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THE ESTABLISHMENT OF GEODETIC GRAVITY NETWORKS IN SOUTH AUSTRALIA

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THE ESTABLISHMENT OF GEODETIC GRAVITY NETWORKS IN SOUTH AUSTRALIA

by

R.S. Mather*

Summary

The establishment of geodetic gravity networks for calculations of the geoid-spheroid separation vector is discussed, with special relevance to South Australia. The results of gravity surveys carried out in previously unsurveyed regions are also presented.

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1. Introduction

The shape of equipotential surfaces of the earth's gravitational field is of importance to geodesists, as all geodetic observations on the earth's surface are made in planes, fixed by reference to that which is tangential to the equipotential surface passing through the observing station. These equipotential surfaces are approximately spheroids of revolution, with departures from the spheroidal model of the order of the square of the flattening (f) (1 in 10^5). It is thus convenient to represent the departures of the geoid from a suitable reference spheroid by means of the vector representing the 3-dimensional non-coincidence between equivalent points on the reference spheroid and the geoid.

The solution vector is conventionally represented by

(a) a linear displacement along the spheroidal normal (N), called the geoid-spheroid separation.

(b) an angular displacement between the vertical and the spheroidal normal, represented as two mutually perpendicular components ξ (in the meridian) and η (in the prime vertical) (Bomford, 1962, 409) called the deflection of the vertical.

The assumption that the spheroidal zenith coincided with the astronomical zenith was acceptable in geodesy till recently, as the main concern was triangulation, involving measurements in a horizontal plane. The use of the Laplace equation (Bomford, 1962, 90), allied with the fact that the deflection of the vertical (ζ) produces errors in horizontal directions of the order of ζ^2(1 in 10^9) (Mather, 1966 a, Sec. 4), ensured the validity of this assumption.

These deflections of the vertical can be determined astrogeodetically (ζ_a), but it should be emphasised that ζ_a is dependent on both the dimensions and the orientation of the reference spheroid. The gravimetric method of determining the deflections of the vertical (ζ_g), on the other hand, is an absolute method for determining the geoid-spheroid separation vector at a point. While the former depends on the rotation of the earth for its evaluation, the latter is governed by differential relationships between surfaces, using vector analysis. The entire method is mathematically neat in that these relationships are established without recourse to approximations. The actual evaluation of the integrals set up, however, permit the use of approximations regarding the shape of the reference surface, as the quantities determined are of the order of f^2. The approximation used is a spherical one, the resulting integrals for N, ξ and η being evaluated by quadratures.

2. The Definition of a Geodetic Gravity Network

The solution of the above integrals for an idealised earth (i.e. no topography exterior to the geoid) are commonly known (Heiskanen and Vening Meinesz, 1958, 65-8) as the Stokes and Vening Meinesz integrals.

Stokes' Integral is

$$N = \frac{R_m}{4\pi\gamma_m} \iint f(\psi)\ \Delta g\ d\sigma = \frac{R_m\,\pi}{4\,\gamma_m\,180^2} \sum_i \text{-----}$$

$$n_i^2 \sum_j f(\psi_{ij})\ \Delta g_{ij}\ \cos\phi_{ij} \qquad \ldots\ldots\ldots (1)$$

where

R_m = mean radius of the earth

γ_m = mean value of gravity over the earth

ψ = angular distance of surface element $d\sigma$ from computation pt.

n = length of side of unit square, expressed in degrees.

ϕ = latitude of surface element $d\sigma$

$$f(\psi) = 1 + \operatorname{cosec} \psi/2 - 6 \sin \psi/2 - 5 \cos\psi - 3 \cos\psi \ldots\ldots\ln\left\{\sin \psi/2 \, (1 + \sin \psi/2)\right\} \ldots\ldots (2)$$

Δg represents the mean gravity anomaly over the surface element $d\sigma$

The Vening Meinesz Integrals are -

$$\xi_k = \frac{206265\,\pi}{4\,\gamma_m\,180^2} \sum_i n_i^2 \sum_j \frac{\partial}{\partial\psi}\left\{f(\psi_{ij})\right\} \ldots\ldots \Delta g_{ij} \cos\phi_{ij} \cos\alpha_{ijk} \, , \; k = 1,2 \ldots\ldots (3)$$

where

$$\frac{\partial}{\partial\psi}\left\{f(\psi)\right\} = -\tfrac{1}{2}\cos\psi/2\ \operatorname{cosec}^2\psi/2 + 8\sin\psi - 6\cos \ldots\ldots\ldots\ldots$$
$$\psi/2 - 3(1-\sin\psi/2)\operatorname{cosec}\psi + 3\sin\psi\ \ln\left\{\sin \ldots\ldots\ldots\ldots\right.$$
$$\left.\psi/2(1+\sin\psi/2)\right\} \ldots\ldots\ldots \quad (3)$$

ξ_1 = component of deflection of the vertical in the meridian = ξ

ξ_2 = component of deflection of the vertical in the prime vertical = η

and

$\cos\alpha_2$ = $\cos(90 - \alpha_1)$, α_1 being the azimuth of surface element from computation point.

The sign conventions are as defined by Bomford (1962, P. 88).

