Mapping the disruption of source magnetization depth estimates by near-surface magnetisations

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SUMMARY

Near-surface magnetisations are ubiquitous across many areas of Australia and complicate reliable estimation of depth to deeper magnetisations. We have selected four test areas in which we use equivalent source dipoles to represent and quantify the near-surface magnetisations. We present a synthetic modelling study that demonstrates that field variations from the near-surface magnetisations substantially degrade estimation of depth to a magnetization 500 metres below the modelled sensor elevation and that these problems persist even for anomalies with significantly higher amplitudes. However, preferential attenuation of the fields from near surface magnetisations by upward continuation proved quite effective in improving estimation of depth to those magnetisations.

Key words: aeromagnetic, survey, depth, near-surface, dipole

INTRODUCTION

Australia has a national airborne magnetic survey coverage acquired primarily by the state and territory geological surveys in collaboration with Geoscience Australia. These data are available for download from the Geoscience Australia Geophysical Archive Data Delivery System (GADDS) portal[1]. Modern surveys are flown with a flight-line spacing of 200 to 400 metres and a nominal terrain clearance of 60 to 80 metres. In many areas the magnetic field data includes expressions of surface or near-surface magnetisations. These are easily recognisable because they are the closest magnetisations to the magnetic field measurements and generate the shortest wavelength field variations. They are superimposed on, and partially obscure field variations of, deeper magnetisations. At four selected locations we have created equivalent source models from sets of magnetic dipoles to emulate and quantify the field variations from the near-surface magnetisations. Shallow-source magnetic field variations are generally under-sampled by the regional surveys and are insufficiently defined for detailed modelling. Nevertheless, they can be represented by equivalent source models. For this application we use dipole magnetisations placed directly beneath the flight-lines and inverted to fit the data. We use these models to summarise the near-surface magnetization by model statistics such as the average spacing and depth of the dipoles, and by total magnetization per unit length of profile. To investigate the influence of these shallow magnetisations on estimation of depth to underlying magnetisations, we then add synthetic, model-computed fields to measured data profiles of field variations from near-surface magnetisations and record the imperfections with which we recover the input models from inversion of the compound data.

DIPOLE EQUIVALENT SOURCE REPRESENTATION OF NEAR-SURFACE MAGNETISATIONS

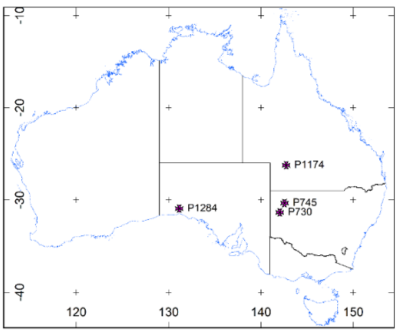

Figure 1 Location of the study areas, named by their GADDS survey index number

[1] https://portal.ga.gov.au/persona/gadds

Figure 1 shows the distribution of four test areas we selected to investigate the influence of near-surface magnetisations on estimation of depth to underlying magnetisations using synthetic modelling. Segments of the total magnetic intensity (TMI) grids at the areas are imaged in Figure 2. In all four areas it is clear from the images that the near-surface magnetisations have structure, with characteristic patterns of dominant wavelengths and trend, as determined by processes controlling the generation and/or redistribution of the magnetization.

