

AIRGrav airborne gravity survey in Timmins, Ontario

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Abstract

Results are presented from an AIRGrav airborne gravity survey flown near Timmins, Ontario, Canada. The survey demonstrates the application of airborne gravity to mineral exploration; the system was able to accurately reproduce existing ground data, with the advantages of rapid data acquisition and uniform sampling of an area that was difficult or impossible to access on the ground.

Introduction

An airborne gravity evaluation survey was flown immediately north of Timmins, Ontario, using the AIRGrav (Airborne Inertially Referenced Gravimeter) system (Elieff, 2003). Four production flights totalling 1836 line kilometres were performed in a four day period to complete the survey.

The survey block comprises an area of 810 km² just north of Timmins, Ontario. Survey operations were based out of Timmins Airport, which lies within the survey area. A Cessna Grand Caravan 208B aircraft was used to fly the survey. The coordinates for the survey boundary are given in Table 1. Terrain elevations within the survey block vary between approximately 250 m and 400 m above mean sea level, with the largest relief in the south west portion of the area. The Mattagami River crosses the survey block from south to north, west of the block centre.

Table 1. Coordinates for the boundary of the Timmins Survey (WGS84 datum, UTM zone 17 N projection).

Corner	UTM east (m)	UTM north (m)
1	452000	5373000
2	452000	5395500
3	488000	5395500
4	488000	5373000

Flight specifications

Primary flight lines were flown north-south and spaced 500 m. East-west tie lines were spaced 5000 m apart. All flight lines were extended beyond the survey boundary to ensure that the gravimetric system had time to settle following turns and was on-line before entering the survey area. The survey was flown at a constant ellipsoid height of 468 m, which is approximately 500 m above mean sea level. This height was chosen to provide safe clearance of the highest terrain features in the survey area. The average terrain clearance was approximately 200 m.

The AIRGrav system

The AIRGrav system is described in detail in Sander et al. (2004) and will be only briefly summarised here. An inertial platform supports three orthogonal accelerometers, which remain fixed in inertial space, independent of the manoeuvres of the aircraft. The acceleration due to the motion of the aircraft is modelled using GPS measurements and subtracted from the measured acceleration values to leave the acceleration due to gravity.

System tests

Gravimeter calibration

The accelerometers within the gravimeter were calibrated before the beginning of the survey. Prior to each flight, the AIRGrav system automatically aligns and calibrates its gyros. Before and after each flight, the consistency of the measured gravity was confirmed by recording data at a fixed location on the ground. The results, presented in Table 2, are given as deviations in these reference measurements from a local gravity value of 9.8082771 m/s² (Canadian Gravity Standardization Network station 9201-1975 – Timmins Airport

Terminal). The values in Table 2 are all within 1 mGal of the local gravity reading, demonstrating the stability and low drift rate of the AIRGrav system.

Table 2. Pre- and Post-flight AIRGrav static readings in mGal relative to a local gravity value of 9.8082771 m/s² (Canadian Gravity Standardization Network station 9201-1975 – Timmins Airport Terminal).

Flight number	Pre-Flight	Post-Flight
1	0.58	0.43
2	0.75	0.13
3	-0.96	0.63
4	-0.02	0.46

Radar and laser altimeter calibration

A test flight to calibrate the radar and laser altimeters was flown. Five passes were flown over a runway at heights from 80 m to 350 m above ground. A ground pass taxiing along the runway was carried out to establish the runway height. The radar and laser altimeter values were compared to the post-flight differentially corrected GPS altitude information to calibrate the altimeters (Figure 1). Ideal altimeters would yield a slope of 1, and an intercept of 0. For the laser altimeter test, the calculated slope was 1.007, and the intercept 0.37 m, while for the radar altimeter the slope was 1.01 and the intercept 1.49 m. These results are well within the expected accuracy of the altimeters.

