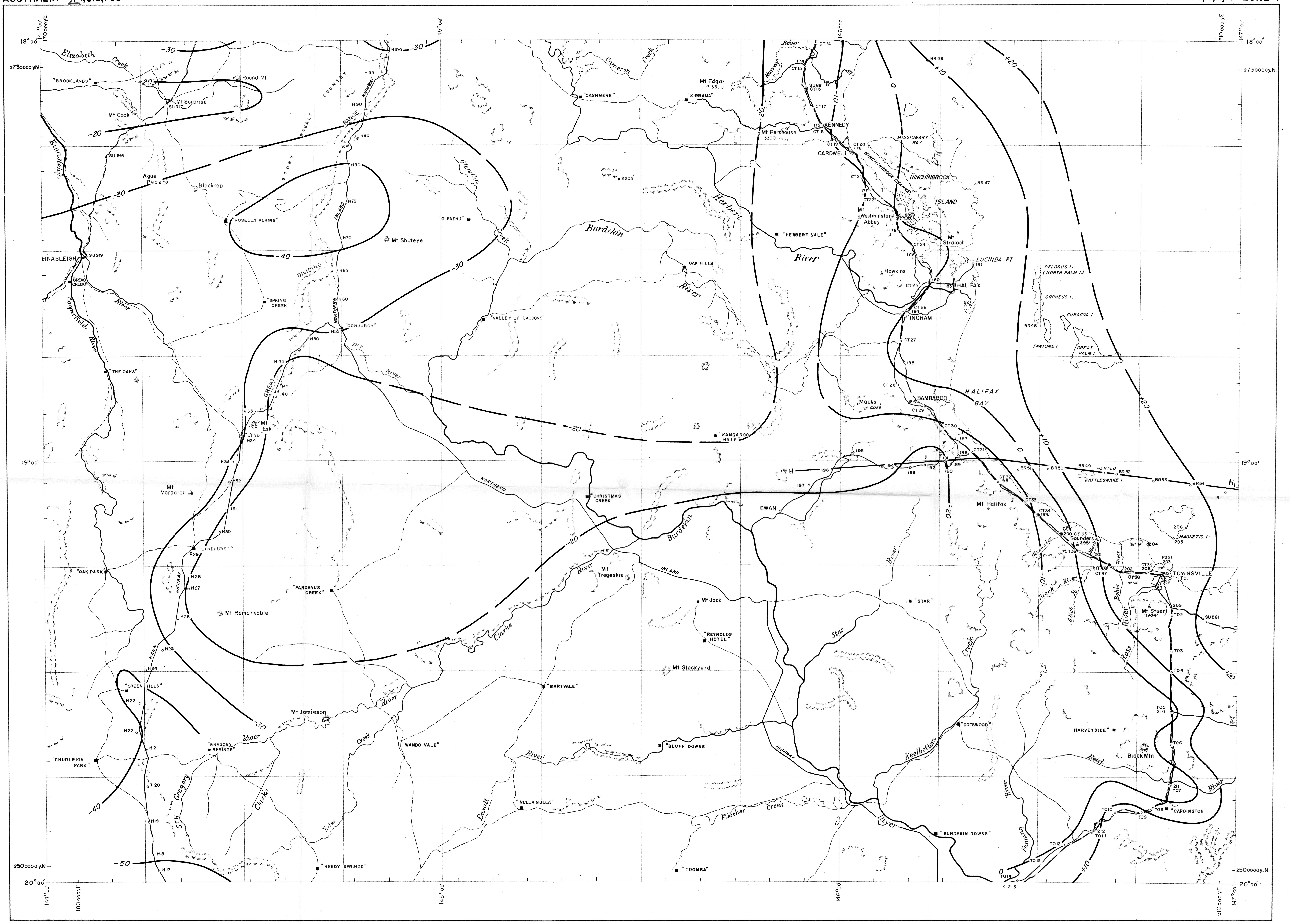
G 69-310

PLATE 5

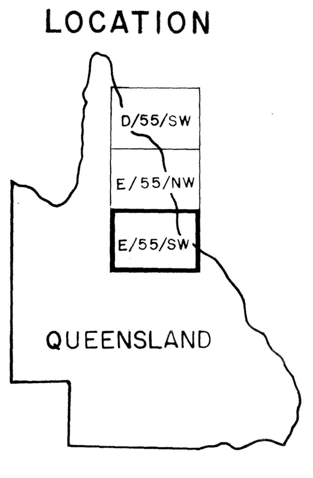
AUSTRALIA 1:1,013,760

E/55/S.W.
QUEENSLAND

E55/9,10,13,14 ZONE 7



LOCATION



MAP DATA

PROJECTION: TRANSVERSE MERCATOR, AUSTRALIAN SERIES.
CONTROL: EXISTING 1 AND 4 MILE MILITARY MAPS.
DETAIL: GRID AND GRATICULE COMPUTED AND COMPILED BY THE GEOPHYSICAL DRAWING OFFICE.
PLANIMETRIC DETAIL FROM 1 AND 4 MILE MILITARY MAPS.
GEOPHYSICAL DATA FROM SYDNEY UNIVERSITY AND B.M.R. SURVEYS.
RELIABILITY: (A) PLANIMETRIC — RELIABLE SKETCH.
(B) GEOPHYSICAL — REGIONAL GRAVITY.

REGIONAL GRAVITY SURVEYS (1954-60)
NORTH COASTAL AREA, QLD

BOUGUER ANOMALIES

SCALE IN MILES

8 4 0 8 16 24 32

LEGEND

TOPOGRAPHY

WATERCOURSE — ROAD
HOMESTEAD — TRACK

GRAVITY

GRAVITY ST-N (B.M.R.) (SYDNEY UNIV.) — GRAVITY CONTOURS IN MILLIGALS
201 STATION NUMBER — GRAVITY HIGH ANOMALY
420.3' ALTITUDE IN FEET — GRAVITY LOW ANOMALY

EXPLANATION

GRAVITY DATUM — CAIRNS PENDULUM STATION EQUALS 978, 499.4 MILLIGALS.

ELEVATION DATUM — M.S.L. CAIRNS.

AVERAGE ROCK DENSITY OF 2.67 g/cm³ HAS BEEN USED FOR THE CALCULATION OF BOUGUER ANOMALIES.

