A new regional-residual separation for magnetic datasets using susceptibility from frequency domain electromagnetic data

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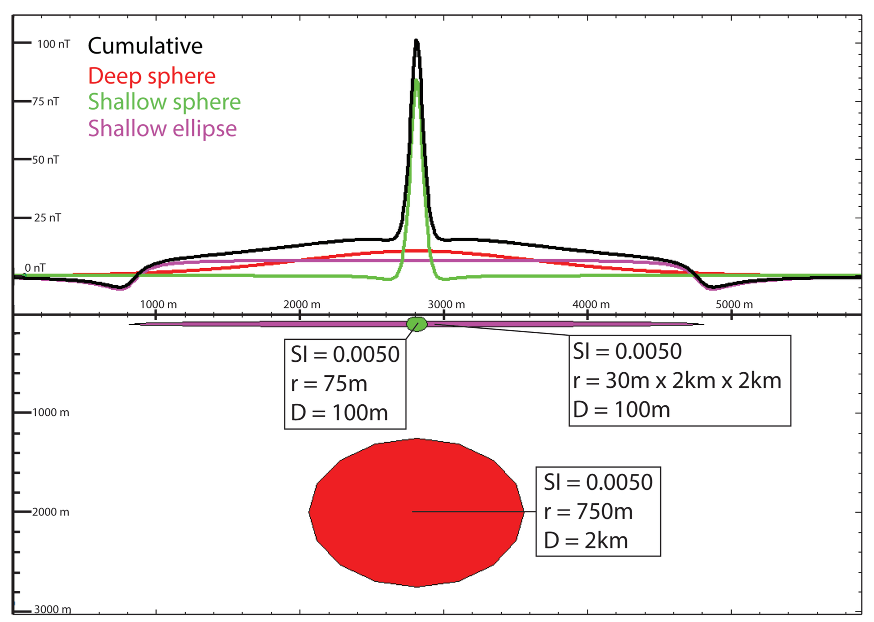
Introduction

Regional-residual separation is one of the most important processing steps applied to potential field data prior to interpretation. The goal is to separate the regional signal caused by deep-seated anomalies from the near surface signal (residual), caused by shallow anomalies and as such, many different techniques have been developed over the years to do so. Classic techniques such as upward continuation (Nettleton, 1954) and match filters (Spector and Grant, 1970) attribute a uniformly smooth field to the regional signal which is subtracted off leaving behind the residual. A review of the more common traditional methods was presented by Hearst and Morris (2001). Newer methods vary greatly with authors advocating wavelet analysis (Fedi and Quarta, 1998), non-linear filters (Keating and Pinet, 2011), forward modeling (Roach et al., 1993) and 3-D inversion algorithms (Li and Oldenburg, 1998). In reality there are benefits and disadvantages to each routine, but the basic assumption all share is long wavelength anomalies must be attributed to deep sources while short wavelength represent shallow sources.

Herein we present a regional / residual separation method that is independent of the wavelength of the source signal. This method uses susceptibility calculated from frequency domain helicopter- borne electromagnetic data (HFEM) transformed into magnetic intensity to separate the near surface magnetic sources from the deeper buried source contributions. The benefit of this technique is HFEM systems have a limited depth of penetration, which is a function of the frequency in the transmitter coil, the conductivity of the medium, and the geometry of the system. This technique is also independent of magnetic remanence and field direction, something that must be considered in all other cases.

Figure 1: A synthetic example illustrating the relationship between body geometry and depth at a constant susceptibility. In most cases it can be assumed that high frequency content is caused by shallow bodies, however long wavelengths may be caused by bodies at depth or large, shallow near surface bodies.



Dataset and study area

Airborne geophysical data come from a 1995 Aerodat multi-parameter helicopter-borne survey flown for the New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division and the Geological Survey of Canada. Survey specifications mandated a 60m mean terrain clearance at 200m flight line separation. Sensors included a 5 frequency electromagnetic (EM) system towed 30m below the helicopter and a magnetometer at 15m below. Recorded coplanar EM frequencies were 853 Hz, 4433 Hz, 32290 Hz. Data were supplied and downloaded from the Geoscience Data Repository DAP application (www.NRCan.gc.ca/geodap) hosted by Natural Resources Canada.

