The Bark without a Dog – Magnetic Anomalies over Holes in a Volcanic Sheet in the greater McArthur Basin, NT

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SUMMARY

Linear strings of circular negative magnetic anomalies in the greater McArthur Basin of the Northern Territory are interpreted as due to holes in an underlying sheet of Kalkarindji flood basalts. Individual anomaly inversion results provide an estimate of the diameter, depth to top, and depth extent of holes in the volcanic sheet. The effective magnetization of the hole is its contrast against the more strongly magnetised sheet. Estimated magnetization contrast values are mostly rotated from a direction antiparallel to the local geomagnetic field, which we interpret as due to the contribution of remanent magnetization within the sheet. We support interpretation of the anomalies as due to holes in the sheet by comparing them with the magnetic expression of distant sheet edges. The linear arrangement of the anomalies is believed to arise from fractures in the sheet, suggesting that the holes developed after the sheet was emplaced, most probably by local escape of fluids, which altered the sheet and destroyed its magnetization.

Key words: magnetic anomaly, reverse, remanent, volcanic sheet, North Territory, greater McArthur Basin.

INTRODUCTION

In this study we investigate several magnetic field anomalies over areas of shallow subcrop of the Kalkarindji flood basalts (known in this area as the Antrim Plateau Volcanics) which cover large areas of the Beetaloo Sub-basin of the greater McArthur Basin (Ahmad et al., 2013). These are massive Cambrian sub-aerial basalt flows with individual flow thicknesses of up to several hundred metres, and a cumulative thickness of over one kilometre in places (Glass et al., 2013). These shallow volcanics have a dominant expression in the magnetic field imagery derived from regional aeromagnetic surveys of the area, which have been flown at 400 metre line spacing and a terrain clearance of 80 to 100 metres. The anomalies are particularly distinctive in the recently acquired NTGS Dunmarra survey.

Magnetic anomalies are generally envisaged as arising from the absolute magnetization of material beneath the anomaly, assuming surrounding magnetizations are insignificant. However, in this study we interpret many discrete anomalies over an area of the Beetaloo Sub-basin as due to contrasts between localised materials of low magnetization against an extensive, more strongly magnetic sheet that surrounds them. Assuming that material infilling holes in the sheet has a negligible magnetization, the magnetization contrast for the holes is approximately the reverse of the magnetization vector of the surrounding sheet. Complications in magnetic field interpretation arise because a material can have an intrinsic magnetization in any direction due to a dominant remanent magnetization. The reasons we interpret these specific magnetic field anomalies as due to holes in a magnetic sheet rather than localised reverse remanent magnetizations, are because texture in the surrounding magnetic imagery strongly suggests the presence of a shallow, extensive volcanic sheet, and because searching far enough away from the anomalies we can locate the magnetic expression of the edge of that sheet. The postulated holes in the sheet may exist either because original protuberances caused the sheet to flow around them, or because the sheet has subsequently been punctured. We prefer the latter interpretation. Many of these discrete magnetic anomalies align in a preferred northwest-southeast trend, which we interpret as being controlled by fractures in the sheet and possibly in the underlying section. These fractures would be the preferred locations for escape of fluids. In places the spacing of the discrete magnetic anomalies along trend is quite regular (varying between 2 and 4 kilometres in different areas). This spacing of the anomalies may be controlled by dewatering processes, or by cross-cutting structures that localise fluid flow. Basic volcanics are readily weathered and altered by persistent or episodic exposure to circulating fluids, and such alteration or weathering can further facilitate and localise fluid flow. One of the first consequences of alteration of basaltic volcanics is a marked reduction in their magnetization, due to alteration and destruction of the magnetite which carries that magnetization. Therefore if fluid flow through a positively magnetised sheet (possibly at the intersection of two fractures) causes substantial alteration and weathering, then that location should be marked by a negative magnetic anomaly, and we propose that this is the explanation of the observed magnetic anomalies. Some support for fluid flow through the volcanic sheet is the discovery of bitumen within the sheet (Matthews, 2009). A likely genesis of this bitumen is that it was formed deeper in the section and has been transported by fluid flow through the sheet.

