COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD No. 1962/141

AUSTRALIAN GRAVITY NETWORK ADJUSTMENT, 1962

by

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SUMMARY

Values of gravity have been revised for the 59 pendulum stations established with the Cambridge pendulums during 1950-51. The revision has been made using all available pendulum and gravity-meter ties between these stations.

It was originally intended to make an adjustment after carrying out an accurate gravity-meter survey connecting 15 pendulum stations between Melbourne and Cairns. However, loop closures showed that the desired accuracy was not obtained on this survey, and the more comprehensive readjustment was undertaken.

The method used was to ascribe gravity values on some arbitrary datum to all stations visited during a survey. The datum was then adjusted so that the average departure of these values from the original Cambridge pendulum values was zero for each survey. (This procedure was necessary because not all surveys had a common datum). The gravity values at each station were then averaged to give an approximate value of gravity for the station. The correlation of each survey with the average value was calculated to determine a sensitivity 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 from the average value. A second approximation was then obtained, using the new sensitivities and calculating a weighted average for each station. The sensitivities 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 the stations. 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 mgal, twelve have an accuracy of 0.2 mgal, and sixteen have an accuracy of 0.3 mgal. The standard errors in the remaining fourteen stations range from 0.4 to 0.7 mgal.

An essential by-product of the adjustment is a revision of the gravity-meter sensitivities used by the Bureau. Wherever possible, BMR surveys were related to the Ferntree Gully/Kallista calibration range, using the adopted value of 55.60 mgal. The resulting adjustment necessary to this group of BMR surveys is to increase the sensitivities 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 included in the adjustment. Values for these stations relative to the Australian network were determined in order to facilitate readjustment of the network when the first-order world gravity network is adjusted by the International Association of Geodesy.

1. INTRODUCTION

In Australia since 1951, all gravity surveys of any extent carried out by the Bureau of Mineral Resources, and most of those carried out by other organisations, have been tied to a network of 59 base stations established with the Cambridge pendulums in 1950-51 (Dooley, McCarthy, Keating, Maddern, and Williams, 1961). It was planned to make a series of gravity-meter traverses between these stations, using the same gravity-meter throughout, in order to arrive at an accurate sensitivity for the gravity-meter, and to determine more precisely the gravity difference between pendulum stations. The calibrated gravity-meter could then be used for comparison with other gravity-meters and for establishing local calibration ranges.

As the first phase of this project, connexions were made between 18 pendulum stations in the eastern states during 1959 and 1960 (Flavelle, in preparation).

Unfortunately, owing to meter breakdowns and to requirements for other aspects of the BMR programme, the network of stations was not completed with the one meter, in fact three were used. Also, several different observers carried out parts of the survey.

A local calibration range was established about 25 miles east of Melbourne in 1951 between Ferntree Gully and Kallista, with a difference in gravity of about 56 mgal between two stations that are about five miles apart. In the first place, a value was adopted for this from the average of a number of gravity-meter measurements using makers' sensitivity values. In 1956 a provisional value of 55.60 mgal was adopted for this range, being based on measurements with Worden gravity meter No. 260, whose sensitivity had been determined from ties between four pendulum stations, viz. Melbourne (Footscray), Yarram, Bombala, and Kallista, with a total range of about 280 mgal.

All gravity meters used on the 1959-60 network survey were calibrated on the Ferntree Gully/Kallista (FG/K) range immediately before and after each section of the survey, and this affords a means of unifying the results. However, the accuracy obtained was not as good as had been hoped for, and some misclosures of 0.5 to 1.0 mgal occurred around loops of total length about 500 miles. Thus the expected accuracy appeared to be not much better than that of the pendulum connexions, for which a mean standard deviation (S.D.) of 0.6 mgal has been estimated (Dooley et al.,1961).

Since 1950, several overseas observers, who have visited Australia with pendulums and gravity meters, have made observations at a number of Australian stations, including the BMR pendulum stations. Furthermore, in connexion with the search for oil and for other reasons, the BMR has conducted several gravity-meter surveys that have included connexions to several pendulum stations.

In reviewing the situation it was decided that, instead of basing the adjustment of the gravity network only on the special network survey, an adjustment would be made using all available pendulum and gravity-meter connexions between base stations. The network was extended to include connexions to Christchurch and Singapore, which are first-order world gravity stations (Morelli, 1959), and to Tokyo, which is connected to the first-order station at Kyoto (Melbourne is the only Australian first-order station). This was done to facilitate readjustment of the Australian base values in the future, so as to conform with the first-order world network when values are formally adopted for these stations. These data did not in general meet the criteria prescribed by Cook (1958) for the simplified method of rigorous least-square adjustment of gravity networks. However, it was considered better to use all available data than to eliminate most of them, or to attempt at this stage a more accurate survey based on Cook's recommendations.

Because of the extent of the computations involved and the difficulties in assigning weights to the various surveys, a rigorous least-square solution was not attempted. Instead a reiterative process was used. An average value of gravity was obtained for each station by using the results of all surveys connecting to it. The departures of the results of the individual surveys from the averages were used to estimate the standard error of a reading for each survey or group of surveys. The correlation of the departures with the average values was also investigated to determine whether a sensitivity-value correction was necessary for gravity-meter results. Next, a weighted average was obtained for each station, by using weights based on the standard errors. This procedure was repeated until successive weighted averages agreed within satisfactory limits.

The assistance of Mr D. Lim in carrying out the computations is acknowledged.

2. DATA USED IN ADJUSTMENT

All data were used that involved suitable gravity measurements between two or more of the 55 stations, comprising 52 of the BMR pendulum stations and the three external stations at Christchurch, Singapore, and Tokyo. Seven of the BMR stations had no suitable connexions. A list of the surveys used, together with the instruments, observers, and other details, is given in Table 1. The connexions are shown geographically on Plates 1, 2, and 3.

Many re-occupations were not exact but wherever possible gravity-meter connexions have been made between the original pendulum stations and all neighbouring stations where gravity readings were made. Such stations could be called 'excentres', following the practice of the International Gravity Commission. For the sake of uniformity, all data were reduced to the original BMR pendulum station, even though in some cases this could no longer be occupied. A list of excentres and their gravity differences from the base station is given in Table 2. Further details of excentres and the measurements between them will be given in a separate report.

The initial data were used in the form of gravity values at the stations. Although pendulum and gravity-meter measurements are in the form of intervals, it was not practicable to use the data in this form because of the large number of intervals involved and the different routes taken by different observers. Each survey was adjusted for internal misclosures before being used, no reference being made to any previous surveys or previously established gravity connexions in this adjustment. In some cases this meant ignoring previous misclosure adjustments, as these had been made to conform with pendulum values at two or more stations.

Cook (1958) has pointed out that the gravity values at stations are in general correlated, the independent observations being the intervals between stations, or more strictly, the actual readings at stations. For the intervals to be independent, each must be measured directly between two base stations. Intermediate stations or loops may be used in this, but no part of this connection should be used in the connection between another pair of base stations.

Few of the data available satisfy these conditions. Many of the data are in the form of closed loops that include visits to several base stations, but the junctions between the sides of the loops do not always coincide with the bases. Some of the data are in the form of large loops, each of which includes several base stations; drift corrections are distributed around the loops. Some intermediate base stations may have been repeated as part of the loop. Under these conditions the gravity intervals between base stations are correlated.

The procedure of making an adjustment based on the individual readings is too complex to warrant consideration. An adjustment based on the intervals would also be very complex, because very few surveys made observations at exactly the same set of stations as another survey; besides that, it is difficult to decide which intervals can be regarded as most-nearly independent.

The procedure of making adjustments for misclosure, although increasing the complexity of the correlation between base-station values, in general reduces the degree of correlation between neighbouring stations. In treating the data, the adopted procedure of making their average values at common stations agree tends to reduce the dependence of the value at any one station on any particular neighbouring value. The values of gravity obtained by different surveys at the same station, and used in calculating the average value at the station, may be regarded as independent of each other. In general, where a station was occupied by several surveys using different observing techniques and visiting different sets of stations, any effects on the average gravity values at the stations of internal correlation in the surveys may be statistically expected to be zero.

For the above reasons, and for the sake of reducing the complexity of the calculations, the values of gravity at the stations were regarded as independent observations and treated accordingly. It is believed that this would not seriously affect the determination of (a) gravity values at the stations, (b) their variance, or (c) the sensitivity-value corrections for the various gravity meters. There may be some effects on the variance calculated for the sensitivity-value corrections, or for the residuals of an individual survey, but these effects would be very hard to assess, and have been ignored in the following treatment.

When the data were supplied in the form of absolute gravity values at the stations, these values were initially listed as supplied. When they were supplied in the form of intervals between stations, a pendulum value was adopted for one station and gravity values at the other stations were calculated from the intervals. The method used for reducing all data to a common basis is described in the next section.

The initial data are set out in Table 3, where each row corresponds to a gravity station, and each column to a survey (or in some cases, to a group of connected surveys) numbered as in Table 1. The gravity stations in Table 3 are arranged in increasing order of absolute gravity value, as this arrangement helps to indicate where substantial corrections to sensitivities are necessary. Some additional notes on the data are given below.

(A) Pendulum measurements (see Plate 1 and Table 1)

No. 1. Cambridge pendulum, BMR 1950-51 The values adopted for these stations in 1957 include a correction for a presumed magnetic effect. These are given by Dooley *et al.* (1961, p.20, Table 7, in column 8, corrected gravity). In making the present readjustment of the gravity values, it was decided to investigate afresh whether there still appeared to be any significant magnetic effect, in the light of the considerable additional data that have accumulated since 1957. Therefore the values used were those of Dooley *et al.* (1961, Table 7, in column 4); i.e. without the magnetic correction.

No. 2. Cambridge pendulums, Jackson 1959. In this case the pendulums were used with a Helmholtz coil to annul the vertical component of the Earth's magnetic field.

No. 5. GSI quartz pendulums, Inoue and Seto, 1959. The results of a tie from Tokyo to Melbourne are reported by Inoue and Seto (1961). Results of a tie from Japan to Singapore in 1958 are also included.

(B) Overseas gravity meters (see Plate 2)

Sensitivities of overseas gravity meters were not adjusted initially. One objective of the adjustment was to compare the sensitivities of the various gravity meters with each other and with the pendulum data, and thus to arrive at corrections to the sensitivities if necessary. Because of this, it was generally necessary that at least three pendulum stations should be occupied for a gravity survey to provide any useful information.

No. 33. La Coste-Romberg geodetic gravity meter, Helfer 1959. This meter was carried on the *Argo* during Expedition Monsoon, to make auxiliary ties in connexion with the seaborne gravity-meter observations. As it was not needed on board while the ship was in northern Australian waters, it was flown from Cairns to the Northern Territory and used on a traverse between Tennant Creek and Darwin for comparison with a BMR Worden meter. Observations were made at several pendulum stations (without repeat drift control) between Cairns and Tennant Creek. The meter observer rejoined the ship at Darwin. Later, a reading was taken at Perth when the ship visited Fremantle.

Zero drift was claimed for this meter. Repeat readings were made along the road traverse from Tennant Creek to Darwin. The data as supplied had no corrections made for drift. The maker's sensitivity value was used.

A multiple correlation of the data with time and absolute gravity was made before incorporating these data, to determine whether any drift correction appeared necessary. A small coefficient of 0.0065 mgal/day resulted; this was not significantly different from zero.

<u>(C) BMR gravity meters</u> (see Plate 3)

As stated in the introduction, most of the gravity meters used by BMR in recent years have been calibrated before, and after, each survey by making measurements between two stations at Ferntree Gully and Kallista (the FG/K range), with an adopted gravity difference of 55.60 mgal. Before 1956, such measurements were comparatively rare and several surveys could not be adequately related to the FG/K range. The sensitivities calculated by the observers and used for reducing the results could not always be relied on, for several reasons:

some observers consistently occupied the wrong station at Kallista,
several values were used for the interval before adoption of the value 55.60 in 1956,
the methods of allowing for drift corrections in some cases were incorrect.

The whole situation has been investigated by Barlow and Flavelle (in preparation), who deduced the most probable sensitivities for all measurements of which records are available on the FG/K range. These are plotted on Plate 4 and show little evidence of long-term drift in sensitivity, but some evidence of short-term changes. Recent measurements show that these are sometimes well outside the limits of reading errors and occur over intervals of a few days. These are being further investigated.

In examining the data before they were used in the adjustment, the sensitivity used by the observer at the time was not necessarily accepted. Instead, a sensitivity was determined from Plate 4, and if necessary the intervals were corrected accordingly.

The data as taken from the files were in general in the form of intervals before adjustment for loop misclosures; the loops were then adjusted afresh, because the original adjustments had been made to conform with pendulum values at two or more stations.

The reports on BMR gravity work listed in Table 1 generally give an account of the surveys with emphasis on geological interpretation, and are not adequate sources of data in themselves. The report by Flavelle (in preparation) is an exception to this. BMR GF numbers refer to the gravity data filing system used in the Bureau, and indicate the source of the actual data used.

The majority of these surveys were not made primarily to establish ties between pendulum stations.

No. 13. Eastern network survey This is the survey, referred to in the introduction, that was intended especially for adjustment of 18 pendulum stations in the eastern part of Australia.

Although parts of this survey were carried out by three different gravity meters over a period of about two years (instead of one gravity meter in about three to four months as originally planned), it was decided to treat the survey as a homogeneous unit, because

(a) the sensitivities of the meters used were connected by observations on the FG/K calibration range,

(b) loop closures in parts of the network surveyed by the one gravity meter were generally no better than those involving two or more.

