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# TIMOR SEA / JOSEPH BONAPARTE GULF MARINE GRAVITY AND SEISMIC SPARKER SURVEY, NORTH-WEST AUSTRALIA 1965

by

GEOPHYSICAL ASSOCIATES PTY LTD

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# FINAL REPORT MARINE SURFACE GRAVITY AND SEISMIC SPARKER SURVEY TIMOR SEA - JOSEPH BONAPARTE GULF NORTHWEST AUSTRALIA

BUREAU OF MINERAL RESOURCES

GEOPHYSICAL ASSOCIATES PROPRIETARY LTD

Houston Texas

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## ABSTRACT

An experimental marine gravity and continuous seismic profile survey was carried out in the Bonaparte Gulf in the period from late July to early October 1965. The survey is called "experimental" because it was planned to serve as a test of the usefulness of these methods, which had not been used previously in Australia, for exploring water covered areas. From the standpoint of demonstrating the effectiveness and usefulness of the methods used the test was quite successful; approximately 3800 miles of traverse were run with gravity and seismic recording.

The gravity instrument used was the LaCoste and Romberg gimbal-mounted marine gravity meter of the type which has been used quite extensively for measuring gravity at sea by government and research organizations and to a limited extent for commercial oil exploration. The seismic profile system was of the "sparker" type. A condenser discharges into a spark in the water creating a seismic pulse. The reflected signal is received by a low-noise multiple receiver towed over 1000 ft behind the boat. The nominal energy of the spark system used was 14,000 joules for each spark discharge and with sparks at about a four second interval.

The ship used for the operation was the motor vessel "Moorah" of about 126 ft length which proved to be fairly satisfactory under the sea conditions encountered during the operation. Weather and sea conditions were quite favourable and lost time was much less than anticipated.

The operation was positioned by a Toran radio-location system which was established for control of an airborne magnetic survey over the same general area. It had been anticipated that the location system could be operated day and night and plans were made originally to operate the ship on a twenty-four hour basis. Early trials showed that reliable location signals could not be obtained at night. The operation therefore was confined to the daylight hours in the time after "sky waves" ceased in the morning until they began in the evening. This limited operation to about seven or eight hours a day at the beginning and eight to ten hours per day at the end of the survey.

The primary control was on east-west lines spaced approximately ten miles apart connected by a number of north-south lines. The survey covered, with this control, approximately  $24,000 \, \text{mi}^2$  in the Bonaparte Gulf south of latitude  $12^\circ$  and east of longitude  $127^\circ$ .

The precision of the gravity observations was somewhat better than anticipated from early experience with the measurement of gravity at sea. So far as we know, this probably is the most accurate survey of its kind which has been made to this time. The statistical probable error, based on the observed gravity differences at intersections of traverse lines and on comparison with underwater gravity meter stations

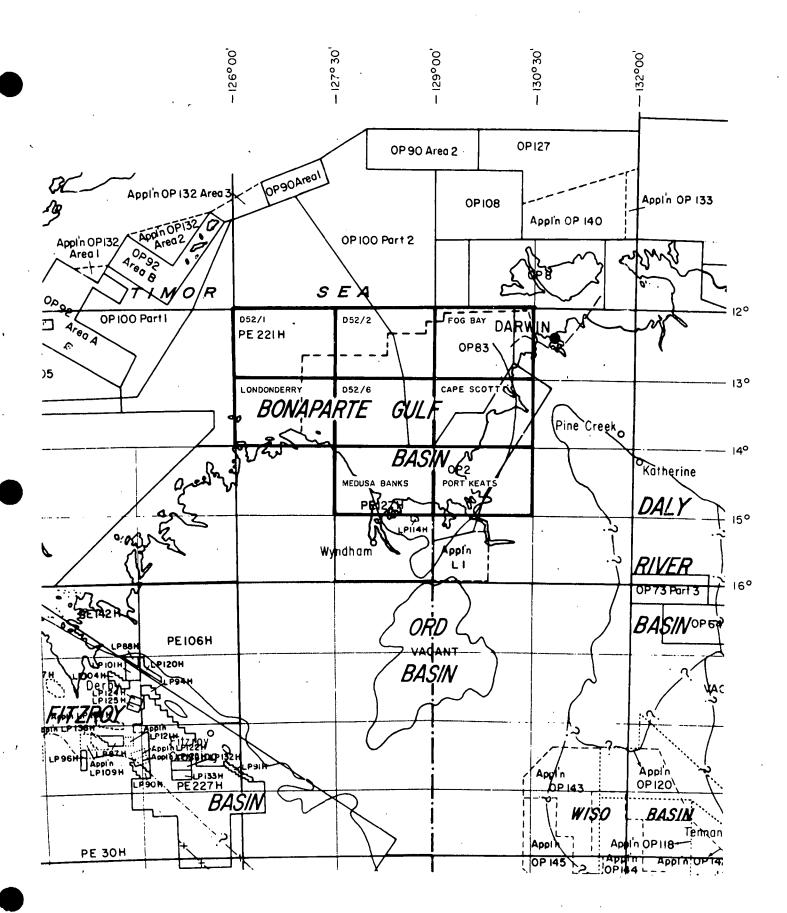
made for that purpose, is about 2.0 mg.

The gravity pattern developed by the survey is dominated by a very large gravity maximum with a north-south axis which apparently is a northward continuation of a maximum shown on shore by the BMR gravity data over the Bonaparte Gulf Basin. Contrary to usual experience in Australia this maximum apparently does not represent a large structural feature which has affected the overlying sediments because airborne magnetic data indicate that the basement is no shallower over this gravity anomaly than in other parts of the offshore Bonaparte Gulf Basin. There are a number of other features developed by the gravity survey which are of smaller magnitude and which quite possibly represent structural features.

A very favourable development in the sparker system was that the quality of the records did not deteriorate at higher boat speeds as had been anticipated. Therefore the sparker records could be obtained at the normal cruising speed of the boat (8-9 knots) and the gravity operation was not penalized by the simultaneous continuous profile recording. The quality of the records and the depths to which reflections can be recognized is variable but, in some cases, fairly definite reflections were recorded to times of about 1.8 seconds which should be at depth approaching 10,000 ft. A parallel magnetic recording of the sparker signal was made and it is possible that later processing may improve the usefulness of these results.

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# I - INTRODUCTION

This report describes the instrumentation, procedures and results from an experimental gravity meter-sparker survey in the Bonaparte Gulf. The operation is called "experimental" because it was designed, in part, as a test of the performance and applicability of the methods and instrumentation which are new to exploration in Australia. Certain sections of this report are adapted from the Geophysical Preview Report on this project by E. R. Smith and J. Stanley.

# II - FIELD OPERATION

The operation was carried out for the Bureau of Mineral Resources by Geophysical Associates Pty. Ltd. under Contract No. C. 507044.

Instruments and operators used were those necessary for measurement of gravity on the moving ship, for stationary gravity measurements on sea bottom from the ship at anchor, and for continuous "sonic" type reflection seismic measurements by an EG&G 14000 joule "sparker" system. In the period 26 July to 8 October 1965, a total of 3740 miles of traverse were observed with the gravity meter and 3708 miles with the sparker system.

# III - FIELD PARTY

The field operations were carried out on the motor vessel "Moorah" under Captain D. Cleary, with C. J. Herrmann as chief scientist. The ship's crew, originally intended for twenty-four hour operation, was supplied by the ship charterer, Succinct No. 1 Pty. Ltd. The technical crew, in addition to Mr. Herrmann who acted as party leader and chief operator, included J. Resta as Sparkarray operator, D. Holt and B. Cohen as technical assistants, and Toran operator J. P. Garnier supplied by Compagnie Generale de Geophysique. More detail on the ship is given in Appendix A.

# IV - INSTRUMENTATION

The shipborne or mobile gravity meter No. S-8 was manufactured by LaCoste and Romberg in Austin, Texas, and is of the gimbal-suspended type. It is described in more detail in Appendix B. A minor modification in chart elapsed time calibration and computer program for data reduction was necessary because the ship's power supply operated at 50 cycles rather than 60 cycles for which the equipment and recorders were designed. This meant that the usual time increments of 2 minutes

and 10 minutes used in reading and reducing the data became 144 seconds and 12 minutes respectively in real time.

The gravity measuring equipment also included a LaCoste and Romberg underwater gravity meter of the type with a single cable which served both to lift the meter and carry the necessary electrical conductors. This equipment was provided to give base-point references for the shipborne meter. The gravity instrumentation is described in more detail in Appendix B.

The "Boomer-Sparkarray" equipment, furnished by BMR, consists primarily of a bank of condensers charged to 3.5 KV and discharged by an electronic trigger circuit. The transducer used was formed from two "Sparkarray" elements used as a single unit making six electrodes from which a spark passes through the water to the surrounding frame when the condensers are discharged. The rated maximum energy available for each discharge is 14 KW-seconds (approximately 10,000 ft lbs), but much of the recording was made with 12 KW-seconds because of a transformer failure. The timing of the spark discharge was controlled by the recording unit. The amplified seismic signal from the detectors is displayed by this unit. The resulting chart is very similar in general appearance to a variable density seismic cross section.

The "Towflex" detector streamer, made by Chesapeake Instrument Company, consists of a long streamlined towing segment, an acoustical insulating segment, and an instrument section consisting of six pairs of hydrophones spaced 30 ft apart. The hydrophones are connected together to give a single-channel input to the impedance matching preamplifier located in the cable. The amplified signal is then transmitted to the recording units through the towing cable. Normally the detector section was towed approximately 1100 ft behind the boat. The streamer was supplied by GAPL. This instrumentation is described in more detail in Appendix C.

A commercial fathometer with depth range of 100 fathoms was installed to give the water depths which are necessary for making Bouguer corrections to the gravity meter observations.

The ship was equipped with an autopilot supplied by GAPL. Basically, this is a servo-mechanism which steers the ship on a constant magnetic heading. Its use reduces horizontal accelerations, particularly of long period, which would result from course correction changes by a human pilot and which are particularly disturbing to the moving gravity meter. The autopilot was in operation at all times when gravity

readings were being made. To further stabilize the ship's motions, the ship's speed was kept approximately constant by running at constant engine r.p.m. Depending on currents, this speed was generally in the range 7 to 9 knots.

The "Toran" location system is a phase comparison method developed by Compagnie Generale de Geophysique of Paris, France. The system is of the type which maintains a pattern of radio waves over the area to be covered from signals emitted from appropriately located radiating stations on shore. These stations had been established for control of a concurrent aeromagnetic survey over the Bonaparte Gulf. The system was made available for control of the ship positions by adding a Toran receiver and operator on the ship. This receiver consists essentially of two (or three) phase meters which measure the phase position within "lanes" corresponding to whole wave lengths in the fixed radiation pattern. The lane count must be maintained from known geographical points at which the position in terms of Toran coordinates is also known.

# V - OPERATIONS

In the original planning it was intended that the ship would operate on a twenty-four hour basis, depending on the Toran system to give usable positions both day and night, and crews and schedules were established accordingly. The intended operating schedule was seven days at sea followed by four days off. The actual starting time was delayed ten days by failure of the Toran equipment to be ready at the anticipated time, on the basis of which the ship had left Brisbane to reach Darwin on 16 July. After two days of preliminary testing without location service, field operations and recording were started on 26 July. From tests during this first cruise it became apparent that the Toran equipment could not be used at night. Furthermore, the lane identification system which it had been anticipated could be used to continue operations after signal interruptions was not usable. It is a common experience for electronic location systems of this type to become unreliable or inoperative neartimes of sunrise and sunset when "sky waves" interfere with the normal signal, but in many areas the signal becomes usable again at night. This was not the case in the Bonaparte Gulf.

With the failure of both the nighttime location signal and the lane identification system, consideration was given to running on dead-reckoning courses at night. Such an operation was not attempted because (1) it would depend on reaching recognizable points or marker buoys to reestablish the lane count, (2) the buoys would have to be large and

expensive to be visible for several miles which probably would be the error of an all-night dead-reckoning run, and (3) the value of gravity observations on dead-reckoning courses would be questionable because of uncertainties in positioning and Eotvos corrections.

To make up in part for the time lost by the ten-day delay at the beginning of the operation and also for the loss of the anticipated nighttime operation, the ship working schedule was increased to ten to fifteen days at sea with three to four days off.

