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DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD No. 1966/45

GRAVITY METER MEASUREMENTS BETWEEN PENDULUM STATIONS, EASTERN AUSTRALIA, 1959-1960

by

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SUMMARY

During 1959 and 1960, gravity meter measurements were made between eighteen pendulum stations in eastern Australia. As a result of these measurements, it has been possible to obtain an estimate of the reliability of the pendulum measurements and to apply a correction to the calibration factors of the gravity meters that were used.

Recommendations are made that should improve the accuracy and reliability of the gravity meter measurements.

1. INTRODUCTION

The calibration of the Bureau of Mineral Resources (BMR) gravity meters is based on the estimated gravity interval between two points at Ferntree Gully and Kallista, near Melbourne. This interval was established by measuring it with a gravity meter that had been calibrated between five Cambridge Pendulum stations in Victoria and southern New South Wales.

One object of the presentsurvey was to establish the accuracy of the pendulum measurements and also to discover if any of the pendulum measurements contain any gross error. In addition, the calibration interval near Melbourne would be improved by measuring the interval with a gravity meter calibrated by measurements over a considerably larger gravity interval. Therefore a series of gravity meter connections between eighteen stations near the east coast of Australia was planned. The gravity interval between the extreme pendulum stations was approximately 1500 milligals. The gravity measurements were made during 1959 and 1960.

2. FIELD METHODS

It was planned that the work should be done in a comparatively short time (a few months), using only one gravity meter and one observer in order to minimise errors due to variations in calibration factors or reading procedures. However, the original meter used developed unsatisfactory drift characteristics and had to be returned to the USA for repairs. This happened again with the second meter, and the resulting delays in arranging replacement meters necessitated a change of observer for the last part of the survey and extended the duration of the survey to about 20 months.

The field measurements were made using Worden gravity meters Nos. 61, 169, and 260. Instruments were calibrated over the Ferntree Gully - Kallista calibration range before and after each field survey (Barlow, 1965). Intervals measured by each meter were (see Plate 1) :

(a) Worden 61

Illilliwa	-	Wyalong
Parkes	-	Walgett
Gilgandra	-	Tamworth
Armidale	-	Parramatta

(b) Worden 169

Mangalore	-	Echuca - Hay
Illilliwa	-	Old Junee
Junee	-	Canberra

(c) Worden 260

All other intervals.

All intervals south of Walgett and Armidale were measured by the author in 1959. The remaining intervals were measured by J. van Son in 1960, using Worden gravity meter No. 260.

Subsidiary stations were set up between each pendulum station for drift control purposes. These subsidiary stations (A, B, C, D, E, F...) were read in the order ABACBCED.... The time interval between successive readings at the same stations was not more than one and a half hours. Station separation varied from three to ten miles and averaged five miles. For purposes of later re-occupations, diagrammatic descriptions were made of each subsidiary station.

Measurements were made using the 'small dial' of each instrument. This necessitated frequent resets of the instrument and whenever this was done, readings were not usually recommenced for at least half an hour.

Whenever possible, the elevation of each subsidiary station was obtained. This has enabled the Bouguer anomaly of each station to be calculated and these data have also added to the regional coverage of the continent. Almost half the elevations were obtained by means of a Western Geophysical Company elevation meter, the remaining values being obtained from existing survey bench marks (mainly railway bench marks). The accuracy of the elevation meter values is considered to be better than ± 5 feet.

In most cases, a subsidiary station close to the pendulum site had to be occupied because the pendulum site was not always immediately accessible. This was later tied to the actual pendulum site when access had been arranged.

3. DATA AND BASIC LOOP

Plate 1 is a map of the eastern part of Australia showing the location of the pendulum stations on the traverses (shown as solid lines) discussed in this record. Dotted lines indicate what is considered to be a more suitable network, i.e., more information would be obtained and the reduction of results would be simpler. The pendulum measurements were made in 1950 and 1951 using the Cambridge Pendulum apparatus (Dooley et al, 1961).