Surveys No. 16, 18, 19, 20, and 21 were also carried out by several observers with different gravity meters over a period of two or three years. However, the sensitivities could be related by observations on the FG/K range or, in some cases, by measurements at common stations in the field survey.

Surveys No. 23, 24, and 25 are of low accuracy, as they rely on observations at pendulum stations for drift control. They were included in the adjustment because they include observations at stations with only one or two other observations, or at stations where other observations are discrepant.

Surveys not used in adjustment

Some extensive surveys were considered unsuitable for inclusion in the adjustment.

Marshall and Narain (1954) made extensive gravity traverses in eastern and central Australia. In general, no tie was made to BMR pendulum stations, although stations were established in the same towns as several of these. Later ties have been made to their stations on the east coast, but the stations in this area are already well connected. It is believed that repeat measurements for drift control were infrequent and the survey was not of sufficiently high accuracy for purposes of base station connexions.

A BMR traverse using Heiland gravity meter No. 58 was made in 1949 from Adelaide to Melbourne (Oldham, in preparation). The only sensitivity value available was that of the makers; thus the survey could not contribute to the adjustment. However, a sensitivity could be assigned after the network adjustment, and this survey, in conjunction with ties to the Mount Gambier pendulum station (No. 7) by the BMR and the South Australian Mines Department, enabled establishment of gravity-meter values at Mount Gambier (see Appendix 2).

Shell (Queensland) Development Pty. Ltd. carried out extensive surveys in south-western Queensland about 1940 to 1942 using Holweck-Lejay pendulums and Thyssen gravity meters. The results appear to be in error by two or three milligals at various places where checks were made, and it is considered that the accuracy of this survey is too low.

A tie was made by Vacuum Oil Co. in 1947 using a Carter gravity meter carried by air from Whyalla/Broken Hill/Alice Springs/ Darwin/Djakarta. Results were reduced to the nearest milligal, and this was not considered of sufficient accuracy to contribute usefully to the adjustment.

Much work has been done by the BMR in the past three years using helicopters, but none of this has involved any reasonably direct ties between pendulum stations.

A pendulum survey was carried out by C. Kerr Grant in the vicinity of Adelaide with the Cambridge pendulums in 1937. The only stations near the network stations were at Adelaide and Whyalla. Kerr Grant's station at Whyalla could not be located for re-occupation, so no contribution could be made to the adjustment.

3. TREATMENT OF DATA

The procedure used in treating the data is described below, starting with the gravity values in Table 3. The procedure is treated mathematically in Appendix 1.

(1) Subtract each BMR pendulum value from all other values in the same row (i.e. for the same station). This is not intended to give any special importance to the BMR pendulum measurements, but is a convenient device for arriving at small numbers which can be used in the subsequent calculations.

(2) Find the average values for the resulting small figures in each column (i.e. for each survey). For this step, the values at the external stations (Singapore, Christchurch, and Tokyo) are ignored.

(3) Subtract each average from all figures in the same column, including the external stations. This reduces all surveys to an approximate common datum, insofar as their average values coincide with the average BMR-pendulum values for common stations.

(4) Find an average value for the resulting figures in each row. The BMR pendulum values are counted as zero for this purpose. This gives a first approximation to the average value of gravity for each station; for a BMR station this is in the form of a difference from the BMR pendulum value; for external stations, it is in the form of an 'absolute' gravity value.

(5) Subtract the average for each row from all figures in the same row. All figures are now small, and represent departures from the first average value of g at each station.

(6) At this stage, the average of the figures in any column is in general not zero. It would be if all stations had been occupied by all surveys, i.e. if all spaces in Table 3 were filled. This means that differences in datum exist between the various surveys and the first averages at common stations.

If steps (2) to (5) are repeated, (the external stations being included in the process), the averages of rows and columns become smaller, after each repetition (see Appendix 1), i.e. the datum of each survey is adjusted relative to the average values at common stations, and then a new average value is obtained for each station using the readjusted datums.

Before proceeding with this reiteration process, however, a correlation is determined between the departures for each survey and the value of gravity at the stations visited (the latter, of course, need be known only within about 10 mgal for this purpose). The information calculated includes a regression coefficient with its standard deviation, a constant (i.e. the average for each column), and the standard deviation of the residuals before and after correlation. 'Student's test' is made to determine whether the correlation is significant in each case.

The results of the correlations are listed in Table 4. The regression factor represents a correction to the sensitivity of a gravity meter to make it agree with the first-average values of g. It is possible that the first-average values could contain a systematic error resulting from erroneous sensitivity values in the gravity-meter data used to obtain them. This would result in a correlation between the pendulum values and the first-average values. Therefore, correlations were determined for the pendulum surveys as well as the gravity-meter surveys, although the pendulum surveys should not need correction for sensitivity value.

In the case of the BMR pendulum survey, however, another reason exists for determining an apparent 'sensitivity value' correction. This is to assess whether the measurements are affected systematically by the Earth's magnetic field. Actually this would be determined more accurately by calculating a correlation of the residuals with the vertical component of the Earth's magnetic field; however, this is highly correlated with the value of gravity over the range of latitude considered (Dooley et al., 1961).

The absence of any significant correlation between any of the pendulum surveys and the first-average gravity values (see Table 4) is taken as evidence that the first-average values contain no systematic 'sensitivity-value' error within the accuracy available, and that no serious magnetic effect exists in the BMR pendulum values. The latter conclusion in contrary to that reached by Dooley et al. (1961), but is based on more extensive data.

(7) Many of the surveys contain only a few stations, or cover a limited range of gravity values, or both. Therefore the sensitivity-value corrections determined are not very accurate. This applies particularly to many of the BMR gravity-meter surveys. Many of these however are related by measurements over the FG/K calibration range. Such surveys are grouped together and an average correction factor is determined.

'Student's test' is applied, and shows that none of the regression coefficients in this group differ significantly from the average. For Surveys No. 19, 20, 21, 29, and 30 (which cannot be adequately related through the FG/K range), individual sensitive-value corrections are used.

The gravity meters used in Surveys No. 7 to 12 by the Woods Hole Oceanographic Institute were supposed to have their sensitivities determined on the North American Calibration Range. However, several of the regression coefficients differ significantly from zero, and differ among themselves. Such variations could be due to non-linear sensitivities (i.e. variation with value of gravity) or to time changes. It was decided to use individual sensitivities for these surveys. A significant regression coefficient was also found for Survey No. 6 (Stahl, 1958).

The same sensitivity is assumed for the two WAPET connexions (31,32); although the coefficient is large, it does not reach the five-percent significance level because of the small number of degrees of freedom (one). However, this correction is used in the absence of any other method of determining an appropriate factor. It is consistent with the evidence of a comparison between WAPET and BMR gravity meters over about a dozen stations in the Kimberley Division of Western Australia.

The adopted sensitivity-value corrections are listed in Table 4.

(8) Next, the standard deviations of the results of each survey are studied so as to establish relative weights to be used in the next averaging process.

Again, many surveys have results at too few stations to establish reliable estimates of errors. Therefore, the smaller surveys are arranged in groups of broadly similar surveys, and estimates of standard deviations are obtained for these groups. These are used to determine weights for all surveys of the group, unless the S.D. for a survey is significantly different from the mean for the group. Thus, No. 2, 4, and 5 of the pendulum surveys are grouped as 'good' pendulum surveys; No. 3 has a S.D. significantly higher than these, and is treated individually. Enough data are available to treat the BMR survey (No. 1) individually.

For gravity meters, the S.D. of the gravity values before and after applying the sensitivity-value correction are considered. If the regression coefficient for an individual survey is used to determine its sensitivity, then the S.D. of the gravity values after correction is used to determine its weight. If the sensitivity-value correction depends mainly on other surveys, the S.D. of the gravity values without applying any correction is used.

Of the international surveys, No. 6, 10, and 12 have exceptionally low S.D. and are grouped together. No. 8 and 9 are also grouped. The network survey is significantly more accurate than other land surveys that included repeated stations. BMR Surveys No. 14, 16-22, 26, and 28, and WAPET Surveys No. 31 and 32 fall in the latter category, and can be grouped satisfactorily for weighting. BMR surveys in which air transport was used (No. 15, 27, 29, 30, 34, and 35) appear to have a somewhat lower accuracy, and have been grouped accordingly. Other surveys that did not have repeated stations (No. 23-25) have a very low accuracy, as might be expected.

The adopted relative weights, approximately inversely proportional to the appropriate variance, are listed in Table 4. Unit weight has been assigned to surveys with variance of about 0.10 $mgal^2$.

(9) The adopted sensitivity-value corrections are applied to the gravity-meter results, as well as the constant correction to make the mean of the residuals zero for each survey. The resulting figures are shown in Table 5, being the first figures entered in each space of the table.

(10) A weighted average for the figures in each row is determined using the adopted weights for each survey as given in Table 4. Each average gives a correction to the first average value of gravity for the corresponding station.

For the BMR pendulum survey, standard errors had previously been determined for the individual stations (Dooley et al., 1961). Therefore the relative weight assigned to each station of Survey No. 1 is based on the S.D. for the individual station, but these weights are adjusted so that their mean gives the same value as for Table 4.

(11) Departures from the mean of each row are determined.

(12) These departures in general do not have zero average for the columns, as stated under step (6). However, before adjusting these figures again, weights are assigned to the rows, i.e. to the stations. These are based on the number of surveys (m) visiting each station, and are taken as approximately proportional to (m - 1)/m. Thus in adjusting the mean datum for each survey, more account is taken of stations at which many other readings have been made.

The weights assigned are as follows:

m	weight
2	0.5
3	0.7
4	0.8
5,6	0.9
7	1.0

A weighted average is determined for each column on this basis.

(13) The procedure of obtaining weighted averages and departures for rows and columns alternately is continued until the adjustments became satisfactorily small. This is the case after two more adjustments to the average gravity values.

Actually at this stage it is not necessary to obtain the residuals after each step. If the row averages are selected for the stations in any individual column, and the weighted average of these is obtained for the column, this gives the necessary adjustment to the column average (with sign reversed - see Appendix 1). By a similar treatment, the next adjustment to the row averages can be obtained from the previous adjustments to the column averages. This makes the arithmetic simple and quick, especially as after one or two iterations the adjustments to most row or column-averages become very small and can be neglected.

The residuals resulting from this process are given as the second entry in each space in Table 5.

(14) A new correlation is now determined from these residuals. The new regression coefficients are small (except for those surveys where the individual coefficients were not applied previously) and very few are statistically significant. One exception is Survey No. 15, which was previously included in the group of BMR surveys related through the FG/K range. In this survey large-dial readings were used, and the large-dial/small-dial ratio was determined at several stations with gravity values distributed throughout the survey. The present work seems to indicate that the large-dial constant determined in this way was not sufficiently accurate. Survey No. 15 is accordingly assigned an individual sensitivity-value correction for the next stage of the calculations. The adopted adjustments to the sensitivity-value correction are shown in Table 5.

(15) The standard deviations of the surveys are again studied with a view to assigning new weights for the surveys. The accuracy determined for most surveys is somewhat better than previously, but Survey No. 1 decreases slightly in accuracy. The S.D. and adopted weights are shown in Table 5.

Some overseas gravity-meter surveys, viz. No. 6, 10, and 12, now have S.D. of about 0.1 mgal, which would give weights of about 8.0 to 10.0. These weights appear excessive, especially as the original data were given only to the nearest 0.1 mgal; therefore it is decided arbitrarily to limit the weights to a maximum of 4.0. Overseas surveys No. 7, 8, 9, and 11 are grouped together, with a lower weight. Other groups remain the same, with slight changes in weights. A substantial improvement occurs in the accuracy determined for the network survey, and the weight of this is correspondingly increased.

(16) Corrections are applied to the residuals for the sensitivity adjustments. The resulting figures are the third entries in the spaces of Table 5.

The calculations are made to the nearest 0.01 mgal to ensure accuracy to 0.1 mgal, but the residuals previously listed in Table 4 have been rounded off to 0.1 mgal. In this final stage of adjustment, they are given to 0.01 mgal to indicate the magnitude of the adjustments, which in many cases are less than 0.1 mgal.

(17) The procedure of taking alternative weighted averages of rows and columns is repeated, using the newly-adopted weights for the columns, and the same weights as previously for the rows.

For the second iteration, no adjustments exceed 0.06mgal and most are much less than this. The final residuals are shown as the fourth entries in Table 5.

(18) The adjustments to the average gravity values at the stations for each major phase of the calculations are listed in Table 6. Those in the last stage are seen to be very small; for only five stations do they exceed 0.2 mgal. Moreover, the larger adjustments occur only at stations of low accuracy, i.e. those with few observations. Therefore it is concluded that the adjustment has proceeded far enough.

It is decided to retain the currently-adopted value of 979,979.0 mgal for the National Gravity Base at Melbourne. Recent overseas pendulum ties indicate that this value is very close to the Potsdam system. Rose (1961) has determined an adjusted value of 979,979.13 mgal. It does not seem worth changing the adopted value by a small amount at this stage, until some value is formally adopted by the International Association of Geodesy as part of the World First-Order Gravity Network.

Final adjusted values are therefore determined for the 52 Australian stations and the three external stations, based on Melbourne = 979,979.0 mgal. These are listed in Table 6, and are rounded off to the nearest 0.1 mgal.

New adopted values are listed also for the remaining seven BMR pendulum stations. For six of these, the adjustments are due solely to the omission of the previously-included (1957) 'magnetic' correction to the pendulum values. For Survey No. 7 (Mount Gambier) it has been possible to evaluate gravity-meter ties from Adelaide and Melbourne in the light of the current adjustment, and thus arrive at an adjusted value for this station (see Appendix 2).

