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Large scale magnetic gradient tensor surveys from TMI data

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SUMMARY

We demonstrate that it is possible to design conventional total magnetic intensity (TMI) surveys that can be used to derive full tensor magnetic gradient (FTMG) data over large areas. It is also possible to apply the same technique to historical survey archives where the magnetic gradients from the target depths are reasonably preserved in the data. This process means that it is then possible to apply a new generation of interpretation techniques developed for FTMG sensor surveys to transformed TMI magnetic surveys. Two surveys covering a total of 132,000 line kilometres illustrate FTMG survey design, transformation and processing results.

Key words: magnetic, tensor, gradient, transformation, TMI.

INTRODUCTION

It is now possible to acquire full tensor magnetic gradient (FTMG) data using a system operated out of Canada, yet there is little general knowledge about the potential value of the data collected by these systems. While there are many publications on the theory, the technology has not yet evolved into a mainstream application despite the promise of increased geological resolution and extraction of associated depth and rock property information. Access to FTMG survey data has been a limiting factor, but it is possible to convert a conventional total magnetic intensity survey to a FTMG survey if the line spacing and terrain is suitable. This transformed data is then available for investigating the properties of the magnetic tensor.

We demonstrate the robustness of the TMI to FTMG conversion method on a FTMG-ready 70,000 line kilometre, 40 metre line spacing helicopter survey along the length of the Agnew-Wiluna Nickel Belt (AWB) in Western Australia. The method is also applied to 52,000 line kilometres of lower resolution public domain data from the Gawler Craton survey in South Australia where the 200 metre line spacing is well suited to FTMG conversion for deeper exploration targets.

The magnetic gradient tensor has sufficient 3D information where a few FTMG sensor measurements along a flight line can be used to compute the direction and distance to an isolated magnetic source. The objective of these studies is to investigate the promise offered by well established, theoretical principles for FTMG data to uncover previously undiscovered exploration targets in new and historical magnetic surveys. We examine the value of the transformed FTMG data for enhancing geological mapping, alteration and magnetic remanence detection image resolution, depth and rock property estimation using the RPD Mapping method (Pratt et al., 2021a).

TMI TO TENSOR TRANSFORMATION

Clark (2013) showed how to compute the magnetic gradient tensor using Fourier transformation of a total magnetic intensity grid and this process is implemented in ModelVision (Pratt et al. 2021b). To demonstrate the robustness of the transformation, we created a modestly complex geological model, computed grids of the TMI and tensor fields and then transformed the model TMI grid to tensor grids for comparison. Figure 1(a) shows the geological model outline over an image of the computed model of the B_{zz} tensor component (vertical gradient of the vertical magnetic component). Figure 1(b) shows an overlay of the contours from the transformed (black) and theoretical (red) B_{zz} grids for a small rectangular section of the survey. The contours are almost indistinguishable, even in the low gradient region. This transformation demonstration was applied to a constant terrain clearance simulated survey over a flat surface. The method works in undulating terrains where the terrain is comparatively flat over two to three times the line separation. A different approach using the equivalent source method is required for surveys in rugged terrain.