INTERPRETATION OF SELECTED FEATURES IN THE MAGNETIC FIELD IMAGERY

Figure 1 shows a TMI image over part of the Beetaloo Sub-basin in the Northern Territory. There are substantial textural variations across the image, which are due to differences in depth to the shallowest volcanic layer. Over much of the image there are sharp variations due to volcanics that are exposed or at a shallow depth below surface. In places this texture includes linear features of northwest-southeast trend, which we interpret as due to fractures of the sheet, causing step discontinuities at its top surface. In the areas marked "C" and "D" the strings of circular negative anomalies are the focus of this study. In contrast to the rough texture of the image over areas of shallow volcanics, there are areas (mostly in the south and east of the map) where the magnetic image is smooth. These are areas outside the shallow sheet, and act as windows to the magnetic expression of deeper sheets. The eastern margin of the shallow sheet is marked by a prominent, sharp linear anomaly, which is positive on north-facing segments of the edge, and negative over south-facing edge segments, as well expressed in area "A" in Figure 1. Figure 2 shows a detail of the TMI image of area "A", together with a modelled traverse. The edge anomalies can be explained as due to a magnetic sheet of susceptibility .016 SI. There is little sensitivity to magnetization direction in modelling a single traverse, and the magnetization might include remanent components parallel or oblique to the local geomagnetic field. The average modelled thickness of the sheet is 350 metres, and the estimated depth to its top is 270 metres over the northern margin, and approximately a hundred metres deeper over the southern margin.