The study area is located within the Bathurst Mining Camp (Figure 3) on the western limb of the Tetagouche antiform. The small 0.25 MT McMaster volcanogenic massive sulphide deposit is located within the study area while the larger 65 MT Caribou deposit lies 1.5 km southwest (McCutcheon et al., 2003). Locally the study area is composed primarily of felsic volcanics of the California Lake and Tetagouche Groups. Lesser amounts of mafic volcanics and shale are also present. The amount of mafic volcanics increases to the Northwest of the study area, approaching the ophiolitic Fournier Group.

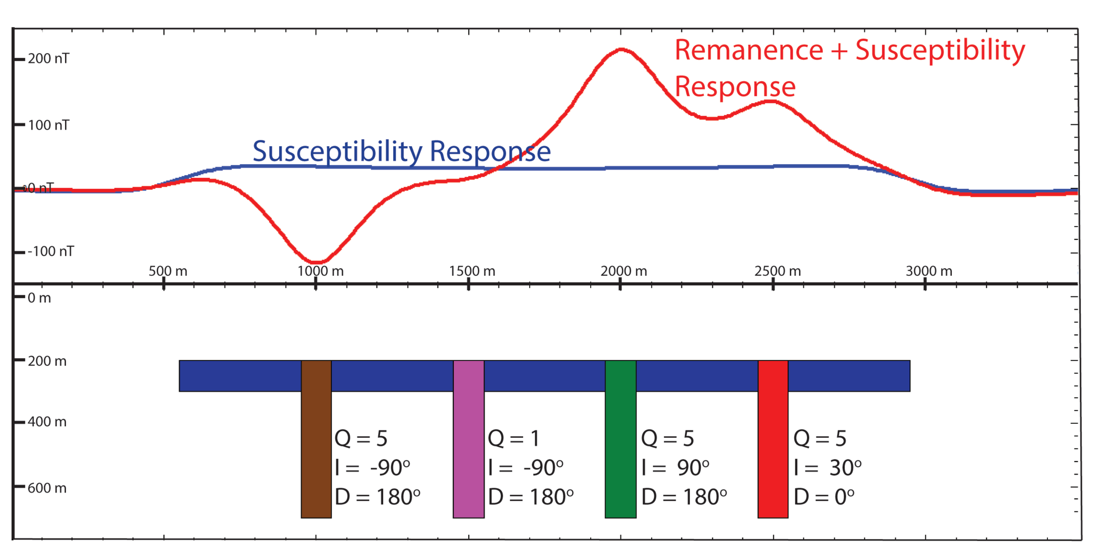


Figure 2: Consider a simple model where a near surface horizontal sheet is intruded by a series of tabular bodies (dikes). If all of the five bodies have exactly the same susceptibility then the observed magnetic anomaly pattern would show the signal for a simple tabular body. If the tabular bodies have a strong remanent magnetisation signal, as diabase dikes often do, then actual observed magnetic anomaly pattern would be very different from the simple single tabular body anomaly.