Underwater meter observations were made at the beginning and end of each day's recording, after the ship had anchored for the night or returned to port, and, usually at the same location, before raising anchor in the morning. This procedure provided reference gravity readings without interferring with normal production. Such interference can be quite costly in recording time if a normal recording cruise is interrupted to make frequent bottom meter readings. Such an interruption, which includes the necessity of considerable running time before reliable gravity recordings can be resumed, results in about one hour's recording being lost for each bottom meter reading. Therefore, all bottom meter readings were made at the beginning or end of the day's work. This procedure has a defect in that the morning reading may not give a good check unless the ship were to anticipate the beginning of the day's line by starting some fifteen minutes ahead of the check point. The objection does not apply at the end of the day's work because a marker buoy is thrown out before reaching the end of the recording and the ship returns to the buoy for anchoring and the evening bottom meter reading.

Favourable factors which developed during the first cruise and continued throughout most of the operation were:

- 1. The Sparker system gave good results at the normal cruising speed of the boat (7-9 knots) which was most suitable for the gravity operation.
- 2. Weather conditions during the working periods were very favourable.

Routine operations were carried out from the time dependable Toran signals were received in the morning until the loss of signals in the evening. This time increased (due to the changing daylight hours) from approximately 7-8 hours at the beginning of the operation to 8-9 hours toward the end of the operation. Toran locations were determined at

10 "minute" intervals on the recording charts, corresponding to 12 minutes in real time. The time units were marked on the several recorder records from the gravity meter, on the Sparker charts, on the fathometer record, and on the Toranlists and records. Thus, all gravity, seismic, depth and location data are correlated.

The operations were in the Bonaparte Gulf northward to latitude 12° and westward to longitude 127°. Within this area, the southern part of the Gulf, mostly that south of latitude 14° was not covered because of a shadow zone in the Toran signals and the extreme northwest part was not completed because of termination of the operating time scheduled. The primary control is on east-west lines with an average spacing of ten miles. These are connected by occasional north-south lines.

The total area within the control lines is approximately 24,000 square miles.

The gravity datum for the entire survey is derived from a gravity station set by BMR on the pier in Darwin at which the ship docked after each cruise.

A summary of the operations is given in the following table:

Beginning of Mobilisation in Australia	1 April 1965			
Beginning of Operation at Darwin	16 July 1965			
Beginning of Survey	26 July 1965			
End of Operation	8 October 1965			
Time at Sea	62 Days			
Time Running (Port to working area, return to				
port, between lines, establishing				
underwater gravity stations)	108.9 hours			
Time Lost - Equipment Failure				
Shipborne Gravity Meter	- 0 - days			
Underwater Gravity Meter	2 days			
Sparkarray	9.1 hours			
Positioning	1.8 hours			
Time Lost Due to Weather	2 days			
Time Recording				
Gravity Meter	447.9 hours			
Sparkarray	447.4 hours			
Line-Miles Recorded				
Gravity Meter	3740 miles			
Sparkarray	3708.5 miles			
Underwater Gravity Meter Stations Observed	58			

# VI - OBJECTIVES

Objectives of the operation, as given in some detail in the Preview Report, can be briefly summarized as follows.

# Geophysical Objectives

These concern the performance of the instrumentation, including the accuracy and reliability of the shipborne gravity meter, the quality and depth penetration of the Sparkarray equipment, the compatibility of the two systems as related to boat speeds, the determination, if possible, of seismic reflection quality and depth in the areas surveyed, and a general evaluation of the applicability of these types of instrumentation, which are new to Australia, to the general problem of surveying the continental shelves.

# Geological Objectives

These concern, primarily, the investigation of any extensions into the continental shelves of the Bonaparte Gulf of the known geological features on land where, in general, areas of large positive Bouguer anomalies correspond to shelf areas and those of strong negative anomalies correspond with basin areas. It is to be expected, from these relations, that extension of the gravity pattern over the continental shelf would serve to indicate extensions of adjacent known shelf and basin areas on shore and the establishment of new areas not presently known or indicated. The sparker results could serve to define the general character and local features of the sedimentary section within the offshore basins.

### VII - RESULTS

# Field Programme and Area Covered

The programme was laid out on east-west lines ten miles apart with occasional north-south tie lines. Because of very favourable weather conditions it was possible, for the most part, to make observations in the planned orientations and without modification because of wave direction. The large tidal range of some 25 ft. produces strong currents in the Gulf and some lines are curved in spite of having been run on constant magnetic course as maintained by the autopilot. For the same reason there is some variation in spacing between lines.

The operation gave regular coverage of most of Bonaparte Gulf south of 12<sup>o</sup> latitude and east of 127<sup>o</sup> longitude.

# Sparker Results

Sparker records were obtained on nearly all the lines of gravity observations. The sparker results vary considerably inquality, particularly in the depth or maximum time at which reliable reflections could be observed. No mapping or discussion of sparker results is included in this report as these records were turned over to the BMR for analysis.

# Precision of Gravity Measurements

In an experimental operation of this kind it is important to determine the precision of the shipborne gravity measurements and the reliability which can be placed on the resulting maps.

There are three separate criteria for determining precision, i.e., (1) by comparison of gravity values at line intersections, (2) by comparison of the shipborne gravity values with those from the gravity meter on bottom, and (3) by comparison with the available nearby gravity stations onshore and some offshore underwater meter stations established by BMR.

The accompanying histogram shows the differences between observed gravity values at 99 line intersections. The probable error may be defined as the value such that half the errors are smaller and half larger. By this definition, the probable error is about 2.4 mg.

The other histogram shows the differences between the shipborne meter (with Eotvos correction) and underwater meter values at 34 underwater meter stations (this number is less than the total number of underwater meter stations observed because some of these were not near enough to a shipborne meter track to make a reliable comparison). Approximately two-thirds of these comparisons show differences of 2.0 mg or less.

From the above data it is indicated that the internal consistency of the gravity measurements is within about 2.0 mg. The general agreement of the marine survey with the adjacent BMR land and near-shore underwater stations is shown by the consistency of values in the area southwest of Cape Scott. There, the BMR underwater and shipborne locations are quite close together and the general gravity pattern from the offshore to the onshore surveys is smoothly continuous.

**ERROR HISTOGRAMS** SHIPBORNE GRAVITY METER SURVEY JOSEPH BONAPARTE GULF N.W. TERRITORY, AUSTRALIA - 25 - 20 - 15 NUMBER OF DIFFERENCES - 10 - 5

- 0

DIFFERENCES FROM UNDERWATER METER VALUES

6 5 4 3 2 1 0 1 2 3 4 5 6 MG

DIFFERENCES AT LINE INTERSECTIONS

O I 2 3 4 5 6 7 8 9 10 11 12 13 MG

# Gravity Maps

The results of the shipborne gravity observations are mapped on standard BMR base maps at scale 1:250,000 in eight sheets as shown by the Index Map. The "stations" shown on these maps are the positions at each of the 10 "minute" (actually 12 minute) intervals on the ship's trace. The station designations are the times of observation. Each even "hour" along the line is numbered by its time and also carries a letter prefix assigned by BMR. The water depth values, in feet, as taken from the fathometer records are also shown at each "station."

# The Gravity Pattern

The gravity contours show a very striking pattern of strong features with a total relief of a little over 100 mg. Over the eastern part of the area (Fog Bay, Cape Scott, and Port Keats Sheets). The gravity axes are nearly all north-south with the entire pattern being dominated by a very strong north-south trending maximum with its axis near or just west of the 129° meridian. To the west of this feature the gravity contours and principal axes have a strongly developed northwesterly trend.

The central maximum is the northward continuation, with a very large increase in amplitude, of the maximum on the north coast of the Bonaparte Gulf Basin, as shown on the BMR regional gravity map with its axis at Keep Inlet and will be referred to as the "Keep Inlet" anomaly. Ordinarily, and in general conformity with gravity patterns in Australia, it would be expected that this great gravity maximum would represent an uplift of the basement surface and that the highest values of +75 mg might be expected to indicate shallow basement depths. Similar high values of +75 mg are shown in the northeast part of the Fog Bay Sheet near Darwin which is near the outcrops of old rocks. In this area the scattered basement depths from the BMR aeromagnetic surveys of 1958 indicated shallow basement so that the gravity and magnetic indications are generally consistent. On the other hand, the magnetic records are very smooth and indicate large basement depths along the Keep Inlet maximal axis. Therefore we are confronted with a very large gravity feature which has no magnetic expression and which is contrary to general experience in other Australian basins.

In general, the gravity over the Keep Inlet maximum is very regular and, on the whole, smoother than over other parts of the survey. This, together with the absence of any magnetic indication of shallow effects, makes it probable that the entire anomaly is of very deep origin. On an east-west profile, at latitude 14°00', the upper half of the large

anomaly can be fitted closely by the theoretical gravity curve for a horizontal line element with the depth to the center of 19 miles. For an assumed density contrast of 0.25 the depth to the top of this density contrast is eight miles. The calculation made on this basis does not fit the lower flanks of the anomaly as the calculated curve is considerably too wide. The anomaly could be fitted more closely with the density contrast being shallower and with relatively steeply dipping flanks in the general form of a horst block. In this form the maximum depth would not be much greater than the 15,000 to 20,000 ft depth to the magnetic basement. The depth figures are not great enough so that, with the normal vertical gradient, the temperature would be high enough for the material to be above the Curie temperature to explain its lack of magnetization. Therefore we have to assume that whatever causes the higher density of the material under the great gravity maximum is not accompanied by a change of magnetite content of the rock.

To the east of the central maximum the north-south trending features are of quite a different character. The maximum near the northeast corner of the Fog Bay Sheet, defined by the +45 mg closed contour, appears to be part of a feature which may be continuous to the south. From the scattered land stations the positive axis can be extended through Fog Bay and the mouth of Daly River. This trend is approximately parallel with the outcrop of older rocks along the eastern margin of the basin. The long belt of steep gravity through Anson Bay shown by the BMR land stations continues on north across the Fog Bay Sheet centered approximately at longitude 130°00' and probably is representative of the east flank of the Bonaparte Basin.

In the southern part of the survey, south half of Cape Scott and north half of Port Keats Sheets, a minimum with its axis approximately along the 129°30' meridian probably is not indicative of a structural basinal axis. This is because its western flank is part of the big central maximum.

An irregular maximal axis begins about ten miles northwest of Cape Scott, continues northwardthrough the closure of the +5.0 contour and to the north edge of the Fog Bay Sheet at the +10.0 contour reversal (longitude  $129^{\circ}23'$ ). It is local enough so that it could represent a structural axis within the basin.

The northwesterly trending features to the west of the central maximal axis are rather large but possibly indicative of structural disturbances. They are approximately parallel with the presumed southwesterly margin of the Bonaparte Gulf Basin. Probably the most interesting of these

is the axis starting near the central part of Sheet D52-6 at the westerly nosing of the central maximum and extending through the elliptical closure of the 35.0 mg contour in the northwestern part of Sheet D52-6 and on through the elongated 35.0 mg closure in the southeastern part of the D52-1 Sheet and near the northwest limits of the survey. This has a gravity relief of approximately 20 mg at its strongest development and is of a magnitude of which could represent a large structure.

The high values in the southwest part of the survey (northwestern part of the Medusa Banks Sheet) of nearly 30 mg parallel outcrops of volcanic rock in the extreme north edge of the Kimberley Block. A maximum axis extends to the east through the kidney-shaped closed 15 mg contour in the northern part of the Medusa Banks Sheet and on southeastward to the north-central part of the sheet. This feature possibly is indicative of a structural axis running eastward into the Bonaparte Gulf Basin.

This discussion of gravity results is written without access to the results of the sparker survey. It is possible that structural features along some of the gravity axes may have affected the overlying sediments to produce disturbances which would be recognizable in the sparker results. Since the sparker records carry the same location numbers as used on the gravity lines, it should be a simple matter to compare individual sparker profiles with the gravity results at critical points where the lines cross the reversals in the gravity contours.

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L. L. Nettleton

# VIII - APPENDIX A, ORGANIZATION OF SURVEY

Geophysical Associates Pty. Ltd., as contractor to the BMR, had overall responsibility for the survey. This included selecting and chartering of the vessel used, procurement (except the seismic signal source which had been previously acquired by BMR), installation of all equipment including the seismic streamer, supply of personnel and management, and conduct of the field operation. Also, GAPL was responsible for the data reduction and mapping (on base maps supplied by BMR) of all gravity results, for progress maps and reports during and following the course of the survey and for the final report.

