Library

COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD No. 1965/142

NATIONAL REPORT ON GRAVITY IN AUSTRALIA TO JUNE 1965

by

J.C. Dooley

Lib.

BUREAU OF MINERAL RESOURCES

RECORD NO. 1965/

NATIONAL REPORT ON GRAVITY IN AUSTRALIA

TO JUNE 1965

by

J.C. Dooley

CONTENTS

ILLUSTRATIONS

SUMMARY

Between 1962 and mid-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 carried out, in which a light aircraft was used to transport three gravity meters along lines of approximately constant 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 GSI pendulum apparatus was purchased in 1962. 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 gravimeters 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 (1962). The present report covers activities during the period since the latter, i.e. from January 1962 to June 1965.

Acknowledgment is made of information supplied by National Standards Laboratory, C.S.I.R.O., Sydney; Physics Department of South Australian Institute of Technology; Universities of Tasmania and Sydney; 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 in the improved regional gravity coverage in Australia has been the use of helicopters by the Bureau of Mineral Resources 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 Bureau itself with chartered helicopters, but since 1962 the whole survey has been let out on contract.

The surveys have progressed to a stage now where between 30 and 40 sheets of the national 1:250,000 series are covered per year, each sheet covering one degree of latitude by one and a half degrees longitude. Station spacing is approximately on a 7 mile grid. Heights are obtained by barometric observations, and a network of spirit level stations is run through the area to be covered to act as tie stations. The areas covered so far are shown on Plate 1 and include a belt through Central Australia and a large portion of Queensland. Positions are obtained from identification of stations on aerial photographs which are used in navigation. A description of the method has been given by Vale (1962) and Hastie (1962).

Many other important contributions to the gravity coverage of Australia have been made by private companies operating under the Petroleum Subsidies Search Act, under which agreements are made between the companies and the government. The government pays a proportion of the cost of the survey, and in return results are made available to the government and may be published after six months after the completion of the survey. In addition many companies have willingly contributed results of surveys which are non-subsidised, or at least such portion of the results as is 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 both in Tasmania and also in the Territory of Papua and New Guinea, in which area they were cooperating with the U.S. Army Mapping Service, the Bureau of Mineral Resources, and the Division of National Mapping. Helicopters were also used in this survey for transport, but the primary purpose of the helicopters was for establishing geodetic survey stations in New Guinea. The resulting coverage is not as evenly spaced as in the helicopter surveys especially designed for gravity work.

The Bureau of Mineral Resources 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 joining the various surveys together, as they had been based on different datums and some companies had used calibration factors which did not agree with those generally adopted. The first attempt at establishing a gravity reference network throughout Australia was made in 1950-51 in which 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 that steps were 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 was made at several stations distributed well in latitude throughout Australia. In 1962 an adjustment was made of the gravity values at the original pendulum stations using all available ties by overseas and also by local observers; the adjustments were made at the original pendulum stations because these had been used for some time for tying local surveys. The available information is shown on Plates 2, 3, and 4. Plate 2 shows the original 59 pendulum stations and also ties with pendulums which have been made between them by observers since 1951. Plate 3 shows the ties which have been made with gravity meters by overseas observers between these stations. Plate 4 shows ties which have been made by local observers, principally the Bureau of Mineral Resources. Although many companies and other authorities have done gravity surveys, few of these have been carried out on such a scale or under suitable conditions for establishing ties between pendulum stations that could be used in adjusting the network.

The local work includes a survey which was carried out in 1960-61 by the Bureau of Mineral Resources with the special intention of making ties between fifteen pendulum stations in the eastern states (Flavelle, 1965). It was originally intended to make an adjustment after carrying out this survey. However, loop closures showed that the desired accuracy was not obtained on this survey, and the more comprehensive readjustment was undertaken. Measurements by observers from Wisconsin University, Expeditions Polaires Francaise, U.C. (University of California, Los Angeles) L.A., and the Geographical Survey Institute of Japan have also been used.

The method used was to ascribe gravity values to all stations visited during a survey on some arbitrary datum. 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 each 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 R.M.S. 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 surveys visiting 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. 15 stations have an accuracy of 0.1 mgal, 12 have an accuracy of 0.2 mgal, and 16 have an accuracy of 0.3 mgal. The standard errors in the remaining 14 stations range from 0.4 to 0.7 mgal.

An essential by-product of the adjustment is a revision of the gravity meter calibration factors used by the Bureau. Wherever possible, B.M.R. surveys were related to the Ferntree Gully-Kallista calibration range, using the adopted value of 55.60 mgal. The resulting adjustment necessary for this group of B.M.R. surveys is to increase the calibration factors by 1.6 parts in 1,000, i.e. to apply a correction factor of 1.0016. This figure has a standard deviation of about 0.2 parts per 1,000.

Connections to Christchurch, Singapore, and Tokyo were included 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.

This adjustment has been described in detail by Dooley (1965a). 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 carried out 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. a line of approximately equal observed gravity values. In this way errors due to uncertain calibration factors in the gravity meters are minimised. Each line was selected so that the gravity values of the stations along it were within 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 2 or 3 hours. The path covered by the survey and the stations established are shown on Plate 5.

At each base station ties were made to as many existing gravity surveys as possible and additional excentres were established as convenient. The complete survey took about 8 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 this survey is unique of its kind as an attempt to establish systematically a uniform network of base stations over a whole continent.