Plate 2 is the closure diagram of the gravity meter traverses. The relative adjustability given to each interval is shown. The adjustability given to each interval is approximately equal to the square root of the number of subsidiary stations within that interval. Two types of adjustments to the loops have been made :

(a) A graphical least-squares adjustment to each interval based on a method described by Smith (1951).

(b) A residual distribution of the small remaining closure errors after the performance of the least-squares adjustment. This reduced the misclosure in each loop to zero.

4. DISCUSSION OF RESULTS

Pendulum values

One of the purposes of the survey was to try to detect any gross error in pendulum measurements. An attempt has also been made to estimate the standard deviation of the pendulum measurements.

Plate 3 shows the observed pendulum values plotted against the differences between pendulum and gravity meter values based on the National Gravity Base Station (N.G.B.S.) at Melbourne. The line, AA', is the line of best fit through these plotted points.

Plate 4 shows the deviations of the individual pendulum stations from the line AA' and also a distribution curve ofthe deviations. Despite the fact that only meagre data are available, two points are apparent :

(a) One pendulum station (Hay) has a deviation of more than two milligals.

(b) There is an indication of a minimum at zero deviation and two maxima at approximately ± 0.5 milligal deviaton. At present no reasonable explanation can be offered for this. However, the number of observations is such that little significance can be attached to the apparent departure from a normal distribution.

The standard deviation of the differences between the gravity meter and pendulum measurements was computed from the deviation of the pendulum values from the line AA' and the value obtained was 0.7 milligal.

A precise estimate of the standard deviation of a particular gravity interval is not possible. The gravity misclosure around the outside loop, Melbourne - Cairns - Melbourne, is 0.41 milligal. However, five of the internal loops have misclosure errors bigger than this.

M. J. Goodspeed (personal communication) has made a study of this matter in connection with the reduction of gravity data by digital computers. He believes that the major factor influencing the reliability of a gravity meter interval is the drift characteristic of the meter. Because it would involve a complete re-examination of the field data, recomputation has not been done in this case. As a unit of adjustability is approximately equivalent to one A-B-A-B gravity connection, the standard deviation per unit of adjustability is assumed to be 0.03 milligal. The value of 0.03 milligal for the standard deviation of an A-B-A-B gravity connection was also obtained from the loop closure calculations.

Calibration factor of gravity meters

Another useful point emerges in connection with the calibration factors of the gravity meters. By using the data over the whole loop it was possible to make a better estimate of these factors, or more correctly, a better estimate of the gravity interval of the Melbourne calibration range.

A method suggested by Cook (1958) has been used to compute the suggested change in calibration factors of the meters. If the assumed gravity meter calibration factor is v and if the corrected factor is v(1 + k) then the formula is, after simplification :

$$k = \frac{\sum(IgIp) - \sum Ig^2}{\sum Ig^2}$$

$$\text{i.e. } k = \sum(Igd)/\sum Ig^2 \qquad \ldots\ldots(A)$$

where Ig is the gravity meter interval, Ip the pendulum interval, and d = Ip-Ig.

The variance (k) is given by :

$$var(k) = (1 + w)\sigma_p^2/Ig^2,$$

where $w = \sigma_g^2/\sigma_p^2$ and σ_g^2 and σ_p^2 are the variances of unit gravity and pendulum measurements, respectively.

Since the mean adjustability of the gravity connection between the pendulum stations is 4 and the standard deviation for a unit of adjustability is 0.03 the standard deviation for the gravity connection is about 10 to 12 milligals.

For $\sigma_g^2 \ll \sigma_p^2$, $w \rightarrow 0$ (σ_g = 0.12 mgal; σ_p = 0.7 mgal)

and $var(k) = \sigma_p^2/Ig^2$ ....B

In Cook's analysis the above formulae are valid only if each gravity interval refers uniquely to one pendulum interval. Therefore, all cross-traverses have been ignored because in general they do not fulfil the abovementioned condition. In addition, the interval involving pendulum station Hay has been omitted. All the interval values are listed in the Appendix; the intervals used for the calculation of the new calibration factor are shown in Table 1.

