A New Technique for Low Magnetic Latitude Transformation: Synthetic Model Results and Examples

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SUMMARY

Traditional methods for processing low magnetic latitude data below ±25° magnetic latitude do not fully resolve anomaly location and may distort the anomaly shape leading to misinterpretation of the data, as well as loss of certain directional anomalies. The principal objective of our research was to develop a new filter that would better position anomalies, reduce anomaly distortion and provide good anomaly shape while attempting to recover structures parallel to the declination direction.

The MTC-LML Filter (Modulus of Total Component at low magnetic latitudes) is based on the calculation of the Modulus of the three magnetic components of the main field (one vertical and two orthogonal horizontal). To test the MTC-LML Filter, a set of synthetic models were constructed composed of complicated magnetic bodies each with different strike directions and depths. Each model was designed to address a specific aspect of the low magnetic latitude problem. The results of synthetic modelling for the MTC-LML Filter were compared with synthetic models of standard transformations and techniques for dealing with low magnetic latitude data. Practical applications of the MTC-LML Filter were then made using survey data.

The filter results for synthetic model and survey data, show better location and shape of model source bodies when compared to the existing standard transformations and techniques. The MTC-LML Filter provides an improved transformation of the data with reliable location and shape of the anomalies above the source, reduced anomaly distortion and better recovery of structure parallel to the declination direction.

Key words: potential field data processing, low magnetic latitude transformation, reduction to the pole, reduction to the equator, total modulus of three components, analytical signal, magnetic magnitude transforms.

INTRODUCTION

Traditional methods of transformation such as Reduction to the Pole (RTP) and Equator (RTE) are accepted as standard procedures at low magnetic latitudes. Other techniques include the Analytical Signal (AS), Total Magnitude Anomaly (TMA) (Gerovska and Stavrev, 2006) and Compound Anomaly (CA; unpublished FROGTECH proprietary filter).

While these methods can solve some of the problems caused by low magnetic latitude, they also result in some limitations. The main difficulties are to do with anomaly shape and location, negative anomalies over induced magnetised source bodies, elongated anomalies perpendicular to the declination direction, and weak or barely detectable anomalies for source bodies with a strike parallel to the declination direction. Combined, these difficulties lead to unsatisfactory processing, enhancement and interpretation of low magnetic latitude data.

The true RTP transformation does not work in low magnetic latitude areas (Li, 2008) due to numerical instability. Noise effects resulting from the calculations may obscure real anomalies. The RTE transformation produces much broader negative anomalies over the induced magnetised bodies with roughly the correct position; however, for source bodies with a strike parallel to the declination direction, anomaly signals are lost during transformation. The amplitude of the Analytical Signal (AS) produces maxima over magnetic contacts, almost regardless of the direction of magnetisation. This solves the problem of remanent and anisotropically magnetised bodies (McLeod et al, 1993), however due to a first derivative order of the AS filter, the regional field is greatly reduced and in some cases noise is enhanced making it difficult to interpret geology from the results.

The Compound Anomaly (CA) (unpublished proprietary filter) is calculated by combining three transformed magnetic components (one vertical and two orthogonal horizontal). The principle of this technique was initially developed by Hou (1979). Professor Hou (Chongchu) proposed a technique to compute the total modulus of the vector of the magnetic field anomaly $|\overrightarrow{Ta}|$ using three transformed components; vertical (*Za*), north horizontal (*Ya*) and east horizontal (*Xa*) represented by the formula:

$$|\overrightarrow{Ta}| = (Xa^2 + Ya^2 + Za^2)^{1/2}$$

The CA was further developed based on the Total Magnetic Intensity (TMI) and the two orthogonal horizontal components. It is similar to the AS but retains the long wavelength information. It provides positive anomalies for both remanent and induced magnetised sources. Anomalies associated with sources oriented parallel to the declination direction are weak in very low magnetic latitudes.

The work of Gerovska and Stavrev (2006) on the Total Magnitude Anomaly (TMA) is based on the calculation of Magnetic Magnitude Transforms (MMTs) from a measured anomalous magnetic field. The calculation of the TMA is the same calculation as that documented by Hou (1979). The result produces anomalies that are closer to the magnetic source's true horizontal position however the technique does not work well in very low magnetic latitudes.

