FALCON test results from the Bathurst Mining camp

SUMMARY

BHP commenced exploration surveying with the world’s first fully operational, airborne gravity gradiometer in October 1999. This gradiometer (called Einstein), together with a later one called Newton, was developed in conjunction with Lockheed Martin by BHP’s FALCON project. Falcon data are acquired by Sander Geophysics Ltd., flying a Cessna Grand Caravan to survey specifications typical of aeromagnetic surveys.

The first FALCON survey was flown over a portion of the Bathurst mining camp in New Brunswick, Canada in order to compare system performance with existing extensive and detailed ground-gravity data.

The ground-gravity data, supplied courtesy of Noranda Minerals Exploration Ltd., were upward continued to the flying height and vertically differentiated to provide vertical gravity gradient data suitable for comparison with the airborne data.

The two data sets compare very well and the results demonstrate that FALCON airborne gravity gradiometer is capable of detecting sources with a vertical gravity gradient signal of greater than 10 Eö and a full-width at half-maximum of 500 m.

Key words: Airborne gravity gradiometry, Bathurst, VMS.

INTRODUCTION

Project Falcon successfully developed two airborne gravity gradiometers (AGGs) in a joint research and development programme between BHP and Lockheed Martin (van Leeuwen, 2000). These AGGs were christened Newton and Einstein. Einstein was delivered first and commenced survey work on 10th October 1999. The first survey was a test survey over part of the Bathurst Mining Camp in New Brunswick, Canada in order to compare system performance with existing extensive and detailed ground-gravity data.

The area is one with detailed ground gravity and the purpose of the test was to verify AGG performance against a truth set of known gravity. In addition, the site is relatively close to the Lockheed Martin facility in Niagara, New York, where the Falcon systems were built.

The AGG is based on technology developed by Bell Aerospace (now Lockheed Martin). Lee (2001) summarises the key features of the instrumentation. Related instruments include the GGSS (Jekeli, 1988) and the 4D gravity gradiometer (Talwani et al, 1999).

GEOLOGIC BACKGROUND

Summaries of the geology of the region and of the base-metal deposits can be found in van Staal et al. (1992) and McCutcheon (1992) respectively.

The Bathurst Camp is a sub-circular area approximately 50 km across located in the eastern end of the Miramichi Highlands in New Brunswick, Canada. It has been explored intensely since the first massive sulphide discoveries were made in the early 1950’s. Overburden is generally thin and resistive hence soil geochemistry, EM and mag were the main tools used to discover the deposits. The Heath Steel deposit is generally accepted to be the first discovery attributed to airborne EM.

It is now the first deposit detected by airborne gravity gradiometry.

Figure 1. Heath Steele – Stratmat geology and massive sulphide ore zones (modified from a 1:20,000 scale map provided by Noranda Minerals Exploration Ltd.

The massive sulphide deposits of the Bathurst Camp are invariably associated with tuffite and silicic volcanic rocks of the Nepisiguit Falls and Flat Landing Brook formations.

Figure 1 shows the Heath Steele area geology. Detailed descriptions of the geology can be found in Wilson (1993), deRoo et al. (1991) and McAllister (1959). Both the smaller Stratmat deposits in the north and the Heath Steele deposits are associated with relatively thin units of argillite and wacke within the mainly rhyolitic felsic tuff sequences. The Heath Steele deposits are also associated with thin iron formations, typical of Brunswick type deposits. The iron formations are not present in the Stratmat deposits.

Many of the deposits have direct, diagnostic magnetic and EM signatures and many are flanked by magnetic anomalies related to intermediate intrusive and volcanic rocks associated with ore formation (Keating et al., 1998).
GROUND GRAVITY

Typically, the deposits have a density of about 4 g/cm³, whereas the host rocks (fine grained sediments, felsic tuffs, or their metamorphic equivalents) have densities between 2.7 and 2.8 g/cm³ (Thomas et al., 1996). This makes gravity an attractive tool for VMS exploration in the Bathurst camp.

Extensive ground gravity data had been collected over the area by Noranda Minerals Exploration who kindly made these data available for comparison with the AGG data. The ground gravity consists of 13,490 stations collected on a variety of locally surveyed grids at 25 m intervals on 100 and 200 m spaced lines. The Bouguer gravity was reduced with a density of 2.85 g/cm³ and included terrain corrections.

Comparison of the elevation data accompanying the ground gravity with the digital elevation model for the area revealed data mis-locations for some gravity sub-grids. These were corrected by horizontal datum shifts. Occasional spikes in the gravity data were replaced with a value predicted from a three point median filter.

AGG DATA ACQUISITION AND PROCESSING

Falcon survey data acquisition was carried out by Sander Geophysics Ltd. (SGL) using a Cessna Grand Caravan (CG-SGZ). On board was Einstein (AGG system serial number 002), a stinger-mounted cesium vapour magnetometer, radar and barometric altimeters, a flight video camera, gust probe, fuel level sensors and a laser profilometer. Subsequent to this survey, a laser scanner was added.

The survey was flown with 100 m spaced lines at a nominal ground clearance of 120 m, using SGL’s drape flying system (Sander, 1998). The lines were 11 km long, at a heading of 65.5°, navigated on DGPS. The survey was designed to cover the ground gravity data. Generally speaking, a minimum line length of 10 km is recommended for AGG surveys, in order to provide sufficient data for good noise reduction in processing.