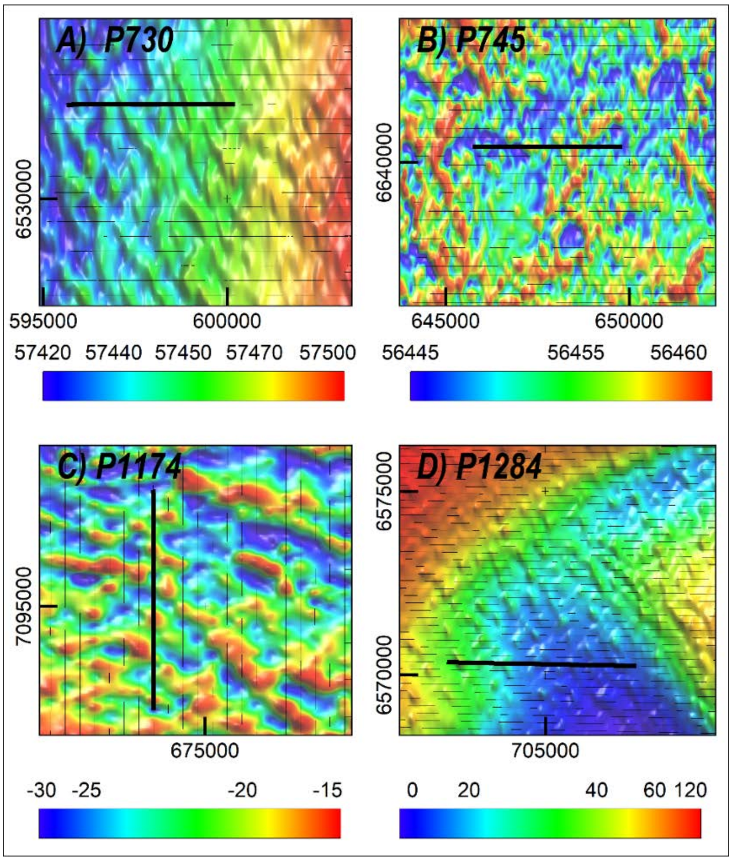

Figure 2 Images of tie-levelled TMI grids (units of nanoTesla (nT)) from the four test areas located in Figure 1. Modelled line segments are shown with thick black lines.

To emulate the lateral variations in the near-surface magnetization that give rise to the grid images in Figure 2 we used sets of dipoles distributed vertically beneath the flight-lines as equivalent sources. Note that the equivalent sources are not intended as exact representations of the magnetization. The external magnetic field of a spherical magnetization depends only on its total magnetization, independent of its volume and intensity of magnetization. We are therefore able to keep the volume of each sphere constant and change only its magnetization intensity (Emilia, 1973).

Inversion of the four line-segments highlighted in Figure 2 are shown in Figure 3. We positioned a source beneath each discrete peak in the measured field and allowed the inversion to move that source backwards and forwards along the profile, to move it vertically, and to change its intensity of magnetization. Field variations of much longer wavelength are emulated with a smooth polynomial function to represent a ‘regional’ or background field. The inversions enforced that the dipole magnetisations could only be positive and therefore the accompanying regional curve is displaced below the average TMI. Figure 3 shows the inversion sections and close fits achieved to the measured field. The measured magnetic field is not all due to magnetization within the plane of section as represented by the model and we know from the field images in Figure 2 that spheres are inadequate to represent the generally elongate magnetisations revealed by the magnetic field imagery, but nevertheless the models provide a quantitative measure of total magnetization along the length of profile modelled, the spacing between centres of magnetization, and abruptness of field variations related to the apparent depth of the dipoles. We hope that we may be able to relate these statistics with the disruption that the near-surface magnetisations cause in estimating depth to magnetisations at greater depth.