We have further developed the technique first published by Hou (1979) to generate a filter for low magnetic latitudes to attempt to retrieve the correct anomaly shape and enhance structure parallel to the declination direction. The Modulus of Total Component at low magnetic latitudes (MTC-LML) is based on the calculation of the Modulus of a set of three magnetic components (one vertical and two orthogonal horizontal).

Test results show that the MTC-LML provides better location of anomalies; more precise imaging of anomaly shape, directly correlates sources to surface geological structures and reduces distortion of the anomalies in low magnetic latitudes. Structures and sources oriented ~NS, parallel to the declination direction, are also retrieved.

METHOD AND RESULTS

All colour shaded relief images of magnetic data have been produced with a NE sun shade. Dynamic range can be gauged by colour range, with high (red) to low (blue).

Theoretical Model Testing

A theoretical 2D grid of TMI computed 100m above surface was created by forward 3D modelling of the TMI response from a set of synthetic magnetic sources having variable source type, width, strike extent, depth, depth extent (DE), dip, magnetic susceptibility and strike azimuth (Table 1). A plan view of the model sources is shown in Figure 1a and a three dimensional view in Figure 1b. More complicated models including remanence have been tested although not included in this paper.

Model Body No.	Depth (m)	Width/ Diameter (m)	DE (m)	Dip (deg)	Magnetic Susceptibility (SI)	Strike Length (m)	Azimuth (deg)
1	500	500*	2000	90	0.03	38900	0
2	1000	9310	500	90	0.01	17800	-30
3	7800/9800	7700	4000	90	0.01	20866	30
4	1000	6000	3000	45	0.025	-	-
5	1500	500*	2000	90	0.05	38900	20
6	100	200*	2000	90	0.01	20000	50
7	1000	7500	1000	90	0.01	10000	-15
8	12515	5030	7404	20	0.01	20000	-30
9	500	980*	-	-	0.01	-	-
10	200	980*	-	-	0.01	-	-
* Width of individual model body for the specified model number							

Table 1. List of parameters for theoretical model sources

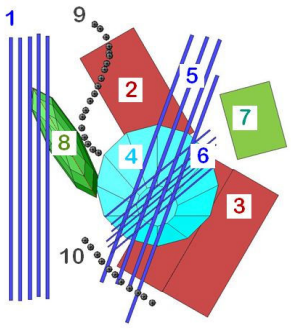

Figure 1a. Plan view of synthetic magnetic source bodies

The problems

The main problems in dealing with low magnetic latitude TMI data are: the anomaly shape is more complex than those observed at higher magnetic latitudes; the anomalies are negative over inductively magnetised source bodies; anomalies are elongated in the direction perpendicular to the declination direction; and anomalies are weak and not visible when source bodies with a long strike length are parallel to the declination direction.

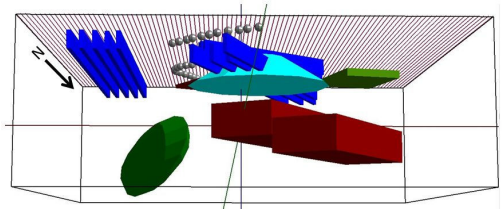

Figure 1b. 3D view of synthetic magnetic source bodies

The images in Figure 2 show synthetic model TMI data associated with a geomagnetic field at variable inclination (I) and declination (D) to highlight the problems associated with data at low magnetic latitudes. Both theoretical and transformed RTP are shown.