Using formulae A and B, values for k and var (k) have been obtained :

$$k = 0.0014$$

$$var(k) = 0.00052$$

i.e. $k + 1 = 1.0014 \pm .0005$

That is, on the basis of the data used in this record, the Melbourne calibration range (which was derived from the nearby Ferntree Gully - Kallista calibration range), for which a value of 52.92 milligals had previously been adopted, should be increased by a factor of 1.0014. The new value would then be 52.99 ± 03 milligals.

Note: Since this record was commenced, Dooley (1962) has made an analysis of all the pendulum measurements and gravity meter connections made in Australia and adjacent countries. On the basis of this analysis he has arrived at a value of 53.04 milligals, which must be regarded as being a better figure than the one quoted above.

5. RECOMMENDATIONS

As the BMR has purchased pendulum equipment and a La Coste & Romberg geodetic gravity meter, some recommendations for additional measurements within the eastern gravity loop are suggested.

The work described in this record does not measure up to the desired standards of accuracy because :

(a) Two different observers were employed on the measurements.

(b) More than onemeter was used.

(c) The calibration factors of Worden gravity meters might vary with time. According to Barlow (1965) the calibration factor decreases with time and superimposed on this is a short term (i.e. in days)oscillation of the value.

TABLE 1

Intervals used for the calculation of the new calibration factor

Ip (mgal)	Ig (mgal)	d (0.01 mgal)	Ig x d ($mgal^2$)	Ig^2 ($mgal^2$)	Interval
306.40	306.34	+6	+18.36	93,844	Melbourne - Wagga
352.60	351.92	+68	+239.31	123,948	Wagga - Walgett
68.30	68.77	-47	-32.32	4,729	Sydney - Canberra
127.50	127.84	-34	-43.47	16,343	Canberra - Bombala
234.20	233.73	+117	+237.46	54,630	Bombala - Melbourne
570.20	570.44	-24	-136.91	325,402	Armidale - Sydney
341.50	339.89	+161	+547.22	115,525	Walgett - Roma
202.10	202.74	-64	-129.75	41,103	Roma - Clermont
172.20	171.52	+68	+116.63	29,419	Clermont - Hughenden
104.30	103.27	+93	+96.13	10,685	Hughenden - Cairns
123.00	123.01	-1	-1.23	15,131	Cairns - Townsville
246.80	246.22	+58	+142.81	60,624	Townsville - Rockhampton
93.00	92.69	+31	+28.73	8,591	Maryborough - Armidale

$$\sum(Igd) = 1,304.19 \text{ mgal}^2$$

$$\sum Ig^2 = 922,545 \text{ mgal}^2$$

(d) Because of frequent resets of the meters the drift rate characteristics were not always good.

The use of the La Coste & Romberg geodetic meter should reduce the effect of factors (c) and (d) Factors (a) and (b) can be overcome by better planning of the project.

Plate 1 shows the traverses read in 1959 and 1960 and also the proposed traverses for a survey that could be carried out with the La Coste & Romberg meter. It should be noted that :

(1) No section of a gravity traverse connecting a pair of pendulum stations is used as a section of a traverse connecting another pair of pendulum stations. If the same link must be covered by sections of more than one traverse, this section must be re-run for each such traverse (e.g. Armidale - Tamworth and Gympie - Maryborough. This point should be followed because of the simplification of calculation using Cook's (1958) method of calibrating gravity meters.

(2) The total length of the proposed traverses is 7,300 miles. The drift rate of the La Coste & Romberg meter is negligible, so that the station interval could be increased considerably and the total survey time should be less than 20 weeks.

6. CONCLUSIONS

The results of the basic loop traverses between Melbourne and Cairns suggest a revised value for the Melbourne calibration range (with respect to the Cambridge Pendulums). The suggested value 52.99 ± .03 milligals is in good agreement with the value of 53.04 milligals, obtained by Dooley (1962) from more extensive data. In view of the relatively small intervals of the Australian calibration ranges, some thought should be given to establishing a 500 to 600 milligals calibration standard as used in Canada (Innes, 1958).

