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Airborne gravimetry takes off in the Western Australia ‘Generation 2’ reconnaissance gravity mapping project

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SUMMARY

In 1974, the Australian Bureau of Mineral Resources, Geology and Geophysics completed a 15-year systematic reconnaissance gravity survey of Australia with stations spaced at 11 km. The 1976 Gravity Map of Australia was a seminal product; half a century later, the data still provide the only coverage for substantial parts of the continent.

In 2005, the Geological Survey of Western Australia, supported by Geoscience Australia, commenced a program of regional ground gravity surveys with 2.5 km station spacing, a sixteen-fold improvement of resolution over the ‘first generation’ BMR data. In 2013, GSWA declared its aim of completing ‘second-generation’ reconnaissance gravity coverage of WA by 2020.

In 2016, with 45% of the State yet to be surveyed in the north and east, and ground access issues slowing progress and making uniform coverage increasingly difficult, GSWA and GA undertook the first government-commissioned regional aerogravity survey in Australia, using the Sander Geophysics AIRGrav system. The 38,000 line-km survey covering 84,000 km² in the East Kimberley region was flown at 2.5 km line-spacing for compatible spatial resolution with GSWA’s regional ground surveys.

We compare airborne with ground gravimetry in the context of the East Kimberley project and conclude that, for reconnaissance surveys: aerogravity costs now approach those of ground surveys; spatial resolution is equivalent; data precision is not a critical factor; and airborne and ground data can be merged seamlessly for interpretation.

Consequently, new aerogravity surveys were commissioned over 264,000 km² of northern WA in the Tanami, northeast Canning and Kidson regions.

Key words: Western Australia, East Kimberley, geophysics, airborne gravity, AIRGrav.

INTRODUCTION

In 1974, the then Australian Bureau of Mineral Resources, Geology and Geophysics (BMR) completed a 15-year, systematic, reconnaissance, land gravity survey of Australia that began in 1959. The average station spacing was 11 km over most of the continent and 7 km in South Australia and Tasmania (Dooley and Barlow, 1976; Anfiloff *et al.*, 1976). These data, supplemented by observations made by State Government and private company organisations, were compiled to produce the 1: 5 000 000 scale Gravity Map of Australia (BMR, 1976).

As a continental-scale map, this was a seminal product in Australia and the world; it had a dramatic effect on the understanding of the crustal geology of Australia. Even today, more than 40 years later, the underlying ‘first generation’ (‘Gen 1’) data — with a station density as low as one station per 150 km², full-wavelength resolution of 22 km, and an estimated Bouguer anomaly precision of ± 1 mGal — still provide the best coverage available over a substantial part of the continent (Figure 1).

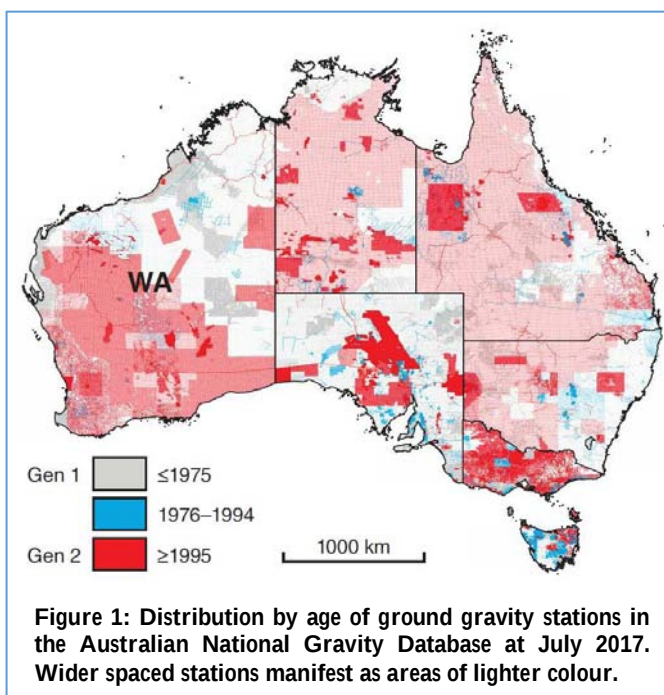
During the following 20 years, the various Federal, State and Territory geological survey organisations continued to carry out regional gravity surveys with higher station densities. However, progress to uniform continental coverage was slow and sporadic, more so in the larger states such as Western Australia, mainly for reasons of the high costs and logistic difficulties of gravity surveying in remote areas. By the late 1990s, advances in gravimeter, positioning and computing technology, and improved infrastructure in remote areas, had combined with a competitive supplier market to bring down gravity survey costs substantially and herald in a ‘second generation’ (‘Gen 2’) of regional ground gravity surveys by the State and Territory geological surveys. More often than not, a nominal station spacing of 4 km was adopted as a quasi-standard, to provide a station density of about six stations per 100 km² and a 2D spatial wavelength resolution of 8 km.

Second-generation gravity mapping in Western Australia

In 2005, GSWA received increased funding from the State government for new pre-competitive geoscience datasets to stimulate the mineral and petroleum exploration sectors. With contract management support from GA through a National Collaboration Framework Agreement, GSWA embarked on its own systematic program of second-generation, regional, helicopter-assisted ground gravity surveys for coverage of the 2.5 million square kilometres of the State, of which, at that time, some 90% was covered only by first-generation data.

