Paper 10

Gravity Mapping in Australia

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ABSTRACT

In the late 1950's the Geology and Geophysics Division of the Australian Bureau of Mineral Resources (now Geoscience Australia) commenced a program to obtain systematic gravity mapping coverage of Australia at the scale of 1:250 000. The coverage was primarily for oil exploration. In order to delineate sedimentary basins of Australia and to determine the potential depths of the sediments, *Bouguer anomaly* maps were envisaged.

To accomplish this task, a systematic grid of gravity stations at approximately 10 km intervals was proposed. As each gravity station had to have its height above sea level, a series of precisely levelled traverses had to cover the whole of the continent. Levelling data was readily available in inhabited areas but the biggest problem was Australian remote areas, particularly deserts.

The Lands and Survey Branch of the then Commonwealth Department of the Interior established levelled traverses through the Canning and Simpson Deserts. Barometric levelling was used for height determination for individual gravity stations.

Helicopters were used as a means of transportation between the gravity stations and aerial photography was the only data source available for determining their geographic positions.

This paper describes the procedures involved and the survey of the Canning Basin, W.A. in 1960.

BIOGRAPHICAL NOTE

Miervaldis (John) Balodis was born in Riga, Latvia in 1921 but moved to Germany during the Second World War where he received accreditation as a surveyor. In 1951 he arrived in Australia and commenced work with the NSW Forestry Commission where he was involved in forest surveys and mapping. Between 1953 and 1956 he worked with the Bureau of Mineral Resources in Melbourne where as OIC of the Gravity Mapping Section he was responsible for the 1:250,000 series Australian gravity mapping program. Following a transfer to Canberra he was involved in the design of the prototype Tectonic Map of the World which was subsequently adopted by the International Geological Commission.

In 1966 he moved to Perth to commence an academic career which culminated with his appointment as an Associate Professor in Cartography at the Curtin University of Technology in 1993. He obtained a Master of Science degree in cartography at the University of Wisconsin, USA, in 1975 and has undertaken several assignments as a consultant in cartography and geodesy in Canada and Latvia. Over the years he has written articles for 52 publications in Australia, Canada and Latvia and presented papers at many Australian and International conferences.

John is a Fellow of the Mapping Sciences Institute, Australia, a Fellow of the Royal Geographical Society, a Fellow of the American Congress of Surveying & Mapping, and a Member of the Institution of Surveyors Australia, and the British Institute of Cartographers.

GRAVITY MAPPING IN AUSTRALIA

Introduction

Resulting from decisions made in the late 1950's by relevant Australian Government authorities, systematic gravity surveys were to cover the mainland of Australia. The primary objective was to obtain gravity data for sedimentary basins. The Canning Basin in Western Australia received top priority. The planning of the continental survey envisaged a 7x7 mile (approximately 10x10 km) grid of gravity stations.

Acknowledgements

This is a belated recognition and tribute to those staff members of the then Bureau of Mineral Resources, Geology and Geophysics who, under the cover of anonymity as public servants often created ingenious and unique solutions to geophysical problems. One of these was to undertake gravity surveys using helicopters as a means of transportation of personnel and equipment from one gravity station to another. With a minimum of surveying and mapping back-up and with problems associated with continuously fluctuating instrument behaviour due to the ascending and descending helicopter, the working parties evaluated the possibilities and found satisfactory practical solutions.

The first helicopter-assisted gravity and geological survey over a limited area in the Canning Basin, W.A. was done by S. Waterlander and J. Weevers in 1957, followed by second one in North Queensland by S. Waterlander and J. Hussin in 1959.

The working party associated with the first attempt in continental survey coverage resolved a number of problems regarding the systematic presentation of gravity data. The initial idea was a joint effort by three geophysicists - Keith Vale, Gerhard Neumann and James "Jim" Dooley. The idea was transformed into reality mainly by Leslie "Les" Williams, James "Jim" Goodspeed, Lynn McN Hastie, Alan Flavelle, Malcolm Reid and Brian Barlow.

Alan Flavelle deserves particular recognition. He was participating in the survey discussed in this paper, and, at a later date, as a geophysicist-in-charge for another operation involving a team of geophysicists, mapping personnel, helicopter pilots, technical and other support staff and accompanying family members, including children + two helicopters, a number of support vehicles and accommodation facilities. His organizational and logistics ability made helicopter-assisted gravity surveys an internationally accepted venture.

I also gratefully acknowledge the assistance of my daughter Gita Pupedis, Lecturer at the RMIT University for the proofreading of this paper and technical help.

Logistics

As there was no precedent for such a survey, a working group was established. The present author was entrusted with the responsibility for the layout and design of a standard gravity map as well as the initial field procedures, including helicopter navigation, for mapping.

A Bell G2 helicopter was used for the transport of personnel and equipment from one gravity station to another. Other support vehicles included International 4-wheel drive trucks, a large truck for camping equipment, a water truck, several Land Rover 4-wheel drive vehicles and a Bombardier caterpillar drive vehicle.

Before the commencement of the survey, a number of field base stations were selected so that from each an area of approximately 20,000 km could be covered. A DC3 transport plane dropped drums of petrol and aviation fuel at those stations. The station positions were marked on aerial photographs that were available for the whole of the Canning Basin.

Methodology

10x10 km grid intersections were marked on aerial photographs. Using a gravity meter, the gravity reading was made at each grid intersection, or a position close to it if terrain conditions did not allow the landing of the helicopter precisely on the station. Since gravity depends on latitude and the elevation of the position, the then Survey Section of the Commonwealth Department of the Interior provided a network of levelled traverses throughout the Canning Basin. A microbarometer reading at each station allowed the calculation of elevation of the position relative to the reference datum. The latitude was measured from existing mapped information and aerial photography. A series of astronomical fixations helped to establish the "sheet corner coordinates" (the corners of standard 1:250 000 map sheets or, as they were at that time 4 miles to an inch or 1:253 440).

Classification of existing gravity surveys

Before continental coverage was commenced, a number of localized gravity surveys were carried out in different parts of Australia. Relative to their purpose and scope, Goodspeed (1961) classified these as:

- regional
- reconnaissance
- semi-detailed
- detailed

Regional survey - is designed to cover an area with as many traverses as conveniently possible, in view of access difficulties, without covering any part of it in much greater detail than any other. The aim is to obtain a broad picture of gravity variations over the area, for correction of later more detailed survey results and to deduce the broad features causing these variations.