In addition, it has been possible to estimate the accuracy of the pendulum measurements and also to suggest that some pendulum measurements have significant errors. Of the eighteen pendulum stations included in the measurements, one appears to be in error by over 2 milligals. The standard deviation of the remaining pendulum gravity meter differences is 0.7 milligal. This may be compared with 0.6 milligal estimated by Dooley et al (1961) for the 59 Cambridge Pendulum stations, and 0.55 milligal estimated by Dooley (1962) for 52 of the stations to which gravity meter connections have been made.

7. REFERENCES

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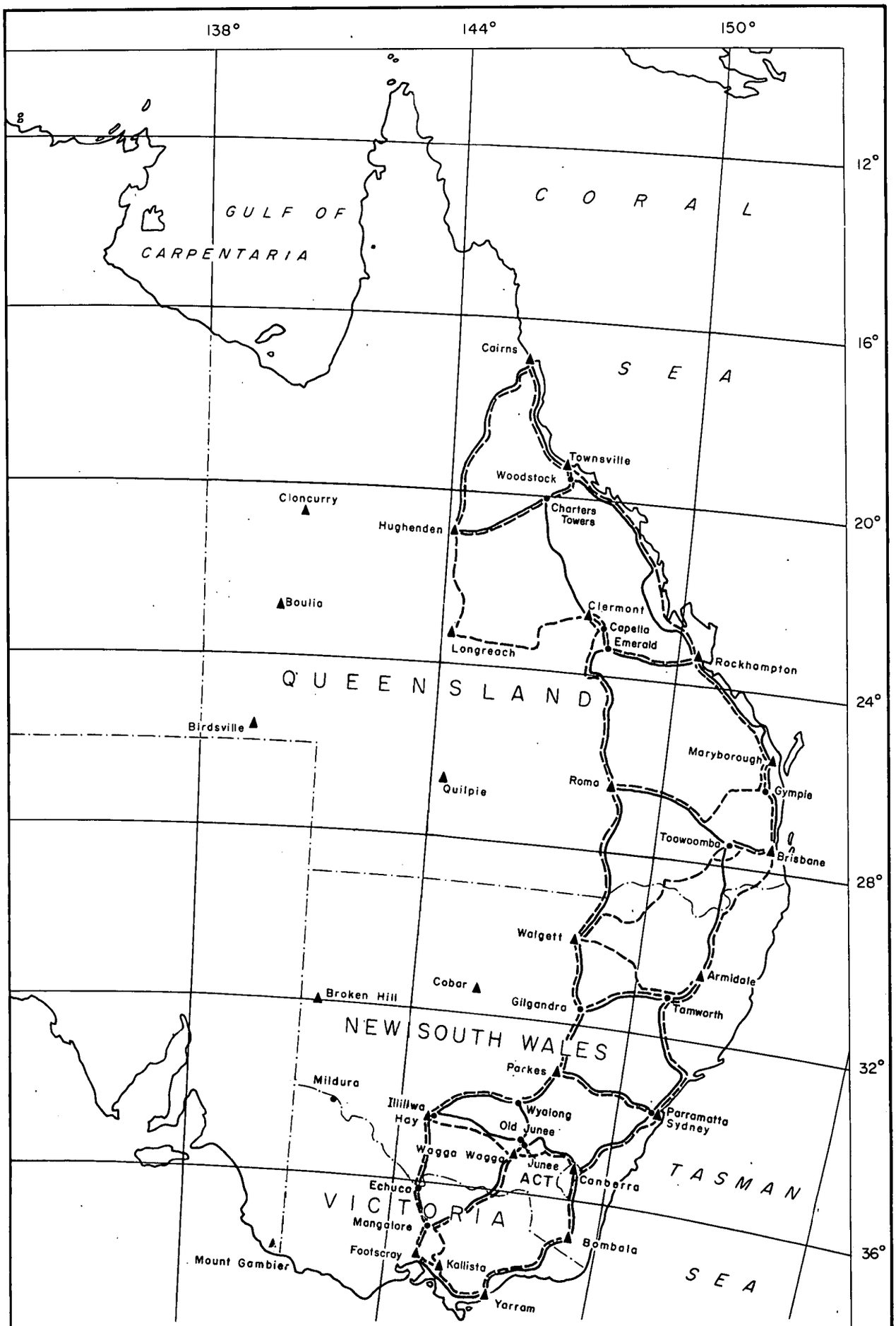
APPENDIX