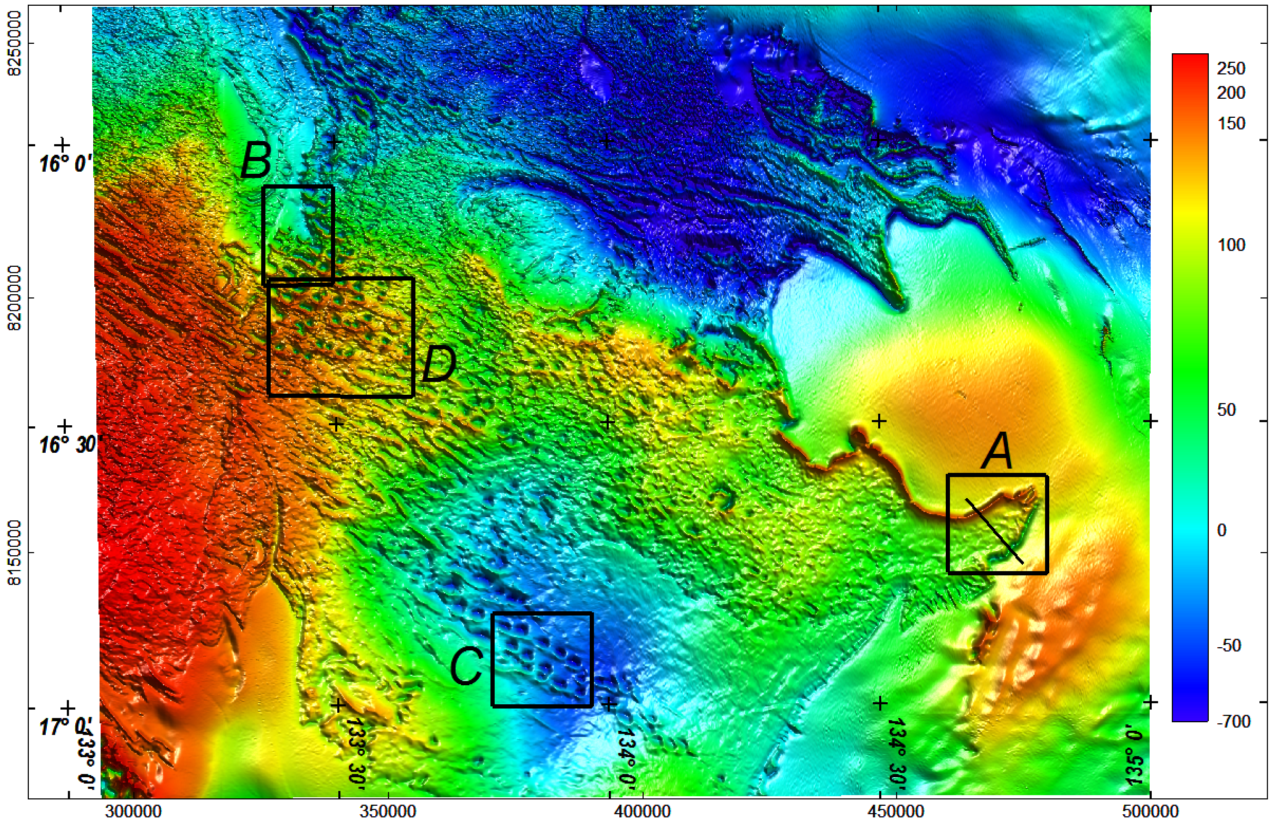

Figure 1 Total magnetic intensity (TMI) image over an interpreted shallow volcanic sheet in the Beetaloo Sub-basin.

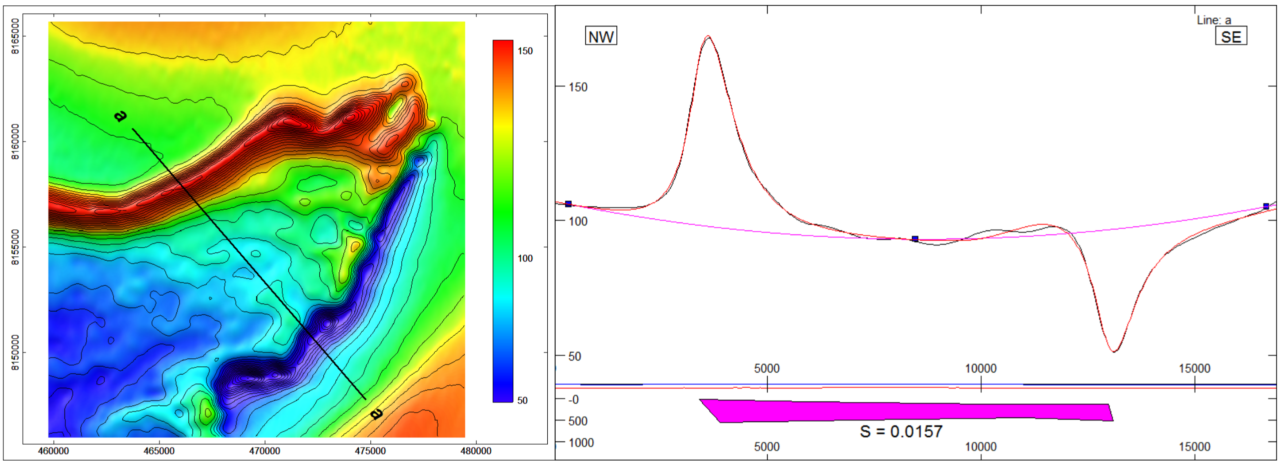

Figure 2 TMI image and traverse location over an interpreted original margin of the volcanic sheet

Figure 3 shows another section of the TMI image (area "B" in Figure 1) also interpreted as covering an edge of the sheet. In this area the edge of the sheet has a much less prominent magnetic signature, which we explain as being due to a tapering of the edge, probably as a result of erosion. In places the edge of the sheet seems to include partial negative circular anomalies, which we interpret as holes in the sheet that have been exposed at its edge, and now form embayments in that edge. Notice that each local protrusion of the sheet has the same pattern of a positive feature towards its northern margin, and a negative feature to its south. Holes in the sheet would therefore be marked by the reverse pattern of a negative in the north (over the southern sheet edge at the hole), and a positive to the south (marking the northern sheet edge at the hole).