Reconnaissance survey - is designed to cover an area with a regularly spaced grid, or as close to this as possible in view of access difficulties. It is assumed that not enough is known of the geology to make any other type of survey possible, but it is implied that there is an expectation that features of interest will be detected, for later more detailed survey, if warranted.

Semi-detailed survey - the traverses are laid out so as to give a broad picture of gravity variations over a known feature or features. The feature may be known from geology, other geophysical methods, or an earlier reconnaissance gravity survey. The aim is to obtain sufficient detail to be able to formulate hypothesis about the underlying structure causing it, which can be tested by later detailed survey, if this is considered warranted.

Detailed survey - traverses are laid out so as to give all information needed to test the hypothesis as to the structures producing a known feature, or to measure the parameters (depth, thickness, shape etc.) of a structure that has been proved in broad outline.

All these surveys were integrated into Australia- wide coverage.

Gravity Anomaly

A theoretical value of gravity may be computed at any point on the earth's surface if the earth were a regular surface without mountains or oceans, and without variations of rock density. The theoretical value is a combined effect of the centrifugal (due to earth's rotation) and gravitational forces. The theoretical value of gravity is a function of the size and shape of the ellipsoid and varies with the latitude at a point of observation.

A gravity anomaly is the difference between observed and theoretical gravity at a point of observation. Observed gravity has to be reduced to the level of the geoid, or mean sea level (MSL) therefore the elevation at a point and the mass between the point and the MSL has to be taken into account. Accurate vertical and horizontal control is, therefore, essential.

To differentiate the gravity "highs" and gravity "lows" (changes in rock densities as against the average density), a series of Bouguer anomaly maps was envisaged.

Bouguer Anomaly

The gravity maps were expressed in terms of isogals of Bouguer anomalies. Schlumberger (2006) defines a Bouguer anomaly as "the remaining value of gravitational attraction after accounting for the theoretical gravitational attraction, the point of measurement, latitude, elevation, the Bouguer correction and the free-air correction which compensates for height above sea level assuming there is only air between the measurement station and sea level. This anomaly is named for Pierre Bouguer, a French mathematician (1698 to 1758) who demonstrated that gravitational attraction decreases with altitude". This leads immediately onto the Bouguer correction.

Bouguer correction (Schlumberger, 2006)

"The adjustment to a measurement of gravitational acceleration to account for elevation and the density of rock between the measurement station and a reference level. It can be expressed mathematically as the product of the density of the rock, the height relative to sea level or another reference, and constant units of mGal (milligals):

0.14185 qh,
where q = rock density in kg/m3
h = height difference between two locations in m

Strictly interpreted, the Bouguer correction is added to the known value of gravity at the reference station to predict the value of gravity at the measurement level. The difference between the actual value and the predicted value is the gravity anomaly, which results from differences in density between the actual Earth and reference model anywhere below the measurement station".

Availability of Data

The following survey data was used for the preparation of 1:250 000 base maps:

- aerial photography (usually at 1:46 500 or 1:85 000 nominal scale)

- controlled or semi-controlled air-photoscale compilations at various scales (slotted template assemblies)

- field notes, maps, sketches, station descriptions

- Department of the Interior, Lands and Survey Branch 4-mile gravity surface control maps showing surveyed gravity station positions and level data

- uncontrolled or semi-controlled 4-mile photomosaics and 1-mile photo indices.

Reliability of Information

The reliability of basic information was accepted as stated on the original compilations and could not be improved on final gravity maps. The reliability was stated on each and every gravity map.

Map Design

The map had to be designed mainly for the use of specialists in the fields of geoscience under the following guidelines:

a. final presentation in black-and-white
b. original compilation at 1:250 000 scale
c. only minimal amount of natural and cultural features to be shown
d. maintain clarity after reduction from 1:250 000 to 1:500 000
e. ready in minimum time (about 4-8 weeks) after the completion of survey, producing an average of thirty 1:250 000 maps a year

Bearing in mind that, at the time of survey, some 45 years ago, all maps had to be prepared and drawn by hand, the maintenance of uniform presentation and clarity was essential.

Robinson (1960) suggested that "this can be achieved by evaluation of given data by combination with other elements in terms of its probable effects on the map reader. To do this requires a full and complete understanding of the purpose or purposes of the map to be made".

Design Features

a. contrast was achieved by using various lineweights
b. topographic and cultural features were shown only to locate or correlate gravity data
c. the title block contained all essential data confined in minimal space
d. lineweights and lettering established experimentally to stand half reduction
e. gravity station positions - small circles for non-permanent stations, double circles for semi-permanent stations
f. gravity station number and elevation
g. gravity variation expressed as isogals of Bouguer anomalies.

The final 1:500 000 version is attached as Appendix 1.

Mapping Procedure

Various stages of 1:250 000 map compilation are illustrated in the flow diagram below (Fig. 1).

