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Constraints on interpreting magnetic spectral depths

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SUMMARY

It is now possible to automate the extraction of magnetic depths over large areas as depth profiles. A depth profile is a graph of the probability of a layer at each depth. Presented in the form of a transect, depth profiles allow layers to be traced across significant distances. The appearance of discontinuous layers, and multiple layers, raises questions for interpretation, here addressed with modelling.

Modelling of layers requires simulating the heterogeneity of the material. Accordingly, a method of modelling is demonstrated where flat prisms are populated with very large numbers of dipoles and their fields accumulated for spectral analysis.

Thick layers give a depth signal in the transects about 20 m below their top surface. The distinction is minor given that the layer is assumed to extend across a 20 km square.

In general, only one depth signal credibly represents the depth of its source. Multiple layers can be picked out on traverses when the deeper layer is sufficiently more magnetised than the layer above it. A weaker depth signal appears closer to a stronger signal. Signals within 100 m of each other tend to merge.

The sensitivity of the method is significantly better when the survey has been flown north-south rather than east-west.

Near-surface layers are not picked up by the method. The sampling frequency of the original survey dictates how close to the surface estimates can be provided. A rough rule of thumb is that no reliable depth estimates can be expected for sources shallower than half the flight line spacing.

Key words: Interpretation, magnetic depths, basalts

INTRODUCTION

Large areas of the Northern Territory and beyond are underlain by extensive flood basalts with few boreholes penetrating these hard layers. Magnetic surveys provide a method of estimating depths to the basalt layers.

In a classic paper, Spector and Grant (1970) modelled extensive magnetic bodies as ensembles of prisms, whose average depth was expressed as the slope of a fitted straight section on the logarithmic power spectrum of a sufficiently large map. Field data often show such a diagnostic behaviour in their power spectra, so the method has since been applied often, such as by Meixner and Johnston (2012), but the method requires human intervention to choose the relevant segment of the spectrum.

Maus and Dimri (1996) show that the geometric information of the sources dominates the spectrum, so depths obtained from the slopes of line segments along the power spectrum are inevitably very noisy. In addition geometric information may be low or absent in parts of the spectrum where depth information might be sought.

Clifton (2013) demonstrated that magnetic layers could be simulated using very large numbers of random dipoles, where random patterns simulate heterogeneity. The slopes along the spectrum are similarly noisy, but scatter around the slopes that would be expected of a single dipole at the characteristic depth.

A large number of models at different depths provided a collection of slope spectra. By collecting the spectral slope of many models and inverting the emerging relationship between model depth and spectral slope, a formula for mass production was obtained, with a criterion for its applicability. Depths indicated by the slopes along the spectrum can be arranged as a depth profile, that is, a graph of probability versus depth. Mass production of spectra across an area allows a series of depth profiles to be arranged in a transect. Depths of layers can be traced along transects across large areas.

Accordingly, some 50,000 depth profiles were derived from the TMI stitch (Clifton, 2010) of the Northern Territory and transects were assembled from them for distribution (Clifton, 2014). An example transect is shown in Figure 1.

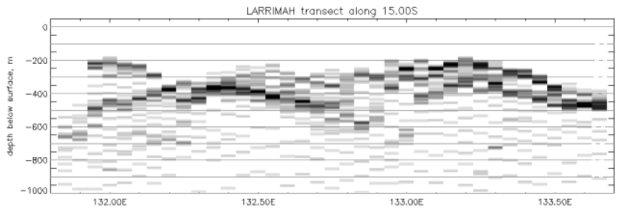

Figure 1. Magnetic depth transect from the NTGS collection. Depth profiles every 0.05° allow magnetic units to be traced across long distances.

Deep layers can be characterised even when near-surface layers are strongly magnetic. However the sampling frequency of most airborne surveys is too wide to provide depths to near-surface bodies. Further, the shallowest consistent signals often appear to be an artefact. Interpreters need criteria to estimate their reliability.

Multiple layers are often apparent, but interfere with each other, causing them to appear and vanish even when the sources would be expected to be continuous.

When a body is too compact to be approximated by a layer, it still gives a signal on the traverses. Again, interpreters need to know how to recognise such signals, and how much information they convey.

