Magnetic and gravity source models of the Gairdner Dolerites

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SUMMARY

The Gairdner Dolerites feature prominently in magnetic and gravity images of South Australia. They are a volcanic intrusive, easily identifiable in SA magnetic images as a set of NNW-SSE linear features. The Gawler Craton Airborne Survey (GCAS) has recently acquired high-resolution magnetic data over these dolerites.

AutoMag analysis of magnetic data from the GCAS data is used to study the large number of Gairdner Dolerite dyke anomalies in the study area. A high-resolution (400 metre station spaced) gravity survey reveals that the larger dykes have detectable gravity expressions. We have inverted two selected dyke magnetic anomalies to derive source models with best-estimated thicknesses of 75 and 97 metres and magnetic susceptibilities of .054 and .029 respectively. These models together with density measurements of over 2,900 kg/m^3 for the dykes and less than 2,600 kg/m^3 for Pandurra Formation which the dykes intrude are used to forward model gravity anomalies with peak amplitudes of 4 to 5 µm/sec^2. We plan more detailed gravity traverses over selected dykes to test combined magnetic and gravity inversion with which to constrain depth to the top of basement (where there is a substantial reduction in density contrast).

Key words: magnetics, gravity, inversion, Gairdner Dolerites, GCAS

INTRODUCTION

The Gawler Craton Airborne Survey (GCAS) in South Australia comprises approximately 1,660,000 line kilometres of magnetic, radiometric and digital elevation data over an area of about 295,000 km^2 (Figure 1). The data surpass the previous patchwork of historical surveys and provide a uniform dataset for geological interpretations of the Gawler Craton (Katona, 2018).

The survey comprises 16 discrete blocks, labelled from 1A to 10. We will focus on magnetic data from block 3B, acquired by Sander Geophysics. This area covers the Carrapateena and Khamsin mineral deposits in the northeast. To the west are the NNW-SSE trending linear features corresponding to the Gairdner Dolerites. These are visible on Figure 2 (at the end of the paper).

The Gairdner Dolerites (also known as the Gairdner Dyke Swarm (Huang et al., 2015) are Neoproterozoic (c. 820-830 Ma) intrusives, dominating the magnetic signature of the region (Foss et al., 2018). The dykes intrude up to the lowermost Adelaidean (Callana Group) above basement. The dyke swarm has a general northwest-southeast trend, with variable trend between dykes and along individual dykes. Their depth extents are unknown.

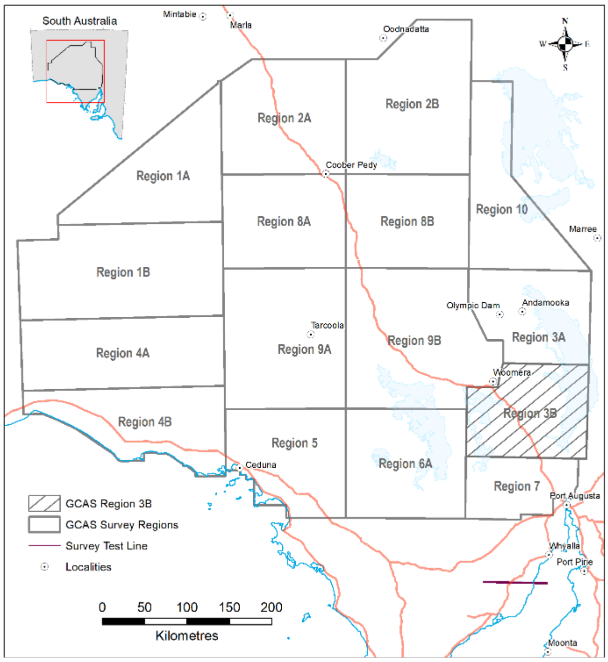

Figure 1. The Gawler Craton airborne survey covers much of South Australia, with area 3B in the southeast of the area.