For a complete solution of these equations, it is necessary to have a world wide gravity coverage, as the summations are taken over the entire surface of the earth. The structure of $f(\psi)$ and $\frac{\partial}{\partial\psi}\{f(\psi)\}$ show that the magnitudes of these functions for $\psi \rightarrow 0$, depend on the cosec $\psi/2$ term, which is very unstable in this range of values. Thus, the accuracy of the value of the gravity anomaly used is more critical for areas closer to the computation point, and these regions require more precise field determinations. It is generally agreed (e.g. Uotila, 1960) that the breakdown of the earth's surface into $5^\circ \times 5^\circ$ squares for the more distant areas, $1^\circ \times 1^\circ$ squares for near areas and iso-anomaly maps for areas in the immediate vicinity of the computation point, give adequate results.

In the Australian determinations, the entire series of computations is being carried out on an electronic computer, the final results being the simple sum of a series of effects. The replacement of the iso-anomaly maps and templates by the use of the electronic computer and square means was based on a study of the spacing of adjacent circular rings necessary to produce the same components in N , ξ and η for a given anomaly, as calculated by Rice (1952) for ξ and η and Uotila (1960) for N . In general, a balance was sought between the variation, with position, of gravity anomalies on the one hand, and the size of the area making the same contribution to the quantity computed, on the other.

As the former changes very slowly over short distances, averaging 9 mgal. per 50 km in South Australia (Mather, 1966 b), it was decided to dispense with the numerous subdivisions within the 4 $0.1^0 \times 0.1^0$ squares in the immediate vicinity of the computation point and use, instead, Sollins' expressions (Sollins, 1947, P.282).

$$\xi_c = \left\{0.1051 \, s + 0.12 \times 10^{-7} \, s^2\right\} \frac{\partial \Delta g}{\partial x} \qquad \text{.......} (6)$$

$$\eta_c = \left\{0.1051 \, s + 0.12 \times 10^{-7} \, s^2\right\} \frac{\partial \Delta g}{\partial y} \qquad \text{.......} (7)$$

where

ξ_c and η_c are the contribution to ξ and η of the inner zone of radius s km.,

and

$\frac{\partial \Delta g}{\partial x}$ and $\frac{\partial \Delta g}{\partial y}$ are the gravity anomaly gradients in the North and East directions respectively, expressed in mgal/km., for evaluation of the innermost zones.

Thus, for the area extending up to $\psi = 1.5^0$ from the computation point, the effects are computed as follows :-

(i) an inner zone of about 10 km. radius, using Sollins' formulae,

(ii) an area exterior to this and extending up to $\psi = 1.5$, where $0.1^0 \times 0.1^0$ square means are used.

In the Australian computation, regions beyond this limit are computed as follows :-

(a) using $0.5^0 \times 0.5^0$ square means for $1.5^0 < \psi < 5^0$.

(b) using $1^0 \times 1^0$ square means for $5^0 < \psi < 20^0$.

(c) using $5^0 \times 5^0$ square means for $\psi > 20^0$.

Keeping in mind the fact that the precision of the gravimetric method is dependent primarily on the available gravity data and is capable, with increase in the latter from satellite orbital analysis and ground surveys, of an accuracy greater than that obtained from relative astro-geodetic determinations, an ideal geodetic gravity network would be one in which every $0.1^0 \times 0.1^0$ square in the region being considered was represented by a single reading.

The error of representation (e_s) is given by

$$e_s = \pm \left\{ \frac{\sum_{i=1}^{n} \left(\Delta g_i - \overline{\Delta g} \right)^2}{n} \right\}^{\frac{1}{2}} \qquad \ldots\ldots\ (8)$$

where $\overline{\Delta g}$ is the mean anomaly over the square considered.

For a $0.1^0 \times 0.1^0$ square, this value is about $\pm$ 3 mgal (Hirvonen, 1956, 2). Unsurveyed areas require representation in computations, and these have to be obtained by field extensions. Under certain regulated conditions, it is possible to extend the field with extension errors which are not materially larger than $\pm$ 3 mgal (Mather, 1966 b).

For immediate needs, however, the spacing of gravity stations in a geodetic net will depend on whether the computations are point to point (e.g. special determinations at Laplace stations, tracking stations, etc.) or on a regional basis. In the former case, the specifications need not be rigidly adhered to. The station spacing could increase from 0.1^0 intervals within $\frac{1}{2}^0$ of computation point, to 0.3^0 to 0.4^0 intervals at points $1\frac{1}{2}^0$ from computation point, provided the terrain permits smooth interpolation. It should be possible, under such circumstances, to obtain satisfactory field extensions to every $0.1^0 \times 0.1^0$ square in the region.

The establishment of such fields in Australia is made difficult by the lack of reference elevations and access limitations.

3. The South Australian Reference System

The gravity reference networks in Australia have been entirely established by the Commonwealth of Australia's Bureau of Mineral Resources, Geology and Geophysics (B.M.R.). Originally, the reference system in South Australia was a network of pendulum stations (Dooley et al, 1961). This has now been superseded by a more extensive survey called the Isogal Regional Gravity Survey, using a battery of gravimeters (Dooley, 1965). The Isogal survey is so called because of the predominatly East - West gravity traverses which comprise the survey. In this method of traversing, with one exception, all gravity differences on a particular traverse were within the small dial range of the gravimeters used (i.e. 50 - 100 mgal.). All traverses were connected to the national gravity base station at Melbourne (value 979,979.0 mgal.), and the "May 1965 Isogal values" of the reference stations established in South Australia are given in Appendix 1, the station locations being shown in Fig. 1. These values are for the present, accepted as final. They would, however, be subject to changes depending on any variation in the Potsdam value, the connection between Melbourne and Potsdam (anticipated change + 0.5 mgal) as well as any international decisions which could affect the value of the Mean Australian Milligal(expected to be of the order of ± 1 part in 3000) (Barlow, private communication). The 4000 stations comprising the existing geodetic gravity network in South Australia to date (Feb. 1966) have been tied into the Isogal survey to provide a unified state system.