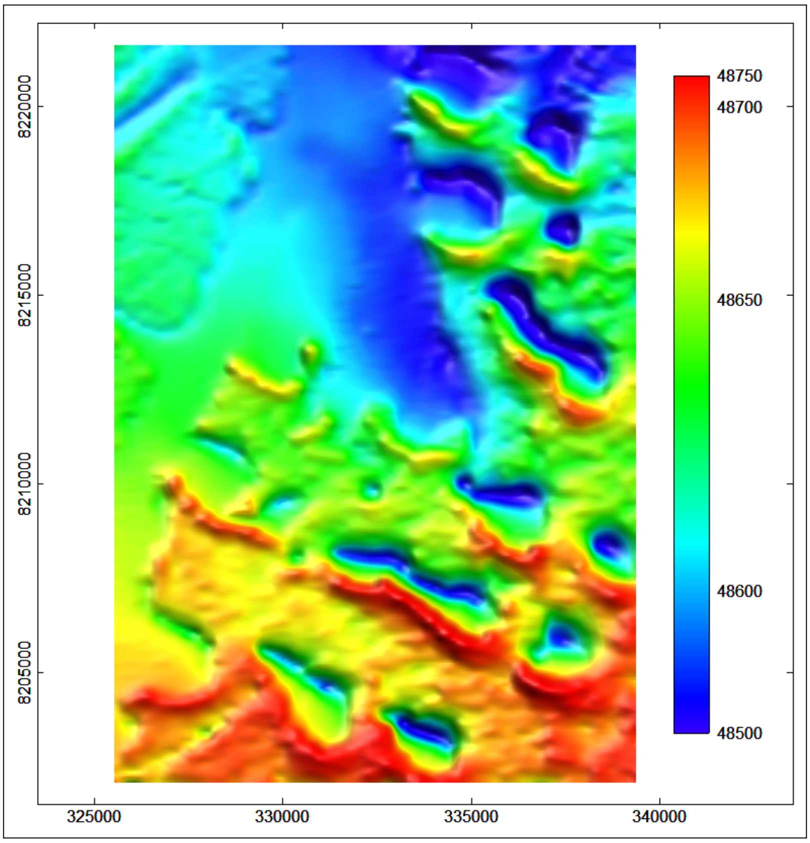

Figure 3 an interpreted erosional sheet margin, where sheet holes now form embayments in the sheet edge

Figure 4 shows a section of the TMI image (area "D" in Figure 1) which has prominent examples of circular anomalies within the shallow volcanic sheet. Some anomalies have peak to trough ratios in excess of 200 nT. The anomalies are aligned in a northwest-southeast direction, with apparent lateral displacements between local segments of generally between 3 and 5 individual anomalies. The anomalies are strongly dipolar, with prominent minima to the north, and maxima to the south. Many of these anomalies are circular enough that their source shape does not substantially influence the orientation of the anomaly dipole. We interpret variable orientation of the diopole from anomaly to anomaly as due to locally varying resultant magnetization directions, due either to variations in the proportional contribution of remanent magnetization or in the remanent magnetization direction. Study of the anomaly contour patterns also reveals significant variation in peak to trough ratios of the anomalies, which is not easily explained by source geometry, but again implies variation in resultant magnetization direction, in this case of the inclination.

A regional palaeomagnetic study of the Kalkarindji basalts by McElhinny and Luck (1970) was only partially successful in recovering an estimate of remanent magnetization for the basalts. Stable magnetizations were only recovered from 14 of the 29 sampled sites, with some of the failed sites ascribed to deep weathering effects or lightning strikes. The quoted remanent magnetization direction of declination 51°, inclination +66° (α95 = 13°) was obtained after substantial cleaning, and represents only a small proportion of the remanent magnetization present. NRM (natural remanent magnetization) measured before magnetic cleaning is the most relevant remanent magnetization statistic for magnetic field interpretation. NRM values are reported for each site but are not statistically analysed. However, inspection of the tabulated site NRM values shows a much higher proportion of normal magnetization than in the final, cleaned magnetizations. Unfortunately there is no mention in the study of magnetic susceptibility values, from which Koenigsberger ratio (Q factor) values could be computed to determine the relative contribution of remanent and induced magnetizations to the magnetic field anomalies.