GSWA adopted a nominal 2.5 km station spacing for these surveys — a sixteen-fold improvement of resolution over the first-generation BMR data. GSWA considered this a more suitable resolution for second-generation coverage than the 4 km ‘standard’ that, even as late as 2015 was still being proposed as a satisfactory spatial resolution for a new generation of continental scale gravity mapping (AMIRA, 2015).

Between 2005 and 2012, with a further funding boost in 2009, GSWA and GA acquired 115,000 gravity stations at 2.5 km station spacing from 15 surveys covering an aggregate area of about 715,000 km², some 30% of the area of the State. In 2013, GSWA declared the aim of completing Gen 2 reconnaissance gravity coverage of the remaining 60% of WA by 2020. Between 2013 and 2016, six more surveys (including road traverses in areas of high population density and intensive land use in the southwest) were completed to yield 60,000 new stations over an aggregate area of 400 000 km², bringing total state coverage with Gen 2 data to about 45% (Figure 1).



By 2016, with coverage of the southwestern half of the State complete, focus moved to the more remote north and east, which is almost entirely under native title determination or claim. GSWA had found that the process of negotiation with traditional owners for ground access was often uncertain and time-consuming, and the costs for meetings and ground assessments could be substantial. Furthermore, even where access was granted, increasingly large areas were being excluded for survey, leaving gaps in the uniformity of survey coverage. Under these circumstances, GSWA gave consideration to the use of aerogravity surveys for application in areas where ground access was unlikely to be obtained in a reasonable time or where access approvals were likely to come with significant exclusion zones.

Terminology and assumptions

In this paper, we use the term ‘aerogravity’ to refer to measurements of either gravity or gravity gradients (or both) from an airborne platform. To distinguish between the two types of measurement we use the terms ‘airborne gravity’ (AG) and ‘airborne gravity gradiometry’ (AGG). Our focus is on AG surveys with limited reference to AGG surveys.

In discussing survey or data accuracy, we follow the definition of ISO 5725 (ISO, 1994), which uses the term “accuracy” to refer to both “trueness” — the closeness of the mean of repeated measurements to an accepted reference value — and “precision” — the closeness of agreement between the repeated measurements. Trueness is a measure of systematic error or “bias” of the system of measurement, while precision, generally expressed as a standard deviation, is a measure of the distribution of random errors or “noise”.

We define the trueness of airborne measurements of gravity anomalies as their closeness to ground data, which we assume to be ‘true’ absolutely. We define the ‘linear precision’ of airborne data as the repeatability of multiple sets of airborne measurements along the same line (‘linear location’) and the ‘areal precision’ as the repeatability within a given area (‘areal location’), estimated from multiple traverse–tie-line intersections. These definitions warrant further explanation.

In an AG survey, the gravimeter samples the gravity field continuously (at very high rates). The raw output is filtered to remove the high-frequency ‘platform acceleration noise’ and to deliver processed measurements of gravity along the flight line. Consequently, a ‘point-located’ value along an AG flight line is actually a weighted average of the gravity field along a segment of line either side of the point, the length of segment dependent on the filter applied. In contrast, a static ground measurement is an observation of the gravity field at a specific point. Therefore, we gauge the trueness of a line of airborne free air or Bouguer anomaly values in relation to a coincident line of static ground gravity values to which a similar filter has been applied and compare the two profiles along the coincident length.

Similarly, we cannot properly compare the linear precision or areal precision of airborne data with the ‘point precision’ (0D) of static ground measurements at discrete sampling points. Rather, we must consider the overall linear (1D) precision as the repeatability of an entire profile, or the areal (2D) precision as the repeatability of an entire grid, which are made by interpolation between static ground observations where there is no knowledge of the shorter wavelength variations of the gravity field between the observation points. It

follows that the linear or areal precision of a set of discrete point observations must vary with the spacing between the observations. In the limit, as sampling density increases and observation spacing tends to zero, linear and areal precision will approach the point precision of the measurement system.

Whereas the punctual precision of static ground observations in a regional survey may typically be about 0.02 mGal, the linear and areal precision at a regional survey station distribution of 2.5 km is likely to be more than an order of magnitude higher. An analysis of ground data from the RJ Smith AG test range in Western Australia (Elieff, 2017) illustrates the effect, and estimates the areal precision of the ground Bouguer anomaly data over the test range at 0.5 mGal for an observation separation of 2.5 km.

GSWA assessment of aerogravity surveying for application in the Gen 2 mapping program

There has been substantial development in aerogravity technology during the past twenty years (Lane, 2004; Geoscience Australia, 2016) and aerogravity surveys are being used increasingly for rapid data acquisition programs and in areas where ground access presents challenges.

Aerogravity measurements are made from a rapidly moving platform and are subject to many ‘errors of motion’. Even after filtering to remove high-frequency acceleration noise, airborne measurements of gravity along the same nominal line are subject to variations in position from factors such as the navigation system, aircraft speed and wind conditions. As a result, the linear precision of measurements along a single flight line of data from an AG survey, estimated from repeated passes along the line, is typically quoted in a range from about 0.5 to 1.5 mGal. The areal precision is generally better for a whole-survey dataset in which noise reduction techniques such as levelling and cross-line filtering can result in an overall areal precision typically around 0.5–0.7 mGal and, in certain circumstances, as good as 0.2 mGal at the target wavelengths (Sander *et al.*, 2003). Therefore, whole-of-survey AG precision is of the same order of magnitude as that from ground surveys with a sparse station distribution.

