Detecting kimberlite pipes at Ekati with airborne gravity gradiometry

Guimin Liu, Peter Diorio, Peter Stone, Grant Lockhart, Asbjorn Christensen, Nick Fitton and Mark Dransfield
BHP Minerals
liu.guimin.g@bhp.com

SUMMARY
From late April to the end of July 2000, a 39,000 line km airborne gravity gradient survey was completed over the Ekati™ mine property in the NWT, Canada. This was the world’s first airborne gravity gradient survey for the purpose of detecting kimberlite pipes. Preliminary data processing was done on site at the Ekati™ diamond mine. Subsequent drilling of gravity anomalies in the year 2000 has resulted in the discovery of two new kimberlite pipes. More anomalies will be drilled in 2001.

The AGG data shows that more than half of the known kimberlite pipes have associated gravity anomalies. Some pipes with a diameter as small as 100 m or less can be detected in the AGG data. The AGG data has a 300 m resolution with an average RMS noise of 7.6 Eotvos in the derived vertical gradient. Laser profilometer data and differential GPS data were also acquired in the survey to construct a detailed digital elevation model for terrain correction.

Besides detecting kimberlite pipes, the AGG data is also useful for mapping details of geological structures. This is complementary to the magnetic data acquired simultaneously with the AGG data.

Key words: Airborne gravity gradiometer, kimberlite, diamonds.

INTRODUCTION
Following the successful deployment of BHP’s first airborne gravity gradiometer (AGG) system (dubbed “Einstein”) in late 1999, the construction of the second AGG system, “Newton” was completed in April 2000 at Lockheed-Martin’s facility in Buffalo, NY, US (van Leeuwen, 2000). These systems were developed by BHP’s Project Falcon for mineral and hydrocarbon exploration to detect small gravity signal variations associated with the exploration targets (Lee, 2001).

Each of the BHP’s AGG systems is installed on a Cessna Grand Caravan aircraft operated by Sander Geophysics Ltd. Also installed on the aircraft are a differential GPS navigation system, a laser scanner and a magnetometer. The GPS and laser scanner data are acquired to build an accurate digital elevation model (DEM) (Stone, 2001) for use in the terrain correction of the AGG data. The laser scanner was not available in time for the Ekati survey and a downward pointing laser profilometer was used instead to build the terrain model. A stinger mounted magnetometer provides high resolution magnetic data.

The Newton system was deployed immediately on the Ekati survey after it was built and this was the first ever AGG survey for diamond exploration. Two small test surveys were carried out to verify the capabilities of the new AGG system before the start of the main survey. The test surveys and the main Ekati survey were completed in three months from late April to the end of July 2000. A total of 39,000 line km was flown.

SURVEY DESCRIPTION
The survey crew from Sander Geophysics Ltd. and the AGG aircraft mobilized to Ekati diamond mine near the end of April 2000. The mine camp is located near the centre of the Ekati survey area and was used as the base for the survey. Two test surveys were performed in early May. Each of these test surveys covers an area of 10 km long by 5 km wide. The Point Lake test survey was flown at 100 m line spacing at the NE-SW flight direction. The Pigeon test survey was flown at the E-W flight direction with most of the survey covered by 100 m spaced lines. A patch (20%) of the Pigeon survey was done at 50 m line spacing. Most of the known kimberlites in the test areas were clearly seen in the AGG data. It was concluded that the performance of the Newton AGG system was satisfactory for kimberlite pipe detection in this environment and the main survey began in mid-May. The vertical gravity gradient data for the Point Lake test was published on BHP’s internet site (http://www.bhp.com >> BHP Minerals >> FALCON).

The two test surveys demonstrated that the 100 m line spacing is satisfactory for kimberlite detection at Ekati and the survey results are not sensitive to flight direction. The main Ekati survey was thus flown at E-W direction at 100 m line spacing with a nominal flight height of 80 m above ground.

The weather at Ekati was cold in early May with occasional snow. The turbulence during survey flights was low. Toward the end of July it became warm and the temperature was often in the mid-twenties during the day. The turbulence was moderately high for afternoon flights. It was often low to moderate for morning flights. The AGG system noise is related to the turbulence during flight however, this noise level is well within the system specification even under the most turbulent conditions in the survey.

Two aircrews were on site for part of the survey. Under good conditions two flights were completed per day with 600 line km in each flight giving a maximum daily production of 1200 line km. On average, however, a daily production rate of 400 line km was achieved for the Ekati survey including the period of mobilisation. There were a few interruptions during the survey due to bad weather, maintenance of the survey aircraft, and repairs of the computer data acquisition system. The AGG system itself performed without problems during the survey.
DATA PROCESSING

The AGG system acquires the differential curvature gradient components $G_{NE}$ and $G_{UV}$ data at a high sampling rate. The raw data from each flight is about 2.5 gigabytes in size. This data is down-sampled to 8 Hz after going through a variety of noise reduction and filtering processes through BHP’s proprietary processing software package. The processed data for different flights are later merged together and converted to the vertical gravity gradient $G_{DD}$ and the vertical gravity $g_D$ for geological interpretation.

