Estimating the pre-mining gravity and gravity gradient response of the Broken Hill Ag-Pb-Zn Deposit

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SUMMARY

Mining of the Broken Hill Ag-Pb-Zn deposit has substantially modified what was originally a positive anomalous mass. When an airborne gravity gradiometer (AGG) survey was flown over the Broken Hill region in early 2003, the measured response reflected the modified mass distribution. To answer the questions “What was the original response of the orebody?” and “Would this response have been detected had the survey been flown prior to mining?”, an estimate of the changes in response brought about by mining activities was made and added to the survey data to produce an image of the pre-mining gravity response.

To estimate the change in response, a 3D model of the mined portion of the deposit was built. An estimate of the change in mass due to mining activities was made and this mass was distributed with uniform density throughout the model. The gravity and vertical gravity gradient response of the orebody model was then calculated, filtered to match the characteristics of the AGG data and added to the observed survey data.

The ‘corrected’ data show distinct gravity and gravity gradient highs over the northern and southern parts of the orebody which hosted the bulk of the reserves. Although the anomalous response is close to the noise levels of the survey data, we can conclude that the AGG survey would have detected an anomalous response from the Broken Hill orebody had the survey been flown prior to mining. However, there are other geological features in the survey area that produce similar anomalies, notably a number of amphibolite units.

Key words: Broken Hill, gravity gradient, airborne survey, density, mining.

INTRODUCTION

Airborne gravity gradiometer (AGG) data were acquired over a 1000 km² area in the Broken Hill district of western New South Wales, Australia, in early 2003 using a Falcon AGG system. Lines were spaced at 200 m intervals and the mean terrain clearance was 80 m (Hensley, 2003). The principal products from the survey were grids of vertical gravity, gD, and vertical gravity gradient, Gdd. The survey was carried out to stimulate exploration in the area and to allow governments to assess the technology for possible use to improve the regional gravity coverage of Australia (Lane et al., 2003).

The planning phase of a geophysical survey includes consideration of the amplitude and spatial extent of anomalies for sources analogous to those being targeted by the survey and for sources that are often described as giving rise to “geological noise”. With this knowledge, specifications for noise levels and the spacing between observations can be drawn up such that there would be a reasonable chance of successfully detecting the response from targets and discriminating this response from features of lesser interest.

There are two complementary ways to obtain knowledge of the gravity response of targets. Forward modelling can be carried out using estimates of the geometry of the target and the density contrast between the target and host. Alternately, the response of real deposits can be studied. Surveys over deposits are best carried out prior to the commencement of mining activities because the logistics are more straightforward at this time, there is less likelihood of interference from anthropological sources, and the physical properties of the deposit are relatively undisturbed.

A century of mining of the Broken Hill Ag-Pb-Zn deposit has significantly altered the distribution of mass and made it impossible to measure the original gravity response of the deposit. Several theoretical gravity and gravity gradient calculations of the Broken Hill deposit geometry have been made previously (eg Pecanek, 1975; Tucker, 1983; Dransfield, 1994). In the present study, a model was constructed to reflect the portions of the ore body that have been mined. This was used in forward model calculations to not only estimate the response of the deposit in its pre-mining state, but to also estimate the change in the response caused by mining activities up to the present. With these estimates, it is possible to ‘correct’ the ground gravity and airborne gravity gradiometer observations for the impact of mining. This result facilitates a discussion on detection of targets similar to the Broken Hill deposit using gravity methods.

METHOD

Preparing a model of the mined portion of the deposit

The Broken Hill deposit is hosted by a distinctive lode horizon that is shown on geological maps. A vertical surface or “curtain” was created along the trace of this unit as an approximation to the steeply dipping plane of the deposit. The outlines of the Lead and Zinc Lodes were digitised from a long section of the deposit (Figure 1 of Johnson and Klingner, 1975), and projected onto the lode horizon curtain using the locations of the Zinc Corporation Main Shaft and NBH No.2 Shaft as reference points.

A 3D block model (“voxel”) with 20 m cubic blocks (“voxels”) was created. The orebody surface passed through 6430 voxels. These voxels, with a total volume of 51 Mm³, were flagged as a “region” that was used to represent the
mined portion of the deposit. The trace of this region can be seen in plan view passing through the North, Blackwood, Block14 and Kintore Pits (Figure 1). The perspective view of the region shows the limited depth extent of the central portion and the northeast and southwest limbs that plunge to more than 1000 m below surface.

Although the primary purpose of this investigation was to produce a correction to be applied to observed data for the effects of mining, we can adapt this result to estimate the anomalous response of the Broken Hill deposit prior to disturbance. Haydon and McConachy (1987) estimated that the complete Broken Hill deposit contained in excess of 300 Mt of ore. Assuming a density of 3.4 t/m³, the total deposit volume would be 88 Mm³. The density contrast to the host would be +0.6 t/m³, and hence the total anomalous mass is 53 Mt. Assuming that the region in the block model used to define the extent of mined ore is a first approximation to the extent of the mined ore plus an additional region covering unmined ore, the anomalous density to be assigned to the mined region would be 1.03 t/m³. This assumption allows the grids of corrections for mining to be scaled to also provide an estimate of the anomalous response of the complete deposit.

The anomalous response of the entire 300 Mt deposit in its pre-mining state is smaller than the correction for the effects due to mining of 200 Mt by a factor equal to the ratio of the density contrasts used in the calculations, 1.03/1.49 or 0.69.

