Terrain corrections for the Balfour gravity survey, Tasmania

prepared for

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April 2009

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Introduction

The gravity survey covers an irregularly-shaped area about 12.4 km by 17.6 km over an area with pronounced variations in the topography in which elevations reach more than 400 m above sea level in the survey area. The stations were mainly acquired at 200 m intervals on east-west traverses at a spacing of 400 m, with some traverses 800 m apart, and some infill at 100 m station spacing. The relief in the area is quite appreciable, and part of the survey lies within regions of fairly steep local topography so that significant terrain effects may therefore be expected in nearby gravity values. The outline of the survey derived from an automatic fence of the gravity data is shown in green in Figure 1 draped on oblique Google Earth images viewed from the southeast and northwest, which gives some idea of the topography in the vicinity of the survey. The terrain corrections are large enough to affect some of the details that may be used in the interpretation of the data. In addition to the usual terrain adjustments, corrections were also calculated to allow for the curvature of the Earth.

The UTM coordinates used for the mapping here are in zone 55 (central meridian 147 degrees E), and are based on the AGD84 datum. All gravity values were reduced using the AHD elevations rather than the WGS84 heights and are given in milligals. Gridding employs minimum curvature methods, and all the gravity grids and images employ a 20 m grid interval. The maps of grid data are presented as colour bitmaps, where the size of the text within the borders is related to the pixel or grid cell size. The location of any pixel can be found readily on the screen by using the cursor to count the numbers of pixels from a plotted coordinate mark. Where shading has been used for the coloured diagrams the illumination is from the northeast, and if no colour scales are given high values are red and low values are blue or purple in the plots. Generally the detail and colour contrasts are better when viewed on the screen than on the paper prints given in this report, and hence the bitmap image files are included with the digital products. The line or vector plot is also given in a bitmap format.

Gravity and elevation data

The initial survey data set contained 1598 observations including all the base readings. Some of the values were repeat stations or multiple base observations that were deleted, and after editing the data set the number of points retained for processing and the final data set was reduced to 1344 gravity stations, including the 2 base stations. The locations of the gravity stations after editing are shown in Figure 2, which includes both UTM and geographic coordinates. The automatic fence boundary used for the grids and images is also included in Figure 2, and is also shown in the elevation images. Note that this provides a fairly loose fence of the data due to the line spacing, which is rather large at the northern and southern ends of the survey compared to the station interval along the traverses in the centre.

The uncorrected Bouguer gravity reduced with the usual processing density of 2.67 gm cm^{-3} is shown as a 20 m grid in Figure 3, where the colour interval is 1.0 milligal. The locations of the gravity stations are also included in Figure 3. Since there is a strong east-west regional gradient in the Bouguer image, a first-order (planar) trend was removed from the grid to give the image in Figure 4, with a colour interval of 0.3 milligal, in which the local variations are much more obvious. Gravity grids with the regional trends removed were used for all the derivative grids and images in order to minimise edge effects in their calculation. The first vertical derivative (FVD) of the uncorrected Bouguer gravity, derived using normal Fourier methods, is shown in Figure 5 in order to highlight local details that may be altered when applying terrain corrections. The derivative plots use non-linear colour scales for optimum colour stretch and hence no colour scales are shown, but high values are red and low values are blue. There is an unavoidable “bullseye” effect in the gridding since the grid interval of 20 m, necessary to retain details near the centre of the survey, is considerably smaller than the relatively large spacing of most of the data traverses. The elevation grid derived from the station AHD values, which range from 144 to 444 m above sea level (a.s.l.), is shown in Figure 6, which has a colour interval of 18 m. The AHD heights were used for processing the gravity data, and at this location are about 3 m higher than the WGS84 (GDA94) heights that are also included in the data set.

When carrying out terrain corrections a regional topographic grid with as much detail as possible is required, especially in the vicinity of the gravity survey. Ideally in this type of terrain the elevation model should extend at least 15 km from the gravity stations. A 25 m grid (or DEM) of the topography in GDA94 coordinates was available from the Tasmanian Department of Primary Industries & Water. This is shown in Figure 7, together with the survey outline. The colour interval is 30 m, and the maximum elevation of 767 m a.s.l. occurs outside the survey area. The elevation grid extends more than 20 km from the survey boundary to the east and south, but only about 10 km to the north, but this should have little effect in calculating terrain corrections, as the topography tends to flatten out to the north. The elevation grid was converted to AGD84 coordinates and regridded at a 20 m interval for processing the gravity data.