Gravity intervals

Pendulum intervals (mgal)	Gravity meter intervals (mgal)	Pendulum minus gravity meter values (0.01 mgal)	Interval
306.40	306.34	+6	Melbourne - Wagga
162.70	163.11	-41	Wagga - Parkes
175.00	176.64	-164	Parkes - Sydney
68.30	68.77	-47	Sydney -Canberra
127.50	127.84	-34	Canberra - Bombala
277.10	277.14	-4	Bombala - Yarram
42.20	43.41	-121	Yarram - Melbourne
307.20	308.64	-144	Melbourne - Hay
56.00	55.24	+76	Canberra - Wagga
0.80	2.30	-150	Wagga - Hay
161.90	100.81	+109	Parkes - Hay
189.90	188.81	+109	Parkes - Walgett
205.30	205.01	+29	Walgett - Armidale
570.20	570.44	-24	Armidale - Sydney
341.50	339.89	+161	Walgett - Roma
190.90	190.48	+42	Roma - Brisbane
202.10	202.74	-64	Roma - Clermont
93.50	94.36	-86	Clermont - Rockhampton
18.90	19.64	-74	Hughenden - Townsville
172.20	171.52	+68	Clermont - Hughenden
104.30	103.37	+93	Hughenden - Cairns
123.00	123.01	-1	Cairns - Townsville
246.80	246.22	+58	Townsville - Rockhampton
151.80	150.57	+123	Rockhampton - Maryborough
147.20	148.29	-59	Maryborough - Brisbane
54.20	55.60	-90	Brisbane - Armidale



