Compilation and production of the 1976 1:5 000 000 Gravity Map of Australia

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In 1976 a coloured 1:5 000 000 Gravity Map of Australia was published by BMR. At that stage the systematic reconnaissance gravity coverage of Australia, initiated by BMR in 1959, was complete, and preliminary gravity values were available from marine coverage of the continental shelf and margins. The map was based on approximately 260 000 gravity observations obtained by various organisations at a cost of about $12 000 000 from 300 surveys. It was produced using a CDC Cyber 76 computer system, Calcomp plotters and cartographic techniques. The computer processing phase took about four months and the cartography about three months. The coloured 1:25 000 000 Bouguer and free-air anomaly maps contained in this issue were also produced from the same data bank.

Sources of data

The data bank used to produce the 1976 1:5 000 000 gravity map of Australia (BMR, 1976) was compiled from the BMR gravity repository (Murray, 1974). This contains information on approximately 600 surveys, comprising more than 500 000 stations, which have been carried out in the Australian region.

All the surveys necessary to provide a complete regional coverage of Australia were processed so that the principal gravity facts were available in computer-compatible format. This process involved punching and digitizing the observations, checking for errors, and adjusting the values to tie in with the Australian Map Grid, the Australian Height Datum and the May 1965 values on the Australian National Gravity Network (Dooley & Barlow, 1976).

Observations from BMR surveys were processed in-house and those from other sources by a private contractor engaged especially for this task. Some surveys were too small or detailed to be used for the 1:5 000 000 scale map and were not processed. Data for surveys carried out in South Australia by the Mines Department and in Tasmania by the University of Tasmania were supplied in computer-compatible format and required only minimum processing.

About 85 percent of the contoured area was covered by surveys carried out either by BMR or private companies under contract to BMR. The remaining areas were covered by surveys carried out by State Mines Departments, private companies, tertiary institutions and the US Navy.

The BMR reconnaissance land surveys used helicopters for transport, microbarometers to determine heights, and Worden or La Coste and Romberg gravity meters (see for example, Fraser, 1973). These surveys were carried out between 1959 and 1974. The average station spacing over Australia is 11 km, except in South Australia and Tasmania where it is 7 km. Land areas surveyed by other organizations have station spacing ranging from 1 to 10 km.

Most of the marine data were obtained during a reconnaissance survey of the Australian continental margins completed for BMR during 1970-73, when about 185 000 km of systematic traversing were completed (Compagnie Generale de Geophysique, 1975). The line spacing varied from 30 to 50 km and the gravity values were based on preliminary hourly values representing an average station spacing of about 15 km along each traverse. Three other BMR surveys over the northwest continental shelf (1965, 1967 and 1968) covered about 59 000 km with a line spacing of 17 km. Values sampled at intervals of 11 km along the traverses were included in the data bank.

There are only three areas where the data coverage is poor (Fig. 1): the Gulf of Carpentaria/Arafura Sea, the Great Barrier Reef, and Bass Strait; elsewhere the coverage is considered adequate for the 1:5 000 000 map.

In some small areas of South Australia and in the eastern part of the Coral Sea, synthetic principal facts were prepared from published gravity anomaly maps because the real principal facts were not available in time. The synthetic stations are not shown in Figure 1, which shows only the locations of real observations. The synthetic principal facts were produced by digitizing the gravity anomaly contours at reasonable intervals and adding these values to the data bank.

Reduction of observations

The anomalies on the maps are based on the Potsdam datum for observed gravity values, and the 1930 International Gravity Formula.

The values of observed gravity are relative to May 1965 Isogal values at stations of the Australian National Gravity Network, which consists of a series of east-west traverses (Isogal traverses) between airports of nearly equal gravity, joined by three north-south traverses (see Fig. 2). This network of some 200 base stations spaced at about 300 km was established over Australia and Papua New Guinea during 1964-1967.

The positions of the helicopter stations were determined using aerial photographs to tie to the Australian Geodetic Datum, and heights by barometer ties to third-order levelling traverses, which in turn are tied to the Australian Height Datum.

A variety of navigation techniques were used on the marine surveys. These were a 'Toran' radio location system in 1965 (~50 m accuracy); a VLF/Omega system in 1967 integrated with dawn and dusk star fixes, radar, and navigation buoys (2-4 km accuracy); and for the remaining surveys a satellite/sonar-Doppler system, with the ship's velocity logs and a VLF/Omega system as backups (1-2 km accuracy).