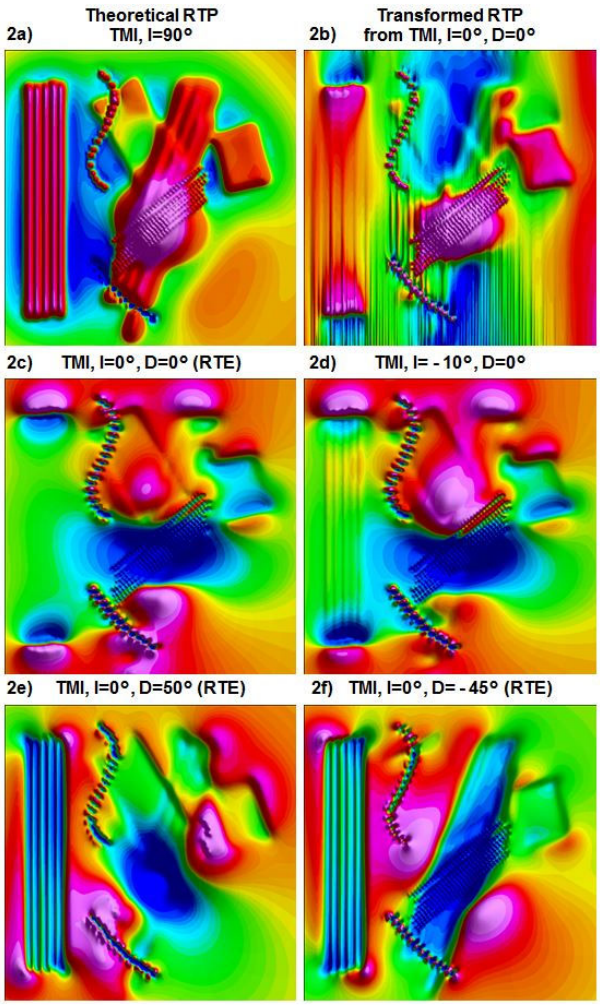

Figure 2. Synthetic model TMI data associated with a geomagnetic field at variable inclination (I) and declination (D).

The TMI (Figure 2a) computed at a geomagnetic inclination of 90 degrees (Theoretical RTP) is best for locating magnetic sources and provides a good relationship between the anomaly shape and the magnetic source. Positive susceptibility bodies produce positive anomalies for the theoretical RTP. It is difficult, however, to achieve a satisfactory RTP at low magnetic latitudes (within ±25°) due to numerical instability of the computation. As the inclination approaches 0 degrees, the calculation for the RTP transformation of the TMI fails as shown in (Figure 2b), where NS artefacts are introduced

parallel to the direction of declination. The TMI (Figure 2c) computed at a geomagnetic inclination of 0 degrees and a declination of 0 degrees (referred to as RTE) provides the location information of most of the shallow and deep bodies however, the NS dyke anomalies (model source body 1), parallel to the declination direction are weak or simply do not appear. When the inclination is near the Equator, anomalies associated with shallow dykes in the same direction as the declination (even with strong susceptibility) are weakened or non-existent. By increasing the geomagnetic inclination to as little as 5 degrees, or to 10 degrees as shown in Figure 2d, the NS dyke anomalies from model source body 1 can be observed.

In contrast, by computing the TMI (or RTE) at a geomagnetic inclination of 0 degrees and a declination of 50 degrees (Figure 2e) the source bodies of the NS trending dyke anomalies (model source body 1) are clearly observed. Anomalies now parallel to the declination direction disappear as observed with model source body 6 (which has an azimuth of 50 degrees). By computing the TMI with geomagnetic inclination of 0 degrees and a declination of -45 degrees (Figure 2f) body 6 is no longer parallel to the declination direction and can now be observed. The anomaly associated with body 2 is weakened and only the edges that are perpendicular to the declination direction can be observed. These edges are mixed with high frequency anomalies and are hardly recognised.

Transformation Methods and Techniques

As a demonstration of the standard techniques for low magnetic latitude and their issues, we present a synthetic model 'located' at a geomagnetic inclination of -5 degrees, and a declination of 0 degrees. The TMI of the synthetic models was computed at an intensity of 30,000nT using a notional north-south line spacing of 500m and a grid cell size of 100m. The resulting TMI image is shown in Figure 3. Outlines of the initial models are superimposed on the image to help identify source anomaly location. The regional has been established by models at depths greater than 10km (body 3 and body 8) with total depths (including depth extent) ranging from 14km to 20km.