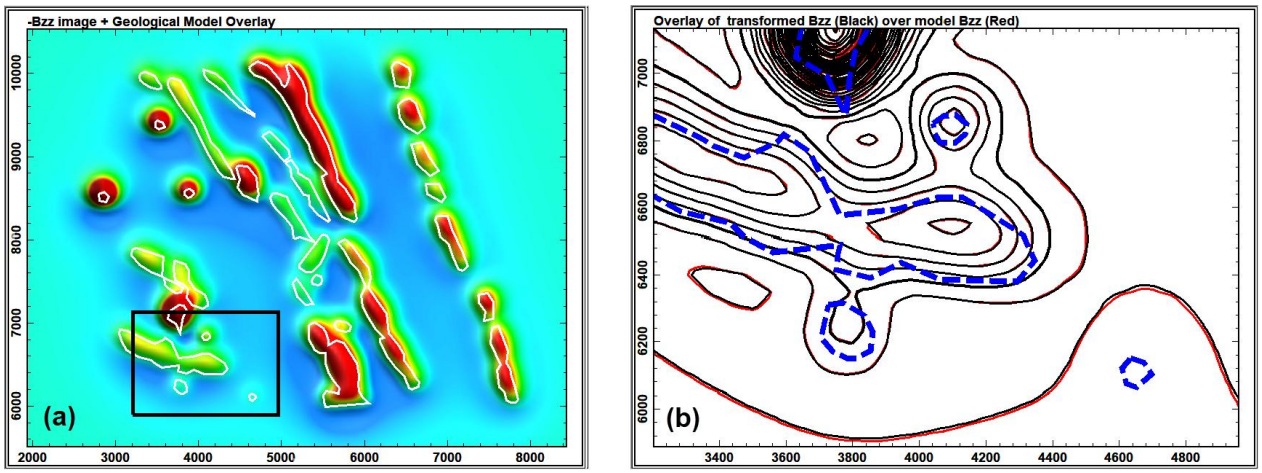

Figure 1: (a) An image of the B_{zz} grid with a white outline of the vertical polygonal-shaped formations with variable magnetic susceptibilities. (b) Contours of B_{zz} for the rectangular sub-area in (a) where the red contours show the theoretical model results and the black contours show the equivalent FFT transformed contours.

AWB NICKEL BELT

The AWB spans more than 150 kilometres and geophysics has been used extensively in the search for new deposits. The komatiites that host the mineralisation are approximately 2.7 billion years old and the structural evolution of the belt is extremely complex. The public domain data consists of a TMI survey flown at 400 metre line spacing which is sufficient to understand the regional context. Even the 40 metre spaced survey flown by BHP oversimplifies the geology but it provides an excellent foundation for integration with the detailed mapping and drilling data that precedes it. Figure 2(a) shows the extent of the AWB survey as a colour overlay of a TMI image on a monochrome image of the regional magnetic data. Figure 2(b,c) shows a comparison of TMI grids from a small area of the 400 and 40 metre spaced surveys. Figure 2(d) shows the transformed $-B_{zz}$ tensor component for the same area, detailing variations in magnetic properties along strike.