Measurement precision is important because it places a lower limit on the amplitude of an anomaly that can be reliably defined in the data. However, for the ‘regional interpretation scales’ of gravity surveys at GSWA’s regional 2.5 km station spacing (5 km minimum full-wavelength resolution), small anomaly amplitude discrimination at the limiting spatial resolution is less of an issue than for detailed surveys with much denser sampling. Of greater importance for GSWA’s second-generation regional survey program is that the spatial resolution of airborne data must be able to match that of the ground data at the target station spacing.

Current AG technology deployed in a fixed-wing aircraft surveying along relatively widely spaced lines can provide along-line wavelength resolution of about 4–6 km. The costlier AGG technology can provide much shorter along-line anomaly resolution — down to 150 m — and AGG providers are now offering mixed-mode ‘full-spectrum’ surveys with gravimeters providing long wavelength measurements to complement the short wavelength AGG data. Cross-line wavelength resolution is, ultimately, a function of survey line spacing: the lower the spacing the better the resolution. By suitable cross-line oversampling with close line spacing, fixed-wing AG surveys reportedly can achieve full-wavelength anomaly resolution as low as 2 km or better (Sander *et al.*, 2003; Wooldridge, 2010).

Therefore, an AG system with a nominal full-wavelength resolution of 5 km along line and a line spacing of 2.5 km (i.e. no cross-line oversampling) should provide 2D resolution at least equivalent with that of ground gravity stations on a regular 2.5 km grid of observations, GSWA’s regional coverage specification.

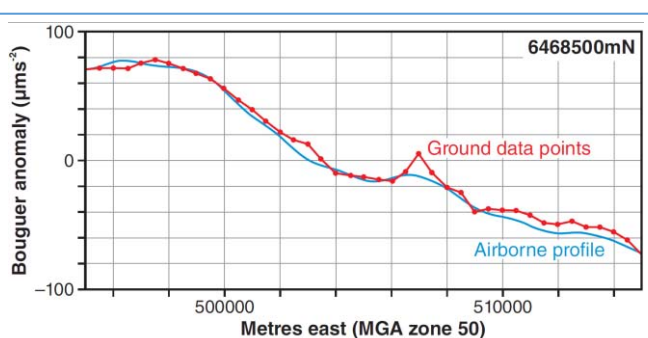


Figure 2: Comparison of normalised airborne and unfiltered ground Bouguer anomaly data at Kauring test range. Ground data points c. 500m spacing. Ground and airborne lines mean northings coincide within 20 m.

To assess the accuracy and spatial resolution equivalence of airborne and ground data, GSWA evaluated data, submitted by a petroleum exploration company, from a large AG survey, flown in 2008 (Airborne Petroleum Geophysics, 2008). The GT-1A survey, with 5 km line spacing over an area of 25,000 km² in the West Amadeus Basin in Western Australia, partially overlapped a GSWA 2.5 km ground survey completed in 2015. Data from a Sander Geophysics’ AIRGrav system test survey flown in 2012 over the RJ Smith airborne gravity test range at Kauring in Western Australia (Sander Geophysics, 2012; Elieff and Sander, 2015) were also reviewed (Figure 2).

GSWA found that the regional airborne data from the 2008 AG survey could be merged seamlessly into the WA state gravity compilation grid and concluded that the precision and resolution of airborne gravity surveys with current technology and at a line spacing of 2.5 km should provide ‘interpretability equivalence’ with regional ground surveys on a 2.5 km grid of stations.

THE EAST KIMBERLEY AIRBORNE GRAVITY SURVEY

In June 2016, Geoscience Australia issued a public request for tender for an airborne gravity survey over some 84 000 km² in the East Kimberley region of WA that encompasses much of the Halls Creek Orogen and parts of younger basins to the north and east (Figure 3). Sander Geophysics Limited (SGL) was selected as offering the best value for money. SGL’s extensive experience with airborne

gravity and the stable noise characteristics of the SGL AIRGrav system were also important considerations for the first regional aerogravity survey being undertaken by the Australian geological survey sector.

SGL completed flying of the 38 000 line-km survey over a period of eight weeks between October and December 2016 with the AIRGrav system installed in a Cessna 208B Grand Caravan owned and operated by SGL. Survey lines were flown east–west at 2.5 km line spacing (25 km tie-lines) in drape mode at a nominal height of 160 m above ground level and at a nominal speed of 50 m/s. Final data were released in February 2017.

The contract value of \$1.12 million inclusive of tax is equivalent to a cost of approximately \$80 per ‘2.5 km equivalent ground station’ for the 13 800 stations that would be required to cover the same areal extent with a helicopter-assisted survey grid. The cost, about 60% more than might be expected for a ground survey, was justified in terms of the overall planning and data acquisition time in the absence of any access issues; and that the survey would provide full and regularly-spaced coverage at the target resolution, including extension of coverage offshore and over otherwise inaccessible areas.