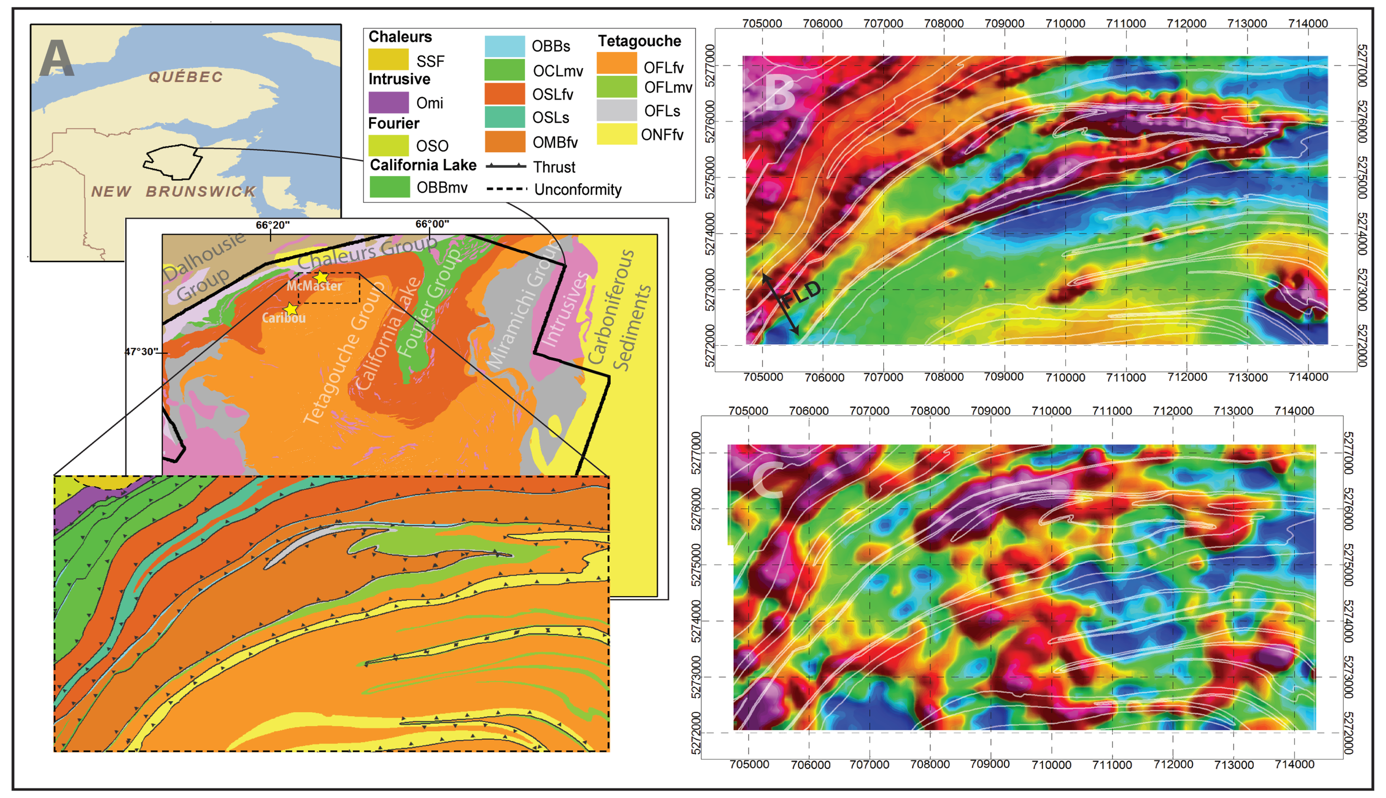


Figure 3: Geologic and geophysical data used for modelling. (A) Location and geology of the study area (from GSC Open File 4128). (B) Total magnetic intensity overlain by geologic contacts. Magnetic responses primarily originate from Tetagouche and California Lake Groups mafic volcanics where there is good correlation between geophysical and geological datasets; though the relationship is not exact. (C) Mid-frequency (4433 Hz) conductivity with geologic contacts overlain. The primary conductivity anomalies through the study area correlate to shale beds. Felsic and mafic volcanic units are resistive below the maximum transmitter frequency.

Method

Magnetic susceptibility (where susceptibility= permeability-1) is recorded as a negative within the inphase component of frequency-domain helicopter-borne electromagnetic systems. This effect is independent of frequency, but is most easily detected at low frequencies where conductivity, which is frequency dependent, is less dominant (Hodges, 2004, Fraser, 1981). Using the homogeneous half-space model developed by (Huang and Fraser, 2000) multiple coplanar frequencies are inverted using a singular value decomposition (SVD) inversion to yield dielectric permittivity, magnetic permeability, and apparent resistivity of a homogeneous half-space. The susceptibility is then modelled as a series of right sided vertical prisms where each prism has a homogeneous susceptibility value equal to the inverted susceptibility. A single body was assigned to each fiducial in the database with width and strike length of 5m x 5m such that there was no overlap between bodies. The topographic surface is used as the bodies Z value which extends to a depth of 100m relative to Z.