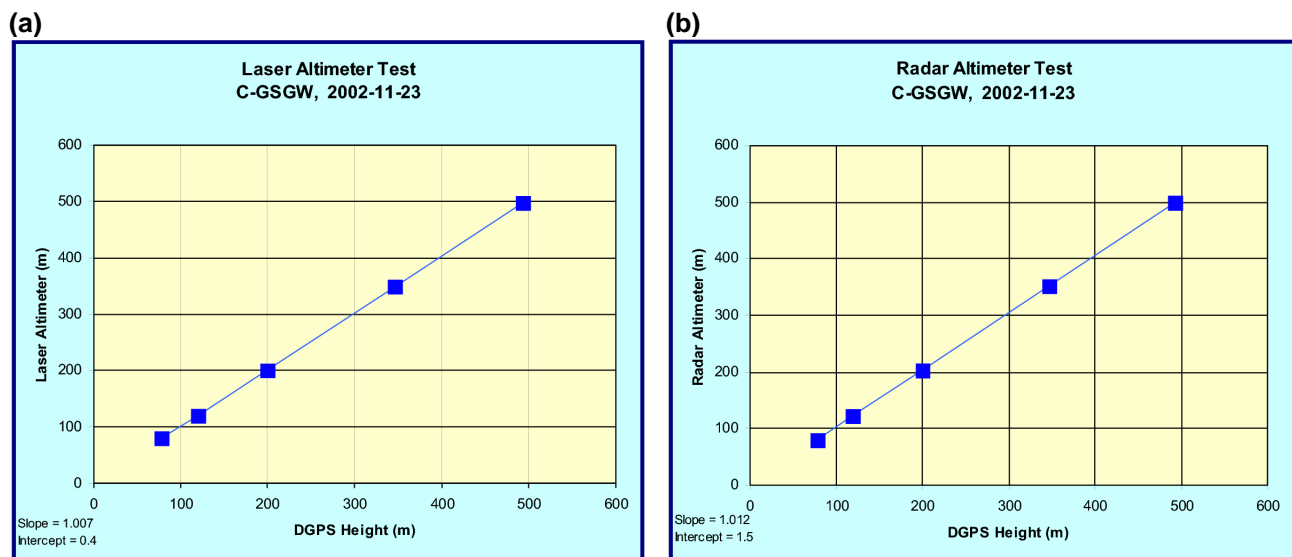


Figure 1. (a) Laser altimeter calibration results. (b) Radar altimeter calibration results.

Digital data compilation

Preliminary processing for on-site quality control was performed in the field as each flight was completed. This included routine printing of data profiles as a hard copy reference, verification of data on the computer screen, and plotting of the DGPS flight path data. Final data processing and map production were performed at Sander Geophysics' head office in Ottawa.

Gravity data

The gravity data processing sequence is described in Sander et al. (2004). Once isolated from the acceleration measurements, the gravity data are corrected for the Eötvös effect and normal gravity. Bouguer anomaly data are derived by applying free-air, Bouguer slab, Earth curvature, terrain and levelling corrections.

Grids of the free air and Bouguer anomaly were generated by filtering the line data to remove high frequency noise and then averaging the filtered line data within the grid using a Fourier domain filter with a

wavenumber mid point equivalent to 2.85 km (0% pass at 2.1 km, 100% pass at 4.3 km), full sine wave, or 1.42 km half sine wave. Note that the filter midpoint is not $(2.1 \text{ km} + 4.3 \text{ km})/2$ because these are wavenumber domain filters. The midpoint is instead $(1/2.1 \text{ km} + 1/4.3 \text{ km})/2$, or about 1/2.85 km.

Positional data

A GPS data processing package, GPSoft, was used to calculate DGPS positions from raw 10 z range data obtained from the moving (airborne) and stationary (ground) receivers. Accurate locations of the GPS antennae were determined by differentially correcting the ground station position data using a permanent GPS reference station. This technique provides a final receiver location with an accuracy of better than 5 cm. The entire airborne data set was processed differentially using the calculated ground station location.

System resolution and accuracy

After the standard processing was completed, the results were evaluated using tests of internal consistency and a comparison with existing ground gravity measurements.

Internal consistency – crossover errors

Internal consistency was measured first by determining crossover errors. The crossover error is the difference between control and traverse line data at each intersection. An 85 s filter (approximately 4 km full sine wave at 50 m/s aircraft speed) was applied to all survey lines for this test. Figure 2 shows a histogram of the errors. The standard deviation of the crossover errors was 0.64 mGal, which indicates an accuracy of $1/(\sqrt{2}) * 0.64 \text{ mGal}$ or 0.45 mGal for the line data.

