An improved pseudo-gravity magnetic transform technique for investigation of deep magnetic source rocks

David A. Pratt
Encom Technology Australia
David.Pratt@encom.com.au

Zhiqun Shi
Encom Technology Australia
Zhiqun.Shi@encom.com.au

SUMMARY

The pseudo-gravity transform is one of many possible FFT techniques that can be applied to aeromagnetic data. It enhances the anomalies associated with deep magnetic sources at the expense of the dominating shallow magnetic sources. This transform is an excellent interpretation tool for the detection of deep, magnetic igneous plutons and volcanic piles and the transformed data can be modelled using conventional gravity modelling tools. It is a suitable tool for interpreting deep-seated mineral plumbing systems associated with known, shallow mineral occurrences.

The pseudo-gravity transform is derived by an integration of the total magnetic intensity grid data using conventional FFT tools. Padding of the grid around the region covered by the survey introduces long wavelength artefacts into the transformed grids. These long wavelength artefacts can obscure the targets that are the object of investigation. A variety of regional residual separation procedures is applied to the transformed grid to minimise the impact of the long wavelength artifacts.

The improved pseudo-gravity transform is applied to the Goulburn 1:250 000 survey in the Lachlan Fold Belt of New South Wales to demonstrate the clear separation of deep sources that are difficult to detect or understand in the context of conventional magnetic image analysis. The results are contrasted with other filter techniques. Interpretive modelling of both the magnetic and the gravity transform data show how to derive more relevant geological information from magnetic surveys. By comparing the pseudo-gravity transform results with lower resolution ground gravity data, it is possible to obtain additional geological information by analysing the correlations.

Key words: Inversion, potential fields, magnetic, gravity, modelling.

INTRODUCTION

Aeromagnetic surveys are now a primary tool for providing uniform coverage of a geophysical parameter over large areas. The consistent coverage allows geologists to interpolate sparse outcrop and drilling data over large areas through the use of appropriate geological models. In general, the interpretation focuses on the interpretation of the shallowest magnetic sources that occur below the regolith or transported cover.

The amplitude of the magnetic anomalies is dominated by the magnetic units that are truncated by the shallowest unconformity. This dominating influence makes it hard to detect deeper geological sources that may be contributing to the magnetic anomalies. Conventional filtering smears out the shallow sources and makes it difficult to separate them from lower amplitude magnetic anomalies associated with deeper magnetic source rocks.

An aeromagnetic survey of the Goulburn 1:250 000 map sheet area, New South Wales, Australia (Figure 1) has been chosen to illustrate the study of the pseudo-gravity magnetic transform. For the purpose of comparison, Figure 2 shows a pseudocolour image derived from regional gravity coverage at an approximate spacing of 4 km.

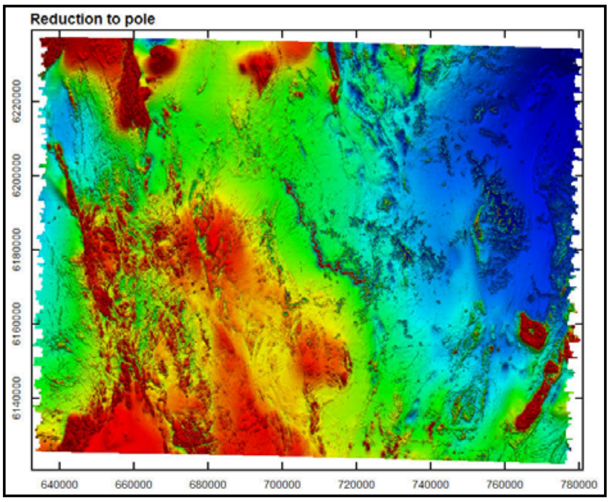

Figure 1. A pseudocolour image presentation of the reduction to pole grid from the Goulburn 1:250 000 aeromagnetic survey.

The pseudo-gravity transform has some special characteristics that reduce the dominance of the shallow magnetic sources and enhances the amplitude of magnetic anomalies from deeper magnetic source rocks. The theory behind the method can be found in texts such as Blakely (1995) and involves an integration of the total field magnetic grid to derive a pseudo-gravity grid.

