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NATIONAL REPORT ON GRAVITY IN AUSTRALIA,

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by

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SUMMARY

Between January 1962 and June 1965, gravity activities in Australia have steadily increased. With the continued use of helicopters for transport, the coverage of the continent has improved substantially, especially in central Australia and Queensland.

The basic gravity reference network was adjusted in 1962 using existing measurements. In 1964, the 'isogal survey' was made, in which a light aircraft was used to transport three gravity meters along lines of approximately constant observed gravity, enabling a more accurate network to be established. Local calibration ranges have now been established at nine centres.

An absolute determination of gravity by a rise and fall method is in progress at the National Standards Laboratory in Sydney.

A set of Japanese pendulum apparatus, manufactured to the design of the Geographical Survey Institute of Tokyo, was purchased in 1962, but results to date have not been satisfactory. It is believed that the trouble is due to the pendulum knife-edges and bearing plates.

Further gravity measurements have been made in Antarctica, on oceanic islands, and on the continental shelf. Studies of the performance of gravity meters have shown some unexpected results, and these are being further investigated.

Automatic computing is being used increasingly in processing and interpreting gravity data. At the South Australian Institute of Technology, calculations of isostatic anomalies, geoid heights, and deflections of the vertical are in progress.

1. INTRODUCTION

This report is intended for presentation at the meeting of the International Gravity Commission of the International Association of Geodesy, to be held in Paris in September 1965.

Previous national reports were prepared by Dooley (1959) and Langron (in preparation). The present report covers activities for the period from January 1962 to June 1965.

Acknowledgment is made for information supplied by the National Standards Laboratory of the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Sydney; the Physics Department of the South Australian Institute of Technology; the Universities of Tasmania and Sydney; the Mines Departments of South Australia and New South Wales; and numerous petroleum exploration companies.

2. REGIONAL GRAVITY SURVEYS

Since 1959, one of the main features of the improved regional gravity coverage in Australia has been the use of helicopters by the Bureau of Mineral Resources, Geology and Geophysics, (BMR) in an attempt to cover most of the potential oil basins and ultimately the whole of the continent. This work was done initially by the BMR itself, using chartered helicopters, but since 1962 the whole survey has been let out on contract.

The surveys have progressed to a stage now where between thirty and forty sheets of the national 1:250,000 map series are covered per year, each sheet covering one degree of latitude by one and a half degrees of longitude. Station spacing is approximately on a seven-mile grid. Heights are obtained by barometric observations, and a network of spirit-level stations is established in the area to be covered to act as tie stations. The areas covered so far are shown in Plate 1 and include a belt through central Australia and a large part of Queensland. Positions are obtained from the identification of stations on aerial photographs, which are used for navigation. A description of the method has been given by Vale (1962) and Hastie and Walker (1962).

Many other important contributions to the gravity coverage of Australia have been made by private companies operating under the Petroleum Search Subsidy Acts, under which approved oil-search surveys are subsidised by the Commonwealth. The Commonwealth pays a proportion of the cost of the survey and, in return, results are made available to the Commonwealth and may be published six months after the completion of the survey. In addition, many companies have willingly contributed results of surveys that have not been subsidised, or, at least, parts of the results that are necessary for inclusion in the gravity map of Australia.

Important contributions have also been made by State Governments and Universities. In particular, the University of Tasmania has carried out surveys in Tasmania, and also in the Territory of Papua and New Guinea, where they were cooperating with the United States Army Mapping Service, the BMR, and the Division of National Mapping. Helicopters were used for transport in this survey, but the primary purpose of the helicopters was for establishing geodetic survey stations in New Guinea. The resulting coverage is not so evenly spaced as in helicopter surveys that are especially designed for gravity work.

The BMR has been compiling all available results of gravity surveys throughout Australia into a gravity map of Australia.

3. GRAVITY REFERENCE NETWORK

In the process of this compilation it became clear that there were many problems in tying the various surveys together, as they had been based on different datums and some companies had used calibration factors that did not agree with those generally adopted.

The first attempt at establishing a gravity reference network throughout Australia was made in 1950-51, when 59 stations were established, more or less evenly distributed throughout the continent, with the Cambridge pendulums (Dooley et al, 1961). However, in recent years it became increasingly apparent that there were many discrepancies between the various stations of this survey, and it was felt necessary to establish the values more accurately.

Between 1950 and 1959, many visits were made by overseas observers, principally from the University of Wisconsin, with both gravity meters and pendulums, and a large number of readings were made at several stations well distributed in latitude throughout Australia.

In 1962 adjustments were made to the gravity values at the original pendulum stations, based on all the available ties by overseas and local observers; the adjustments were made at the original pendulum stations because these stations had been used for some time for tying local surveys. The available information is shown in Plates 2, 3, and 4. Plate 2 shows the original 59 pendulum stations and also the pendulum ties that have been made between them by observers since 1951. Plate 3 shows the ties that have been made with gravity meters by overseas observers between these stations. Plate 4 shows ties that have been made by local observers, principally the BMR. Although many companies and other authorities have made gravity surveys, few of the surveys have been made on a scale sufficient, or under conditions suitable, for establishing, between pendulum stations, ties that could be used in adjusting the network.

The local work includes a survey made in 1960-61 by the BMR with the special intention of making ties between fifteen pendulum stations in the eastern states (Flavelle, in preparation). It was originally intended to make an adjustment after carrying out this survey, but loop closures showed that the desired accuracy was not obtained, and the more comprehensive readjustment of 1962 was undertaken.

Measurements by observers from Wisconsin University, Expeditions Polaires Francaise, University of California, Los Angeles, and the Geographical Survey Institute of Japan have also been used in the readjustment.

The method used (Dooley, 1965a) was to ascribe, on some arbitrary datum, gravity values to all stations visited during a survey. The datum was then adjusted so that the average departure of these values from the pendulum values was zero. (This procedure was necessary because all surveys did not have a common datum). All the gravity values at a station were then averaged to give an approximate value of gravity for the station. The correlation of observed values for each survey with the corresponding average values was calculated to determine a calibration factor adjustment where necessary. Each survey (or in some cases a group of surveys) was then assigned a weight according to its root-mean-square departure of observed values from average values. A second approximation was then obtained, using the new calibration factors and calculating a weighted average for each station. The calibration factors and weights were re-determined in relation to the second average, and a third approximation was calculated by the same procedure. The changes between the second and third approximations were found to be small enough to indicate that another repetition of the procedure was not warranted.

