Towards automated mapping of depth to magnetic/gravity basement — examples using new extensions to an old method

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SUMMARY

The Euler method of automating depth to source from potential field data has undergone resurgence in popularity, with several new extensions to the method developed. Perhaps the most revolutionary of these provides a solution of the structural index as part of the inversion process. Previously, structural index was a required input parameter. Many solutions are generated with the Euler method, and care is used to select the most accurate. Accuracies of depth estimates within ±15% of depth of actual source below acquisition height are achieved.

Examples of Euler depth results from across three representative areas of Australia are used to demonstrate the utility of the method. Data are presented by several methods, including full 3D visualisation, which allows the solutions to be integrated with other data and inversion results. A depth to basement map of the Springvale 1:250 000 map sheet area in Queensland has previously been generated using the Naudy technique, and those results provide a useful comparison with depths derived using the Euler method. A small area in the eastern Yilgarn, Western Australia, contains an elongated sedimentary basin overlying shallow basement cross-cut by numerous dykes and faults. The magnetic expression of basement can be traced from near surface to a few hundred metres depth under basin cover. This is a good test of the method for providing estimates along the incline from outcrop to increasing thickness of cover. Basement to the eastern Gawler Craton (Olympic sub-domain) lies under several hundred metres of cover, and Euler depth estimates for this area are also examined.

Key words: Depth to basement, Potential Field, Euler.

INTRODUCTION

A large proportion of older basement regions of the Australian continent is covered with a variable thickness of sedimentary and regolith material, which obscures most direct geological signatures of the basement architecture (Figure 1). Interpretations of magnetic and gravity potential field survey data provide a means to gaining an indirect insight into the underlying geology, and the continent is now well covered by such data (Milligan *et al*., 2003). Mineral exploration activity continues to spread from areas of outcropping and subcropping basement into areas with greater thickness of cover. For resource exploration purposes, one of the most useful inferences that may be derived from analyses of potential field data is the depth of crystalline basement beneath the cover.

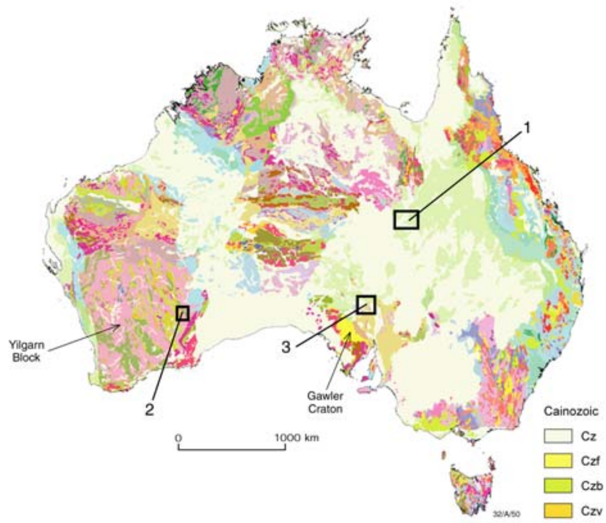

Figure 1. Geology of Australia (from Shaw *et al*. 1996), showing the extent of cover material. Example areas for analysis are: 1. Springvale 1:250 000 map sheet, 2. Portion of the Cundeelee 1:250 000 map sheet, 3. Olympic Cu-Au Province (part) of the eastern Gawler Craton.

With the large quantities of data now available for analysis, it is desirable to use semi-automated methods of estimating depth to basement. A number of such methods have been published over the last few decades, with one of the most enduring being Euler deconvolution (Thompson, 1982). This has recently undergone resurgence in popularity, with extensions to the original method now providing a solution of structural indices as well as other parameters (Reid *et al*., 1990; Nabighian and Hansen, 2001; FitzGerald, Reid & McInerney, 2003). Li (2003) has published a useful summary and guidelines for best use of several depth estimation methods, including Euler.

While a detailed examination of solutions, including the many error estimates that are generated, may provide more accurate results for selected detailed areas of interest, the aim here is to take a "broad brush" approach to quickly provide first-pass depth information from large quantities of data over large areas. We restrict our analyses to grid data, but acknowledge that, particularly for very near-surface depth estimation, better results may be obtained by using profile data.