The method has received little attention in practical exploration problems and has remained largely a geophysical curiosity. We attribute this lack of interest to some inherent weaknesses in the raw pseudo-gravity output. The long wavelengths in the data are enhanced and tend to dominate anomalies associated with shallow sources. Since the method uses integration of the total magnetic field grid, it is subject to the adverse impact of edge effects beyond the boundaries of the survey data. Most geophysical FFT processing packages extrapolate the survey grid beyond the edge of the data using a method known as padding. The quality of the padding method has an impact on the longer wavelengths that feed back into the survey area through the integration of the padded areas.

This research presents a methodology for overcoming the inherent limitations of the pseudo-gravity method, by reducing the impact of the high-amplitude, long-wavelengths anomalies that dominate the pseudo-gravity transform.

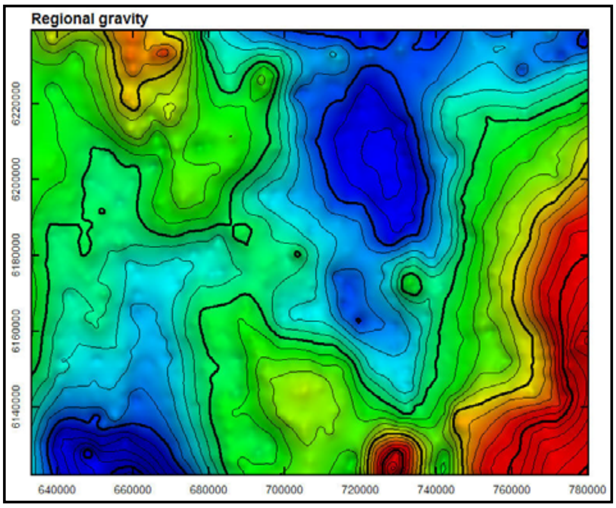

Figure 2. A pseudocolour image presentation of the regional gravity grid for the Goulburn 1:250 000 map sheet.

CONVENTIONAL FILTERING

Conventional low-pass filtering tends to smear the short wavelengths with the longer wavelengths and makes it difficult for the interpreter to understand the geological implications of the image. Upward continuation (Figure 3) diminishes the impact of the shallow sources relative to the deep magnetic sources and has the advantage that the upward continuation height can be compensated for during modelling.

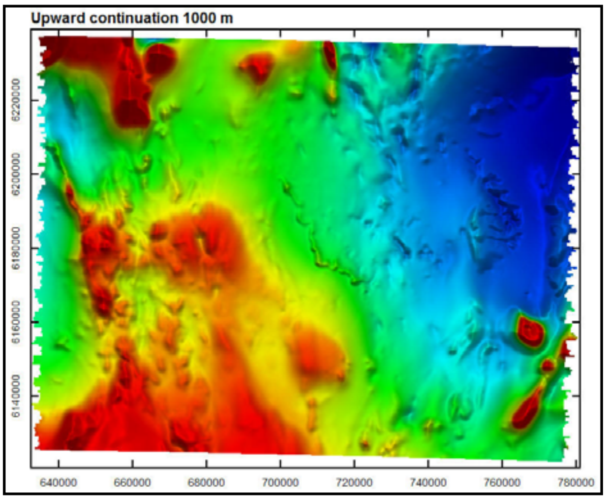

Figure 3. A pseudocolour image presentation of a 1 km upaward continuation of the reduction to pole grid from the Goulburn 1:250 000 aeromagnetic survey.

This image is used for comparison with the results from the pseudo-gravity transform.

THE ENHANCED PSEUDO-GRAVITY TRANSFORM

The pseudo-gravity transform was applied to the total magnetic intensity grid from the Goulburn survey (Figure 1) using the FFT filter package available in Oasis montaj. An image of the output from this process is shown in Figure 4. The broad, north south trend in the RTP image becomes the most dominating feature in the pseudo-gravity image and it is difficult to recognize the small-scale features. The dynamic range of the short wavelength features that is evident in the magnetic image is much lower in the pseudo-gravity image.