It is important that the topographic grid used for the terrain corrections should match the gravity station heights, as a mistie of 1 m between the grid and a station will lead to a spurious terrain correction of around 0.1 milligal. For this survey the differences between the gravity station AHD elevations and the regional DEM average only 0.13 m. That is, the DEM tends on average to be very slightly lower than the observed station elevations, although the differences at the stations ranged from –14 m to 19 m. The DEM grid was therefore warped locally to fit each gravity station height exactly, and was then used for all the terrain calculations. Part of the adjusted 20 m DEM grid in a 23 km by 28 km area centred on the gravity survey is shown in Figure 8, where the maximum height is 661 m a.s.l. and the colour interval is 25 m. This section of the 20 m grid of the adjusted elevation data is also included with the digital data sets.

Gravity corrections and grids

Terrain corrections are added to the Bouguer value to compensate for the mass deficit in valleys adjacent to a point or the upward gravity acceleration or pull from nearby hills that are higher than the gravity station. The terrain is treated as a network of polygons, each of square cross section similar to the grid cell size, where the upper surface (the ground) is a sloping plane. In the vicinity of a gravity station the surface is treated as triangular facets, in order to give a more accurate representation of the surface where the gravity effects are likely to be more important. For a gravity station, the gravity response of each polygon is then calculated, allowing for the height of the station, and the effects of all polygons are summed to give the complete terrain correction at that point. The adjusted 20 m elevation grid for the whole area shown in Figure 7 was used for the terrain calculation.

Some idea of the expected corrections can be obtained by calculating them on a uniform grid across the area. The terrain corrections were estimated at 200 m intervals across an area centred on the survey, and are plotted in Figure 9 for a density of 2.67 gm cm^{-3}, with a colour interval of 0.1 milligal. The maximum correction in Figure 9 is 5.51 milligals with a mean of 0.28 milligal, and the variations are much as expected from the topography. From Figure 9 it can be seen that significant terrain corrections may occur over parts of the survey area. For the gravity data, the corrections are calculated exactly at each location rather than being interpolated from the correction grid in Figure 9, which serves only to show the anticipated adjustments to the data. The terrain correction is directly proportional to the density employed, and hence can readily be estimated for a range of different densities. The maximum terrain correction at the actual station locations is 5.53 milligals with a mean of 0.34 milligal for a density of 2.67 gm cm^{-3}. The grid of the station terrain corrections is plotted in Figure 10 with the station locations, where the colour interval is also 0.1 milligal. The terrain corrections are significant when compared to the range of Bouguer values in Figures 3 and 4, and will therefore affect some of the details in the gravity grids.

Corrections for the curvature of the Earth are often neglected in reductions of gravity data, but can become significant in areas of pronounced topography. Hence curvature (Bullard B) corrections were also estimated using the exact equations of LaFehr (1991). These do not depend on the local density and are subtracted from the data. For this data the corrections range from 0.20 to 0.58 milligal, and mainly result in a bulk shift to the gravity values. The terrain-corrected Bouguer gravity including curvature adjustment for a density of 2.67 gm cm^{-3} is shown in Figure 11, and the corrected Bouguer gravity minus the regional trend is given in Figure 12, and these grids are included with the digital products. The corresponding FVD of the completely corrected Bouguer grid is shown in Figure 13. From a comparison between Figures 3 and 11, Figures 4 and 12, as well as Figures 5 and 13, it can be seen that applying terrain and curvature corrections has made a considerable difference to some of the details, especially in the areas with steeper topography. Bouguer values including the curvature corrections are given in the data set in addition to just the terrain-corrected data.

Some further enhancements of the corrected Bouguer grid are shown in order to highlight details in the data. Fractional derivatives can also be carried out in the Fourier domain, and the vertical derivative of order 0.5 (0.5 VD) is given in Figure 14. This derivative is intermediate between the Bouguer grid (minus the regional trend) in Figure 12 and its FVD in Figure 13, and hence it retains some of the longer wavelengths while enhancing the details. Residuals were created by subtracting grids smoothed with two-dimensional Hamming operators from the corrected Bouguer grid. The residual grid using an operator width of 1000 m, which effectively retains spatial wavelengths up to about 1000 m, is shown in Figure 15, with a colour interval of 0.04 milligal. The residual with a larger operator 2000 m wide retains longer wavelengths, as shown in Figure 16, in which the colour interval is 0.06 milligal. The tilt derivative, which is a geometrical function of the horizontal and vertical derivatives, is shown in Figure 17. This derivative acts as a type of automatic gain control, and so can often reveal low amplitude and short wavelength features in the data. The FVD, 0.5 VD, residual and tilt derivative grids are also included as digital products.