With all depth estimate methods, it is difficult to quantify the reliability of the solutions. This is particularly true for the Euler method, where there is an oversupply of depth estimates and culling is required to retain only the best. Where possible, it is desirable to test depth estimates obtained against other sources, such as those from different potential field depth methods, from drilling, or from seismic interpretations. Also, as pointed out by Li (2003), the quality of the estimates will depend largely on the quality of the original data.

Another factor to be considered is the depth that is being measured. Ideally, this is the top of a source body, or the centre of a discontinuity. This may not be the same as the depth to crystalline material intersected in a borehole, and is often deeper. This may be due, for example, to destructive weathering of magnetite, or intrusive sources not reaching the top surface of basement.

Figure 2 shows an example of regional Euler depths solutions generated from the magnetic grid of South Australia (published by PIRSA in 2003) compared with an image derived from bore-hole depths to basement. The cross-section plots indicate that while there is general agreement between the two datasets, these Euler solutions are always deeper than the bore-hole depths.

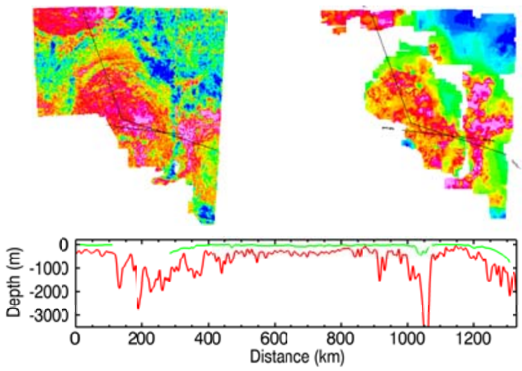

Figure 2. Euler magnetic depth image (top left) and drill-hole basement depth image (top right) for South Australia. The graph compares depths along the major profile from NW-SE. Euler depths (red), drill-hole depths (green)

This paper presents examples of analyses from three areas, as shown in Figure 1.

METHODS

'Extended' Euler deconvolution has been implemented by FitzGerald *et al.* (2003) following the methods of Mushayandebvu *et al.* (2001) and Nabighian and Hansen (2001). There are several implementations of the extended equations, of which the most comprehensive allows the estimation of depth, structural index, strike and associated errors. As depth is the primary interest here, the two Hilbert equations (FitzGerald *et al.*, 2003) are used, which allow solutions for spatial position, structural index (SI) and the regional constant β.

For magnetic data, the SIs are 0 for a contact, 1 for a fault (small step), 2 for a horizontal cylinder, and 3 for a sphere. These are theoretical model-derived estimates of field fall-off rates and should be integer values. In practice, solutions to the equations provide non-integer values of the SI, which are rounded to the nearest integer values for subsequent analysis.

Selection criteria used for the initial culling of solutions require depth estimates that are less than zero (below ground), an empirical selection of β for each SI range and a dip greater than 20°, where dip is the angle below the horizontal from the centre of the window to the solution position. These criteria were determined from model studies (FitzGerald *et al*., 2003).

Large numbers of solutions still remain after the initial selections. They tend to be distributed in clusters and sprays of solutions still occur, although to a lesser extent than in the traditional method. Active areas of research are the analysis of such clusters (e.g. Mikhailov *et al*., 2003) and spatial sorting (e.g. Silva and Barbosa, 2003) to locate reliable solution centres.

With many solutions generated for an area, an important issue is how to use and visualise them. One possibility is to consolidate depth estimates into horizontal bins and display them as two-dimensional grid surfaces. This technique should be used with caution, as it is easy to interpolate across large areas where there are no solutions, thus inferring the "basement" has this smooth continuity. Alternatively, they may be left as point solution sets and displayed in map form using symbols, where the colour and size are determined according to various parameters (such as depth, SI and uncertainty), or displayed in a 3D-visualisation environment. Visualisation of data in three dimensions provides a much better appreciation of the spatial distribution of depth solutions and their relationships with other information.

Several areas of high-quality airborne magnetic data have been analysed using the extended Euler method, and the results are detailed below.