The enhanced pseudo-gravity transform is derived from the standard pseudo-gravity transform by removing long wavelength anomalies that are associated with FFT processing artefacts and deep crustal magnetic sources. Conventional low-pass and upward continuation filters were considered, but a modelling approach was adopted to remove the influence of magnetic sources that are beyond the zone of exploration interest. The pseudo-gravity data can be modelled using conventional 3D modelling and inversion methods, where the density is considered as a pseudo-density defined by the relationship

$$\rho = \mathbf{k}\mathbf{H}/\gamma\ ,$$

where ρ is the density contrast, **k** is magnetic susceptibility, **H** is the total magnetic field intensity and γ is the universal gravitational constant. This relationship assumes that the magnetisation is induced and no remanence is present.

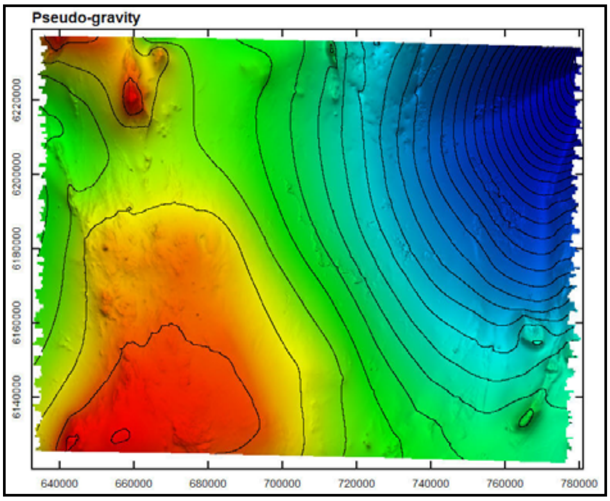

Figure 4. Pseudocolour image of the pseudo-gravity grid derived from the processing of the Goulburn total magnetic intensity grid.

Figure 5 illustrate the results from modelling and inversion of the pseudo-gravity data along 10 traverses using 8 spherical bodies to represent an equivalent source solution that models the long wavelengths in the pseudo-gravity transform. The spherical bodies have the advantage of providing depth information about the data you are removing from the grid and they are very easy to use in inversion. The depths can also be constrained to a minimum depth to ensure that no shallow geological sources are eliminated from the data. A stacked profile map is used to present the match between the pseudo-gravity and the modelled response. The map shows the location of the spheres derived from inversion and the colours represent the density contrasts. Note that the outer lines represent the edge of the survey map sheet.

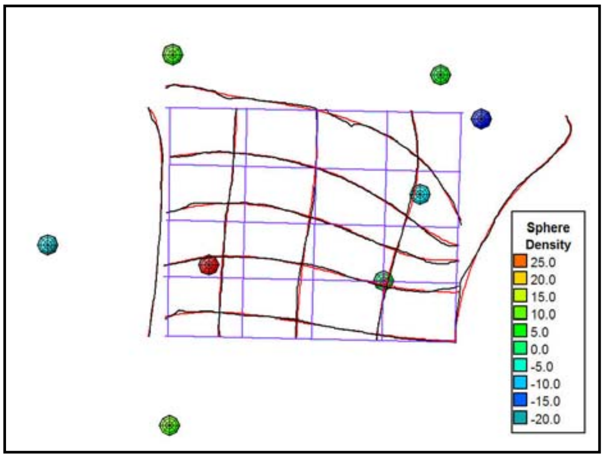

Figure 5. Model spheres and stacked profiles of the computed model response and pseudo-gravity data along 10 lines resampled from the pseudo-gravity grid.

The modelling process started with 3 spheres and progressed to 8 in this example where the RMS residual of the mismatch between the data and model reduced to 1.03% of the data range. The shallowest sphere is at a depth of approximately 10.5 km and is located to the north of the upper left corner of the survey area. Other body depths range from 12 to 100 km.

A model grid is computed at every grid node in the pseudo-gravity grid and subtracted to produce an enhanced pseudo-gravity residual grid (Figure 6). This image represents 1.03% of the pseudo-gravity data range and holds the majority of the useful geological information.