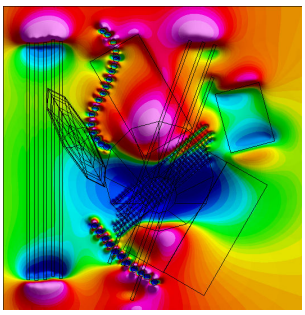

Figure 3. TMI image derived from multiple synthetic 3D magnetic sources, shown as wire frame outlines

Standard transformations and techniques for dealing with low magnetic latitude TMI data were computed from the TMI grid and the results are shown in Figure 4. Strong NS artefacts are evident in the RTP (Figure 4a) and erroneous background anomalies are generated making the transformed RTP unsuitable in low magnetic latitudes. With the RTE (Figure 4b), anomalies are stretched in the EW direction and NS structures are weak or non-existent. Anomalies are lost for source bodies that strike along the same direction as the declination direction.

The AS (Figure 4c) retains the correct location for magnetic source bodies. Horizontal locations from the AS are highly accurate but due to the first derivative order of the filter, the regional field is greatly reduced, and in some cases noise is enhanced, making it difficult to interpret geology from the results.

The CA (Figure 4d) produces positive amplitudes for all anomalies that, in areas with remanent magnetisation, can assist in interpretation of lithologies and major structures. For deep sources broad elongated anomalies in the EW direction still appear and NS structures parallel to the declination direction are weak. Note that the TMA is not represented here as it does not work well for model data at this inclination and declination.

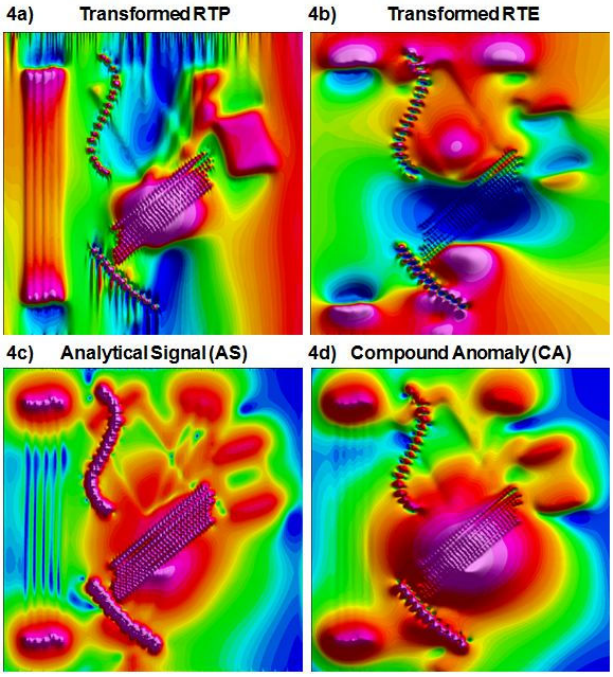

Figure 4. Synthetic model comparison of the standard transformations and techniques for dealing with LML data

The MTC-LML Filter (shown in Figure 5) was developed to attempt to retrieve the correct shape of the broad EW anomalies and to enhance the weak NS striking dyke anomalies. The result shows that the MTC-LML Filter provides the correct shape and better location of the majority of sources; specifically the enhancement of NS oriented anomalies. The MTC-LML Filter also emphasises the boundary of the source rather than the centre of the source, particularly for broad shallow bodies.

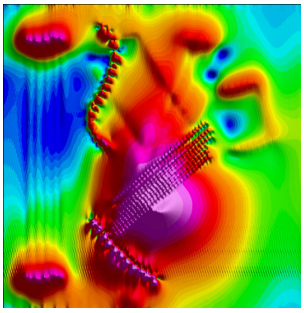

Figure 5. Synthetic model MTC-LML Filter result shows better location and shape of model source bodies

Application to Field Data, Peru

Both traditional methods of transformation and the MTC-LML Filter were applied to single sensor aeromagnetic survey data acquired in Peru and made available for analysis by First Quantum Minerals Ltd. The magnetic inclination is -4.1° and the declination is -3.9°. The survey was flown with a flight-line spacing of 70m north-south direction at a nominal terrain clearance of 30m. The radiometric dataset and surface geology are used to test the anomaly position and shape of the low magnetic latitude filter results.