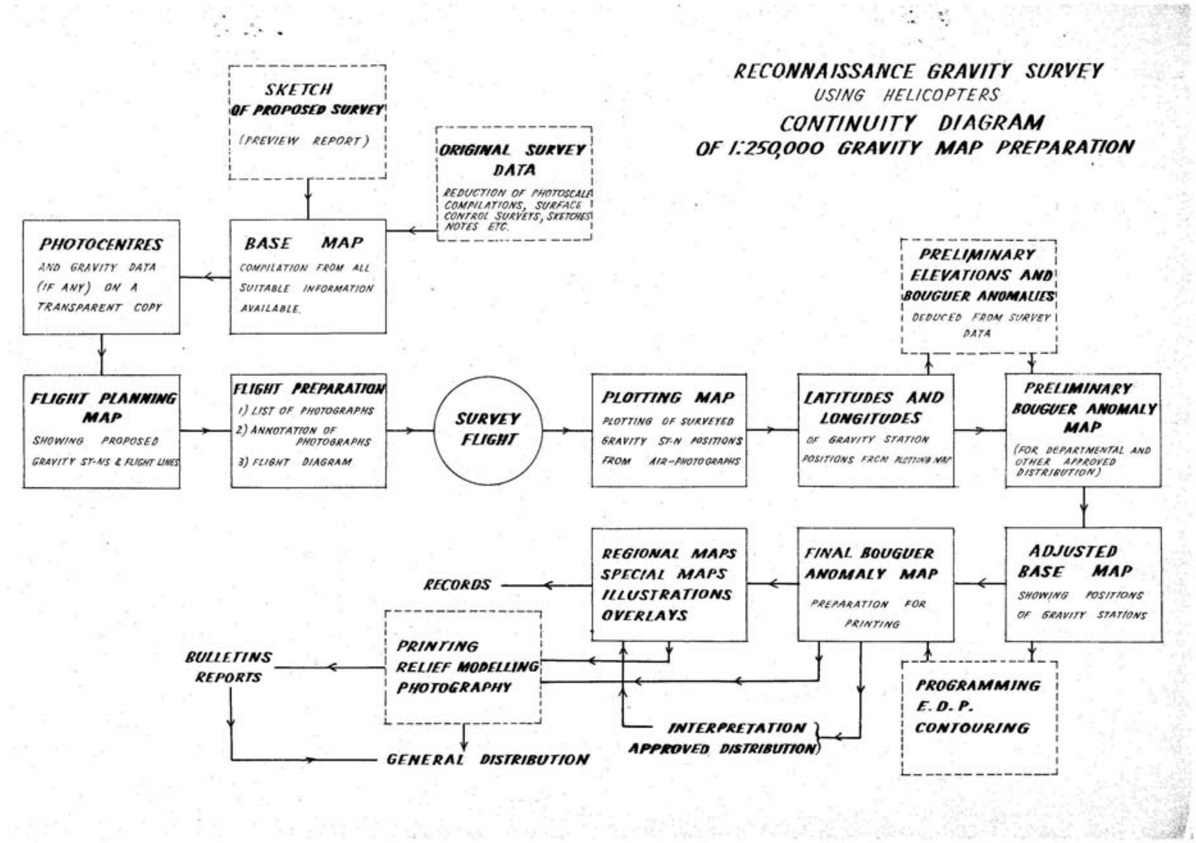


Figure 1

1. Base Mapping

1.1 The base grid and graticule were prepared on a stable drawing base at 1:250 000 in Australian Series Transverse Mercator projection based on Clarke's 1858 spheroid. The 10000 yard grid tables from the Australian Military Survey authorities, generally described as "sheet corner coordinates" were used.

1.2 Slotted template assemblies (photoscale compilations usually by National Mapping, Royal Australian Survey Corps and State mapping agencies) were reduced to 1:250 000 scale either photographically or by the pantograph, whichever was more practicable. Higher accuracy was obtained by using the pantograph. However, if too much detail was involved, photographic reduction was used. Wire-suspended ARISTO precision pantograph No 1227 was used.

1.3 Gravity surface control data (surveyed gravity station positions and levelling information), prepared by the Lands and Survey Branch, Department of the Interior was then plotted on the base grid.

1.4 Generalisation of detail (horizontal control, topographic and cultural features) was coordinated with the geophysical staff members.

1.5 The base map was then fair-drawn on a stable polyester base such as .003" Permatrace (both sides matt) or Cronaflex.

1.6 A transparent copy on a polyester base (Ozafilm) was made from the base map. The photocentres were plotted on this map from the photoscale compilations. This map was titled as a "flight planning map" only as long as the flight planning was completed. The same map was then used in the field for the plotting of gravity station positions. Finally it became a "preliminary Bouguer anomaly map" after interpolating contours at 5 milligal intervals, drawn in pencil. The complete procedure is described later.

2. Aerial Photography

Complete aerial photo coverage was required for each 1:250 000 map. The photocentres of two adjacent air photographs were transferred on each photograph and indicated with a pin-prick and circled. All photographs were labelled and separated for each run.

3. Photomosaics and Assemblies

One linen-mounted copy of a photomosaic or a photo assembly for each 1:250 000 map area was required in the field office as part of the basic information. The mosaics available were usually at the scale of four miles to one inch (1:253 440), and photo assemblies, generally known as photo indices, at the scale of one mile to one inch (1:63 360).

Previously described operations were carried out at Head Office, before the commencement of the survey.