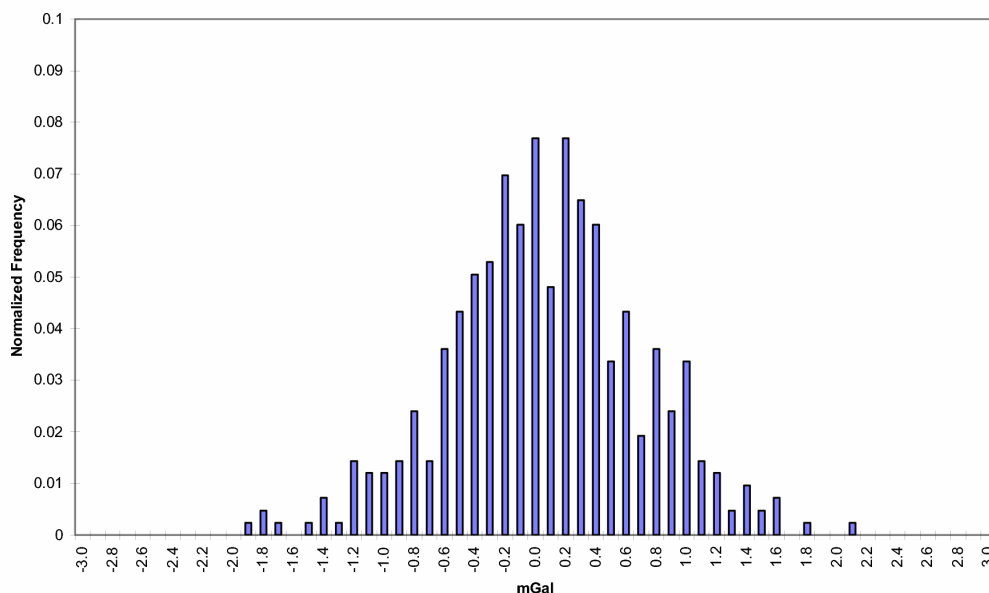


Figure 2. Histogram of flight line and tie line crossover errors. The standard deviation of the errors was 0.64 mGal.

A second test of internal consistency was provided by measuring the difference between two grids, one made from the odd and the second from the even numbered lines (Sander et al., 2002). These grids are two independent data sets of 1 km spaced lines. The 2.85 km spatial filter described earlier was applied to each grid. The standard deviation of the differences between these two grids was 0.29 mGal. This represents a noise level of $0.5 * 0.29 \text{ mGal}$ or 0.15 mGal on the full data set of 500 m spaced lines.

External consistency – ground data comparison

Further evaluation of the data was made through comparisons of the airborne data to ground Bouguer gravity data acquired in previous years. The ground data consists of several distinct sets of data points. The largest and most recent survey was performed in 2001 and has 573 stations within the AIRGrav survey area. A further 213 ground readings taken between 1949 and 1970 supplement the 2001 survey, for a total of 780 ground readings. A map showing the relative location of the airborne survey flight lines and all ground data points is given in Figure 3.

A grid was created from the ground data points using a minimum curvature gridding algorithm and 250 m grid cell size, matching the AIRGrav data grid. This may appear to be a relatively coarse grid cell size given 500 m line spacing, but this spacing was considered adequate given the filters used on the airborne data and the spacing of ground points. Areas that were more than three grid cells away (750 m) from a ground data point were left as nulls in the grid, indicating places where ground coverage is incomplete. The AIRGrav grid and the ground grid are given as [Figures 4](#) and [5](#), respectively.

As these figures show, the AIRGrav and ground data match very well. They are displayed in [Figures 4](#) and [5](#) with identical contours, colour levels, and grid cell sizes. After tying AIRGrav ground readings at the airport to the known gravity value at the airport (see [Table 2](#)), a small constant offset was found to be present between the airborne and ground data in the survey block. This offset results from a combination of errors in the ground data set, errors and noise in the airborne data, differences in terrain heights used for Bouguer corrections in each data set, and other systematic data reduction differences. The offset was easily removed by applying a single shift to the entire airborne data set. The average difference between the airborne and ground data points, 1.4 mGal, was added to the AIRGrav grid. This is the simplest and most reliable way of tying the airborne data to existing ground surveys. No other adjustments, such as stretching or tilting, are necessary.

A more direct comparison of the ground and airborne data is provided in [Figure 6](#). The ground data were first upward continued by 200 m, the average aircraft height above the ground. These data were then subtracted from the AIRGrav data to produce the difference grid shown in this figure.

The best way to quantitatively compare the ground data set with the AIRGrav data is on a point-by-point basis. A simple grid comparison is less valid because there are many cells within the grid that do not contain an observation. The values in these cells are entirely dependent on the grid interpolation method. For each ground reading, the east and north UTM coordinates were used to select a value from the AIRGrav grid. The ground readings were upward continued by 200 m, the average aircraft height above the ground. For the 780 ground readings that fall within the AIRGrav survey boundary, the standard deviation of the differences between the air and ground readings was 0.62 mGal. It should be noted that this statistic of the differences between ground and airborne data includes the errors present in the ground data, and hence represents an upper limit on the noise in the airborne data.