Optimum Bouguer density

The data was processed using the usual density of 2.67 gm cm^{-3}, since this is normally assumed to be a reasonable approximation to the surface density. A change in the Bouguer density may affect the patterns observed in the gravity plots, and hence the density should ideally correspond to the near-surface lithologies, especially if the anomalies of interest have low amplitude. For example, if the density used is too high in some places there may be a correlation between apparent gravity troughs and topographic maxima, which becomes less for lower densities. In order to select an optimum density for the corrections, variations in the topography can be compared with the gravity. Ideally the cross correlation between elevation and gravity residual grids can be used to find an optimum density where the correlation is closest to zero. This is equivalent in two dimensions to the long-established procedure of comparing sets of gravity and elevation profiles (Nettleton curves) for different densities. The cross correlation was carried out using residual operators of 3 different sizes for the gravity and elevation grids in order to test local features with a range of spatial wavelengths. From this process the optimum near-surface density appears to be between 2.3 and 2.4 gm cm^{-3}, perhaps closer to the latter value, which may be consistent with sandstone lithologies, although significant lateral variations in the near-surface density no doubt occur.

The terrain and curvature corrected Bouguer gravity for a reduction density of 2.4 gm cm^{-3} is shown in Figure 18, and the gravity grid minus the regional trend is shown in Figure 19. The maximum terrain correction for this density is 4.97 milligals. Decreasing the Bouguer density has had a significant effect on the shape and amplitude of the gravity details throughout the survey area (cf. Figures 11 and 12). The FVD for this density is shown in Figure 20, and the 0.5 VD, residuals for 1000 m and 2000 m operators, and the tilt derivative are given in Figures 21, 22, 23 and 24 respectively. Grids of the completely corrected Bouguer values, as well as minus the regional trend, and the FVD, 0.5 VD, residual and tilt derivative grids for a density of 2.4 gm cm^{-3} are also included with the digital products. Gravity values, including terrain and curvature corrections, were also generated for a range of Bouguer densities from 2.2 gm cm^{-3} to 2.8 gm cm^{-3}. The ASCII gravity data set includes the simple Bouguer values as well as the adjusted values for these densities in addition to the standard density of 2.67 gm cm^{-3}.

Although grids and images are provided here for a density of 2.4 gm cm^{-3}, caution should be exercised when using data or grids reduced with this density as the corrections may distort or reduce the gravity effects of real near-surface structures of interest, particularly in zones that also have a topographic expression. It is suggested that in interpreting the gravity data it may be safest to model the free-air data in 2 or 3 dimensions from the surface downwards, including the topography, so that allowance can be made for lateral variations in the near-surface density.

Reference

LaFehr, T.R. 1991. An exact solution for the gravity curvature (Bullard B) correction. Geophysics, vol. 56 (no. 8), pp. 1179-1184.

List of digital products (data, grids and images)

All grids are in Geosoft format (*.GRD) and also ERMapper format (*.ERS header file and binary grid file with no extension). Coordinates are in UTM zone 55 using the AGD84 datum. The interval for all the grids is 20 m.

1) BALFOUR_GRAVITY.DOC
   Word document of text of gravity processing report

2) BALFOUR.DAT
   ASCII file of survey gravity data, including terrain and curvature corrected values, 38 fields (see format listing)

3) HEADER.DAT
   ASCII file of header records for BALFOUR.DAT data set

4) ELEV.GRD and .ERS
   Topographic grid adjusted using survey data, 20 m interval

5) BOUG240.GRD and .ERS
   Bouguer gravity, terrain and curvature corrected, density 2.4 gm cm^{-3}

6) BOUG240_TREND.GRD and .ERS
   Bouguer gravity, terrain and curvature corrected, minus first order trend, density 2.4 gm cm^{-3}

7) BOUG240_FVD.GRD and .ERS
   First vertical derivative of terrain and curvature corrected Bouguer gravity, density 2.4 gm cm^{-3}

8) BOUG240_05VD.GRD and .ERS
   0.5 order vertical derivative of terrain and curvature corrected Bouguer gravity, density 2.4 gm cm^{-3}

9) BOUG240_RESID1.GRD and .ERS
   Residual of terrain and curvature corrected Bouguer gravity, 1000 m operator, density 2.4 gm cm^{-3}

10) BOUG240_RESID2.GRD and .ERS
    Residual of terrain and curvature corrected Bouguer gravity, 2000 m operator, density 2.4 gm cm^{-3}

11) BOUG240_TILTDERIV.GRD and .ERS
    Tilt derivative of terrain and curvature corrected Bouguer gravity, density 2.4 gm cm^{-3}