In early 1965 a visit was made by U.S. Air Force observers carrying 4 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 returning by the same route. An observer from the Bureau of Mineral Resources travelled with this party with a fifth La Coste geodetic gravity meter. Results of these observations have improved the accuracy of the east-coast chain, and these have been combined with 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 passing 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 milligals.

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

Mr. 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 vacuo through two planes at a known vertical separation (about 50 cm) and the time intervals 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 with a photo-diode, the output from which is amplified and used to operate a pair of counters, and is also displayed on a C.R.O. screen and photographed. Using 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 BMR in 1962 from Sokkisha Ltd. of Japan. These were manufactured according to the design of the Geographical Survey Institute, Tokyo.

A measurement was attempted between Tokyo and Melbourne on delivery of the equipment (Langron, 1965c). Measurements were made at Tokyo before shipment and at Melbourne after delivery; the pendulums and swinging chamber were then returned to Japan, and a repeat measurement was made by Japanese observers using their own timing and other equipment. The measurement showed a discrepancy of about 2½ milligal from other measurements.

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 which may seriously affect the results. Further investigations are in progress.

Convenience of operation, reliability and portability could be considerably improved by re-designing the electronics, 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, 8 local gravity meter calibration ranges were established throughout Australia by the Bureau of Mineral Resources, each with an interval of 50 to 60 mgal. Gravity intervals of 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 Range was established in the first place from pendulum stations in Victoria of the Cambridge pendulum survey and was revised as a result of the 1962 adjustment of pendulum stations through Australia. The Ferntree Gully - Kallista Range was replaced by a somewhat 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 range relative to the others is estimated to be ± 0.02 milligals or ± 0.04%. The establishment of these 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, as the Geophysical Branch of the Bureau of Mineral Resources will be transferring to Canberra during 1965. The 9 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 to occur in periods of less than 1 hour. The effect is being further investigated. A La Coste and 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 measurements have been made in Antarctica in association with seismic traverses for ice thickness determination based on Wilkes. The location of these traverses is shown on Plate 6. The 1962 work has been described by Kirton (1965), and the 1963 work by Walker (in preparation).

The gravity meters which were taken to Antarctica for the ice thickness work were also used to make ties between the Australian ~~mainland and Antarctica. Langron (1965) has made a study of all the Australian~~ mainland and Antarctica. Langron (1965b) 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 also of stations along the coast. The values obtained have an accuracy no better than ± 5 or 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 at Mawson and by the Russians at Mirny; 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 Geodetic meter carried ~~out~~ by plane from McMurdo to Wilkes. It is hoped to make pendulum measurements when the Bureau's 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 B.M.R. observers who visited the islands primarily to reoccupy secular variation magnetic stations. The results of these measurements have not yet been published.

9. GRAVITY OBSERVATIONS AT SEA

A contract has been let by B.M.R. 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 (S.A.) was carried out by Beach Petroleum Ltd. (Sprigg and Stackler, 1965). A normal land gravity meter was lowered to the sea bottom with an observer in a diving bell to depths ranging to 150 ft. 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, much data has been accumulated which enables a study 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 gravitymeter 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 carried out to study the effects of temperature and pressure on gravity meters. Further tests are planned.

11. AUTOMATIC COMPUTING OF GRAVITY DATA

The B.M.R. is making extensive use of automatic computing methods for reduction of gravity data (Langron, 1965a). 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 machine at Monash University, Victoria, but the C.S.I.R.O. C.D.C. 3600 computer will be used when 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 ~~programmes~~ for the final evaluation of Free Air and Bouguer Anomaly values with provision for up to 5 different densities in the Bouguer correction. A programme for 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 finalized shortly.

Field data is entered in specific form principally to facilitate punching up and retrieval of data. The station is given an 8 figure number, the first 4 figures of which specify the year and the identifying serial number of the survey; the second 4 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 2-dimensional cross section analysis programme has been developed and used extensively for interpretative gravity reports. A 3-dimensional programme will be developed for the faster C.D.C. 3600, with its larger storage capacity.

Standard curves have been calculated for the gravity anomaly of 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 C.D.C. 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 1° latitude by 1½° 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. 84 maps have been printed to date.

A revised Bouguer anomaly map of Australia is being prepared incorporating all gravity data that has been revised as above. The map has been largely prepared on the basis of reduction in scale of 1:500,000 Bouguer anomaly maps. As the densities used for the Bouguer correction in these maps vary from area to area so 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 on 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 B.M.R. 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 to determine the best possible values for mean anomalies of $1^\circ \times 1^\circ$ and $\frac{1}{2}^\circ \times \frac{1}{2}^\circ$ 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 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 $\frac{1}{2}^\circ \times \frac{1}{2}^\circ$ and $1^\circ \times 1^\circ$ 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 $1/10^\circ \times 1/10^\circ$ squares for South Australia.

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

(iii) Computation of mean anomalies within South Australia is in hand, and will be completed by end of September.

(iv) Investigations (i) and (ii) above will be commenced in greater detail now as the Institute has taken delivery of its own gravimeter (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 B.M.R. Geophysical Laboratories at Footscray, a suburb of Melbourne. With the Geophysical Branch of B.M.R. moving 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 arises then of designating a new National Base. A site has not yet been selected, but could be in Melbourne, Sydney, or Canberra. The following considerations are relevant.

Melbourne. Has been the ultimate reference base in Australia for all measurements for 15 years. 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.

Accessible by sea and air, but not an international airport at present.

Sydney. The major international airport in Australia. Accessible by sea.

Absolute determination of gravity is in progress.

Has been visited by most international observers.

