Extending magnetic depths past 1000 m

Roger Clifton*
NT Geological Survey
50 Smith Street, Darwin
Also at UWA
Roger.Clifton@NT.gov.au

Desmond FitzGerald
Intrepid Geophysics
3 Male Street, Brighton, Australia
Des@Intrepid-Geophysics.com

SUMMARY

Doubling the number of points in the power spectrum and improving the method of fitting slopes to it at low frequencies, improves an existing method of obtaining depths to equivalent magnetic layers. The method assumes that a TMI anomaly is due to layers of random dipoles, so that the depth to each layer is obtained by inverting the slope of the power spectrum for depth, as if it were that of a single dipole. So far the method shows depths between 200 and 800 m. The improvement allows the tracking of equivalent layers down to at least 1500 m, doubling its useful range.

By way of demonstration, a key indicator of some extensive gas-rich shales, the Derim Derim dolerite is tracked away from its intersection in boreholes. Using regional magnetic data alone, the dolerite is picked out at depths down to 1500 m.

Key words: Magnetic depths, equivalent layers, dipoles, power spectrum, Velkerri, Derim Derim.

INTRODUCTION

The Velkerri Formation of the Beetaloo Basin is currently being explored for hydrocarbons. Although some boreholes exist, the Velkerri Formation is not highly sampled over a large area of the basin. However, a mafic intrusive of similar or somewhat younger age, the Derim Derim dolerite is associated with it in the stratigraphic column (Ahmad et al, 2012). Regional geomagnetic surveys of various quality do cover the entire area and provide field data from which we can make depth estimates to the Derim Derim dolerites. A magnetic depth technique is needed to track the Derim Derim away from the boreholes, and thus to track the Velkerri.

Magnetic depths are notoriously noisy. The most frequently used method, Euler (Reid et al, 1990), suffers from interference from the pervasive basalts and ferruginised surfaces of the Northern Territory. The most used spectral method, due to Spector and Grant (1970), requires a subjective pick of the characteristic slope along the power spectrum. For broadscale mapping of magnetic depths, an automated technique is required.

An automated method of obtaining depths to equivalent layers is described by Clifton (2015). A window of 20 x 20 km is moved in 5 km steps across regional TMI data. The sources of the TMI in the window are assumed to be approximated by equivalent layers of randomly located dipoles. The power spectrum of each equivalent layer separates (at the lower frequencies) into the power spectrum of a single dipole at that depth, and at the higher frequencies, a white spectrum of its distribution in the layer. Since the slope along the power spectrum of a single dipole is entirely defined by its depth, the slope along the power spectrum gives an independent estimate of depth at each frequency. The clustering of these resulting depth estimates indicates the presence of an equivalent layer of dipoles. Dipoles at middle depths dominate middle frequencies of the power spectrum, while strong enough signals at lower depths dominate lower frequencies. Obtaining sufficient depth estimates at the deep end to form a respectable cluster is limited by the number of low-frequency points on the spectrum. Depths are routinely obtained down to 600 or 800 m. Depths transects prepared by this method are now available for the NT (Clifton, 2013).

The method is vulnerable to the survey parameters used to collect the data. In particular, the shallower depth estimates are damaged by flying east-west (Clifton 2016). Unfortunately, many of the surveys covering the Beetaloo Basin are flown east-west. However the damage is limited to the shallower depths and we have the prospect that such surveys will yield reliable depths greater than 600 m.

Explorers generally want to see deeper than their mines are likely to go. Six or eight hundred metres is not deep enough. We need more points at the lower frequencies on the power spectrum to be able to see depths greater than 1000 m.

METHOD AND RESULTS

The number of points on the power spectrum was doubled by resampling the regional grid from 80 m to 40 m cell size. The method of extracting the slope of the power spectrum at low frequencies was improved by shortening the number of points in the fit as the fitted line segment progresses towards the lowest frequencies.

After applying these improvements, and otherwise using the same procedure that is used in Intrepid, a 20 km window was taken through the data in 5 km steps, and depths were taken from the slope of the power spectrum of each window sample. Each set of depth was displayed vertically in a depth profile, and successive depth profiles were aligned in a depth transect. Equivalent layers may be traced as they reappear across the transect.