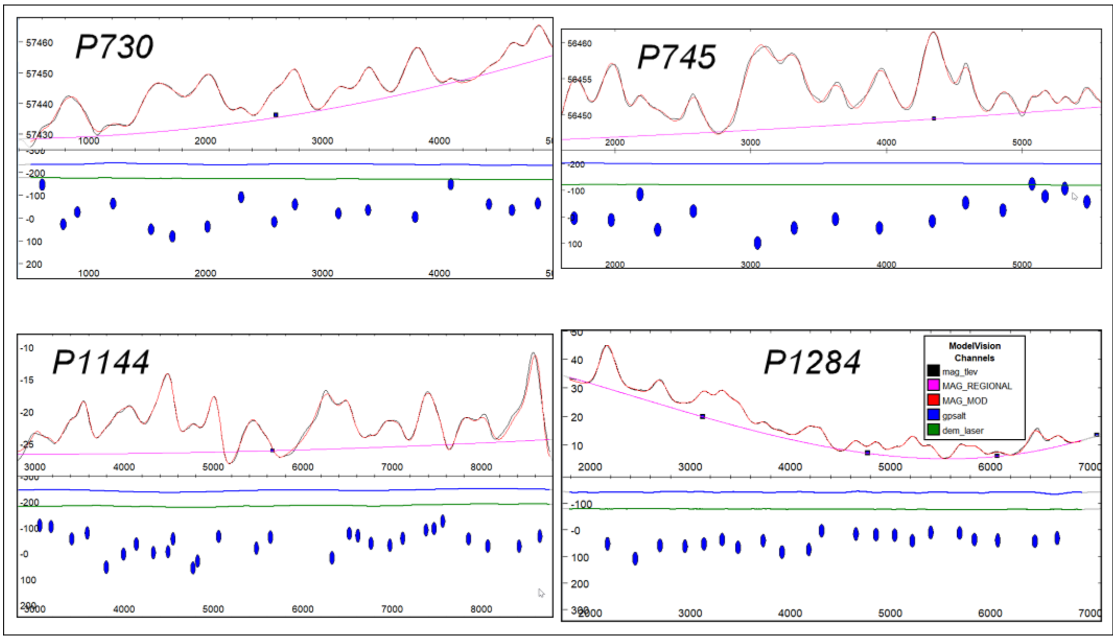

Figure 3 Equivalent-source dipole models of the shallow magnetisations on the four sections located on Figure 2

SYNTHETIC MODEL INVERSION STUDY

Figure 4 shows a compound magnetic profile generated by adding the field computed from two subsurface magnetization models to a TMI profile measured from the P730 survey (in New South Wales) containing field variations due to near-surface magnetisations. The anomaly over the source at a depth to its top of 150 metres below sensor has a width similar to the other field variations along the profile and would only be evident because of its higher amplitude. The anomaly from the deeper body causes a broader increase in the field but does not include any characteristics from which its depth could be reasonably estimated because the expression of that magnetization is substantially overprinted by field variations due to the shallower magnetisations.

Figure 5A shows magnetic profiles over these two bodies with intensities of magnetization three- and nine-times stronger. For the narrower anomaly due to the shallower magnetization, disruption by the superimposed fields of the near-surface magnetisations are not visually evident, as they are for the wider anomaly from the deeper magnetization.

Figure 5B shows cross-sections of models derived from inversion of these profiles. For the shallower magnetisations, the depths are all underestimated (by a maximum of 30% and average of 19%). For the examples shown, the error in depth is maximum for the strongest magnetization but this is not repeated at different locations. Disruption is more extreme for the deeper magnetization (despite the fact that the larger volume chosen for that body produces an anomaly of similar amplitude to that of the equivalent shallower magnetization). As noted for Figure 4, the weakest deep magnetization does not produce an anomaly that supports estimation of depth. For the intermediate and strong magnetisations the depth to magnetization is underestimated by 57% and 20% respectively, showing that an increase in anomaly amplitude is a crude and only moderately effective factor in improving the depth estimate. Because the overlying magnetisations are uncorrelated with the deeper magnetization, an improvement can be expected in precision of the depth estimate by a factor of √N for a multi-line inversion of N lines but this will rarely improve the value by a factor >2.

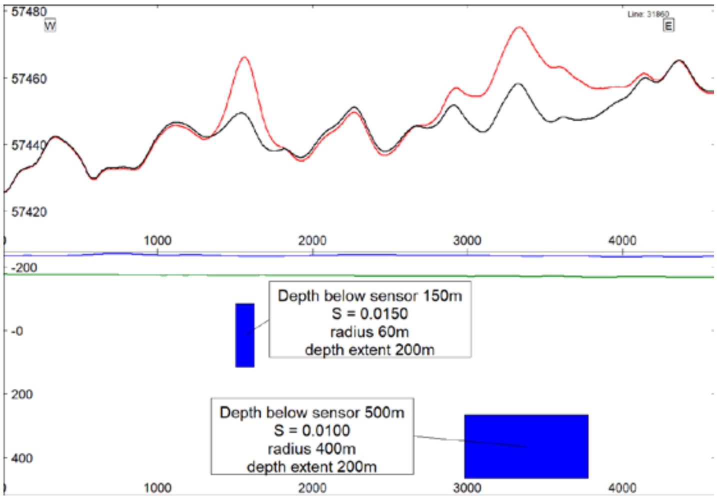

Figure 4 TMI measured from near-surface magnetisations (black curve) and with the addition of deeper magnetization models (red curve)