Difference from Melbourne is about 300 mgal. Difference has been measured many times and should be accurate, provided the Australian milligal is correct.

Canberra. Accessible by air, but not as readily as Sydney or Melbourne. Not accessible by sea.

No pendulum connections since B.M.R. Cambridge survey 1950-51. Several gravity meter connections to Melbourne, but not as many as Melbourne-Sydney. Difference from Melbourne is about 360 mgal.

Convenient to new B.M.R. headquarters - B.M.R. does most gravity control work. However new B.M.R. 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.

REFERENCES AND BIBLIOGRAPHY

The following list contains references quoted in the text of this report, and also a list of published material and B.M.R. unpublished Records relating to gravity surveys or measurements issued during the period 1962 to mid 1965.

BARLOW, B.C. 1965 Establishment of gravity meter calibration ranges in Australia, 1960-61. Bur. Min. Resour. Aust. Rec. 1965/19

BARLOW, B.C. The Australian isogal survey, 1964. (in preparation).

BIGG-WITHER, A.L. 1963 The correlation of gravity profiles with sub-surface structures in the Great Artesian Basin. Ibid. 1963/166

DALY, J. and LANGRON, W.J. 1963 Darwin-Katherine region, reconnaissance gravity survey, Northern Territory, 1959. Ibid. 1963/28.

DOOLEY, J.C. 1959 National Report on gravity in Australia, May, 1959. Ibid. 1959/97.

DOOLEY, J.C. 1963a Onslow-Derby regional gravity traverse, W.A., 1953. Ibid. 1963/13.

DOOLEY, J.C. 1963b Results of Southwest Pacific submarine gravity survey, 1956. Ibid. 1963/43

DOOLEY, J.C. 1965a Australian gravity network adjustment, 1962. Bur. Min. Resour. Aust. Rep. 72 (in press).

DOOLEY, J.C. 1965b Gravity surveys of the Great Barrier Reef and adjacent coast, North Queensland, 1954-60. Ibid. 73 (in press).

DOOLEY, J.C., McCARTHY, E., KEATING, W.D., WILLIAMS, L.W., and MADDERN, C.A.	1961	Pendulum measurements of gravity in Australia, 1950-51. Bur. Min. Resour. Aust. Bull. 46
EVERINGHAM, I.B.	1965	Poole Range gravity survey, W.A. 1953 Bur. Min. Resour. Aust. Rep. 97 (in press)
FLAVELLE, A.J. and GOODSPEED, M.J.	1962	Fitzroy and Canning Basin reconnaissance gravity surveys, W.A., 1952/60. Bur. Min. Resour. Aust. Rec. 1962/105.
FLAVELLE, A.J.	1965	Eastern Australian gravity meter ties between pendulum stations, 1959-60 (in preparation).
GUNSON, S.	1963	Southwest Pacific submarine gravity survey operations, 1956. Bur. Min. Resour. Aust. Rec. 1963/42.
GUNSON, S. and WILLIAMS, L.W.	1965	Gravity survey of Port Phillip Bay and adjacent areas, Vic., 1957-8. Ibid. 1965/64.
HASTIE, L. McN.	1962	Two methods of gravity traversing with helicopters. Ibid. 1962/134
KIRTON, M.	1965	Wilkes geophysical survey, Antarctica, 1963. Ibid. 1965/24
LANGRON, W.J.	1962a	Amadeus Basin reconnaissance gravity survey using helicopters, 1961. Ibid. 1962/24
LANGRON, W.J.	1962b	Regional gravity traverse, Roma to Quilpie, 1960. Ibid. 1962/47
LANGRON, W.J.	1962c	Amadeus Basin, gravity measurements along seismic traverses, 1961. Ibid. 1962/169
LANGRON, W.J.	1962d	National report on gravimetry, 1st June, 1959 to 31st Dec. 1961. Bur. Min. Resour. Aust. (unpubl.)
LANGRON, W.J.	1965a	Programming gravity data. APEA J. 1965 (in press).

LANGRON, W.J.	1965b	Gravity ties to Australian Antarctica, 1954-62 (in preparation).
LANGRON, W.J.	1965c	Pendulum gravity measurements, Tokyo-Melbourne, 1962-3 (in preparation).
LONSDALE, G.F.	1962	Great Artesian Basin reconnaissance gravity surveys using helicopters, Queensland, 1961. Bur. Min. Resour. Aust. Rec. 1962/14
LONSDALE, G.F.	1963a	Longford gravity survey, Vic., 1960 Ibid. 1963/106.
LONSDALE, G.F.	1963b	Daly Waters - Nutwood Downs regional gravity traverse. Ibid. 1963/136
MAGELLAN PETROLEUM CORPORATION	1965	Tambo-Augathella aeromagnetic and gravity survey, Queensland, 1959. Bur. Min. Resour. Aust. P.S.S.A. Publ. 31 (in press)
MUMME, I.A.	1963a	Geophysical survey of the Officer Basin, S.A. Trans. Roy. Soc. S. Aust., 87, p. 119.
MUMME, I.A.	1963b	An evaluation of the crustal thickness in the Maralinga area, S.A. Ibid., 87, p. 197.
NEUMANN, F.J.G.	1964	Normanton-Daly Waters reconnaissance gravity survey, Queensland and N.T., 1959-60. Bur. Min. Resour. Aust. Rec. 1964/131.
NEUMANN, F.J.G.	1965	Blair Athol coalfield gravity survey, Queensland. Bur. Min. Resour. Aust. Rep. 94.
OLDHAM, W.H.	1963	Adelaide - Melbourne regional gravity traverse, 1949. Bur. Min. Resour.Aust. Rec. 1963/27

PAPUAN APINAIPI PETROLEUM COMPANY 1962 Boulia gravity survey, Queensland <u>Bur. Min. Resour. Aust. P.S.S.A. Publ</u>. 37

RADESKI, A. 1962 Regional gravity survey, Central and Northern Australia, 1959. <u>Bur. Min. Resour. Aust. Rec</u>. 1962/6.