TO ACCOMPANY RECORD No 1963/163

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

G 69-309-1

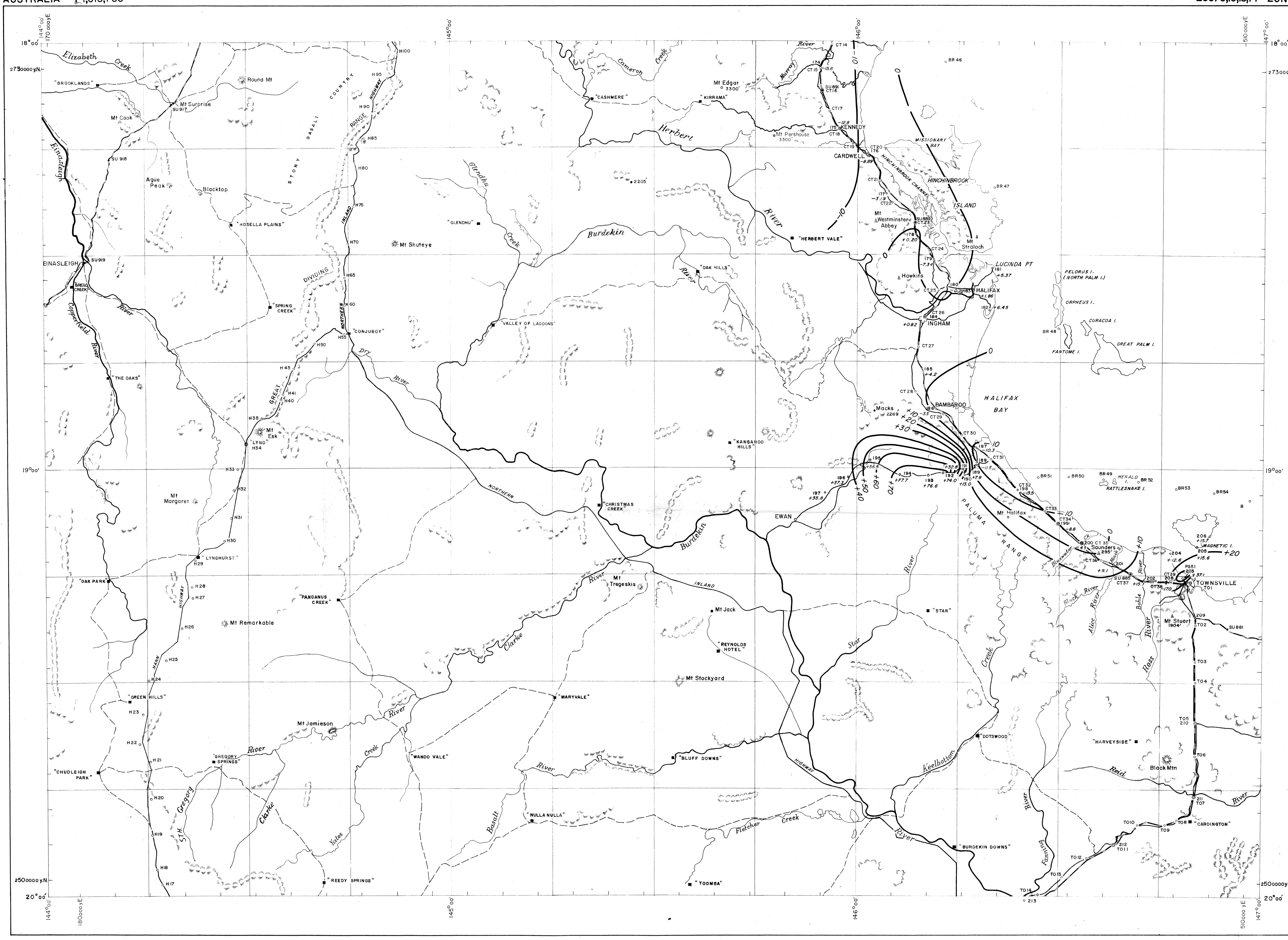
PLATE 6

E/55/S.W.

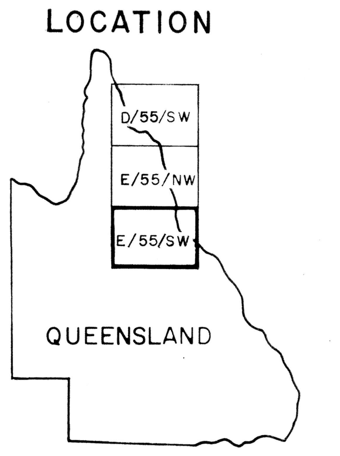
QUEENSLAND

AUSTRALIA 1:1,013,760

E55/9,10,13,14 ZONE 7



LOCATION



MAP DATA

PROJECTION: *TRANSVERSE MERCATOR, AUSTRALIAN SERIES.*

CONTROL: *EXISTING 1 AND 4 MILE MILITARY MAPS.*

DETAIL: *GRID AND GRATICULE COMPUTED AND COMPILED BY THE GEOPHYSICAL DRAWING OFFICE.*

PLANIMETRIC DETAIL FROM 1 AND 4 MILE MILITARY MAPS.

GEOPHYSICAL DATA FROM SYDNEY UNIVERSITY AND B.M.R. SURVEYS.

RELIABILITY: *(A) PLANIMETRIC — RELIABLE SKETCH.*

(B) GEOPHYSICAL — REGIONAL GRAVITY.

REGIONAL GRAVITY SURVEYS (1954-60)

NORTH COASTAL AREA, QLD

FREE-AIR ANOMALY MAP

SCALE IN MILES

8 4 0 8 16 24 32

LEGEND

TOPOGRAPHY

WATERCOURSE — *ROAD*

HOMESTEAD — *TRACK*

GRAVITY

GRAVITY ST-N (B.M.R.)