METHOD AND RESULTS

A TMI image derived from the new GCAS survey data of Block 3B is shown in Figure 2. A comprehensive investigation of the Gairdner dyke swarm in this survey block is described in the area report (Foss et al., 2018). Here we focus specifically on a small area in the south-west of the block, as located in Figure 2. This area is covered by a gravity survey with a station spacing of 400 metres. Figure 3 shows an image of the vertical derivative of Bouguer gravity with an overlay of RTP (reduced-to-pole) contours. Such strong correspondence of the magnetic and gravity fields in mapping dykes is unusual. We ascribe this correspondence to the relatively close spacing of the gravity stations (correspondence of the gravity and magnetic fields is more cryptic outside the area of this detailed gravity survey), the considerable width of some of the dykes, and the fact that the dykes intrude above basement into the overlying, lower density formations. Density measurements from the state physical property database provide an estimate of density for the Gairdner dolerite of ca. 2900 kg/m^3 (40 samples) and for the Pandurra Formation ca. 2580 kg/m^3 (670 samples) for a density contrast of 300 to 350 kg/m^3.

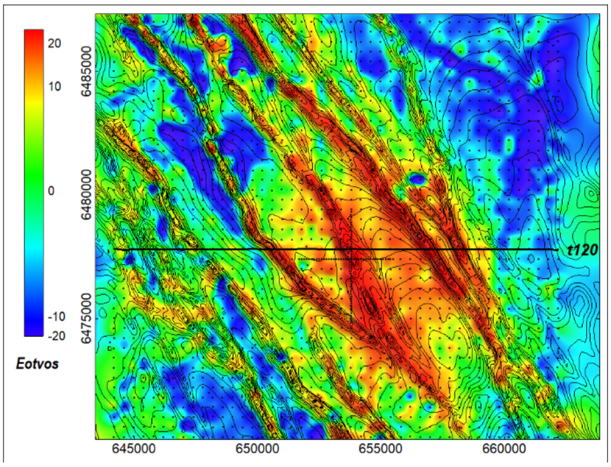

Figure 3. Colour image of the vertical derivative of Bouguer gravity with an overlay of RTP contours and gravity stations. T120 is the line of section constructed from the gravity stations and a near-coincident flight-line from the GCAS survey.

In this modelling and inversion study we utilise the line data for the airborne magnetics, and station profiles selected from the ground gravity data. This avoids inherent smoothing in the gridded data which does not retain the true curvatures of the fields of these shallow sources. ModelVision^{TM} was used for modelling and inversion. ModelVision includes the AutoMag^{TM} model generator based on adaption (Shi, 1991) of an analysis developed by Naudy (1971). Automated magnetic source estimators rarely provide satisfactory results but the simple, consistent and predictable sheet geometry of the Gairdner dykes is especially suitable for this method of analysis. Continuity of the anomalies over considerable strike extent confirms that the sources conform to ‘2D’ assumptions of consistent property and geometry. Once the strike azimuth is determined, the dyke is then characterised by its cross-section parameters (thickness, depth to top, depth extent, dip and magnetization). A profile vertical derivative FFT filter (again highly appropriate because of the anomaly consistency from line to line) was applied to increase resolution of the analysis. Figure 4 shows the east-west magnetic flight-line as located in Figures 2 and 3. Measured TMI is shown in the second track and the profile vertical derivative of TMI is shown in the upper track. This filter clearly sharpens the dyke anomalies and very effectively removes the long wavelength ‘regional’ variation due to deeper and more distant sources. AutoMag computes the anomaly of a nominated dyke source in a window of chosen width, and that signature is run along the profile as a cross-correlation operator (in this case utilising the vertical derivative filter output). The inverted correlation coefficient is shown in the third track (optimum values are minima). Where this coefficient dips below a selected threshold a source solution is triggered, and a simple look-up inversion is employed to adjust that solution from its initial values. The discrimination capability of AutoMag derives from the solutions being fully prescribed seed bodies which can be activated and tested by forward computation. The close match of the filter-derived and forward computed vertical derivative of TMI in the upper track of Figure 3 illustrates how well these simple source models fit the data. The corresponding computed TMI anomalies in the second track are also similar to the measured TMI anomalies, but are variably displaced from them by the superimposed fields of more distant sources.

A detailed comparison of the correspondence between gravity and magnetic signatures of the dykes as imaged in Figure 3 is shown along an east-west traverse of gravity stations in Figure 5. The lower track of Bouguer gravity variation shows local maxima of about 1 km width (3 to 4 stations) over the dykes. The gravity profile vertical derivative filter also highlights these dyke anomalies as shown in the upper track of Figure 5, but not as effectively as the magnetic field measurements on the coincident aeromagnetic flight-line. The upper track of Figure 5 includes a magnetic field traverse generated by sampling the TMI grid at the gravity stations. This resampled magnetic traverse detects many but not all of the more prominent dyke anomalies, but at a substantially reduced resolution. The expression of most of the dykes is highly dependent on a single station.

