Inverse and forward modelling using random dipoles – case study

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SUMMARY

A recently published method of automatically finding magnetic depths to magnetic layers is demonstrated, finding depths to significant details in the magnetic basement under Melville Island, Northern Territory.

By using a method that simulates a magnetic basement as a series of layers of random dipoles, the depths to basement are satisfactorily obtained. Multiple layers appear in the results. However the inversion method used has coarse horizontal resolution, and the layers may be separated horizontally within the sample.

To resolve the ambiguity a forward model, also composed of layers of dipoles, is built on the information obtained from the inversions. Forward modelling requires Fourier convolution for speed. The cycle of analysis is logically completed by comparing the synthetic depth profile with the depth profile obtained by inverting the survey data.

Key words: magnetic depths, modelling, random dipoles

INTRODUCTION

A method of finding magnetic depths (Clifton, 2015) simulates the heterogeneity of magnetic bodies by assuming that the source of signal is one or more layers of randomly located dipoles. A layer of dipoles contributes shape characteristic of the depth, across a range of frequencies on the power spectrum. Often a second or even a third layer contributes the shape characteristic of their depths to other parts of the spectrum. Inversion to depths results in a depth profile, and a series of depth profiles in a transect resembles a noisy seismic section. The method works well when the magnetic bodies are wide, have at most a gentle gradient and the ground above is magnetically quiet.

Corresponding forward modelling, that is, using random dipoles to represent geological bodies, requires adding the fields of so many dipoles that adding them in sequence would be impossibly slow. However, by multiplying the 3-D Fourier transform of their locations with the transform of a single dipole, and inverting the product, the field due to the assembly is achieved in seconds (Clifton, 2016). A depth profile may then be taken for comparison with the depth profile of the original.

Melville Is. is covered by the largely non-magnetic Cretaceous Money Shoal Basin, believed to be underlain by the Precambrian Pine Creek Orogen (Ahmad and Munson, 2013). A subduction zone, the Timor Trench lies 300 km north-west of the islands.

An airborne magnetic survey (NTGS, 2006) was flown on north-south flightlines 400 m apart. Figure 1 shows the magnetic image lacking in surface detail, with a clear magnetic basement crossed by a series of parallel lines. If these are faults related to the subduction of the Australian plate, one would expect them to be deepening to the north-west.