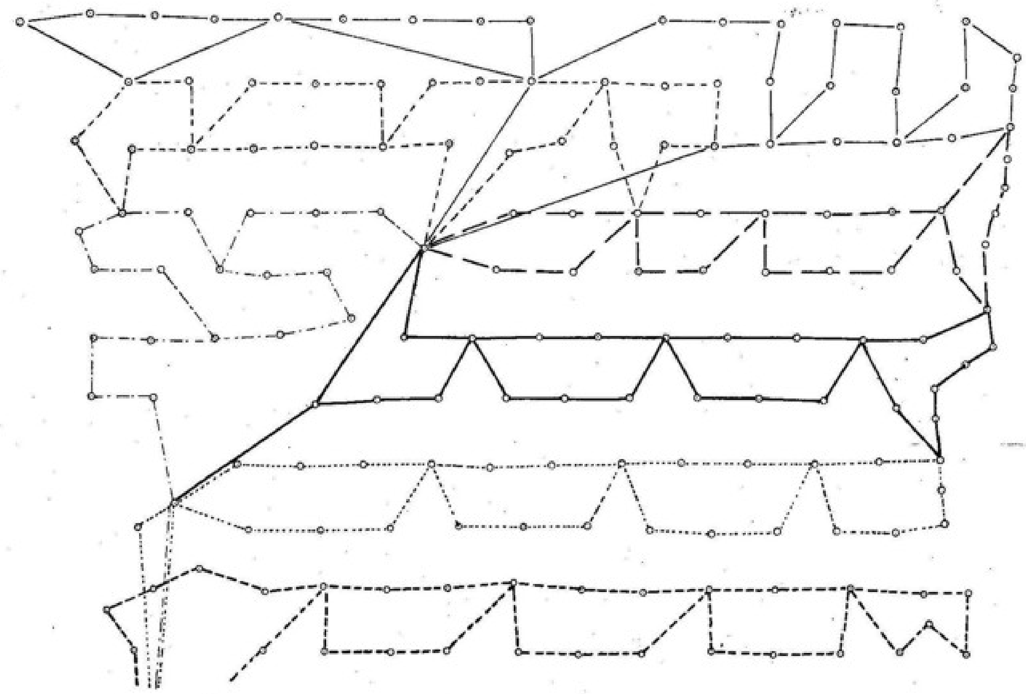
Field Procedures

1. Flying Methods

An approximate 7x7 mile (10x10) km grid was plotted on the planning map. Each grid intersection was a gravity station. The stations were connected with a proposed flight line. Originally a "line" method (Fig. 2a) was envisaged for helicopter flights because they followed the pattern of the flight lines of original aerial photography. However, the time intervals for each line flight kept increasing in relation to the periodic base barometer reading thus introducing additional error. Although a more difficult flying pattern was caused by the "cell" method of flying (McN.Hastie et. al. 1962) (Fig. 2b), the flight time intervals for each cell in relation to base barometer readings were more uniform and, therefore, more accurate.

Relevant aerial photographs were selected from the flight planning map for each flight. They served a dual purpose - for visual navigation of the flight path and for the marking of the gravity station positions.

A. LINE METHOD OF FLIGHT PLAN



B. CELL METHOD OF FLIGHT PLAN

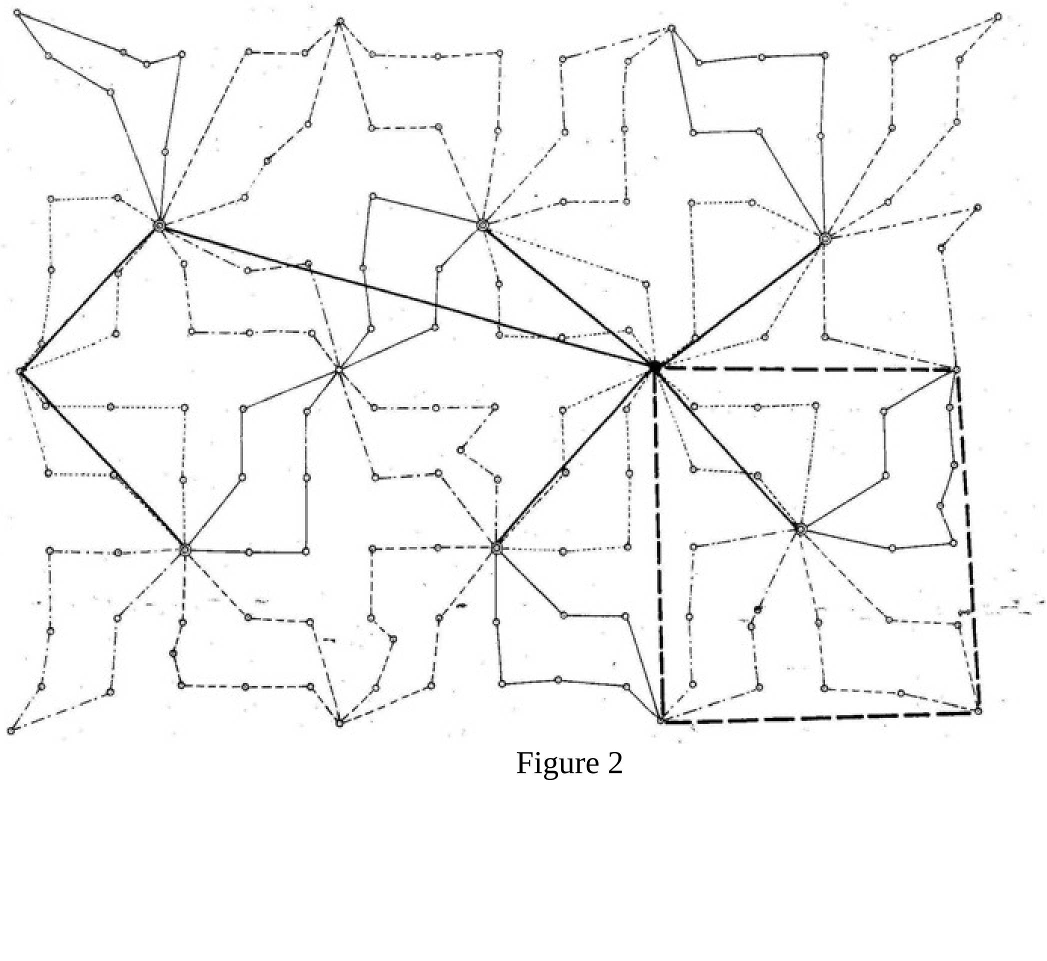


Figure 2

2. Recording and Mapping Procedures

a. The identification of gravity stations had to be limited to seven figure numbers for data processing in a computer (UNIVAC). However, the final map could not be overcrowded with figures, therefore the system of numbering differed on the map and the computation sheets as follows:

> Gravity stations with absolute elevation values were marked with traverse number and station number e.g. gravity station 81-2 on the map was shown as 1008102 on the computation sheets. Similar notation was used for helicopter gravity stations and for those gravity stations whose elevations had been computed from microbarometer readings. Assuming a four-figure number was used for each year's survey, the gravity station 1 on the map was shown as 620001 on the computation sheets, the first two figures indicating the year of survey. This was essential to avoid repetition of station numbers in marginal areas from previous surveys.
>
> Gravity station numbering for each sheet commenced from the north-west corner of the 1:250 000 map continuing towards the south-east, generally following the flight plan. Separate flights were numbered as required in each case.

b. Gravity station positions were connected with proposed flight lines, base camps, fly camps and repeat gravity stations were indicated.

c. A list of photographs was prepared for each flight. This was essential in case of repeat flights being required (because of erroneous readings of gravity or barometer, sharp local variations of gravity, erratic behaviour of instruments etc.). The list was prepared from the flight planning map.

d. Selection of required air-photographs from the list (only odd air photographs were selected as the normal 60% overlap was not essential for air navigation and/or positioning). The remaining air-photographs were kept as back-up in case of the helicopter running into difficulty during the survey.

e. Matching the air-photos and marking the overlap was done with coloured grease pencil. The preceding photograph always covered the adjacent one (Fig. 3). This was to ensure correct flight sequence as the gravity flight line did not coincide with the original flight when the photographs were taken. Flight directions were indicated on air-photos.