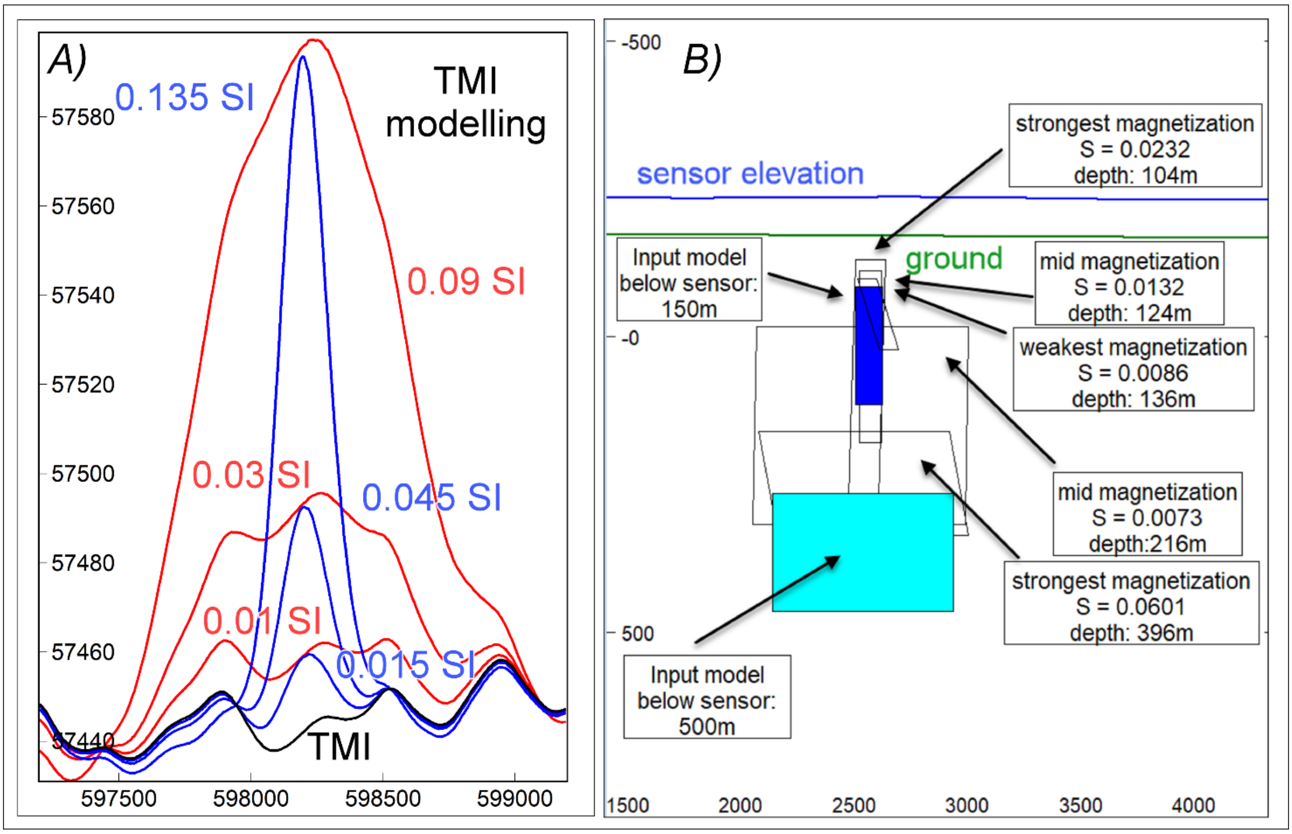

Figure 5A) Profiles of measured TMI with added computed fields from 150 m (blue) and 500 m (red) bodies, and B) cross-sections of the input (filled blue and cyan) and inversion (outline) bodies

MITIGATION BY UPWARD CONTINUATION

The most serious degradation of the depth estimates from below the near-surface magnetisations were for the wider anomaly of the magnetization at 500 metres depth. This anomaly has longer wavelength variation than the field variations of the near-surface magnetisations and can be enhanced by application of upward continuation filters that emulate measurement of the magnetic field at higher elevations. Upward continuation preferentially attenuates the shorter wavelength ‘noise’ from the shallow magnetisations to increase the signal to noise ratio for the deeper anomaly. There are drawbacks that all wavelengths are reduced in amplitude and that error as a percentage of depth from the sensor to the magnetization will be greater for the increased (apparent) sensor elevation. There is no advantage of this method for the magnetization at 150 metres depth because the shallower body has similar wavelengths to the field variations of the near-surface magnetisations. Figure 6 shows the substantial reduction in amplitude of the field variations from the near-surface magnetisations for the track interpolated back onto the flight-line from the 200 metre upward continued TMI grid. These field variations are very similar to those computed from our dipole equivalent source model at that higher elevation (after a base-line shift of the estimated background or regional field).