Another AIRGrav survey with very similar specifications was recently flown over a petroleum basin. The internal consistency as measured by crossover errors was the same as that obtained for the Timmins survey, but the agreement with ground gravity data was better than that obtained for the Timmins Surveys (0.35 mGal in the petroleum basin compared with 0.62 mGal in Timmins). There are a number of potential reasons for the difference. We believe two factors are the most significant in this instance. First, the geological signal in the Timmins area has shorter wavelengths and larger amplitudes. The attenuation of these geological signals with flying height would be greater than over a petroleum basin where sources may be several kilometres deep, and consequently have long wavelengths and small amplitudes. A low-pass filter applied to the airborne data is also more likely to alter the geological signal in Timmins than in a petroleum basin where longer frequencies are dominant. Second, the quality and sampling of ground data points is variable in ground surveys. The standard deviation of differences includes any errors in the ground data. Where ground data are higher quality, the standard deviation of the differences between airborne and ground data sets will be smaller since errors in each data set should not be correlated.

Details in the Bouguer gravity grids can be enhanced by calculating the first vertical derivative (FVD). [Figures 7](#) and [8](#) show the FVD of the AIRGrav Bouguer gravity and the upward continued ground gravity data grids, respectively. Again, all the significant features in the ground data are clearly captured by the AIRGrav system.

There is good correspondence between the AIRGrav gravity data and features shown on geological maps of the area. [Figure 9](#) shows the first vertical derivative of the AIRGrav grid with a geological overlay. As expected, gravity highs tend to be associated with higher density rock types.

Discussion

The survey results show that the AIRGrav system can be used to quickly acquire gravity data. Only four flights over four days were needed to complete the survey covering 810 km². The data were evenly sampled and hence the final data represent a consistent grid dataset. The survey was flown at a relatively low altitude (200 m average terrain clearance) and in normal daytime conditions.

Laser altimeter data were combined with the post-flight differentially corrected GPS data to create a digital terrain model. High resolution magnetic data can be acquired concurrently with gravity data during a survey, although they were not required in this instance because of existing coverage in the area.

The accuracy and resolution of airborne gravity data depend in part on aircraft speed and survey line spacing. The results obtained on this survey could be enhanced by flying closer line spacing or by flying the survey at a slower ground speed using a helicopter. Doubling the line spacing to 250 m or using a helicopter to fly at approximately 50 knots (25 m/s) would have the effect of reducing errors (if the filter length is unchanged) or increasing resolution (by producing the same error level with a shorter filter).

In this example, the survey was flown with 500 m line spacing. The data were low-pass filtered to a wavelength of 2.85 km. An analysis of flight line and tie line crossover errors indicated a standard deviation of 0.64 mGal, suggesting a noise level of 0.45 mGal for the data. The method of odd and even line number grids revealed differences with a standard deviation of 0.29 mGal, suggesting a noise level of 0.15 mGal for the data. A comparison with upward continued ground gravity data produced a standard deviation of 0.62 mGal, which represents an upper limit on the accuracy of the airborne data.

Following on from this evaluation survey, three larger survey areas in the Timmins region were flown at 500 m and 1 km line spacing with the AIRGrav system to upgrade the present ground gravity coverage (see announcements on the Discover Abitibi website; www.discoverabitibi.com). These data are expected to assist regional mapping for mineral exploration purposes.