4. The Existing Gravity Data in South Australia

In addition to the B.M.R.'s control network of a very high order of accuracy, there are numerous regional surveys carried out for prospection purposes, in which gravity stations have been established with a high degree of relative precision. The number of such stations available is much more than an order greater than the number of stations acceptable for a geodetic network. In several such cases, both elevations and gravity were on arbitrary datums and had to be connected and converted to the unified "May 1965 Isogal system". In this manner, a unified network was established on a state-wide basis, with the co-operation of the South Australian Department of Mines and certain petroleum companies and the distribution of stations in the geodetic gravity network established is shown in Fig. 2.

It can be seen that, while the northern and eastern portions of the State have been well surveyed gravimetrically, the centre and the west are not. Surveys in these regions are vital if any absolute determinations of deflections of the vertical are to be carried out in the Woomera area, where the tracking stations are sited. The station spacing on such a project will depend entirely on the nature of the determination. For isolated determinations, a station spacing of 0.1^0 in the immediate vicinity of stations to be orientated and one of 0.2^0 to 0.25^0 for regions further away, would enable a reasonable orientation, with an accuracy approaching that of astronomical determinations to be effected, after adequate field extension.

5. The Organisation of Field Work

The difficulties of access, coupled with the lack of an adequate network of levelling, give rise to special problems in the establishment of geodetic gravity networks in Australia. The B.M.R. has been establishing gravity networks on a 7-mile grid, using helicopters for transport, in very inaccessible regions in Central Australia. The heights are determined using barometric methods, controlled by third order spirit levelling. (Dooley, 1965). Up to 40 stations can be established in a normal helicopter working-day by this means.

The accessible regions in Australia are confined to the coastal areas, which, by virtue of the lack of gravity determinations at sea in the Southern Ocean are unsuitable as locations for computation points. In these regions, land based transport can be used. A rate of progress of about 15 points a day is rather difficult to maintain, unless the access is good.

The quantities measured are differences in both height and gravity and require connection to an absolute value for obtaining the height and gravity value. Elevations so established by barometer, using the double base technique, are claimed to have standard errors of the order of ± 3 meters per single difference in height. This is probably true if the reference stations are correctly sited with respect to the field station. In the South Australian coastal region, frontal pressure movements occur frequently and have to be taken into consideration when siting the base barometers.

Conventionally, the two bases are so located in relation to the area to be covered by the roving station as to completely span the range in elevation covered by the latter. In the region considered, it was found necessary, in addition, to determine the general trend of frontal movements from the daily weather maps and to devise base station layouts to be diagonal to the direction of such movements. In this manner, corrections were applied to the roving station values, by considering its position in relation to the two base stations and the time lag between the occurrence of similar phenomena at each one in turn. This is probably an over-simplification when considering inland areas. In such cases, it would be necessary to use more than two bases, on each of which should be sited a self-recording device. Such bases should be so sited around the working area so as to detect any possible changes which occur, other than diurnal ones.

6. The Accuracy of the Determinations

The basic reading unit on modern gravimeters is 10^{-1} mgal, with interpolation down to 10^{-2} mgal. The daily drift on most gravimeters hardly exceeds 0.2 mgal. However, it does not follow that the drift is either linear or even of the same sign between successive drift checks. Short term effects (Barlow, 1965, 14) can be either -

(i) systematic, e.g. the variation of calibration factor with

  (a) temperature (about 0.1% per 10^0C.)

  (b) pressure variations within the oscillation chamber (about 0.06% per 10 m.m. of Mercury).

or

(ii) erratic.

These variations can be as large as 0.1 % and are not predictable. The Worden Geodesist gravimeter used on the survey described in the next section was tested by repeating an established loop of five stations a number of times. It maintained a reasonable consistency of reading in accordance with linear drift on all laps with the exception of one occasion, when it unaccountably dropped 0.16 mgal in the gravity difference (0.3%). Such a variation could produce adjustment errors of nearly 0.1 mgal.

However, it can generally be assumed, even on the basis of a single drift check per day, that gravimeters give results which establish differences of gravity with an accuracy of ± 0.1 mgal.

The use of barometers with adequate control (e.g. with microbarographs established around an area 40 to 50 miles square), could give differences in elevation whose accuracy, with respect to the base stations is of the order of ± 3 metres.

The anomaly used in the South Australian calculations (Δg) is given by

$$\Delta g = g - \gamma + \frac{2\gamma_m h}{R_m} - \Delta g_c \qquad \ldots\ldots\ldots (9)$$

where

g = observed gravity,

γ = theoretical gravity given by the International gravity formula

$$\gamma = 978.0490(1 + 5.2884 \times 10^{-3} \sin^2\phi - 5.9 \times 10^{-6} \sin^2 2\phi) \qquad \ldots\ldots\ldots (10)$$

h = elevation of station above geoid.