" " (SYDNEY UNIV.) — *GRAVITY CONTOURS IN MILLIGALS*

201 *STATION NUMBER*

GRAVITY HIGH ANOMALY

420.3' *ALTITUDE IN FEET* — *GRAVITY LOW ANOMALY*

EXPLANATION

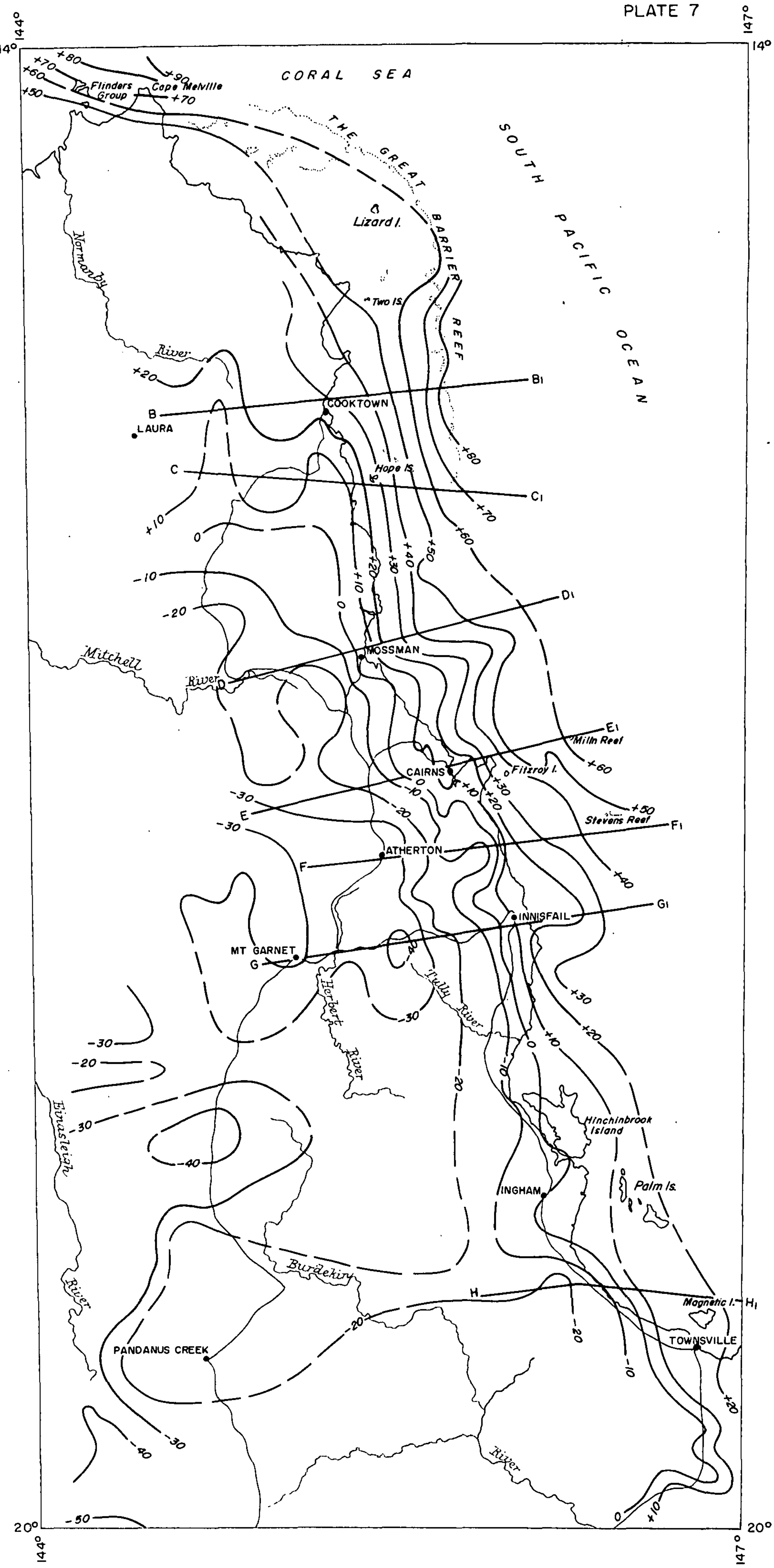
GRAVITY DATUM — CAIRNS PENDULUM STATION EQUALS 978,499.4 MILLIGALS.

ELEVATION DATUM — M.S.L. CAIRNS.

AVERAGE ROCK DENSITY OF 2·67 g/cm^3 HAS BEEN USED FOR THE CALCULATION OF BOUGUER ANOMALIES.