Comparison of the MTC-LML Filter with standard transformations and techniques for the Peru Survey is shown in Figure 6. With reference to the images, it is clear that the RTP (Figure 6c) produces strong NS trending artefacts (parallel to the declination direction). The RTE (Figure 6d) stretches the anomalies EW (perpendicular to the declination direction) and does not retain source bodies along the declination direction. The AS (Figure 6e), while correctly locating both induced and remanent magnetised sources (southwest corner), breaks anomaly trends, removes the long wavelength information and is difficult to interpret. The CA (Figure 6f), provides good correlation with geology and radiometric data. The MTC-LML Filter (Figure 6b) shows good anomaly location and shape of magnetic source bodies without distortion and retains anomalies from both induced and remanently magnetised bodies. Note that positive anomalies are derived from both induced and remanently magnetised bodies similar to the AS filter. Other filters are required to assess the presence of negatively magnetised bodies.

Direct comparison of the data with respect to the radiometric and digital elevation model (DEM) data has helped to confirm the location and continuation of near-surface sources. Anomaly location corresponds well with the radiometric signature for this area.

CONCLUSIONS

The MTC-LML Filter was developed to attempt to accurately position anomalies (both in shape and location) and retrieve directional anomalies parallel to the declination direction. The Filter was designed to highlight subtle NS trends and reduce the broad EW elongated anomalies to a more 'normal' shape. The Filter produces positive amplitudes for all anomalies (induced and remanent) which in areas with remanent magnetisation can assist in interpretation of lithologies and major structures.

The effectiveness of the MTC-LML Filter has been tested using theoretical TMI data generated from synthetic models and survey data. The results are favourable when compared to standard transformations and techniques for dealing with low magnetic latitude data. Analysis of the MTC-LML Filter demonstrates the advantages in tackling the difficulties that occur in low magnetic latitude areas.

One of the limitations of the MTC-LML Filer is the potential to enhance subtle NS artefacts parallel to the declination direction, which are typically lost in low magnetic latitude data. Verification of flight line direction relative to geological features is recommended in order to assess whether the trends are real or artefacts from the survey itself.

Together with the standard techniques used for processing low magnetic latitude data (such as the AS, CA and TMA), the MTC-LML Filter provides an effective tool for interpreting magnetic data in low magnetic latitude areas.

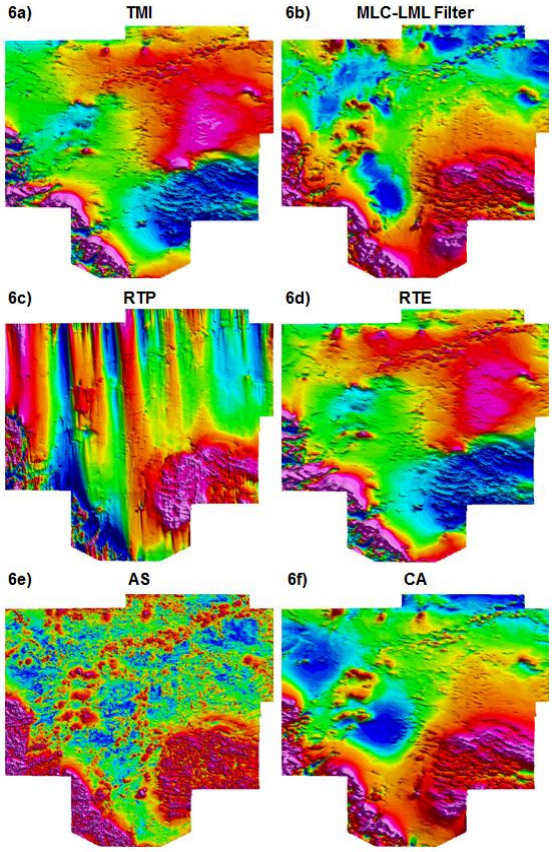

Figure 6. Comparison of the standard transformations and techniques for the Peru Survey data

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