Tested in Figure 1, the method easily reaches 1500 m.

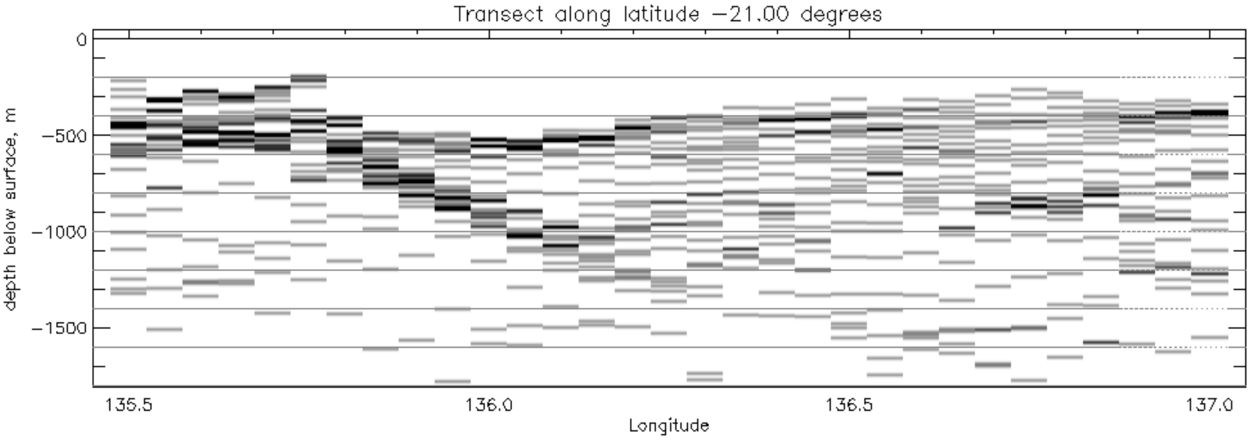

Figure 1: Magnetic depth transect with parameters selected for depth, using regional data. A descending basalt can be traced as it tilts downwards and appears to sole out at 1500 m.

A slope interpreted through a sequence of depth estimates needs to be corrected downwards for the implied tilt of the layer. In the case of a tilted dolerite sheet, the depth signal assigned to the centre of the sample is close to the depth at its extremity. With a sample size of 20 km the maximum displacement implied is 10 km. Consequently the image of a concave syncline has artificially steeper sides.

The dominant depth signal comes from the heterogeneity in the uppermost 40 m of a horizontal layer, implying a usually negligible correction of 20 m. However realistic bodies are not horizontal across 20 km, so the depth signal can be considered to be coming from the shallowest part of the body. Conversely, any greater thickness than 40 m is concealed and a maximum thickness of the body cannot be estimated unless there is some increase in heterogeneity at depth, indicating the presence of a different layer. Layers within 40 m are represented closer to their true depth.

So far, several boreholes have penetrated the Derim Derim dolerite, providing known intersections that can be extended out horizontally using a geophysical method such as this one. The Derim Derim dolerite was intersected in borehole Tarlee S3, at 1480 m depth. The corresponding depth profile crossing the borehole is seen in Figure 2. As a dolerite, the Derim Derim is more challenging to pick out than a basalt – an intrusive is inevitably intermittent. Further, there is no certainty that it will always intrude the same layer in the stratigraphy, and may reappear several times vertically. Being thinner, its signal is weaker too.