The difference between the '1957' adopted values and the newly-adopted values is also listed in Table 6. This figure should be used for correcting data that have been reduced using '1957' values.

(19) Standard errors are determined for each station initially from the sum of the weights of the surveys making observations there. As a check, a standard deviation of the weighted mean is determined from the residuals of the observations at the station after adjustment. An F-ratio test (Weatherburn, 1947 p. 199) is applied to the two estimates of S.D. (or variance). If they are significantly different, then the second estimate is used; otherwise the original estimate from the weights is accepted as the more reliable.

The S.D. for each station is listed in Table 6. The figures are rounded off to 0.1 mgal, with some preference for rounding off to the higher value rather than the lower.

4. CONCLUSIONS

Gravity values at Australian base stations have been adjusted on the basis of pendulum and gravity-meter connexions between them and ties to neighbouring first-order world network stations.

The relative values at stations have been found with the following estimated standard errors:

S.E. 0.1 mgal	- first-order stations at Singapore, Christchurch, and Melbourne and at 14 other Australian stations.
S.E. 0.2 mgal	- 12 Australian stations and Tokyo.
S.E. 0.3 mgal	- 16 stations
S.E. 0.4 mgal	- 7 stations
S.E. 0.5 mgal or greater	- 9 stations

These standard errors are apart from any possible systematic residual sensitivity error that may be present.

It is proposed that the Australian stations be classified as follows:

First class stations,	S.E. 0.1 mgal
Second class " ,	S.E. 0.2 mgal
Third class " ,	S.E. 0.3 mgal

In Table 7, the stations are listed under these classes, each with its adopted gravity value, and the adjustment to the '1957' adopted value.

Gravity surveys should be tied wherever possible to the first class stations, or if this is not practicable, to second or third class stations. This will enable incorporation of the survey results in the Australian network on a uniform basis. Field work in the future will be directed towards improving the accuracy of the network, and base stations may be raised in class when enough observations have been made to justify this. Also, additional stations may be added to the network from time to time. Probably many stations already exist with the required accuracy; however, it would be difficult to publish details of all such stations. The Bureau of Mineral Resources issues maps annually showing areas in Australia covered by gravity surveys. If a survey is proposed in an area where a base station is not conveniently accessible but where other gravity surveys have been made, information on suitable tie-stations will be provided by the Bureau on request.

The sensitivities previously used by the BMR should be increased by a factor of 1.0016. From the standard deviations of the sensitivity-value corrections shown in Table 4, this figure would appear to be accurate to within $\pm .0002$, corresponding to $\pm$ 0.5 mgal over the whole network. However it is possible that this estimate is too small, because of the effects of correlation in the individual surveys, or of undisclosed systematic effects. Provisional values for calibration ranges established in all state capitals and at Alice Springs and Townsville should also be increased by this factor. The revised values for these calibration ranges are given by Barlow and Flavelle (in preparation).

It is perhaps too early to define a long-range calibration chain of stations in the sense of the International Calibration Lines recommended by the International Gravity Commission. However, the chain of stations Melbourne/Sydney/Brisbane/Rockhampton/Cairns provides a tentative chain for internal use should this be required, with a range of 1479 mgal. These stations are connected by frequent air services, and have gravity intervals from about 300 to 500 mgal. Intermediate stations at Canberra, Maryborough, and Townsville are also available. All are first class stations.

The use of excentres is of course generally desirable where air transport is used in making readings at the calibration stations. Details of suitable excentres for the above provisional calibration chain will be given in a later report.

A chain of stations covering a greater range, and also connected by convenient air services, could be provided by Melbourne/Adelaide/Leigh Creek/Oodnadatta/Alice Springs/Darwin, with possible intermediate stations at Tennant Creek and Daly Waters. However, the accuracy of the gravity values at Leigh Creek and Oodnadatta needs improving, so that the large interval of 1100 mgal between Adelaide and Alice Springs can be broken up. The total range here would be 1663 mgal.

A third chain is possible around the western coast, from Albany to Darwin, with a range of 1389 mgal. However, as Perth and Darwin are the only first class stations in this chain, a considerable amount of work is necessary to bring this to a satisfactory standard of accuracy.

Either of the first two chains could be extended another 470 mgal by including Hobart in the chain; however, no pendulum observations have yet been made in Tasmania, and the existing gravity-meter ties are not accurate enough.

The Bureau of Mineral Resources has on order a set of pendulum equipment from the Geographical Survey Institute in Japan. This will be used to increase the accuracy of the network and to extend it where necessary. However, it will probably be some years before the accuracy of the first class stations can be substantially improved.

The datum of the network as a whole, and possibly the basis of the sensitivities, may need revision when gravity values for the first-order world network stations are adopted by the International Gravity Commission. The fact that the relation between the Australian network and first-order stations at Singapore, Christchurch, and Kyoto (through Tokyo as an excentre) should facilitate this revision. It is expected that changes will be small, probably not more than 0.5 mgal relative to the Potsdam system. Revision of the absolute basis of the Potsdam system will of course necessitate further revision of the datum of the network.

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APPENDIX 1

MATHEMATICAL TREATMENT OF AVERAGING PROCEDURE

In this appendix, the mathematical procedure used for adjusting the average values of gravity at the stations is considered. It is shown that the sum of squares of the residuals is least when the (weighted) average of the residuals for each row and each column is zero. Further, it is shown that the process of adjusting the averages alternately of rows and of columns so that the average values of the respective residuals is zero (as described in Section 3 of this report) is a convergent process, i.e. successive adjustments decrease in magnitude, and that the least-square condition stated above is approached.

The treatment is given for the case where weights are applied to the columns but not to the rows. The case where no weights are applied can obviously be dealt with by putting all weights equal to unity. The extension of the treatment to the case where the rows are weighted as well as the columns is straightforward and leads to the condition that the weighted average (instead of the direct average) of the residuals in each column should be zero.

Consider an array of elements a_{ij} arranged in M rows (i = 1, 2,...., M) and N columns (j = 1, 2,...., N). There are no values of a_{ij} for some values of i and j. Let there be m_j figures present in column j, and n_i figures present in row i. Summation with respect to i and j will be indicated as $\sum_i$ and $\sum_j$ respectively, and will be taken to indicate sums for all locations in the particular row or column for which figures are present, ignoring the vacant locations.

Consider a_{ij} for any row i as uncorrelated independent estimates of a quantity of c_i. The a_{ij} in any column j are regarded as fixed relatively to each other, but subject to a constant correction d_j to be determined. Thus the residuals after adjustment will be

$$b_{ij} = a_{ij} - c_i - d_j \qquad \ldots\ldots (1)$$

Now the best estimate of the variance of the observations as a whole is s^2, where

$$vs^2 = \sum_i \sum_j w_j \, b_{ij}^2 \Big/ \sum_i \sum_i w_j \qquad \ldots\ldots (2)$$

where w_j are weight factors applied to the columns j, and v is the number of degrees of freedom, given by

$$v = \sum_i n_i - (M + N)$$

$$= \sum_j m_j - (M + N)$$

Let $S^2 = \sum_i \sum_j w_j \, b_{ij}^2$

Then as the other factors in equation (2) are independent of c_i and d_j, the problem of minimising s^2 by suitable choice of c_i and d_j is the same as that of minimising S^2. We have

$$S^2 = \sum_i \sum_j w_j \, (a_{ij}^2 + c_i^2 + d_j^2 - 2\, a_{ij}\, c_i - 2\, a_{ij}\, d_j + 2\, c_i\, d_j)$$

$$= \sum_i \sum_j w_j \, a_{ij}^2 + \sum_i (c_i^2 \sum_j w_j) + \sum_j m_j \, w_j \, d_j^2 - 2 \sum_i (c_i \sum_j w_j \, a_{ij})$$

$$- 2 \sum_j (w_j \, d_j \sum_i a_{ij}) + 2 \, {}_j \, (w_j \, d_j \sum_i c_i) \qquad \ldots\ldots (3)$$

$$\therefore \frac{\partial S^2}{\partial c_i} = 2c_i \sum_j w_j - 2 \sum_j w_j \, a_{ij} + 2 \sum_j w_j \, d_j \qquad \ldots\ldots (4)$$

$$\text{and } \frac{\partial S^2}{\partial d_j} = 2m_j \, w_j \, d_j - 2w_j \sum_i a_{ij} + 2w_j \sum_i c_i \qquad \ldots\ldots (5)$$

Putting

$$\frac{\partial S^2}{\partial c_i} = \frac{\partial S^2}{\partial d_j} = 0$$

we get

$$\sum_j w_j \, (a_{ij} - c_i - d_j) = 0 \qquad \ldots\ldots (6)$$

$$\text{and} \quad \sum_i (a_{ij} - c_i - d_j) = 0 \qquad \ldots\ldots (7)$$

$$\text{or} \quad \sum_j w_j \, b_{ij} = \sum_i b_{ij} = 0 \qquad \ldots\ldots (8)$$

Thus the least-square adjustment requires the weighted sums of all rows and the sums of all columns to be zero.

Alternatively, equations (6) and (7) can be written as

$$c_i = \frac{\sum_j w_j \, (a_{ij} - d_j)}{\sum_j w_j} \qquad \ldots\ldots (9)$$

$$\text{and} \quad d_j = \frac{\sum_i (a_{ij} - c_i)}{m_j} \qquad \ldots\ldots (10)$$

Equation (9) gives a formula for c_i if d_j is not changed, and equation (10) gives the formula for d_j if c_i is not changed. Next, it will be shown that successive alternative applications of (9) and (10) approach simultaneous satisfaction of (6) and (7) convergently.

Let the initial values of the array be designated as ${}_oa_{ij}$, the presubscript denating the sequence of operations. Let

$${}_od_j = \sum_i {}_oa_{ij} / m_j \qquad \ldots\ldots (11)$$

$${}_1a_{ij} = {}_oa_{ij} - {}_od_j \qquad \ldots\ldots (12)$$

$${}_1c_i = \sum_j (w_j \; {}_1a_{ij}) / W_i \qquad \ldots\ldots (13)$$

where $W_i = \sum_j w_j$ for row i

$${}_2a_{ij} = {}_1a_{ij} - {}_1c_i \qquad \ldots\ldots (14)$$

$${}_2d_j = \sum_i {}_2a_{ij} / m_j \qquad \ldots\ldots (15)$$

$${}_3a_{ij} = {}_2a_{ij} - {}_2d_j \qquad \ldots\ldots (16)$$

From (14), (15), and (16) we get

$$\frac{\sum_i ({}_1a_{ij} - {}_1c_i)}{m_j} \qquad \ldots\ldots (17)$$

From (11) and (12), we have

$$\sum_i {}_1a_{ij} = 0 \qquad \ldots\ldots (18)$$

Therefore

$$- {}_2d_j = {}_3a_{ij} - {}_2a_{ij} = \sum_i {}_1c_i / m_j \qquad \ldots\ldots (19)$$

Similarly, we get

$$-{}_3c_i = {}_4a_{ij} - {}_3a_{ij} = \sum_j (w_j \; {}_2d_j) / W_i \qquad \ldots\ldots (20)$$

or in general, where k is an even number, we have

$$-{}_kd_j = {}_{k+1}a_{ij} - {}_ka_{ij} = \sum_i {}_{k-1}c_i / m_j \qquad \ldots\ldots (21)$$

$$-{}_{k+1}c_i = {}_{k+2}a_{ij} - {}_{k+1}a_{ij} = \sum_j (w_j \; {}_kd_j) / W_i \qquad \ldots\ldots (22)$$

From (13) and (18) it follows that

$$\sum_j w_j \sum_i {}_1a_{ij} = \sum_i W_i \; {}_1c_i = 0 \qquad \ldots\ldots (23)$$

If all locations in the array are filled, then all W_i are equal, and we have

$$\sum_i {}_1c_i = 0 \qquad \ldots\ldots (24)$$

Thus from (14), (18), and (24) it follows that

$$\sum_i {}_2a_{ij} = 0$$

From (13) and (14), we have

$$\sum_j w_j \; {}_2a_{ij} = 0$$

Therefore ${}_2a_{ij}$ satisfies equation (8) for b_{ij}

If all locations are not filled, this is not true in general. As W_i is positive for all values of i, it follows from (23) that there must be both positive and negative values of ${}_1c_i$ unless all are zero.

From(20), (15), (14) and (18), we have

$$ {}_3c_i = \frac{1}{W_i} \sum_j \left[\frac{w_i}{m_j} \sum_i {}_1c_i \right] $$

This expression is of the same order as ${}_1c_i$ if ${}_1c_i$ are all of the same sign. With mixed signs, however, the magnitude of the expression must be smaller, and will in general be much smaller, as $\sum_i {}_1c_i$ would be statistically expected to be close to zero. Similarly, in general the magnitudes of ${}_{k+1}c_i$ will be less than those of ${}_{k-1}c_i$, and those of ${}_kd_j$ will be less than those of ${}_{k-2}d_j$ for $k > 2$. Thus ${}_kc_i$ and ${}_kd_j$ both decrease with increasing k, and from (6) and (7) we see that as k increases ${}_ka_{ij}$ approaches b_{ij} in satisfying equation (8).

Note that the magnitudes of ${}_2d_j$ are not necessarily less than those of ${}_0d_j$. If ${}_0d_j$ are all zero, it is possible for ${}_1c_i$ to have non-zero values, leading to non-zero values of ${}_2d_j$. This condition occurs when fresh entries are made in the table after correcting for sensitivity values.

APPENDIX 2

EVALUATION OF TIES TO MOUNT GAMBIER

The following gravity-meter measurements were used in this assessment :

(a) Adelaide to Melbourne, including stations at Bordertown (SA) and Horsham (Vic) in 1949 with Heiland gravity meter No. 58.