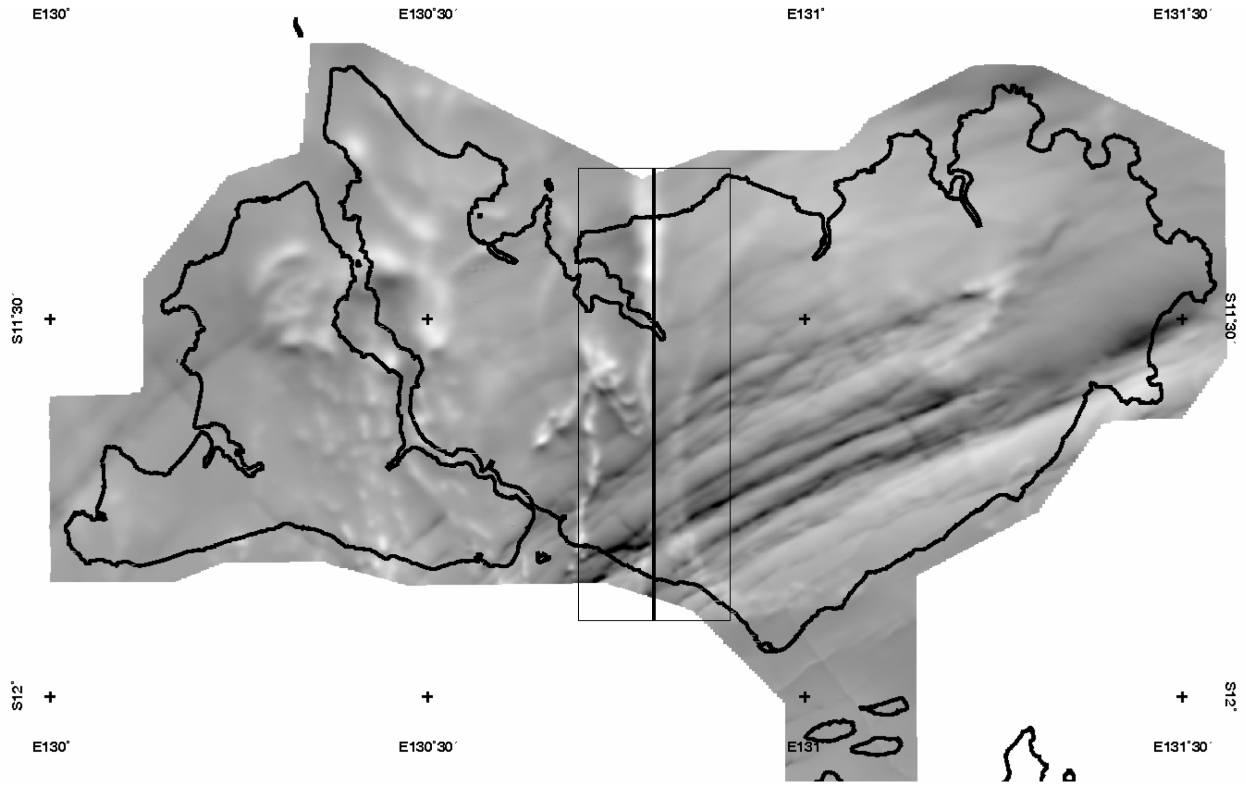

Figure 1: Total magnetic intensity image of Bathurst and Melville Islands. A subset, 20 km wide, is selected for analysis.

The NTGS distributes magnetic depth transects across the Northern Territory (Clifton, 2013), among which are transects crossing the Tiwi Islands. As they share the same default parameters for the rest of the Northern Territory, these transects do show a basement declining to the north-west, but they are improved by reprocessing with optimum parameters.

The presentation at the ASEG conference in August, 2016 will use Intrepid's GeoModeller to create magnetic depth profiles, and test forward models using Fourier convolution. For the moment, reworking a transect and building a model using random dipoles are demonstrated below.

METHOD AND RESULTS

The magnetic depth transect along the line in Figure 1 shows what appears to be multiple equivalent layers to the south and a declining basement northwards. Reworking the transect (Figure 2) confirms the appearance of multiple layers. Where the magnetic body has significant thickness, the equivalent layer appears near its top surface. What appears to be a layer around 200 m is an artefact at the limit of the method due to the 400 m wide spacing of the survey flight lines.

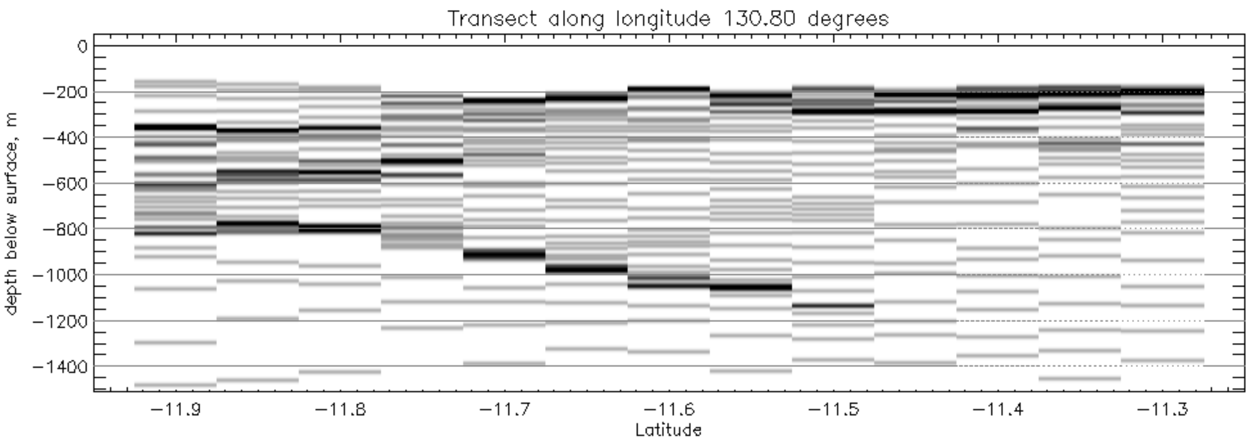

Figure 2. Transect of depth profiles along the line of 130.8° East on Figure 1. The tops of three layers can be distinguished in the southmost three depth profiles. A declining basement can be picked out across the middle of the figure.

Comparison with Figure 1 suggests that the three layers are due to three steps in the basement. A forward model is in order to test whether the depths on the profiles are reasonable. See Figure 3.