The bodies were then subjected to a magnetic field of 55,079 nT; the IGRF at the time of data acquisition, at 90° inclination and 0° declination, such that the magnetic peak occurs over the centre of the body and is equivalent to the reduction to magnetic pole filter. Resultant magnetic anomalies were then resampled back into the database at each fiducial 30m above the topographic surface. In essence the flight characteristic (azimuth, path and sensor height) and sampling frequency are all equivalent to the original survey specifications. The products were then inspected in both grid and profile form.

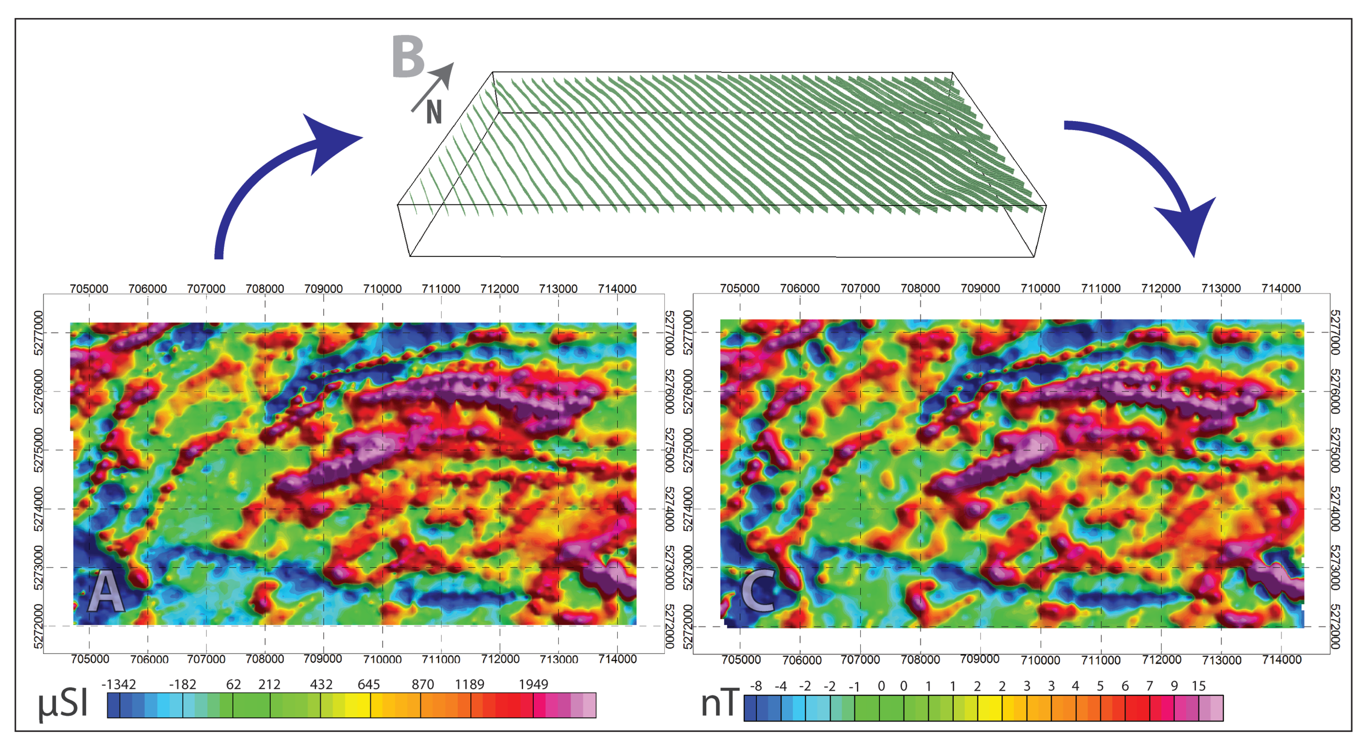


Figure 4: Modelling sequence. (A) Susceptibility is inverted from coplanar frequency domain EM. (B) Forward model. Susceptibility is transformed into a series of 5m x 5m x 100m vertical right sided prisms which is subjected to earth magnetic field. (C) Calculated magnetic anomaly.