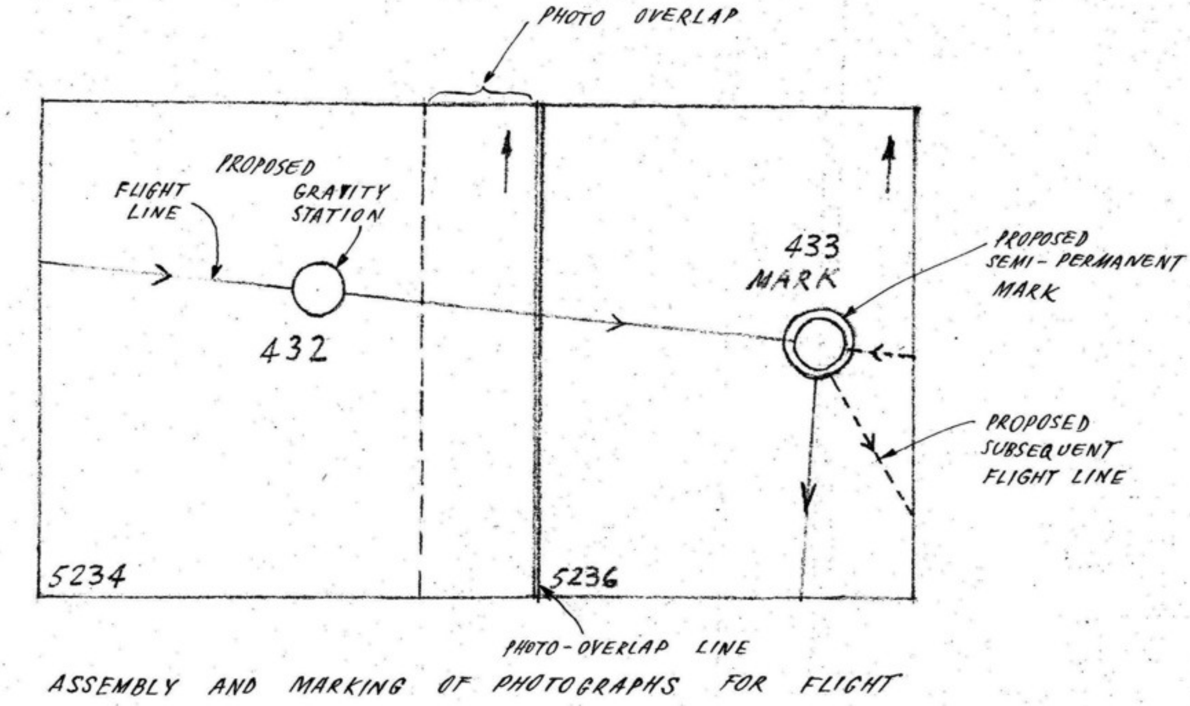


Figure 3

3. Selection of Gravity Station Positions

The station positions on air-photos were determined from the flight planning map. However, readily recognizable terrain conditions nearest to the plotted position were taken into account. In desert areas where the first helicopter gravity surveys were executed, relief is relatively monotonous - mainly sand dunes interrupted by relatively few rock outcrops, a few dry creek beds and very few waterholes. Longitudinal sand dunes and sand ridges were by far the dominant features. Patches of mulga, spinifex and other desert vegetation helped with position recognition on the ground. The worst terrain feature for positioning was a continuous sandy plain with few recognizable features.

If the gravity station position on the air-photo could not be positively identified from the flight planning map, the general guidelines for the selection of the position were as follows:

a. Sandy or stony desert plains

Even a minor change of relief which could be recognizable in the field could be used as a station position.
Depressions whose outlines could be recognized on air-photos.
Vegetation, (particularly if the air photo was of relatively recent date).
Any type of discolouration on the air-photo that could be recognized in the field.

b. Longitudinal sand dunes

These could be easily confused, particularly where the path of the helicopter flight followed across the dunes. Their recognition in the field, however, was not difficult, particularly in

sections where they were broken, had been disrupted or flattened (Fig. 4). The station position was selected at or near the end of the point of sand dune disruption.
In all cases, the selection of the gravity station position should conform with the surrounding general elevation of the area because both gravity meter and microbarometer readings require appropriate corrections for terrain and local barometric pressure effects.