SEEDSMAN, K.R. 1964 Geophysical Exploration in the South Australian portion of the Murray Basin. <u>APEA J</u>., 1964, p. 90

SHIRLEY, J. Pendulum gravity measurements, Eastern Australia, 1964 (in preparation).

VAN SON, J.H. 1965 Regional gravity traverses Wiluna/ Alice Springs/Oodnadatta, 1962 (in preparation.)

SPRIGG, R.C. and STACKLER, W.F. 1965 Submarine gravity surveys in the St. Vincent Gulf, S.A. <u>APEA J</u>., 1965 (in press).

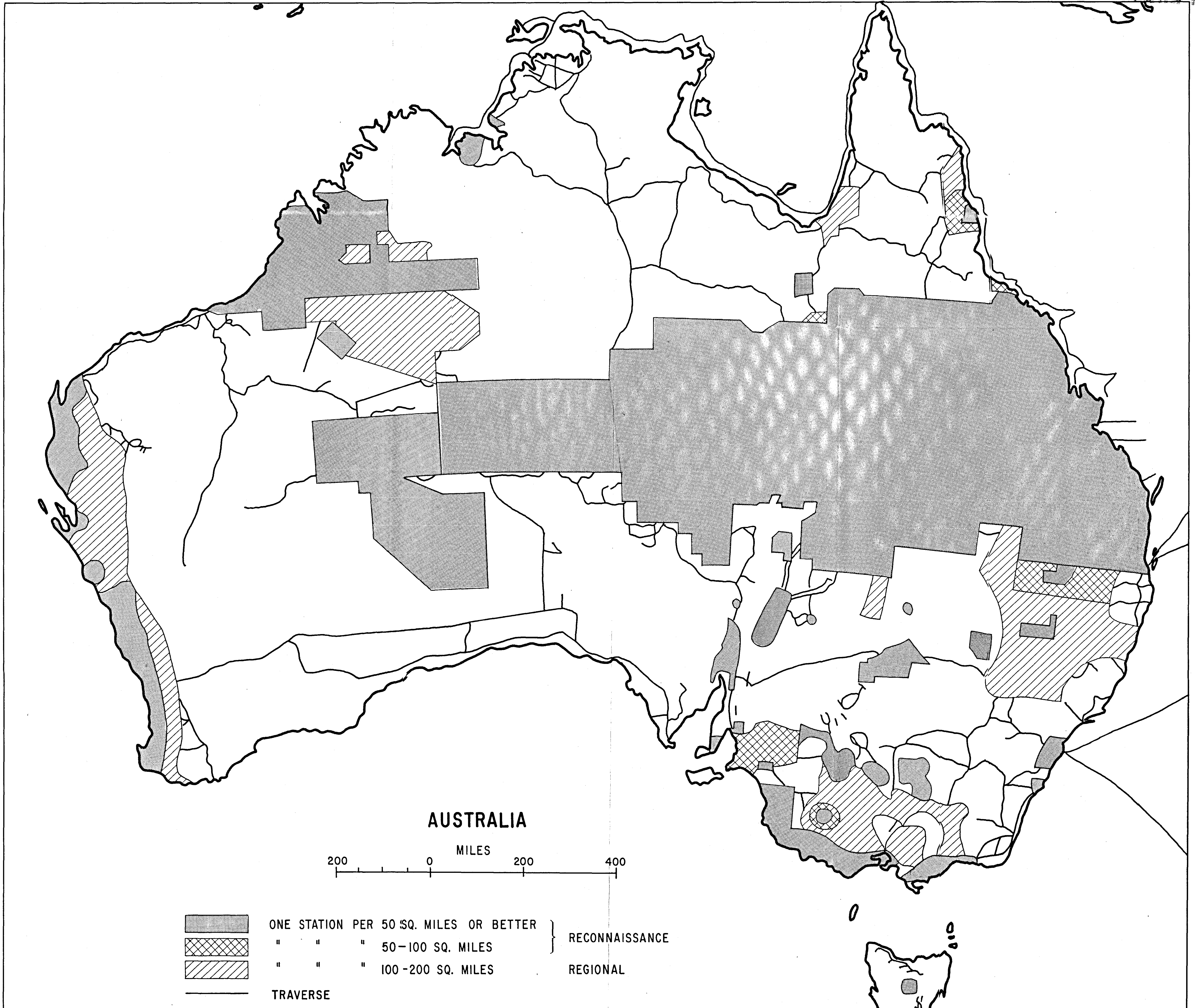
STACKLER, W.F. 1963 The place of accurate gravity in Australian exploration. <u>APEA J</u>., 1963 p. 80.

THYER, R.F. 1963 Geophysical exploration in Australia. <u>Geophysics</u>, 28, p. 273.

WALKER, D.J. 1965 Antarctic ice-thickness measurements near Wilkes, 1963 (in preparation).