Figure 4 also shows the location of 7 adjacent flight-line segments over an anomaly which we have modelled. The flight line sections through the inversion model are shown in Figure 5. We have run the inversion allowing both the spatial parameters of the model, and its magnetization, to change. The resulting estimates of depth below surface, 270 metres, and depth extent, 265 metres, are quite consistent with the values estimated over 130 kilometres away in area "A" over the edge of the sheet. The estimated intensity of magnetization of just less than 1 A/m is equivalent in strength to an induced magnetization of .025 SI. For this particular anomaly the estimated resultant magnetization direction of declination 195°, inclination +37° is rotated by only 12° from the direction antiparallel to the local geomagnetic field (the direction expected for a contrast against a purely induced magnetization).

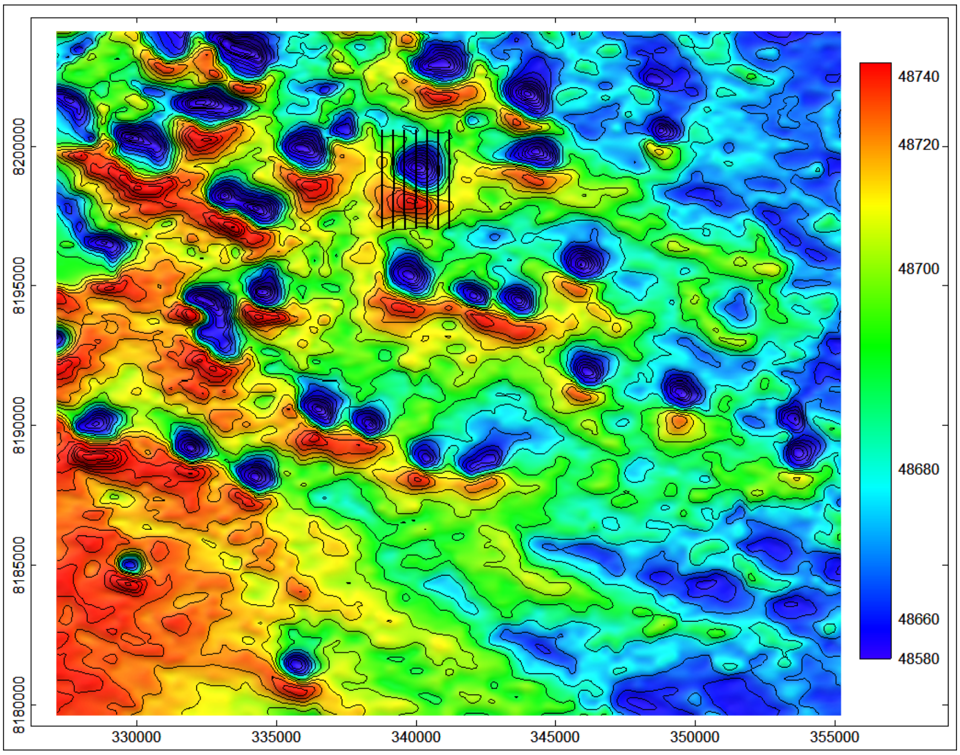

Figure 4 TMI image over sub-area D sown in Figure 1, with flight-lines over a modelled anomaly