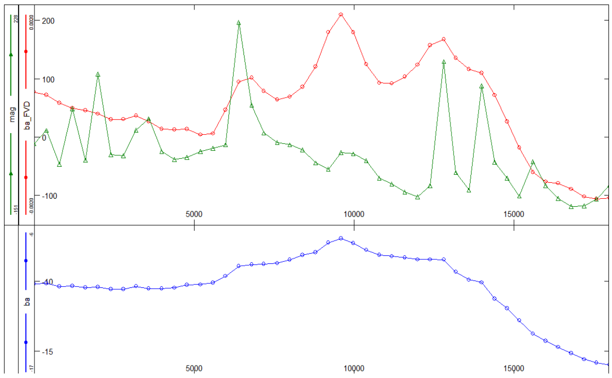

Figure 5. The same traverse as for Figure 3: (lower track) measured Bouguer gravity, (upper track) the vertical derivative of Bouguer gravity (red) from a profile filter of the gravity measurements and (green) TMI interpolated from the GCAS TMI grid at each gravity station.

AutoMag provides an automated analysis of the dykes, but more reliable source information can be recovered by a dedicated and exhaustive analysis of each anomaly in isolation. This is performed by single-anomaly inversion using the AutoMag solutions as starting models. Figure 6 shows an inversion of the dyke labelled “A” in Figure 4. The inversion was performed to minimise the data misfit between the vertical derivatives of the measured and model-computed TMI (as shown in the upper track of Figure 6), with the same advantages as in using the vertical derivative in AutoMag. The best-fit model has a thickness of 75 metres, a depth to top below surface of 55 metres, an apparent magnetic susceptibility (including any remanent magnetization contributions to the magnetization) of 0.054 SI and a dip of 89 degrees to the west. Despite best efforts to optimise the model there are inherent limits to the sensitivity of each parameter. In particular, for such thin bodies once the depth extent exceeds about 4 times depth to the top there is low sensitivity to the actual depth extent. Also, across a wide range of thickness and magnetization, there is low sensitivity to the individual values of those parameters provided their product is kept near-constant.

Figure 7 shows the gravity anomaly (and in the top track the vertical derivative of gravity) for the magnetic dyke A model with a density of 2,900 kg/m^3 against a background of 2,580 kg/m^3, computed at the ground surface. The most readily detectable central section of the anomaly with width 400 to 600 metres has an amplitude variation of about 5 µm/sec^2 and a vertical derivative expression of almost 50 Eötvös. The measured gravity variation between the station apparently

directly above the dyke and those 400 metres away is only about half of that predicted from the magnetic model. This suggests that the dyke may not be as wide as expected, the density is less than expected, or the position of the gravity station relative to the dyke is incorrect. Dependence on a single measurement does not support speculation about this misfit, which requires closer spaced gravity stations (we plan a new gravity survey at 50 metre spacing or closer). Clearly the vertical derivative filter of the gravity data as shown in Figure 5 is at best illustrative of the location of some anomalies rather than of their shape or amplitude.

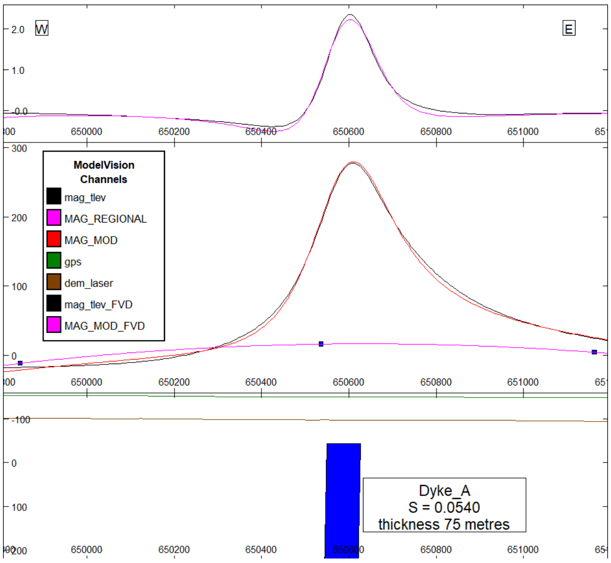

Figure 6. Dyke A: magnetic inversion model, centre track measured and computed TMI, upper track vertical derivative of measured and computed TMI.