The observed gravity values at sea have been reduced to free-air anomalies (FAA) in milligals, according to the formula:

$$\mathrm{FAA} = g_o - g_n + 7.5\,\mathrm{Ve}\cos\phi \qquad \ldots.(1)$$

where g_o is the observed gravity, g_n the normal value of gravity depending on latitude ϕ, and obtained from the 1930 International Gravity Formula:

$$g_n = 978\,049.0\,(1 + 0.005\,288\,4\sin^2\phi - 0.000\,005\,9\sin^2 2\phi) \qquad \ldots.(2)$$

and Ve is the eastward component of the ship's speed in knots used to calculate the Eotvos correction.

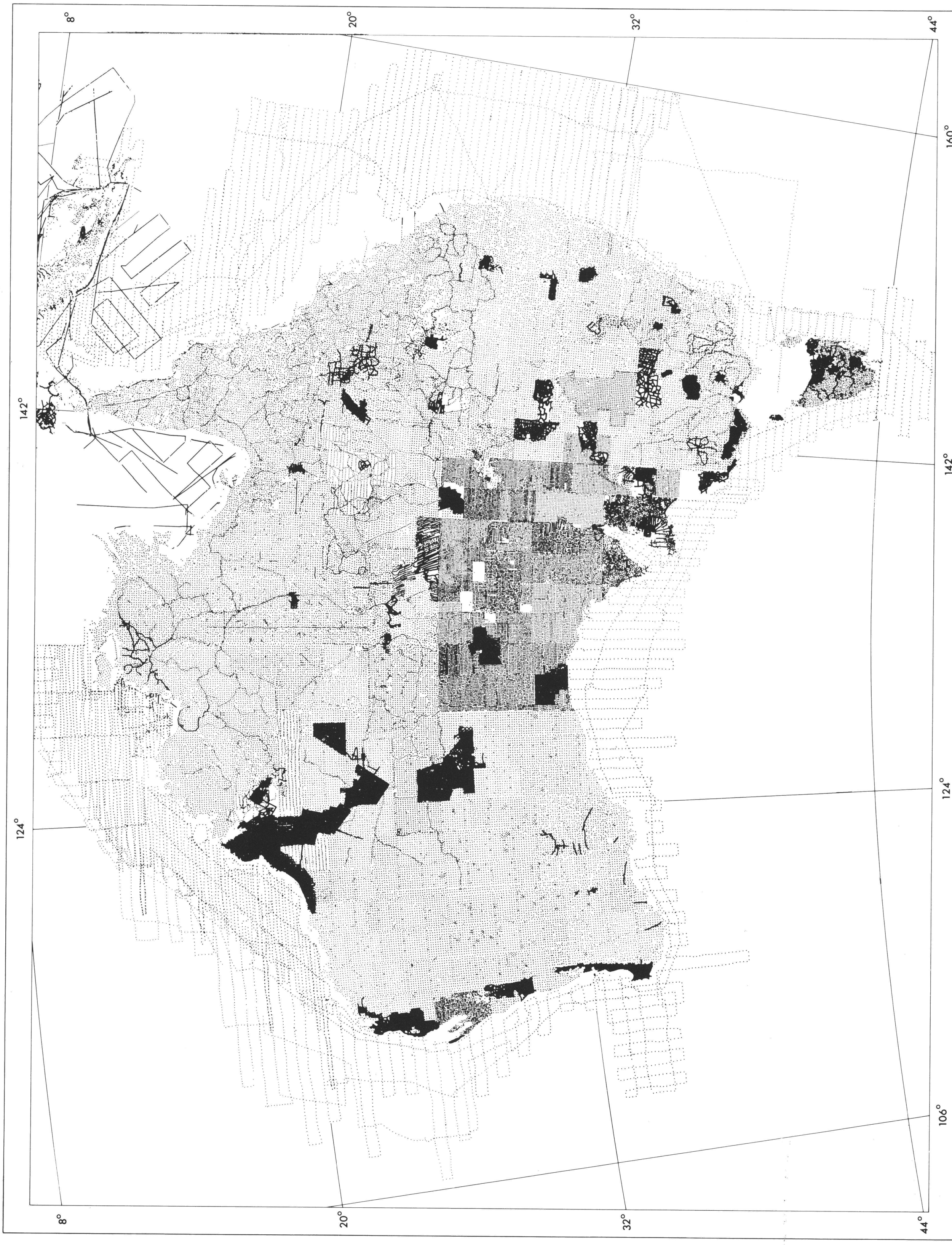

Figure 1. Distribution of data used to produce the 1:5 000 000 gravity map.