Estimated standard errors were determined from a consideration of the total weight of all observations at each station, and of the residual departures of observations at each station. These represent errors in the relation of the gravity value at a station to the network as a whole, and not in absolute values. Fifteen stations have an accuracy of 0.1 milligal, twelve have an accuracy of 0.2 milligal, and sixteen have an accuracy of 0.3 milligal. The standard errors in the remaining fourteen stations range from 0.4 to 0.7 milligal.

An essential by-product of the adjustment is a revision of the gravity meter calibration factors used by the BMR. Wherever possible, BMR surveys were related to the Ferntree Gully-Kallista calibration range, using the adopted value of 55.60 milligals. The resulting adjustment necessary for this group of BMR surveys is to increase the calibration factors by 1.6 parts in 1000, i.e. to apply a correction factor of 1.0016. This figure has a standard deviation of about 0.2 parts per 1000.

Connections to Christchurch, Singapore, and Tokyo were inc uded in the adjustment. Values for these stations relative to the Australian network were determined so as to facilitate readjustment of the network when the first-order world gravity network is adjusted by the International Association of Geodesy.

As the result of the 1962 adjustment, a reasonably accurate chain of stations was established along the east coast of Australia.

As the next phase in establishing an accurate national reference network, a survey known as the 'isogal survey' was made in 1964 (Barlow, in preparation). The principle used was to survey a series of lines roughly east-west across Australia with gravity meters, each line following an isogal, i.e., in this case, a line of approximately equal observed gravity values. In this way, errors due to uncertain calibration factors of the gravity meters are minimised. Each line was selected so that the gravity values of the stations along it were within the small dial range of the gravity meters, that is about 50-60 milligals. A chartered light aircraft was used to transport three gravity meters (sometimes four) and an observer between base stations at intervals of about 100 miles. Gravity meter drift was established by flying each tie with at least two repeats, i.e. in the form ABAB; if satisfactory results were not obtained from the first flight, the observer was instructed to make an additional repeat. In general, very few additional repeats were necessary. Repeat observations were obtained at each station within two or three hours. The paths covered by the survey and the stations established are shown in Plate 5.

At each base station, ties were made to as many existing gravity surveys as possible and additional excentres were established where convenient. The complete survey took about eight months and included ties to Tasmania. It is proposed that several more east-west traverses in central and western Australia will be flown in 1966 in order to complete the network. Possibly some north-south traverses in central and western Australia will also be flown.

It is believed that, as an attempt to establish systematically a uniform network of base stations over a whole continent, this kind of survey is unique.

In early 1965, a visit was made by United States Air Force observers carrying four geodetic gravity meters, which were read along a chain of stations from Darwin down the east coast of Australia and to New Zealand, and then back along the same route. An observer from the BMR travelled with this party with a fifth La Coste & Romberg geodetic gravity meter. Results of these observations have improved the accuracy of the east-coast chain, and these have been combined with the results of the 'isogal survey' to establish values for the reference stations throughout Australia. Results to date indicate a standard error of 0.1 milligal in the gravity value at a station relative to the basic east-west traverse that passes through that station. A standard error in the gravity value at a station relative to the network as a whole is expected to be about 0.2 milligal.

Approximately 95% of the gravity surveys in Australia are already tied to the new network and nearly all of the remainder will be tied during 1966.

4. ABSOLUTE MEASUREMENT OF GRAVITY

G.A. Bell of the National Standards Laboratory, Sydney, is planning to make an absolute measurement of 'g'. A body will be projected vertically upwards in a vacuum through two planes at a known vertical separation (about 50 cm) and the time intervals will be measured between successive passages through each plane. The moving body is a metal corner reflector, which is on one arm of a Michelson interferometer. The measuring planes are defined by mirrors in the second arm of the interferometer, and the passage of the corner reflector through the positions of zero path difference is indicated by the occurrence of interference fringes in white light.

The fringes are detected by a photo-diode, the output from which is amplified and used to operate a pair of counters; the output is also displayed on a cathode ray oscilloscope and photographed. By this technique, the required time intervals can be measured with an accuracy of the order of 20 nanoseconds.

The vertical separation of the stations will be measured interferometrically using optical multiplication or laser techniques.

5. PENDULUM MEASUREMENTS

A set of quartz pendulums and associated equipment was purchased by the BMR in 1962 from Sokkisha Ltd of Japan. These were manufactured according to the design of the Geographical Survey Institute, Tokyo, (G.S.I.).

Measurements were made at Tokyo before shipment of the equipment and at Melbourne after delivery (Langron, in preparation). The pendulums and swinging chamber were then returned to Japan and a repeat measurement was made by Japanese observers using their own timing and associated equipment. On the return of the pendulums and swinging chamber to Melbourne, a repeat Melbourne measurement was made. The results of this work showed a discrepancy of about 2½ milligals from previously published values.

Six pendulum stations along the east coast of Australia were reoccupied during 1964, repeat readings being made at all stations (Shirley, in preparation). The gravity intervals obtained differ considerably from the currently accepted values, although each determination has a low mean error as estimated from internal consistency. The results indicate that the timing and other electronic sections of the equipment operate satisfactorily, but there is some alteration from station to station in the operating conditions of the pendulums. The difference between the periods of two pendulums changes erratically between stations. This suggests that the prime cause of the discrepancies is some anomalous behaviour associated with the pendulums themselves, or with the knife-edges and supports.

Micro-profiles of the knife-edges show that one has a flat area, which may affect the swinging. The agate bearing plates have been tested with optical flats and some departures have been noted that may seriously affect the results. Further investigations are in progress.

Convenience of operation, reliability, and portability could be considerably improved by re-designing the electronic equipment, especially by the use of transistors and some changes in lay-out. However, this will not affect the accuracy of the timing, which appears to be adequate.