γ_m and R_m are defined as in equation (i).

Δg_c is the differential attraction of the topography between the observation point and the corresponding point on the geoid, without recourse to "the removal of matter". The expression is complex (Mather, 1966 c), but the principal term is given by

$$\Delta g_c \doteq - 4\pi k \rho h \qquad \ldots\ldots\ldots (11)$$

where

k is the gravitational constant

and

ρ the density of the earth's crust.

Thus Δg_c is approximately equal to twice the Bouguer reduction, making the total reductions due to the height terms approximately $+ 0.08\ h^{met}$ mgal. (Heiskanen and Vening Meinesz, 1958, 153).

Therefore, the error in the anomaly, due to the error in the station height only, is less than 1 mgal if the height error does not exceed 12 metres. This establishes that the height and gravity measuring accuracies are compatible, with minimal effort, if

$$e_h \ngtr \pm 3 \text{ metres}$$

$$e_{\Delta g} \ngtr \pm 1/4 \text{ mgal.}$$

7. The Adelaide Hills Survey

The above criteria for station spacing and precision in heighting were adopted for a geodetic gravity survey in the Adelaide Hills area. The survey was carried out with the South Australian Institute of Technology's Worden Geodesist gravimeter (No. 744). This instrument, purchased in 1965, has a world-wide range with a basic reading unit of approximately 0.1 mgal. The calibration factor provided by the Makers was found to be 0.5% higher than the value obtained by calibration of the gravimeter on the Adelaide calibration range, provided by the B.M.R. This appears to be in agreement with the general experience of other observers (Barlow, 1965, 10) that Worden calibrations are generally 0 to 0.3% , and those of the World Wides up to 0.4% higher than the B.M.R. standard. The latter is based on a "standard gravity interval" between two stations in Victoria, which difference was originally determined by pendulum observations. This was further amended as a by-product of the Australian gravity network adjustment in 1961 (Dooley, 1965), using gravimeter ties between all pendulum stations in Australia. This provided a revised value for the calibration factor of all gravimeters. Barlow (1965, Sec. 7) reports that this new set of differences agrees "fairly well with both the ', Recent American ' and the '1957 European ' systems described by Morelli (1957)". This is also in agreement with values obtained by the United States Air Force, using a battery of four La Coste and Lamberg gravimeters, when the results obtained were found to agree with the Mean Australian Milligal to approximately 2 parts in 5000 (Whalen, 1961).

All gravity values established in this survey were based on the calibration factor provided by the Adelaide calibration range, and adopting the "May 1965 Isogal" values for the terminals of the base (see Appendix 1). The essential data, necessary for geodetic use, of the stations established are given in Appendices 2 and 3. The first set of stations were established in August 1965 and the second in November 1965.

7. Conclusion.

For low and mid-latitudes, the ideal gravity station spacing on a geodetic gravity network, for regional geoidal studies, is at 0.1^{o} intervals. When access is both difficult and expensive, and provided the topography is not excessively variable, an adequate network could be established by increasing the station spacing (s) to $0.2^{o} < s < 0.3^{o}$, and performing field extension by any reasonable method of 2-dimensional analysis to obtain values at 0.1^{o} intervals. The interpolated values so obtained are unlikely to have errors much in excess of the error of representation for $0.1^\circ \times 0.1^\circ$ squares ($\pm$ 3 mgal).

For determinations at specific points, the station spacing criteria could be relaxed with increase of distance from the computation point. In areas with average gravity variations, suggested values of s are

for $\psi < 0.1^\circ$	$s = 0.1^\circ$
$0.1^\circ < \psi < 0.5^\circ$	$0.1^\circ < s < 0.2^\circ$
$0.5^\circ < \psi < 1.0^\circ$	$0.2^\circ < s < 0.3^\circ$
$1.0^\circ < \psi < 1.5^\circ$	$0.3^\circ < s < 0.4^\circ$

Areas in which the gravity anomaly gradient (using any anomaly which is free from height correlation) is greater than 15 mgal per 50 km should be more closely investigated, if the relaxed criteria are adopted.

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REFERENCES

1. Barlow, B.C. "Establishment of gravity meter calibration ranges in Australia" 1960 - 1961, B.M.R. Rec. 1965/19, 1965.
2. Bomford, G. "Geodesy" 2nd Edition, Oxford University Press, 1962.
3. Dooley, J.C., McCarthy, E., Keating, W.D., Maddern, C.A., and Williams, L.W. "Pendulum Measurements of gravity in Australia"1950 - 51, B.M.R. Bull.46, 1961.
4. Dooley, J.C. "National Report of Gravity in Australia". Jan. 1962 - June 1965. B.M.R. Rec. 1965/62, 1965.
5. Heiskanen, W.A. and Vening Meinesz, F.A. "The earth and its gravity field" McGraw Hill, 1958.
6. Hirvonen, R.A. "On the precision of the gravimetric determination of the geoid" Trans. A.G.U. 37, 1 - 8, 1956.
7. Mather, R.S. "The geodetic uses of gravity". 9th Survey Congress, Perth, 1966.
8. Mather, R.S. "The extension of the gravity field in South Australia" UNICIV Rep. (To be published shortly) 1966 b.
9. Mather, R.S. "The anomaly to be used in Stokes' integral for a postulated topographical model exterior to the geoid". UNICIV Rep. (To be published shortly) 1966 c.
10. Rice, D.A. "Deflections of the vertical from gravity anomalies" Bull. Geod., 25, 285 - 312, 1952.