**Gravity and gravity gradient calculations**

The gD response at a terrain clearance of 80 m was calculated for a grid of observation points with 50 by 50 m spacing using the GRAV3D program (Li and Oldenburg, 1998). The Gdd response was calculated using standard Fourier methods that assume that the observations are on a level surface. At Broken Hill, this is a sound approximation.

The Gd and Gdd data from the Broken Hill AGG Survey were derived by spatial transformation from measured Gnc and Guv gravity gradients (Hensley, 2003). The spatial transformation can be carried out using Fourier, equivalent source or spatial convolution methods. These methods produce slightly different outputs, but in each case the products are band-limited to wavelengths between several hundred metres and several kilometres. These bandwidth limitations need to be considered when comparing forward model calculations with survey data.

**RESULTS**

The Gdd corrections for the effects of mining, tailored to the characteristics of the AGG Fourier method Gdd data, exceed 20 Eo over the mid-northeastern and mid-southwestern portions of the deposit (Figure 2). As previously discussed, the pre-mining response of the deposit that is obtained after applying these corrections is likely to be only 2/3rd of the amplitude of the corrections. RMS noise estimates for Falcon Gdd data low pass filtered to 400 m wavelength are given by Dransfield et al. (2001) as 5 to 9 Eo. This would suggest that an anomaly of 12 to 15 Eo associated with the Broken Hill deposit would be several times larger than the standard deviation of the noise. At this S/N ratio, the anomaly would be detectable but not well defined.

The corrections in Figure 2 have been applied to the AGG Fourier method Gdd data (Figure 3) and the AGG equivalent source method Gdd data (Figure 4) for a portion of the Broken Hill survey area. These images represent an estimate of the response that would have been measured had the survey been flown prior to mining.
The response of the deposit is much more distinct in the image of AGG equivalent source method Gdd data. It is not clear whether this is an indication of the superior noise rejection characteristics of the equivalent source processing method or whether the corrections should have been filtered more harshly to match the less well defined characteristics of the AGG equivalent source method Gdd data. Such filtering would have broadened the anomaly and reduced the peak amplitude, making the response of the deposit less distinct.

Figure 2. Gdd correction for the effects of mining calculated at a terrain clearance of 80 m and +400 m low pass filtered. Note that this image covers a slightly larger area than Figure 1, but the same area as all of the subsequent figures.

Anomalies of similar character to the response associated with the deposit are present elsewhere in the data. There are a number of amphibolite units present in the Broken Hill district, and these have a significant positive density contrast relative to the host rocks. The average density of these units is around 3.05 t/m$^3$ (Maidment et al., 1999; Lane et al., 2003). These units are seldom more than 10 m in thickness, but may be stacked parallel to each other (B. Stevens, pers. comm.) to produce a significant gD or Gdd response. Amphibolites are the presumed source of the features labelled in Figure 1; Round Hill (RH), a trend sub-parallel to Amphibolites are the presumed source of the features labelled in Figure 1; Round Hill (RH), a trend sub-parallel to Amphibolites are the presumed source of the features labelled in Figure 1; Round Hill (RH), a trend sub-parallel to.

Ground gD observations for the Broken Hill district were extracted from the 2004 edition of the Australian National Gravity Database managed by Geoscience Australia (Murray, 1997), gridded, upward continued by 80 m, low-pass filtered at a wavelength of 400 m, then transformed to Gdd. These Gdd data can be directly compared with the AGG Gdd data. The locations of the ground observations are shown in Figure 5, superimposed on an image of sample spacing, defined as the square root of the area of the Voronoi cell surrounding each observation. The observations with 500 m spacing in the immediate vicinity of the deposit were acquired in 1997, and hence these data would reflect the gravity response subject to a similar degree of modification to that present at the time of the AGG survey data.

An image of the first vertical derivative of the ground gD data, Gdd, adjusted for the effects of mining is shown in Figure 6. This can be compared to the AGG Gdd data shown in Figure 3 and Figure 4. Where very detailed ground data are available, around Thorndale and Round Hill, the ground data provide a clearer picture of the Gdd response than the AGG data. There are smooth patches in the central and northwest portions of the image which reflect under-sampling of the gD response, and severe aliasing of the derived Gdd response. In these areas, the AGG data provide a more evenly sampled and accurate picture of the Gdd response.

CONCLUSIONS

After applying corrections for the effects of mining, the Gdd anomaly of the Broken Hill Ag-Pg-Zn deposit can be seen as a positive feature in AGG data. The anomaly amplitude is only a small multiple of the noise level, and hence is not well defined.

Of equal significance from a mineral exploration perspective is the fact that there are other features in the AGG survey data that have a similar expression. Several of these features have been attributed to amphibolite units. Others remain the subject of ongoing exploration (D. Isles, pers. comm.).

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REFERENCES


Figure 3. ‘Corrected’ AGG Gdd response for Fourier processing method (2.75 g/cm$^3$ density for terrain corrections, 400 m low pass filtering).

Figure 4. ‘Corrected’ AGG Gdd response for equivalent source processing method (2.75 g/cm$^3$ density for terrain corrections, unknown low pass filtering characteristics). (RH = Round Hill feature, A = amphibolite feature, T = Thorndale features)

Figure 5. Image of sample spacing for ground gravity observations. The locations of the observations are shown as black dots.

Figure 6. First vertical derivative of ground gD data (i.e. Gdd) upward continued by 80 m, 400 m low-pass filtered and ‘corrected’ for the effects of mining.