6. CALIBRATION OF GRAVITY METERS

During 1960 and 1961, eight local gravity meter calibration ranges were established throughout Australia by the BMR, each with an interval of 50 to 60 milligals. Gravity intervals for these calibration ranges were determined by using groups of at least three gravity meters calibrated between Ferntree Gully and Kallista in Victoria. The value of the Victorian calibration range was established, in the first place, from pendulum stations established in Victoria during the Cambridge pendulum survey of 1950-51 and was revised as a result of the 1962 adjustment of pendulum stations throughout Australia. The Ferntree Gully - Kallista calibration range was replaced by a more convenient one between Ferntree Gully and Ferny Creek in 1962.

The results of the measurements at the stations have indicated the magnitude of variations in calibration factors of the gravity meters used, and an estimate of the accuracy of the measurement of each interval has been made. Many small inconsistencies appear to be present, but the accuracy of each calibration range relative to the others is estimated to be ± 0.02 milligal or ± 0.04%. The establishment of these calibration ranges has been described by Barlow (1965), who gives station descriptions, values for each range, and details of the measurements.

A new gravity meter calibration range was established near Canberra in 1965, because of the transfer of the Geophysical Branch of the BMR to Canberra during 1965. The nine centres in which gravity meter calibration ranges have now been established are Melbourne, Sydney, Canberra, Brisbane, Adelaide, Perth, Hobart, Alice Springs, and Townsville.

During the calibration range measurements, erratic changes have been detected in the calibration factors of all gravity meters used. These changes do not appear to be correlated with temperature or internal or external pressure of the gravity meters. Changes of 0.1% have sometimes been observed in periods of less than one hour. The effect is being further investigated. A La Coste & Romberg geodetic gravity meter appears to have advantages over the quartz type of gravity meter in that the calibration factor is more constant with time; however, defects in the screw apparently cause some variations with latitude, and drift tares need to be watched.

7. GRAVITY MEASUREMENTS IN ANTARCTICA

During 1962, 1963, and 1964, gravity measurements were made in Antarctica in association with seismic traverses for ice thickness determination. This work was based on Wilkes and the positions of the traverses are shown in Plate 6. The 1962 work has been described by Walker (in preparation), and the 1963 work by Kirton (1965).

The gravity meters that were taken to Antarctica for the ice thickness work were also used to make ties between the Australian mainland and Antarctica. Langron (in preparation) has made a study of all the Australian gravity measurements between Australia and Antarctica and has adjusted the values of the main base stations and stations along the coast. The values obtained have an accuracy no better than ± 5 to ± 10 milligals because of problems associated with calibration over the range involved, establishment of drift of the gravity meters, and the effects of temperature.

Pendulum measurements have been made by Strickholm (pers. comm.) at Mawson and by the Russians at Mirny (Boulenger, pers. comm.); however, there are tares associated with these measurements and a reliable value cannot be obtained. Probably the most reliable value to use as a base station in Antarctica for the adjustment of the Australian work was that established by Sparkman. This measurement was made with a La Coste & Romberg geodetic gravity meter carried by plane from McMurdo to Wilkes. It is hoped to make pendulum measurements when the BMR G.S.I. equipment is working satisfactorily.

8. GRAVITY MEASUREMENTS ON OCEANIC ISLANDS

Gravity ties have been made to Australian Territorial Islands including Lord Howe Island, Nauru, Ocean Island, Christmas Island, and Cocos Island. These were made by BMR observers, who visited the islands primarily to reoccupy secular variation magnetic stations. The results of these gravity measurements have not yet been published.

9. GRAVITY MEASUREMENTS AT SEA

A contract has been let by the BMR for a gravity survey using a La Coste & Romberg surface ship gravity meter. The survey will take place off Wyndham in the Timor Sea, north of Australia. Observations will be controlled by an underwater gravity meter, which will be read at periodic intervals.

A gravity survey of St. Vincent's Gulf, South Australia, was made by Beach Petroleum N.L. (Sprigg & Stackler, 1965). A normal land gravity meter and an observer in a diving bell were lowered to the sea bottom to depths of up to 150 feet. Positions were surveyed by theodolite from the shore. The accuracy of the survey approached that of land surveys.

10. PERFORMANCE OF GRAVITY METERS

As a result of the measurements on calibration ranges, the 'isogal survey,' Antarctic measurements, and other field work, a large amount of data has been accumulated that enables studies to be made of the performance of gravity meters over a wide variety of conditions and of the accuracy that can be expected from them. The use of several gravity meters simultaneously on some of these projects has been especially valuable in this respect.

In addition, some special projects have been undertaken to study the behaviour of gravity meters under controlled conditions. On one occasion four gravity meters were used continuously night and day for a period of about one week. One gravity meter was alternatively kept stationary while the others were carried back and forth between the two stations of the Melbourne calibration range; every few hours the stationary meter was interchanged with one of the moving ones.

Experiments have also been made to study the effects of temperature and pressure on gravity meters. Further tests are planned.

11. AUTOMATIC COMPUTING OF GRAVITY DATA

The BMR is making extensive use of automatic computing methods for the reduction of gravity data (Langron, 1965). The main objectives are the reduction of gravity data from various sources to a common datum, its integration into regional maps, and the rapid retrieval of data to meet a particular requirement.

Programmes have been developed for a Ferranti 'Sirius' computer at Monash University, Victoria, but the Control Data Corporation (CDC) model 3600 computer of the CSIRO in Canberra will be used as soon as practicable after the Geophysical Branch moves to Canberra in 1965.

Programmes have been developed for the reduction of field barometric readings, the least-square adjustment of heights and observed gravity values, sorting of these results into a particular order, and for the final evaluation of free-air and Bouguer anomaly values with provision for up to five different densities in the Bouguer correction. A programme for the reduction of field data to the observed gravity stage, including corrections for drift and base-station values, is under development; it involves the application of polynomial and mean-slope techniques to the drift curves. It is expected to be finalised shortly.

Field data are entered in specific form, principally to facilitate punching-up and retrieval of data. The station is given an eight figure number, the first four figures of which specify the year and the identifying serial number of the survey; the second four figures specify the individual station. The method of entries will enable information to be retrieved for particular studies, e.g. long-term instrument behaviour, revision of values when new control data are available, averaging values for preparing regional maps, calculation of isostatic anomalies, statistical investigations, or geodetic calculations.