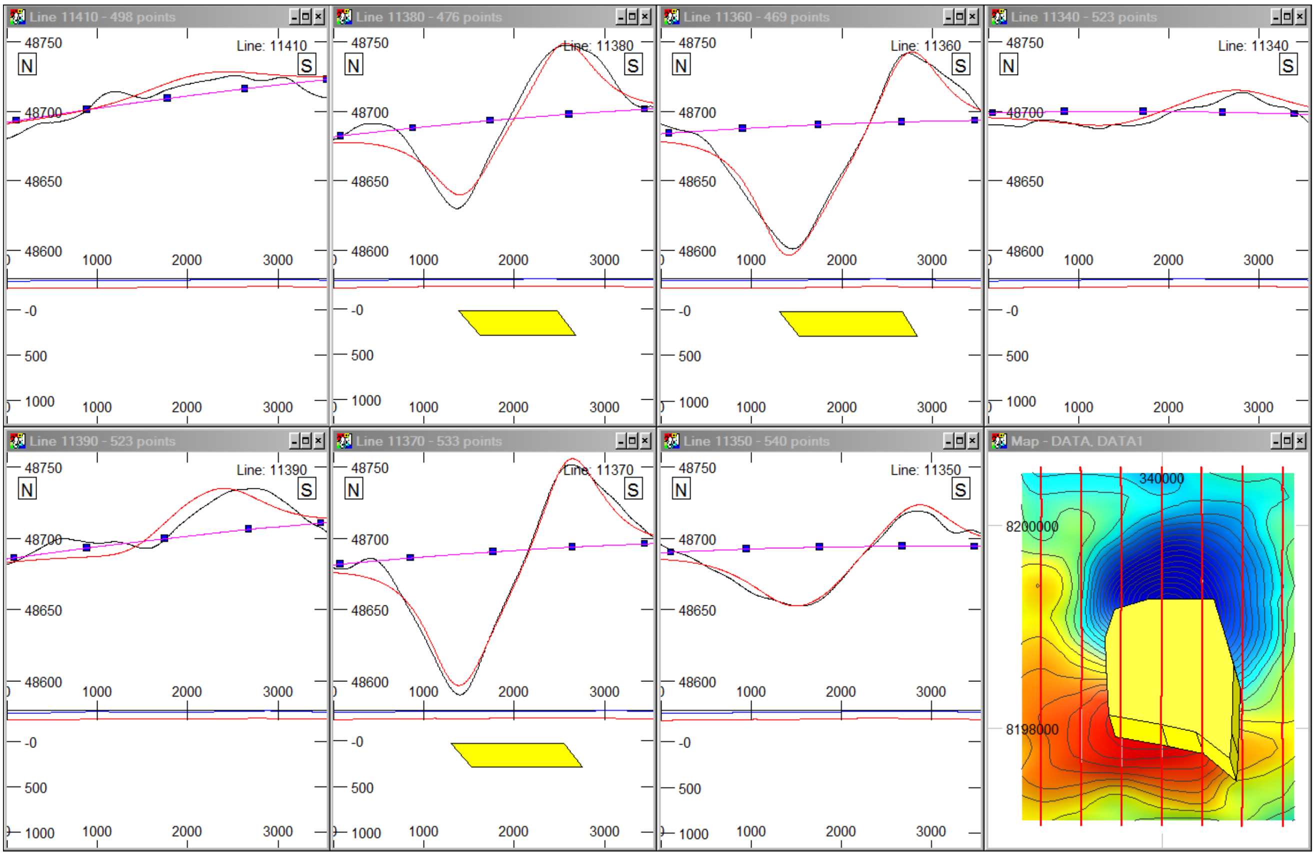

Figure 5 Inverted flight lines over an interpreted 'hole in the sheet' anomaly

CONCLUSIONS

We have established by inversion that circular, predominantly negative magnetic anomalies over a Kalkarindji basalt sheet are consistent in magnetization contrast and depth extent with the explanation that they are due to holes in that sheet. Variation between anomaly peak to trough ratios and dipole orientation suggests that the magnetization contrast is not uniformly directed, and may include a component due to remanent magnetization of variable direction and/or variable proportion relative to the induced magnetization. These anomalies provide the opportunity to estimate lateral variations in sheet thickness and magnetization. We believe that the holes may be due to local destruction of the sheet at fracture intersections, which have acted as conduits for fluid flow.

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