For land stations the simple Bouguer anomaly (BA) is used:

$$BA = g_o - g_n + 0.3086h - 0.0419\varrho h \quad \ldots. (3)$$

where h is the altitude in metres and ϱ is taken as 2.67 t/m³. No terrain corrections have been applied.

Accuracy of anomalies

The usual precision within each helicopter land gravity survey is better than 0.3 mGal for observed gravity differences, better than 5 m for altitude, and about 0.1 minutes of arc for latitudes and longitudes, resulting in

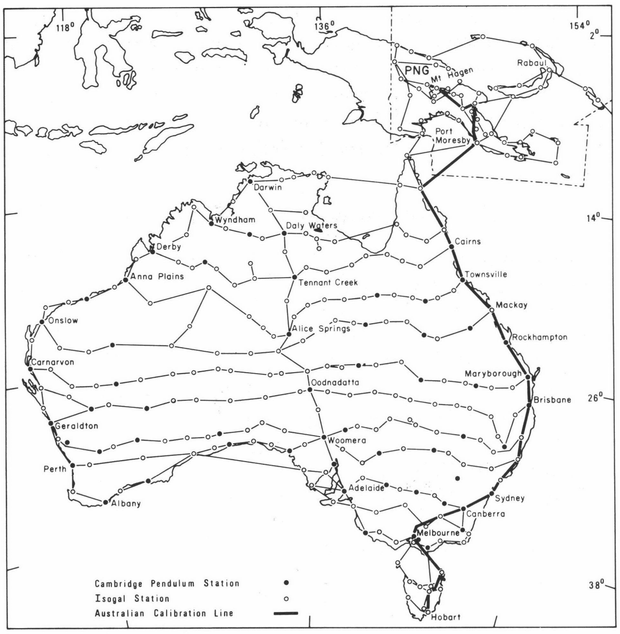

Figure 2. Australian Gravity Network.

Bouguer anomalies with a relative precision of about 1 mGal. The precision of ties between surveys is better than 0.5 mGal and 10 m, or about 2 mGal in Bouguer anomaly. Gravity values of the national network are estimated to have a standard error of 0.2 mGal relative to the network as a whole.

Terrain corrections within mainland Australia are less than 0.2 mGal over 80 percent of the area, and less than 2 mGal for the remainder of the area except in small areas of very steep topography, where the corrections may reach 10 mGal.

For the marine surveys the precision of the free-air anomalies can be estimated from the root-mean-square deviation (rms) of the differences of the gravity misties at line intersections. For the regional surveys over the north-west shelf the rms values varied from about 4 mGal in 1965 to about 2 mGal in 1968. On the survey of the continental margins the rms differences were about 6 mGal. The lower precision of this survey is largely due to a decrease in the precision with which the parameters affecting gravity could be measured in deep water (for instance, unknown ocean currents reduce the positioning accuracy).

There are two known small systematic errors in the anomalies:

1. the mean Australian milligal scale is now known to be smaller than the absolute scale by about 5 parts in 10^4, and
2. anomalies on the Potsdam system using the 1930 normal gravity formula differ from anomalies on present world standards because of an improved reference ellipsoid, which was adopted in 1967; and a revised international datum for observed gravity, which was adopted in 1971.

The correction C in milligals to the mapped anomaly at any point X is given by:

$$C = \text{Anomaly}\,(1967/71) - \text{Anomaly}\,(1930/65) \quad \ldots \textbf{(4)}$$

where Anomaly (1967/71) is calculated with 1971 datum and scale, and the 1967 ellipsoid; and Anomaly (1930/65) is calculated with the 1930 ellipsoid and the 1965 datum and scale.

Since the free-air and Bouguer corrections are the same in both systems we can write:

$$C = [g_o(1971) - g_n(1967)] - [g_o(1965) - g_n(1930)] \quad \ldots\ \textbf{(5)}$$

$$= [g_o(1971) - g_o(1965)] - [g_n(1967) - g_n(1930)] \quad \ldots\ \textbf{(6)}$$

$$\text{Now } g_n = \gamma_e\,(1 + A\sin^2\phi + B\sin^2 2\phi) \quad \ldots\ \textbf{(7)}$$

where γ_e = equatorial gravity
= 978 049.0 (1930) or 978 031.8 (1967)
A = 0.005 288.4 (1930) or 0.005 302.4 (1967)
B = 0.000 005.9 (1930 and 1967)
the values for the coefficients are taken from Coron (1972).