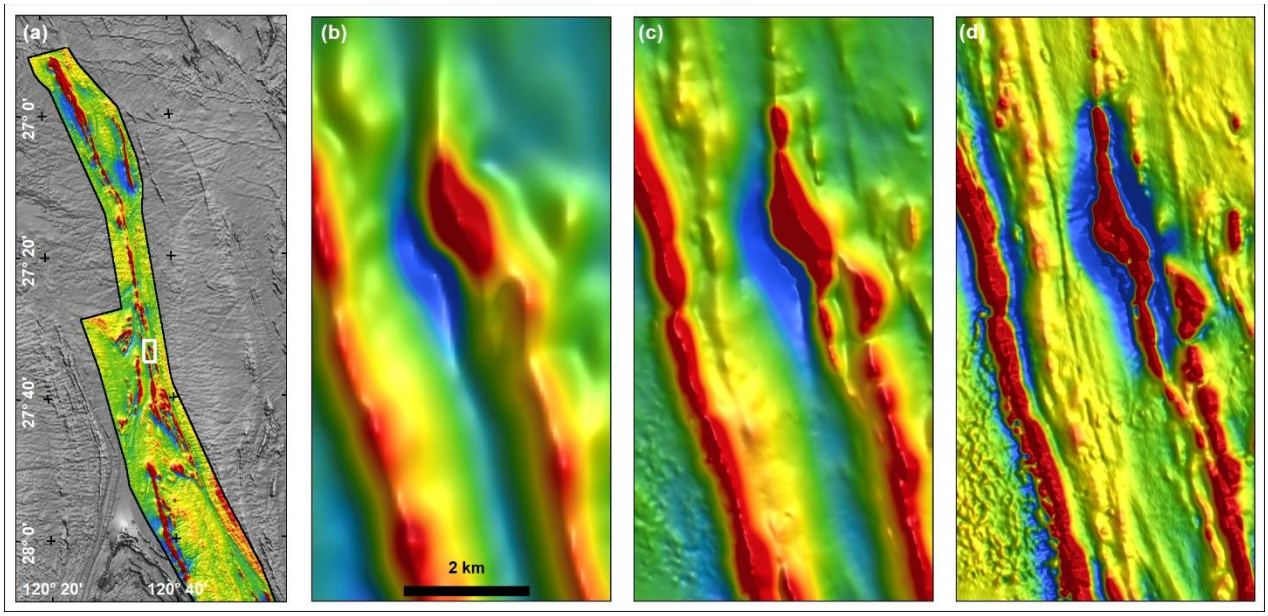

Figure 2: The detailed, tensor-ready TMI survey is overlain on a monochrome image of the 400 metre government survey (a). A white rectangle shows the location of detailed colour image comparisons for the 400 metre TMI grid (b), 40 metre spaced helicopter TMI grid (c) and -Bzz grid transformed from the detailed helicopter TMI grid (d).

The high resolution survey was designed for direct targeting of remanently magnetised massive sulphides, structural mapping, geological mapping, mining engineering input for future mining operations and assistance with ground water resources research. RPD Mapping was applied to the helicopter survey data

to produce 70,000 kilometres of magnetic tensor line data, grids of all the tensor channels and other tensor related products such as the normalised source strength (NSS). The rock properties data provides additional benefits by condensing the important information to a simplified point dataset that is then overlain on any other image product, cartographic map or GIS data set without obscuring the underlying information. It was especially useful when adding an attributed symbol set to a 3D visualisation of the geology draped over terrain.

OLYMPIC DAM DOMAIN

Three areas were selected from the PACE Copper Gawler Craton Airborne Survey covering the Prominent Hill, Olympic Dam, Oak Dam and Carrapateena deposits (Fig. 3a). These areas were selected for their association with IOCG deposits where the mineralisation is dominantly associated with haematite that produces a definitive gravity anomaly. Apart from Oak Dam (West), the economic deposits have some association with a nearby magnetic anomaly, but the association is not definitive. Oak Dam (East) has a smaller gravity anomaly and high amplitude magnetic anomaly with sub-economic mineral grades.

Figure 3b shows a monochrome B_{zz} image of the Olympic Dam region which is designed to highlight changes in depth through loss of sharpness from discrete edges as the depth of cover increases. We reverse the sign of B_{zz} in the southern magnetic hemisphere so that high susceptibility areas have warmer tones or colours and low susceptibilities have darker tones. While similar in appearance to the first vertical derivative, B_{zz} produces sharper images and provides more visual sensitivity for depth contrast and the detection of edges. The level of magnetite destruction that has occurred in the Olympic Dam region is extreme when compared with the imagery from Prominent Hill and Carrapateena. In Figure 3b there are many multi-directional, semi-linear features defining major structural zones that suggest significant fluid flow for long periods with subsequent oxidation of the magnetite to haematite. Some of these features intersect in the vicinity of the Olympic Dam mine.