GRAVITY METER MEASUREMENTS BETWEEN PENDULUM STATIONS EASTERN AUSTRALIA

TRAVERSE PLAN

SCALE

100 0 100 200 300 400 MILES

LEGEND

▲ Primary Gravity Station — Existing Traverse

• Intermediate Gravity Station --- Proposed New Traverse

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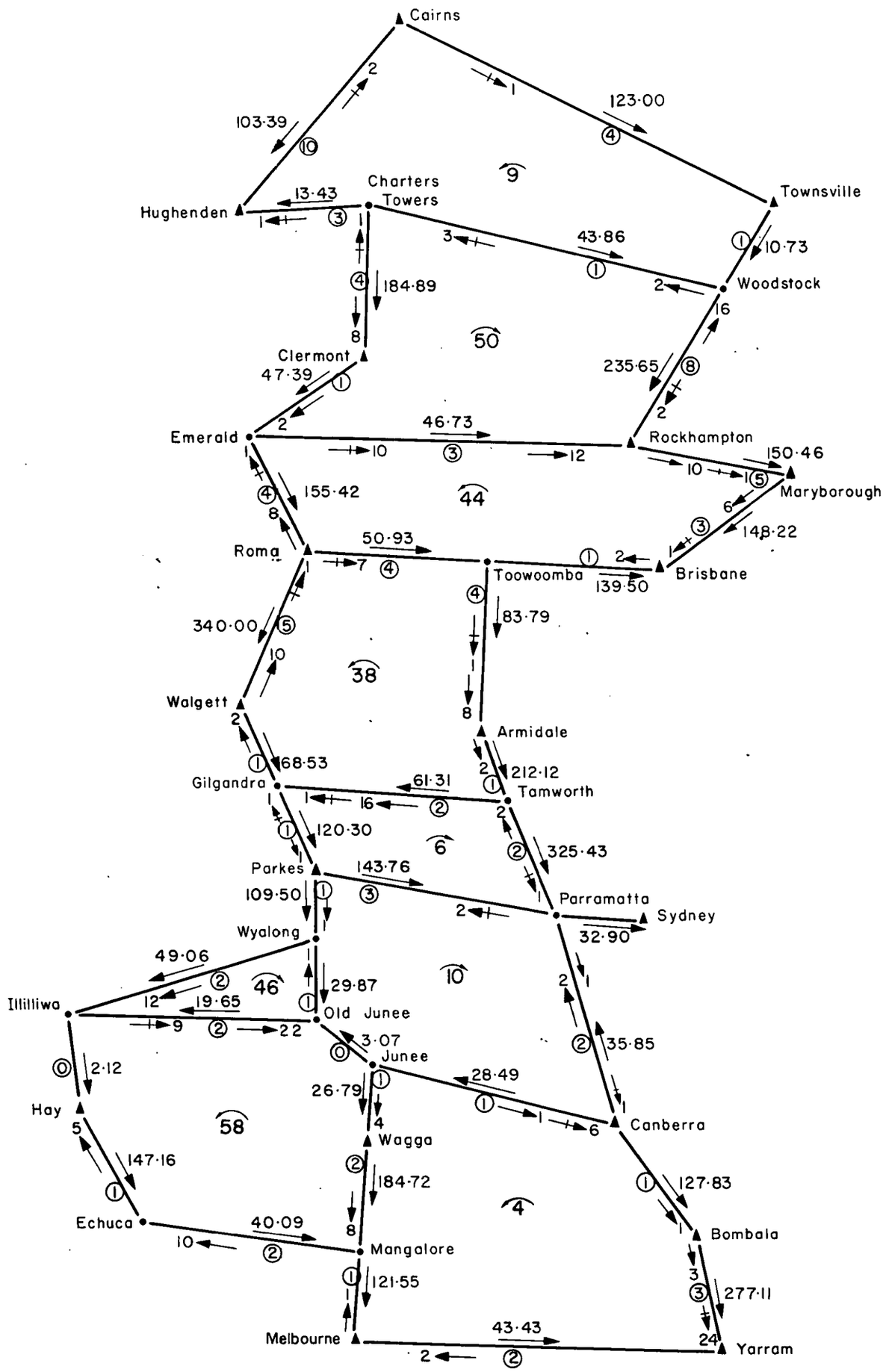