Hence

$$g_n(1967) - g_n(1930) = -17.2 + 13.6\sin^2\phi \quad \ldots\ \textbf{(8)}$$

Also

$[g_o(1971) - g_o(1965)]$ at X = $[g_o(1971) - g_o(1965)]$ at Sydney
+ $[\Delta g(1971) - \Delta g(1965)]$ for X−Sydney
$= -13.88 - b.\Delta g\,(1971)$ .... **(9)**

Where 1 + b is the scale correction factor
and $b = -5.08 \times 10^{-4}$ (Wellman *et al.*, 1974)

Neglecting differences in g_o caused be elevation and geological differences we get

$$g_o \approx g_n = \gamma_e\,(1 + A\sin^2\phi + B\sin^2 2\phi) \quad \ldots\ \textbf{(10)}$$

$$\Delta g \text{ for } (X - \text{Sydney}) = \gamma_e A(\sin^2\phi_X - \sin^2\phi_{\text{Sydney}}) \quad \ldots\ \textbf{(11)}$$

Neglecting the terms in $b\gamma$, and ${}_eB$ we get

$$g_o(1971) - g_o(1965) = -13.88 + 2.63\sin^2\phi_X - 0.82 \quad \ldots\ \textbf{(12)}$$

$$= -14.70 + 2.63\sin^2\phi_X \quad \ldots\ \textbf{(13)}$$

Substituting **(8)** and **(13)** in **(6)** we finally get

$$\mathbf{C} = 2.5 - 11.0\sin^2\phi \quad \ldots\ \textbf{(14)}$$

Processing the data

The programs used to compile the map are based on those described by Murray (1974). These search several files for data in specified areas; sort the data into an appropriate form, and then plot the station positions and contour the gravity values. Editing facilities are available in the sort package to add, remove or amend the data. These programs have been modified and improved since a Cyber 76 computer system became available late in 1973. The Cyber system provided the capacity for large on-line data storage and fast processing (1.2 million characters of central processor core memory and 32.5 million characters of on-line disc memory), which was essential for the production of the map.

The first stage of processing involved extracting data from the computer files, survey by survey, and checking the station locations, the elevation, observed gravity, and Bouguer anomaly values. Each survey was then stored separately pending the accumulation of sufficient data to form an aggregate file. Aggregate files of up to 50 000 observations were then formed by concatenating several surveys. Next, they were plotted to ascertain the station coverage.

During the second processing stage four files corresponding to a four-fold division of Australia along 24°S and 132°E were created; each file had a manageable size of less than 100 000 observations.

During the third stage, data in each sector file was checked to eliminate errors. The files were first sorted to eliminate duplicates, and then plotted to check the final station coverage. Each sector was then contoured using a program which did not smooth the data, and errors thus detected were rectified. The final checking involved contouring and listing principal facts in 1:1 000 000 map areas; these maps provide a complete gravity coverage of the Australian region at the same scale and projections as the World Aeronautical Charts, ICAO series. The final data bank used for the 1:5 000 000 map consisted of about 260 000 land and marine gravity observations as shown on Figure 1.

Smoothing and contouring gravity anomalies

The first step in preparing the contours was to generate an approximately square reference grid, over the whole map area, with a spacing of about 6 minutes of arc. Each grid point was assigned a value equal to the average of all observations lying within the grid square centred on the point. Grid points having no observations within their grid square were assigned a value equal to that of the nearest grid point based on observations. The extrapolation of grid values to areas without data extended to one degree to enable small offshore gaps to be contoured.

The values on the grid were then smoothed to produce a surface of minimum curvature using the iterative method described by Briggs (1974). The method of drawing contour lines from the gridded values involved a four-point cubic interpolation between grid points to find contour cuts, and then a cubic spline to fit the cuts. Because the contour lines were based on the computed grid values and not directly on the anomaly values, they were precise to only about half a grid spacing, or about 3 minutes of arc.

The base map was scribed on a flatbed plotter using data provided by Division of National Mapping, Department of National Resources. The gravity contours were produced in several sections on a drum plotter; map compilation, final hand-scribed contours, and colour-separation masks were prepared in the Geophysical Branch Drawing Office.

The completed map is at the same scale and projection as the Tectonic Map of Australia and New Guinea 1971, and the Geological Map of the World—Australia and Oceania, 1965-1967—prepared on behalf of the Commission for the Geological Map of the World.

To produce the coloured 1:25 000 000 Bouguer and free-air maps presented in this issue, observations from the Gulf Rex were added to the data bank to fill gaps in the Coral and Arafura Seas. The free-air map was prepared from an unpublished 1:2 500 000 map and the Bouguer/free-air map was prepared from the 1:5 000 000 gravity map.

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