Acknowledgements

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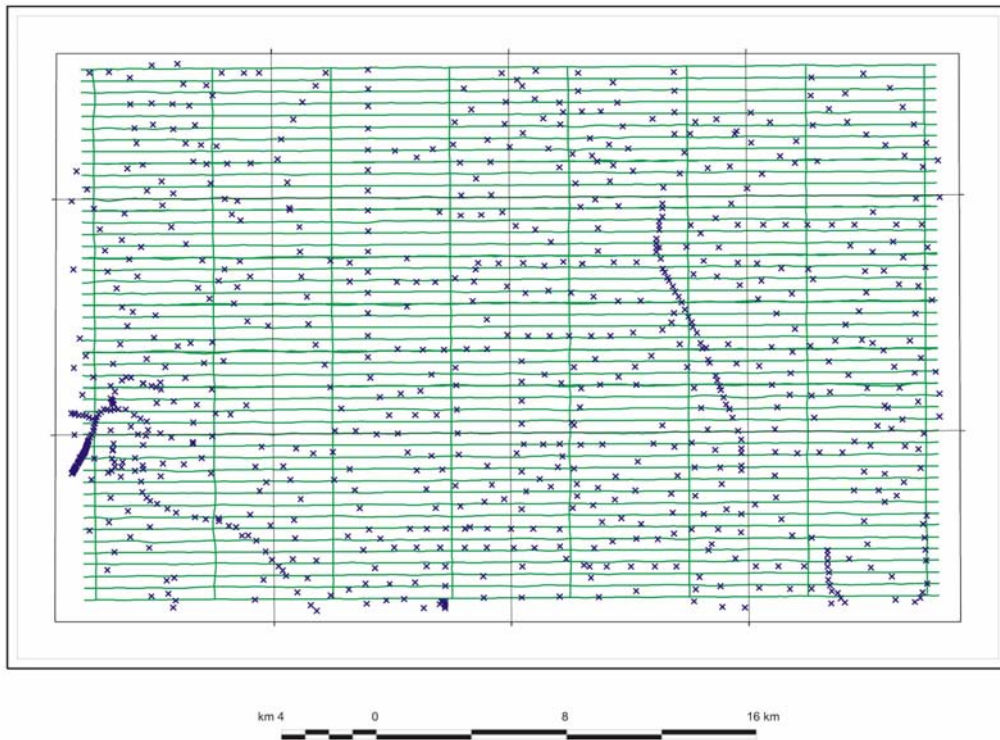


Figure 3. Map of gravity data coverage. AIRGrav flight lines are shown as green lines, and ground data points as blue crosses.

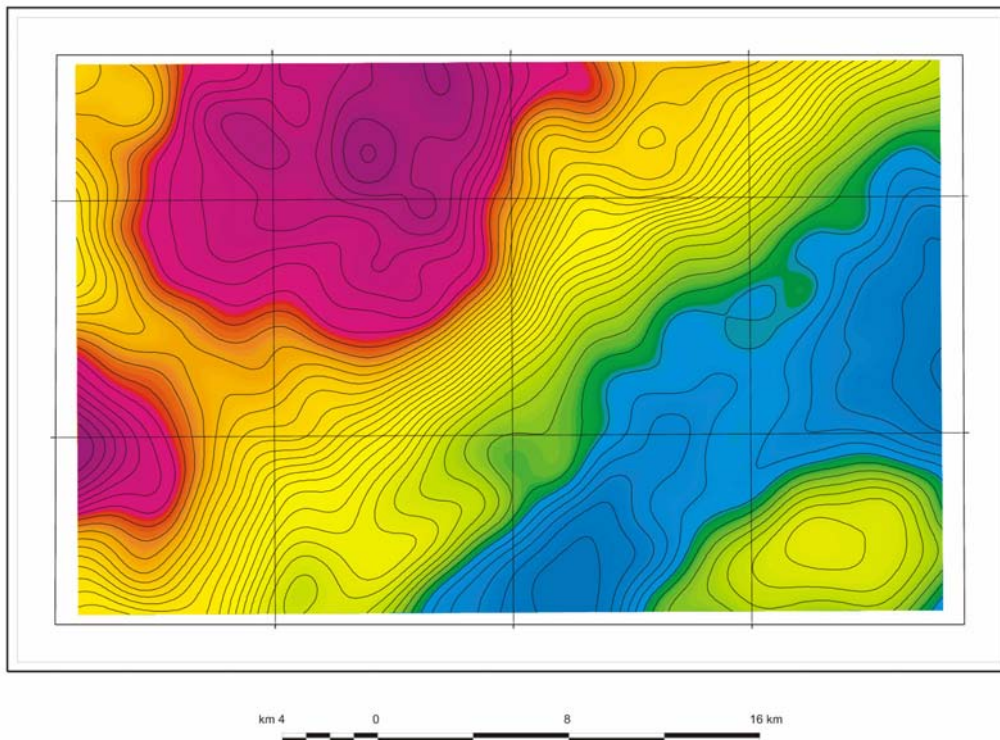


Figure 4. AIRGrav Bouguer data grid with 1 mGal contour levels and 10 km UTM graticule. Note that all subsequent figures are shown with the same 10 km UTM graticule.