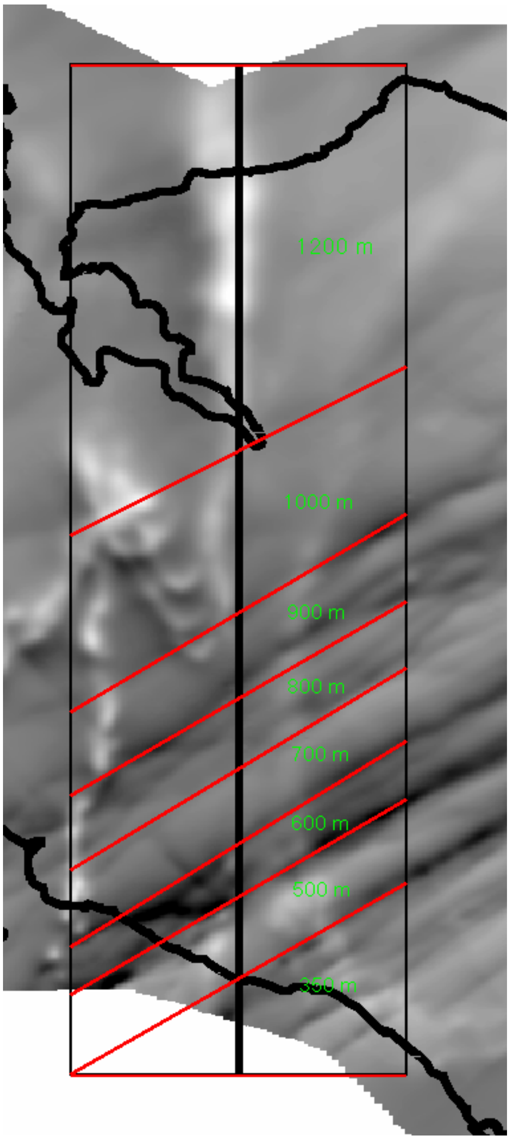

Figure 3. Plan view of a model with a series of horizontal steps, deepening to the north-west. The model is 20 km wide, the width of the samples taken from the original survey grid to create the depth profiles in Figure 2.

So that the model yields synthetic depth profiles, the bodies in the model must also be composed of heterogeneous bodies. Their heterogeneity is simulated by a random distribution of dipoles. An arbitrary thickness of 70 m has been assigned in this case, sufficient to give an equivalent layer near their top surfaces.