11. Sollins, A.D.
"Tables for the computation of deflections of the vertical from gravity anomalies", Bull. Geod, 6, 279 - 300, 1947.

12. Morelli, C.
"Calibration Standard" Sp. St. Gr.5, Section iv (Gravimetry), I.A.G., I.U.G.G. xith Gen. Assembly, Toronto, Part 3, 1957.

13. Uotila, U.A.
"Investigations on the gravity field and shape of the earth" Ann. Acad. Sc. Fenn., Ser. A III, Geologica, 55, 1960.

14. Whalen, C.T.
"The West Pacific Calibration Line Survey" 1964 - 65, Phase Rep. 3 USAF Gravity Div., 1381st Geodetic Survey Squadron, 1966.

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APPENDIX 1

Isogal Gravity Base Stations Within South Australia Established by The Bureau of Mineral Resources Geology and Geophysics

Abbreviations used :-

A/S	Airstrip
B.M.	Bench Mark
C.S.	Calibration Station
D.C.A.	Department of Civil Aviation
D. of I.	Department of Interior
H.S.	Homestead
M/P.	Mile Post
Pass. Term.	Passenger Terminal
P.S.	Pendulum Station
R.S.	Railway Station
S.S.M.	State Survey Mark
P.M.	Permanent Mark

APPENDIX 2

ADELAIDE HILLS GEODETIC GRAVITY SURVEY, SOUTHERN AREA

Date:- August, 1965 Gravimeter:- Worden Geodesist 744

Survey carried out by South Australian Institute of Technology

Stn.	Latitude ° ' " S.	Longitude ° ' " E.	Gravity (mgal)	Ht. (Met)	Remarks
S.A.I.T	34 55 18	138 36 20	979723.6	37	
1	35 00 00	138 30 40	979728.1	00	Glenelg(sea lev.)
2	35 00 06	138 36 25	979693.3	223	Windy Point
3	34 59 45	138 59 45	979624.0	582	Crafers
4	35 00 35	138 47 40	979682.8	312	Verdun
5	34 59 39	138 54 08	979654.5	425	Nairne
6	35 00 02	138 59 30	979678.0	295	Kanmantoo
7	35 06 05	138 59 57	979715.0	167	Balyarta
8	35 06 10	138 54 00	979687.8	328	Mr. Barker
9	35 06 20	138 47 50	979683.5	362	Echunga
10	35 05 50	138 42 10	979674.2	398	Mt. Bold
11	35 06 10	138 36 05	979683.8	352	Clarendon
12	35 06 05	138 30 30	979734.3	100	Port Stanvac
13	35 12 10	138 30 15	979752.0	70	Willunga
14	35 11 49	138 30 15	979747.0	85	Mt. Miller
15	35 12 00	138 35 40	979745.6	89	McLaren Flat
16	35 12 25	178 41 55	979707.2	295	Horsham
17	35 11 55	138 48 00	979698.1	325	Paris Creek
18	35 11 50	138 54 20	979713.2	216	Gemmells
19	35 11 50	138 59 50	979741.2	77	Woodchester
20	35 18 11	138 59 32	979761.3	22	Langhornes Creek
21	35 17 49	138 54 18	979754.2	46	Strathalbyn
22	35 17 56	138 48 16	979737.3	169	Giles Hill
23	35 18 06	138 45 18	979746.9	118	Bull Creek
24	35 17 39	138 35 36	979713.3	329	Willunga
25	35 22 15	138 29 07	979741.3	220	Myponga
26	35 24 26	138 35 52	979736.6	282	Mt. Jagged
28	35 24 13	138 48 41	979766.3	28	Gilberts
29	35 24 18	138 54 20	979773.9	15	Milang (west)
30	35 23 50	139. 00 00	979774.0	3	Milang
31	35 29 35	138 59 49	979782.8	3	Yaaringerie

/contd. . .

APPENDIX 2 (Cont'd)

Stn.	Latitude o ' "	Longitude o ' "	Gravity (mgal)	Ht. (Met)	Remarks
32	35 29 38	138 54 52	979778.3	18	Clayton
33	35 29 53	138 47 48	979791.0	3	Goolwa
34	35 30 36	138 42 16	979784.6	41	Middleton
35	35 29 30	138 36 36	979784.9	57	Hindmarsh Valley
36	35 29 55	138 30 42	979784.7	73	Inman Valley
37	35 00 07	139 05 51	979698.0	189	Rockleigh
38	35 01 20	139 11 50	979719.5	68	Pallamana
39	35 00 17	139 16 49	979722.1	55	Hoffmann
40	35 05 45	139 17 40	979740.7	1	Toora
41	35 05 36	139 12 12	979724.4	88	Kindura
42	35 06 50	139 05 55	979713.0	156	Monarto
43	35 13 52	139 06 44	979752.0	36	Harriot Hill
44	35 11 04	139 11 40	979739.6	56	Camel
45	35 12 04	139 17 39	979740.3	16	Carinya
46	35 18 25	139 05 38	979763.0	8	Bower Downs
47	35 18 20	139 12 10	979761.4	2	Humphrey
48	35 19 32	139 19 54	979760.7	3	Rocky Farm
49	35 22 05	139 18 35	979766.5	3	Nalpa
50	35 22 15	139 06 10	979770.7	3	Tolderol
27	35 24 14	138 41 45	979742.6	223	Mosquito Hill