TO ACCOMPANY RECORD No 1963/163

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS G 69-311



CAPE MELVILLE TO TOWNSVILLE
BOUGUER ANOMALIES

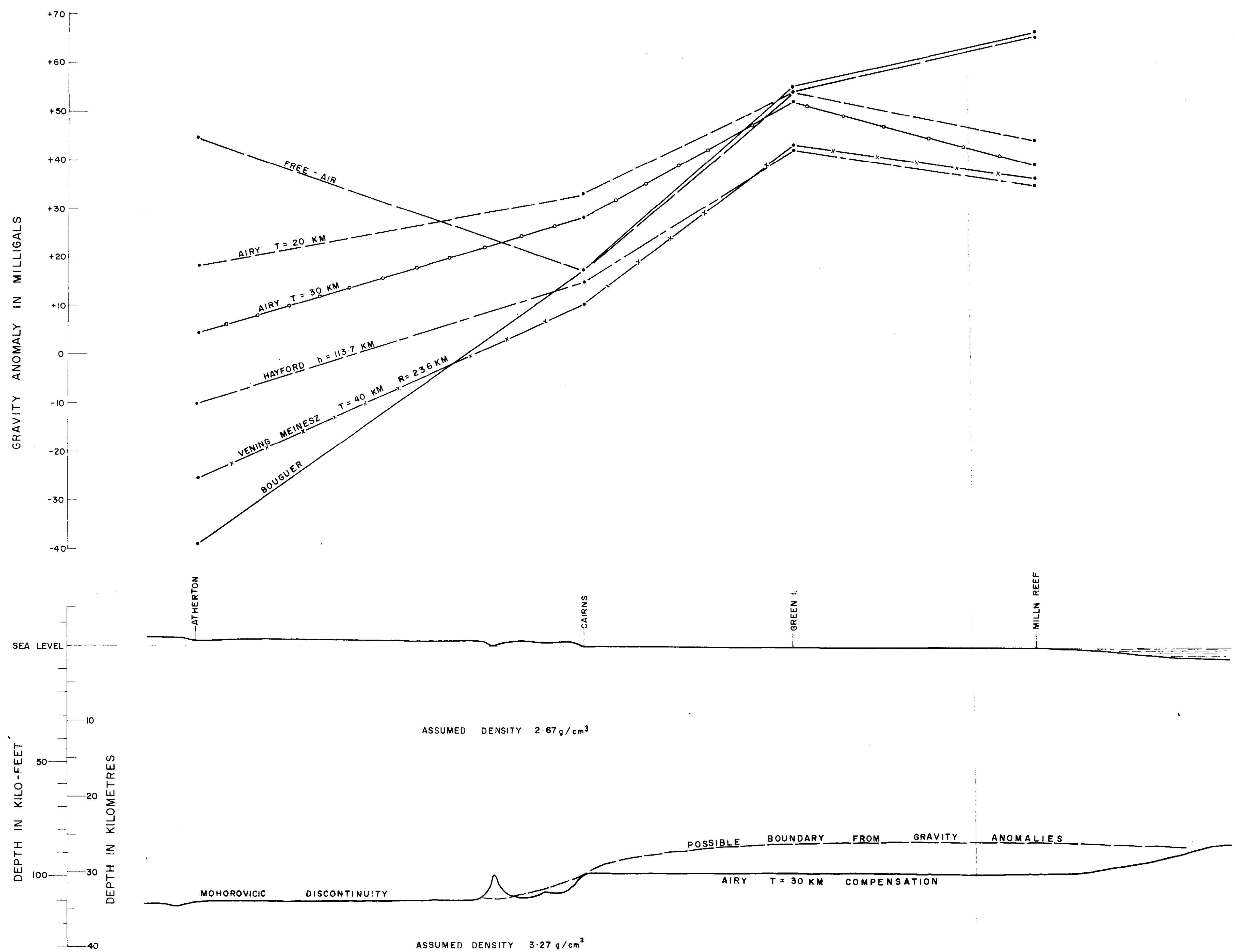
40 0 40 MILES 80

CONTOUR INTERVAL 10 MILLIGALS

DENSITY = 2·67 g/cm³

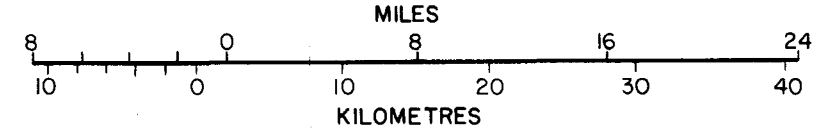
TO ACCOMPANY RECORD No 1963 / 163

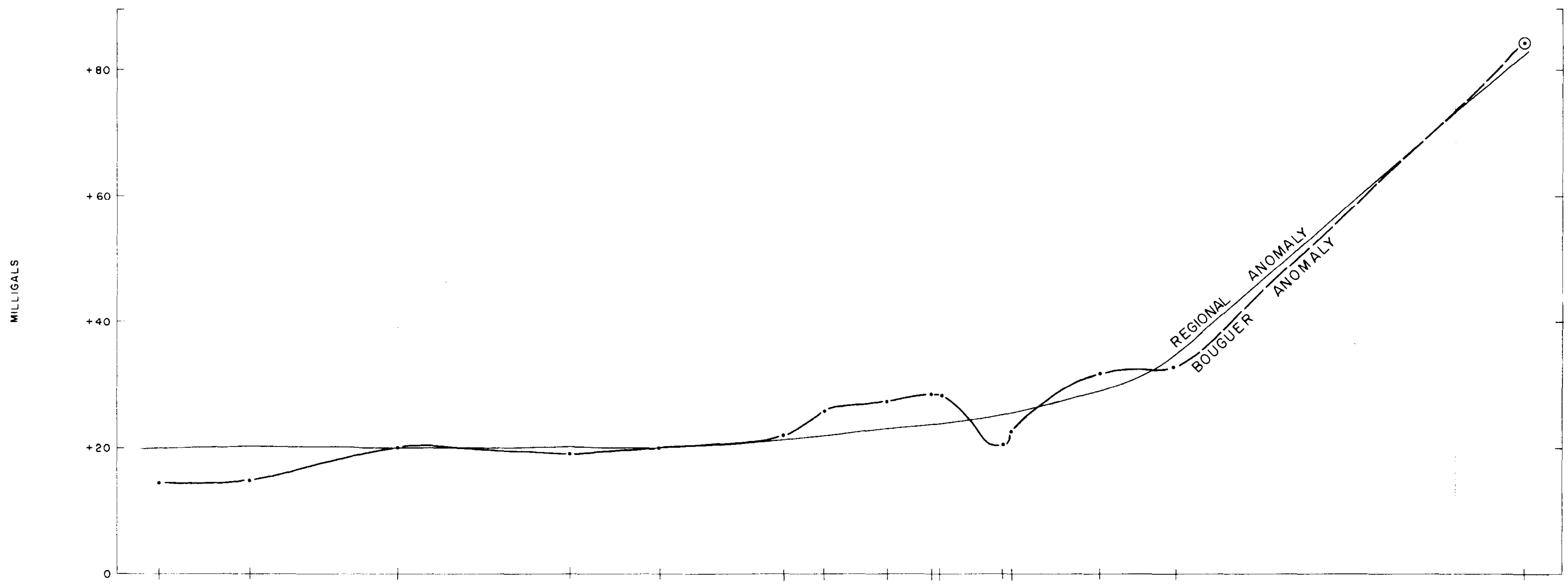
GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS G 231-24

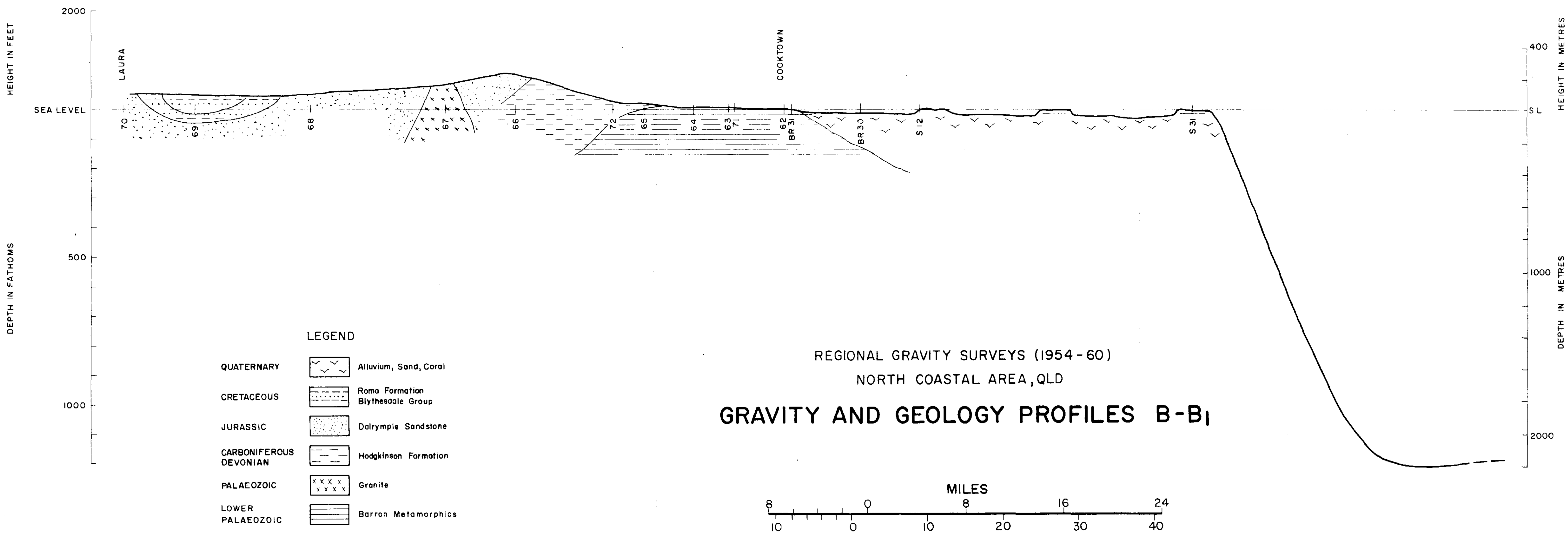


REGIONAL GRAVITY SURVEYS (1954 - 60)
NORTH COASTAL AREA, QLD.