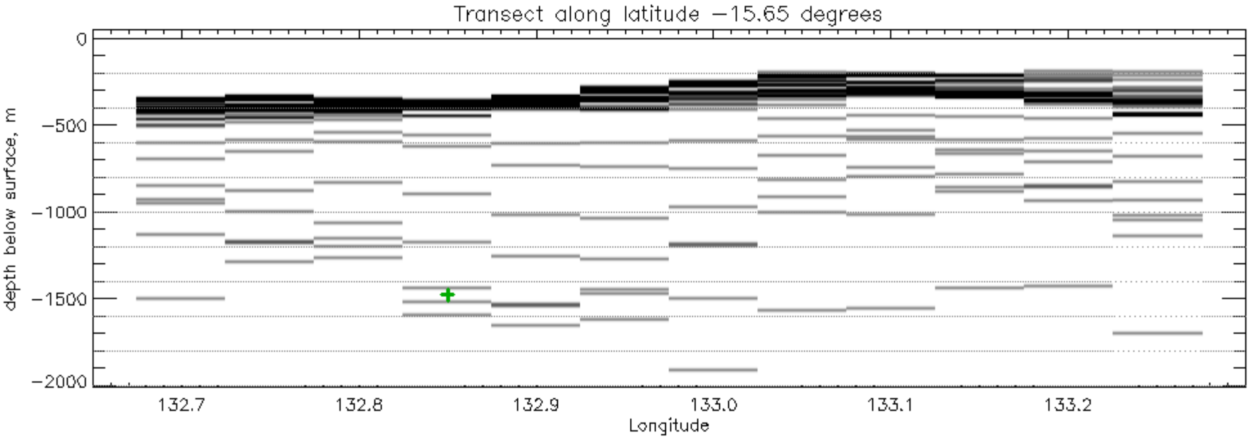

Figure 2: Magnetic depth transect across the location of borehole Tarlee S3. The intersection with the Derim Derim dolerite is shown with a small green cross. The signature of the dolerite appears across eight depth profiles, which corrects to 0.30°, about 30 km. The implication is only that the dolerite appears within 10 km of each coordinate, not that it is continuous.

When the edge of the sheet appears in a depth transect, there is something of an overshoot on the depth transect. Because the sample is 20 km across and overlapped every 5 km, the edge would have occurred at some point in the first 5 km of its last window, so it is proper to shorten the apparent extent by 5 km. Consequently the appearance of spanning eight depth profiles, approximately 40 km, should be corrected by 5 km at each end to 30 km.

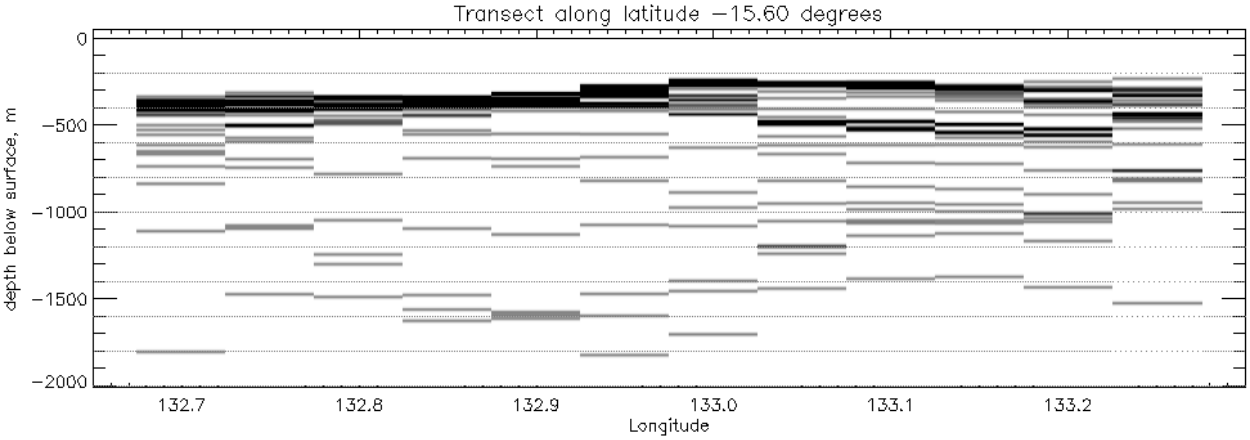

Figure 3: Magnetic depth transect 5 km north of borehole Tarlee S3. The signature of the dolerite can be traced across 11 depth profiles. The certainty that they are indeed the same body decreases with distance from the borehole. On the east, another layer begins to appear 400 m higher in the column.