APPENDIX 3

ADELAIDE HILLS GEODETIC GRAVITY SURVEY, NORTHERN AREA

Date:- November 1965. Gravimeter:- Worden Geodesist 744

Survey carried out by South Australian Institute of Technology

Stn.	Latitude ° ' "	Longitude ° ' "	Gravity (mgal)	Ht. (Met)	Remarks
1	34 41 57	138 41 06	979693.7	51	Elizabeth
2	34 42 10	138 47 56	979665.0	230	One Tree Hill
3	34 53 37	138 54 09	979646.3	428	Lobethal
4	34 54 45	138 47 54	979618.7	564	Forrest Range
5	34 54 26	138 42 20	979651.4	366	Norton Summit
6	34 35 44	138 48 00	979672.7	144	Gawler
7	34 36 01	138 54 02	979664.3	183	Lyndoch
8	34 42 08	138 53 00	979655.2	244	South para(Bridge)
9	34 41 42	139 00 03	979621.3	425	Mt. Crawford
10	34 42 47	139 05 47	979637.3	380	Springton
11	34 48 05	139 00 19	979632.6	409	Birdwood
12	34 53 49	138 59 27	979635.3	457	Mt. Torrens
13	34 30 25	139 00 33	979636.3	295	Nuriootpa
14	34 24 08	138 59 41	979636.1	278	Koonunga
15	34 18 02	138 59 20	979624.9	290	Bagots Well
16	34 18 22	138 53 46	979620.9	300	Sugar loaf Hill
17	34 24 04	138 54 30	979636.4	267	South Kapunda
18	34 23 43	138 47 40	979653.3	180	North Freeling
19	34 18 03	138 48 22	979624.0	287	East Base (Trig)
20	34 17 52	138 42 20	979634.1	211	West Base
21	34 24 09	138 42 17	979658.2	155	Hamley Bridge
22	34 53 34	139 29 21	979729.9	90	S.E. Weidenhofers Hill
23	34 53 55	139 24 19	979708.3	104	S.W. -do-
24	34 48 33	139 29 47	979722.0	91	Kakoonie
25	34 47 23	139 24 08	979708.6	77	Nagot's Hill
26	34 42 09	139 29 48	979724.6	45	Marne River
27	34 41 39	139 25 01	979714.9	81	Black Hill
28	34 41 21	139 18 34	979683.1	107	Cambrai
29	34 47 53	139 18 40	979693.7	91	Punthari

/cont'd . .

APPENDIX 3 (Cont'd).

Stn.	Latitude ° ' "	Longitude ° ' "	Gravity (mgal)	Ht. (Met)	Remarks
30	34 54 02	139 06 47	979664.0	311	Adobe Hut trig.
31	34 42 11	139 10 10	979653.8	273	Saunder Creek
32	34 36 57	139 09 57	979639.4	321	Keynes
33	34 31 54	139 31 54	979700.2	80	Swan Reach (west)
34	34 30 19	139 24 19	979686.8	90	Martin's Trig.
35	34 30 16	139 18 11	979673.7	94	Black and White Hill
36	34 30 07	139 14 38	979667.8	160	Towitta
37	34 30 26	139 08 57	979620.0	409	Moculta
38	34 30 17	139 05 09	979624.7	368	Angaston
39	34 37 20	138 59 41	979606.4	476	Pewsey Vale
	35 00 18	138 56 28	979669.2	350	Brunkunga Camp

Place and Traverse		B.M.R. Station No.	Observed Gravity (mgal)	Remarks
Mt. Davies;	EW6	6491.9083	978,957.65	Concrete floor, Mining camp
Kenmore Park;	EW6	6491.9082	892.37	A/S
De Rose Hill;	EW6	6491.9081	975.45	Windsock A/S
Abminga;	EW6	6491.9019	963.37	Railway Sign, AP29
Flycamp 4;	EW6	6491.9020	979,017.11	French Petroleum Co.
Poepell's Corner	EW6	6491.9021	015,70	A/S
Mt. Willoughby;	EW7	6491.9018	092.02	A/S
Oodnadatta;	EW7	6491.0136	099.94	A/S
Wongela Base;	EW7	6491.9017	142.96	SP/95 Camp No. 1
Mungerainie;	EW7	6491.9016	147.71	H.S. and A/S
Innaminka;	EW7	6491.9015	115.14	A/S
Cook;	EW8	6491.9099	320.91	Concrete floor A/S
Maralinga;	EW8	6491.9100	283.88	A/S
Tarcoola;	EW8	6491.9101	333.93	A/S
Woomera;	EW9	6491.0138	372.75	A/S
Leigh Creek;	EW8	5099.9937	319.87	P.S.37
Wooltana;	EW8	6491.9103	350.37	Closest strip A/S
Quinabie;	EW8	6491.1104	334.72	H.S. Shell base Frome
Nullabor;	EW9	6491.9120	405.75	Petrol bowser H.S.
Pintumba;	EW9	6491.9119	457.21	Gate A/S
Ceduna;	EW9	6491.0110	452.42	A/S D.C.A.
Lake Everard;	EW9	6491.9118	447.15	Phone drum A/S
Hawker;	EW9	6491.9117	979,394.27	Cricket pitch A/S
Mannahill;	EW9	6491.9116	445.75	Reid A/S