(b) Melbourne to Horsham during 1955-56, part of Survey No. 16 used in the adjustment.

(c) Adelaide to Bordertown, by SA Mines Department in 1954 using Worden 204 and North American AG1-91. This has common readings at 16 stations with survey (a).

(d) Survey in south-western Victoria by BMR using Heiland 53 in 1950-51, in which a tie was made between Horsham and Mount Gambier.

(e) Survey in south-eastern South Australia by SA Mines Department with North American AG1-91. This survey has 17 stations common with survey (d).

Using the adjusted values for Melbourne and Adelaide from Table 7 to determine a sensitivity (0.1100) for Heiland 58, Survey (a) gives:

Bordertown : 979,837.3 mgal

Horsham : 979,867.2 mgal
(level crossing)

Survey (b) gives, using the revised sensitivity

Horsham : 979,867.0 mgal

From the results of survey (d), and using a sensitivity of 0.09005 for Heiland 53 (determined on the FG/K range and applying the correction factor of 1.0016) we get

Mount Gambier to Horsham : 126.9 mgal

Adopting Horsham : 979,867.1 mgal, this gives

Mount Gambier : 979,994.0 mgal

If the sensitivities of Worden 204 and AG1-91 in survey (c) are adjusted so as to give the best least-square fit with Heiland 58 at all stations between Adelaide and Bordertown, the revised values for Bordertown are :

Worden 204	:	979,836.9
AG1-91	:	979,837.0
Heiland 58	:	979,837.3

The mean value for Bordertown is 979,837.1. Using a sensitivity of 0.1108 for Heiland 58 to determine a sensitivity for AG1-91, SA Mines Department gave a value of 158.7 mgal for Mount Gambier to Bordertown by survey (e). If the revised factor 0.1100 is used for Heiland 58 this becomes 157.6 mgal, and we get

Mount Gambier : 979,994.7 mgal

Previously, a comparison was made between readings at 17 BMR and SA Mines Department stations common to surveys (d) and (e). Using the then-adopted sensitivity for AG1-91, this gave an interval of 154.8 mgal for Mount Gambier to Bordertown. Using the revised sensitivity for Heiland 53 (0.09005 mgal/scale div.), the comparison shows that the AG1-91 sensitivity is 0.96 per cent too low, i.e. the interval should be 156.3 mgal. Thus we get another value from survey (e) of

Mount Gambier : 979,993.6 mgal

As the second method of determining the sensitivity correction of AG1-91 is probably less accurate, we may give double weight to the first of these two values, and adopt a value of 979,994.3 mgal for survey (e).

The three values now available are as follows:

BMR pendulum survey	979,992.8 mgal, weight 0.35
Surveys (a), (b), and (d)	979,994.0 mgal, weight 0.6
Surveys (b), (c), and (e)	979,994.3 mgal, weight 0.6

where the weights have been assigned in accordance with the findings of this report for the various types of survey. This gives a weighted average value of 979,993.8 mgal.

From the weights of the surveys, the variance of the mean is estimated as 0.065 $mgal^2$. However, from the residuals a figure of 0.169 $mgal^2$ is obtained. The adopted S.D is based on this, and becomes 0.4 mgal.

TABLE 1.

SOURCES OF DATA USED

No.	Institution (1)	Date of survey	Area of Survey	Instruments	Observer(s)	Method of transport	Drift (2) control	Basis of calibration	Base Station	Adopted value	No. of Stations	Reference &/or BMRGF No. (3)	Remarks
(A) PENDULUMS													
1	BMR	1950/51	Australia	Cambridge (mu-metal case)	McCarthy, Newman, Ingall & Williams	Road	C		Melbourne	979,979.0	52	Dooley et al. (1961, Table 7, col. 4, p.20)	Values used are those without 'magnetic correction' (see text)
2	CU	1959	U.K. - Aust.	Cambridge (Helmholtz coil)	Jackson	Air	C	-	Melbourne	979,979.0	3	Jackson (1960)	
3	WHOI	1957	Pacific	Gulf	Rose	Air	C	-	Madison	980,368.9	7	Woollard & Rose (1960, Table II-15, col. 6)	Results used are 'Mean tare corrected g'
4	WHOI	1958	Far East & Pacific	Gulf	Iverson	Air	C	-	Madison	980,368.9	8	Idem, Table II-21, col. 5	(Results used are 'Mean tare corrected g')
5	GSI	1959	Tokyo - Melbourne	GSI	Inoue and Seto	Ship	C	-	Melbourne	979,979.0	2	Inoue & Seto (1961) Harada et al. (1958)	A previous tie from Japan to Singapore has been included in this
(B) GRAVITY METERS - OVERSEAS VISITORS													
6	EPF	1952/53	France - Antarctica	Western 42EQ	Stahl	Air	CZ	Paris-Toulouse - Pic du Midi	Paris Obs. C	980,943.7	5	Stahl (1958)	
7	WHOI	1950	World loop	Worden 10e	Muckenfuss	Air, road, rail	B	Cambridge pends. U.K. - Africa - Australia	Washington, Commerce Base	980,119.0	23	Woollard et al. (1952); also Woollard (1959)	Some figures differ slightly in the two references. The later figures have been used for preference
8	WHOI	1954	World loop	Worden 10f	Bonini	Air	C	Gulf pends., N. America	Washington, CIW Geophys. Lab.	980,100.7	10	Bonini and Woollard (1957); also Woollard (1959)	The first reference generally gives values at airport stations only; the second gives values at pendulum station also where visited
9	WHOI	1954	World loop	Worden 147	Bonini	Air	C				10		
10	WHOI	1957	Pacific	Worden	Rose	Air, road	C	ditto	Madison	980,386.9	17	Woollard (1959)	Gravity meter carried in conjunction with pendulum survey (No. 3)
11	WHOI	1958	World loop	Worden	Laudon	Air, road	C	ditto	Madison	980,386.9	15	Woollard (1959)	
12	WHOI	1958	U.S.A. - Antarctica	La Coste geodetic No. 1	Sparkman	Air	CZ	ditto	Madison	980,386.9	6	Woollard (1959)	
33	UCLA	1960	Q. & N.T.	La Coste geodetic	Helfer	Air & ship Road	CZ AZ	Makers	Darwin	978,316.2	8	Harrison (1961).	Gravity meter used in connection with Scripps Expedition Monsoon - see text
(C) GRAVITY-METER SURVEYS BY BMR													
13	BMR	1959/60	Eastern Australia	Wordens 61, 169, 260	Flavelle, van Son	Road	A	FG/K	Melbourne	979,979.0	18	Flavelle (1962): 59512/3, 59521, 60501	Survey planned for adjustment of basic network
14	"	1960	N.T. & north-eastern W.A.	Worden 260	Douglas	Road	A	FG/K	Darwin	978,316.4	6	60545, 61511	
15	"	1959	Northern Australia	Worden	Radeski	Air	A	FG/K and L.D. to H.D. ratio	Townsville	978,623.8	12	Radeski (1962). 59519/20	Use was made of commercial airline services on outback 'station' runs
16	"	1955/56	Victoria	Wordens 260, 169	Williams, Gunson	Road	A	FG/K	Melbourne	979,979.0	5	56104, 57505, 59511.	
17	"	1954/55	Southern W.A. & S.A.	Worden 140	van der Linden, Gunson	Rail trolley and road	A	FG/K	Ceduna	979,451.8	6	Gunson and van der Linden (1956). 54024, 54034/5, 55001/3	
18	"	1957/60	Western & northern Queensland, southern N.T.	Wordens 140, 61, 260, 274	Waterlander, van Son, Barlow	Road	A	FG/K	Cloncurry	978,650.7	9	57010/1; 58030/2; 59020/1; 59025/6; 59507; 60510	
19	"	1950/52	Perth Basin (W.A.)	Worden 61; Norgaard	Everingham	Road	A	Makers	Perth	979,394.3	4	Thyer and Everingham (1956). 52015, 60105	
20	"	1952/54	Carnarvon Basin (W.A.)	Wordens 61, 140; Western 29; Atlas F21	van Son, Waterlander, Gunson	Road	A		Watheroo	979,216.2	4	Chamberlain, Dooley, and Vale (1954). 53003, 53010/2, 55026, 56013/4, 60103	
21	"	1953/56	Canning & Fitzroy Basins (W.A.)	Wordens 61, 140; Atlas F21; Heiland 53	van Son, Waterlander	Road	A	FG/K	Port Hedland	978,645.2	6	53017, 54004/6/7, 55021, 56001, 56007/9, 56014	
22	"	1951	Melbourne - Wagga	Worden 61	Wiebenga	Road	A		Melbourne	979,979.0	3	51103	
23	"	1953	Onslow - Derby	Worden 61	Everingham, Dooley	Road	D		Onslow	978,772.5	4	53045	
24	"	1954	Townsville - Rockhampton	Atlas F21	Dooley	Road	D	FG/K	Rockhampton	978,870.2	3	58528/9	
25	"	1954	Brisbane - Sydney	Atlas F21	Dooley	Road	D	FG/K	Brisbane	979,168.9	3	58528/9	
26	"	1954	Cairns - Townsville	Atlas F21	Dooley	Road	A	FG/K	Cairns	978,500.1	2	54101, 58528	
27	"	1960	Broken Hill - Leigh Creek	Worden 169	Reid	Air	A	FG/K	Leigh Creek	979,320.5	2	Reid (1962). 60539	
28	"	1953?	Canberra - Wagga	Atlas F21	Gunson	Road	A	FG/K	Canberra	979,615.6	2	53111	
29	"	1955	Melbourne - Brisbane	Worden 140	Gunson	Air	A	Makers (L.D.)	Melbourne	979,979.0	4		
30	"	1955	Melbourne - Brisbane	Worden 169	Gunson	Air	A	Makers (L.D.)	Melbourne	979,979.0	4		
34	BMR & GSI	1960	Sydney - Tokyo	Worden 140	Goodspeed and Kuda	Air		FG/K	Sydney	979,685.1	2	Williams, Goodspeed, & Flavelle (1961). 59508	
35	" "	1960	Sydney - Tokyo	Worden 169									
(D) SURVEYS BY OTHER AUSTRALIAN ORGANISATIONS													
31	WAPET	1954/56	Carnarvon Basin (W.A.)	Worden	Garrett	Road	A	unknown	Carnarvon	978,942.5	2	Private communication	
32	WAPET	1954/56	Perth Basin (W.A.)	Worden	Garrett	Road	A	unknown	Perth	979,394.3	2	Private communication	

NOTES TO TABLE 1

(1) Institutions - abbreviations used

BMR : Bureau of Mineral Resources, Australia
CU : Cambridge University, England
WHOI : Woods Hole Oceanographic Institution, U.S.A
GSI : Geographical Survey Institute, Japan
EPF : Expeditions Polaires Francaises, France
UCLA : University of California, Los Angeles, U.S.A
WAPET : West Australian Petroleum Exploration Co., Australia

(2) Drift Control

A Stations repeated at intervals less than one day
B Stations repeated at intervals of a few days
C Base stations repeated at intervals of some weeks or months
D No repeated readings; drift determined from pendulum values
Z Zero drift claimed for gravity meter

(3) BMRGF No. is a reference to the filing system for gravity data used by BMR

Australian Gravity Network Adjustment 1962

TABLE 2

Summary of excentres

	BMR PENDULUM STATION	EXCENTRE	g ex - g p	SURVEYS TIED TO EXCENTRE
1	Melbourne	Footscray A	+0.2	16, 22
		Footscray C	0	3
		Essendon airport	-17.0	10, 11, 29, 30
4	Canberra	Fairbairn airport	+3.4	7, 10, 11, 29, 30
5	Sydney	Mascot airport	+13.1	10, 11, 29, 30
		University Geol. Dept	-2.7	25
8	Adelaide	Parafield airport	-19.2	10
		West Beach airport	-4.6	10
		Old observatory	+3.3	
10	Ceduna	Airport, ANA Building	+0.2 est.	7
12	Forrest	Airport, near hangar	0 est.	7
14	Kalgoorlie	Airport, ANA Building	+0.4	7
17	Perth	Guildford airport	+5.4	32
		Northam, station 214	+26.7	17
19	Watheroo	Peg 1, by gate	+1.9	19
20	Geraldton	Airport, waiting room	0	7, 32
		Railway station	-3.8	19, 20
24	Carnarvon	Airport, passenger lounge	0	7, 31
25	Onslow	Airport, Vacuum Oil Co. Building	+0.5	7, 31
26	Port Hedland	Airport, field gate	0	7, 23.
27	Anna Plains	Well, opposite homestead	+0.1	21
28	Derby	Corner of hangar	0	7
29	Halls Creek	Airport	-1.9	15
30	Wyndham	Airport, aeradio building	0 est.	7
32	Darwin	Airport, international passenger lounge	-1.0	7
		BMR assay lab.	-2.2	2,3,4,10,11,12
33	Daly Waters	Airport, hangar	+0.1	7, 8, 9
		Post Office	+0.6	11
34	Tennant Creek	Airport, aeradio building	0	7, 8, 9, 10, 11
35	Alice Springs	Airport, dining room	+0.1	7
36	Oodnadatta	Airport, aeradio building	+0.4	7, 11
39	Kallista	External station	+0.07	
		K2	+0.19	22
46	Armidale	Booth block, University	-0.9	7
47	Brisbane	Physics building, old University	-0.2	7
		Geol. Dept, University, Gulf pendulum station	0	3, 4, 11, 12
		Eagle Farm airport	-10.5	29, 30
48	Maryborough	Railway station	+1.7	7
49	Rockhampton	Airport	+3.3	7
51	Townsville	Airport, passenger lounge	+0.1	7, 10, 11, 12
		Airport, RAAF building	+0.7	34, 10, 11, 12
		Charters Towers	-33.1	18
52	Cairns	Old TAA passenger lounge	0	7
55	Cloncurry	Airport passenger lounge	+0.1	7
57	Birdsville	Airport	+0.1	15
58	Quilpie	Airport	+0.4	15
59	Roma	Airport	-0.2	15
	First Order Stations			
	Christchurch	Airport (Harewood)	-12.5	8, 9, 10
	Singapore	Kallang airport	+0.7	7, 8, 9
		RAF Changi airport	-0.7	11
		Geography Dept University	+0.7	2, 4
	Other stations			
*	Tokyo, weights & measures	Tokyo, GSI	-28.3	5
		Chiba, GSI	-15.4	5
		Hakone	-82.3	34, 35

* This station is given by Morelli (1960 p.28 rev) as 83.8 mgal higher than the first order station at Kyoto.