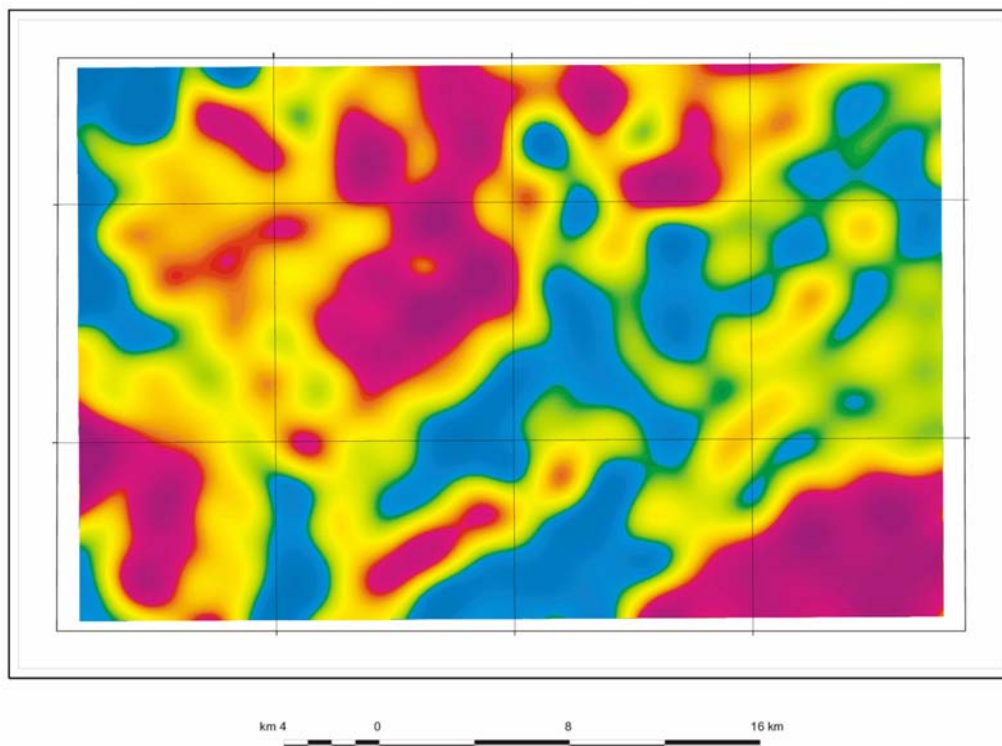


Figure 7. First vertical derivative of the AIRGrav Bouguer gravity grid.

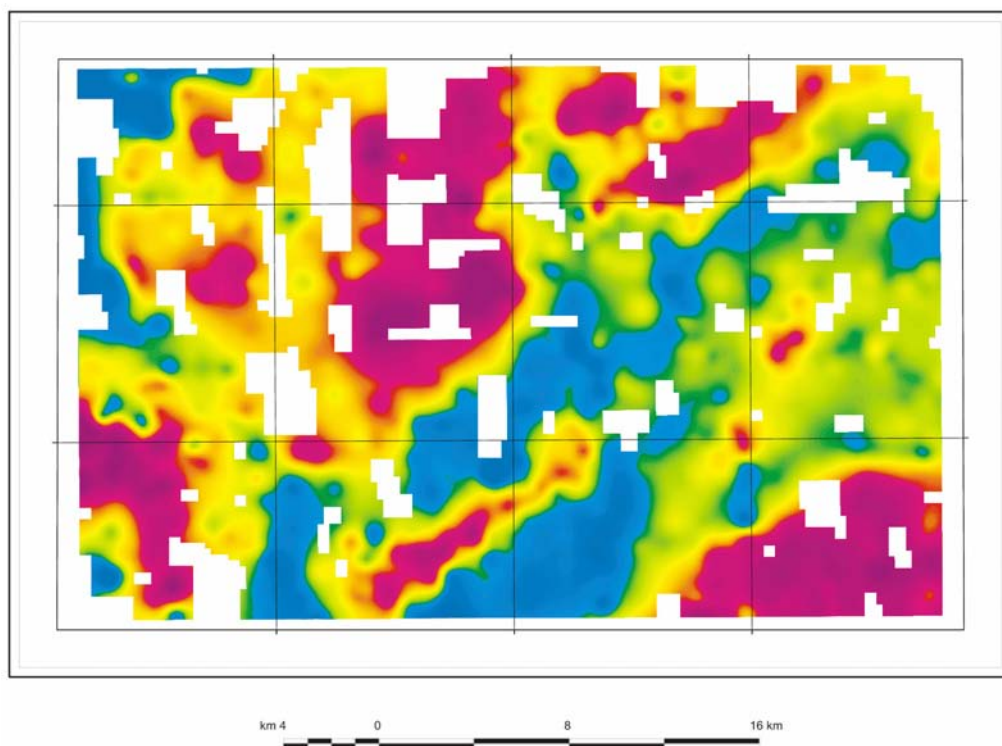


Figure 8. First vertical derivative of the ground Bouguer gravity grid after upward continuation by 200 m.