Remanence also poses a question for interpreters as to whether a remanent body is being characterised in the same way as non-remanent bodies. Because the power spectrum of the dipole (see for example, Blakely 1995) is insensitive to polarity, the prospects are good but need to be tested.

These questions of interpretation have been tested using the same modelling process of populating geometric shapes with large numbers of randomly located dipoles. This presentation reports on the results.

METHOD AND RESULTS

The field of a single dipole was calculated across an area of 10 km square and the depths down to 500 m. Model prisms were then populated with locations of dipoles and the field accumulated at the plane of the observer. A nominal survey area of 20 km square was sampled and the power spectrum obtained.

The original modelling had been done with slabs of minimal thickness and the formula accurately estimated the depths to similar thin slabs. Thick slabs still gave a signal resembling that of a thin body. To test the question of what part of the body was represented by signal on the transects, slabs of various thicknesses and depths were trialled. In Figure 2, a slab between the depths of 280 and 350 m is seen to give a signal on the depth profile at approximately 300 m. When bodies are thicker than about 50 m, variations in depth and thickness of the models gave results that indicated that the signal mainly comes from around 20 m into the body.

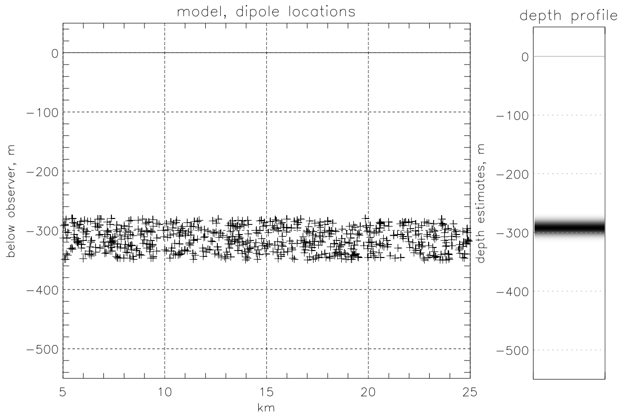

Figure 2. Model of a thick slab and its depth profile. The crosses mark the locations of 1000 randomly placed dipoles. Depth is below the observer, as if a ground survey, whereas an airborne survey would need ground clearance to be subtracted to give depth below surface.

Because the absolute value of the magnetic field is ratioed out when taking a slope along the logarithmic spectrum, a near-surface signal is typically still obtained in field data even where a magnetic image shows the absence of significant magnetic bodies. Accordingly a thick stack of weakly magnetic material was simulated, with its top 80 m below the observer. Signal is obtained at 120 m. See Figure 3.

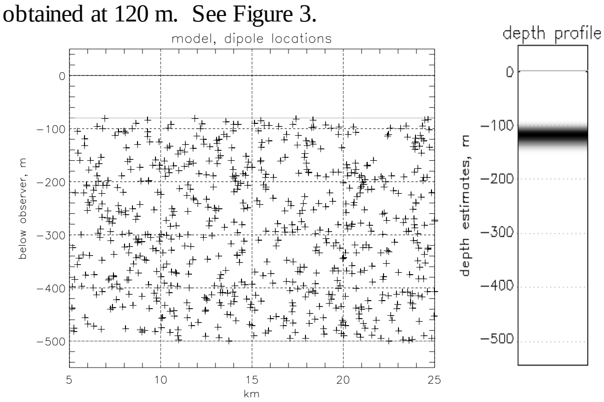

Figure 3. Weakly magnetic material from 80 m below observer to depth simulated with 1000 dipoles. When sampled at high resolution of 10 m x 10 m, a signal appears at 120 m.

This topmost signal in a traverse should always be questioned, because it may arise from material of negligible magnetisation in the absence of a stronger layer nearby. In the presence of a strongly magnetised body, the near surface signal often vanishes. In Figure 4, a strongly magnetised body is placed in a weakly magnetic country rock.