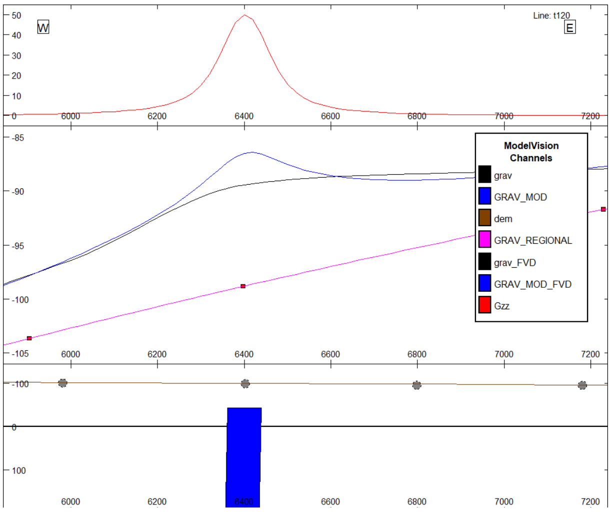

Figure 7. Dyke A: gravity response computed from the magnetic inversion model, centre track Bouguer gravity, upper track vertical derivative of gravity. The grey points are existing gravity stations.

Figure 8 shows inversion of a second magnetic anomaly, "B" as located in Figure 4. This inversion model is similar to model A, but with decreased apparent magnetic susceptibility of .03 SI, increased thickness of 105 metres, decreased depth to top of 37 metres and dip 69° west. Forward modelling gravity at ground level using this magnetic model produces gravity expressions quite similar to those for Dyke A as shown in Figure 9, with a gravity variation across 600 metres of about 4 µm/sec^2 and a vertical derivative expression of about 40 Eötvos. Absence of a recognised measured gravity anomaly for this dyke is clearly explained by the distribution of gravity stations as shown in Figure 9, with the closest gravity station almost 150 metres from the modelled dyke margin.

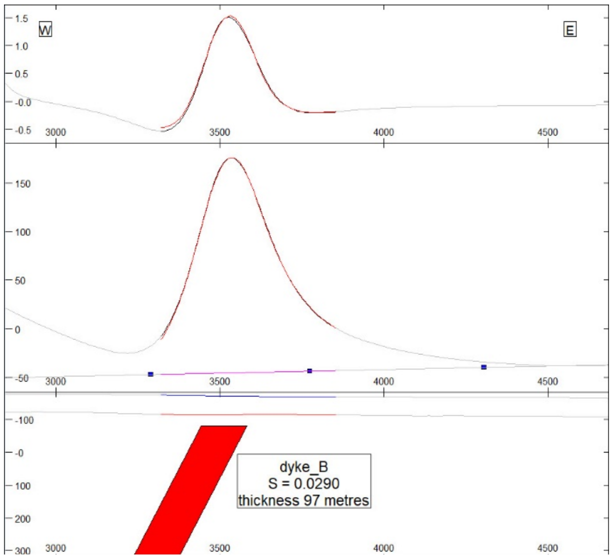

Figure 8. Dyke B: magnetic inversion model, centre track measured and computed TMI, upper track vertical derivative of measured and computed TMI.

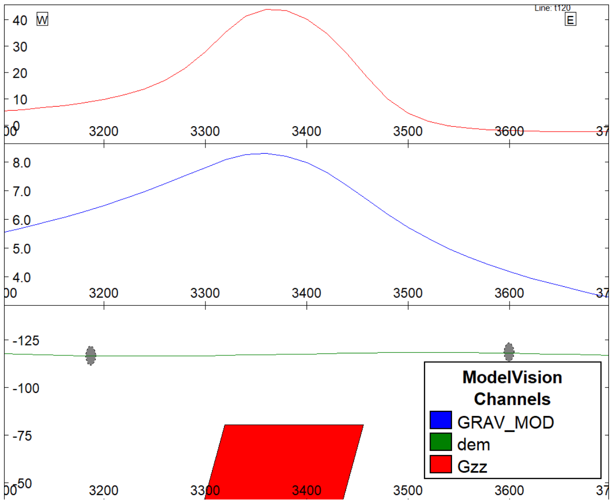

Figure 9. Dyke B: gravity response computed from the magnetic inversion model, centre track Bouguer gravity, upper track vertical derivative of gravity. The grey points are existing gravity stations.