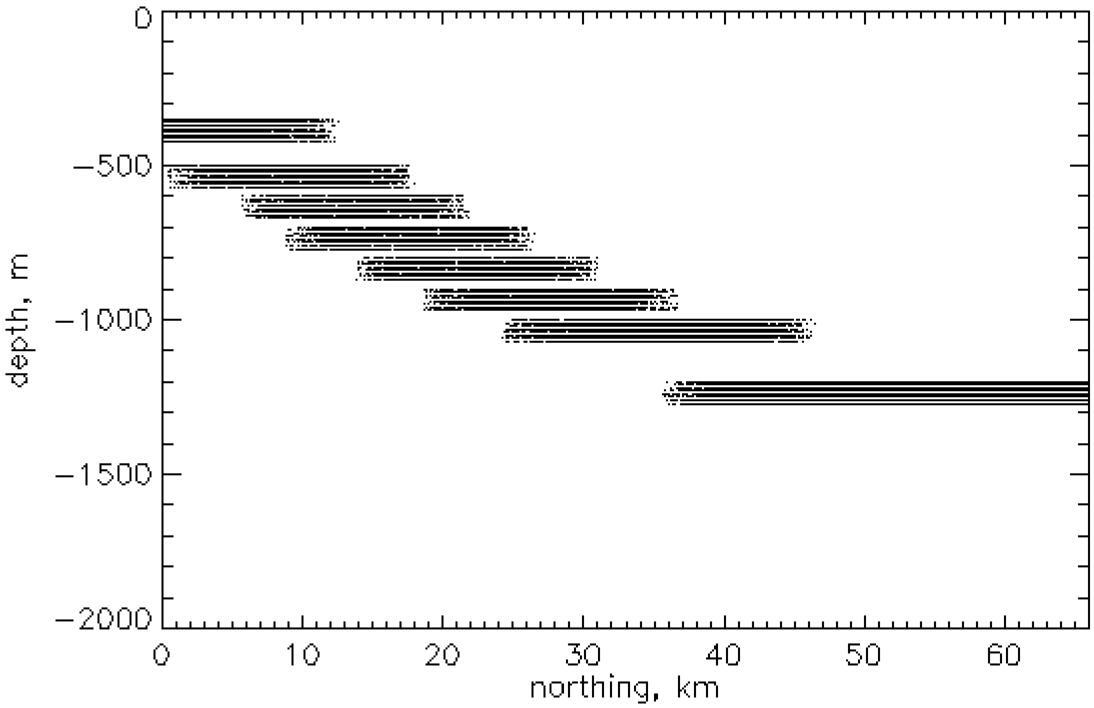

Figure 4. Side view of 55000 dipoles randomly located in the model of Figure 3. The aliasing pattern is an illusion, the distribution of dipoles is in fact random on an array of nodes 80 m apart horizontally and 10 m vertically. More than 70% of the nodes are empty and many of the nodes have more than one dipole assigned to them.

At this point in the procedure, the model would then be inverted using the facility for a Fourier convolution, obtaining a series of depth profiles to be compared with the original depth profiles on Figure 2. Inevitably, the cycle would be repeated, with improvements in the position of the horizontal and vertical boundaries until the significant depths evident in the synthetic depth profiles were close to those in the original depth profiles.

Moreover, the processing that gave rise to Figure 2 can be repeated for further information about the basement. In particular, Figure 2 fails to indicate how deep the basement is at the north end of the transect. The information can be dug out of the data by adjusting the parameters to maximise deep resolution. By examining only the lowest frequencies, below 0.3 cycles per kilometre, and using the shortest line segment fits, the deepest signal can be extracted. See Figure 5.

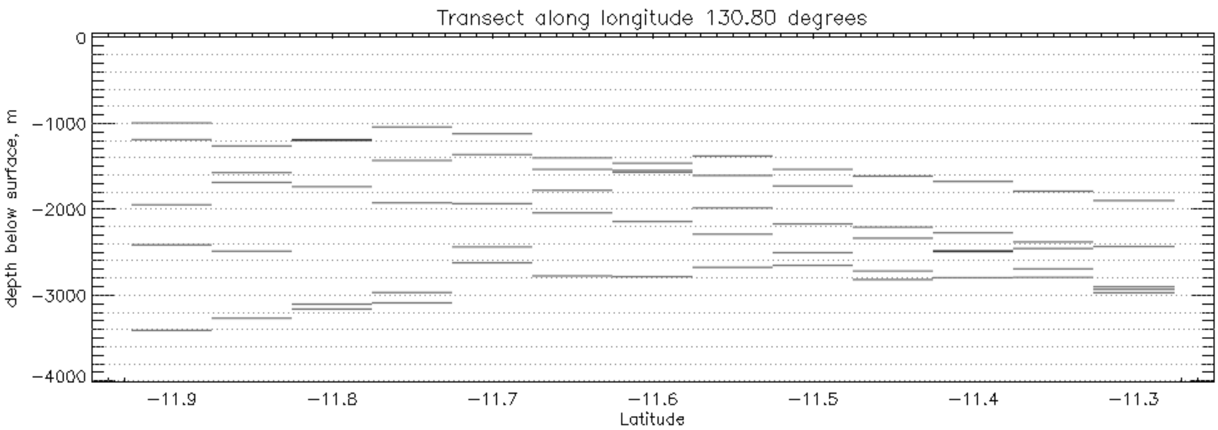

Figure 5. Deepest signal available using this method on 20 km samples, using frequencies below 0.3 cycles per kilometre and a short line fit. The result is inevitably noisy. Here, only the uppermost signals are credible.

The noise level is high, so confirmation is needed from neighbouring transects. In this case, continuation from the lines in Figure 2 lend a measure of respectability to the topmost sequence of lines in Figure 5. The sequence indicates that the basement sinks to 2000 m at the north end of the transect, useful information to be fed back into the model.

The maximum resolvable depth is constrained by the width of the samples. If the width of the grid sample is doubled, the maximum obtainable depth can be doubled. However bodies that do not extend at similar depth across much of the larger sample may be lost from the analysis, their signal blurred out across a range of depths.

CONCLUSIONS

Using commercially available software, a user is able to conveniently obtain a series of depth estimates to extensive magnetic bodies. A range of parameters allow weak signals to be teased out from the noise. A corresponding, rapid forward modelling procedure is available to test the depth signatures of hypothetical bodies of arbitrary shape.

The magnetic basement under Bathurst and Melville Islands descends towards the north-west in a series of steps at determined depths. The method is too coarse to resolve whether the steps are folded or faulted.

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