After considering several other ships, the motor vessel "Moorah" was chartered in Brisbane from Succinct No. 1 Pty. Ltd. The principal characteristics and dimensions are:

Type Twin screw, single rudder, cargo ship
Speed
Length
Beam
Draft
Tonnage
Engines 4 GM 671 diesel, 160 h.p. each (2 on each shaft)
Accommodation

# (a) Personnel

BMR Supervisor	E. R. Smith
GAPL Party Leader and Chief Operator	C. J. Herrmann
Assistant Meter Operator	D. J. Holt
Seismic "Sparkarray" Installation and	
Test Engineer	Marty Klein
"Sparkarray" Operator	J. Resta
Assistant "Sparkarray" Operator	B. Cohen
Toran Operator	J. P. Garnier
Computer and Interpreter (Brisbane)	P. A. Elkins
Assistant Computer (Brisbane)	D. B. Eaton
Ship's Captain	D. Cleary
Supply Agents (Darwin)	W. D. Gibbons (GAPL)
	Pty. Ltd. (ship charterer)

# (b) Equipment

- i) Gravity
- 1 LaCoste and Romberg Surface Ship Gravity Meter
- 1 LaCoste and Romberg Underwater Gravity Meter
- 2 Steel wire armoured, 13 conductor, underwater meter cables, 1000 ft each
- 1 Set meter handling equipment, including power winch, slip-ring connection assembly and pantograph-crane
- ii) Seismic
- 1 EG&G Recorder
- 1 Rola Magnetic Tape Recorder
- 1 Set Power Supplies and Triggering Units
- 1 14,000 watt-sec Sparkarray and Power Cable
- 1 Chesapeake Hydrophone Array
- iii) Positioning
- 1 Set "Toran" Radio Positioning Equipment, installed on boat; Toran control stations at Cape Fourcroy, Pearce Point, and Cape Talbot
- iv) Auxiliary
- 1 Recording fathometer, 100 fathom range
- 1 Automatic Pilot
- 1 Generator, 7.5 kva, 220 volt, 50 cycles
- 1 Generator, 35 kva, 220 volt, 50 cycles

The equipment was installed in Brisbane, which required modification of the interior of the ship and provision for air conditioning of the instrument quarters, (several kilowatts of electrical power are dissipated by the gravity and seismic equipment).

The ship sailed from Brisbane for Darwin on 3 July anticipating com-

mencement of operation on 17 July. Docking was arranged at Boom Wharf, Darwin. Arrangements were made in Darwin to provide food, fuel, and water at the end of each cruise of the survey.

Arrangements were made by BMR to use the "Toran" radio positioning network to provide locations. This net was being established by Compagnie Generale de Geophysique for control of an airborne magnetic survey over much the same area. Toran receivers were installed after the ship arrived at Darwin.

At the end of each trip, gravity and sparker records were sent to Brisbane, location records to CGG in Paris, and magnetic tape sparker records to BMR. The gravity data processing required listing of data and punching IBM cards in Brisbane, correlation with other punched cards made by CGG in Paris, shipment of card decks to Melbourne for calculation on the IBM 7044, returning calculation print out to Brisbane for adjustment, and mapping of final gravity. (For details, see Appendix C.) Sparker records were labelled and auto-positive transparencies made so that prints can be made by BMR as required.

# IX - APPENDIX B, SUMMARY OF PREVIOUS GEOLOGICAL AND GEOPHYSICAL EXPLORATION

The previous exploration in the area around the Bonaparte Gulf is listed, with bibliographic references in the Geophysical Preview Report by Smith and Stanley, in chronological order. The following is abstracted from that report.

The basin was first evaluated for possible petroleum prospects in 1948 and its outlines defined. The possible extension of the basin to the edge of the continental shelf was suggested in 1952.

In 1955 geological and gravity surveys were carried out in the area of the surface expression of the Bonaparte Gulf basin.

In 1956 geological work and stratigraphic drilling were done in the Keep River area and gravity work was done south and southeast of Port Keats. BMR did its first seismic work and some gravity work in the basin.

In 1957 geological work in the basin was continued and gravity surveys were made by private companies and by BMR.

In 1958 BMR operated a marine underwater gravity meter along the coast between Darwin and Wyndham and carried out an extensive aeromagnetic survey over the Paleozoic sediments and a large part of the gulf.

In 1959 some gravity and geological work was carried out by private companies and the Spirit Hill No. 1 test was started and suspended at a depth of 2,458 ft.

In 1960 private companies began seismic work and the Spirit Hill test was deepened to 3,003 ft. and completed as a water well.

In 1961 a marine seismograph survey was carried out and detailed gravity work was done in the Carlton area. Studies of recent carbonate sediments in the Sahul shelf were reported.

In 1962 seismic surveys were carried out on the lower Keep River and between Keep River and Nimbing areas which led to the drilling of Bonaparte No. 1 in 1963 and 1964. A refraction seismograph survey on Bathurst Island developed a high speed layer (17, 000 to 20, 000 ft/sec) dipping toward the east which also was a good reflecting horizon.

In 1963 further seismograph work was carried out whick extended that of the Nimbing area of 1962, indicating a closed structure and a north-

south fault. The Bonaparte No. 1 test was started in July and suspended at 10,283 ft in December. Two aeromagnetic surveys were carried out, one extending over the northwest continental shelf and the other over the Anson Bay area. An extensive seismic survey was made at Point Pearce.

In 1964 Alliance carried out a third seismic survey in the Bonaparte No. 1 area using the multiple surface coverage method. This resulted in changes of the structural picture around the test which was deepened to a total depth of 10,530 ft. The Bonaparte No. 2 was drilled to a total depth of 7008 ft on an indicated structural apex farther south. The test flowed gas from the interval 4694 to 4760 ft at one and one-half million cubic feet per day, but other tests yielded salt water. Australian Aquataine carried out marine seismic surveys in the Queens Channel and Flattop Bank areas and also land seismic surveys. Previous gravity surveys were followed up by gravity observations at seismic shot points. Other companies carried out marine seismic surveys over the shoal areas near the edge of the continental shelf.

# X - APPENDIX C, THE MARINE SURFACE GRAVITY METER

# X 1. INSTRUMENTATION

# The Shipborne Gravity Meter

The moving gravity meter used in the survey of this report is the LaCoste and Romberg S-meter No. 8. The meter is substantially the same as those which have been used for several years for measurement of gravity at sea by the Hydrographic Office of the U.S. Navy and by certain oceanographic institutions. The meter also is substantially the same as that used for gravity measurements in the air.\*

Basically, the mobile gravity meter is a LaCoste and Romberg land gravity meter which is suspended on gimbals and has very high damping. The meter is adjusted to nearly infinite sensitivity. This adjustment, combined with the high damping, results in a meter response which is controlled primarily by the damping and, therefore, the rate of motion of the beam rather than its deflection is a measure of the gravity effect. The primary response may be visualized by a simple analogy. A flat dish is filled with a highly viscous liquid and contains a heavy ball (a ball bearing), Figure 1-A. The ball will not move if the dish is horizontal. This corresponds to a balanced position of the meter. If the dish is tilted (Fig. 1-B), the ball will move at a rate proportional to the tilt and inversely proportional to the viscosity of the liquid. In a similar manner, if the gravity meter is not balanced, the beam moves at a rate proportional to the amount by which it is unbalanced and inversely proportional to the damping. Thus, the primary response to changes in gravity is a change in the rate of deflection of the beam.

The schematic block diagram (Fig. 5) shows the basic components of the instrumentation, their connections, and their functions in terms of abbreviated mathematical expressions of their inputs and outputs.

# Vertical Accelerations

Because the vertical motions aboard ship have instantaneous accelerations of the order of thousands to hundreds of thousands of milligals, the gravity measurement is made in a very "noisy" background. The

<sup>\*</sup>Tests of an Airborne Gravity Meter, <u>Geophysics</u>, Vol. 25, No. 1 (February, 1960) pp. 181-202.

Quantitative Evaluation of Precision of Airborne Gravity Meter, Journal of Geophysical Research, Vol. 67, No. 11 (October, 1962) pp. 4395-4410.

vertical accelerations are greatly reduced by the damping and then further reduced by electrical filtering in the outputs. Since the average elevation does not change, there is no cumulative effect from the vertical accelerations if the instrument is carefully adjusted so that its upand-down motions are symmetrical.

# Horizontal Accelerations

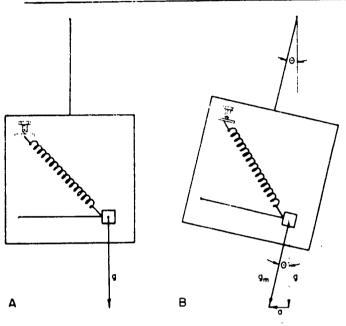
The horizontal accelerations are quite a different problem. Their effect is always in the direction to increase the apparent gravity and they must be measured and eliminated. If the meter is stationary and hangs vertically, (Fig. 2-A) gravity acting through the vertical axis is measured correctly. If the meter is subjected to a horizontal acceleration, (Fig. 2-B) it is deflected from the vertical by the angle  $\theta$  and the total acceleration measured is the vector sum of the true acceleration g and the horizontal acceleration, g and the horizontal acceleration, g and the total acceleration vector, affecting the meter is too large by the factor g and must be continuously corrected by this amount.

The meter is equipped with two horizontal accelerometers (HAM's) which measure the longitudinal and transverse components of the deflection from the vertical. The HAM acts as a long period level to give a reference for measurement of the deflection of the suspended meter from the vertical. Its basic component is a long horizontal bar (Fig. 3) suspended at its centre and very carefully balanced so that it has a period of about two minutes. A servo-motor controlled by photocells responsive to the position of the bar within its case acts through a gear train to keep the case parallel with the bar and therefore level. The angular position of the case with respect to the meter is measured electrically to give the value of the deflection,  $\theta$ . Thus, the HAM serves as an effective level reference for motions with periods less than about 1.5 minutes. For longer period motions the HAM will begin to follow the motion and the HAM correction becomes incomplete. This is a primary reason for always operating the boat under the control of an autopilot to prevent long period swings in heading which would introduce long period horizontal accelerations that would not be completely compensated.

Usually the instrument is set so that the longitudinal HAM is parallel with the long axis of the ship and measures accelerations from pitch  $(A_1)$  while the transverse or cross HAM measures acceleration from roll  $(A_C)$ . The cross HAM component is usually larger. The effects of the horizontal accelerations have the magnitude  $(A_1^2 + A_C^2)/2g = A_h^2/2g$ , where  $A_1$  and  $A_C$  are the longitudinal and cross components of horizontal

 $\ddot{X} + D\dot{X} + KX = M(g+a)$ FOR D VERY LARGE,  $\dot{X} = \frac{M(g+a)}{D}$ 

FIG I



 $g_{m}^{2} = g^{2} + a^{2}$   $g_{m} = \sqrt{g_{m}^{2} - \sigma^{2}}$   $= g_{m}(1 - \frac{\sigma^{2}}{2g}) \text{ (because } \sigma^{2} < g^{2})$   $= g_{m}(1 - \frac{\sigma^{2}}{2g}) \text{ (because, for small angles, } 0 = a/g \text{)}$ 

SERVO MOTOR

HAM

GRAVITY

METER

TOTAL CORRECTION .  $\frac{1}{2}(\theta_L^2+\theta_c^2)$   $\theta_L$  = DEFLECTION OF LONGITUDINAL HAM  $\theta_c$  = DEFLECTION OF CROSS HAM
FIG 3

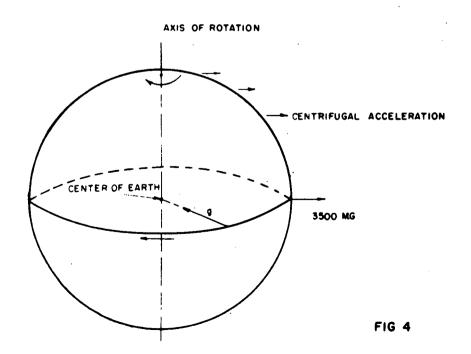
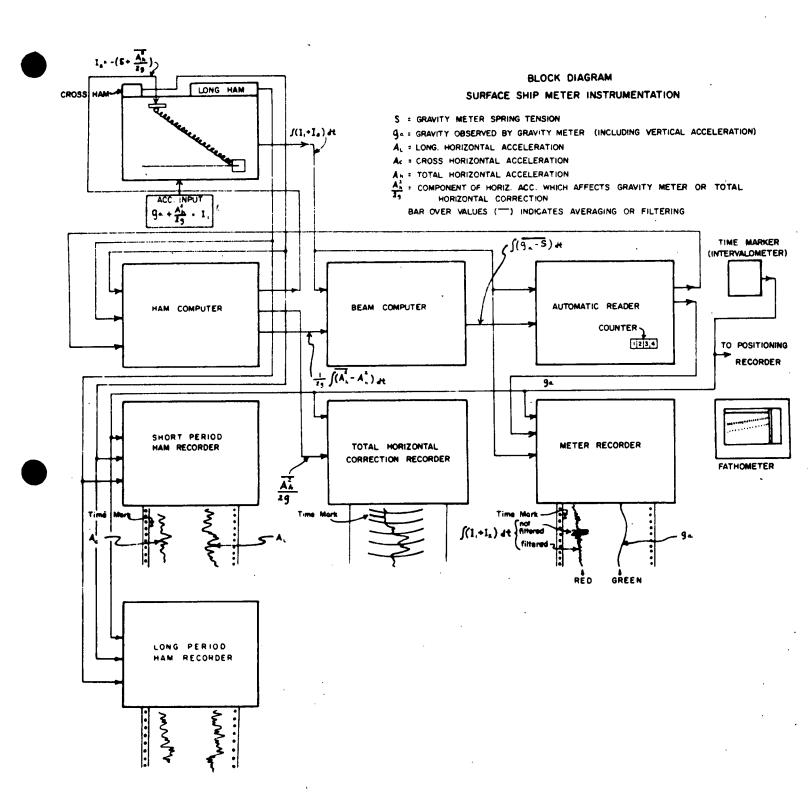


FIG 2



acceleration and  $A_h$  is the total horizontal acceleration. The HAM computer continuously determines this quantity and feeds it back (as a component of  $I_2$  in the block diagram) so that it does not appear in the corrected meter output.