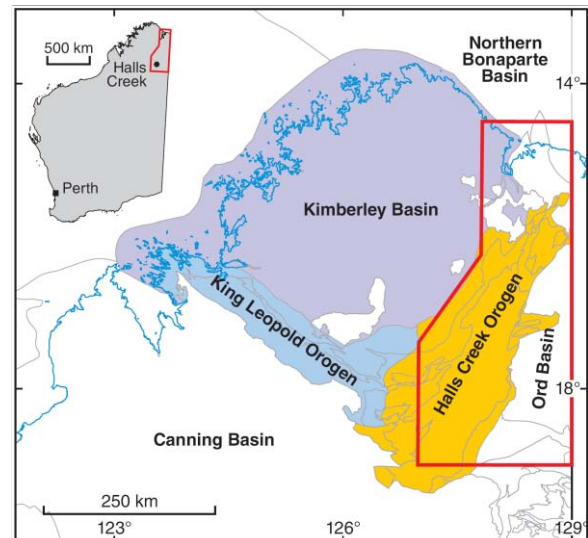


Figure 3: East Kimberley survey location map

AIRGrav system, data processing and data deliverables

Details of the AIRGrav (Airborne Inertially Referenced Gravimeter) system have been described by Argyle *et al.* (2000) and Ferguson and Hammada (2001).

Briefly, the AIRGrav system comprises three orthogonal accelerometers mounted on a Schuler-tuned inertial platform, which maintains the accelerometers fixed in inertial space, independent of aircraft manoeuvres and motion up to ‘moderate’ levels of turbulence. Dual-frequency, differentially-corrected GPS measurements are used to model the movements of the aircraft in flight and compute aircraft inertial accelerations. The aircraft accelerations are subtracted from the total accelerations in the three orthogonal directions to provide ‘raw’ gravity data as measurements of the horizontal components of the gravity vector in addition to the vertical component.

The raw gravity data were processed in SGL’s proprietary software with the application of standard corrections to reduce the vertical gravity data to free air and terrain-corrected Bouguer anomaly values on the AAGD07 datum (Tracey *et al.*, 2007). Shuttle Radar Mission (SRTM) digital elevation model data at 3 arc-second resolution (approximately 100 m) were used to calculate the onshore Bouguer corrections using a density of 2670 kg/m³. For offshore corrections, bathymetric data at a resolution of 9 arc-seconds from the Australian Bathymetry and Topography Grid (June 2009) were used with a seawater density of 1020 kg/m³. The resultant gravimetric data were levelled in two steps: a single constant shift determined from pre- and post-flight ground static recordings was applied for each flight; followed by tie-line levelling of the line data using smoothly varying corrections based on groups of intersections. Earth tide corrections were not explicitly computed because the line levelling adjustments compensate for any gradual long-wavelength changes, including those from Earth tides.

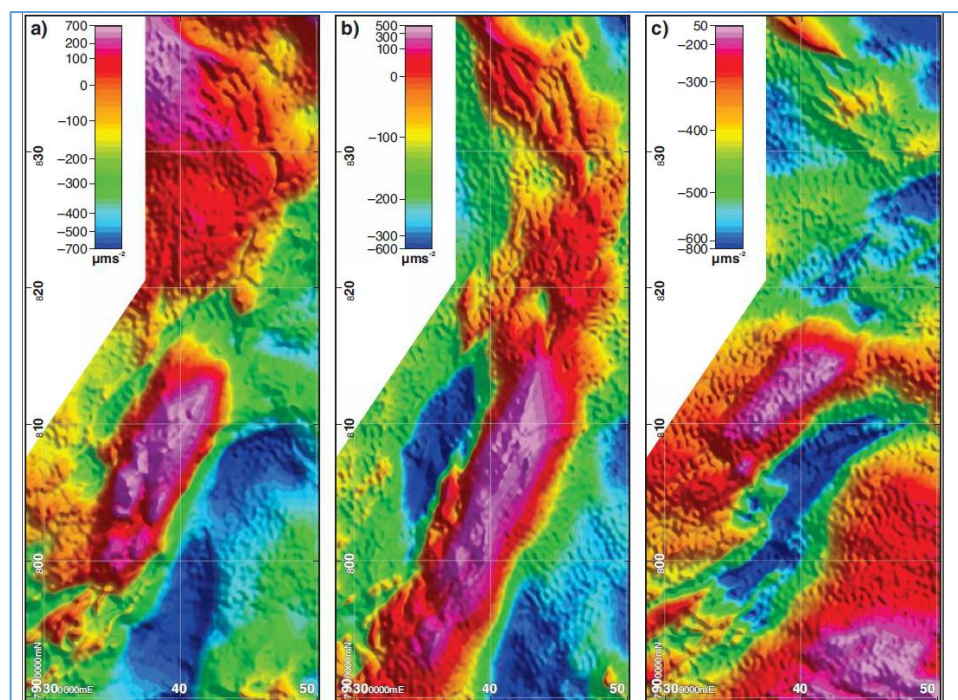


Figure 4: East Kimberley Bouguer anomaly vector components: (a) vertical, (b) east, (c) north. Coordinates in MGA52.

The acquisition and data processing are described in detail in the survey operation reports, which are contained in the GSWA data delivery package (Sander Geophysics, 2017). Included in the data package are the processed data for the three components of the gravity vector (Figure 4), as well as the unfiltered total and aircraft accelerations and the various correction values applied.