RESULTS

1. The Springvale 1:250 000 map sheet area of Queensland.

An estimated depth to magnetic basement contour map was published for the Springvale 1:250 000 map sheet area by Meixner (1997). Depths were estimated using the Naudy method on magnetic profile data acquired at 80 m above ground level with E-W flight lines spaced 400 m apart. Figure 3 shows the localities of the depth estimates and a grid of interpolated depth to source. A major difference between this image and the published contour map is the inclusion here of relatively shallow solutions in the central NW-SE-trending zone. These were interpreted as sources within cover, and excluded during production of the published contours. This emphasizes the value of the interpreter's knowledge in geophysical analyses.

The Naudy solutions provide an opportunity to compare Euler depths with another method. Euler estimates have been calculated from a grid of the airborne magnetic data (80 m cell size) using a kernel size of 15. Structural indices from 0.5 to 3.25 were included.

Meixner (1997) suggested that the accuracy of the Naudy depths is within ±15% of the actual depth of source below acquisition height. A subset of eleven Euler solutions was obtained by selecting solutions that were less than 50 m horizontally from the Naudy estimates. Of these 11 pairs of depth estimates, eight overlapped in depth if a similar accuracy was assumed for the Euler solutions, and the other three Euler depths were less than 20% from the closest Naudy error boundary.

While this comparison is not a rigorous test for all the Euler solutions, it does give some confidence that they may be used in a first-pass exercise to gain knowledge of depth-to-basement variations.

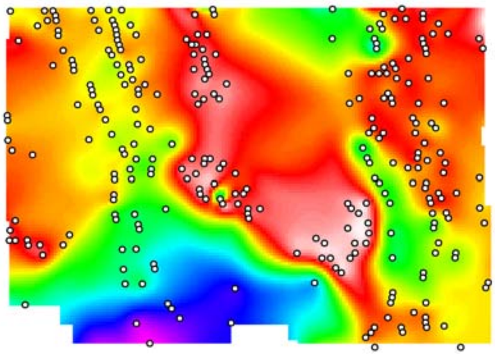

Figure 3. Estimated depths below ground surface to magnetic basement for the Springvale 1:250 000 map sheet area (after Meixner, 1997). Linear colour ramp, with white (high, -43 m) to magenta (low, -3423 m). Symbols indicate calculated Naudy depth positions. EW width 150 km.

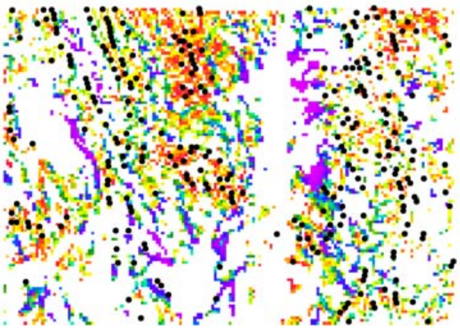

Figure 4. Averaged Euler depth solutions for the Springvale 1:250 000 map sheet area. Histogram equalised colour ramp, with red (high, 0 m) to magenta (low, -9329 m). Solid black circles are positions of Naudy estimates.

Figure 4 shows Euler solutions for all structural indices, using the culling method already described. The solutions have been averaged into 1000 m horizontal bins and are displayed as an image. Although large areas with no data are not interpolated, the depths compare favourably with the image of Figure 3.

2. Permian basin on the Cundeelee 1:250 000 map sheet.

On the Cundeelee sheet in the southeastern Eastern Goldfields a graben-like structure has been identified in aeromagnetic data (A. Whitaker, pers. comm.). It is elongated and open to the northeast with a length of at least 75 km and a width of 10 to 15 km, and provides a good opportunity for the testing of automated depth analysis methods.

Figure 5 is an image of the total magnetic intensity, reduced to the pole (TMI, RTP), using a northwest gradient operator. The graben is clearly visible as a zone where shorter wavelengths are attenuated. Superimposed upon this image are some representative depth solutions, which show the cover material increasing in depth from near-surface outcrop (red) to deepest (magenta) as the center of the basin is approached. The prominent circular feature is the “Cundeelee Intrusive”, with a drill-hole depth of around 560 m. This is in agreement with the Euler solutions.