TABLE 3

TABLE 3 INITIAL DATA AND RESIDUALS FROM FIRST AVERAGE

Initial data given in mgal; 978,000 to be added to tabulated figures

Residuals in units of 0.1 mgal

SURVEY No. / STATION	1	2	3	4	5	6	7
S 32 33	316.4 2 389.3 7	81.0 4 316.5 2	316.2 5	81.3 4 317.0 4	80.6 -2	83.5 5 319.0 3	82.4 1 318.1 1 390.6 3
30 31 29	416.7 10 425.6 5 462.0 -12						416.8 -7
52 28 34	500.9 2 520.1 - 2 528.0 - 5		498.6 -16	500.7 -3			502.9 5 522.5 5 530.5 3
53 27 51	604.8 1 624.1 - 7 623.8 - 1		622.1 -13	623.2 -10			626.4 8
26 55 35	645.7 - 1 651.3 - 2 654.0 3						647.5 0 653.6 4 655.5 0
23 25 50	747.2 8 772.9 - 4 776.9 3						775.3 2
54 56 49	790.3 1 792.4 - 6 870.4 - 3						872.2 -2
24 59 57	942.8 - 3 978.9 - 2 1003.4 0						945.6 7
58 48 21	1006.9 - 2 1022.2 3 1074.9 5						1023.4 -2
36 46 47	1100.4 3 1115.0 2 1169.8 0		1168.9 -4	1170.0 -1		1172.3 1	1101.3 -5 1115.0 -15 1171.4 -1
19 20 14	1216.2 - 2 1270.8 11 1290.8 4						1270.6 -8 1291.6 -3
12 37 45	1306.1 - 5 1320.5 7 1320.3 2						1307.9 -4
16 17 11	1343.0 - 3 1394.4 - 1 1438.7 2						1396.4 2
10 41 44	1451.8 - 1 1455.5 5 1510.1 7						1454.3 6
4 40 42	1616.7 - 3 1656.8 6 1671.9 12						1618.7 0
6 5 18	1672.7 2 1685.1 - 5 1705.5 - 1		1686.2 11	1686.4 5		1687.8 -2	1687.5 2
8 3 T	1722.9 - 9 1744.2 - 2			1805.9 6	1805.4 2		1725.7 1
39 1 2	1909.0 - 2 1979.0 0 2021.2 - 3	1979.0 -1	1979.8 13		1979.2 0	1980.9 -6	1981.0 2
C			2509.4 11	2508.8 -3			2510.0 -5

SURVEY No. / STATION	8	9	10	11	12	33	13
S 32 33	81.1 1 316.0 -7 388.8 -2	80.5 -9 316.0 -10 386.9 -5	315.2 -4	79.3 -3 314.6 -6 386.1 -15	315.8 -4	31[illegible].2 388.6	
30 31 29							
52 28 34	528.8 -1	529.1 -2	499.7 -3 527.4 -5	499.7 0 526.5 -10	500.7 1	500.4 528.6	502.2 16
53 27 51			623.5 2	623.0 1	623.9 0	623.7	606.6 10 626.2 14
26 55 35	653.8 -4	654.2 -3	652.8 -3	652.7 0		651.7 653.6	
23 25 50			775.3 -6				778.1 6
54 56 49			869.7 -4	869.6 -1			872.5 8
24 59 57							980.[illegible] 8
58 48 21			1021.1 -2				1023.0 1
36 46 47	1170.1 -1	1171.1 5	1113.2 -9 1169.2 1	1099.3 2 1168.6 -2	1169.6 -1		1115.7 0 1171.3 6
19 20 14							
12 37 45	1320.3 0	1320.7 1		1319.0 2			1320.8 -2
16 17 11						1395.0	
10 41 44							1509.6 -7
4 40 42	1617.1 -4	1617.8 0	1616.7 3	1616.7 7			1617.4 -6 1670.4 -12
6 5 18	1686.1 1	1685.6 4	1672.3 5 1685.7 7	1684.5 -1	1685.7 2		1672.7 -7 1686.2 -4
8 3 T	1724.3 0 1805.4 -1	1724.6 0 1805.3 -5	1723.4 2	1723.4 6			1745.3 -1
39 1 2	1910.2 5 1980.0 5	1910.2 2 1980.0 2	1979.0 6	1979.0 10	1979.0 0		1979.0 -10 2022.4 -1
C	2508.8 -4	2509.5 -1	2508.6 4				

SURVEY No. / STATION	14	15	16	17	18	19	20	21
S 32 33	316.4 13 388.7 12							
30 31 29	414.0 -7 423.7 -3	415.9 4 424.7 -2 464.7 17						461.4 -4
52 28 34	528.1 1	529.6 15						518.6 -3
53 27 51		623.8 2			605.1 -11 623.9 0			623.5 2
26 55 35	652.7 0	651.4 1 654.1 6			650.7 -3 653.8 3			645.2 8
23 25 50							775.1 9	744.2 -8
54 56 49		790.0 0			789.7 -1 793.1 6			
24 59 57		1002.9 -2			978.1 -6 1003.1 2		944.9 9	
58 48 21		1006.6 -2			1007.0 4			1072.5 -5
36 46 47								
19 20 14				1290.6 -1		1217.3 13 1268.3 -10	1216.2 -11 1269.8 -7	
12 37 45		1318.5 -11		1307.8 9				
16 17 11				1344.0 3 1394.8 -2 1438.7 -2		1394.3 3		
10 41 44		1453.3 -15		1451.8 -5				
4 40 42			1656.0 -6					
6 5 18						1705.3 1	1685.1 -5	1685.1
8 3 T			1745.1 4				1806.7 -8	1806.7
39 1 2			1909.3 -1 1979.0 -3 2022.3 5					
C								

SURVEY No. / STATION	23 22	24 25	26 27 28	29	30	31 32	FIRST AVERAGE	STATION
S 32 33							80.6 316.2 388.6	S 32 33
30 31 29							415.7 425.1 463.2	30 31 29
52 28 34	520.8 0		500.1 0				500.7 520.3 526.5	52 28 34
53 27 51	625.8 5	623.4 1	623.5 2				604.7 624.8 624.0	53 27 51
26 55 35	645.6 -7						645.8 651.5 653.8	26 55 35
23 25 50	772.5 -13	775.7 -3				774.6 6	746.4 773.3 776.6	23 25 50
54 56 49		870.2 1					790.2 793.0 870.7	54 56 49
24 59 57						942.5 -13	943.1 979.1 1003.4	24 59 57
58 48 21							1007.0 1021.9 1074.4	58 48 21
36 46 47		1116.8 23 1168.9 -6		1172.8 10	1169.6 -4		1100.1 1114.8 1170.0	36 46 47
19 20 14						1271.3 14	1216.4 1269.7 1290.4	19 20 14
12 37 45			1320.5 2				1306.6 1319.0 1320.1	12 37 45
16 17 11						1394.3 -4	1343.3 1394.5 1438.5	16 17 11
10 41 44			1456.4 10				1451.9 1455.0 1509.4	10 41 44
4 40 42			1616.7 2	1619.2 1	1617.1 -2		1617.0 1656.2 1670.6	4 40 42
6 5 18	1672.8 3	1683.4 -19	1671.6 -3	1687.8 1	1685.9 0		1672.5 1685.6 1705.6	6 5 18
8 3 T							1723.8 1744.4 1805.5	8 3 T
39 1 2	1909.0 -3 1979.0 0			1979.0 -21	1979.0 -3		1909.3 1979.0 2021.5	39 1 2
C							2509.2	C

TABLE 4

SENSITIVITY - VALUE CORRECTIONS AND WEIGHTS

Survey No.	m	v	First Correlation: b x10^-3	S_b	P	b adopted	V	V'	w adopted	Second Correlation: b	S_b	P	b adopted	V	V'	w adopted	Total b adopted
PENDULUMS																	
1	52	50	+0.05	±0.15		0	0.268	0.267	0.4	-0.19	±0.15		0	0.298	0.296	0.35	0
2	3	1	-0.21	0.05		0	0.048	0.0031	1.0	-0.21	0.04		0	0.050	0.003	0.8	0
3	7	5	+1.06	0.43	0.06	0	1.432	0.652	0.1	+1.19	0.46	0.05	0	1.691	0.839	0.1	0
4	8	6	-0.08	0.18		0	0.141	0.136	1.0	+0.11	0.24		0	0.099	0.038	0.8	0
5	3	1	+0.02	0.17		0	0.034	0.034	1.0	+0.19	0.15		0			0.8	0
OVERSEAS GRAVITY METERS																	
6	5	3	-0.49	0.11	<0.01	-0.5	0.180	0.011	3.5	-0.04	0.06		-0.04	0.011	0.099	4.0	-0.54
7	28	26	-0.11	0.17		-0.2	0.240	0.236	0.4	-0.08	0.13		-0.08	0.141	0.139	0.8	-0.28
8	14	12	+0.15	0.08		+0.2	0.105	0.093	1.0	+0.01	0.05		0	0.071	0.071	0.8	+0.2
9	14	12	+0.37	0.14	0.02	+0.4	0.200	0.125	1.0	-0.04	0.12		-0.04	0.104	0.103	0.8	+0.36
10	17	15	+0.52	0.08	<0.01	+0.5	0.143	0.036	3.5	+0.09	0.04	0.05	+0.09	0.016	0.012	4.0	+0.59
11	15	13	+0.73	0.20	<0.01	+0.7	0.380	0.191	0.5	+0.04	0.20		+0.04	0.201	0.201	0.8	+0.74
12	6	4	+0.17	0.12		+0.2	0.037	0.024	3.5	-0.07	0.08		-0.07	0.015	0.015	4.0	+0.13
33	8	6	+0.07	0.50		0.1	0.103	0.089	1.0	-0.03	0.50		0	0.09	0.09	1.0	+0.10
BMR GRAVITY METERS																	
13	16	16	-1.47	0.19	<0.01	-1.4	0.641	0.135	0.8	-0.28	0.10	0.015	-0.25	0.063	0.042	2.0	-1.65
14	6	4	-2.30	3.19		-1.4	0.656	0.581	0.4	-1.66	2.10		-0.25	0.397	0.344	0.6	-1.65
15	12	10	-2.06	0.47	<0.01	-1.4	0.707	0.239	0.3	-1.20	0.45	0.02	-1.20	0.445	0.258	0.4	-2.6
16	5	3	+1.23	2.46		-1.4	0.212	0.175	0.4	+0.91	0.96		-0.25	0.098	0.075	0.6	-1.65
17	6	4	+0.71	1.01		-1.4	0.222	0.198	0.4	-3.5	2.4		-0.25	0.204	0.133	0.6	-1.65
18	9	7	+1.43	1.21		-1.4	0.322	0.269	0.4	+1.85	0.90	0.08	-0.25	0.319	0.198	0.6	-1.65
19	4	2	-0.50	2.5		-0.5	0.88	0.87	0.4	+0.27	1.33		+1.11	0.699	0.683	0.6	-0.23
20	4	2	-4.23	1.20	0.08	-4.2	1.137	0.158	0.4	+0.06	0.12		0	0.031	0.028	0.6	-4.2
21	6	4	+0.06	0.46		+0.1	0.328	0.328	0.4	-0.57	1.06		-0.60	0.241	0.225	0.6	-0.5
22	3	1	-1.58	1.25		-1.4	0.106	0.041	0.4	+0.29	1.12		-0.25	0.072	0.067	0.6	-1.65
23	4	1	-5.77	5.15		-1.4	0.650	0.289	0.1	-3.20	4.92		-0.25	1.192	0.836	0.1	-1.65
24	3	1	-4.57	4.35		-1.4	2.35	1.12	0.1	-3.88	5.54		-0.25			0.1	-1.65
25	3								0.4				-0.25			0.6	
26	2	0							0.3							0.4	-1.65
27	2	0				-1.4											
28	2	0							0.4							0.6	
29	4	2	-3.50	1.22	0.10	-3.5	1.703	0.330	0.3	0	1.14		0	0.434	0.434	0.4	-3.5
30	4	2	+0.28	0.37		+0.3	0.041	0.032	0.3	-0.02	0.33		0	0.027	0.027	0.4	+0.3
34	2	0				-1.4			0.3				-0.25			0.4	-1.65
35	2	0															
OTHER GRAVITY METERS																	
31	2	1	-12.5	1.4	0.07	-12.3	1.695	0.020	0.4	-1.85	1.05		-1.80			0.6	-14.1
32	2																

m = number of stations visited by each survey

v degrees of freedom

b - proportional departure of sensitivity from average

S_b - standard error of b

All figures for b and S_b should be multiplied by 10^{-3}

P = probability of occurrence of b

V = variance of residual gravity values before correcting sensitivity (unit $mgal^2$)

V' = " " " " " after " " " "

w = weight assigned to survey

Surveys grouped together for determination of b or w are indicated by brackets.