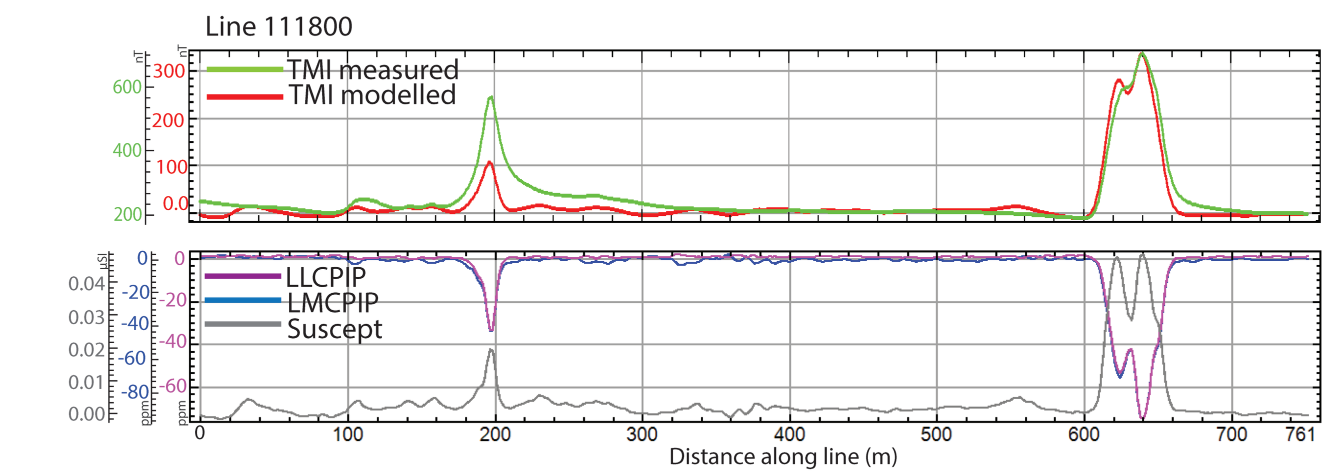


Figure 5: Profile along line 111800. There is good correlation between measured and modelled magnetic anomalies (Top) where susceptibility is successfully recovered from low (LLCPIP) and medium (LMCPIP) coplanar in-phase data (Bottom).

Results

The correlation between the modelled magnetic signal and observed magnetic residual anomalies is excellent (Figures 7). Magnetic anomalies appear sharper in some cases, and the first order regional trend is absent. The prominent linear features in the upper half of the map resulting from mafic volcanic rocks appear distinct, being able to individualize close magnetic anomalies and even discriminate some to a higher resolution than the observed magnetics. The recovered model is in fact more consistent with the geologic interpretation in some places especially for some continuous units.

The modelled magnetics will lack any regional signal, limited by the depth of penetration of the EM system. Therefore, cross referencing the modelled TMI with measured residual should show if sufficient or insufficient separation has been performed and where further processing is necessary. For example, in some places there is still low amplitude, long wavelength signal in the recorded residual, which is absent from the transform. In these locations it is likely that the residual magnetic signal was inadequately removed from the regional.

Though overall there is good correlation between datasets, at some locations discrepancies exist. In places where large conductive anomalies exist, the effect of conductivity is dominant, preventing any meaningful susceptibility from being calculated at these locations. Typically the inversion solved for massively negative values, producing large negative anomalies in the modelled magnetics. Anthropogenic sources can also pose major problems. In our example a highway creates an artificial low which without due diligence could be misinterpreted for something of geologic significance.

A remanently magnetised body exists in the southeastern corner of the study area (M1 in Figure 7), whose geometry is well defined by the modelled magnetics, in contrast to the measured residual. Susceptibility recorded by an HFEM system is independent of the magnetic direction, while filters applied to measured residuals must assume purely inducing magnetisation, therefore remanently magnetised bodies should be detectable.

To do so, apparent susceptibility is calculated on the TMI data and plotted against the values obtained by the EM susceptibility inversion at each grid cell location (Figure 8). The standard "apparent susceptibility" filter approach assumes that all magnetisation is induced; that there is no remanence. The first observation is that there is good correlation among the majority of samples, though there is likely a DC shift between datasets. If remanence was absent a single population cluster would exist, however, a distinct second population of high inverted susceptibilities – low apparent susceptibility is also present. In plan view 91 % of these values plot directly over the southeastern anomaly. The cross-plot indicates that the calculated apparent susceptibility values are systematically higher than the equivalent EM susceptibility values. This observation suggests a component of positive inclined remanent magnetisation.