ISOSTATIC ANOMALIES







REGIONAL GRAVITY SURVEYS (1954-60)

NORTH COASTAL AREA, QLD

GRAVITY AND GEOLOGY PROFILES B-B₁

MILES

8 0 8 16 24

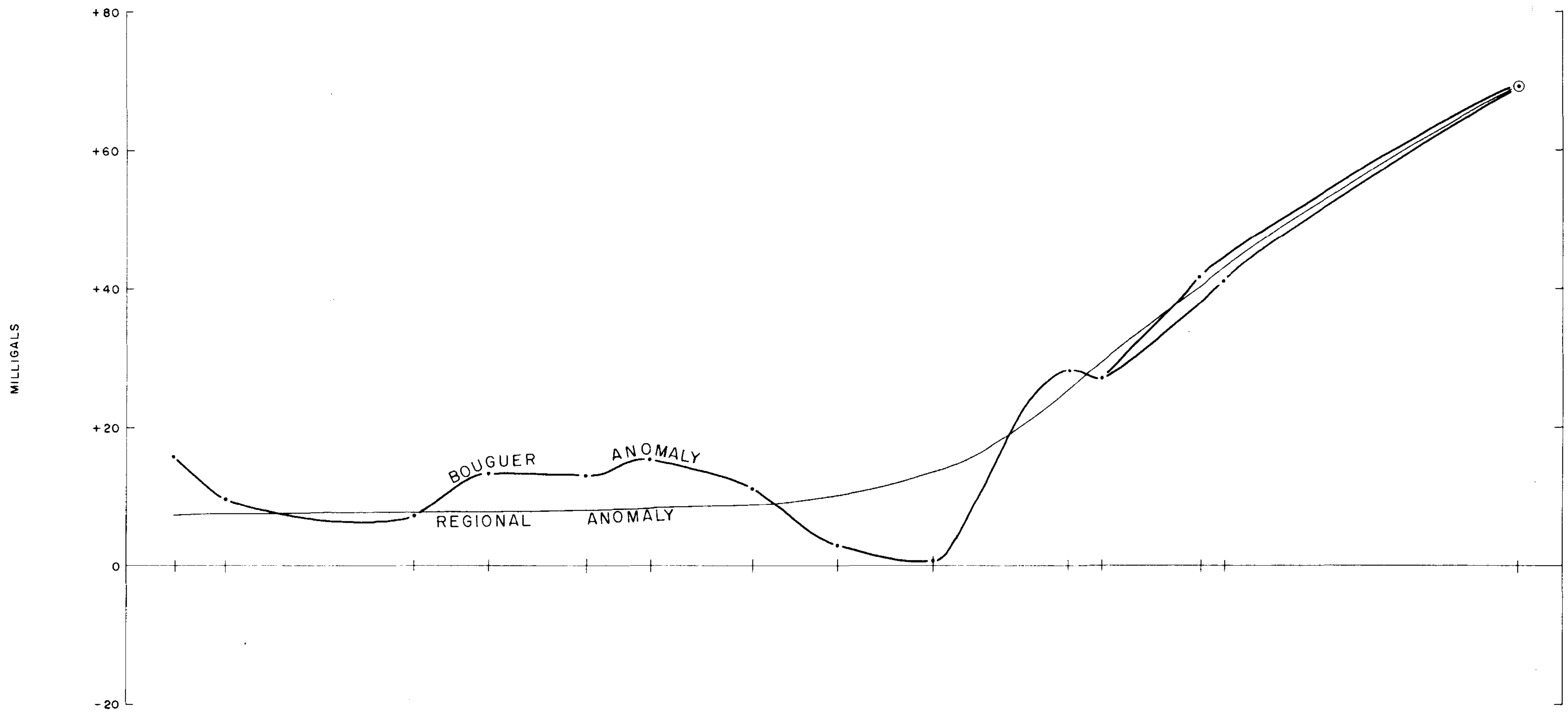
10 0 10 20 30 40

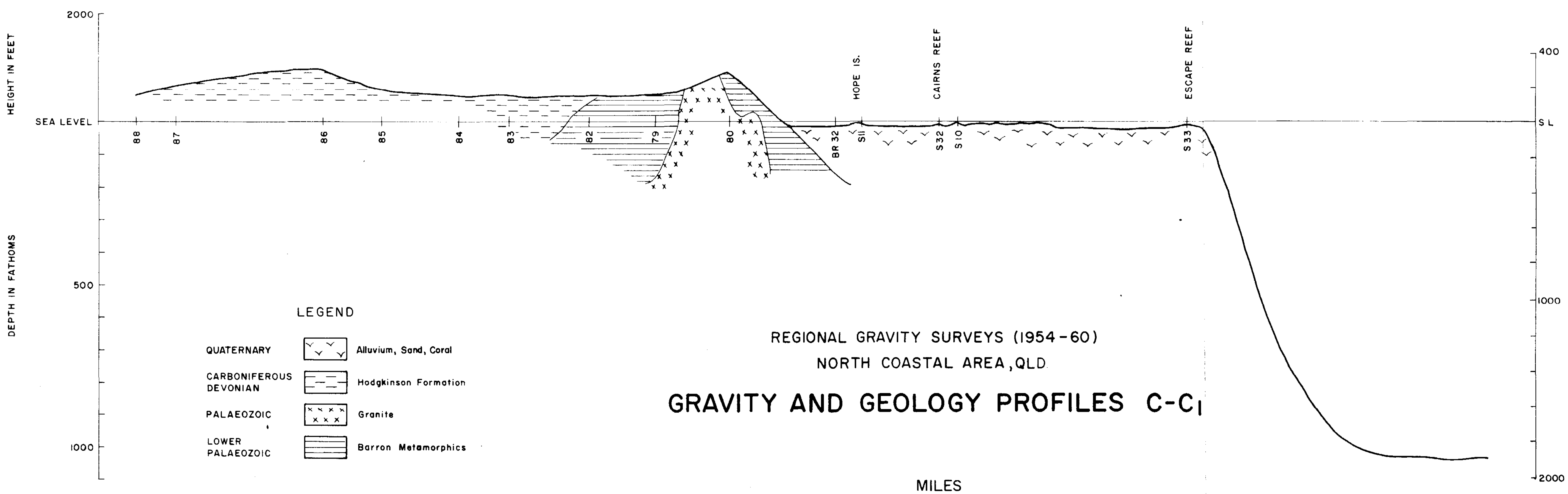
KILOMETRES

VERTICAL SCALES AS SHOWN

TO ACCOMPANY RECORD No 1963/163

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics. D55/B2-17





REGIONAL GRAVITY SURVEYS (1954-60)

NORTH COASTAL AREA, QLD.