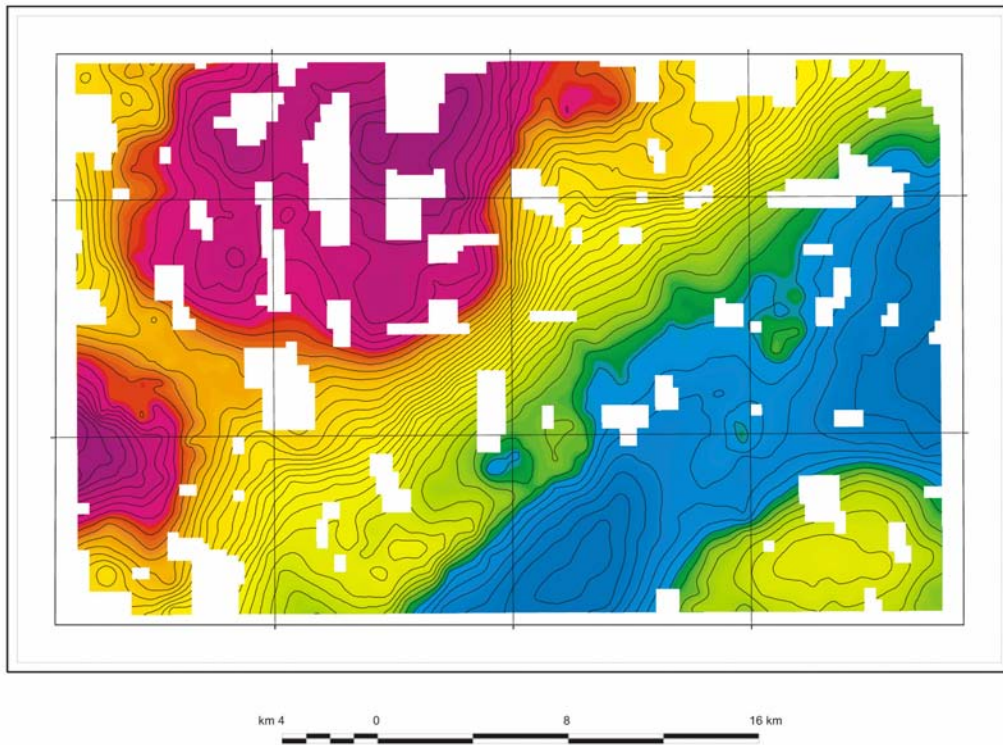


Figure 5. Ground Bouguer data grid with 1 mGal contour levels.