Our hope in measuring ground gravity and magnetic profiles is not just to record the gravity variations inadequately sampled by the existing survey, but that combined gravity and magnetic modelling may allow us to constrain depth to basement, because we anticipate that the gravity anomalies of the dykes are effectively determined only by their top section through the overlying low density formations, with just a minor contribution to the anomaly from the much smaller density contrast of the deeper portion of the dyke intruded into basement. We also hope that the expected higher sensitivity of the magnetic modelling of the top of the dyke will reduce that element of uncertainty in the gravity model, providing greater sensitivity to its base.

CONCLUSIONS

Estimates of depth to top, thickness and magnetic susceptibility of the Gairdner Dolerite dykes across the GCAS 3B Torrens area have been derived by AutoMag analysis. A 400 metre station-spaced survey over a part of this area reveals that the wider dykes also have detectable gravity expressions, with predicted amplitudes of up to 5 µm/sec^2. These anomalies arise predominantly from the high density contrast between the dykes and formations overlying basement. We plan a ground gravity and magnetic survey to investigate the feasibility of constraining depth to basement from a combined gravity and magnetic inversion.

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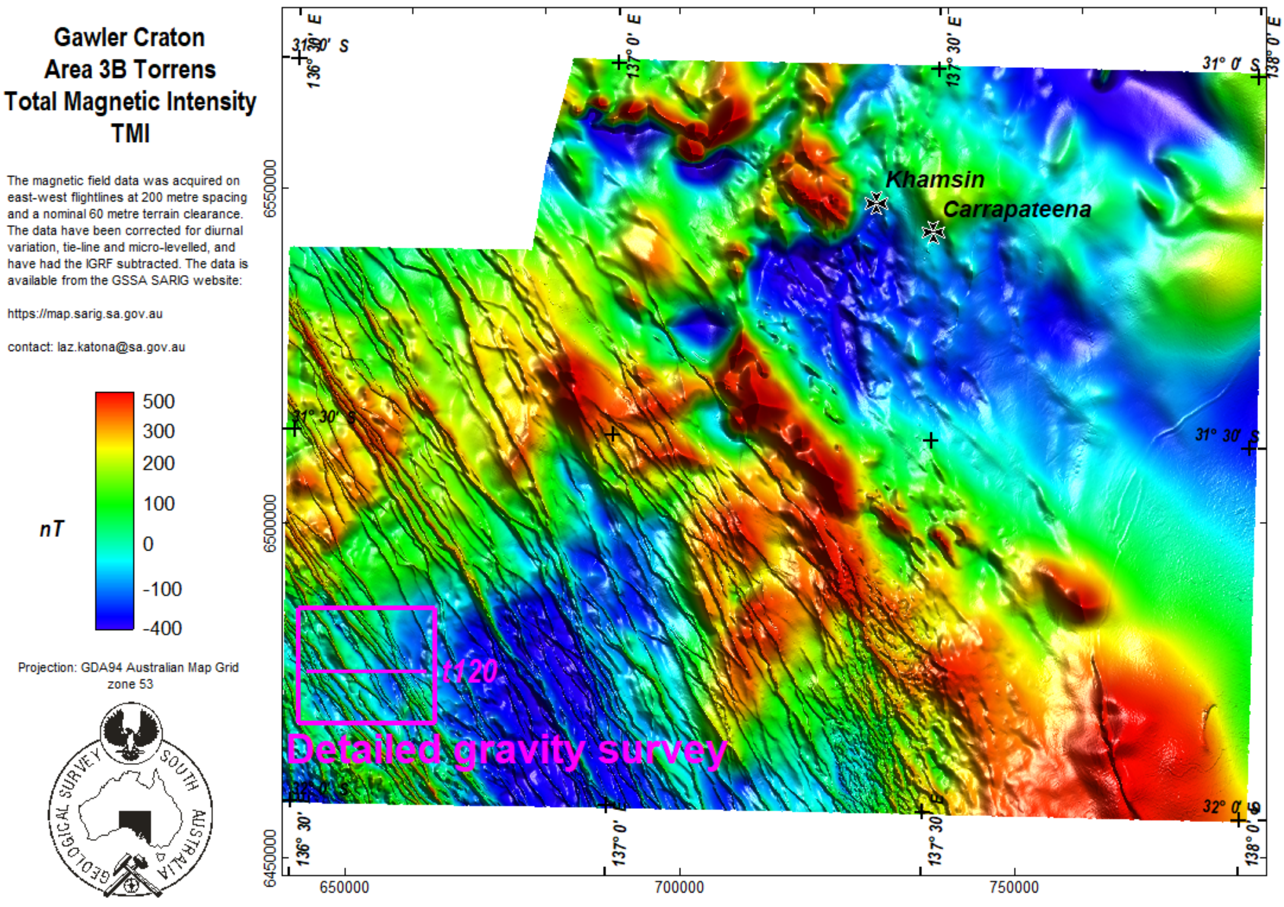