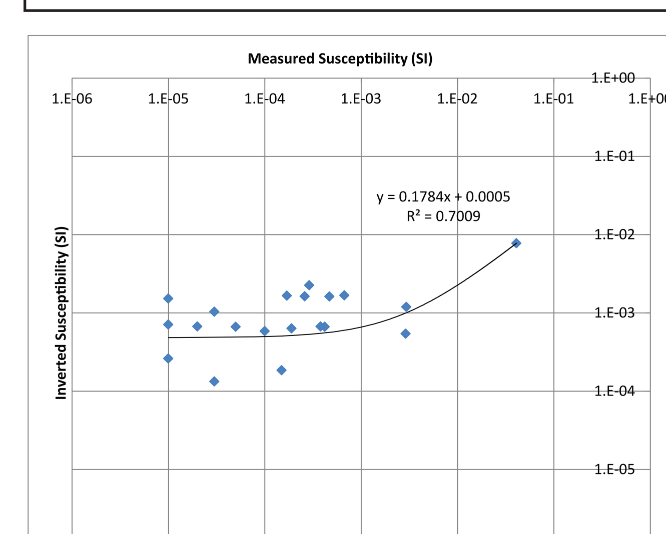
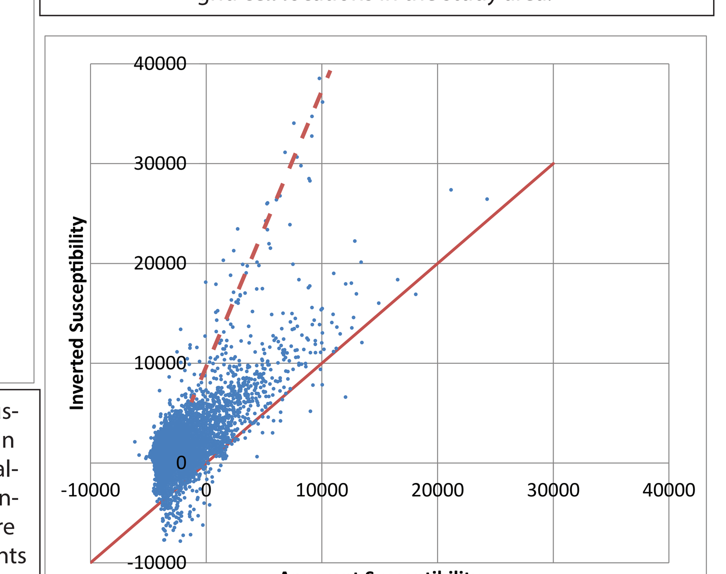


Figure 6 (Above): Measured susceptibility against inverted susceptibility at equivalent locations. There is good correlation in areas of low conductivity which may fit a linear trend line. Calculated susceptibilities tend to have higher values. Where conductive bodies exists (n =4), large negative susceptibilities are calculated. These values and corresponding field measurements have been removed from the graph.

Figure 8 (Below): Apparent susceptibility calculated from magnetics plotted against values from inverted susceptibility at all grid cell locations in the study area.