The outputs of the longitudinal and cross HAM's are recorded (Fig. 5). The two traces of the short period (S.P.) HAM recorder show the detail of the changes in the angles  $\theta_1$  and  $\theta_C$  and therefore of the two components of motion. The traces of the long period (L.P.) HAM recorder are filtered to display the long period components of motion. This record is used when monitoring the meter output trace to judge those times when the record should be smoothed manually through disturbing accelerations not completely removed by the HAM's. A separate recorder (Esterline Angus type) makes a record of the total horizontal correction (A $^2_h/^2g$ ) which also can be used to judge the reliability of the results.

# Meter Output and Automatic Reader

The electrical signal proportional to the meter beam position is filtered to eliminate short period effects and gives an output which is proportional to the average beam deflection. This output is the accumulated deflection due to the input acceleration,  $I_1$ , with the HAM correction, (i.e.,  $\int \left(I_1+I_2\right) dt$ ) which goes to the beam computer and also to one pen of the meter recorder.

In one form of the system, the beam deflection signal, after further filtering (i.e.,  $\int (\overline{g_a} - S) dt$ ) and amplification, is recorded as the "average beam" position. Its slope is computed, in the data reduction process, from differences in values of the average beam position at two "minute" intervals. This slope, multiplied by a slope sensitivity factor (the K factor of the data reduction) gives the amount to be added or subtracted from the spring tension to give the gravity value. This slope calculation system was used for data obtained after the first two trips.

In an alternative form of the system, when the newly developed "automatic reader" is used, the beam position versus time function is differentiated electronically and the spring tension is continually modified to keep the beam approximately balanced. This combination provides an output which is directly proportional to the gravity effect desired (i.e.,  $g_a$ ) goes to a strip recorder. The value also is displayed digitally by a counter.

The automatic reader did not perform properly during this operation. During the first cruise the feed-back mechanism failed but the integrator and counter were valid and were plotted manually on the records. During the second cruise the integrator also failed and values were calculated from spring tension and slope readings. This failure does not affect the gravity meter itself but requires a change in the methods of recording and of computing gravity values from the records. The first two cruises were computed from gravity values from the automatic reader record or its counter or were calculated manually. For all later cruises average beam positions were listed for the computer input and final values calculated using a variation of the computer programme which calculates slopes from differences in these readings.

## Underwater Meter

The underwater meter used was the over-damped or H-type LaCoste instrument with a 13-wire cable (as distinguished from an earlier design which used an "elevator" and a 47-wire electrical cable). With the newer design and a special armoured cable the meter is lowered on a single line rather than having a lifting line separate from the electrical cable. This elimination of the heavy electrical cable is a definite advantage, especially in operating in deep water where the earlier cable arrangement gave considerable trouble.

A pantograph-crane (developed from many years experience in the Gulf of Mexico) was installed to let the meter down over the side of the ship until it is near the water before being released on the lifting line. This avoids the meter swinging against the side of the ship in rough weather. A special winch was installed carrying 1000 ft of the armoured cable. The circuits were brought out from the winch cable by a very specialized waterproof slip-ring assembly.

# X 2. DATA OUTPUT AND RECORDING

This section is concerned with the several items of data necessary for calculating final gravity values, their sources, and how they were recorded. Each of these items is normally recorded at two-minute intervals. The speeds of the recording charts are determined by 60 cycle synchronous motors such that minutes of time coincide with lines on the charts. However, the power supply was at 50 cycles and the charts ran at 5/6 their normal speed. Thus the chart minute lines were 72 seconds apart. These lines were kept as the basic reference system, which means that in each place in this report where "minutes" are referred to, these "minutes" are 72 seconds, each "hour" is 72 minutes

of real time, and each real day is comprised of 20 "hours" of chart divisions. These irregular time units are enclosed in quotes (e.g. "minutes") to distinguish them from real times.

Simultaneous time marks were made at 10 "minute" intervals by separate pens at the edges of the beam and HAM records and by interrupting the total correction signal so that the pen dropped back to zero. Also, time was written on the records manually at each 20 "minute" mark, including the fathometer and "Toran" positioning records. These time references serve to correlate the several items of data in time and location.

Brief comments on each of the records are given in the following paragraphs.

# Beam Record

The meter recorder (see block diagram, Fig. 5) is a Texas Instruments "Servicorder" with three pens and a rectilinear scale. The central red line is a record of the meter beam position. The magnitude and period of the motions of the pen were controlled primarily by the vertical motions of the ship.

The much smoother, wider ranging green line referred to as "average beam" is a heavily filtered and magnified record of the beam position. The amplitude is magnified approximately 60 times. Observe that when the green line swings full scale, the centre of the wiggles of the red line will move about  $1\frac{1}{2}$  small divisions. The slope of the green line is a measure of the amount by which the meter is off balance. A slope down to the right (i.e., in the direction of increasing time) means that gravity is lower than the manually recorded STCU\*\* value; an upward slope means the value is higher. The meter spring tension value was written on the chart (mostly with numbers between 6300 and 6500). The gravity (in counter units), is the spring tension value plus the slope in small scale divisions per "minute") times a K-factor of about 1.4 (or 0.7 when slopes are measured by differences over two "minute" intervals). The calibration factor is slightly nonlinear but is about 1.027; a change of one STCU in about one milligal.

As the average beam position (green line) steepens, a spring tension change was made (usually by 10 STCU, but sometimes 5 or 15 or other

<sup>\*\*</sup> Spring Tension Counter Unit

amounts). At such changes there is a relatively sharp change in slope. No normal slope changes are abrupt because of the filtering. Occasionally the average beam pen zero is shifted manually without a change of slope to keep the record on scale.

For the first two cruises, the counter on the automatic reader operated part of the time and gave values corresponding to the spring tension plus slopes as outlined just above. These values were plotted on the record or filled in by calculation where not plotted. For all cruises after the second, the automatic reader was inoperative and values were calculated, in the data reduction procedures, by the slope method (see page 18).

# Water Depth

Water depths were obtained from the record of the fathometer which was operated at all times during which gravity observations were made. The fathometer operates in ranges of 0-50 fathoms or 50-100 fathoms. Times were written manually on the fathometer records, usually at ten "minute" intervals, to correlate with other data.

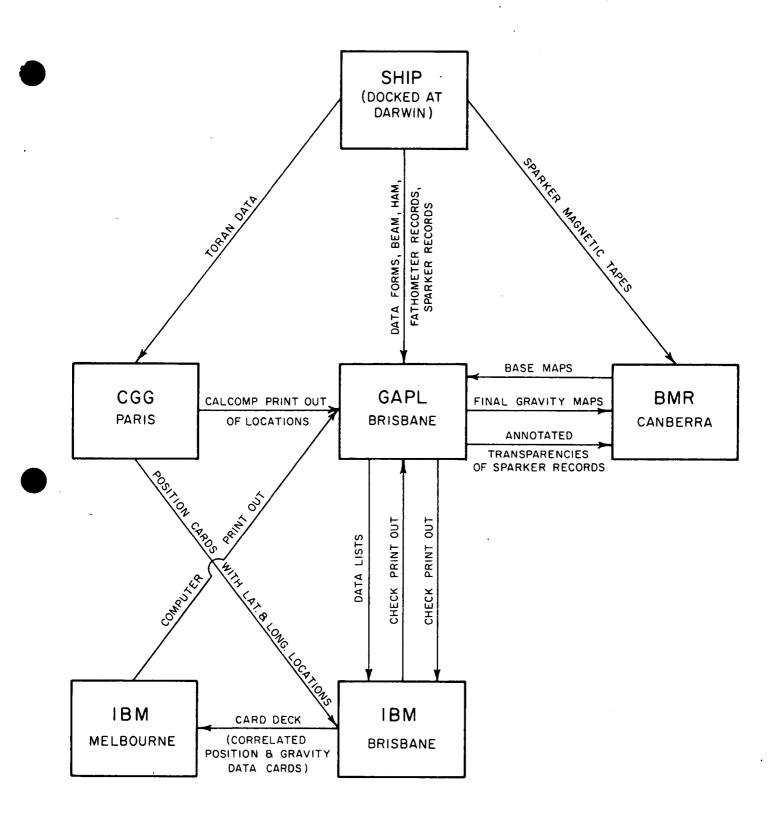
# Data Listing

The data lists, from which the gravity calculations were made, are in two forms. For the first two cruises, there is listed, for each two "minute" interval, the water depth in fathoms and the gravity value in STCU, as read from the plotted or calculated gravity values on the beam record. For all cruises after the second, a different form was used on which was listed the water depth, the spring tension counter units (STCU), and the average beam position in two columns. These two columns are used to provide continuity of slope values where there is a change in spring tension or an offset beam record.

# X 3. DATA REDUCTION

The handling of the data from the field to final mapping was carried out as indicated by the data flow diagram, Figure 6.

In Brisbane, the data lists were made from the meter beam records in one or the other of the two forms mentioned just above. These lists were sent to the IBM office in Brisbane for punching cards for each two "minute" interval. The Toran location data were processed in Paris and IBM cards, with latitude-longitude position, were supplied for each 10 "minute" interval. Because of an incompatibility in the system used



FLOW DIAGRAM OF DATA HANDLING

in Paris these cards had to be repunched by IBM in Brisbane. For each cruise, the two sets of cards were correlated and sent to Melbourne for the calculations to be made on an IBM 7044. This was the only electronic computer in Australia with the speed and storage capacity required to handle the type and amount of data processing needed. The print out sheets from the computer were sent to Brisbane for plotting final results. In the meantime, CGG in Paris sent machine calculated print out sheets at scale 1:250,000 on which locations at 10 "minute" intervals (approximately two miles at normal boat speed of 9 knots) were shown. These locations were transferred to BMR base maps at the same scale.

# Machine Calculation and Print Out

The data of the computer operation are shown in two sets of print out sheets. The first set titled "Data List" is a print out of the output and final results. The other headings on the data list are time; water depth in fathoms; latitude and longitude in degrees, minutes, and seconds; and spring tension counter units (STCU) which is the value from the recorder counter or from the output record after smoothing according to the pencil line on the strip chart.

For the output data sheet the first column or point number is the time (in the 20 "hours" system). The Eotvos correction is printed out in milligals corresponding to the uncorrected observation at the corresponding time. It consists of the STCU value converted to milligals by a calibration table which is stored in the computer memory, plus a base constant to put the value on the BMR datum. "Total corr." is the sum of Eotvos, water depth, and latitude corrections. The "two min" value is the sum of the station gravity and total correction. The "6 min ave.," "10 min ave.," and "14 min ave." values are averages of the two "minute" values over 3, 5 and 7 station intervals centred at the time corresponding to the point number, and correspond with averages over 7.2, 12, and 16.8 minutes, respectively, in real time. Because of generally smooth operating conditions the values plotted are from the 6 "minute" averages.

The various steps in the data reduction carried out by the electronic computer are reviewed in the following paragraphs.