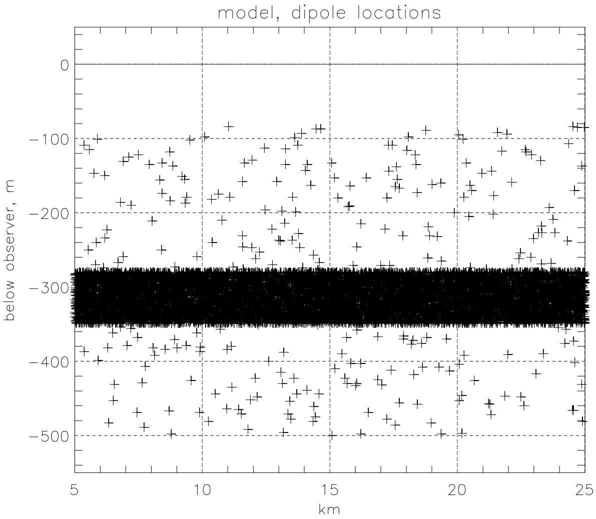

Figure 4. Strongly magnetised body in a weakly magnetised country rock, simulated with 20,000 and 500 dipoles.

The near surface signal no longer appears, instead the main signal comes from the stronger body even though it is deeper. The survey method samples the field along lines whose spacing incompletely samples shorter wavelengths. The depth profiles arising from different survey styles are shown in Figure 5.

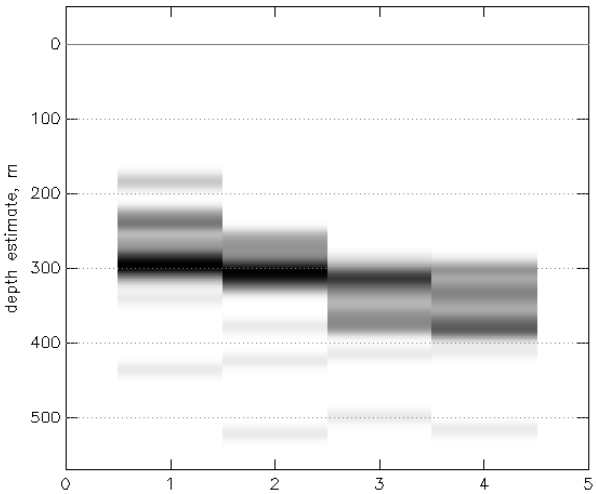

Figure 5. Depth of profiles for the model in Figure 4 from sampling lines running north-south. With 10 m sampling, the first depth profile accurately places the stronger body as well as noise from the country rock. The second results from lines 200 m apart, the third from lines 400 m apart and the fourth from lines 500 m apart.

As the sampling spacing increases, the capacity of the method to accurately estimate the depth of a body shallower than the spacing decreases (Figure 6). Other simulations show the wider surveys giving good estimates for deeper bodies than the spacing.

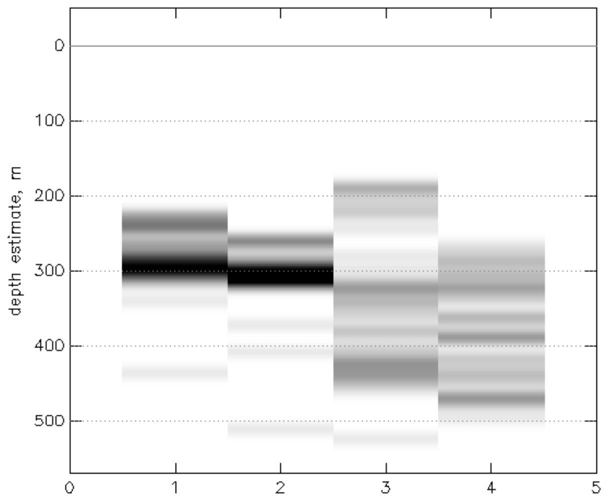

Figure 6. Depth profiles for the model in Figure 4 from sampling lines running east-west. With 10 m sampling, the first depth profile clearly and accurately places the stronger body. The second profile results from lines 200 m apart, the third from lines 400 m apart and the fourth from lines 500 m apart.

As in Figure 5, the signal in Figure 6 often appears to be lost in depth profiles from surveys of wider spaced resolutions. However a series of such noisy profiles can still allow a signal to be traced across a transect. Signals from deeper than the flight line spacing have wavelength information from both directions so are more reliable.

Although most of the Northern Territory magnetic stitch was collected on lines 400 m running north-south, much of the older surveys had flightlines running 500 m apart, in either direction. Interpretation of such traverses is aided by knowledge of the flight lines used.