GRAVITY AND GEOLOGY PROFILES C-C$_1$

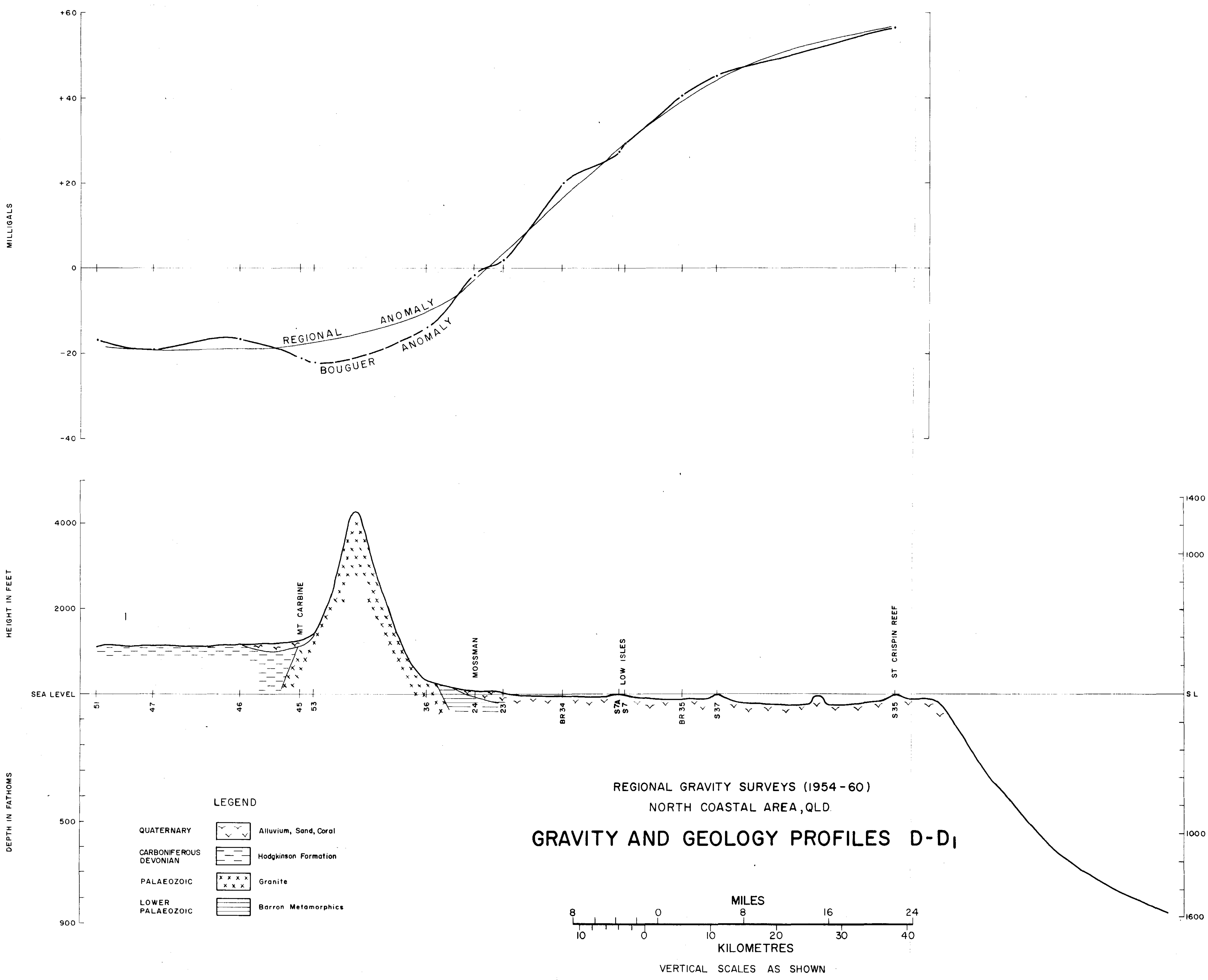
MILES
8 0 8 16 24
10 0 10 20 30 40
KILOMETRES

VERTICAL SCALES AS SHOWN

TO ACCOMPANY RECORD No 1963/163

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics. D55/B2-18

PLATE 11



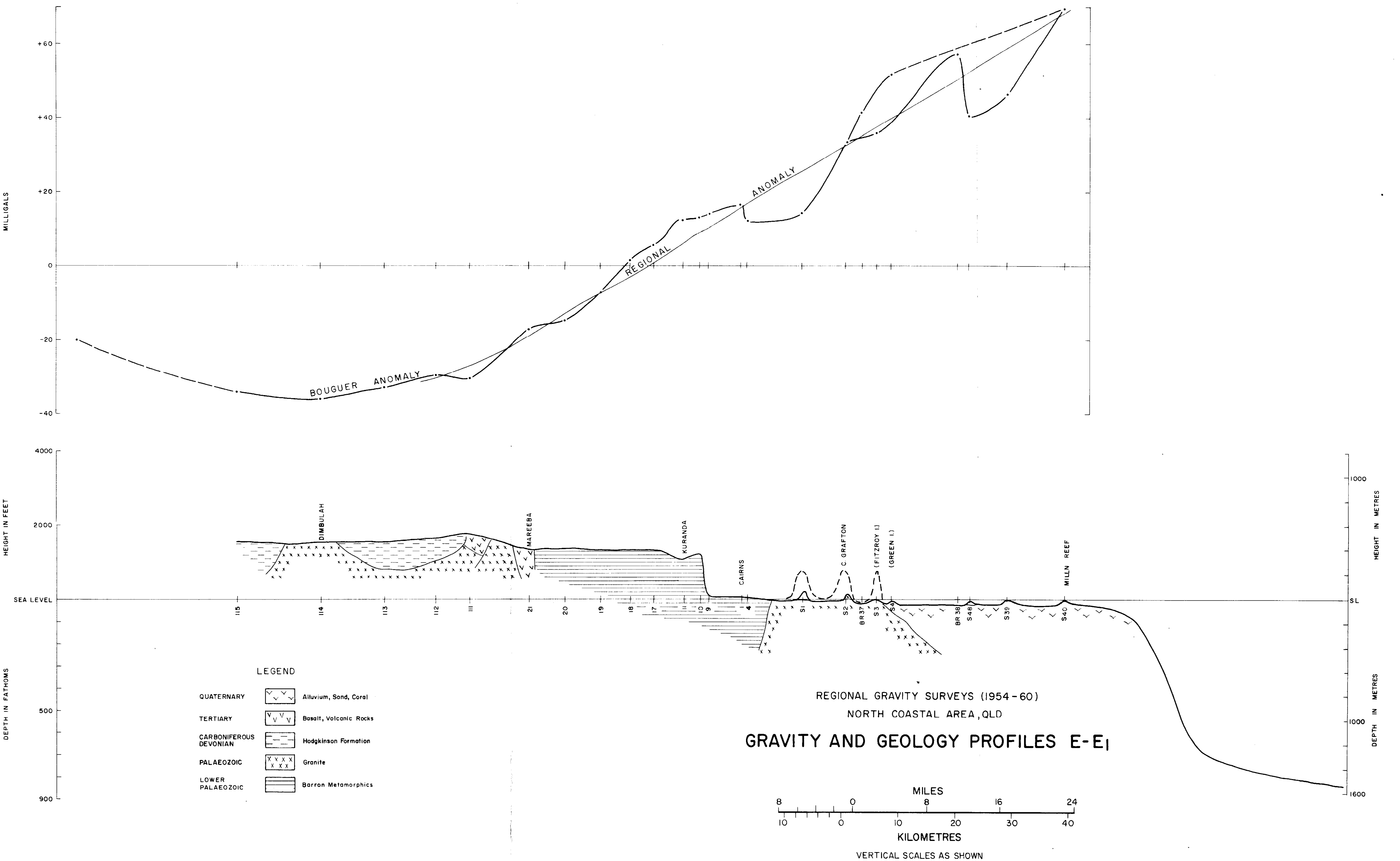
REGIONAL GRAVITY SURVEYS (1954-60)

NORTH COASTAL AREA, QLD.