Figure 2. The Gairdner Dolerites are seen clearly as NNW-SSE linear features in the west portion of the Total Magnetic Intensity for area 3B of the GCAS.

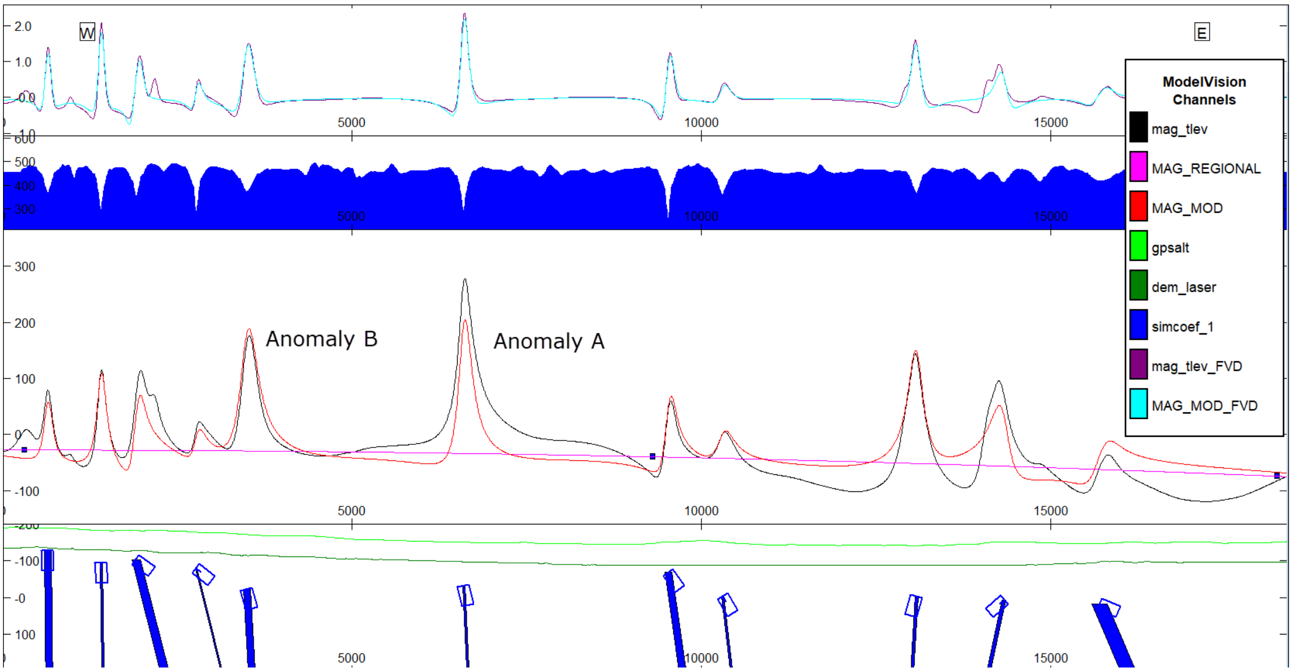

Figure 4. Flight line AutoMag section with solutions and converted bodies (track1), measured, regional and computed TMI (track 2), AutoMag similarity coefficient (track 3) and the vertical derivative filler of measured and computed TMI (track 4).