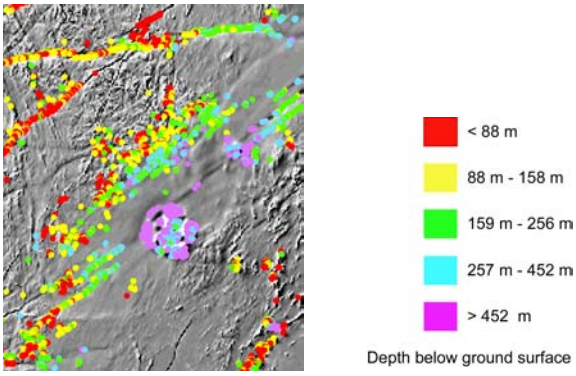

Figure 5. Total magnetic intensity for a portion of the Cundeelee 1:250 000 map sheet area. A northwest gradient operator has been applied, and the symbols represent Euler depths, from near surface (red) to 600 m (magenta). Image width represents 50 km

3. Olympic Cu-Au Province of the eastern Gawler Craton.

Magnetic basement to the Olympic Dam region of the eastern Gawler Craton lies beneath several hundred metres of regolith cover. The Gawler Mineral Promotion Project of Geoscience Australia has produced a detailed grid of aeromagnetic data by seamlessly merging the publicly available data: these data now form part of the Geoscience Australia archive. Direen and Lyons (2002) have published a geophysical interpretation of these data, and the corresponding gravity data.

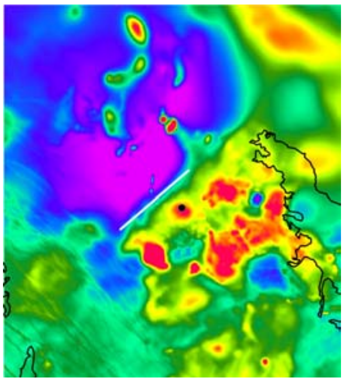

Figure 6. Image of TMI, RTP for the Olympic Dam region. Red (high) to magenta(low), linear colour stretch. Solid dot marks Olympic Dam mine and the white line represents the Todd Dam fault. For location refer to Figure 1. Image width represents 134 km.

Figure 6 shows an image of the TMI, RTP, with the location of Olympic Dam mine and also the Todd Dam fault. NW-SE-trending linear anomalies in the SW are the Gairdner Dyke swarm.

Euler solutions have been generated, and an example image of binned depths is displayed in Figure 7. Calibrations against known depths from drill-holes suggest the accuracy of the solutions is within ±15%. The depth contrast across the Todd Dam fault is clearly visible, and the dyke swarm is imaged as a region of elongate trends with shallow depths. Visualisation of the depth solutions has been improved as part of this project by incorporating them into a 3D environment (Figure 8). Direct incorporation of Euler clustered solutions into 3D geological modelling is also being investigated.

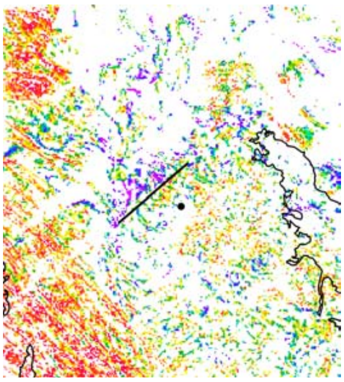

Figure 7. Euler depth image for the area shown in Figure 6. Near surface depths (-40 m) in red to deep (-6 km) (magenta).

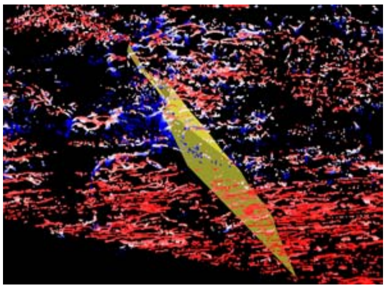

Figure 8. An example of visualising solutions in a 3D environment, viewed from the NW. The inclined plane represents a section of the Todd Dam fault, with deeper solutions to the north (left) of the fault as blue. Shallow (red), intermediate (white), deep (blue) colour depth representation. The shallow Gairdner Dyke Swarm shows as red in the foreground.

CONCLUSIONS

The Euler method provides a rapid means to estimate depth from potential field data. Improvements to the method, and to visualisation environments, make it viable to quickly gain an insight into regional depth-to-basement variations. Improved accuracy will be achieved with careful attention to detail, calibration using other methods and spatial sorting. Depth solutions within ±15% of those observed by the Naudy method are achieved, and within ±15% of true magnetic basement depth where this is known from drilling. Although not shown here, the method is also applicable to gravity data.

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