12) BOUG267.GRD and .ERS

Bouguer gravity, terrain and curvature corrected, density 2.67 gm cm^{-3}

13) BOUG267_TREND.GRD and .ERS
Bouguer gravity, terrain and curvature corrected, minus first order trend, density 2.67 gm cm^{-3}

14) BOUG267_FVD.GRD and .ERS
First vertical derivative of terrain and curvature corrected Bouguer gravity, density 2.67 gm cm^{-3}

15) BOUG267_05VD.GRD and .ERS
0.5 order vertical derivative of terrain and curvature corrected Bouguer gravity, density 2.67 gm cm^{-3}

16) BOUG267_RESID1.GRD and .ERS
Residual of terrain and curvature corrected Bouguer gravity, 1000 m operator, density 2.67 gm cm^{-3}

17) BOUG267_RESID2.GRD and .ERS
Residual of terrain and curvature corrected Bouguer gravity, 2000 m operator, density 2.67 gm cm^{-3}

18) BOUG267_TILTDERIV.GRD and .ERS
Tilt derivative of terrain and curvature corrected Bouguer gravity, density 2.67 gm cm^{-3}

19) FIGURE*.BMP
Bitmap images of the diagrams in this report

Appendix

Format of ASCII gravity survey data set (BALFOUR.DAT)

Coordinates are based on the AGD84 datum with both AHD and WGS84 elevations. The Cartesian coordinates are in UTM zone 55 and gravity values are in milligals. The data set contains 1344 stations including the 2 base stations, and processing employs the AHD elevations. For densities from 2.2 to 2.8 gm cm^{-3}, including a density of 2.67 gm cm^{-3}, Bouguer values are given with terrain corrections and also with both terrain and curvature corrections. The terrain correction is only listed for 2.67 gm cm^{-3}, as the correction is directly proportional to the density employed. The curvature correction is independent of density. The header records are in a separate ASCII file (HEADER.DAT)

1)	Line number	I8
2)	Station number	I8
3)	Easting (metres)	F15.3
4)	Northing (metres)	F15.3
5)	Longitude (decimal degrees)	F13.7
6)	Latitude (decimal degrees)	F13.7
7)	Elevation WGS84 (metres)	F10.3
8)	Elevation AHD (metres)	F10.3
9)	Observed gravity (milligals)	F12.3
10)	Anomalous gravity (milligals)	F10.3
11)	Free-Air correction (milligals)	F10.3
12)	Bouguer correction (2.67 gm cm^{-3})	F10.3
13)	Terrain correction (2.67 gm cm^{-3})	F10.3
14)	Bullard B curvature correction (milligals)	F10.3
15)	Bouguer gravity (2.2 gm cm^{-3})	F10.3
16)	Terrain corrected Bouguer (2.2 gm cm^{-3})	F10.3
17)	Terrain/curvature corrected Bouguer (2.2 gm cm^{-3})	F10.3
18)	Bouguer gravity (2.3 gm cm^{-3})	F10.3
19)	Terrain corrected Bouguer (2.3 gm cm^{-3})	F10.3
20)	Terrain/curvature corrected Bouguer (2.3 gm cm^{-3})	F10.3
21)	Bouguer gravity (2.4 gm cm^{-3})	F10.3
22)	Terrain corrected Bouguer (2.4 gm cm^{-3})	F10.3
23)	Terrain/curvature corrected Bouguer (2.4 gm cm^{-3})	F10.3
24)	Bouguer gravity (2.5 gm cm^{-3})	F10.3
25)	Terrain corrected Bouguer (2.5 gm cm^{-3})	F10.3
26)	Terrain/curvature corrected Bouguer (2.5 gm cm^{-3})	F10.3
27)	Bouguer gravity (2.6 gm cm^{-3})	F10.3
28)	Terrain corrected Bouguer (2.6 gm cm^{-3})	F10.3
29)	Terrain/curvature corrected Bouguer (2.6 gm cm^{-3})	F10.3
30)	Bouguer gravity (2.67 gm cm^{-3})	F10.3
31)	Terrain corrected Bouguer (2.67 gm cm^{-3})	F10.3
32)	Terrain/curvature corrected Bouguer (2.67 gm cm^{-3})	F10.3

33)	Bouguer gravity (2.7 gm cm^{-3})	F10.3
34)	Terrain corrected Bouguer (2.7 gm cm^{-3})	F10.3
35)	Terrain/curvature corrected Bouguer (2.7 gm cm^{-3})	F10.3
36)	Bouguer gravity (2.8 gm cm^{-3})	F10.3
37)	Terrain corrected Bouguer (2.8 gm cm^{-3})	F10.3
38)	Terrain/curvature corrected Bouguer (2.8 gm cm^{-3})	F10.3