GRAVITY AND GEOLOGY PROFILES D-D$_1$

TO ACCOMPANY RECORD No 1963/163

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics. E 55/B2-20



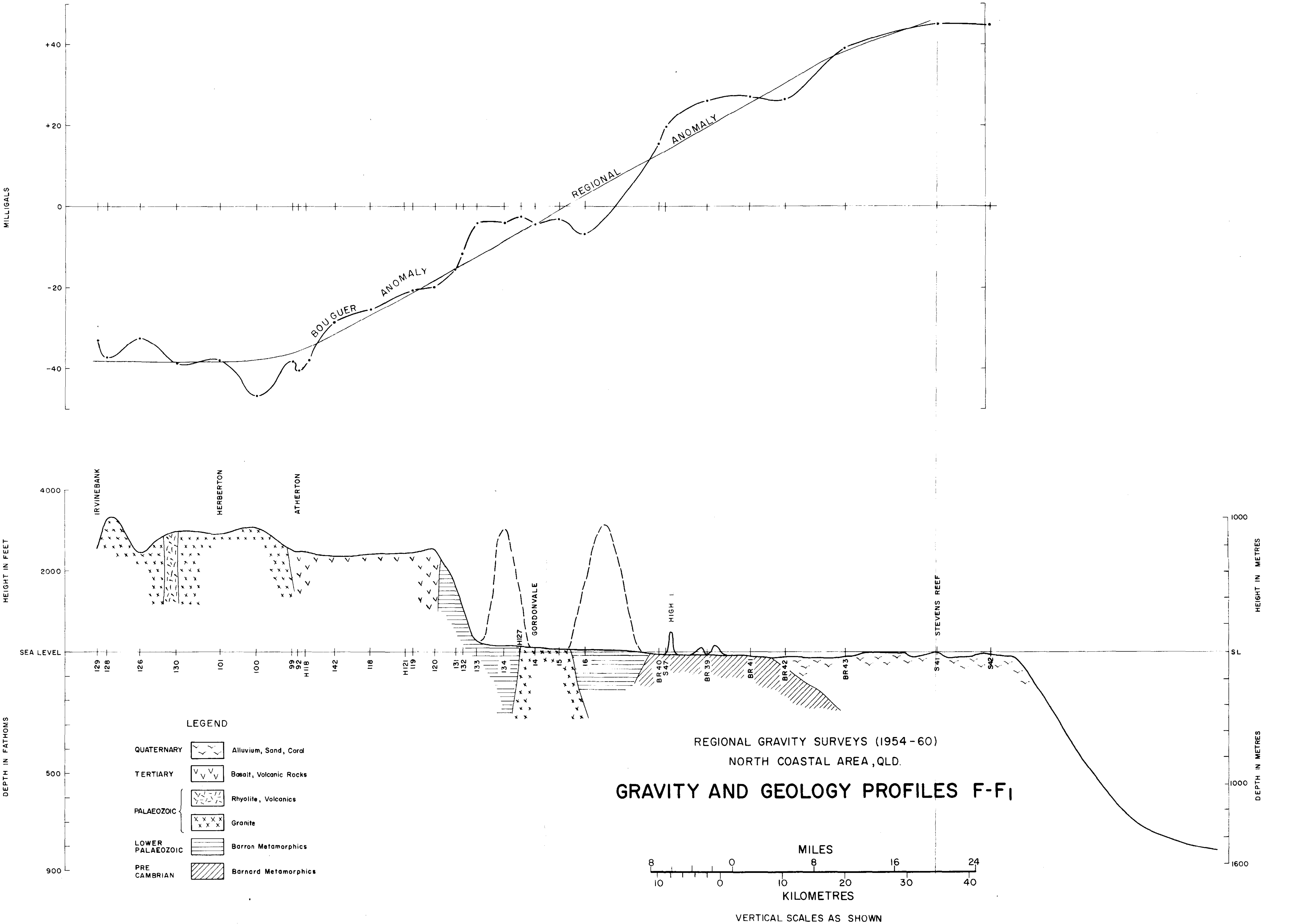
REGIONAL GRAVITY SURVEYS (1954-60)

NORTH COASTAL AREA, QLD

GRAVITY AND GEOLOGY PROFILES E-E1

TO ACCOMPANY RECORD No 1963/163

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics. E55/B2-21



REGIONAL GRAVITY SURVEYS (1954-60)