# Water Depth Correction

The water depth correction replaces sea water with rock to the surface. Its value is d (.0129 ( $\sigma_r$  -  $\sigma_w$ ) x 6) in mg per fathom, where d

is water depth in fathoms,  $\sigma_r$  and  $\sigma_w$  are densities of rock and water, respectively. The computer programme calculates values for free-air gravity and Bouguer gravity for densities of 1.90, 2.20, 2.67; the Bouguer map is made from the values for density 2.20. For a density of 2.20 the correction is 0.091 mg/fathom so that a 100 fathom change in water depth makes a change of approximately 10 mg in the Bouguer correction. There is no free-air correction since there is no change in elevation.

# **E**otvos Correction

The Eotvos correction results from the effect on the gravity meter from relative motion over a rotating earth and results from the modification of the outward centrifugal force of the earth's rotation (Fig. 4). The effect depends on the speed and course of the ship and its latitude. At the latitude of the Bonaparte Gulf, the effect is about 7.5 mg/knot in the east or west component of the ship's speed. The correction is positive when moving eastward and negative when moving westward.

Based on previous experience, the Eotvos corrections were calculated over a time interval of 20 "minutes" but, because of the good quality of positioning, was reduced to 10 "minutes" after the first two cruises. Because the course and speed of the boat are nearly constant for each line, the results are not very sensitive to the choice of this interval. From a subroutine in the computer, the calculations are made directly from the latitude-longitude positions as given on the IBM cards. The basic formula for the Eotvos correction is  $E = 2V_e \otimes \cos \phi$  where:

# Latitude Correction

The latitude correction is calculated by the electronic computer directly from the basic formula for theoretical gravity at sea level,  $g_0 = 978.0490 \ (1 + 0.0052884 \sin^2 \phi - 0.0000059 \sin^2 2\phi)$  which gives values corresponding to the table, for instance, in Nettleton's "Geophysical Prospecting for Oil," pp. 139-143.

# Station Gravity

The station gravity value is the observed gravity converted from STCU

to mg and with a base constant applied to reduce it to the BMR datum (see section below on Base Ties).

# Total Correction

The total correction, as shown by the fourth column of the IBM print out, is the sum of the water depth, latitude, and Eotvos corrections.

# Base Ties

The station gravity is consistent with the BMR base net. A station, with a value of 978,316.96 was set by BMR at Boom Wharf, Darwin, where the ship docked. Readings of the surface ship meter were made at the docks at the beginning and end of each cruise.

An example of the determination of the base constant is as follows:

Shipborne meter still reading at dock		6449 STCU
Equivalent gravity value from meter		
calibration	=	6618.45 mg
Tide at time of still reading		11 ft
Base value, BMR system, at dock		978, 316. 96
Elevation of base station above water		17.5 ft
Tide at time of reading		15 ft
Elevation correction, base station to ship		
$17.5 \times .094 + 4(.094013)***$	=	+1.97 mg
Gravity value at ship = 978, 316. 96+1. 97		978,318.93
Base constant = 318.93 - 6618.45	=	- 6299.52
(978000.00 is subtracted in the computer		
programme)		

\*\*\*The first term is free-air correction to water level at time of base station observation. The second term is correction for 4 ft tidal change (15 ft to 11 ft) and includes free-air correction (factor .094) less Bouguer correction for water (factor .013).

# X 4. MAPPING GRAVITY RESULTS

Locations derived from the Toran data and reduced to rectangular coordinates were supplied by CGG from Paris in the form of a Calcomp print out or machine plotted map at scale 1:250,000 (approximately 1 in = 4 miles). Latitude-longitude listings also were available from a

computer print out supplied by CGG. The locations mapped and listed are usually at 10 "minute" intervals but occasionally at other intervals. Latitude-longitude positions of a number of test points were plotted on the BMR map quadrangles at scale 1:250,000. It was found that only very minor adjustments were required to fit the Toran positions to those maps, and locations at 10 "minute" intervals were transferred directly from the Calcomp maps to the BMR base maps. Gravity values from the 6 "minute" average values of the IBM print out list, for density 2. 20, were plotted on profile sheets with a separate plot for each segment of the line. At the location of any intersection of a cross line the gravity value from that line was plotted at the time corresponding to the location of the intersection. Also, the values for any underwater meter stations were shown on the profiles.

As an example, a portion of the profile for line 13 has been printed from the original and is included with this report. Some explanatory notes have been added to make clear the adjustment and mapping procedure.

It was obvious from inspection of the profiles that there were some gravity changes which were too sharp to represent real changes in gravity and must be due to disturbances to the meter, mostly from excess motions. These changes were eliminated by drawing a smooth curve along the profile from the observed values. At the same time, this curve was adjusted to pass through any underwater station values and to adjust the differences at line intersections.

The individual segments were designated in accordance with the same system used for identifying all observational data. The lines were plotted at a horizontal scale of 1 in = 20 "minutes" and a vertical scale of 1 in = 1 mg. The intersecting lines and the bottom meter stations are identified on the profile sheets. All the generally east-west lines were plotted with the right hand side corresponding to the east direction. This means that the time scale may run either from right to left or left to right depending on the direction on which the line was actually run in the field.

After the smooth lines were drawn and adjusted the value was read at each 10 "minute" line of the profile sheet. These are the values which were posted on the maps at the location corresponding to the times on the profile sheet.

After the adjustments were made and values posted the contours were drawn at 5 mg interval as shown on the final maps. In a few places there are minor irregularities which might be removed by small changes

in the adjustment of final values, but, on the whole the values posted from the smooth curves of the profile sheet were contoured without difficulty.

Transparencies of the profile sheets are furnished so that the source of all the data on the final maps is readily available.

#### XI - APPENDIX D, THE SEISMIC SPARKARRAY CONTINUOUS PROFILER

(Adapted from Preview Report by E. R. Smith and J. Stanley)

#### Introduction

The early methods of continuous seismic profiling at sea evolved from standard depth sounding equipment and techniques. Under favourable conditions, it had been found that the sound pulses used had effectively penetrated a considerable thickness of unconsolidated sediments. The transducers used in depth sounders are generally of low power and use frequencies in the 10 to 15 kilocycle range. Subsequent developments to increase the penetration have been directed toward increasing the power of the source and decreasing the frequency. There has also been considerable improvement in the receiving equipment used.

One of the earliest developments was the "sparker" system, which produced a simulated explosion in the form of a high-voltage spark fired under water. Penetrations of the order of 1000 ft have been recorded with high power "sparker" units. A number of other repetitive sources have been developed such as the gas gun which produces a low-frequency pulse by igniting a mixture of gases such as propane, oxygen, and air in a chamber. The bottom of the chamber is submerged in the water.

Dr. H. E. Edgerton has developed a new electrical energy device to produce a low-frequency repeatable pulse, which has been called the Sonar Boomer. He has also devised a spark system called "Sparkarray" which uses an array of spark gaps, to increase the power and low-frequency content of the pulse. The backup equipment for either of these sources is essentially the same; the "Sparkarray" was used for the present survey. The equipment was manufactured by Edgerton, Germeshausen, and Grier, Inc., (EG&G) of Boston, Massachusetts, U.S.A.

### Discharge System

The three basic components of the sound source system are the power supplies, the capacitor banks, and the transducer or spark-system.

The power supplies were connected to a 35 KW, 50 cycle, 220 volt diesel engine driven generator installed on the ship for this purpose and also to supply the air conditioning units. Each power supply requires an average of 2000 watts to provide high voltage d. c. (at 3500 to 4000 volts) for the capacitor banks. The capacitor bank takes the high voltage d. c. from the power supply unit and, upon being triggered,

delivers the stored electrical energy to the spark system. The standard capacitor bank contains 10 energy storage capacitors connected in parallel to give a total bank capacity of 160 microfarads. The 2000 watt-second capacitor banks have 320 microfarad modules which are used to provide the additional energy storage required for the higher power system as used. A high-voltage trigger impulse, which is keyed from the recorder unit, causes a spark gap in the capacitor bank to become conductive, allowing all the capacitors to discharge into the sparkarray simultaneously.

Theoretically, the maximum firing rate is limited by the ratio of the desired total stored energy to the power supplied. In actual practice, line losses and voltage fluctuations may reduce this considerably. The formula recommended by the manufacturers is:

Minimum Firing Time = 
$$\frac{\text{Total Energy Stored}}{\text{Power Supplied}}$$
 x 1.6

There were six power supplies, six 2000 watt-second capacitor banks, and two 1000 watt-second capacitor banks available for use in the present survey, making the total energy of the system 14,000 watt-seconds (approximately 10,000 ft-pounds). These were assembled as two separate units operating into two separate "sparkarrays." Thus the minimum firing time should be:

$$\frac{3 \times 2000 + 1000}{3 \times 1000}$$
 x 1.6 = 3.7 seconds

or a firing rate of about once every four seconds.

During the first cruise one high-voltage transformer failed, reducing the available power to 12 KWs. A replacement transformer, sent from Boston, failed on the second cruise. At the beginning of the fourth cruise (September 8) a rewound transformer was installed, restoring the power to 14 KWs for the remainder of the operation.

The sparkarray transducer system output was also reduced during the first two cruises because of breakdown of the connections between the power cable and the spark electrodes reducing the number of effective sparks. The termination arrangement was then modified by Mr. Herrmann and the trouble eliminated.

# Sparkarray Transducer

The sparkarray is an alternative transducer which was used instead of the "Boomer," for which the system was originally designed. The "Boomer" utilizes the same equipment (power supplies, capacitor banks, and trigger circuit) to produce a high-voltage and high-current discharge through a coil whose magnetic field actuates a flat plate. The "Sparkarray" represents a return to the earlier method of producing the acoustic pulse by creating a high-voltage spark under water. By using a high capacitance, lower voltage (3600 volts) discharge system, and an array of six spark electrodes, lower frequencies and more energy output are obtained.

# Hydrophone Array Receiver

The seismic receiving system used for the survey was designed and manufactured by Chesapeake Instrument Corporation and is designated their Model 12 "Towflex" Seismic Profiling System. The special design features incorporated in this system are aimed at reducing the self noise of the system and its response to external noises. The basic principles used to overcome these problems are:

## 1. Hydrophone Ship Separation

The hydrophone receivers are displaced approximately 1000 ft from the ship so that they are removed from the noise radiating from the towing vessel.

### 2. Hydrophone Array Formation

A number of hydrophone elements are used in the system and are spaced at suitable intervals so that they discriminate against horizontal noises caused by the ship and its wake and the sea itself.

## 3. Array Hydrodynamic Stability

The array must tow stably in the water, otherwise towing will provide added array self-noise. To achieve a stable tow, a uniformly neutrally buoyant array must be provided in the water medium. This design requirement necessitates uniform neutral buoyancy in every device used in the receiver system. Lightweight hydrophones, couplings, and oil must be provided to obtain this design objective.

# 4. Array Configuration

The Model 12 "Towflex" configuration contains 12 Model PC-100 pressure compensated, acceleration cancelling hydrophones placed within a three inch diameter oil-filled hose section. A pair of hydrophones is located every 30 feet. The overall length of this section is approximately 150 feet, and the hydrophones are spaced to provide vertical directivity in the region of 75 This section comprises the active "Towflex" receiver, and is furnished with an impedance matching preamplifier. This receiver section is connected to a low frequency isolator section, which consists of a strain relieved soft elastomer section providing attenuation of low frequency cable perturbation and cableborne bone-conducted noise. Three hundred feet of neutrally buoyant stabilizing cable and 800 feet of 2000-pound breaking strength tow cable were furnished with the system. A shipboard electronics package containing the power supply and a post amplifier with selectable outputs of 0, 20 db and 40 db gain, for operation under varying sea state and noise conditions, were included with the system.

## Recorder

The firing of the transducer is triggered by the recording unit, which then receives the signal from the hydrophone array and, after amplification and filtering, records it in variable density form on an electro-chemical sensitive paper. The recording head contains a helix wire mounted on a revolving drum and a steel blade loop electrode. The special electro-chemical paper is placed between the two electrodes and slowly advanced by means of rubber pressure rollers. As the helix wire electrode revolves, its contact point with the blade electrode sweeps across the paper. To make a graphic impression on the paper, current is passed from the blade electrode at the point of contact through the paper to the helix electrode. The current, which varies with the instantaneous signal strength received from the hydrophone array, produces a chemical reaction which deposits iron ions on the paper in proportion to the current, thus giving a variable density type display.

The rotation of the helical head and the initiation of the triggering pulse are ganged together so that they are always synchronised. Thus, the recorded traces for each successive firing appear adjacent to each other on the paper with their initial times synchronised. The paper speed is usually adjusted so that the adjacent traces are almost touch-

ing, thus enabling coherent signals to be easily traced across the record. The rotation (or sweep) speed may be adjusted to give various time (or depth) scales.