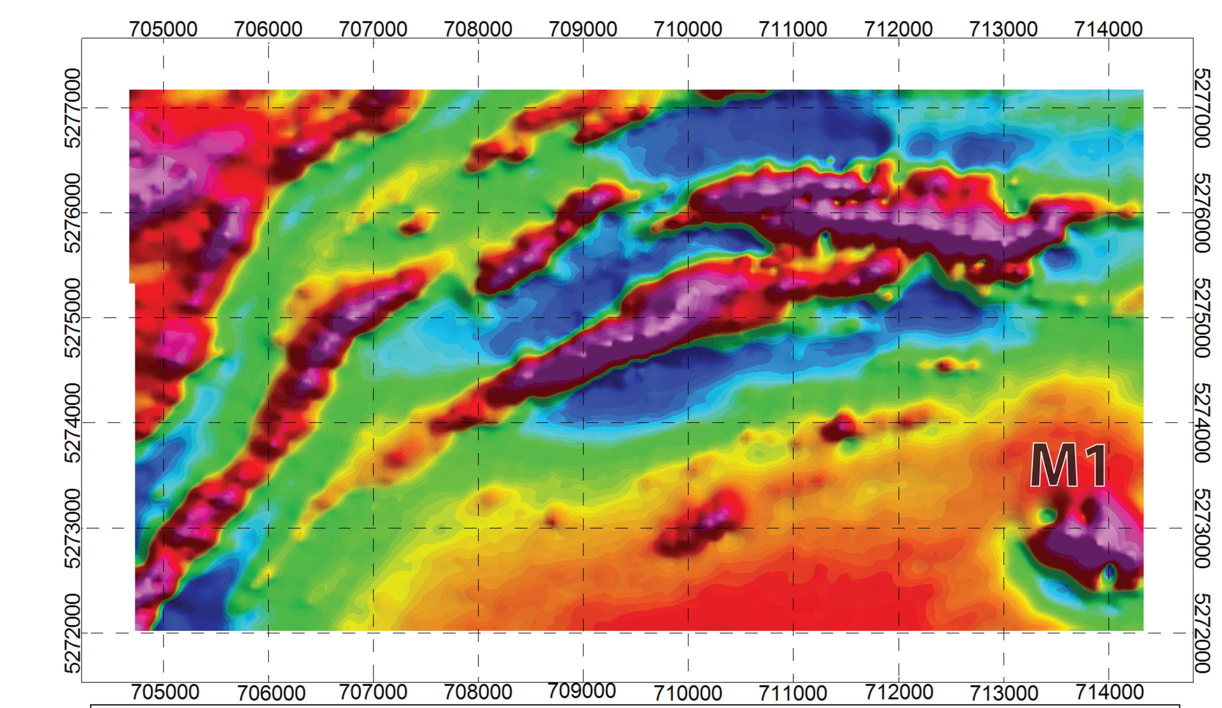
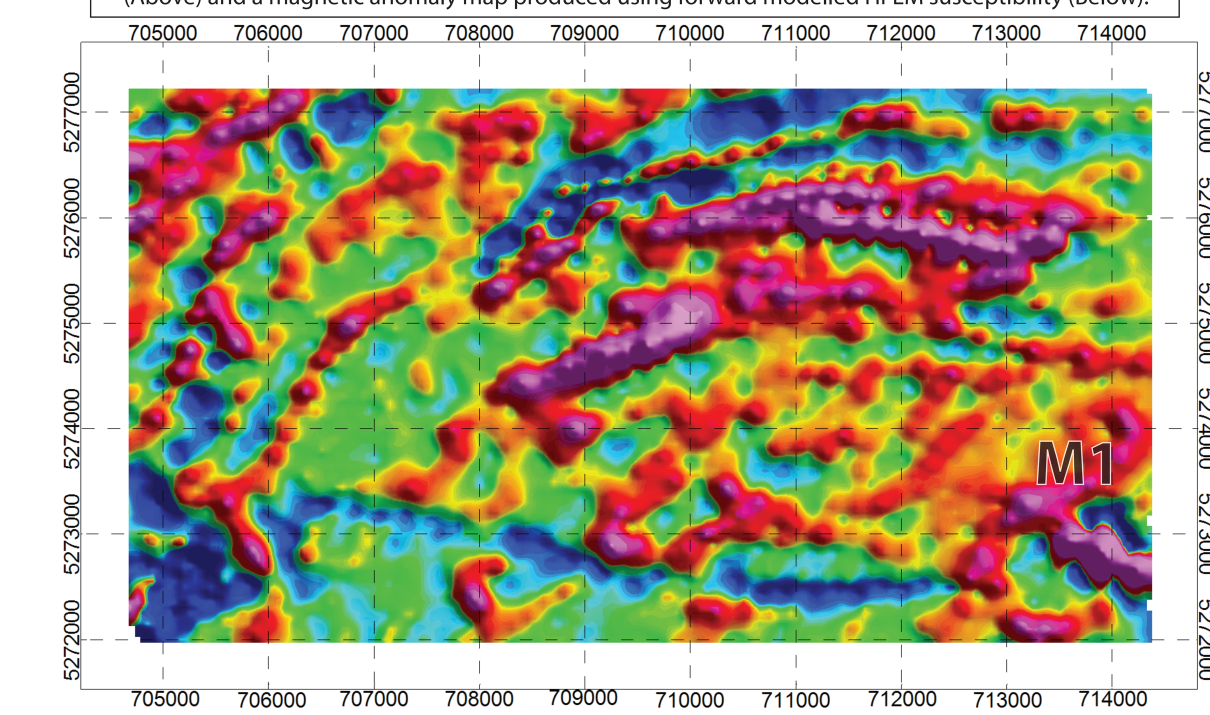