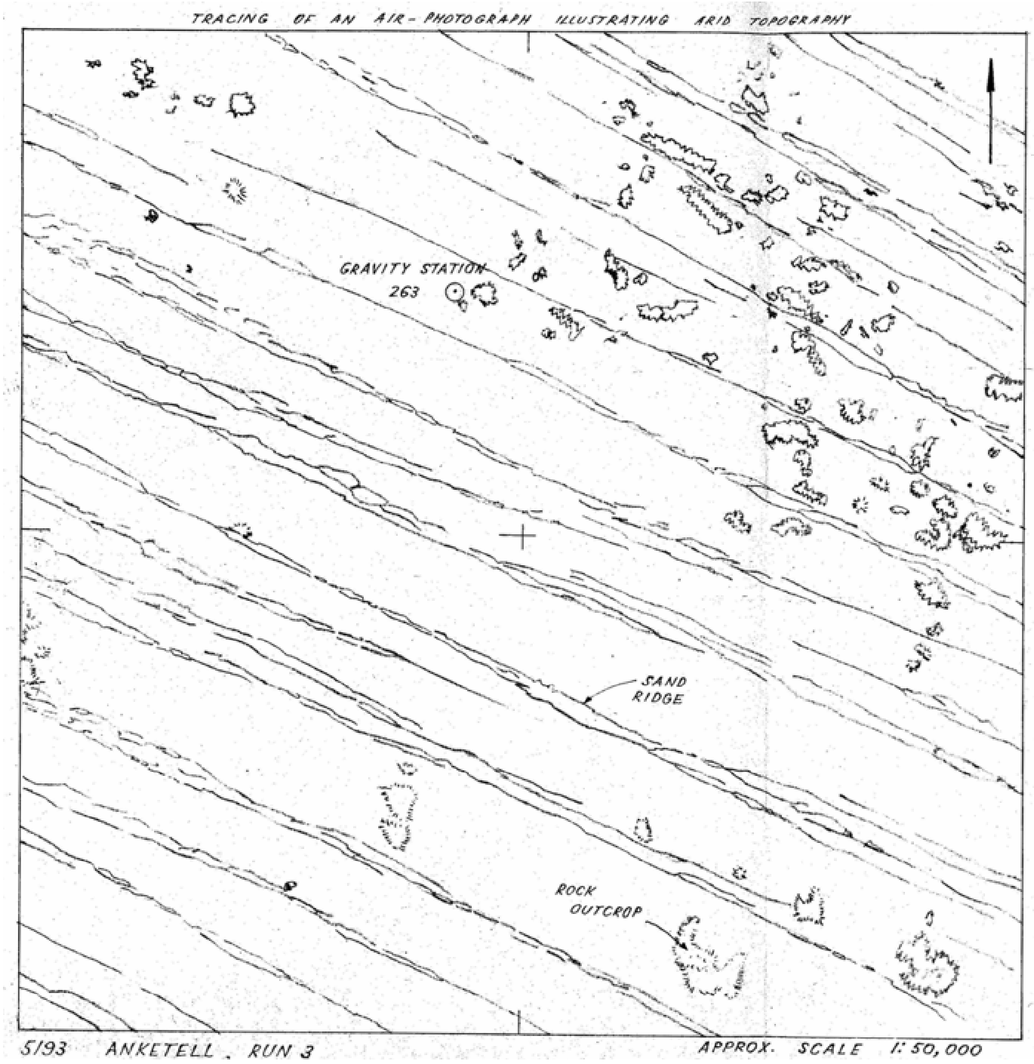


Figure 4

c. <u>Other areas</u>

Whilst this particular survey did not encounter areas other than desert, the planning considered forest areas where the station sites should be sufficiently large for helicopter operation. The undergrowth in open forest areas may not be recognizable from air-photos and could interfere with helicopter operation. In dense forests, the cutting of heliports could be required (Nettleton et. al. 1960). He also suggested that helicopter should be provided with appropriate landing equipment in swampy areas.
In cultivated and/or grazing areas, the best positions of gravity station sites are near road, railway, watercourse and fence intersections.

In all cases, the two most important aspects in visual air navigation and gravity station position recognition were, firstly that the air photos were taken from a great height (depending upon the air photo scale, say 5 000 – 10 000 m) and the helicopter was flown at the height of 150-350 m, therefore the navigator had to reconcile these differences, and, secondly, the date of air photographs. If the photo was older than, say, five years, the chances were that the desert features had substantial changes not only in loose sand dune configuration but also in ground discolouration and vegetation. In areas of significant cultural features, the changes could even be more substantial.

After consideration of conditions in 3. a, b, and c, the proposed gravity station was then marked on the air-photo with an approximate 2 cm diameter circle and numbered appropriately.

4. Permanent Marking of Air-photos and Data Verification

The navigator and/or gravity meter reader marked the location of the gravity station on the air-photo with a pin-prick. That was done during the helicopter landing. In doubtful cases, the nearest approximation of the position was indicated in the field book and an appropriate note made on the back of the air-photo.

Semi-permanent ground marks indicated those gravity stations requiring repeat readings. Such stations were shown with different symbols.

After the completion of the flight, the air photos were returned to the field drawing office. The actual station numbers were verified against the field book and the proposed numbers. The station number as it appeared on the final map was marked on the back of the air-photo as follows:

1223
*
BMR GRAVITY STATION 1962

A list of gravity stations and the total daily mileage was then recorded for each day's flight. The order of gravity station numbers entered on barometric height and gravity computation sheets had to be reconciled with the actual flight order.

5. Plotting of Gravity Station Positions

a. <u>Procedure</u>
From air-photos of completed flights, the gravity stations were plotted on a 1:250 000 photocentre map. Each station was plotted from at least two nearest and adjacent photocentres and, in doubtful cases, also from the closest photocentre of the adjacent run. The point of intersection of the distance between the gravity station position and two adjacent photocentres would be the nearest approximation to the true position of the gravity station. This method, whilst theoretically not acceptable, was sufficient for all practical purposes.

b. <u>Accuracies</u>

The size of a pin-prick at 1:46 500 or the photo scale, assuming the diameter of an average pin prick being 1/70" (0.36 mm) represents 55.3 ft (16.86 m) of actual distance. The same pin-prick at 1:250 000 scale assuming the average diameter of a pin-prick on a polyester plotting base, 1/150" equals 46.3 yards (42.34 m). The size of an average circle representing the position of a gravity station on final map is 1/25" (1 mm) diameter or 277.6 yards (253.99m) on a 1:250 000 map. Furthermore, the required latitude reading accuracy to the tenth of a minute of an arc of latitude at 1:250 000 scale amounts to 183.25 m in actual distance.

The accuracy of the final Bouguer values, which is a different problem from that of mapping, will not be discussed, but it is assumed that the standard error may be somewhat between one and two milligals (Flavelle, 1962).

c. <u>Latitude and Longitude Values</u>
The values of latitude and longitude for each gravity station were measured from the plotting sheet by transparent graphical Transverse Mercator projection latitude / longitude scale. The values were estimated to the nearest tenth of a minute of an arc of latitude and longitude and entered in a gravity survey computation form.

The verification and checking of each step of previously outlined procedures was absolutely essential.

6. Preliminary Bouguer Anomaly Map

After reduction of Bouguer anomalies (Dobrin, 1952, Heiskanen et. al, 1958, Nettleton, 1940 and others), the preliminary Bouguer anomaly values are shown on the map with plotted and numbered gravity stations in terms of isogals. General principles of contouring have been described by Clark (1950), Robinson (1960), Ferrand (1962). The contouring was done in pencil on a paper copy of a plotting sheet with the contour interval of 5 milligals that was adopted for all 1:250 000 gravity maps.

Ferrand (1961) suggested: "We do not think it is safe to use a contour spacing smaller than, at least 4Ea where Ea is an error on Bouguer anomaly".