A two-dimensional cross-section analysis programme has been developed and used extensively for interpretative gravity reports. A three dimensional analysis programme will be developed for the faster CDC 3600, which has a larger storage capacity.

Standard curves have been calculated for the gravity anomaly due to a sloping fault for a number of different slopes and for various depth ratios of the top to the bottom of the fault plane. These have been prepared in standardised linear co-ordinates and also in bilogarithmic co-ordinates to facilitate interpretation of this type of anomaly.

Programmes have been developed by the South Australian Institute of Technology for use on the CDC 3600 for isostatic reductions and the calculation of geoid heights and deflections of the vertical from gravity anomalies.

12. GRAVITY MAP OF AUSTRALIA

The results of helicopter gravity surveys are plotted at a scale of 1:250,000 on sheets of the national map system, each sheet covering one degree of latitude by one and a half degrees of longitude. Any other data from previous surveys are adjusted in accordance with the most recent base-station values and calibration data, and are then incorporated in the map. Preliminary dyeline copies of the maps are issued at this scale. They are later reduced to half scale and printed at 1:500,000. Eighty four maps have been printed to date.

A revised Bouguer anomaly map of Australia is being prepared to incorporate all gravity data that has been revised as above. The map has been prepared on the basis of reduction of the 1:250,000 scale Bouguer anomaly maps. As the densities used for the Bouguer correction in these maps vary from area to area, the resulting map is not prepared on the basis of a uniform density, but changes of density occur in different areas. It is proposed to prepare a map showing Bouguer anomalies calculated for a density of 2.67 g/cm^3, and also free-air anomaly maps.

The compiled map is being prepared at a scale of 1:2,500,000 in four sheets, corresponding to the Tectonic Map of Australia prepared by the BMR. A reduced version is also being prepared on one sheet at a scale of approximately 1:12,500,000, or 1 inch = 200 miles; on this map the main regional features can be seen at a glance.

13. RESEARCH IN PHYSICAL GEODESY

Research in physical geodesy is being carried out at the South Australian Institute of Technology under the direction of R.S. Mather in the following fields:

(a) The interpolation of gravity data to determine the best possible values for mean anomalies of one-degreee and half-degree squares from the available data, and the estimate of the probable error of the mean values adopted.

(b) The use of Fourier Series to extend available gravity data over limited regions (where resort to spherical harmonics is is uneconomical) so as to obtain more complete field representations.

(c) The processing of available gravity data to produce close anomaly field maps and mean anomalies (with estimates of accuracy) for half-degree and one-degree squares.

(d) The use of correctly interpolated data to map the geoid by determination of N (separation of geoid and spheroid) and of ξ and η (deflections of the vertical).

Progress to date

(i) Programming (on CDC 3600 computer at Canberra) for effecting isostatic reductions is now complete. Programmes are functioning satisfactorily. Mean heights have been estimated for one-tenth-of-a-degree squares for South Australia.

(ii) Programmes are available for computing N, ξ , and η on CDC 3600. Data are incomplete for the fringe zones. Computations will begin on receipt of data from the BMR.

(iii) The computation of mean anomalies within South Australia is in progress and will be completed by the end of September 1965.

(iv) Investigations (i) and (ii) will be commenced in greater detail now, as the Institute has taken delivery of its own gravity meter (Worden geodetic No. 744).

Further geodetic projects are envisaged, but, providing staff requirements are met, the above research should be completed by the end of 1966.

14. NATIONAL GRAVITY BASE STATION

The National Gravity Base Station is at present located in the BMR Geophysical Laboratories at Footscray, Melbourne. When the Geophysical Branch of the BMR moves to Canberra, the building in which the laboratories are housed will be used for other purposes, and access to the base may no longer be feasible. The problem then arises of designating a new National Base. A site has not yet been selected, but could be in Melbourne, Sydney, or Canberra depending to some extent on the following considerations:

Melbourne. Melbourne has been the ultimate reference base in Australia for all measurements for fifteen years. It has been visited by almost all international observers.

Gravity ties to a new site within a few milligals could be made accurately, and would not affect adjustments to the International First Order network in progress.

It is accessible by sea and air, but is not an international airport at present.

Sydney. Sydney is the major international airport in Australia and is accessible by sea. Absolute determination of gravity is in progress.

It has been visited by most international observers.

The difference from Melbourne is about 300 milligals; it has been measured many times and should be accurate, provided the Australian milligal is correct.

<u>Canberra.</u> Canberra is accessible by air, but not so readily as Sydney or Melbourne. It is not accessible by sea.

There have been no pendulum connections with Canberra since the BMR Cambridge survey of 1950-51. Several gravity meter connections to Melbourne have been made, but not so many as between Melbourne and Sydney. The difference from Melbourne is about 360 milligals.

A National Base at Canberra would be convenient to the new BMR headquarters (the BMR does most of the gravity control work). However, the new BMR building appears to be unsuitable because of vibrations, and another site would have to be selected. It should be possible to choose a site in Canberra with less interference from industrial and traffic vibrations and microseismic activity than is possible in Melbourne or Sydney.

A site will be selected after seeking the advice of the International Gravimetric Bureau and appropriate working groups.