ASSESSMENT OF THE DATA

The AIRGrav pre- and post-flight vertical gravity static measurements — whose averages were applied as a constant shift to in-survey measurements — were tied to the value of gravity at the local base station, which in turn was tied to Australian Fundamental Gravity Network station #1993929189 at Kununurra airport. They are then, by definition, true. The average precision of the static measurements, after application of a 100 s cut off low pass filter to eliminate variations due to windshake of the aircraft while parked, was 0.08 mGal.

The trueness of the final levelled airborne gravity values relative to ground data was gauged by comparing two airborne profiles with ground data from a 2007 exploration company survey in the south of the airborne survey area (Daishsat, 2007). The ground data were acquired on a 1 km grid in an area of gentle gravity relief with no prominent short-wavelength anomalies. Two 35 km long lines of the ground data points in north-south and east-west directions coincide with two segments of airborne lines. The airborne lines were flown on different days and the coincidence on both sets of lines is within a distance of 50 m laterally. The airborne Bouguer anomaly profiles match the ground profiles, filtered with a 5000 m low-pass filter to simulate the airborne data filter, to within 1% (Figure 5).

In order to monitor the stability and repeatability of the AIRGrav system in survey mode, a 50 km test line was established in the survey area near the Kununurra operations base. The line was flown before survey operations began and at regular intervals during the course of the survey. The location was chosen to align approximately with a section of road along which ground measurements made at 400 m spacing in 2011 had defined two very distinct, 5 mGal gravity anomalies with widths of 1.2 km and 5 km (labelled ‘N’ and ‘B’ respectively in Figure 6a). Thus, the test line is suitable for verifying the minimum spatial resolution of the airborne data as well as the linear precision of the data. Because the airborne survey line does not coincide closely with the path of the ground data points, the test line data cannot properly be used to gauge the trueness of the airborne data (i.e. closeness to the ground data).

From the 18 passes along the repeat test line (Figure 6 b), the linear precision of the Bouguer gravity data after filtering with a 100 second low-pass filter is 0.54 mGal (Sander Geophysics, 2017).

The average airborne values from the 18 passes were used to check along-line spatial resolution of the airborne data, after normalisation and detrending of both the airborne and ground data. The narrow negative anomaly appears in the airborne profile as a 5 km wide anomaly — consistent with the 5 km filter length — with half the amplitude of the ground response (Figure 7a). This is approximately the same amplitude as the ground anomaly upward continued to the nominal survey height of 160 m (not shown). The broad (5 km-width) positive ground gravity anomaly is well represented in the airborne 100 s (5 km) filtered data both in terms of width and amplitude (Figure 7b).

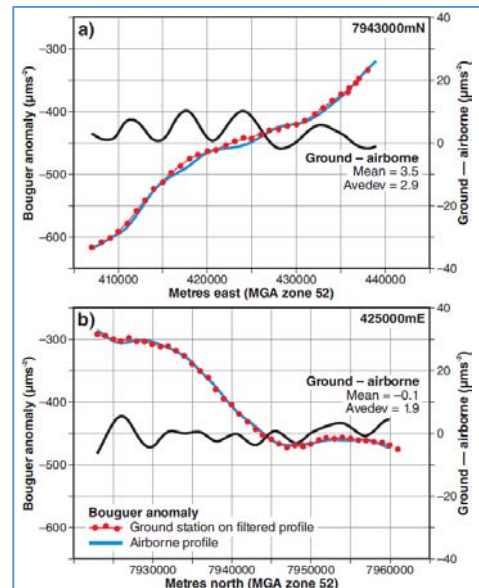


Figure 5: Correspondence of ground and airborne data along coincident profiles. (a) East-west ground profile 7943000N, airborne L1019. (b) North-south ground profile 425000E, airborne T106.

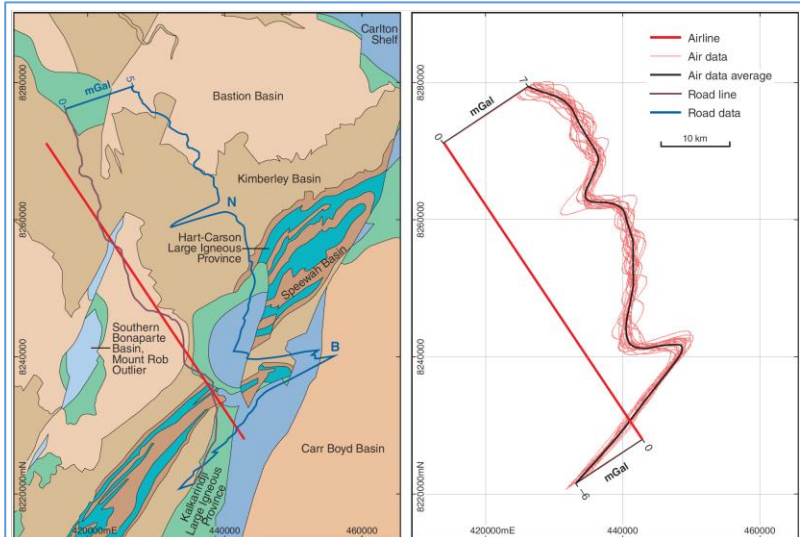


Figure 6. (a) Location of airborne test line in relation to ground traverse on local geology (for geology detail and legend see GSWA, 2016). Ground Bouguer anomaly profile with narrow (N) and broad (B) anomalies indicated. (b) Airborne Bouguer anomaly profiles from 18 passes (red) and average (black).