Final Bouguer Anomaly Map

After verification and adjusting all quantities measured and calculated, the final Bouguer anomaly map was prepared.

The original base map was checked against all reliable information available. All amendments and the date of revision were shown. Gravity station positions were transferred from the original field plotting sheet to the base map, including station numbers with their respective values.

The title block was designed separately so that one title block could be used for all maps, leaving a blank space where required to allow for the differences in text on each map.

An Ozafilm copy was made of each base map combined with the title block. After checking and editing all data, the isogams of Bouguer anomalies were incorporated and the final map fair-drawn on the combined Ozafilm copy.

Printing

For the distribution of Bouguer anomaly maps to approved users, the maps were printed at 1:250 000 scale. Normally this applied to the final maps only; the exceptions being those preliminary maps whose completion could not be possible within the foreseeable future.

The arrangements at that time were that the negatives and plates were made by private contractors in Melbourne and the printing was done by the Division of National Mapping, Canberra.

Procedure

a. Black paper print was made from the fair-drawing on the Ozafilm.

b. The print was altered to show printing (1:500 000) scale on the left upper corner and touched-up where necessary.

c. Appropriate scale reduction was made.

d. A 15x18" (381x457 mm) continuous tone film negative was made from the print by the contractor.

e. The negative was checked and amended, if required.

f. A plate was made by the contractor.

g. The required number of copies were printed.

Alternative Method for the Plotting of Gravity Stations

This method was applicable only in those areas where controlled or semi-controlled photoscale compilations were not available.

The gravity station positions from air-photos were plotted on an uncontrolled or semi-controlled photomosaic, usually at the scale of 4 miles to 1 inch (1:253 440).

The positions of all features known by their geographical position (e.g. trigonometrical stations, astronomical fixations, fence corners, railway stations etc) were identified on air-photos and subsequently plotted on a photomosaic. A network of known positions was thus obtained.

The distances between known stations were computed and compared with the mean scale of actual distances on the photomosaic. The approximation of graphical positioning of appropriate meridians and parallels (e.g. 15' interval for 1:250 000 maps) became possible.

The resulting meridians and parallels on the mosaic did not necessarily correspond to their true positions (Fig. 5a). The lines could be distorted (Fig. 5b) in most cases. The reliability of the positioning of meridians and parallels depended upon the number and distribution of known control points on any 1:250 000 map area.

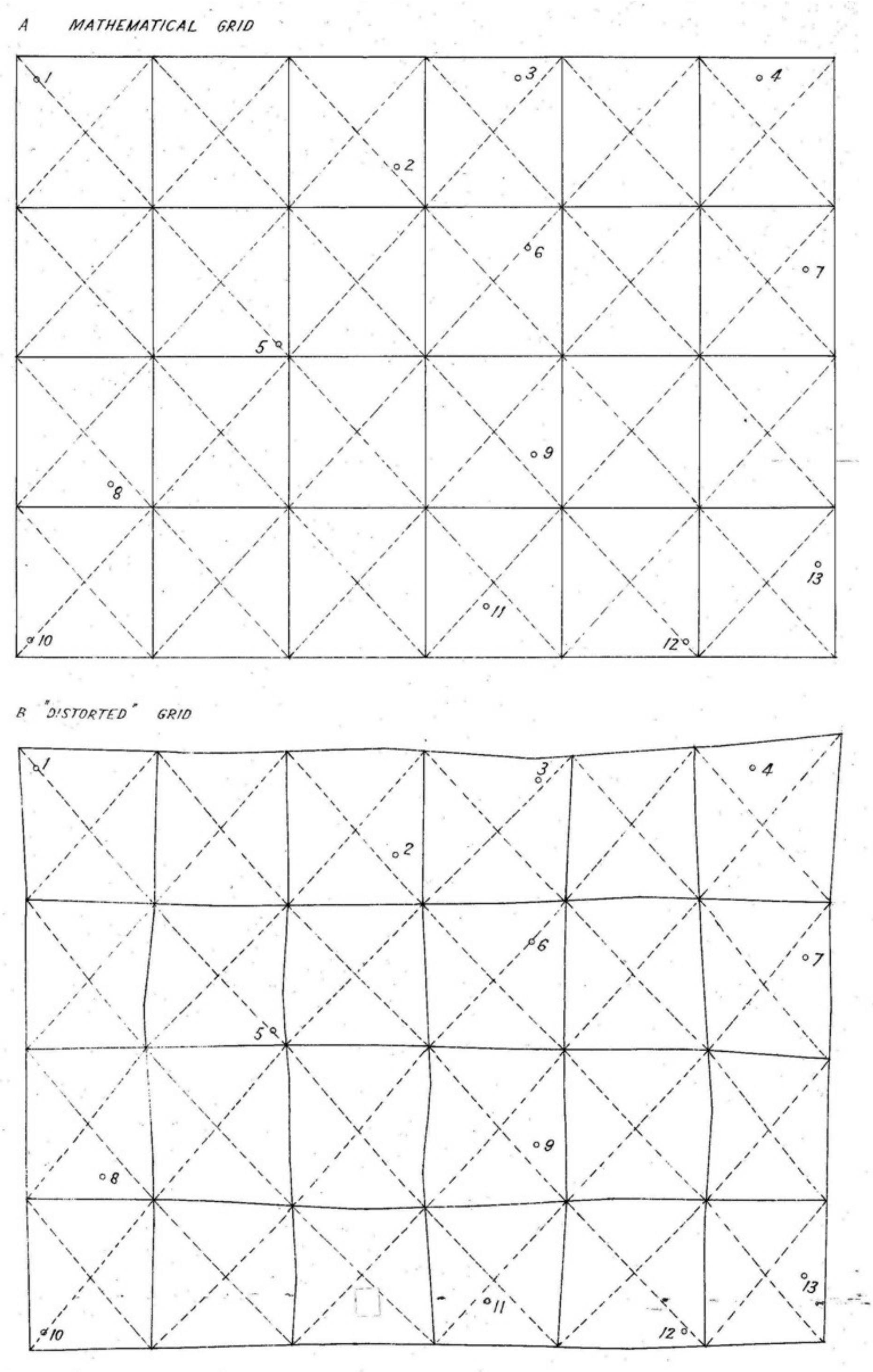


Figure 5

The polygons between the established graticule on the photomosaic were connected by diagonals as illustrated in Fig. 5 and the gravity station positions plotted on 4-mile photomosaics from air-photos within the areas divided by graticules and diagonals were transferred to accurate graticule by graphical adjustment of the gravity station positions relative to surrounding grid lines.