The presence of another layer 400 m above the putative dolerite raises the question that the same dolerite has intruded 400 m higher in the ground, perhaps higher in the column. A transect further 5 km north (Figure 4) suggests the same conclusion, but the stronger signal may only be extinguishing the evidence of the lower body.

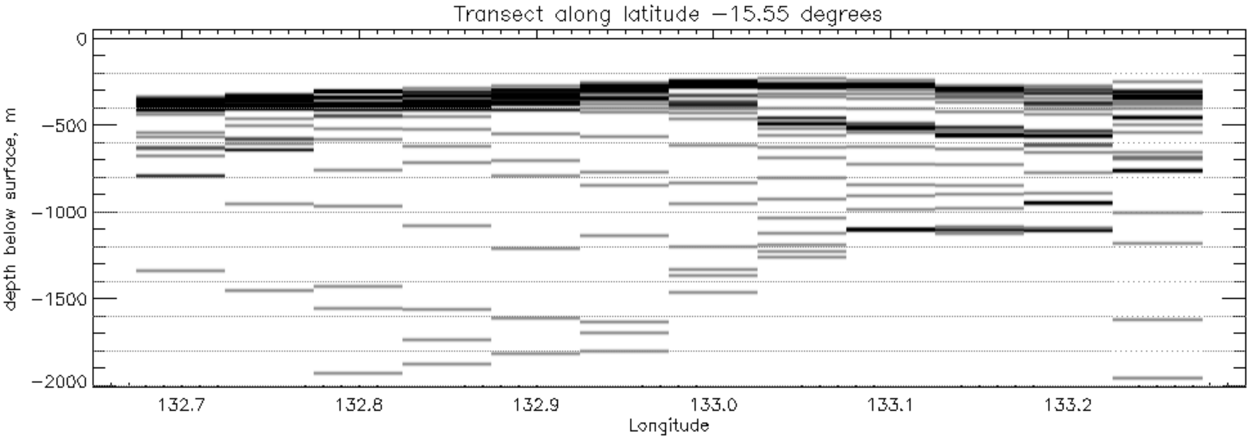

Figure 4: Magnetic depth transect 10 km north of borehole Tarlee S3. The signature of the dolerite near 1500 m persists, but on the east, three profiles appear to show several layers before becoming a single well-defined layer at 1100 m.

CONCLUSIONS

Further depth transects in the area can be studied for the presence of the dolerite, and indeed any other mafic layers indicated in the boreholes. Confidence can be increased when a dolerite extended through the depth transects from its appearance in one borehole appears at the correct depth in another borehole. However boreholes are presently sparse in the Beetaloo Basin. As more boreholes are put in, the dolerite can be traced further. Its association with the Velkerri will no doubt attract attention from explorers.

In other transects elsewhere, what appears to be coherent layers - appearing at nearby depths on adjacent profiles - can be picked out down to 3000 m. However at this depth the number of fits contributing to the depth signal has decreased to one, similar to noise, so confidence in the signal drops. What is needed is more points on the spectrum, to increase the number of fits at each low depth.

Nevertheless, the depth range of the method has been increased beyond 1000 m, approximately doubled. The method is likely to be used increasingly by interpreters.

REFERENCES

Ahmad, M., Dunster, J.N. and Munson, T.J., 2012. McArthur Basin, in Ahmad and Munson, compilers, Geology and mineral resources of the Northern Territory: Northern Territory Geological Survey, Chapter 15.

Clifton, R., 2013. Magnetic depth profiles across the Northern Territory, NTGS Technical Note 2013 – 001: Northern Territory Geological Survey.

Clifton, R., 2015. Magnetic depths to basalts: extension of spectral depths method: Exploration Geophysics 46, 284-296.

Clifton, R., 2016. Forward modelling of spectral depths using 3D Fourier convolution. Exploration Geophysics -. https://doi.org/10.1071/EG15092

Reid, A. B., Allsop, J. M., Grasner, H., Millett, A. J., and Somerton, I. W., 1990. Magnetic interpretation in three dimensions using Euler deconvolution: Geophysics 55, 80-91

Spector, A. and Grant, F.S., 1970. Statistical models for interpreting aeromagnetic data: Geophysics, 35, 293-302.