Overall, the internal coherency of the AIRGrav data is apparent in the various gridded datasets (Figure 4). The estimated overall areal precision for the entire survey computed from the RMS value of traverse-tie intersection differences of the vertical Bouguer gravity after filtering with a 50 s half-wavelength low pass filter is 0.52 mGal with 0th order corrections and 0.47 mGal after final levelling. An “odd-even difference” test (Sander *et al.*, 2002), in which two grids made from alternate lines 5 km apart were compared, yielded an estimate of 0.46 mGal.

CONCLUSIONS, CONSEQUENCES AND CONTEMPLATIONS

GSWA considers that a standard of 4x linear (16x areal) increase in resolution is a better specification for second-generation regional coverage of the State to replace the 11 km station spacing (22 km wavelength resolution) of the first-generation 1976 BMR coverage. Hence, the choice of a target 2.5 km grid of stations for ground surveys and 2.5 km line spacing for the East Kimberley airborne survey.

With this line spacing, the East Kimberley AIRGrav filtered free air and Bouguer anomaly profiles closely match ground data profiles on coincident lines. The overall data precision of about 0.5 mGal standard deviation manifests itself in the gridded datasets as high frequency ‘noise’ which is largely removed in final 2D spatial filtering to smooth the data to the nominal target survey spatial resolution of 5 km.

As expected, the airborne data after filtering cannot resolve features of width less than the nominal 5 km full-wavelength resolution of the filter. Apparent anomalies in the airborne data with wavelengths about 5 km must be regarded with caution if the amplitude is less than 2.0 mGal (4 standard deviations of the precision measure of 0.5 mGal). Anomalies of amplitude greater than this are likely to be real; however, they may be the attenuated response of a narrow anomalous density contrast rather than the ‘true’ ground amplitude response of a broader feature. Features of width greater than 5 km appear to be well resolved in both amplitude (within the limits of the data precision) and wavelength. At a whole-of-survey level, the new data incorporate seamlessly into the WA State gravity 400m-cell compilation grid (Brett, 2017).

The internal coherence displayed in images of the horizontal component data indicates that these contain interpretable information, despite the lower degree of precision relative to the vertical component data. GSWA has successfully generated coherent grids of the gradient tensor computed from the vector component grids and has included these in the data package. However, while interpretation of gravity vector and tensor components are regularly reported in AGG publications, there has been relatively little demand from exploration and geological mapping institutions for the delivery of horizontal component data from AIRGrav surveys and use of these data appears to have been limited to geodetic applications (e.g. McLeish and Ferguson, 2016).

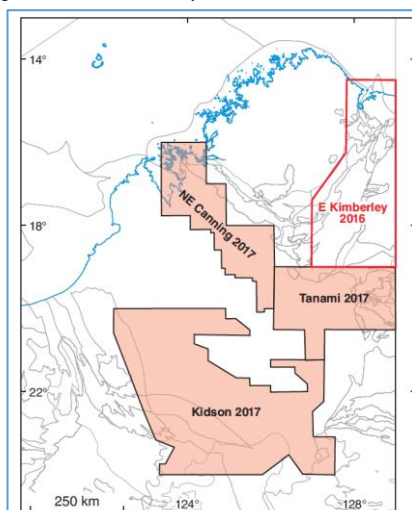


Figure 8: GSWA/GA aerogravity surveys in WA

By all measures, the East Kimberley survey has met the expectations of both GSWA and GA to the extent that two new aerogravity survey contracts were awarded for coverage of the areas in Figure 8 with different aerogravity technologies. The prices tendered for the latest surveys indicated that prices for large aerogravity surveys are trending downwards so that airborne surveys are increasingly cost-competitive with ground surveys at this scale as price-point thresholds are breached with economies of scale.

If present funding levels are maintained, GSWA plans more surveys to cover the remainder of the state that still has only first-generation coverage. Under the current circumstances of airborne technology, price, and access to funding, GSWA anticipates that the second-generation coverage in Western Australia will have a longevity of at least 20–30 years given that the next generation whole-of-state coverage will require 1 km full-wavelength resolution (i.e. 500 m ground station spacing or airborne line spacing) or better. This will be achievable only with aerogravity surveys, of corresponding resolution and precision, as the air–ground cost differential changes dramatically in favour of airborne surveys at this acquisition density. While current AGG technology can provide this spatial resolution, the present cost of acquisition renders continental coverage at this scale prohibitively expensive.

Finally, the assessment of the East Kimberley data raised two suggestions that we are presently contemplating. While we are not wholly convinced of their validity or practicality, we present them for wider discussion.