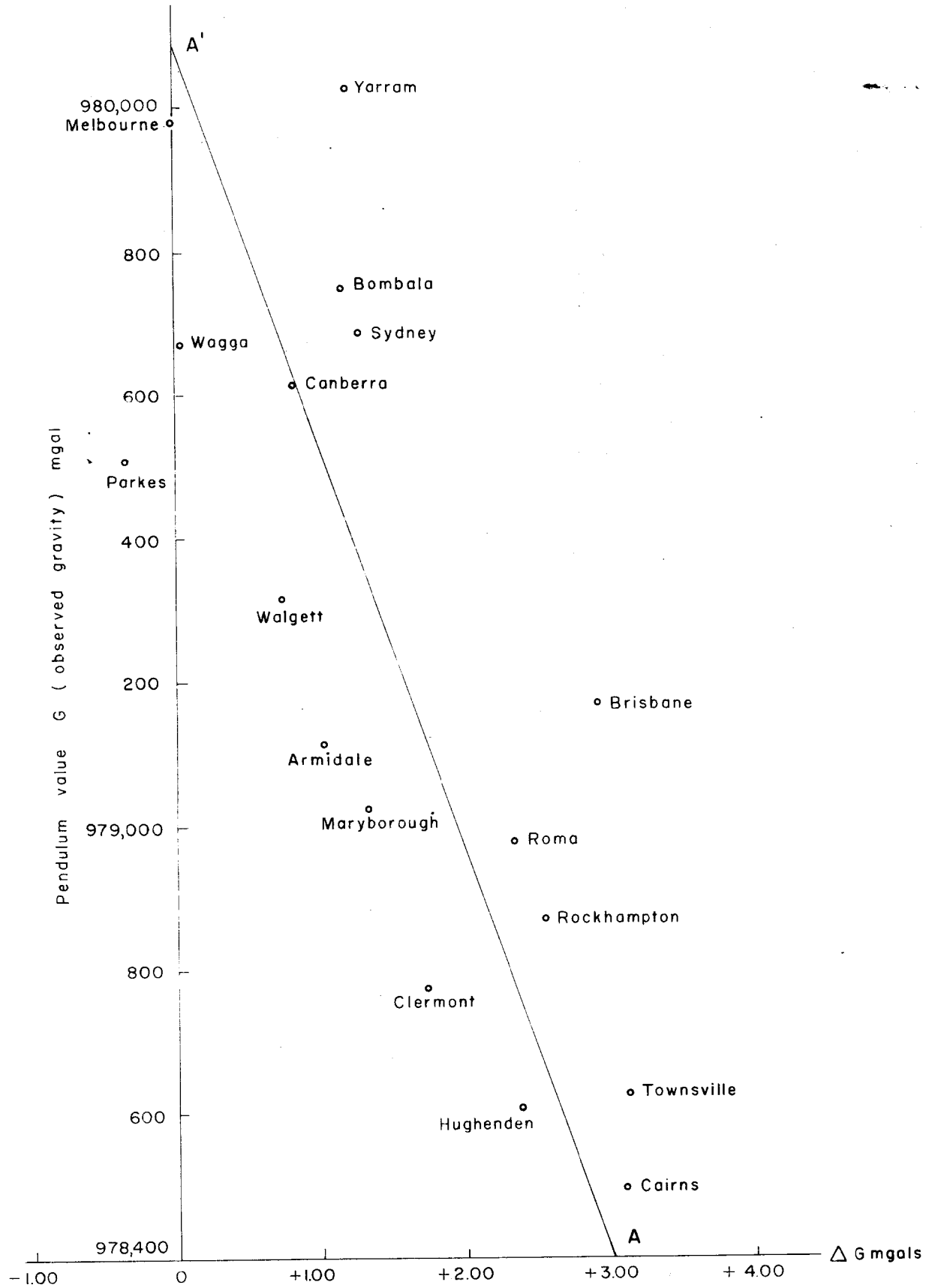
GRAVITY METER MEASUREMENTS
BETWEEN PENDULUM STATIONS
EASTERN AUSTRALIA

CLOSURE DIAGRAM OF GRAVITY MEASUREMENTS

LEGEND

▲ Primary Gravity Station
• Intermediate Gravity Station
127·83 Gravity Difference (in milligals)
9 Misclosure (in $\frac{1}{100}$ milligalls)
3 Misclosure Adjustment (in $\frac{1}{100}$ milligals)
1 Residual Adjustment " " "
② Adjustability of Interval

Station	Pendulum Value	Meter value, based on N.G.B.S. Melbourne	Meter value minus pendulum value (ΔG)
Melbourne	$^{979}979.00$	$^{979}979.00$	0
Yarram	$^{980}021.20$	$^{980}022.41$	+1.21
Bombala	$^{979}744.10$	$^{979}745.27$	+1.17
Canberra	616.60	617.43	+0.83
Wagga	672.60	672.67	+0.07
Hay	671.80	670.37	-1.43
Parkes	509.90	509.56	-0.34
Sydney	684.90	686.20	+1.30
Walgett	320.00	320.57	+0.75
Armidale	114.70	115.74	+1.04
Roma	$^{978}978.50$	$^{978}980.86$	+2.36
Brisbane	$^{979}169.40$	$^{979}171.34$	+2.94
Maryborough	021.70	023.05	+1.35
Rockhampton	$^{978}869.90$	$^{978}872.48$	+2.58
Clermont	776.40	778.12	+1.72
Hughenden	604.20	606.60	+2.40
Townsville	623.10	626.24	+3.14
Cairns	500.10	503.23	+3.13