Part of the data processing involves the construction of a high-resolution DEM from the laser profilometer data and the differential GPS data. This elevation model is then used in the removal of terrain response from the data.

Besides terrain correction, self-gradient corrections were also applied to the data. The self-gradient correction removes the effect of the gravity gradients from the mass distribution of the AGG system, the aircraft and the aircrew.

Much of the data processing was done on site. Preliminary $g_D$ and $G_{DD}$ results were obtained on site for a majority of the survey area. To convert $G_{NE}$ and $G_{UV}$ data to $G_{DD}$, the survey area was divided into a number of rectangular blocks. This is due to the large computer memory required in the computation of $G_{DD}$ from $G_{NE}$ and $G_{UV}$. Preliminary terrain-corrected $G_{DD}$ and $g_D$ results were computed for each block within a few days after the data was acquired for that block.

The final data processing was done at the Melbourne data processing centre. This involved the construction of a DEM grid for the entire survey, computation and removal of the terrain effects, the computation of the $G_{DD}$ and $g_D$ results for sub-divided blocks of the survey, and merging of the results into a single $g_D$ and $G_{DD}$ grid for the survey.

SURVEY RESULTS

Figure 1 shows an image of the $G_{DD}$ result for the entire Ekati survey. Many kimberlite pipes show up as gravity lows (dark colour) on this image. Only three of them are annotated.

Of the 136 known kimberlite pipes, about 55% of them have associated gravity lows, some of which are weak anomalies. As well as the larger pipes some small pipes are clearly evident on the gradient image. Pipes as small as 100m in diameter sometimes have a recognisable anomaly. This should be qualified by two factors. Firstly the gravity anomaly is often augmented by the presence of a water or sediment filled depression or crater over the pipe and secondly the diameter of the pipes is often only crudely estimated from limited drilling and geophysics.

Soon after the survey was completed, five gravity anomalies from this data were drilled and two new kimberlite pipes were discovered. More anomalies have been identified from this data set and will be drilled in the year 2001.
Fig. 1. Vertical gravity gradient $G_{DD}$ from the Ekati survey. The image on the right shows an enlarged section of a south-east part of the image on the left. Two dykes separated at just over 300 m are resolved on the right image, in which the white bar has a horizontal dimension of 300 m.

Fig. 2. Vertical gravity $G_D$ from the Ekati survey.

COMPARISON WITH PIGEON TEST DATA

The $G_{DD}$ image from the Pigeon test area is shown in Figure 3. The main survey covered this same area at the same flight altitude and direction again in late June. This portion of the main survey is shown in Figure 4. The Falcon Pipe, several other kimberlite pipes and some geologic structures are clearly seen in both images in Figures 3 and 4. This demonstrates the repeatability of the Falcon survey data.

Turbulence, which is often related to temperature, was higher in late June than in early May. This results in higher noise for the main survey (7.6 Eotvos RMS) compared to the Pigeon survey (5.4 Eotvos RMS). Because of the higher noise, the two NW-SE dykes clearly observable in the Pigeon test $G_{DD}$ data (west of the Falcon pipe, Figure 3) are not as clear in the Ekati survey $G_{DD}$ data in Figure 4.
Detecting kimberlite pipes at Ekati with airborne gravity gradiometer

CONCLUSIONS

The Ekati Falcon survey data demonstrates the AGG system is a useful tool in the search for kimberlite pipes. Two new kimberlite pipes have already been discovered from the use of the survey data. The data has a resolution of 300 m with a RMS noise of 7.6 Eotvos in the derived $G_{DD}$ data. Kimberlite pipes, some with a diameter as small as 100 m, and thin dykes were detected in the AGG data. Besides detecting kimberlite pipes, the AGG data is also useful for mapping details of geological structures. This is complementary to the magnetic data acquired simultaneously with the AGG data.

ACKNOWLEDGEMENTS

We are grateful for the permission of BHP Diamonds Inc. to publish this paper. We would like to thank Rob Ellis for his assistance in processing the data and the FALCON team for their support and technical contribution: Dr Edwin van Leeuwen, Dr David Boggs, Dr Maurice Craig, Mr Peter Cupit, Dr Mark Downey, Ms Anna Dyke, Mr Nigel George, Dr James Lee, Dr Xiong Li, Dr Ken McCracken, Mr Arthur Madder, Ms Asmita Mahanta, Ms Norma Malouf, Dr Tim Monks (Deceased), Dr Graeme O’Keefe, Mrs Marion Rose, Mr Chris Rowland, Mr Bob Turner. Sander Geophysics Ltd. flew the Ekati survey under a contract with BHP Minerals.

REFERENCES