For most of the operation the recording was with a total vertical time scale of two seconds (with 0.1 sec timing lines) and paper speed of about  $2\frac{1}{2}$  inches for each 10 "minute" interval. Part of the recording was with a time scale of 2.5 seconds and with 0.4 sec timing lines.

A choice of six filter bands was available in the recorder. These have cutoff slopes of 30 db per octave and have the following band widths:

<b>20</b> - 80 cps.	80 - 200 cps.	200 - 800 cps.
800 - 2000 cps.	2000 - 8000 cps.	8000 - 20,000 cps.

The filter bands may be combined in any way to give wider band widths. For most of the recording the 20 - 80 cps. filter pass band was used. The output of the hydrophone array was also recorded on one-fourth inch magnetic tape with a commercial recorder. The tracks were recorded sequentially on the tape, without filtering, and may be played back at some later date using more sophisticated processing techniques in order to improve the signal-to-noise ratio.

## Operation

The sparkarray equipment was operated continuously during almost all the gravity recording periods. The sparkarray assembly with six electrodes was lowered into the water on the port side of the ship. Its position was controlled by one line from a cargo boom which supported the forward end of the sparkarray assembly and also carried the electrical cable and a second line from the rear of the assembly secured to a davit on the ship. With these two lines the location, depth, and attitude of the sparkarray transducer could be controlled so that it was held in a position about 10 ft from the hull, near the stern of the ship, and approximately 10 ft below the surface.

It was found in early tests of the system that the record quality did not deteriorate as expected with increase of boat speed. It had been anticipated that the best records would be obtained at speeds of around four knots but the variable speed tests showed that better records were obtained at the normal cruising speed of about 8-9 knots. Therefore, throughout the survey, the boat was operated at its normal cruising speed which was also the optimum speed for operation of the gravity equipment and the two systems proved to be quite compatible with each other.

## XII - APPENDIX E, LOCATION STATION SYSTEM

The "Toran" location system used for positioning the boat throughout the gravity meter-sparker operation was developed by Compagnie Generale de Geophysique of Paris, France. The system had been contracted to control an aeromagnetic survey over the Bonaparte Gulf. Arrangements were made by BMR to use the same system for the ship operation. This could be done by simply adding the proper receiving equipment on the boat as the Toran system is one which can serve an unlimited number of mobile receivers.

"Toran" is one of several radio location systems which depend on a fixed pattern of standing electro-magnetic waves over the area to be covered. One pair of radiating stations lays down a set of hyperbolic coordinates or "lanes" such that there is a phase change of 360° in passing from one lane to another. A second similar pair of stations on a base line which is at an angle with that of the first pair provides a second set of "lanes" which intersects the first. If the positions of the radiating stations are accurately known, the geometry of the lanes can be precisely determined and the lanes can be drawn on a map. If the ship starts from a point at which its positions interms of the electronic "lane" coordinates is known and moves to another point, the number of lanes and fractions of a lane between the points will permit determining the position of the ship on a map by scaling on the chart on which the lanes are drawn.

The receiving equipment on the ship includes phase meters which measure the electronic phase at all times. When the ship crosses from one lane to another the phase meter makes a 360° rotation. By counting the number of whole rotations plus the fractional rotation to a given position, that position can be located by scaling the fractional phase between the appropriate lanes in the two hyperbolic systems. This can be done on the ship so that, if desired, its location can be determined at sea. The same operations can be carried out by an electronic computer which translates the hyperbolic coordinates to rectangular geographic coordinates. These positions then can be plotted by an electronic position plotter such as "Calcomp" which locates points accurately by an electro-mechanical system controlled by a magnetic tape which is the output of the position calculation operation of the electronic computer.

The above general principles of operation apply to several location systems in addition to Toran, such as Decca, Raydist, and Loran, but the details of the electronic transmitting and phase measuring systems are

somewhat different.

In the Toran system the two fixed transmitters of a pair each radiate a pure unmodulated continuous wave signal at a frequency of about two megacycles/second. The difference between the two frequencies is a low frequency, usually about 80 cycles/second. The moving receiver picks up the signals from the two stations and consequently the 80 cycle beat frequency. The phase angle of the beat is measured by a comparison with a beat reference signal and this phase varies proportionally to the difference in the distance of the mobile receiver from each of the two fixed transmitters. This difference will be constant for all points of a hyperbola the foci of which are located at the two fixed transmitters.

The two transmitters at the fixed focal points are independent of one another, i.e., they are neither interlocked nor synchronized. The small frequency fluctuations and phase shifts which are practically unavoidable for independent transmitters are continually compensated by the use of a fixed receiver and transmitter. This fixed receiver produces a low-frequency beat signal from the difference in frequency of the two focal point transmitters. This reference signal is transmitted to the moving station by a third fixed transmitter which is modulated by the beat reference signal. This signal serves as the reference with respect to which the phase changes at the mobile station are measured. Any effects of small shifts of frequency or phase at the focal transmitters will affect the local phase and reference phase alike and therefore such shifts are completely and continuously compensated. Thus, the equipment required to produce one set of hyperbolas includes: (1) the two fixed focal point transmitters radiating pure continuous wave signals, (2) a stationary compensation receiver which produces the beat reference signal from the signals received from the two focal point transmitters, and (3) a fixed reference transmitter, the signal of which is modulated by the beat reference signal.

For the Timor Sea network used for the Bonaparte Gulf survey the specific locations and frequencies used were:

For Couple AA'	Location	Frequency	Latitude	Longitude
Focal Point A Focal Point A'	Cape Fourcroy Pearce Point	1894 Kcs. 1894+80 Kcs.	11°45'30.33 '' 14°22'15.266''	130°01'53.02 " 129°21'59.358"
Reference Transmitter	Cape Hay	1815 Kcs.		

For Couple BB'	Location	Frequency	Latitude	Longitude
Focal Point B' Focal Point B' Reference Transmitter	Cape Talbot Pearce Point Cape Fourcroy	1705 Kcs. 1705+80 Kcs. 1635 Kcs.	13°47'45.83 '' 14°20'57.659''	126°44'32.92 " 129°22'17.537"

The general operation of the Toran system was quite satisfactory during the daylight hours. As for other radio-location systems of this general type there were difficulties at certain times because of interference from "sky waves." These are signals which are reflected from electron layers in the upper atmosphere and arrive at times which are delayed slightly from the wave transmitted directly over the sea surface. These delayed signals produce interference which confuses the phase relations on the boat and prevents accurate positioning.

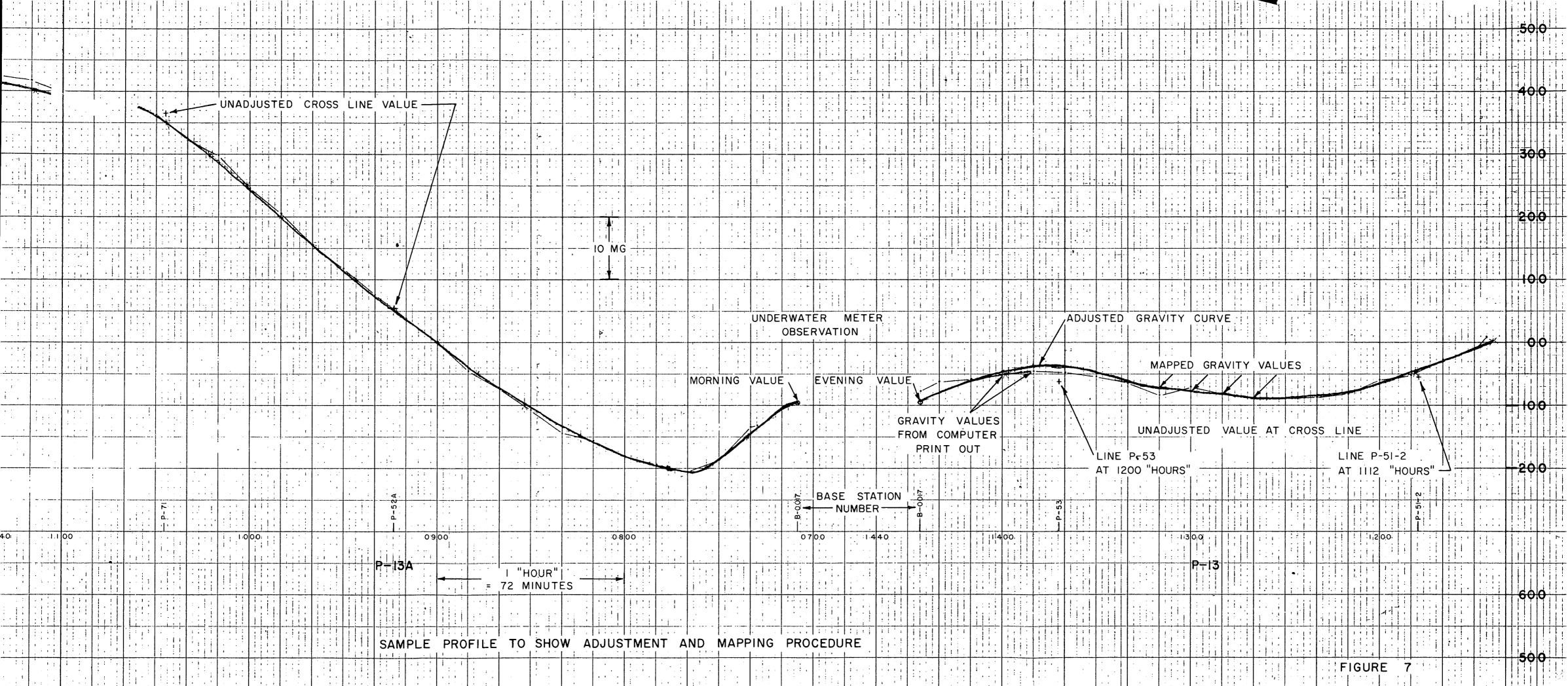
As mentioned earlier, it had been hoped that it would be possible to operate on a twenty-four hour basis. It turned out, however, that the sky-wave interference persisted through the night and therefore operation was limited to the time between the fading of the sky-wave interference in the morning, usually shortly after sunrise, and its commencement in the evening, usually at or shortly before sunset.

At the beginning of each trip, the Toran receivers were "calibrated" at a marked point where the location in Toran coordinates had been established previously. This gave the "lane count" which was carried, usually to the end of the 10-day trip, until it could be checked at the same or another calibration point.