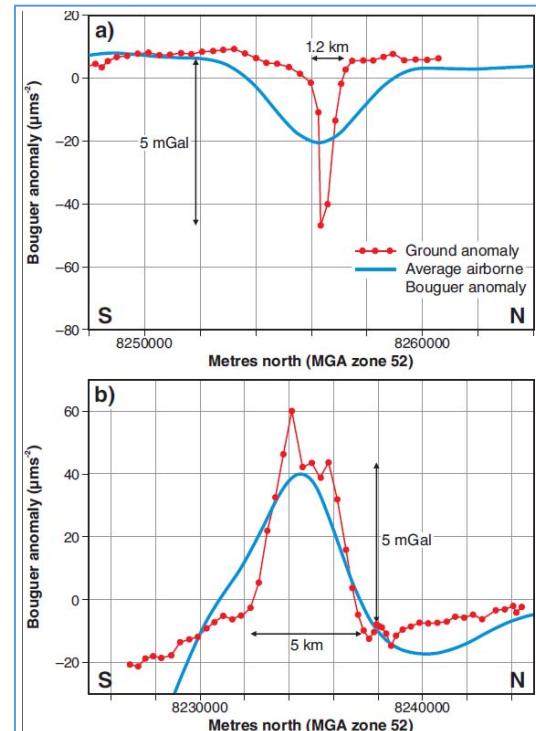


Figure 7. Airborne spatial resolution of test line ground anomalies: (a) narrow anomaly, (b) broad anomaly. Distance along profile is foreshortened because of line orientation.

The need for tie lines

Tie-lines are generally flown at 10 times the line spacing, adding up to 10% to the cost of a survey. Traditionally, tie lines are used to level the data using network adjustment methods; to provide an independent check on flight-line features; and to provide an estimate of data precision. Arguably, data acquisition quality has evolved to the point where feature confirmation is no longer an issue; and data precision can be estimated by other methods. White and Beamish (2015) described a methodology to level airborne magnetic data without orthogonal tie-lines.

We have attempted to produce a ‘levelled’ grid from the East Kimberley dataset excluding the tie-lines by decorrugating and microlevelling the unlevelled, 100 s-filtered Bouguer line data after adjustment with the pre-and post-flight static corrections.

The result is very close to that achieved from tie-line levelling (Figure 4a), with the difference grid (Figure 9a) showing little coherence. The suggestion is that an aerogravity survey with an instrument with consistent noise character might, in suitable circumstances, be flown without tie-lines and still yield a good result. If the configuration of an airborne survey is such that tie lines could be eliminated, there would be a cost reduction of up to 10%, making the survey that much more cost competitive compared to a ground survey at these acquisition line-densities.

Airborne point data in the national gravity database

We are considering how AG data might be included in the national gravity database. As discussed, the point-located AG values are not specific point measurements but a weighted mean of measurements along the flight line before and after the nominal data point, with extremely high correlation between neighbouring points. Nevertheless, we see that airborne profiles closely reflect profiles constructed from ground data points at a regional scale (Figure 5) and that the filtered East Kimberley airborne data after gridding merge seamlessly with existing ground data. Therefore, we can argue that the airborne survey data provide a good representation of the gravity field at the target wavelengths of the survey and that sampling this ‘field representation’ at a spacing compatible with the minimum wavelengths contained might be a proxy for ground sampling of the actual gravity field at the same spacing.

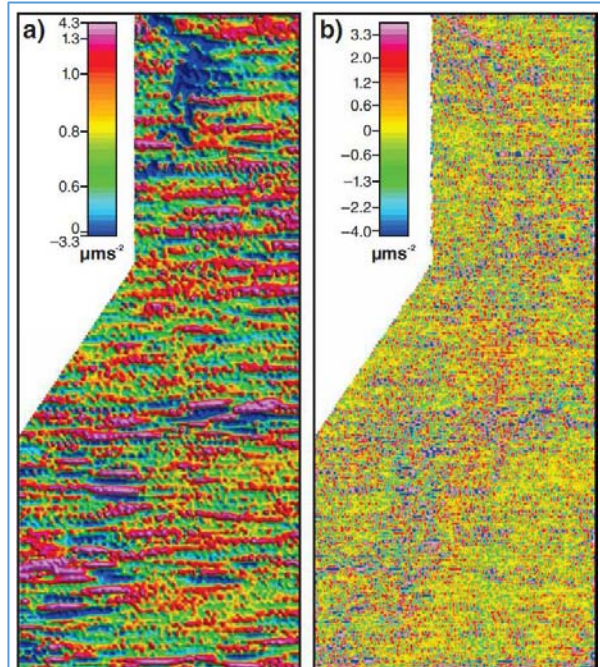


Figure 9. Difference grids between final tie-line levelled Bouguer data in Figure 4a and (a) decorrugated field data without tie-lines; (b) gridded points from the tie-levelled line data resampled at every 100th point (~ 2.5 km).

We have tested this idea by resampling the levelled AIRGrav Bouguer anomaly data every 100 points (2.5 km for 2 Hz recording at the nominal flying speed of 50 m/s), equivalent to the 2.5 km grid of stations in GSWA ground surveys. The difference between the ‘resampled grid’ and the levelled grid of Figure 4a is shown in Figure 9b. There is little coherency in the difference grid indicating that most of the information in the airborne dataset has been retained in the resampled dataset. Thus, it is being suggested that suitably resampled ‘points’ from the final AG line or grid dataset could be added to the national database as ‘equivalent ground stations’ with appropriate metadata.