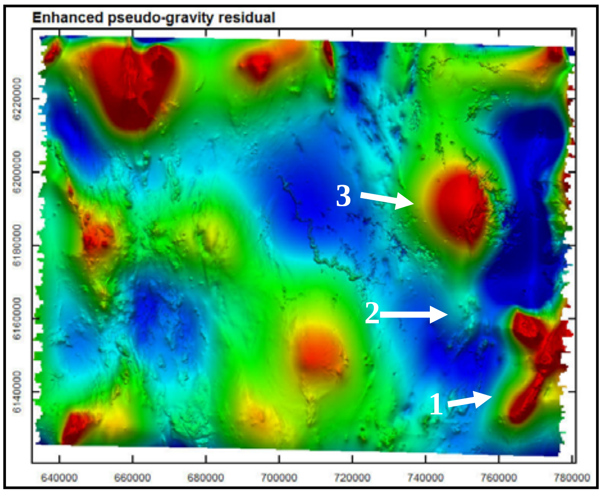

Figure 6. Image of the enhanced pseudo-gravity residual grid produced by subtracting the model grid from the original Goulburn pseudo-gravity grid.

The residual image is better suited to qualitative map interpretation procedures because it is much easier to see the differing contributions of shallow and deep sources. The image also exhibits a significant reduction in the high-amplitude, short-wavelength magnetic anomalies associated with shallow magnetic rocks. This reduction in amplitude makes it easier to analyse the anomalies associated with deeper magnetic sources.

Three anomalies have been highlighted in Figure 6 to illustrate the enhancement of anomalies associated with deep magnetic contrasts. Anomaly 1 (Figure 6) is beneath a dominating magnetic anomaly associated with an outcrop of the Devonian, Lumley Granite (Figure 7). The longer wavelengths from the deeper rock unit are barely evident in the magnetic image, but are easily recognised in the enhanced pseudo-gravity image. Anomaly 2 has been enhanced in the pseudo-gravity residual image, but it is not as well defined as Anomaly 1. Anomaly 3 has a very high amplitude but not clearly evident in the original magnetic image. While the anomaly is real, it is sensitive to the high gradient on the edge of the deep low in the north eastern corner of the pseudo-gravity image (Figure 4). It is a consistent feature of the residual separation procedure, but sensitive to the number of spheres used in the model inversion.

The broad, high-amplitude anomalies give a clearer indication of depth persistence of high magnetic susceptibility material than can be inferred from the magnetic image. Modelling can also be used to test the assumptions about the depth distribution of the magnetic rocks.

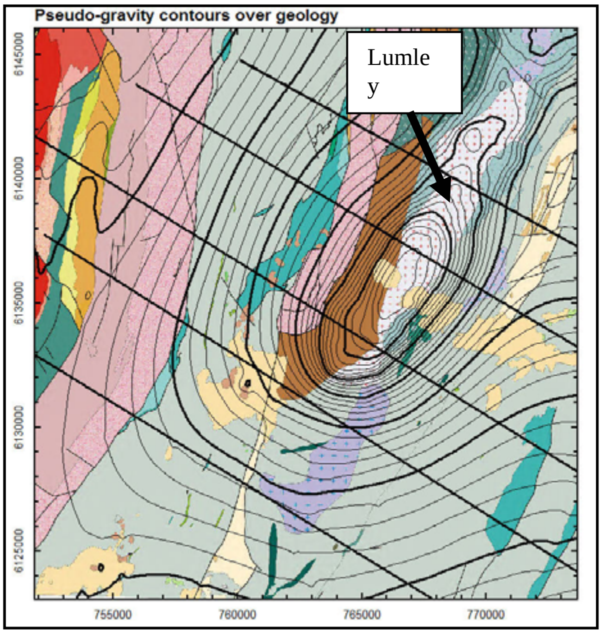

Figure 7. Pseudo-gravity contours of Anomaly 1 superimposed on the solid geology map from the Goulburn 1:100 000 map sheet. Traverse lines show the control lines used for magnetic modeling.

GRAVITY MODELLING OF DEEP SOURCES

An important outcome of the pseudo-gravity transformation is the ability to use conventional modelling to investigate suspected deep magnetic source rocks. Anomaly 1 in Figure 6 has been chosen to illustrate the modelling process and test the existence of a previously unknown deep magnetic source. Figure 8 shows a cross-section view through the model for the central profile shown in Figures 7 and 9.

The model section shows a deep high pseudo-density (susceptibility) unit that has a density (0.16 g/cc) that is 8 times greater than the pseudo-density associated with the Lumley Granite outcrop (0.02 g/cc). The precision of the depth modelling is compromised by the shallower source, but varied between 4000 and 5000 metres depending upon the geological constraints.