TABLE 5.

RESIDUALS FROM FURTHER AVERAGES

In each column first two figures are in units of 0.1 mgal. Final two figures are in units of 0.01 mgal.

STATION	WEIGHT w_i	SURVEY No. & WEIGHTS, w_j No. 1 (0.4, 0.35)	No. 2 (1.0, 0.8)	No. 3 (0.1, 0.1)	No. 4 (1.0, 0.8)	No. 5 (1.0, 0.8)	No. 6 (3.5, 4.0)	No. 7 (0.4, 0.8)	No. 8 (1.0, 0.8)	No. 9 (1.0, 0.8)	No. 10 (3.5, 4.0)	No. 11 (0.5, 0.8)	No. 12 (3.5, 4.0)	No. 33 (1.0, 1.0)	No. 13 (0.8, 2.0)
8 32 33	1.0 1.0 0.9	2 2 15 13 7 7 63 65	2 1 14 14 0 1 12 12	4 4 45 44	3 4 44 42 4 5 51 49	-2 -2 -19 -18	0 -1 -07 -08 0 0 03 02	-1 -1 -20 -23 0 1 00 -03 2 2 10 11	4 3 31 30 -5 -4 -37 -38 0 0 -01 +02	-3 -3 -40 -41 -5 -5 -51 -50 -1 0 -03 00	0 0 09 06	4 3 38 36 0 7 -01 -03 -10 -10 -100 -98	-3 -1 -11 -13	1 0 00 -02 1 1 17 19	
30 31 29	0.8 0.7 0.7	10 15 146 168 5 9 84 86 -12 -10 -106 -111						-8 -2 -27 -06							
52 28 34	1.0 0.8 1.0	2 1 07 07 -2 -3 -34 -32 -5 -4 -44 -48		-17 -18 -173 -174	-5 -4 -37 -37			4 3 26 31 4 3 25 26 2 3 21 16	1 2 16 13	2 3 28 25	1 -1 -06 -07 -2 -1 -07 -12	4 3 36 36 -6 -5 -51 -55	2 2 18 18	-2 -2 -26 -21 2 2 29 28	4 2 03 02
53 27 51	0.7 0.7 1.0	1 4 41 52 -7 -8 -80 -93 -2 -3 -36 -35		-14 -14 -146 -146	-10 -11 -113 -113			6 5 45 45			4 3 29 29	4 3 24 25	1 1 03 04	-1 -2 -31 -30	-1 2 05 15 3 2 -04 -04
26 55 35	0.8 0.8 1.0	-1 -3 -34 -36 -2 -1 -10 -27 3 2 23 20						-1 -3 -33 -36 2 4 41 23 -1 0 [illegible] -10	-2 -2 -16 -18	0 1 05 03	0 -1 -03 -07	3 3 30 27		3 4 45 28 -1 -1 -07 -04	
23 25 50	0.5 0.9 0.8	8 11 111 115 -4 -3 -29 -32 3 7 65 68						2 4 35 31			-4 -1 -09 -07				-2 1 -03 -01
54 56 49	0.7 0.5 0.9	1 0 00 -03 -6 -7 -70 -86 -3 -2 -18 -22						-2 -1 -12 -17			-2 -1 -07 -12	1 2 23 19			1 3 19 14
24 59 57	0.8 0.7 0.7	-3 -6 -59 -72 -2 -3 -29 -32 -0 -2 -24 -41						7 5 47 33							3 2 16 10
58 48 21	0.7 0.8 0.5	-2 -4 -45 -71 3 4 39 47 5 4 38 31						-2 -1 -13 -06			-1 0 01 08				-4 -2 -29 -22
36 46 47	0.7 0.9 1.0	3 4 36 44 2 10 94 97 0 -1 -09 -08		-5 -5 -49 -49	-2 -2 -13 -14		2 1 14 16	-5 -5 -54 -47 -15 -8 -78 -76 -1 -2 -17 -17	0 -1 -08 -06	6 7 65 67	-8 -2 -20 -18 1 0 -06 -06	2 2 20 27 -2 -3 -30 -29	-1 -1 -06 -05		-3 4 31 33 3 2 18 18
19 20 14	0.7 0.9 0.4	-2 -4 -38 -34 4 1 18 120 2 5 44 51						-7 -9 -88 -65 -2 -2 -23 -17							
12 37 45	0.7 0.9 0.5	-5 -6 -62 -57 7 8 69 74 2 3 31 41						-3 -5 -49 -45	0 1 07 00	2 2 15 08		0 0 -02 -10			-3 -2 -17 -08
16 17 11	0.7 0.9 0.5	-3 -3 -32 -38 1 -5 -24 -12 2 1 11 12						3 1 13 19						-1 -2 -22 -15	
10 41 44	0.7 0.7 0.5	1 -2 -21 -12 5 2 24 -02 7 8 81 100						7 6 65 53							-5 -4 -37 -18
4 40 42	1.0 0.5 0.5	-3 -5 -36 -35 6 6 70 71 12 18 177 185						1 0 03 03	-4 -3 -34 -32	0 0 01 03	1 1 01 01	4 3 31 32			-2 -2 -16 -16 -8 -2 -14 -09
6 5 18	0.9 1.0 0.5	2 -2 11 20 2 4 -25 -18 3 -3 -37 -42		10 8 86 84	4 3 32 31		-1 -1 -05 -05	3 0 06 04	-1 -1 -13 -13	3 2 21 21	3 1 5 13 5 3 18 16	-6 -7 -73 -72	-1 0 01 00		-3 -4 -30 -22 +1 -1 -02 -04
8 3 7	0.9 0.7 0.8	-3 -2 -38 -57 -2 -2 -28 -75			5 5 50 45	1 2 17 15		2 3 35 33	0 1 12 14 -3 -2 -17 -21	-1 0 06 08 -7 -6 -60 -64	-1 0 -06 -08	1 2 20 21			4 1 23 06
39 1 2	0.9 1.0 0.7	-2 -3 -32 -29 -0 -1 -14 -11 -3 -12 -122 -140	-2 -3 -05 -05	12 12 119 116		0 0 02 03	-1 -1 -03 -04	4 3 34 31	4 4 36 35 4 4 44 43	0 0 -02 -03 0 0 03 02	2 1 05 02	4 3 28 26	-2 -1 -00 -02		-1 -2 -01 -04 9 1 29 08
0	0.9			10 14 141 145	-4 0 -06 +11			-2 -1 05 09	-6 -3 26 20	-5 -1 -01 +05	-3 1 -05 -01				
	Σw_i		3.0	4.9	7.8	2.9	3.9	24.8	13.4	13.4	15.2	14.3	6.0	7.6	14.6

STATION	No. 14 (0.4, 0.6)	No. 15 (0.5, 0.4)	No. 16 (0.4, 0.4)	No. 17 (0.4, 0.6)	No. 18 (0.4, 0.6)	No. 19 (0.4, 0.6)	No. 20	No. 21	No. 22	No. 23	No. 24, 25, 26, 27, 28	No. 29 (0.4, 0.4)	No. 30 (0.4, 0.4)	No. 31, 32	v_i	STATION
8 32 33	8 6 57 53 7 5 47 47														[illegible]	8 32 33
30 31 29	-11 -7 -75 -56 -7 -5 -56 -56	-1 3 -14 13 -7 -4 -83 -76 12 14 101 96						-2 -1 -18 -25							[illegible]	30 31 29
52 28 34	4 3 29 23	9 9 81 82						-4 -3 -38 -33	2 2 17 22		-1 -1 -15 -17				[illegible]	52 28 34
53 27 51		-2 -4 -62 -56			-12 -10 -25 -79 -1 -3 -29 -21			3 2 13 03 7 7 71 72	2 9 89 79 -5 -4 -62 -45	-1 -4 -61 -41	1 1 13 14				[illegible]	53 27 51
26 55 35	-1 -2 -19 -26	-1 -1 -18 -6 4 3 15 17			-4 -2 -27 -19 3 3 26 28										[illegible]	26 55 35
23 25 50							-3 -1 -12 -13	-7 -5 -56 -19	-7 -5 -47 -47	-2 1 07 03				-1 1 -05 -01	[illegible]	23 25 50
54 56 49		0 -1 -13 -11			1 1 04 06 8 7 84 53					3 4 39 34					[illegible]	54 56 49
24 59 57		-1 -3 -02 -14 -1 -1 -01 -20			-1 -2 -22 -20 7 4 45 33		4 2 12 06							-1 -1 -05 -01	[illegible]	24 59 57
58 48 21					9 6 66 45			-4 -4 -17 -21							[illegible]	58 48 21
36 46 47						11 9 80 81 -12 -6 -88 -72	-4 -5 -51 -49 2 3 25 26			22 28 271 293 -7 -9 -97 -55		-3 -4 -37 -36	-1 -1 -09 -08		[illegible]	36 46 47
19 20 14				-3 -2 -23 -16										2 2 12 24	[illegible]	19 20 14
12 37 45		-4 -5 14 11		7 7 63 66							-4 -3 -33 -53				[illegible]	12 37 45
16 17 11				2 2 29 32 -3 -4 -12 -5 -2 -1 -11 -10		1 2 21 19								-1 -2 -12 -17	[illegible]	16 17 11
10 41 44		-6 -8 -84 -38		-3 -4 -42 -53							0 4 42 11				[illegible]	10 41 44
4 40 42			-3 -6 -61 -46								2 3 27 26	4 4 40 43	0 1 11 12		[illegible]	4 40 42
6 5 18						1 -1 -06 -02	-1 -1 -16 -13	-1 -1 -16 -13	0 0 -06 -03	-12 -16 -150 -154	-3 -3 -31 -31	6 5 49 48	2 1 11 10		[illegible]	6 5 18
8 3 7			2 2 19 08				1 1 19 19	1 1 19 19							[illegible]	8 3 7
39 1 2			0 0 07 11 -1 -1 03 04 8 1 17 02						-2 -2 -18 -17 2 1 21 18			-5 -6 -56 -58	-2 -2 -15 -17		[illegible]	39 1 2
0															[illegible]	0
Σw_i	5.1	3.9	3.8	4.0	5.9	3.9	1.8	1.6	2.8	2.9	1.9	4.0	4.0	1.8		