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REFERENCES

- Airborne Petroleum Geophysics, 2008. SPA704.5 Amadeus Basin Project, Western Australia; airborne GT-1A gravity project: [Dataset and Report] in Geological Survey of Western Australia airborne geophysics database, MAGIX registration no. 70369, <http://www.dmp.wa.gov.au/magix>.
- AMIRA International, 2015. P1162. Unlocking Australia’s hidden potential. An Industry Roadmap – Stage 1: AMIRA International Limited, Melbourne.
- Anfiloff, W., Barlow, B.C., Murray, A., D. Denham, D., and Sandford, R., 1976, Compilation and production of the 1976 1:5000000 Gravity Map of Australia: BMR Journal of Australian Geology & Geophysics, J (1976), 273-276.

Argyle, M., Ferguson, S., Sander, L., and Sander, S., 2000, AIRGrav results: a comparison of airborne gravity data with GSC test site data: *The Leading Edge*, October 2000, 19, 1134-1138.

BMR, 1976-Gravity Map of Australia, 1:5000000: Australian Bureau of Mineral Resources (Geoscience Australia), Canberra.

Brett, JW 2017, 400 m gravity merged grid of Western Australia 2017 version 1: Geological Survey of Western Australia, Perth. <http://www.dmp.wa.gov.au/geophysics>.

Daishsat Geodetic Surveyors, 2007. Gravity survey job no. 07036: [Dataset] in Katchan, G., and Hawke, P., 2009, Surrender Report, Giant Placer Project: E80/3616, 3617, 3618 & 3619, Combined Reporting No. C 14/2008: GSWA WAMEX database report no. A80794 (<http://dmp.wa.gov.au/wamex>). Data available from Australian National Gravity Database, survey no. 200760 (<http://ga.gov.au/gadds>).

Dooley, J. C., and Barlow, B. C., 1976, Gravimetry in Australia, 1819-1976: *BMR Journal of Australian Geology & Geophysics*, J (1976), 261-271.

Elieff, S., 2017, An illustration of the impact of sampling on precision: *Preview* 2017 (190).

Elieff, Stefan H. P. and Sander, Luise, 2015. Results from SGL's AIRGrav airborne gravity system over the Kauring airborne gravity test site: *ASEG Extended Abstracts 2015: 24th International Geophysical Conference and Exhibition*: pp. 1-4.

Ferguson S.T., and Hammada Y. (2001) Experiences with AIRGrav: Results from a New Airborne Gravimeter: In Sideris M.G. (eds) *Gravity, Geoid and Geodynamics 2000. International Association of Geodesy Symposia*, vol 123: Springer, Berlin, Heidelberg.

Geological Survey of Western Australia, 2016, 1:500 000 State interpreted bedrock geology of Western Australia, 2016: Geological Survey of Western Australia, digital data layer, www.dmp.wa.gov.au/geoview.

Geoscience Australia, 2016, Airborne gravity 2016 asega videos: [Internet] Geoscience Australia, Canberra. Retrieved from <http://www.ga.gov.au/scientific-topics/disciplines/geophysics/gravity#heading-1>.

ISO, 1994, Standard ISO 5725-1:1994(en), Accuracy (trueness and precision) of measurement methods and results — Part 1: General principles and definitions. International Organization for Standardization, Geneva. Retrieved from <https://www.iso.org/obp/ui/#iso:std:iso:5725:-1:ed-1:v1:en>.

Lane, R.J.L., editor, 2004, Airborne Gravity 2004 – Abstracts from the ASEG-PESA Airborne Gravity 2004 Workshop: *Geoscience Australia Record* 2004/18.

McLeish, M. and Ferguson, S., 2016, Some Examples of AIRGrav Vector Gravity Data and Comparison with Ground Truth. Airborne Gravimetry for Geodesy Summer School, U.S. National Geodetic Survey / NOAA. Retrieved from https://www.ngs.noaa.gov/GRAV-D/2016SummerSchool/presentations/day-4/7MarianneMcLeish_Sander_AIRGrav.pdf.

Sander, S., Ferguson, S., Sander, L., and Lavoie, V., 2002, Measurement of noise in airborne gravity data using even and odd grids. *First Break* volume 20.8 August 2002, 524-527.

Sander, S., Lavoie, V., and Peirce, J., 2003. Advantages of close line spacing in airborne gravimetric surveys: *The Leading Edge*, February 2003, 22, 136–137.

Sander Geophysics, 2012, Technical Report, Kauring Gravity Test Site, Western Australia 2012 for Victoria State Government Department of Primary Industries: [Dataset and Report] in Geological Survey of Western Australia airborne geophysics database, MAGIX registration no. 70942, <http://www.dmp.wa.gov.au/magix>.

Sander Geophysics, 2017, Technical Report, East Kimberley Airborne Gravity Survey, Western Australia 2016 for Geoscience Australia: [Dataset and Report] in Geological Survey of Western Australia airborne geophysics database, MAGIX registration no. 71156, <http://www.dmp.wa.gov.au/magix>.

Tracey, R., Bacchin, M., and Wynne, P., 2007. AAGD07: A new absolute gravity datum for Australian gravity and new standards for the Australian National Gravity Database: *ASEG Extended Abstracts* 2007, 1-3. <https://doi.org/10.1071/ASEG2007ab149>.

White, JC and Beamish, D, 2015. Levelling aeromagnetic survey data without the need for tie-lines: *Geophysical Prospecting*, 2015, 63, 451–460

Wooldridge, A., 2010. Review of modern airborne gravity focusing on results from GT-1A surveys: *EAEG, First Break*, v28, 85–92.