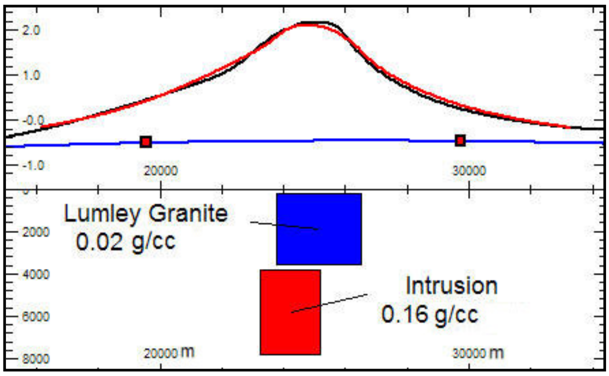

Figure 8. Central cross-section pseudo-density inversion model of the Lumley Granite outcrop (blue) and high pseudo-density intrusion (red).

ModelVision Pro was used to perform a user-guided, multi-body 3D inversion using multiple lines across Anomaly 1. A map view of the inversion results is shown in Figure 9. The dominant magnetic anomaly at this location (Figure 1) is associated with an outcrop of the magnetic Lumley Granite. It is not obvious in the magnetic image that there is a deeper magnetic source masked by the Lumley Granite anomaly.

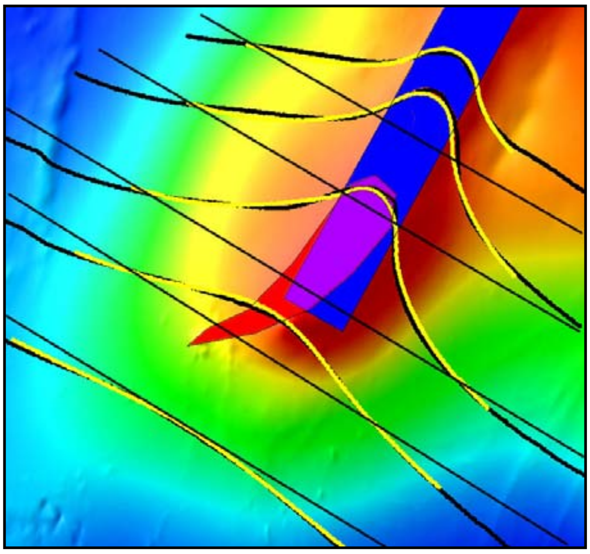

Figure 9. Map view of the dual body inversion of the pseudo-gravity residual data. The red body corresponds to a deep, high magnetic susceptibility body and the blue body corresponds to the outcrop of the Lumley Granite.

With the knowledge of the depth, map location and probable magnetic properties of the magnetic unit, it is possible to apply geological principles to the interpretation. The deep source is confined to the southern end of the Lumley Granite outcrop and may represent a later phase of intrusion, with higher magnetic susceptibility.

CONCLUSIONS

The enhanced pseudo-gravity method provides a new way of looking for deep magnetic sources that are hidden from the interpreter in conventional magnetic image displays. The results have benefits for both qualitative and quantitative methods of interpretation.

The method can be used with regional gravity data to enhance the value of broadly spaced gravity data by evaluation of the positive, negative or neutral correlation between the datasets.

Qualitative interpretation allows the geoscientist to recognise relationships in the image map that lead to an understanding of the three-dimensional distribution of rock units. Once an idea has been postulated, it can be tested with gravity modelling of the pseudo-gravity data.

There are benefits with this method for studying large volcanogenic systems where the distribution of magnetite at depth may provide new information on ore-forming processes. There is also a benefit for geoscientists who are developing regional three-dimensional geological models. Broadly spaced gravity data are often inadequate to provide the depth information needed to constrain the modelling process.

ACKNOWLEDGMENTS

The authors would like to acknowledge the New South Wales Department of Mineral Resources for permission to use the aeromagnetic, gravity and geological data for the Goulburn 1:250 000 map sheet area and their helpful comments during the research.

The authors wish to acknowledge Encom Technology for permission to publish the results of this research. The software products, Encom ModelVision Pro and Profile Analyst were used to produce the various examples that illustrate the principles of the enhanced pseudo-gravity transform.

REFERENCE

Blakely, R. 1995 Potential theory in gravity and magnetic applications, Cambridge University Press, 441p.