WEST AUSTRALIAN PETROLEUM COMPANY 1962 Burlee gravity survey, W.A. <u>Bur. Min. Resour. Aust. P.S.S.A. Publ</u>. 38

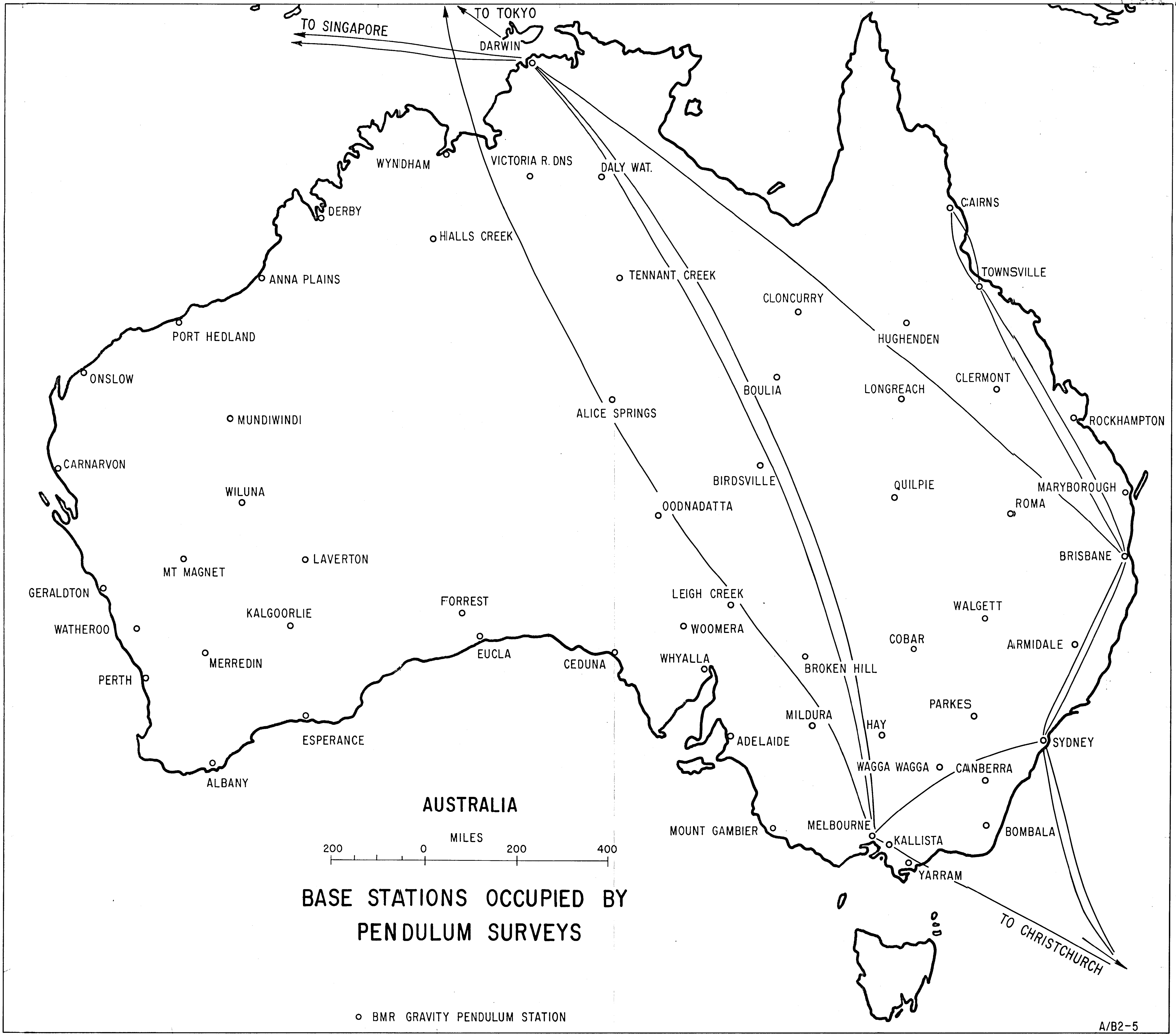
VALE, K.R. 1962 Reconnaissance gravity surveys usng helicopters for oil search in Australia. <u>Bur. Min. Resour. Aust. Rec</u>. 1962/130