Place and Traverse		B.M.R. Station No.	Observed Gravity (mgal)	Remarks
Streaky Bay;	EW10	6491.9131	979,547,09	A/S
		6491.1131	553.20	Council building
Cowell;	EW10	6491.9132	979,644.24	Verandah of Pass. Term. A/S
		6491.1132	644.18	A/S D.C.A. B.M.
Adelaide;	EW10	6491.0108	719.02	West Beach A/S
		6491.0208	704.28	Muckenfuss, Parafield A/S
		6491.0508	704.38	John Hall, Parafield A/S
		6491.0408	722.67	W. Lowndes, Outside new Observatory.
		6491.0908	722.39	Zelman, Physics School
		6091.0108	706.66	Adelaide Calibration Station 1
		6091.0208	644.05	-do- 2
Waikerie;	EW10	6491.9133	654.36	A/S
Mt. Gambier;	EW12	5099.9907	993.65	P.S.7
		6491.0107	977.22	Pass. Term. A/S

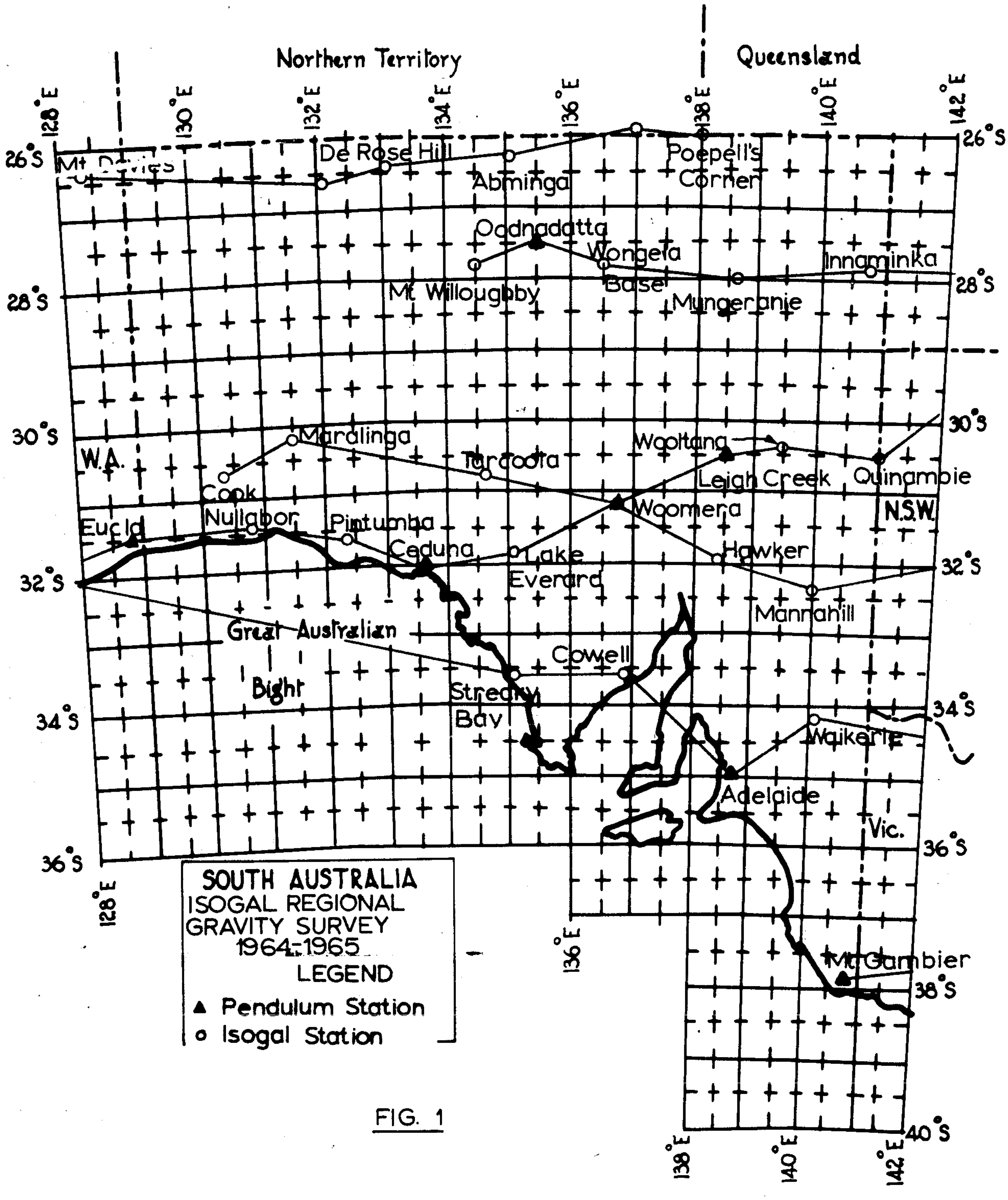
Northern Territory
Queensland
W.A.
N.S.W.
Vic.
128°E
130°E
132°E
134°E
136°E
138°E
140°E
142°E
26°S
28°S
30°S
32°S
34°S
36°S
38°S
40°S
Mt Davies
De Rose Hill
Abminga
Poepell's Corner
Oodnadatta
Wongela
Base
Mt Willoughby
Mungeranie
Innaminka
Maralinga
Tarcoola
Wooltana
Leigh Creek
Quinambie
Cook
Nullabor
Pintumba
Woomera
Eucla
Ceduna
Lake Everard
Hawker
Mannahill
Great Australian Bight
Cowell
Streaky Bay
Waikerie
Adelaide
Mt Gambier
SOUTH AUSTRALIA
ISOGAL REGIONAL
GRAVITY SURVEY
1964-1965
LEGEND
▲ Pendulum Station
○ Isogal Station