This "distorted graticule" (as it was called "distorted grid") method, without having any appeal from either a mathematical or survey point of view, worked out quite satisfactorily within the limits of reconnaissance and regional gravity survey positioning requirements.

The results of controlled photocentre plot and "distorted graticule" of the same area were compared. No significant change in the resulting Bouguer anomaly pattern was observed.

Reference to Trade Names

Reference to trade names or trade marks carries no implication of preference and/or quality of their products.

CONCLUSION

Gravity surveys using helicopters as rapid transportation from one gravity station to another were singularly successful in the production of Bouguer anomaly maps. This method was developed in Australia and later adopted internationally. A significant part of the Earth's surface is now covered by maps showing gravitational data.

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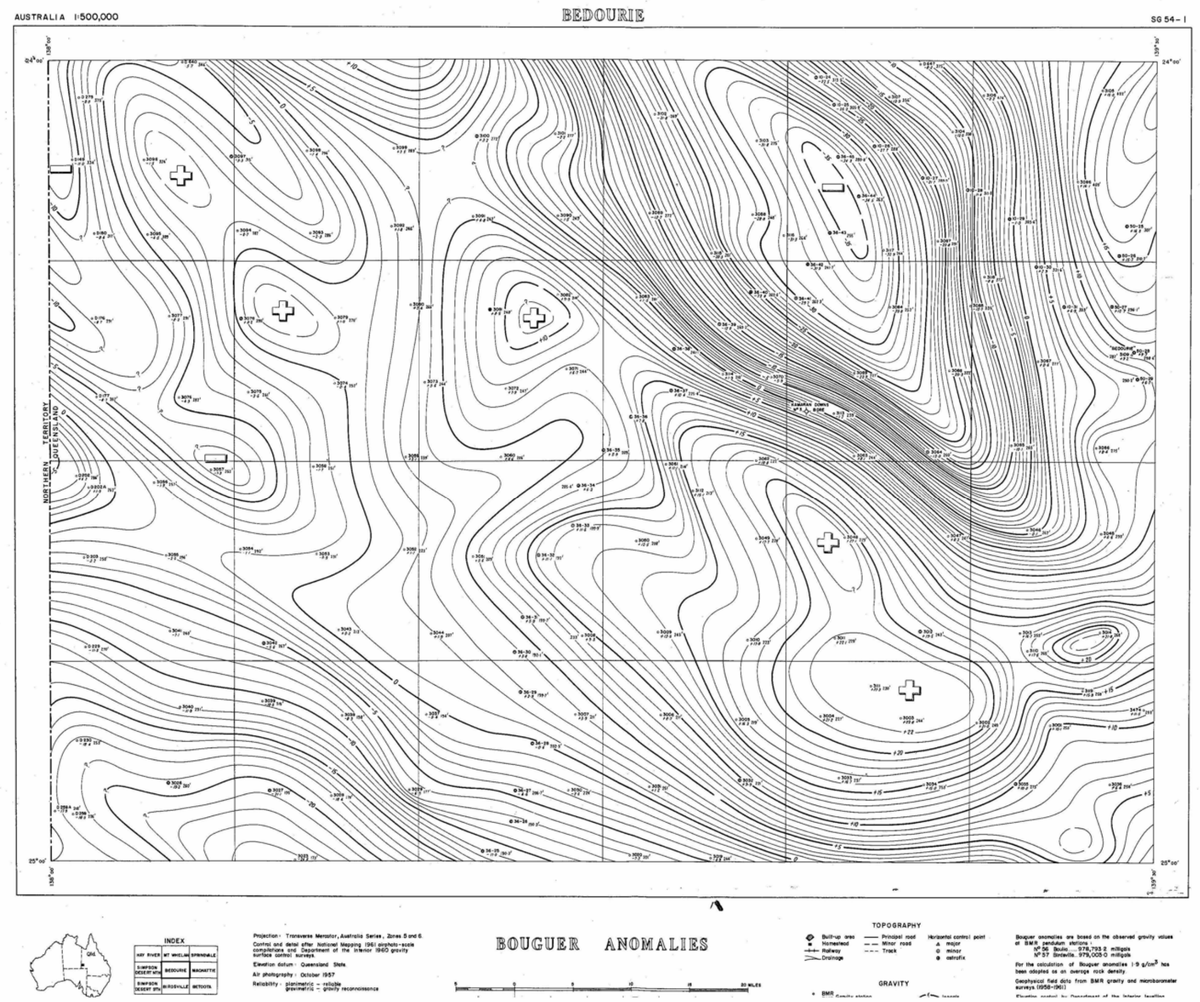
Appendix 1


AUSTRALIA 1:500,000
BEDOURIE
SG 54-1
NORTHERN TERRITORY
QUEENSLAND
INDEX
HAY RIVER
MT WHELAN
SPRINGVALE
SIMPSON DESERT NTH
BEDOURIE
MACHATTIE
SIMPSON DESERT STH
BIRDSVILLE
BETOOTA
Projection: Transverse Mercator, Australia Series, Zones 5 and 6.
Control and detail after National Mapping 1961 airphoto-scale compilations and Department of the Interior 1960 gravity surface control surveys.
Elevation datum: Queensland State.
Air photography: October 1957
Reliability: planimetric – reliable
gravimetric – gravity reconnaissance
BOUGUER ANOMALIES
20 MILES
TOPOGRAPHY
Built-up area
Homestead
Railway
Drainage
Principal road
Minor road
Track
Horizontal control point
major
minor
astrofix
GRAVITY
Bouguer anomalies are based on the observed gravity values at BMR pendulum stations:
Nº 56 Boulia.....978,793·2 milligals
Nº 57 Birdsville...979,005·0 milligals
For the calculation of Bouguer anomalies 1·9 g/cm³ has been adopted as an average rock density.
Geophysical field data from BMR gravity and microbarometer surveys (1958-1961)