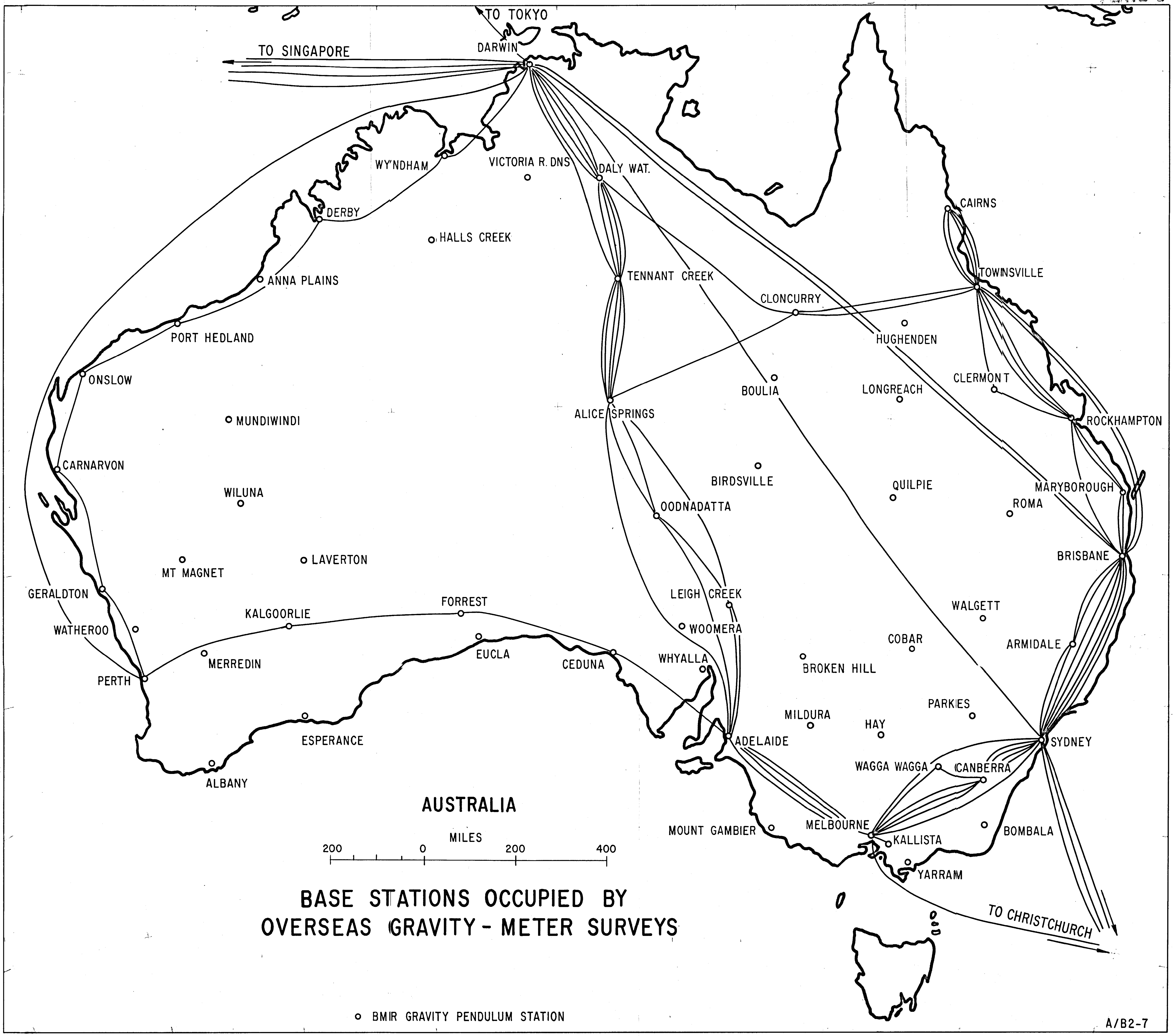
GRAVITY SURVEYS AS AT 1-11-64

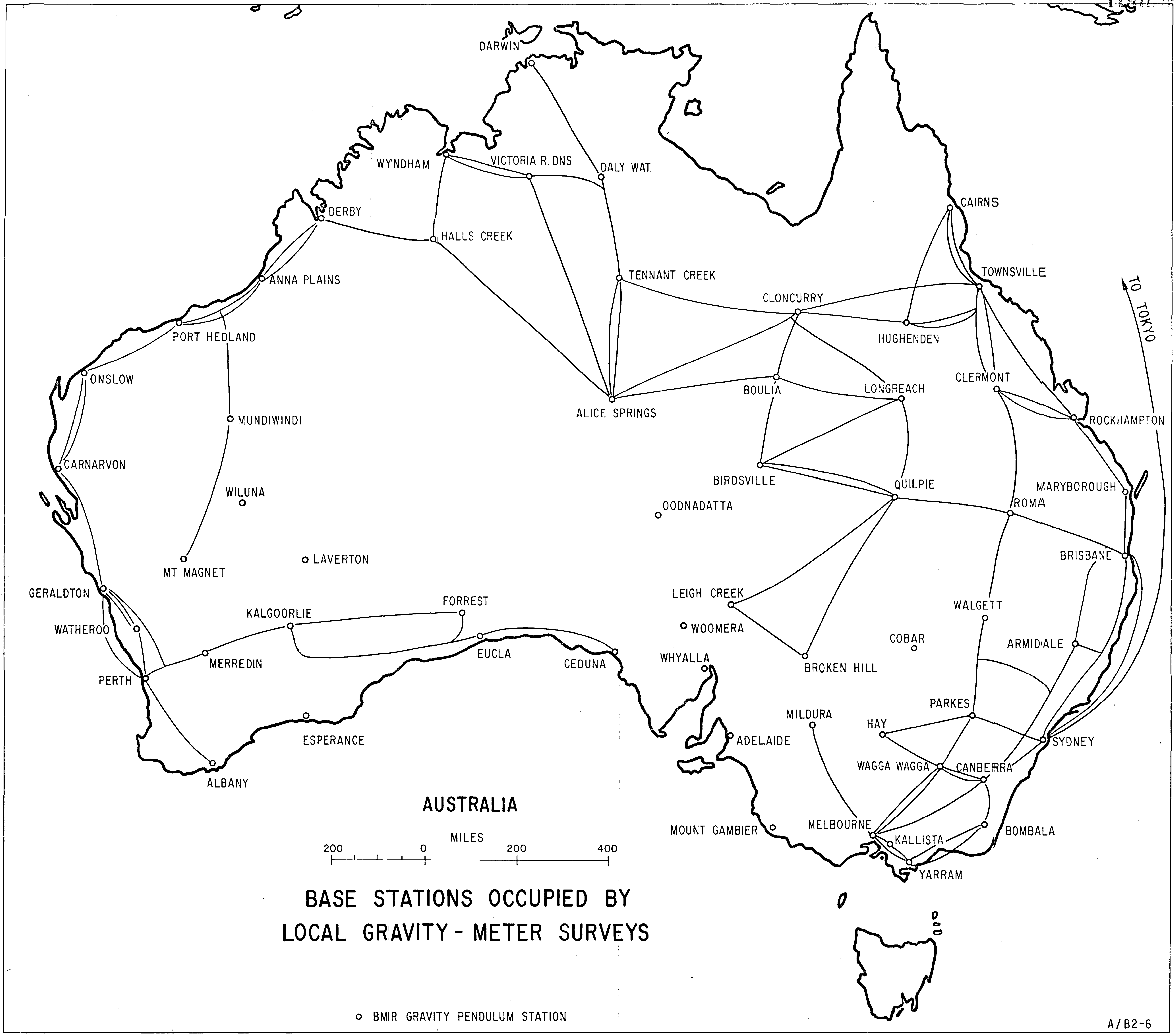
A/B2-3

PLATE 2

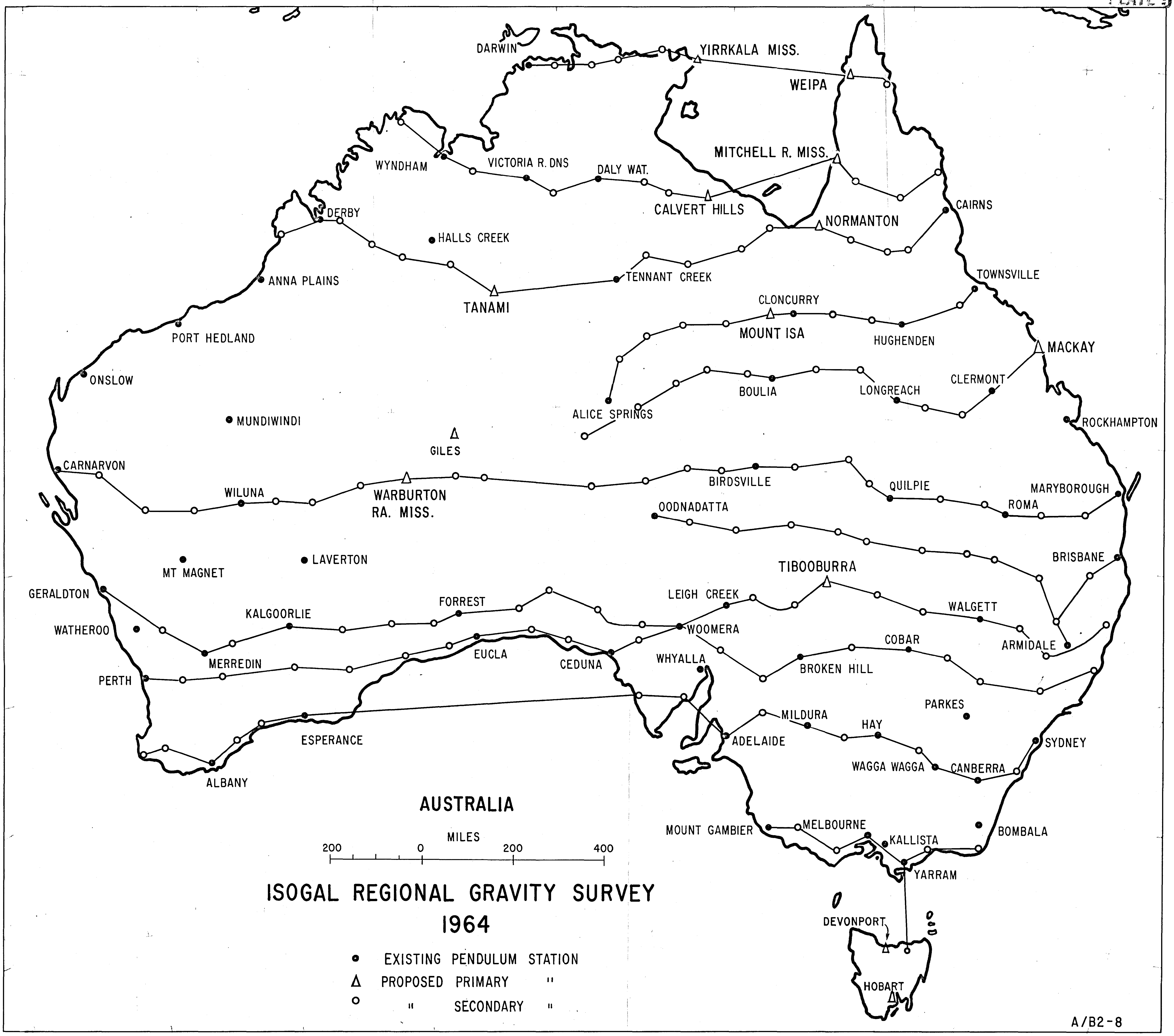


BASE STATIONS OCCUPIED BY PENDULUM SURVEYS


TO TOKYO
TO SINGAPORE
DARWIN
WYNDHAM
VICTORIA R. DNS
DALY WAT.
DERBY
HALLS CREEK
ANNA PLAINS
TENNANT CREEK
CLONCURRY
PORT HEDLAND
ONSLOW
MUNDIWINDI
ALICE SPRINGS
BOULIA
LONGREACH
HUGHENDEN
CAIRNS
TOWNSVILLE
CLERMONT
ROCKHAMPTON
CARNARVON