FIG. 1

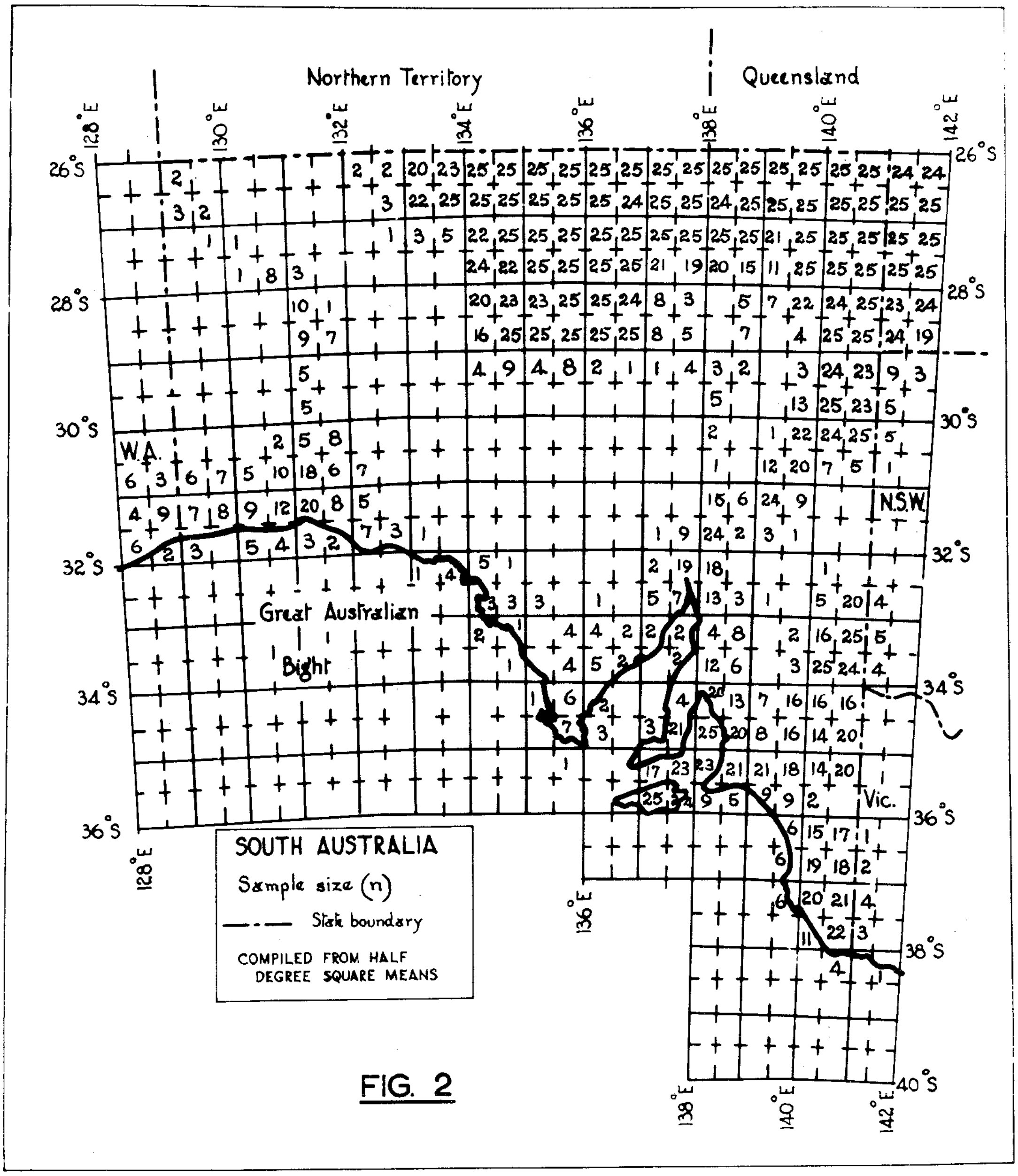
Northern Territory
Queensland
W.A.
N.S.W.
Vic.
Great Australian Bight
128°E
130°E
132°E
134°E
136°E
138°E
140°E
142°E
26°S
28°S
30°S
32°S
34°S
36°S
38°S
40°S
SOUTH AUSTRALIA
Sample size (n)
State boundary
COMPILED FROM HALF DEGREE SQUARE MEANS

FIG. 2