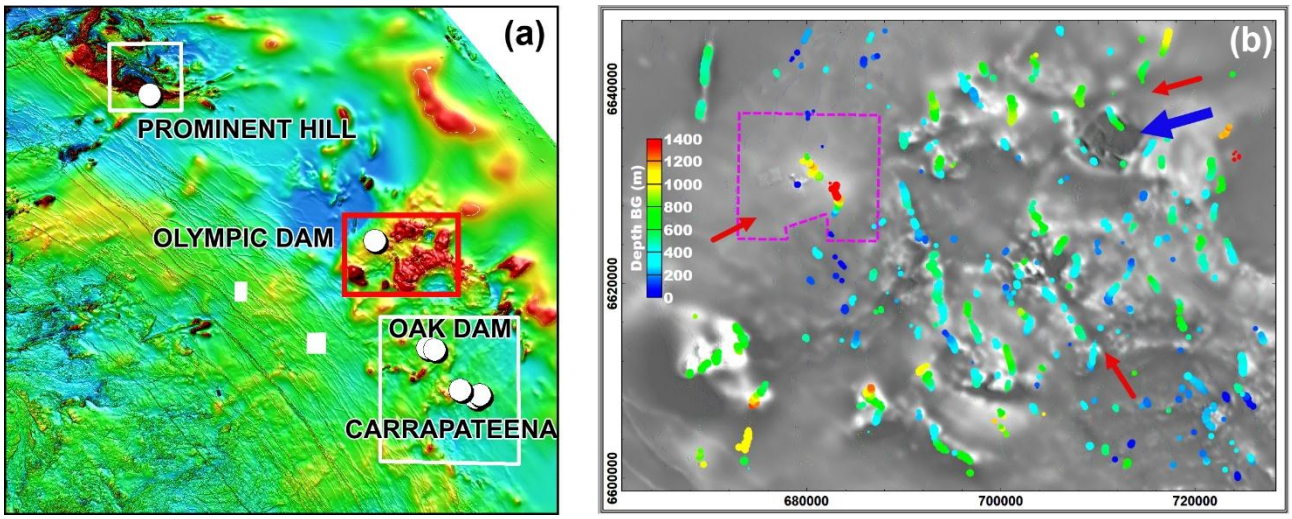

Figure 3: (a) An overview image of the Gawler Craton survey showing the location of the Prominent Hill, Olympic Dam and Oak Dam/Carrapateena FTMG project sub-areas. The TMI image uses a linear colour stretch with the white dots showing the location of major BHP - Oz Minerals deposits. (b) A monochrome image of the inverted B_{zz} tensor component derived from the TMI grid is useful for imaging the pervasive alteration and magnetite destruction (red arrows) and remanently magnetised intrusion (blue arrow). A semi-linear stretch is used to enhance depth variations while depressing the very high amplitude anomalies. An overlay of the RPD Mapping depth estimates is displayed as colour coded symbols. The Olympic Dam mining lease is outlined in purple.

The dark linear trends sit inside a broad region of non-zero magnetic susceptibility and thus locally create the equivalent of a zone of reversely magnetised material. A slightly darker, semi-square anomaly to the north-east of Olympic Dam is produced by a remanently magnetised source that is believed to be associated with a mafic gabbro within the Moody Suite. Interestingly, there are positive, linear anomalies passing though the feature that are most likely caused by magnetite destruction of the original remanently magnetised rocks.

The coloured symbol overlay represents the final depth results produced by the application of the RPD Mapping process to the tensor line data computed from the TMI grids (Pratt et al., 2021a). The depths range

from the surface to more than 1400 metres. Depths increase to the north-east as basement deepens below the Wallaroo Group basin along the eastern margin of the Gawler Craton. Depths ranging from 800 to 1400 metres are estimated beneath Olympic Dam and are believed to be associated with the unoxidised magnetite that is found below the top section of the deposit (Skirrow et al., 2019).

We applied the RPD Mapping processes to the three study areas and produced tensor grid and line data products. Grids of the six tensor channels and normalised source strength provided the base suite for imaging and other derivative products. The FTMG line data provides the primary input for the RPD Mapping physics-based and AI-constrained inversion which produces a solution for every anomaly on every line in the survey. The attributed point set carries a lot of information about each anomaly, its neighbouring anomalies and quality estimates for each solution. The attributes are then condensed to the best quality estimates for location, depth below ground, azimuth, magnetic susceptibility, remanence (where appropriate) and a geological shape classification.

Since the IOCG targets are not expected to be magnetic, the results from the study are used to better understand the geological context with special emphasis on magnetite destruction and depth. The NSS parameter is especially useful for recognising magnetite destruction, particularly in the context of a local residual gravity anomaly. Since the public domain gravity data station density varies dramatically, the FTMG data provides an excellent geological context for recognising possible gravity indicators in sparsely sampled regions. A knowledge of the magnetic depths further aids this interpretive process.

CONCLUSIONS

Full tensor magnetic gradient data can be derived from conventional magnetic survey that are specifically designed to extract the gradient data from the total field sensor data. The method is also suitable for extracting FTMG data from historical surveys that reasonably preserve the gradient data and it opens up new exploration opportunities to derive more geological information from our data archives. These methods don't replace measurement of the magnetic tensor gradients which has obvious advantages for shallow geology, rugged terrain and low inclination magnetic fields.

The resampling of the magnetic tensor grids back onto the original flight lines allows us to utilise the most reliable part of the transformed data and then apply line-based quantitative interpretive processing techniques at the full resolution of the data. This technique allows the same interpretive processes to be applied to measured or transformed FTMG data for extraction of magnetic rock properties, magnetic source depths, formation trends and geological shape information.

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