Two slabs can be distinguished on the depth profile when the deeper slab is has a stronger magnetic signal than the shallow slab in certain proportions. In Figure 7, a series of simulations is presented. In each, a thin slab is held at 160 m depth, about as shallow as the technique can detect. A deeper thin slab is placed variously from 100 m deeper to 340 m deeper.

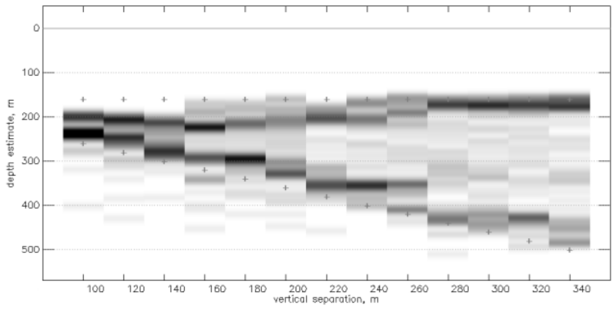

Figure 7. Simulations of pairs of thin slabs, sampled at high resolution. Crosses mark the depths of the slabs in the models.

Depth estimates for pairs of slabs appear to be drawn toward each other, even when they are separated by as much as 260 m. These simulations were run with sampling frequency of 80 m in both directions, allowing discrimination of pairs even when the separation was only 100 m. When sampled at the standard airborne survey spacing of 400 m, discrimination of pairs weakens and the shallower slab is less accurately placed, erring deeper in each case. See Figure 8.

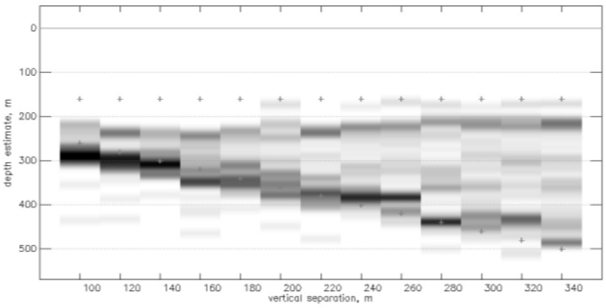

Figure 8. Simulations of pairs of thin slabs, sampled at standard survey resolution of north-south lines, 400 m apart. Crosses mark the depths of the slabs in the models.

Compact, strongly magnetic bodies dominate each of the depth profiles of samples that overlap them. In the case of 20 km square samples, resampled at 5 km intervals, such bodies can be identified by the same character appearing on four adjacent profiles.

CONCLUSIONS

Magnetic depth traverses of depth profiles obtained by transforming power spectra from repeated sampling across a large TMI grid allows the depth signal to be traced by eye through other information rendered as noise.

Modelling with prisms populated by large random distributions of dipoles allows structures of concern to be tested for their depths signatures.

The procedure allows interpreters to see through magnetic near-surface layers to deeper layers below. Near-surface layers shallower than half the flight line spacing are not represented.

Multiple layers can be represented on the spectrum, when the layers have certain relative strengths. More often, deeper layers are masked by the stronger signal of shallower layers.

Thick layers are represented as relatively thin lines placed near their top boundary. The signal represents an average across a square 20 km on side, and is relatively insensitive to variations in the width of the layer inside the sample.

In the absence of strongly magnetic layers, a spurious signal can appear at depths of about half the flight line spacing.

Compact bodies can overwhelm depth profiles that overlap them. They can be identified by a characteristic repetition.

ACKNOWLEDGMENTS

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REFERENCES

Blakely, R.J. 1995. Potential Theory in Gravity and Magnetic Applications, Cambridge University Press

Clifton, R., 2010. Magnetic stitch of the Northern Territory, Northern Territory Geological Survey, 2010.

Clifton, R., 2013. Magnetic depths to basalts -- extension of Spector Grant method. ASEG Conference and Exhibition 2013, Extended Abstracts.

Clifton, R., 2014. Magnetic depth profiles across the Northern Territory, Northern Territory Geological Survey, revised, 2014.

Maus, S. and Dimri, V., 1996. Depth estimation from the scaling power spectrum of potential fields? Geophysical Journal International, 124, 113-120.

Meixner, A.J., and Johnston, S., 2012. An iterative approach to optimising depth to magnetic source using the spectral method. ASEG Conference and Exhibition, 2012, Extended Abstracts.

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