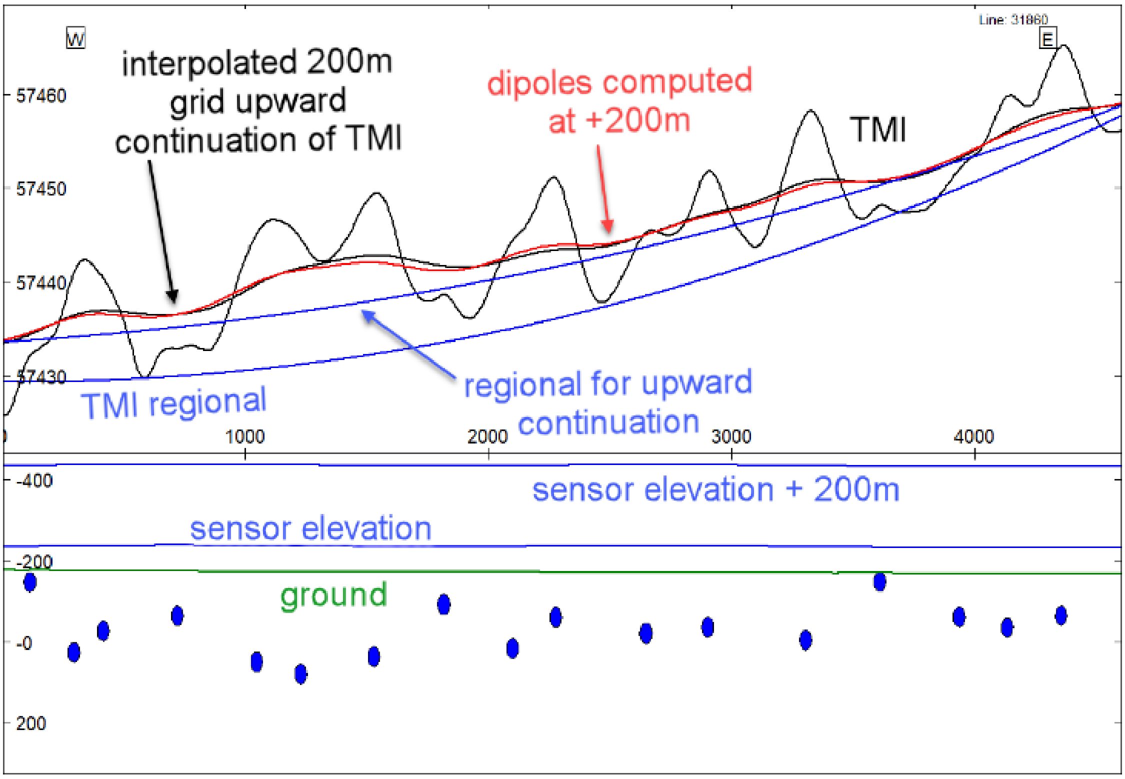

Figure 6 section of measured and model computed TMI and 200 m upward continued tracks

New input model fields were generated by adding the 200 metre upward continued TMI track to model fields computed at that 200 metre higher elevation. The resulting compound profiles are shown in Figure 7A. The smoother and simpler curves for the profiles from the intermediate and strong magnetisations appear more suitable for source depth estimation than the equivalent curves before upward continuation (see Figure 5A). The profile for the weaker magnetization also provides a more substantial expression of that magnetization than before upward continuation, and in this case supports estimation of a source depth. Cross-sections of the three inversion models are shown in Figure 7B. The average error in the depth estimates is 3% with a maximum of 5%. The upward continuation provides a clearly superior estimate of source depth than the primary TMI data.