TABLE 6

SUMMARY OF ADJUSTMENTS AND VARIANCES

Station	Previous Adopted Value	Pendulum Value Without Magnetic Correction	To BMR Pendulum Value	SUCCESSIVE ADJUSTMENTS After First Correlation	After second Correlation	Total Adjustments (a)	New Adopted Value	Correction to Previous Adopted Value	Variance from Weights	Variance from Residuals	Degrees of Freedom	Significance	Adopted Standard Error
S				+0.1	0	+0.03	978,080.6		0.0104	0.0083	7		0.1
32	978,315.5	978,316.4	-0.2	0	+0.03	-0.24	316.2	+0.7	0.0053	0.0036	12		0.1
33	388.6	389.3	-0.7	0	+0.01	-0.76	388.5	-0.1	0.0196	0.039	6		0.2
30	415.9	416.7	-1.0	-0.4	-0.26	-1.73	415.0	-0.9	0.050	0.127	3		0.3
31	424.9	425.6	-0.5	-0.4	0	-0.97	424.6	-0.3	0.077	0.246	2	<0.05	0.5
29	461.4	462.0	+1.2	-0.2	+0.07	+1.00	463.0	+1.6	0.083	0.272	2	<0.05	0.5
52	500.1	500.9	-0.2	+0.1	-0.01	-0.18	500.7	+0.6	0.0069	0.0069	9		0.1
28	519.4	520.1	+0.2	+0.1	-0.02	+0.21	520.3	+0.9	0.062	0.029	3		0.3
34	527.4	528.0	+0.5	-0.1	+0.08	+0.41	528.4	+1.0	0.0105	0.0094	8		0.1
53	604.2	604.8	-0.1	-0.3	-0.16	-0.63	604.2	0	0.034	0.086	2		0.2
27	623.2	624.1	+0.7	+0.1	+0.09	+0.82	624.9	+1.7	0.125	0.094	2		0.4
51	623.1	623.8	+0.1	+0.3	-0.09	+0.24	624.0	+0.9	0.0064	0.0112	12		0.1
26	645.2	645.7	+0.1	+0.2	+0.02	+0.25	646.0	+0.8	0.056	0.086	3		0.3
55	650.7	651.3	+0.2	-0.2	+0.22	+0.15	651.4	+0.7	0.031	0.0130	4		0.2
35	653.6	654.0	-0.3	0	+0.06	-0.31	653.7	+0.1	0.0099	0.0027	9	<0.05	0.1
23	746.6	747.2	-0.8	-0.4	+0.01	-1.26	745.9	-0.7	0.143	0.220	1		0.4
25	722.5	772.9	+0.4	-0.2	+0.08	+0.21	773.1	+0.6	0.042	0.0152	5		0.2
50	776.4	776.9	-0.3	-0.4	-0.02	-0.79	776.1	-0.3	0.0154	0.0080	4		0.1
54	789.8	790.3	-0.1	+0.1	-0.01	-0.08	790.2	+0.4	0.071	0.0026	2	<0.05	0.2 (c)
56	791.9	792.4	+0.6	+0.1	+0.12	+0.75	793.2	+1.3	0.100	0.464	1	<0.05	0.7
49	869.9	870.4	+0.3	-0.2	+0.08	+0.11	870.5	+0.6	0.0124	0.0044	5		0.1
24	942.5	942.8	+0.3	+0.3	+0.08	+0.61	943.4	+0.9	0.042	0.041	3		0.2
22	954.1	954.4					954.4	+0.3 (d)					0.5 (d)
59	978,978.5	978,978.9	+0.2	0	+0.08	+0.21	979.1	+0.6	0.033	0.014	2		0.2
57	979,003.0	979,003.4	0	+0.2	+0.18	+0.31	979,003.7	+0.7	0.071	0.050	2		0.3
58	006.5	006.9	+0.2	+0.2	+0.27	+0.60	007.5	+1.0	0.077	0.112	2		0.3
48	021.7	022.2	-0.3	-0.1	-0.11	-0.58	021.6	-0.1	0.0141	0.0090	3		0.1
21	074.7	074.9	-0.5	+0.1	+0.05	-0.42	074.5	-0.2	0.100	0.065	1		0.3
15	100.2	100.4					100.4	+0.2 (d)					0.6 (d)
36	100.1	100.4	-0.3	0	-0.08	-0.45	100.0	-0.1	0.053	0.077	2		0.3
46	114.7	115.0	-0.2	-0.8	-0.01	-1.08	113.9	-0.8	0.0137	0.070	4	<0.01	0.3
47	169.4	169.8	0	0	+0.04	-0.03	169.8	+0.4	0.0052	0.0035	13	0.05	0.1
19	216.0	216.2	+0.2	+0.2	-0.09	+0.24	216.4	+0.4	0.056	0.167	2		0.4
20	270.6	270.8	-1.1	-0.1	-0.23	-1.50	269.3	-1.3	0.034	0.120	4	<0.01	0.4
14	290.6	290.8	-0.4	-0.1	-0.05	-0.62	290.2	-0.4	0.056	0.038	2		0.3
12	305.9	306.1	+0.5	+0.1	-0.07	+0.46	306.6	+0.7	0.067	0.158	2		0.3
37	320.4	320.5	-0.7	+0.1	+0.05	-0.62	319.9	-0.5	0.033	0.0094	5		0.2
45	320.0	320.3	-0.2	-0.2	-0.05	-0.52	319.8	-0.2	0.042	0.033	1		0.2
16	342.9	343.0	+0.3	0	+0.04	+0.27	343.3	+0.4	0.100	0.095	1		0.3
38	371.3	371.5					371.5	+0.2 (d)					0.5 (d)
17	394.3	394.4	+0.1	+0.1	-0.10	+0.03	394.4	+0.1	0.026	0.0050	5	<0.05	0.1
43	396.3	396.5					396.5	+0.2 (d)					0.5 (d)
11	438.6	438.7	-0.2	0	+0.04	-0.23	438.5	-0.1	0.100	0.0096	1		0.3
10	451.7	451.8	+0.1	+0.1	+0.08	+0.21	452.0	+0.3	0.056	0.120	2		0.3
41	455.3	455.5	-0.5	+0.2	+0.28	-0.09	455.4	+0.1	0.083	0.0135	2		0.3
44	509.9	510.1	-0.7	-0.1	-0.24	-1.11	509.0	-0.9	0.042	0.194	1	<0.05	0.4
9	569.8	569.9					569.9	+0.[illegible] (d)					0.5 (d)
4	616.6	616.7	+0.3	0	+0.01	+0.24	616.9	+0.3	0.0091	0.0038	9		0.1
13	620.7	620.8					620.8	+0.1 (d)					0.5 (d)
40	656.7	656.8	-0.6	0	-0.15	-0.82	656.0	-0.7	0.100	0.334	1		0.4
42	671.8	671.9	-1.2	-0.6	-0.05	-1.92	670.0	-1.8	0.048	0.167	1		0.3
6	672.6	672.7	-0.2	0	-0.04	-0.31	672.4	-0.2	0.013	0.0085	4		0.1
5	684.9	685.1	+0.5	+0.2	+0.01	+0.64	685.7	+0.8	0.0050	0.0041	15		0.1
18	705.5	705.5	+0.1	-0.1	-0.09	-0.16	705.3	-0.2	0.100	0.002	1		0.3
8	722.8	722.9	[illegible]	-0.1	+0.03	+0.76	723.7	+0.9	0.0132	0.0124	5		0.1
3	744.1	744.2	[illegible]	+0.2	+0.17	+0.50	744.7	+0.6	0.036	0.0422	2		0.2
T				+0.1	+0.05	+0.08	805.1		0.025	0.0286	5		0.2
39	909.0	909.0	+0.2	+0.2	-0.03	+0.30	909.3	+0.3	0.030	0.0148	4		0.2
1	979.0	979.0	0	0	+0.07	0	979.0	0	0.0048	0.0019	15	<0.05	0.1
7	979,992.8	979,992.8				+0.5 (b)	979,993.3	+0.5			1		0.4
2	980,021.2	980,021.2	+0.3	+0.7	+0.25	+1.18	980,022.4	+1.2	0.037	0.040	2		0.2
C				-0.4	0	-0.47	508.3		0.0130	0.0066	5		0.1

Notes
(a) This includes -0.07 mgal to bring the adjustment at Station No. 1 (Melbourne) to zero.
(b) This figure was determined after the main network adjustment was complete (see text).
(c) Although the variance from residuals suggests a S.D. of less than 0.1, this was not adopted because of the small number of surveys visiting this station.
(d) The only adjustment at these stations is the removal of the magnetic correction. The S.D. is the same as used by Dooley et al. (1961).

TABLE 7.

Adopted gravity values of base stations, 1962.

(Corrections to '1957' values are given after new value).

First-order world network stations.
(S.E. 0.1 mgal)

	Singapore	978,080.6
1	Melbourne	979,979.0
	Christchurch	980,508.3

Australian first class stations
(S.E. 0.1 mgal)

4	Canberra	979,616.9	+0.3
5	Sydney	665.7	+0.8
6	Wagga	672.4	-0.2
8	Adelaide	723.7	+0.9
17	Perth	394.4	+0.1
32	Darwin	978,316.2	+0.7
34	Tennant Creek	528.4	+1.0
35	Alice Springs	653.7	+0.1
47	Brisbane	979,169.8	+0.4
48	Maryborough	021.6	-0.1
49	Rockhampton	978,870.5	+0.6
50	Clermont	776.1	-0.3
51	Townsville	624.0	+0.9
52	Cairns	500.7	+0.6

Australian second class stations
(S.E. 0.2 mgal)

2	Yarram	980,022.4	+1.2
3	Bombala	979,744.7	+0.6
24	Carnarvon	978,943.4	+0.9
25	Onslow	773.1	+0.6
33	Daly Waters	388.5	-0.1
37	Leigh Creek	979,319.9	-0.5
39	Kallista	909.3	+0.3
45	Walgett	319.8	-0.2
53	Hughenden	978,604.2	0
54	Longreach	790.2	+0.4
55	Cloncurry	651.4	+0.7
59	Roma	979.1	+0.6

Australian third class stations
(S.E. 0.3 mgal)

10	Ceduna	979,452.0	+0.3
11	Eucla	438.5	-0.1
12	Forrest	306.6	+0.7
14	Kalgoorlie	290.2	-0.4
16	Merredin	343.3	+0.4
18	Albany	705.3	-0.2
21	Mt. Magnet	074.5	-0.2
26	Port Hedland	978,646.0	+0.8
28	Derby	520.3	+0.9
30	Wyndham	415.0	+0.9
36	Oodnadatta	979,100.0	-0.1
41	Broken Hill	455.4	+0.1
42	Hay	670.0	-1.8
46	Armidale	113.9	-0.8
57	Birdsville	003.7	+0.7
58	Quilpie	007.5	+1.0

Other Stations

S.E. 0.4 mgal

7	Mt. Gambier	979,993.8	+1.0
19	Watheroo	216.4	+0.4
20	Geraldton	269.3	-1.3
23	Mundiwindi	978,745.9	-0.7
27	Anna Plains	624.9	+1.7
40	Mildura	979,656.0	-0.7
44	Parkes	509.0	-0.9

S.E. 0.5 mgal

9	Whyalla	979,569.9
13	Esperance	620.8
22	Wiluna	978,954.4
29	Halls Creek	463.0
31	Victoria River Downs	424.6
38	Woomera	979,371.5
43	Cobar	396.5