Acquisition took place between 10 and 17 October 1999 in generally poor weather conditions. This limited production and also meant that the survey was flown in higher turbulence than desired.

We estimate turbulence by the RMS vertical acceleration, in milli-g, over the frequency band from 0.3 to 10.0 Hz. The Bathurst survey was completed in three flights with turbulence often reaching 110 mg (with occasional spikes to 180 mg) and averaging 60 mg. In general, we (and the aircrew) prefer to restrict survey flying to turbulence below 90 mg.

These high levels of turbulence led to high gravity gradient noise. The standard deviation of the difference between the Noranda and the AGG vertical gravity gradient grids is 9.0 E-6. If all the error is in the AGG data, then this suggests an upper limit of 9 E-6 RMS noise.

The key processing steps, in order of application, were: correction for residual aircraft acceleration effects (called post mission compensation or PMC), demodulation and filtering, correction for gravitational effects of the aircraft and platform (self-gradient), terrain correction and transformation to vertical gravity and vertical gravity gradient. The bandwidth limiting step was the post-demodulation filtering with a 6 pole Butterworth filter at a cut-off of 0.125 Hz. At the nominal ground speed of 50 m/s this corresponds to a wavelength of 400 m.

Improvements to the AGG systems and processing software since the Bathurst survey have reduced the sensitivity to turbulence and typical AGG survey noise in the vertical gravity gradient can be as low as 5 E-6 RMS at a 0.18 Hz cutoff frequency.
aerial photographs. Comparison of this DEM with one generated from the elevations recorded for the Noranda ground gravity surveys revealed an RMS difference of 4.4 m and a mean difference of 37 m. The latter is simply a datum shift and the laser profilometer data from the Falcon survey were used to fix the DEM datum to WGS84. The RMS difference is due mostly to registration errors in horizontal locations for some of the ground data. Comparison of the NBGIC DEM data with the data from the laser profilometer showed that the NBGIC DEM has an elevation accuracy of 1 to 2 m.

The AGG measures the differential curvature components of the gravity gradient tensor relative to a north, east, down coordinate system. Dransfield (1994) fully describes the various components of the gravity gradient tensor. The AGG curvature components are transformed to vertical gravity and vertical gravity gradient in the processing. Since these are explicitly in the NED coordinate system, with down positive, we refer to these outputs as $g_D$ and $G_{DD}$.

The geographic coordinates on all results shown here are in UTM zone 19 referenced to the WGS84 datum.

RESULTS

The final vertical gravity gradient map produced from the FALCON survey is presented in Figure 5. This is to be compared with the “ground truth”, the vertical gravity gradient map produced from the ground gravity and shown in Figure 2. In addition, the TMI data, collected as part of the FALCON survey, are presented in Figure 4.

Study of the two vertical gravity gradient maps shows considerable similarity. All of the main features associated with the gabbroic intrusives and the ore-bearing horizons, visible in the Noranda data are also mapped by the AGG, including even the subtle sub-linear trend running through the centre of the survey area and parallel to the two ore-bearing trends.

The AGG measures gravity gradients relative to an arbitrary gravity gradient datum. As a consequence the processed vertical gravity gradient data are also only accurate to some arbitrary datum and the vertical gravity results can only be known to some unknown linear trend. Thus we expect that any linear trends in the vertical gradient calculated from the ground gravity will not be present in the AGG vertical gradient.

This is observed in the Bathurst survey results, with a clear linear trend in the Noranda gravity gradient (from high in the east to low in the west) which is not present in the AGG data.

All data sets demonstrate key features of the geology of the region. Gabbroic intrusives (shaded in pink in Figure 1) are clearly visible at 5 239 000 N, 720 000 E and at 5 245 000 N, 718 000 E. In addition, the broader magnetic features at the StratMat and Heath Steele deposits coincide with stronger gravity features suggestive of intrusives associated with these deposits but not visible in the surface geology.

Some resolution is lost in the AGG data as expected given the strong filtering necessary for noise reduction in this first FALCON survey.

Figure 5. The AGG vertical gravity gradient. The data are only shown here for the region covered by ground gravity. The location of the sulphide deposits are marked in black.

The banded iron formation associated with the Heath Steele and Brunswick deposits in the south is well mapped in the TMI and the coincident ore-bearing horizon is clear in the vertical gravity gradient maps. The StratMat deposits are not on a BIF but the associated linear trend is again mapped by the gravity. Also visible in the gravity is a more subtle linear feature, parallel to and between the other two, extending south-west from a known sulphide deposit.

Finally, a comparison of Figure 3 and Figure 5 shows that the terrain corrections have been effective with no obvious correlations between elevation and vertical gravity gradient.

CONCLUSIONS

We have successfully demonstrated the capabilities of the first, fully-operational, airborne gravity gradiometer in a FALCON survey over the Heath Steele and StratMat deposits in the Bathurst mining camp. The results have been compared with known detailed ground gravity and show excellent correspondence. The differences, in linear trend and at very short wavelengths, are well explained by the known characteristics of the AGG.
The results are consistent with the estimated vertical gravity gradient noise of 9 E\text{ö} RMS in a 0.125 Hz bandwidth for this survey. Subsequent improvements to the AGG have resulted in a reduction in the noise to 5 E\text{ö} RMS over a 0.18 Hz bandwidth.

In addition, the AGG data, combined with the TMI data also collected on the FALCON survey, show a clear correspondence with the main geological features of the survey area, particularly those features associated with the distribution of VMS deposits.

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REFERENCES