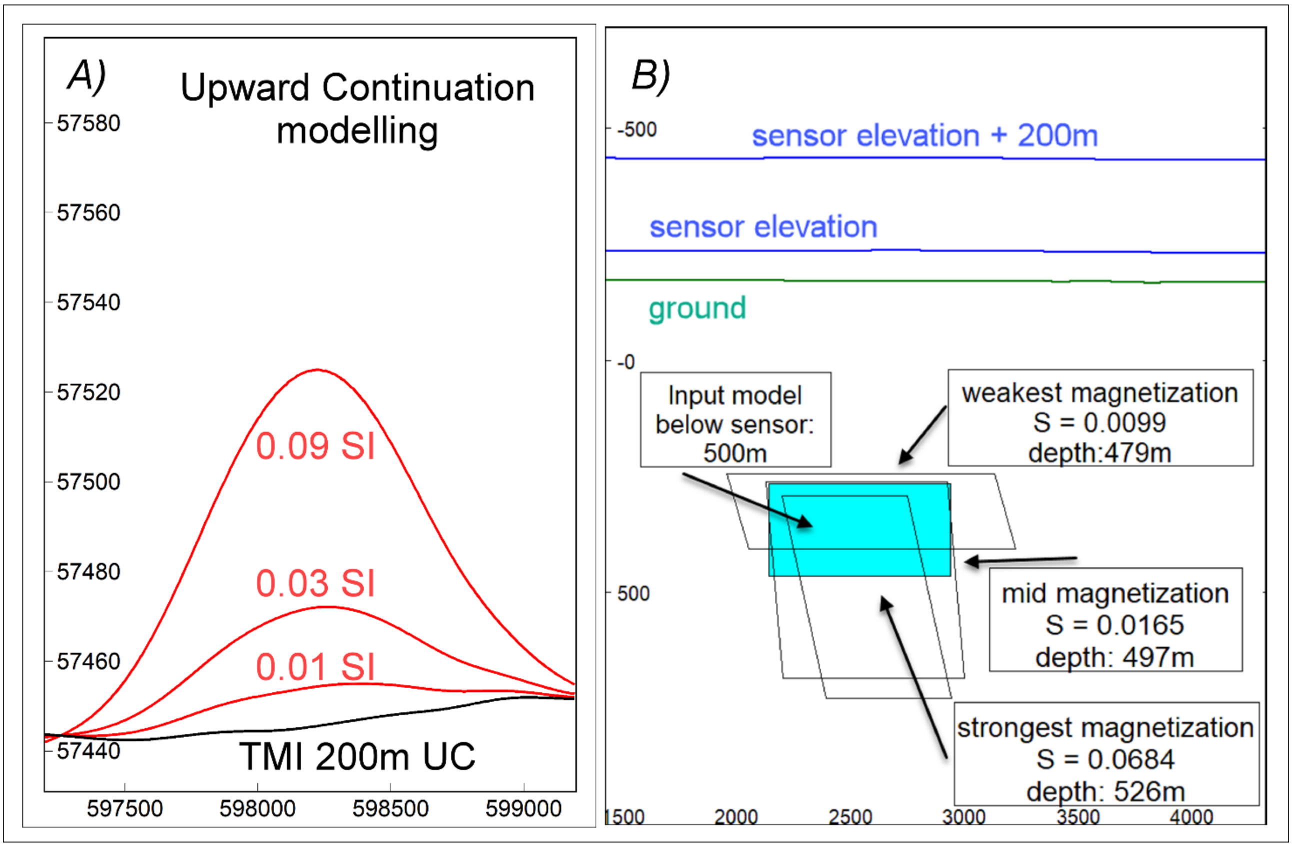

Figure 7 A) Profile showing 200 m upward continued TMI (black curve) with added computed fields for the 500 m body (red curves), and B) cross-sections of the input (filled cyan) and inversion (outline) bodies

CONCLUSIONS

We have developed an equivalent source dipole model to help quantify magnetic field variations due to near-surface magnetisations. We have inverted measured magnetic field variations over near-surface magnetisations to which we have added synthetic model magnetic fields and show that the magnetic fields due to the near-surface magnetisations significantly degrade estimation of depth to those lower magnetisations. However, upward continuation appears to provide an effective means to attenuate the fields from the near-surface magnetisations and improve estimation of depth to deeper magnetisations.

ACKNOWLEDGMENTS

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REFERENCES

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