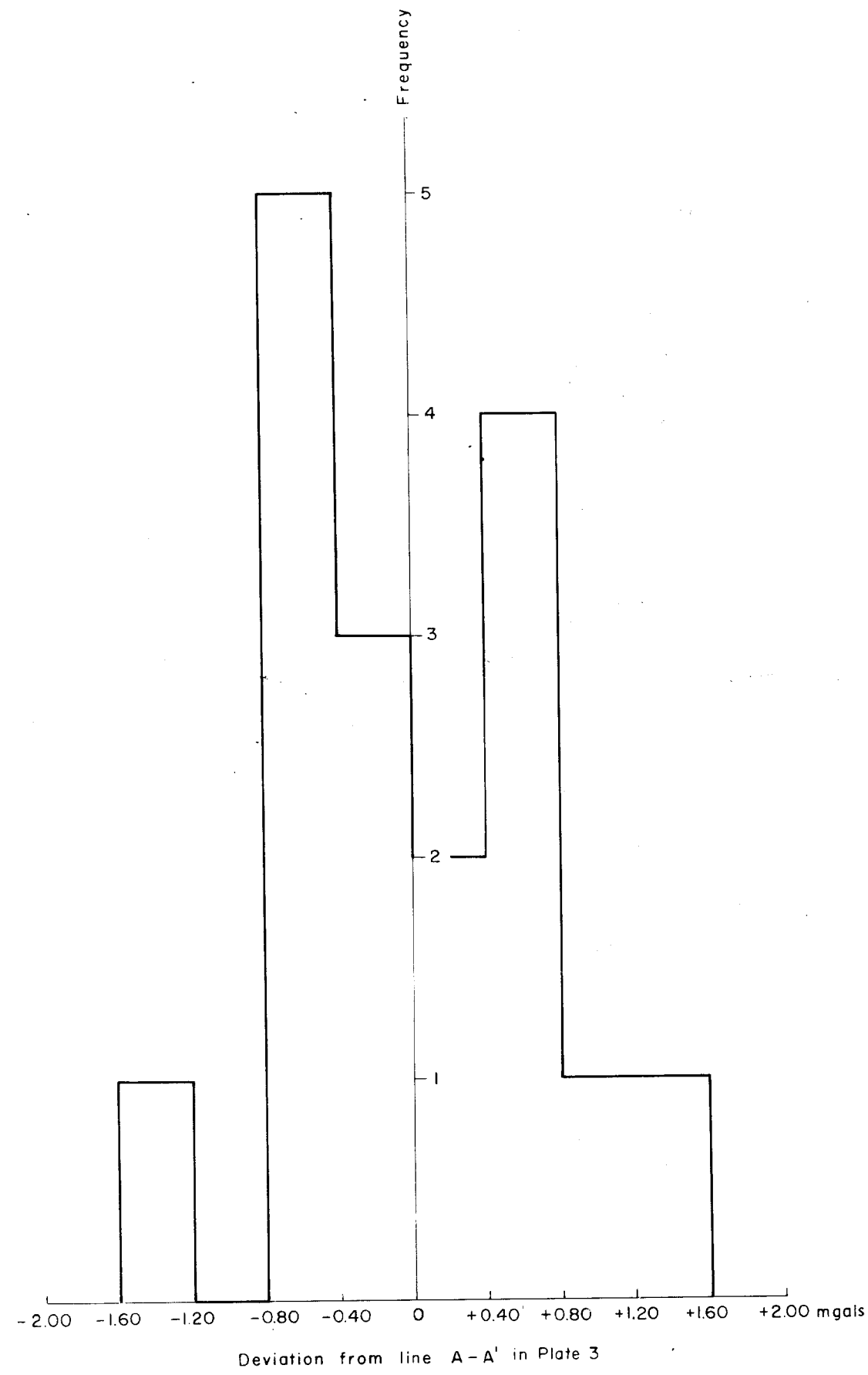


Difference between gravity meter and pendulum values
(ΔG) versus pendulum value G

To accompany Record No. 1966/45

Station	Deviation (0.01 mgal)	Station	Deviation (0.01 mgal)
Cairns	+30	Walgett	-63
Townsville	+53	Sydney	+56
Hughenden	-24	Wagga	-69
Clermont	-52	Canberra	-3
Rockhampton	+40	Bombala	+54
Maryborough	-61	Yarram	+107
Roma	+38	*Hay	-214
Armidale	-70	Brisbane	+129
Melbourne	-22	Parkes	-139

* This station not used in Plates 3 and 4



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