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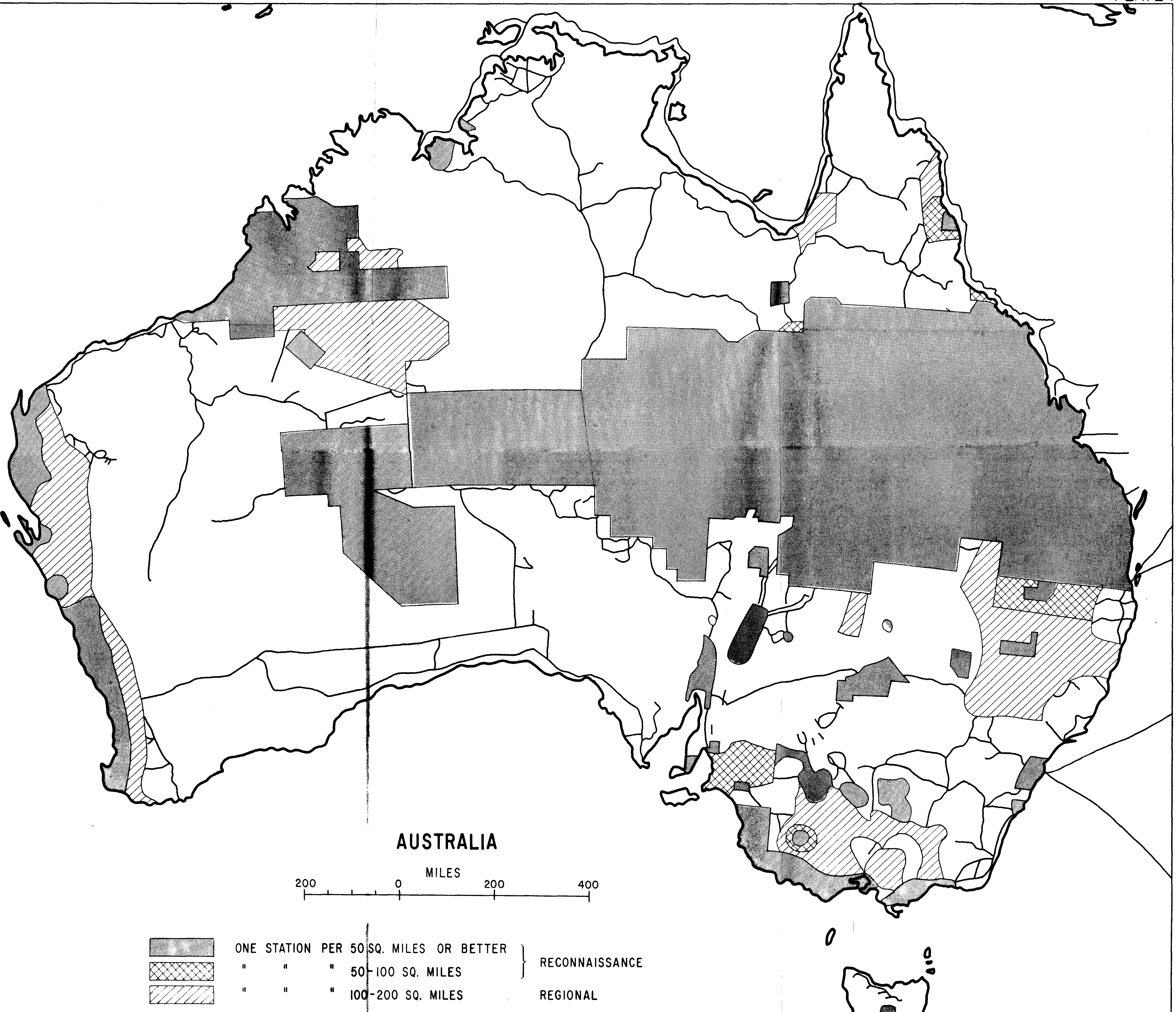
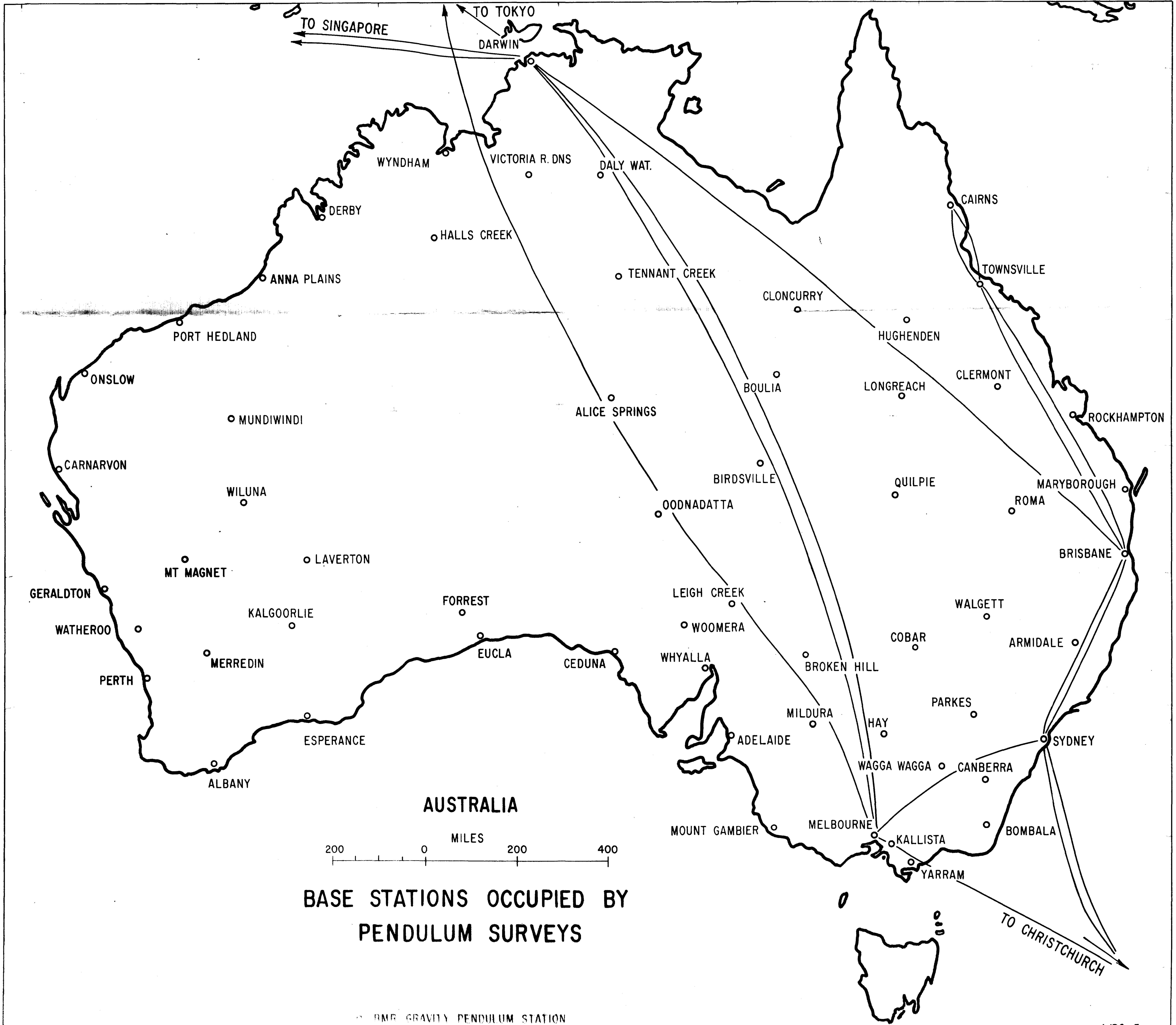