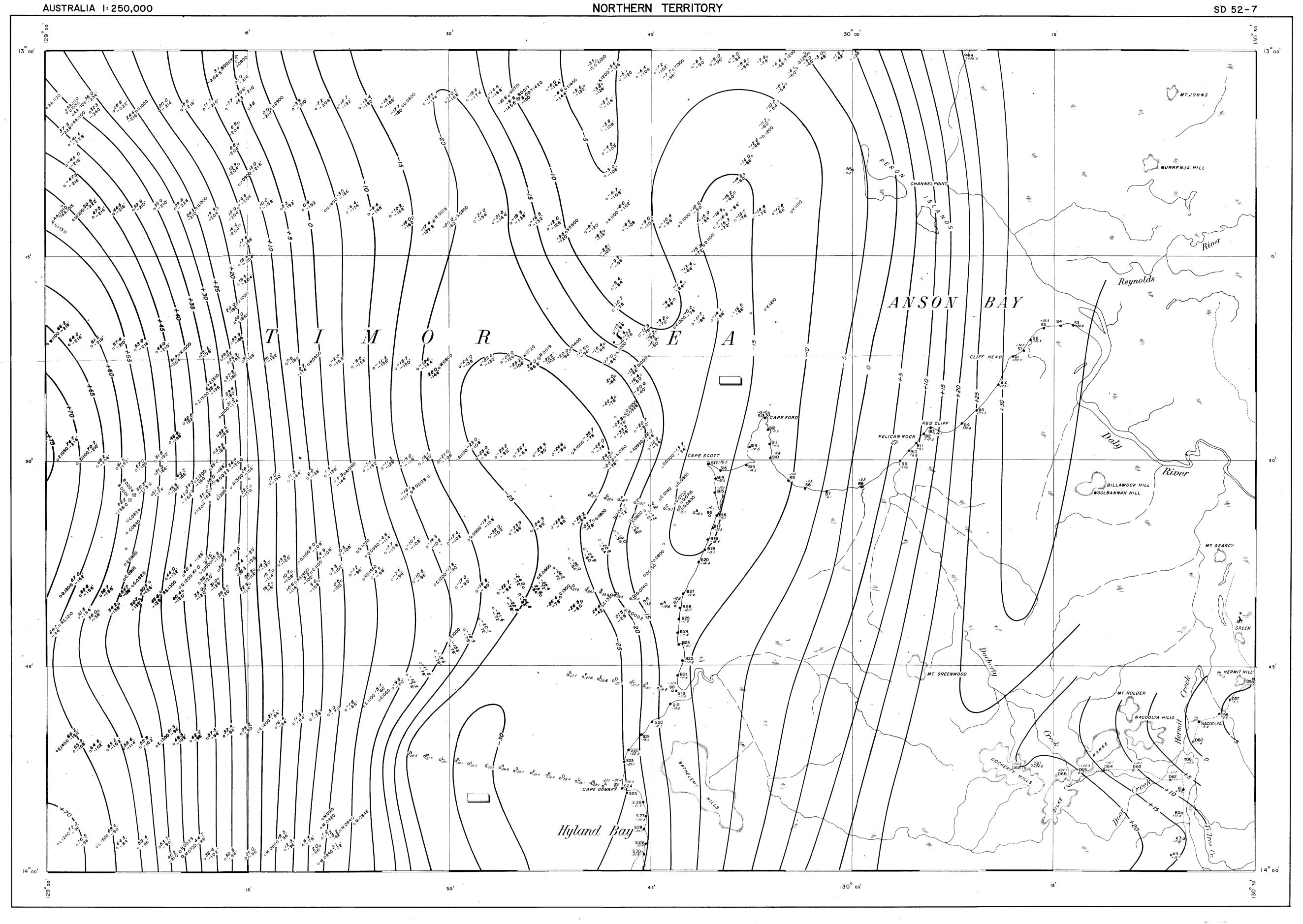
During the gravity meter-sparker runs the Toran phase meters were read and recorded at each 10 "minute" interval. These numbers gave the readings in lanes and fractions of a lane of the hyperbolic Toran coordinates. On reaching Darwin these data were mailed to the CGG office in Paris and processed on their electronic computer system to produce values in geographical coordinates. These locations were plotted by the Calcomplocator at scale 1:250,000, and these sheets were returned to the GAPL office in Brisbane. A second computer operation was carried out to translate the rectangular coordinates into a latitude-longitude system. The latitude-longitude coordinates were placed on IBM punched cards with one card for each 10 "minute" station. These cards were then sent to the IBM office in Brisbane to be correlated with another set of cards containing the gravity data. It was found, when the first cards were received in Brisbane, that the reference system

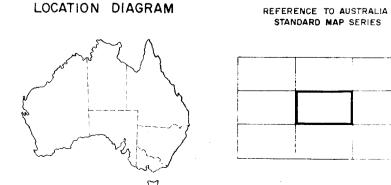
used by CGG (which was a serial number system for each cruise) was not compatible with the time reference system used for the gravity records; therefore it was necessary to make a corrected set of position cards to be compatible with those of the gravity data.

The precision of the Toran locations appears to be entirely adequate for this operation. The theoretical precision is about 0.01 lane which, at points near the baseline between the focal point transmitters, is of the order of three or four meters. At remote points where the distances between lanes become greater and the intersection angles are less favourable the errors may well be at least ten times this amount, but this is still insignificant at the 1:250,000 scale at which the results were mapped.



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Projection: Transverse Mercator, Australia Series Planimetry

Station Bouguer Anomaly reliability Standard Deviation — 1 milligal

Contour interval 5 milligals

TOPOGRAPHY GRAVITY

Bouguer anomaly (milligals)

Elevation (feet)

Low anomaly

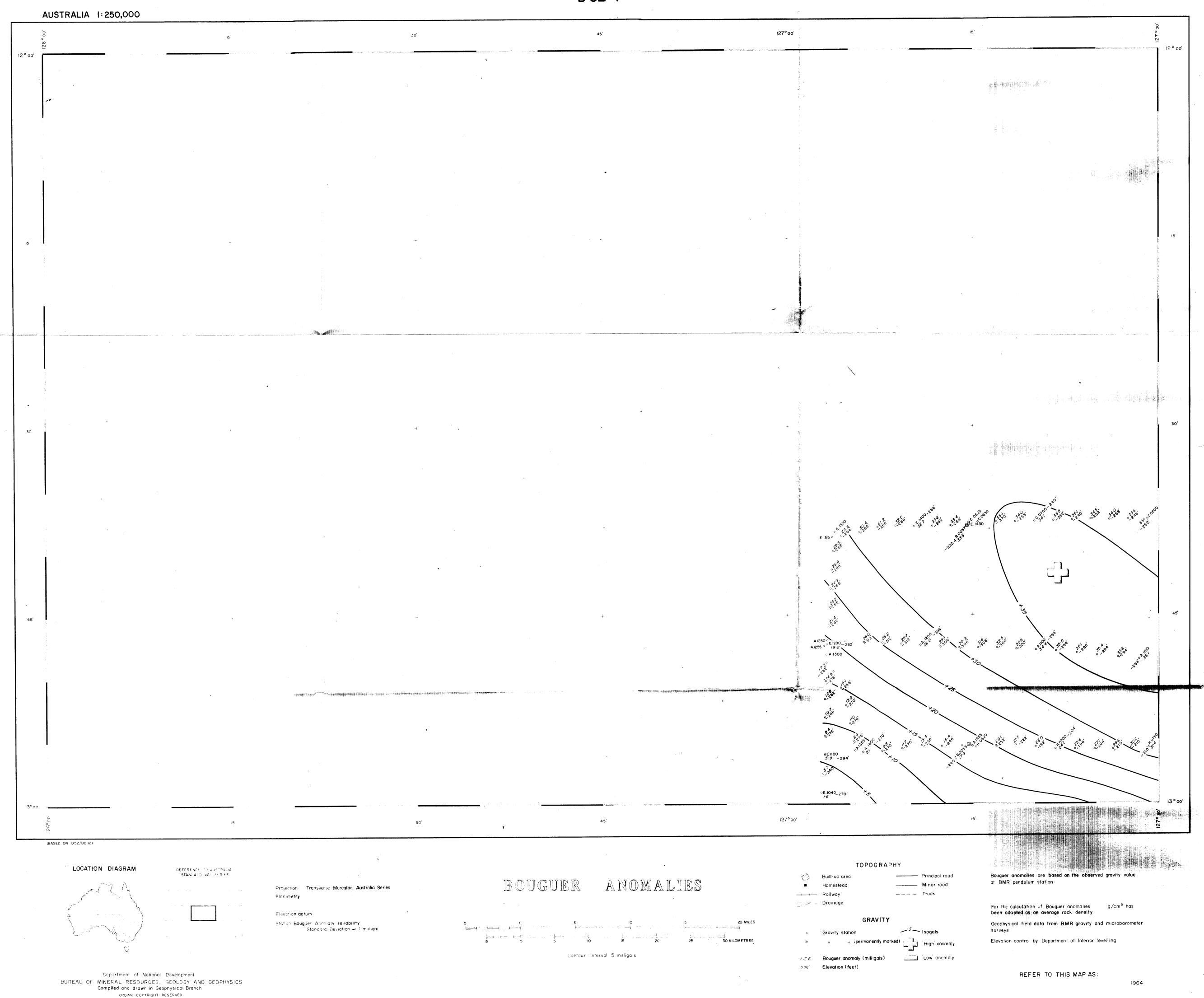
Bouguer anomalies are based on the observed gravity value

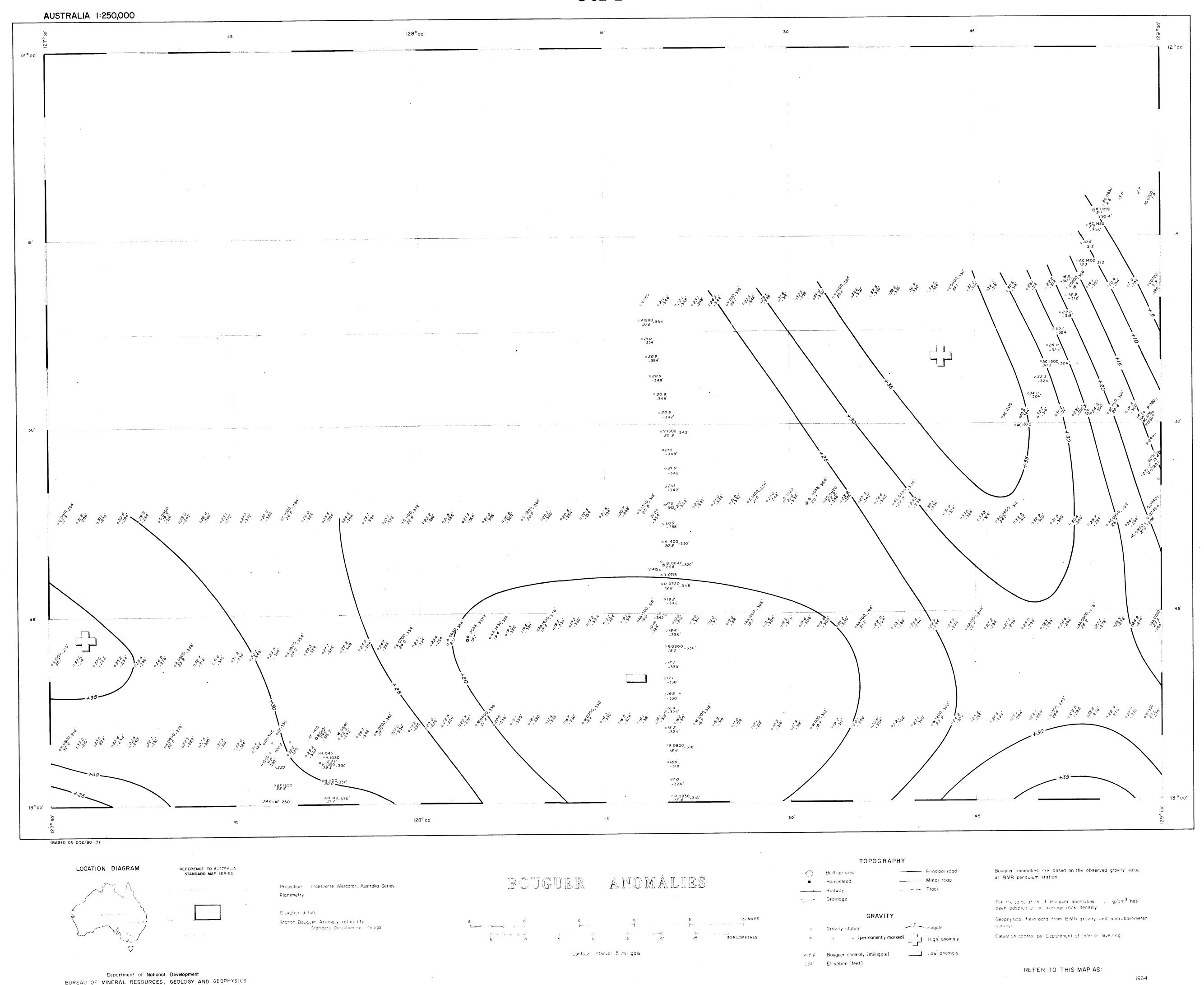
For the calculation of Bouguer anomalies Geophysical field data from BMR gravity and microbarometer Elevation control by Department of Interior levelling

REFER TO THIS MAP AS:

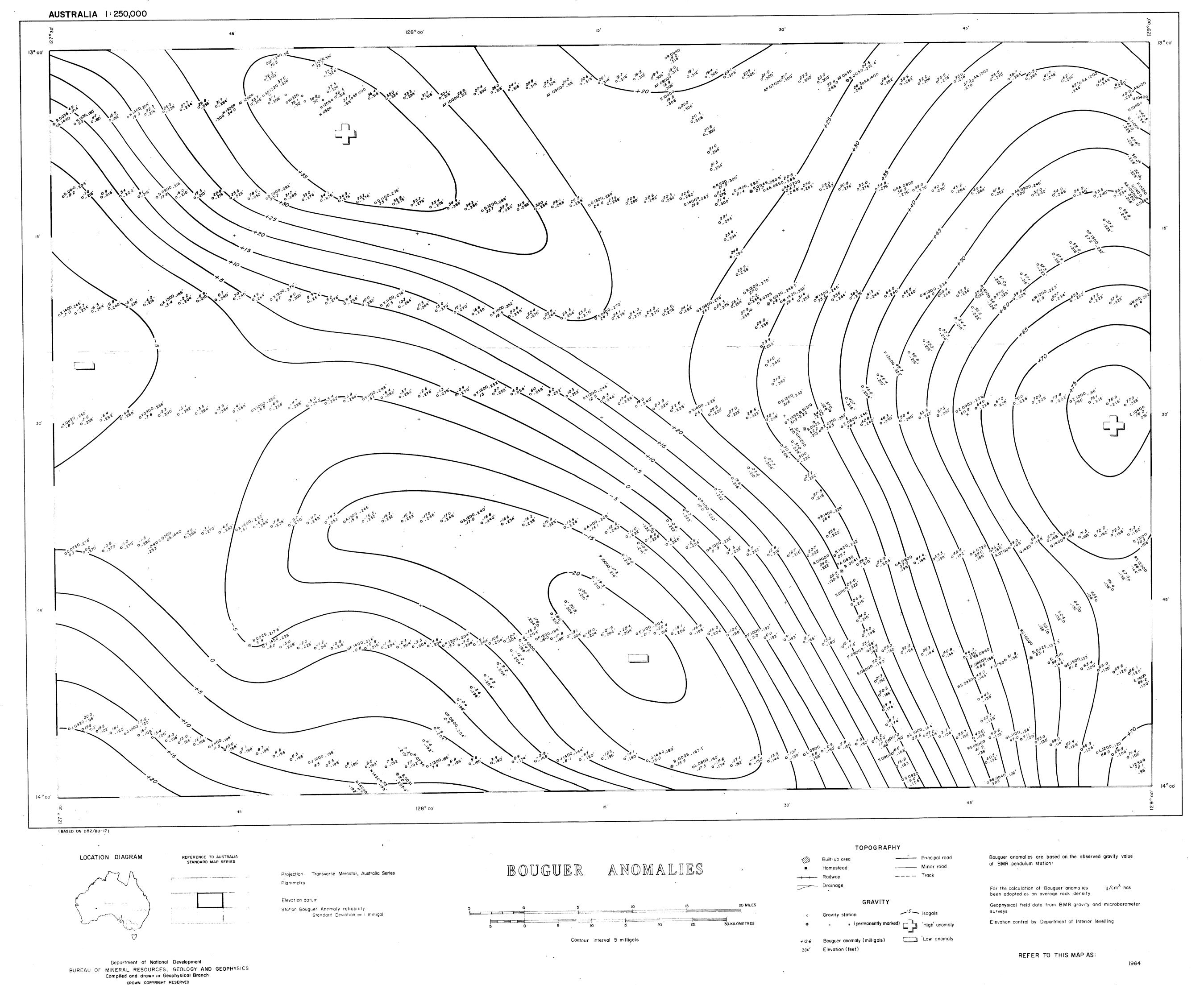
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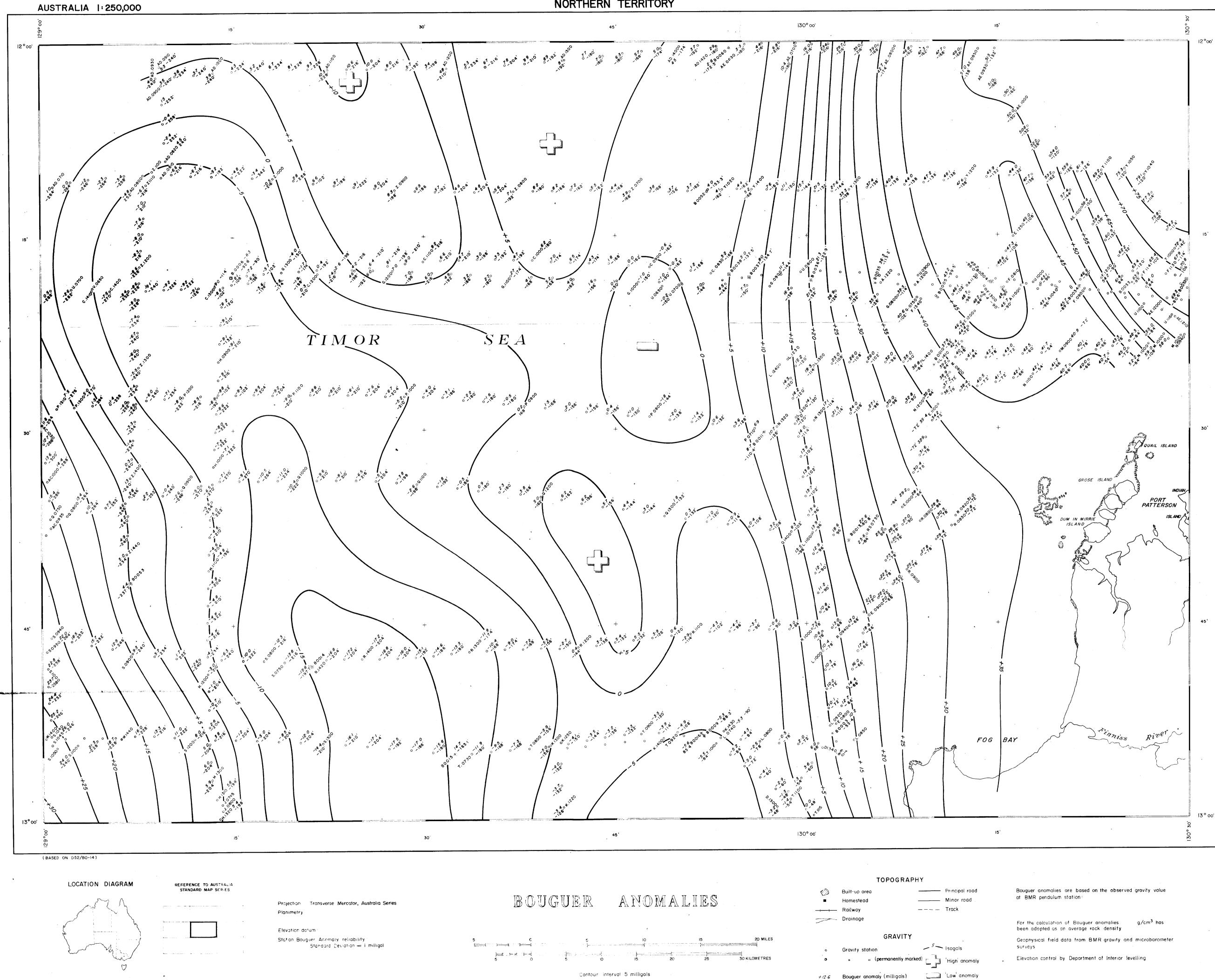
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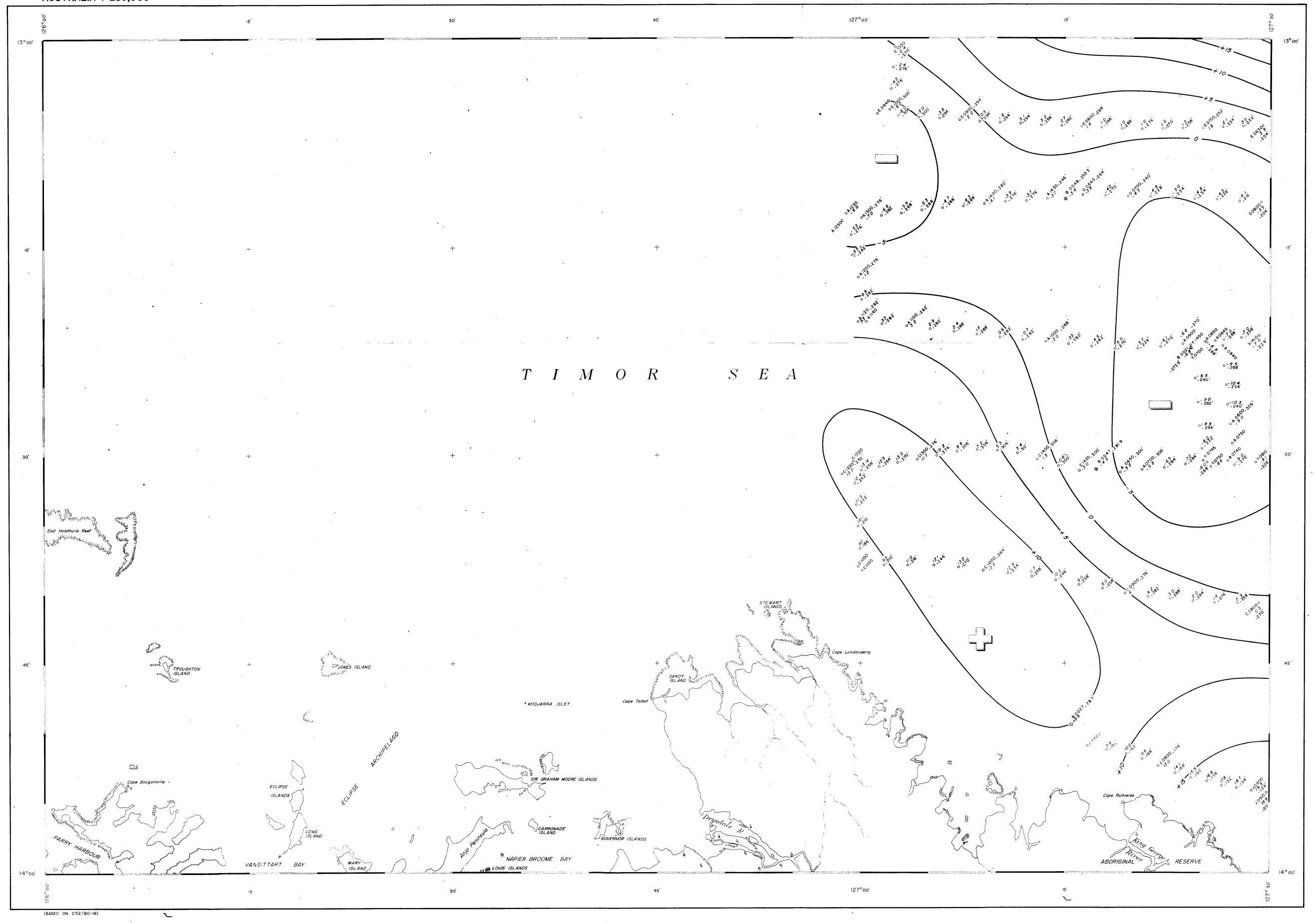


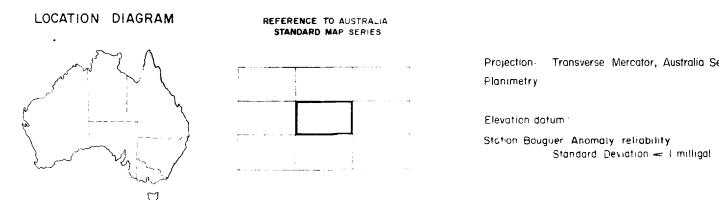
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Elevation (feet)





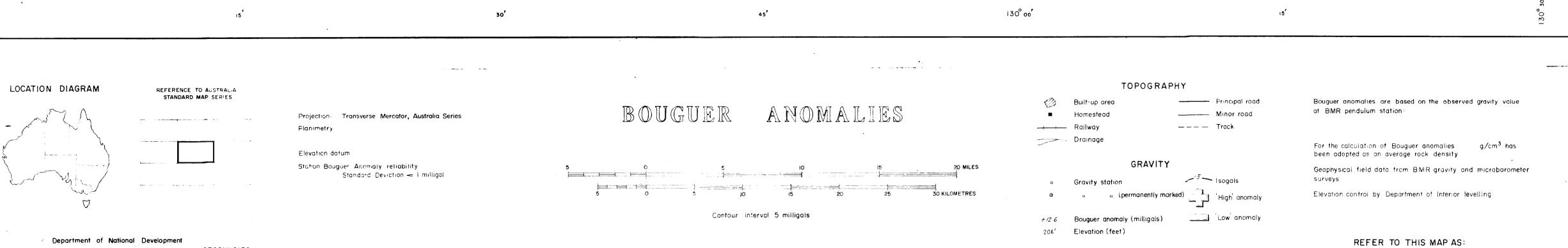
Projection Transverse Mercator, Australia Series Planimetry Elevation datum:

BOUGUER ANOMALIES Contour interval 5 milligals

TOPOGRAPHY Built-up area Homestead -+---- Railway Drainage GRAVITY Gravity station Low anomaly +12.6 Bouguer anomaly (milligals)

Bouguer anomalies are based on the observed gravity value at BMR pendulum station: For the calculation of Bouguer anomalies  $$\rm g/cm^3\ has$  been adopted as an average rock density Geophysical field data from BMR gravity and microbarometer Elevation control by Department of Interior levelling

REFER TO THIS MAP AS:



15° 00**″**