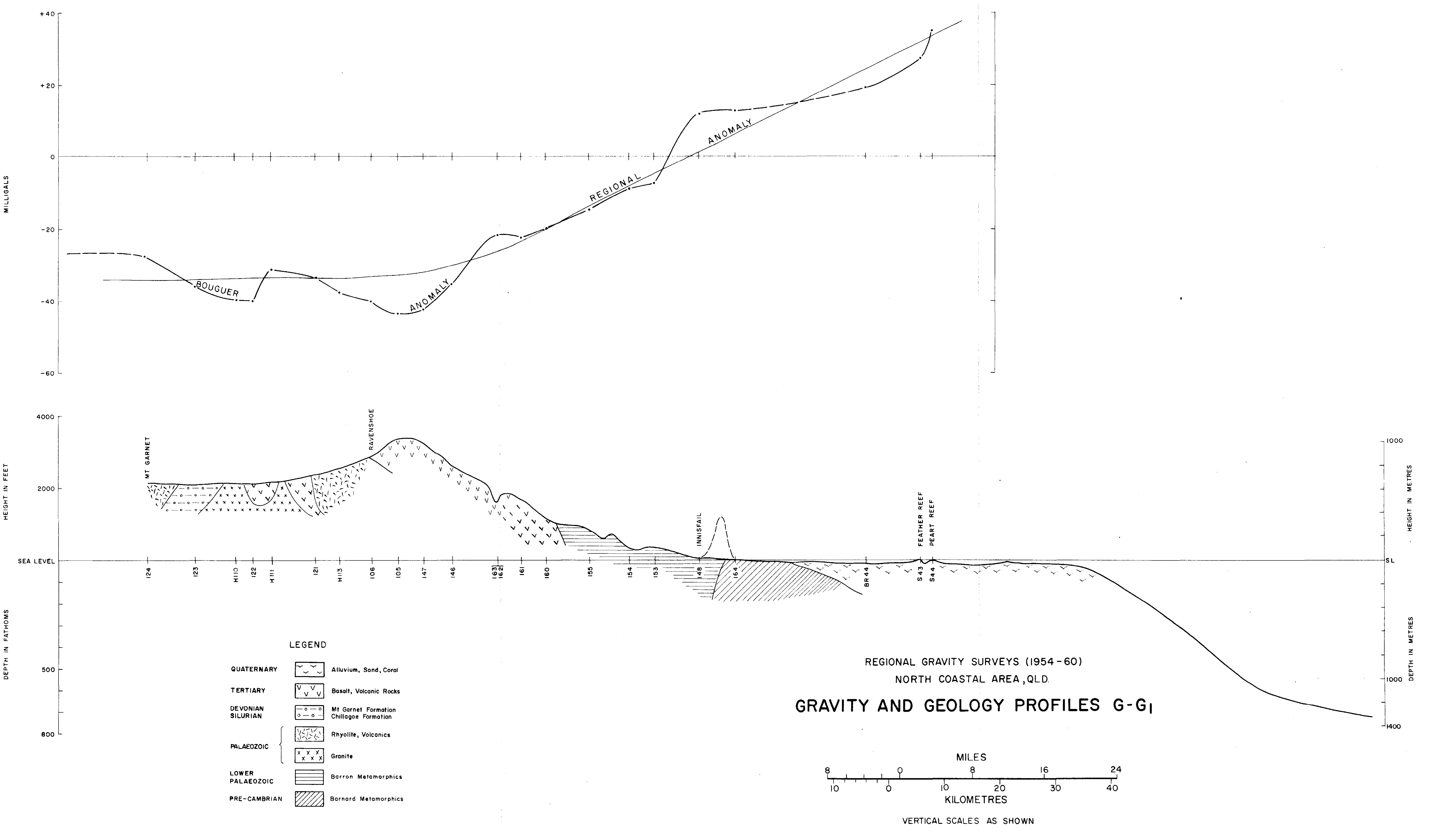
NORTH COASTAL AREA, QLD.

GRAVITY AND GEOLOGY PROFILES F-F1

TO ACCOMPANY RECORD No 1963/163

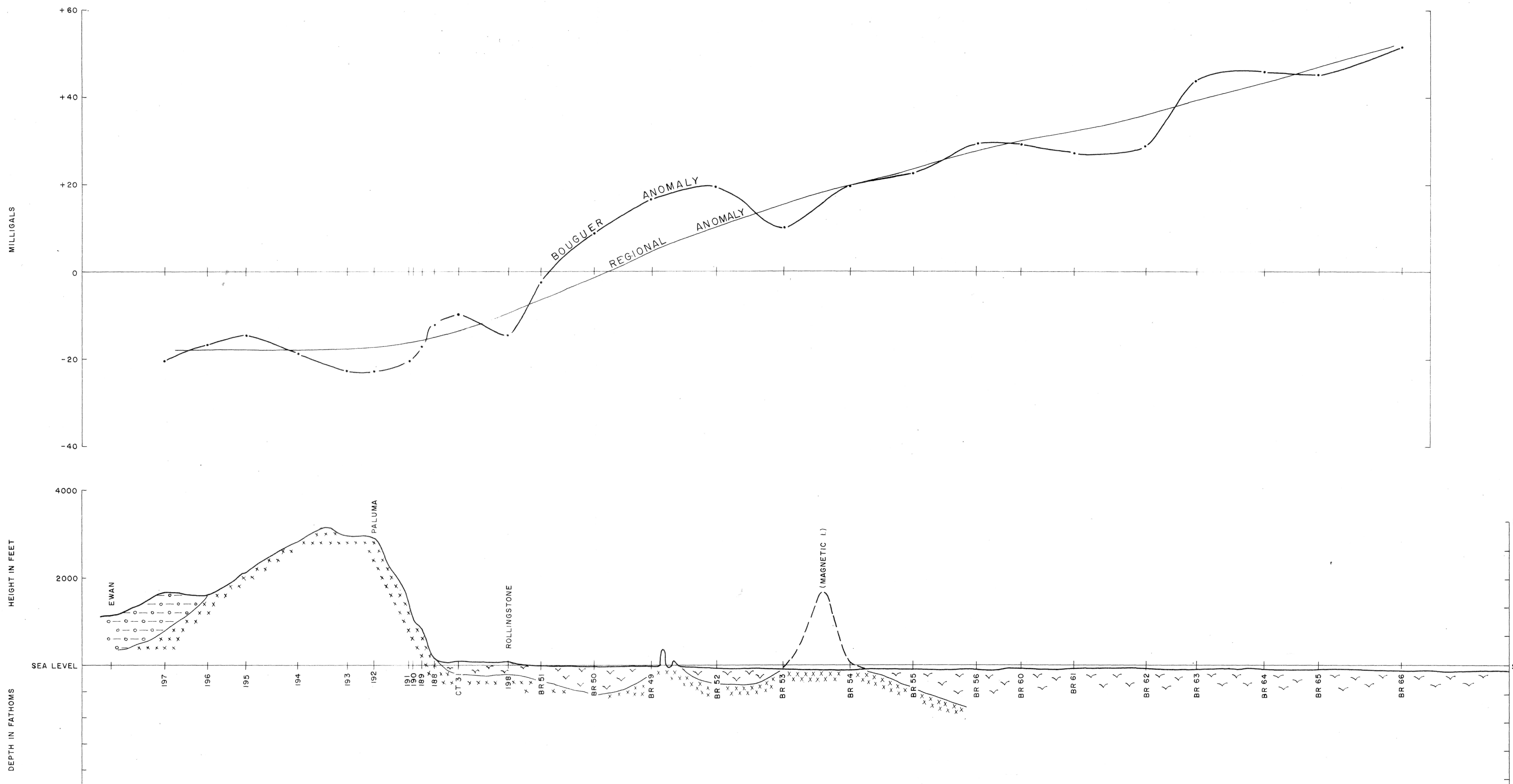
Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics. E55/B2-22

PLATE 14



TO ACCOMPANY RECORD No 1963/163

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics. E55/B2-23



LEGEND

QUATERNARY		Alluvium, Sand, Coral
DEVONIAN SILURIAN		Mt Garnet Formation Chillagoe Formation
PALAEOZOIC		Granite

REGIONAL GRAVITY SURVEYS (1954-60)

NORTH COASTAL AREA, QLD.

GRAVITY AND GEOLOGY PROFILES H-H1

MILES
8 0 8 16 24
10 0 10 20 30 40
KILOMETRES

VERTICAL SCALES AS SHOWN

TO ACCOMPANY RECORD No 1963/163

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics. E55/B2-24