GRAVITY SURVEYS AS AT 1-11-64

TO ACCOMPANY RECORD No 1965/162

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics

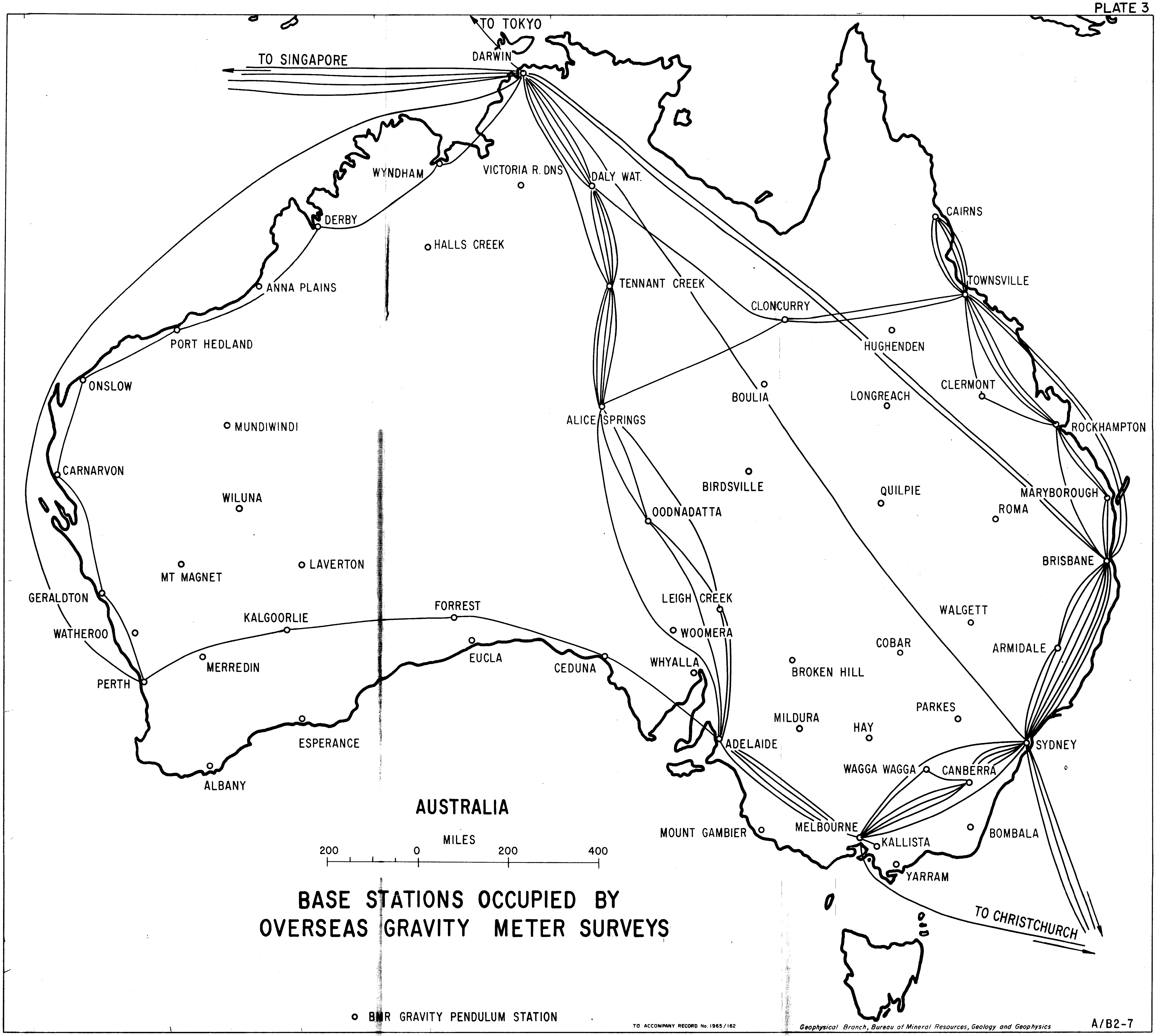
A/B2-3



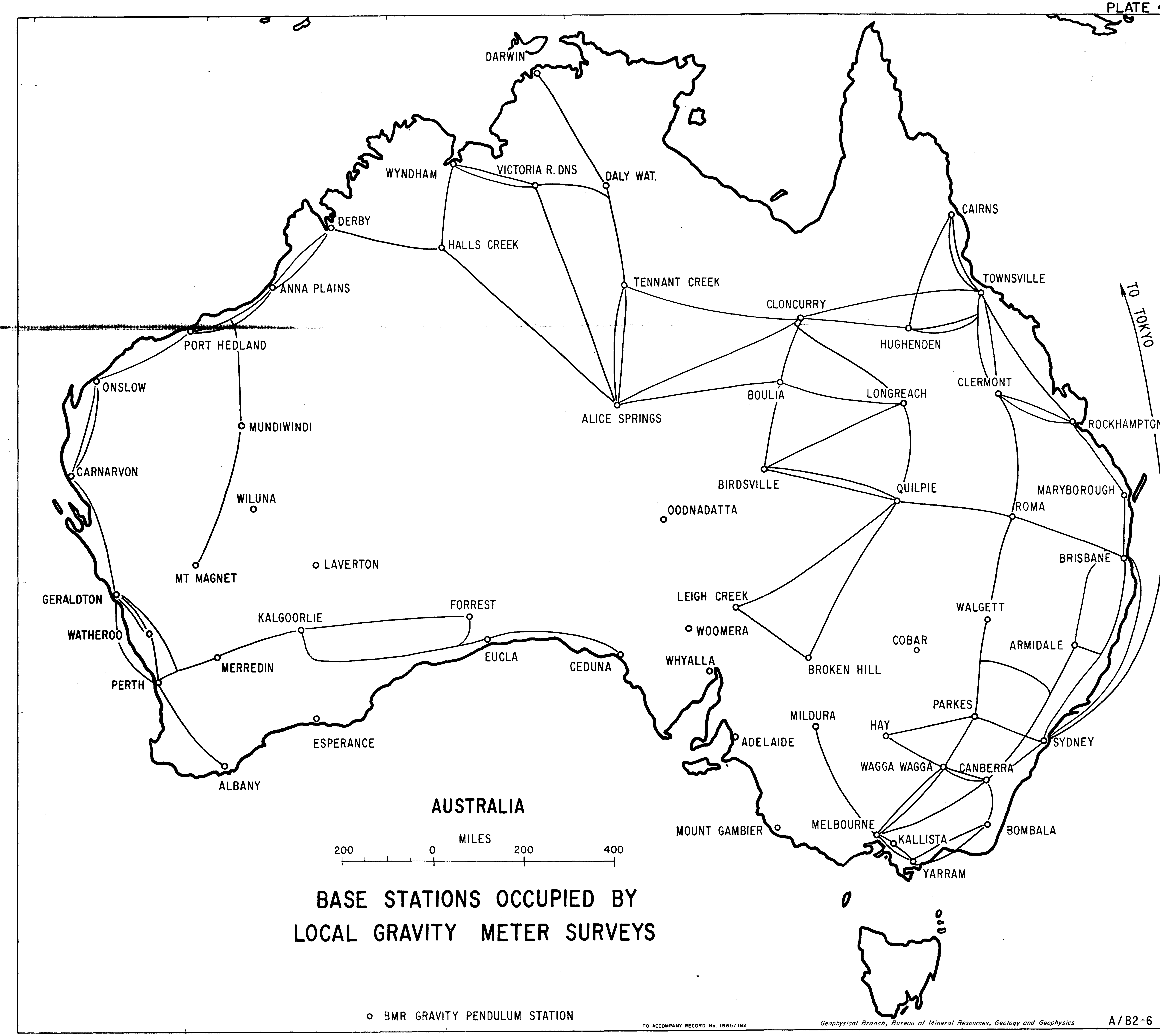
BASE STATIONS OCCUPIED BY PENDULUM SURVEYS

To accompany Record No. 1966/162

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics A/B2-5



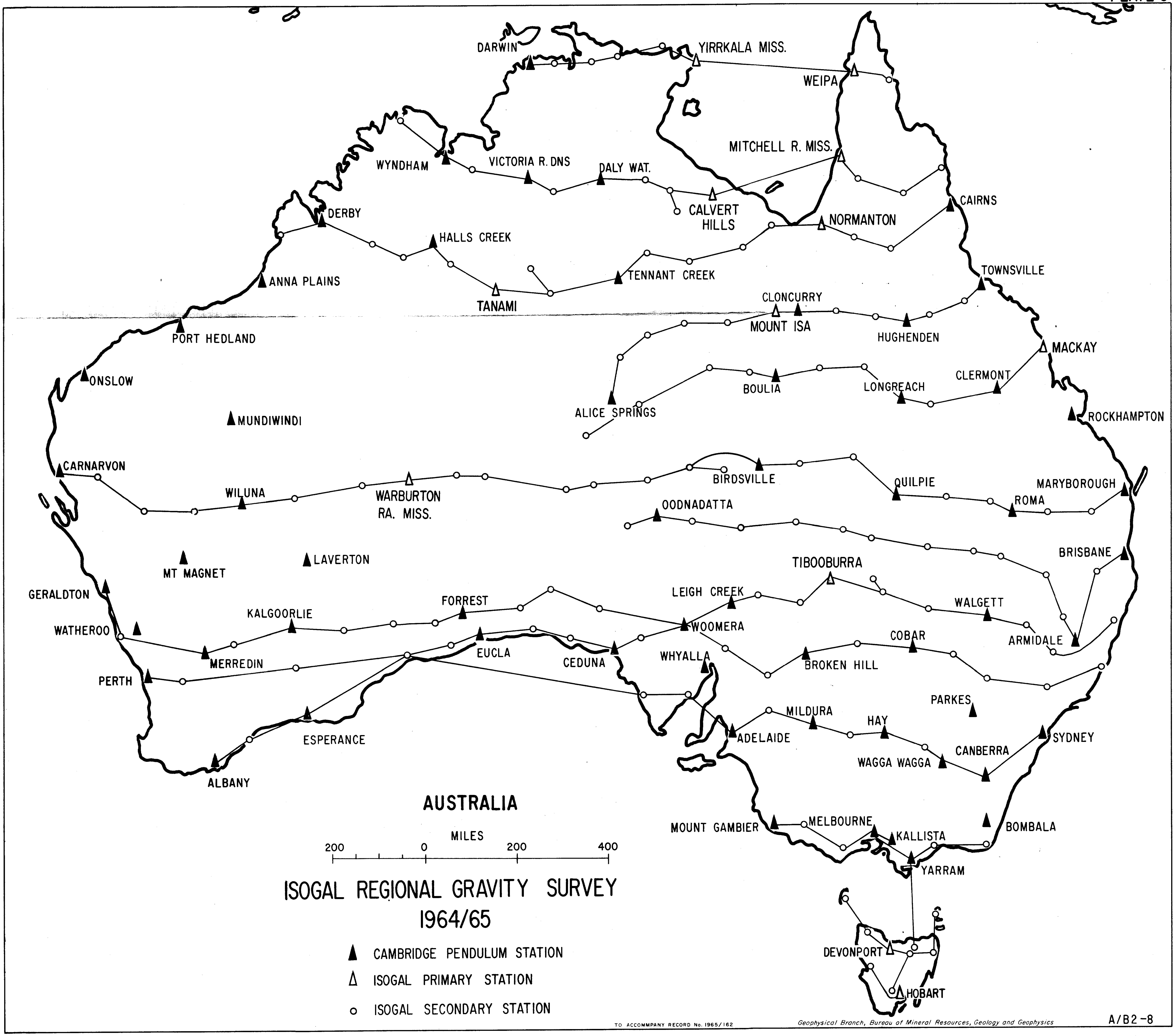
BASE STATIONS OCCUPIED BY OVERSEAS GRAVITY METER SURVEYS



BASE STATIONS OCCUPIED BY LOCAL GRAVITY METER SURVEYS

○ BMR GRAVITY PENDULUM STATION

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics


AUSTRALIA
ISOGAL REGIONAL GRAVITY SURVEY
1964/65
MILES
200
0
200
400
CAMBRIDGE PENDULUM STATION
ISOGAL PRIMARY STATION
ISOGAL SECONDARY STATION
DARWIN
YIRRKALA MISS.
WEIPA
MITCHELL R. MISS.
WYNDHAM
VICTORIA R. DNS
DALY WAT.
CALVERT HILLS
NORMANTON
CAIRNS
DERBY
HALLS CREEK
TENNANT CREEK
TANAMI
ANNA PLAINS
TOWNSVILLE
CLONCURRY
MOUNT ISA
HUGHENDEN
PORT HEDLAND
MACKAY
ONSLOW
BOULIA
LONGREACH
CLERMONT
ALICE SPRINGS
MUNDIWINDI
ROCKHAMPTON
CARNARVON
BIRDSVILLE
QUILPIE
MARYBOROUGH
WILUNA
WARBURTON RA. MISS.
ROMA
OODNADATTA
MT MAGNET
LAVERTON
BRISBANE
TIBOOBURRA
GERALDTON
LEIGH CREEK
WALGETT
FORREST
KALGOORLIE
WOOMERA
WATHEROO
ARMIDALE
COBAR
MERREDIN
EUCLA
CEDUNA
WHYALLA
BROKEN HILL
PERTH
PARKES
MILDURA
HAY
ESPERANCE
ADELAIDE
SYDNEY
CANBERRA
WAGGA WAGGA
ALBANY
MOUNT GAMBIER
MELBOURNE
KALLISTA
BOMBALA
YARRAM
DEVONPORT
HOBART
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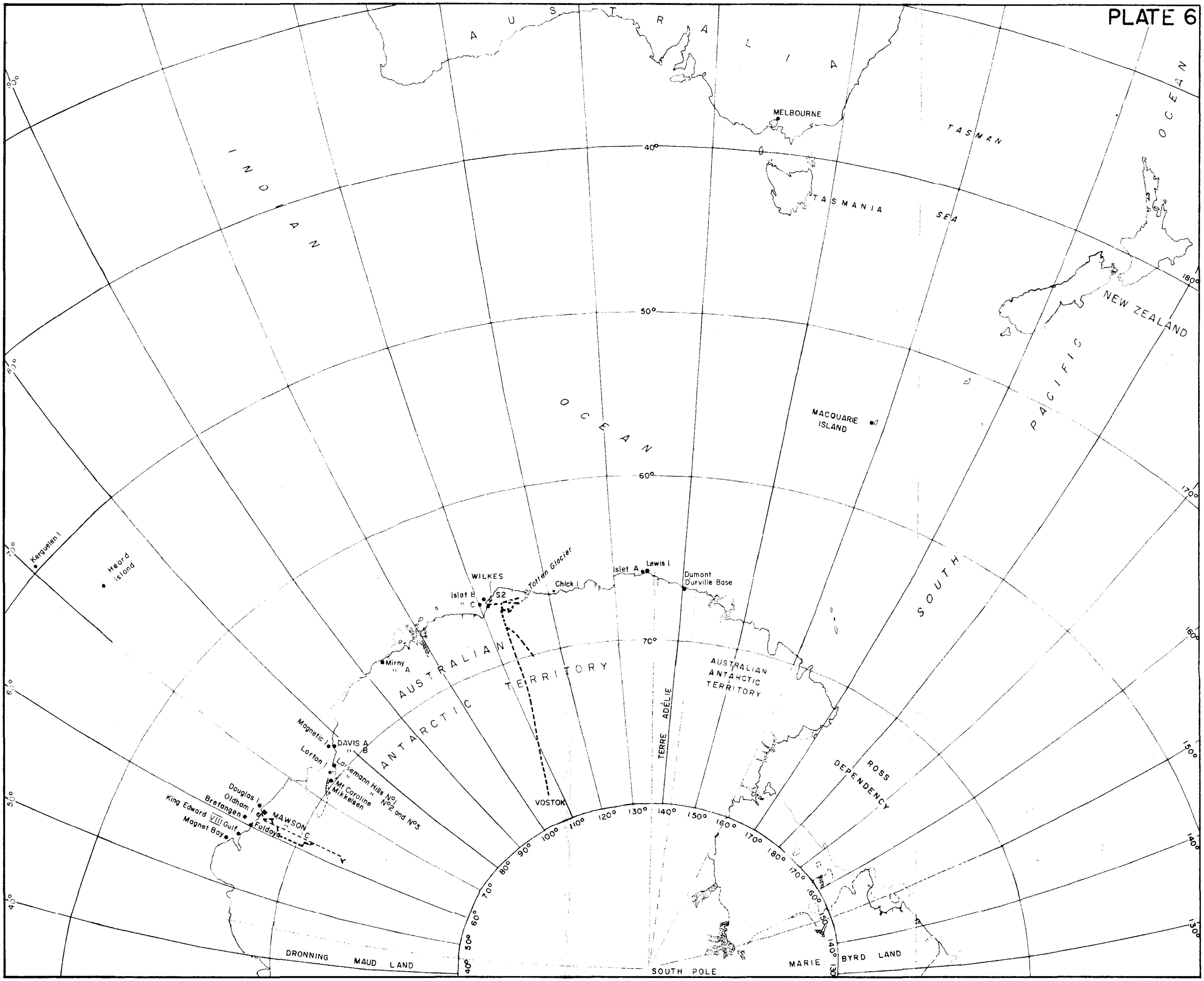

LEGEND

- Gravity station
- - - ANARE Ice thickness traverses

SCALE IN MILES

100 0 100 200 300 400 500 600 700 800

GRAVITY OBSERVATIONS IN ANTARCTICA

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G65-137