WILUNA
BIRDSVILLE
QUILPIE
MARYBOROUGH
ROMA
OODNADATTA
BRISBANE
MT MAGNET
LAVERTON
GERALDTON
WATHEROO
FORREST
KALGOORLIE
LEIGH CREEK
WOOMERA
WALGETT
ARMIDALE
COBAR
MERREDIN
EUCLA
CEDUNA
WHYALLA
BROKEN HILL
PERTH
PARKES
MILDURA
HAY
ESPERANCE
ADELAIDE
SYDNEY
WAGGA WAGGA
CANBERRA
ALBANY
AUSTRALIA
MILES
200
0
200
400
MOUNT GAMBIER
MELBOURNE
KALLISTA
BOMBALA
YARRAM
TO CHRISTCHURCH
BASE STATIONS OCCUPIED BY
OVERSEAS GRAVITY - METER SURVEYS
o BMR GRAVITY PENDULUM STATION
A/B2-7



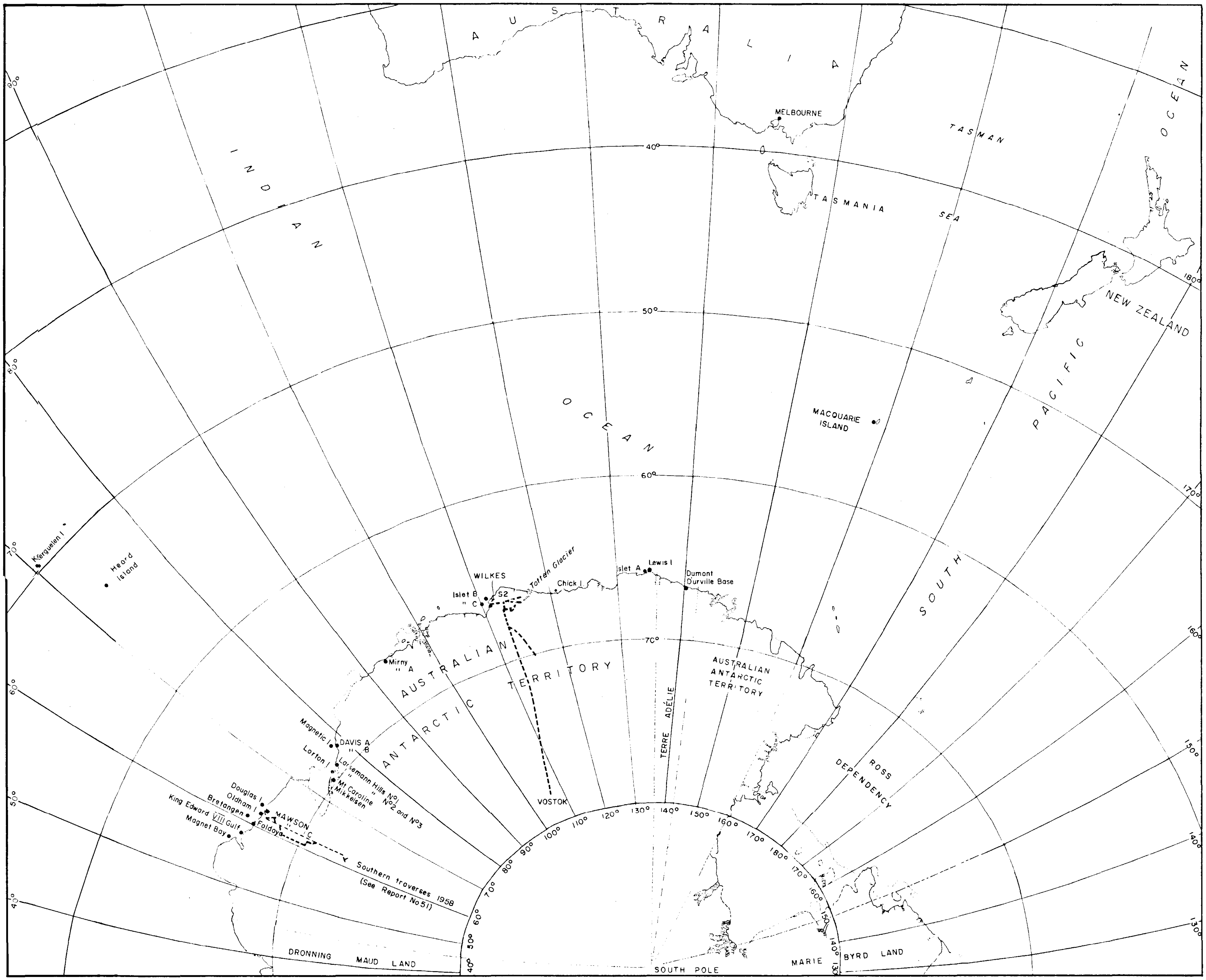
BASE STATIONS OCCUPIED BY LOCAL GRAVITY - METER SURVEYS



ISOGAL REGIONAL GRAVITY SURVEY 1964

- ● EXISTING PENDULUM STATION
- Δ PROPOSED PRIMARY "
- ○ " SECONDARY "

A/B2-8



GRAVITY OBSERVATIONS IN ANTARCTICA

LEGEND

- Gravity station
- - - ANARE Ice thickness traverses

SCALE IN MILES

100 0 100 200 300 400 500 600 700 800

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics G65-137