Figure 7: Comparison between a residual magnetic anomaly from an upward continuation separation (Above) and a magnetic anomaly map produced using forward modelled HFEM susceptibility (Below).



Conclusion

Herein we have presented a method of forward modelling magnetic field anomalies from electromagnetic data with application to regional - residual separation of magnetic data and detection of remanently magnetized source bodies.

Overall there is excellent correlation between the recorded and modelled magnetic anomalies. Most large high amplitude anomalies are recorded in both datasets. Long wavelength anomalies which persist in the residual measured magnetics are absent in the forward modeled solution suggesting that an improper residual was processed and an iterative method of processing residual dataset, using any method is suggested.

A comparison of EM derived susceptibility and TMI based apparent susceptibility provides a method for rapidly locating the presence of remanently magnetised source bodies. The magnitude of the TMI apparent susceptibility to the EM susceptibility provides a direct indication of the polarity of the remanent magnetic signal: a positively inclined remanence will produce an increased apparent susceptibility; a negatively inclined remanence will produce a reduced apparent susceptibility.

Interference which affects EM systems, such as anthropogenic sources, can influence the inverted susceptibility and in turn the modelled magnetics. As well, conductive bodies impair the susceptibility inversion from deriving any meaningful results. Having additional EM frequencies (beyond the three available from the survey used) will provide better ability to separate conductivity from susceptibility effects. In this study we assumed a uniform effective source depth for all modelled bodies though it is possible that the depth extent might vary across a project area. This would produce minor fluctuations in the computed susceptibility values. Future work should focus on incorporating this information into the modelling routine to improve results and minimize assumptions.

References

Fedi, F. and Quarta, T., 1998, Wavelet analysis for the regional-residual and local separation of potential field anomalies: Geophysical Prospecting, 46, 507 – 525.
Fraser, D.C., 1981, Magnetite mapping with a multicoil airborne electromagnetic system: Geophysics, 46, 1579 – 1593.
Hearst, R.B., and Morris, W.A., 2001, Regional gravity setting of the Sudbury Structure: Geophysics, 66, 1680-1690.
Hodges, G., 2004, Mapping conductivity, magnetic susceptibility, and dielectric permittivity with helicopter electromagnetic data 74th Annual Meeting, SEG, Extended Abstract, 660 - 663.
Huang, H. and Fraser, D.C. 2000. Airborne resistivity and susceptibility mapping in magnetically polarizable areas. Geophysics, 65, 502 – 511.
Keating, P. and Pinet N., 2011, Use of non-linear filtering for the regional–residual separation of potential field data: Journal of Applied Geophysics, 73, 315 – 322.
Li, Y. and Oldenburg, D. W., 1998, Separation of regional and residual magnetic field data: Geophysics, 63, 431 – 439.
McCrutcheon, S.R., Luff, W.M., and Boyle, R.W. 2003. The Bathurst Mining Camp, New Brunswick, Canada: History of discovery and evolution of the Geologic Models. In Massive Sulfide Deposits of the Bathurst Mining Camp, New Brunswick, and Northern Maine. Edited by W.D., Goodfellow, S.R., McCutcheon, and J.M., Peter. Economic Geology Monograph 11, pp. 17-35.
Nettleton, L.L., 1954, Regionals, residuals, and structures: Geophysics, 19, 1 – 22.
Roach, M.J., Leaman, D.E., Richardson, R.G., 1993, A comparison of regional – residual separation techniques for gravity surveys: Exploration Geophysics, 24, 779 – 784.
Spector, A. and Grant, F.S., 1970, Statistical models for interpreting aeromagnetic data: Geophysics, 35, 293 – 302.

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