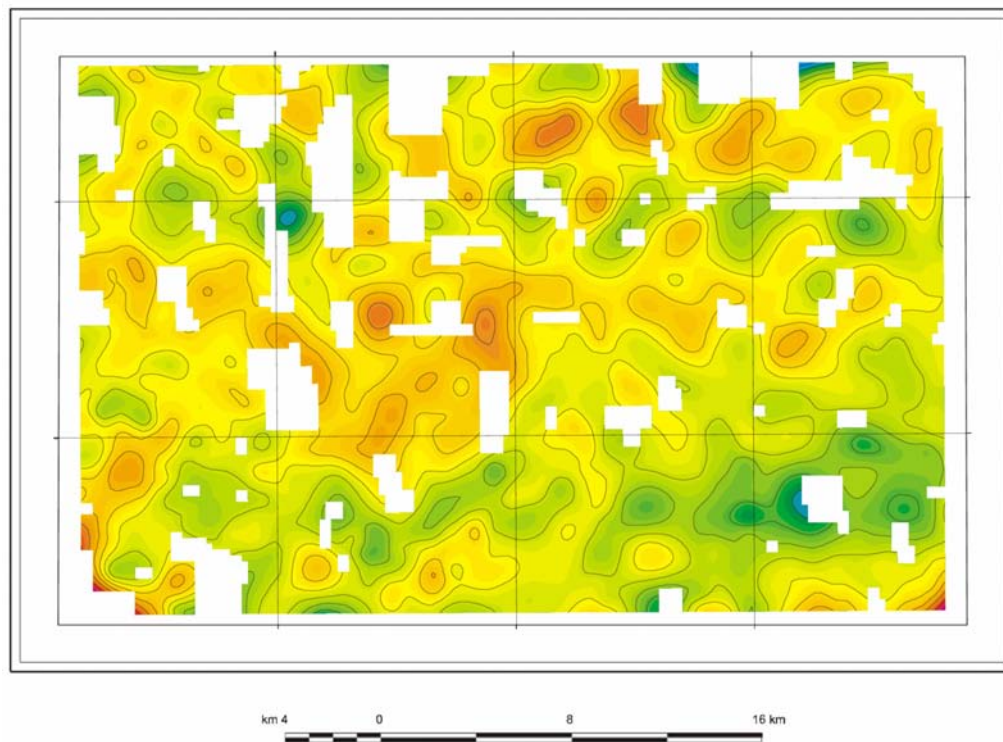


Figure 6. Image of the difference between Bouguer gravity values from AIRGrav and upward continued ground data. The contour interval is 0.5 mGal.

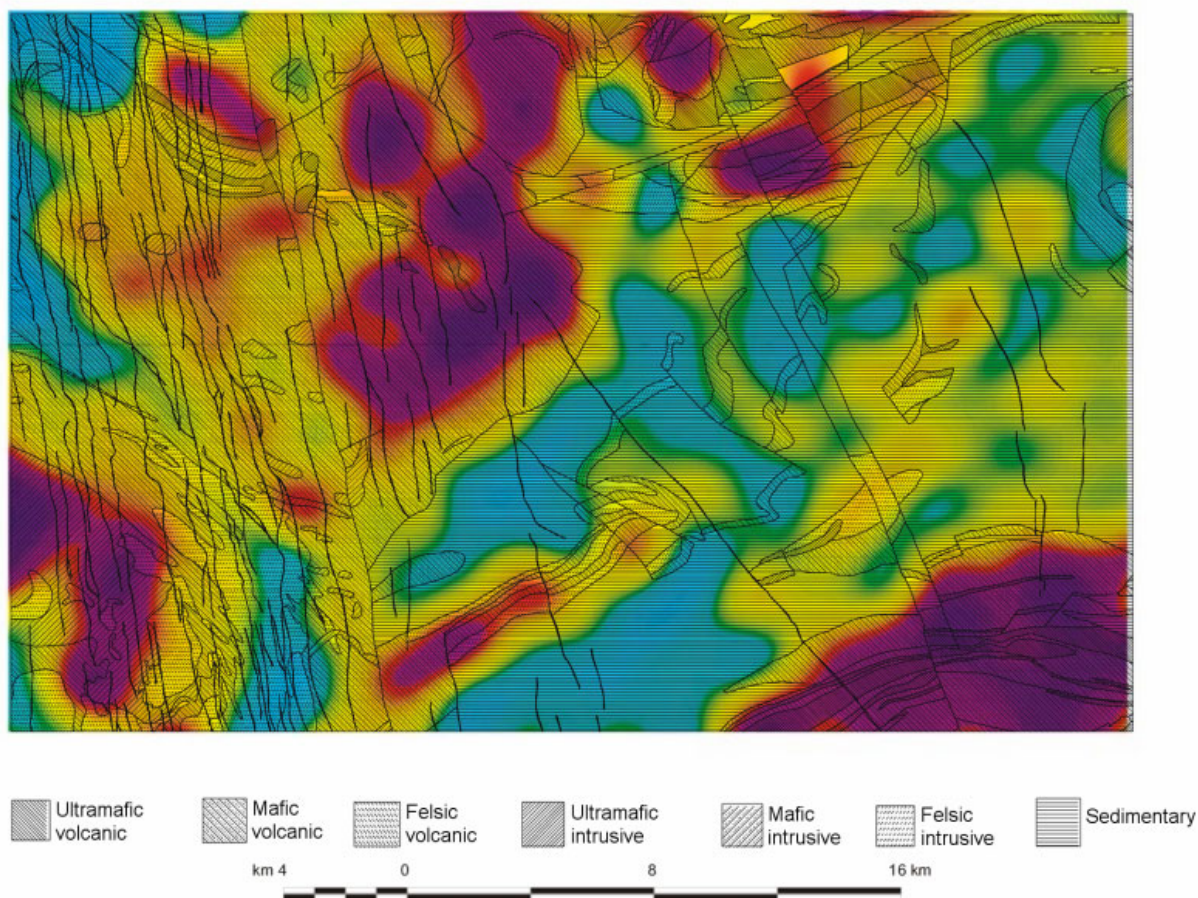


Figure 9. First vertical derivative of the AIRGrav Bouguer gravity grid with geology overlay.