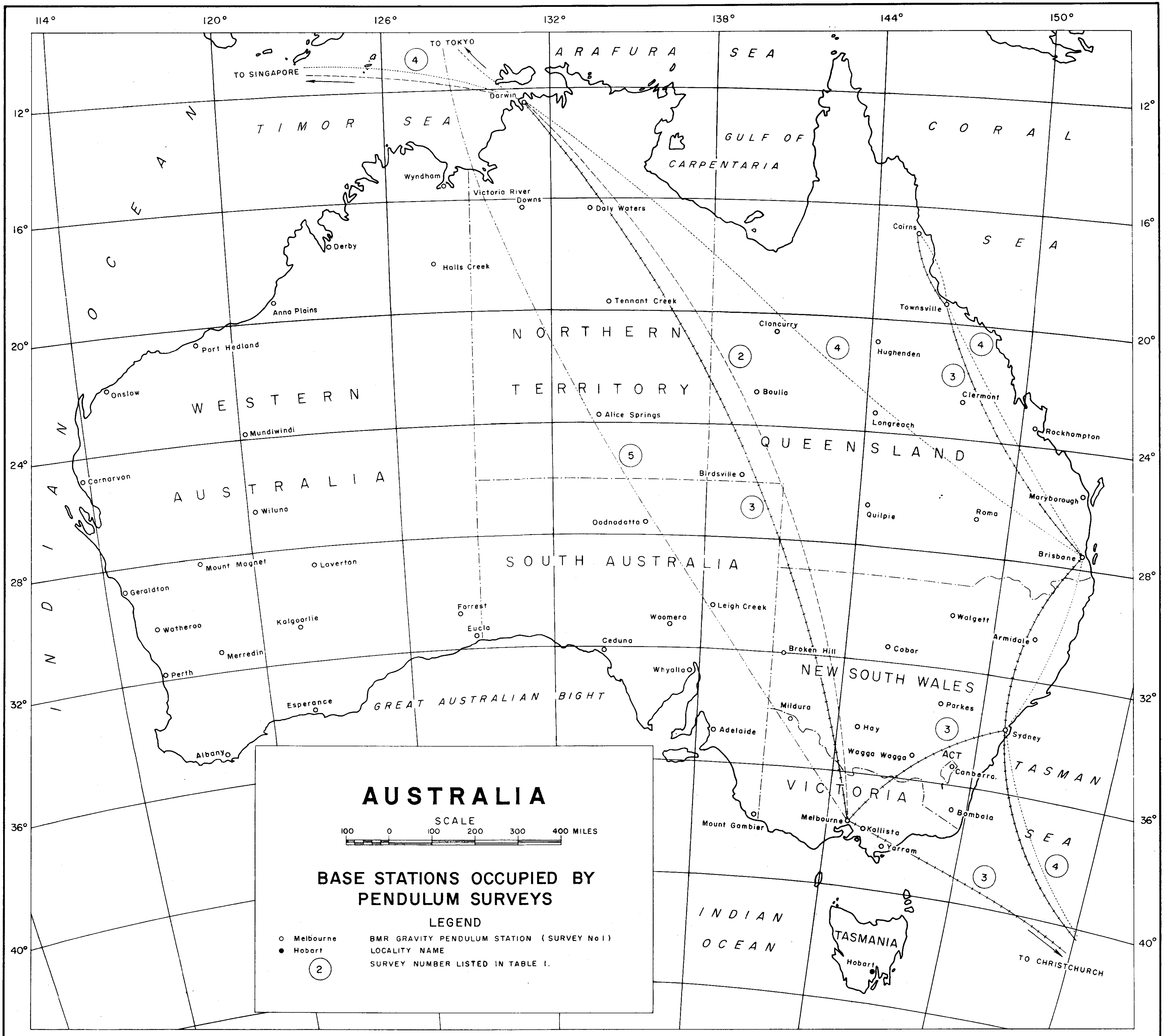
S.E. 0.6 mgal

15	Laverton	979,100.4

S.E. 0.7 mgal

56	Boulia	978,793.2

PLATE I



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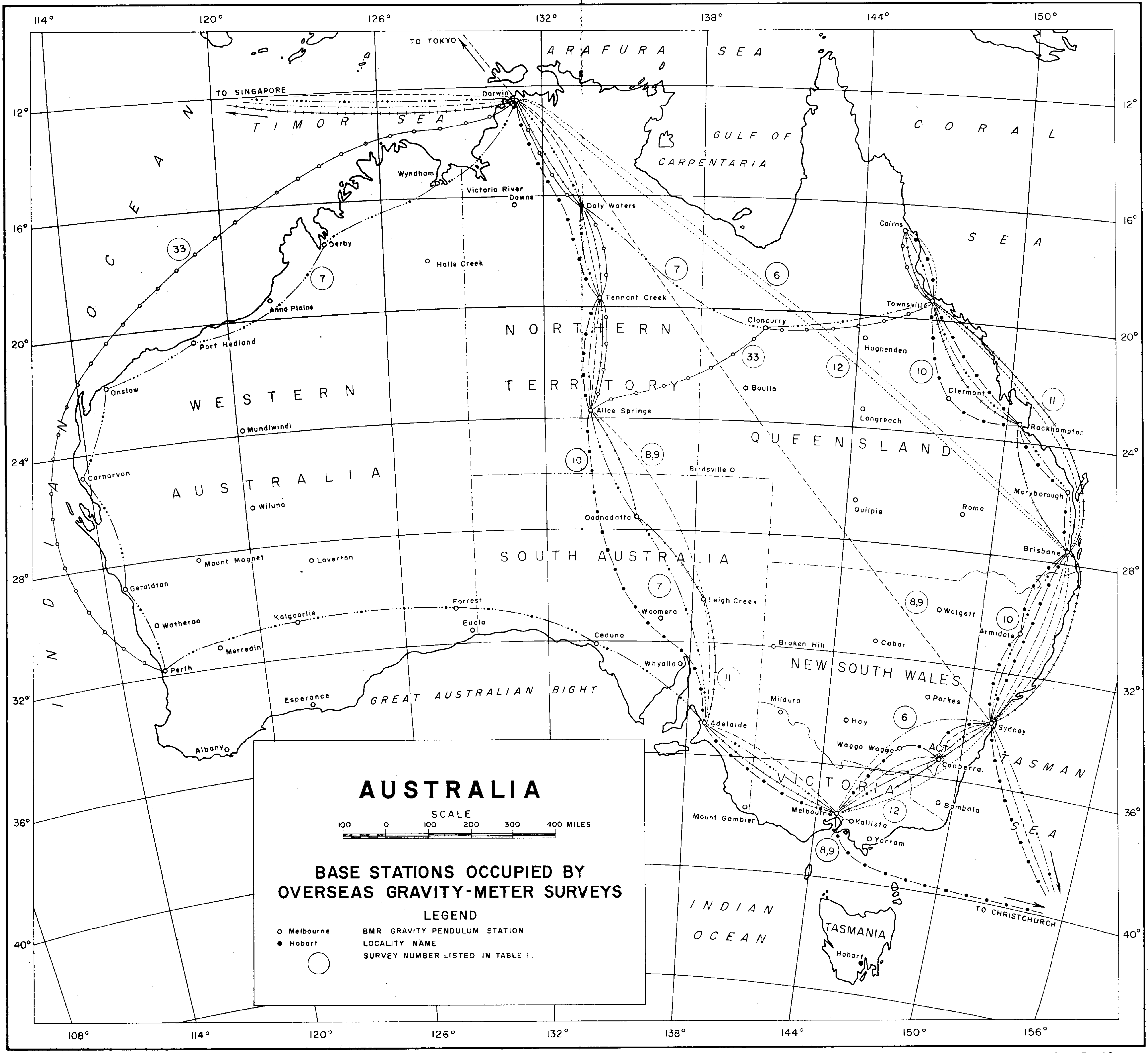
TO ACCOMPANY RECORD NO. 1962/141


AUSTRALIA
SCALE
100 0 100 200 300 400 MILES
BASE STATIONS OCCUPIED BY OVERSEAS GRAVITY-METER SURVEYS
LEGEND
Melbourne BMR GRAVITY PENDULUM STATION
Hobart LOCALITY NAME
SURVEY NUMBER LISTED IN TABLE I.
TO TOKYO
TO SINGAPORE
TO CHRISTCHURCH
ARAFURA SEA
TIMOR SEA
GULF OF CARPENTARIA
CORAL SEA
INDIAN OCEAN
TASMAN SEA
GREAT AUSTRALIAN BIGHT
NORTHERN TERRITORY
WESTERN AUSTRALIA
QUEENSLAND
SOUTH AUSTRALIA
NEW SOUTH WALES
VICTORIA
TASMANIA
ACT
Darwin
Wyndham
Victoria River Downs
Daly Waters
Derby
Halls Creek
Anna Plains
Port Hedland
Onslow
Tennant Creek
Cloncurry
Hughenden
Cairns
Townsville
Clermont
Rockhampton
Alice Springs
Boulia
Longreach
Mundiwindi
Carnarvon
Wiluna
Birdsville
Quilpie
Roma
Maryborough
Brisbane
Oodnadatta
Mount Magnet
Laverton
Geraldton
Leigh Creek
Walgett
Woomera
Watheroo
Kalgoorlie
Forrest
Eucla
Armidale
Ceduna
Broken Hill
Cobar
Merredin
Perth
Whyalla
Esperance
Mildura
Parkes
Hay
Adelaide
Sydney
Albany
Wagga Wagga
Canberra
Melbourne
Mount Gambier
Kallista
Bombala
Yarram
Hobart
114° 120° 126° 132° 138° 144° 150° 156°
108°
12° 16° 20° 24° 28° 32° 36° 40°

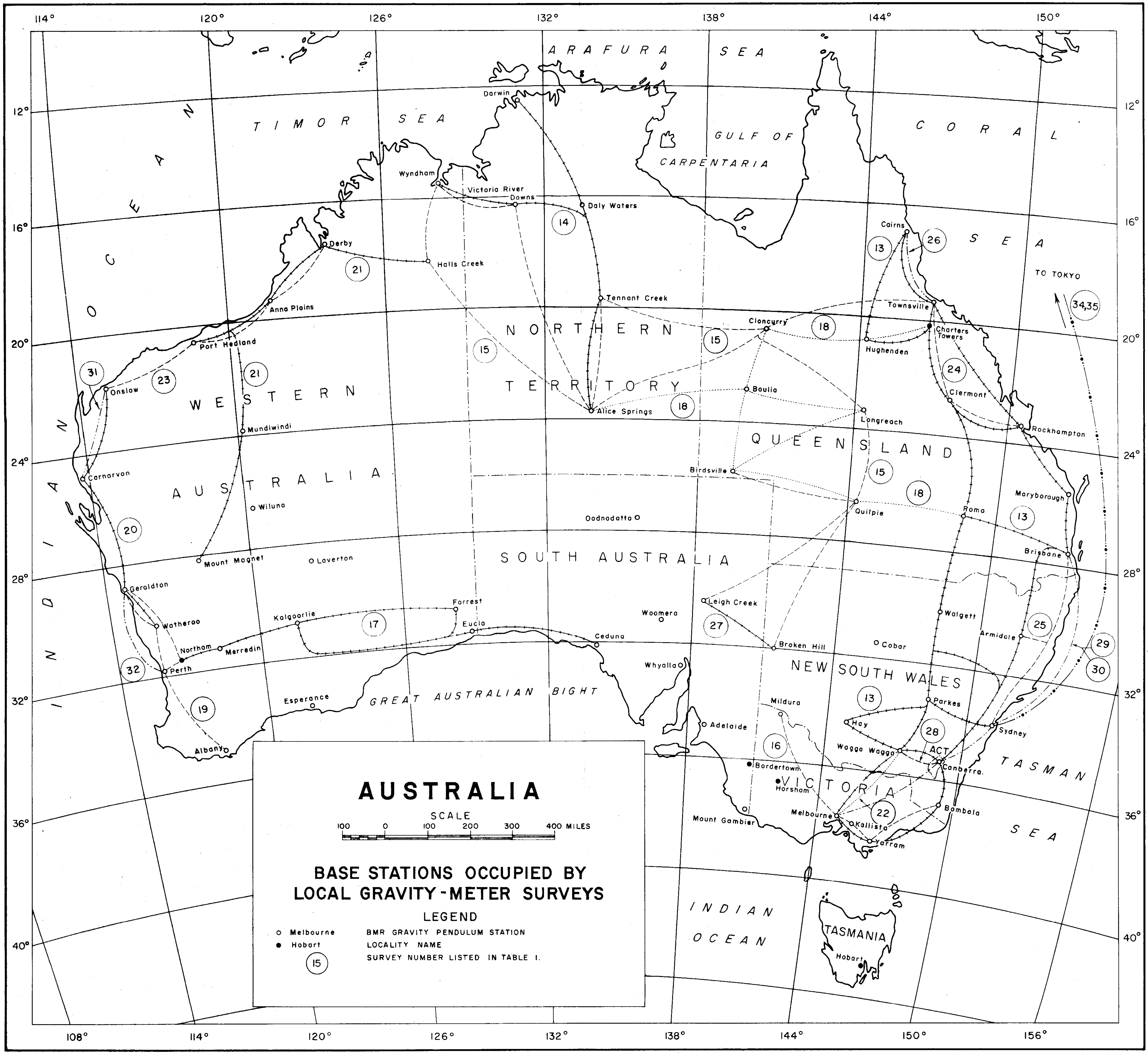
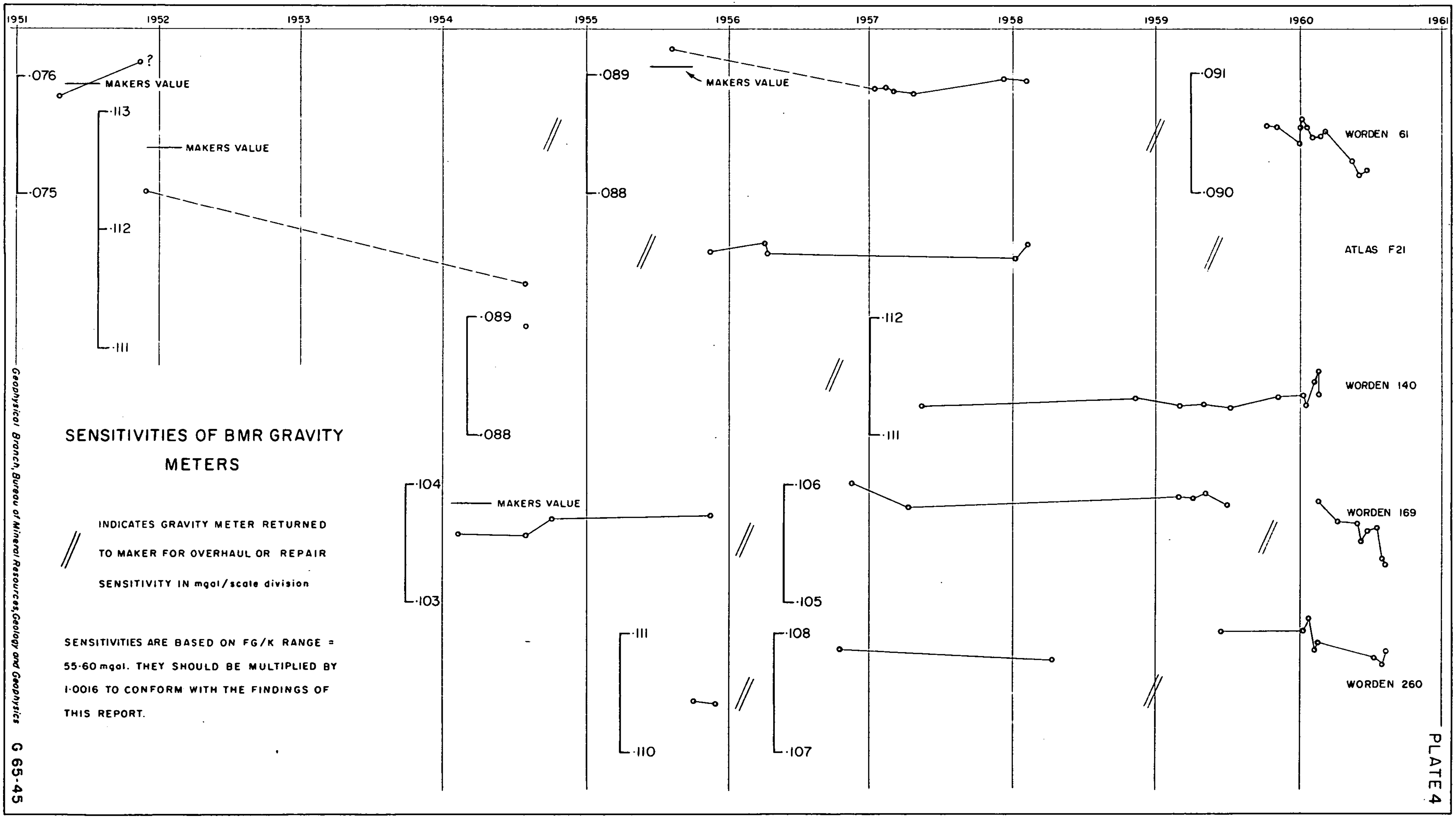

AUSTRALIA
SCALE
100 0 100 200 300 400 MILES
BASE STATIONS OCCUPIED BY
LOCAL GRAVITY-METER SURVEYS
LEGEND
Melbourne BMR GRAVITY PENDULUM STATION
Hobart LOCALITY NAME
15 SURVEY NUMBER LISTED IN TABLE I.
ARAFURA SEA
TIMOR SEA
GULF OF CARPENTARIA
CORAL SEA
INDIAN OCEAN
GREAT AUSTRALIAN BIGHT
TASMAN SEA
WESTERN AUSTRALIA
NORTHERN TERRITORY
QUEENSLAND
SOUTH AUSTRALIA
NEW SOUTH WALES
VICTORIA
ACT
TASMANIA
TO TOKYO
Darwin
Wyndham
Victoria River Downs
Daly Waters
Derby
Halls Creek
Tennant Creek
Anna Plains
Port Hedland
Onslow
Mundiwindi
Alice Springs
Carnarvon
Wiluna
Mount Magnet
Laverton
Geraldton
Watheroo
Northam
Merredin
Kalgoorlie
Forrest
Eucla
Ceduna
Perth
Esperance
Albany
Cloncurry
Boulia
Longreach
Birdsville
Quilpie
Oodnadatta
Woomera
Leigh Creek
Whyalla
Broken Hill
Cobar
Adelaide
Mildura
Bordertown
Horsham
Mount Gambier
Melbourne
Kallista
Yarram
Bombala
Canberra
Wagga Wagga
Hay
Parkes
Sydney
Armidale
Walgett
Brisbane
Roma
Maryborough
Rockhampton
Clermont
Charters Towers
Townsville
Hughenden
Cairns
Hobart
12° 16° 20° 24° 28° 32° 36° 40°
114° 120° 126° 132° 138° 144° 150° 156° 108°

PLATE 4



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TO ACCOMPANY RECORD No. 1962/141