What's new in interpretation of magnetic data?

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In the Modern era of depleting resources, the Exploration strategy is to integrate several geophysical data to offer a more cost effective way of reducing finding costs and improving discovery rates. Traditionally the Magnetic Method has been routinely used as a secondary Reconnaissance tool for exploration purposes. The development of more accurate magnetometers, aircraft positioning using GPS, better data collection procedures, gradiometers measuring horizontal and vertical gradients in the total magnetic field, compensation software / hardware for suppressing airplane noise has resulted in marked improvement in the data acquisition quality and resolution. This has resulted in the ability to collect High Resolution and Super High Resolution aeromagnetic (SHRAM) data. By flying closer to the ground with decreasing flight line spacing, there is a dramatic increase in resolution; the helicopter-borne SHRAM data can detect even the subtlest sedimentary magnetic anomalies that are created in the shallow sedimentary section. The data quality and resolution of high resolution aeromagnetic surveys now provide levels of detail that are compatible with those derived from seismic, well and surface geological data. This necessitates using data processing techniques that can give accurate information of the magnetic sources. With the large volumes of aeromagnetic data being collected, an important goal in the interpretation is to determine the type and location of the magnetic sources. With improved data processing procedures like wavelength filtering, tilt derivative, etc., it is now possible to isolate weak anomalies resulting from the subdued magnetic sources occurring within sedimentary strata. Over the years, different methods have evolved to estimate the source parameters; it is necessary to have a method that not only gives the location of the magnetic source, but it should also be able to isolate sources occurring at different depths and resolve the type of the magnetic source.

A variety of methods for interpretation of gridded magnetic data, based on the derivative of the magnetic field have been developed, to determine the magnetic sources and estimate their depths (Blakely, 1995). Amongst them, the Euler de-convolution method uses the first order derivative for depth estimation, but it requires an assumption about the nature of the source (structural index). If (x_0, y_0, z_0) is the position of a magnetic source whose total field f is measured at (x, y, z) and the total field has a regional value of B then Euler's equation reduces to:

$$(x - x_0)\frac{\partial f}{\partial x} + (y - y_0)\frac{\partial f}{\partial y} + (z - z_0)\frac{\partial f}{\partial z} = N(B - f)$$

The degree of homogeneity N is interpreted as a structural index (SI) (Thompson, 1982; Reid et al., 1990) which represents the source type and is a measure of the rate of change of field with distance. The user must choose the structural index that best fits the data. The choice of a proper structural index is crucial in order to attain correct depths and converging solutions over magnetic contacts. An index that is too low gives depths that are too shallow, and an index that is too high gives estimates that are too deep. The correct index for a particular feature gives the best solution clustering and consequently the best depth estimates.

The Analytic signal method is very useful for delineating magnetic source location (Roest et al, 1992); the amplitude of the simple analytic signal peaks over magnetic contacts. Therefore it can also be used to find horizontal locations and depths of magnetic contacts. This method is very useful at low magnetic latitudes as it is independent of the inclination of the magnetic field. However, if more than one source is present, then the shallow sources are well resolved but the deeper sources may not be well resolved. The complex Analytic signal of a structure is given by:

$$A = |A|\exp(j\theta) \text{ where } |A(x, y)| = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2 + \left(\frac{\partial f}{\partial z}\right)^2}$$

A is known as the Analytic signal of the field, f is the magnitude of the total magnetic field and θ is the local phase or tilt angle. Tilt derivative utilizes the ratio of the vertical derivative to the absolute value of the horizontal derivative and θ the tilt angle or tilt derivative (Verduzco et al, 2004) defined as

$$\theta = \tan^{-1}\frac{\partial f / \partial z}{\partial f / \partial h}$$

where the total horizontal derivative is

$$\frac{\partial f}{\partial h} = [(\frac{\partial f}{\partial x})^2 + (\frac{\partial f}{\partial y})^2]^{\frac{1}{2}}.$$

It maybe noted that the tilt angle is restricted to lie between $+90^0$ and -90^0 regardless of the amplitudes of the vertical and horizontal derivatives. The tilt angle has the attractive property of being positive over the sources, crosses through zero at or near the edge of a vertical sided source and is negative outside the source region (Miller and Singh, 1994). The tilt derivative of the Reduced-to-pole fields have anomaly zero crossings located close to the edges of structures. Salem et al (2007) have shown that half-distance between $+45^0$ and -45^0 contours provide an estimate of the source depth for vertical contacts. The amplitude of the horizontal derivative of the tilt angle is related to the reciprocal of the depth to the top of the source. The tilt angle overcomes the problem of the shallow and deep sources by dealing with the ratio of the vertical derivative to the horizontal derivative; the tilt derivative will be relatively insensitive to the depth of the source and should resolve shallow and deep sources equally well.

In a very recent paper, Salem et al (2008) have developed a new method for interpretation of gridded magnetic data based on the Tilt derivative; the method estimates both the horizontal location and depth of the magnetic sources without specifying prior information about the nature of the source. In fact, the structural index of the source is inferred by using the second order derivatives of the field and the estimate of structural index can provide a means of distinguishing between reliable and spurious depth estimates. They utilize the derivative of the tilt angle with respect to the x, y, z directions as the wave numbers k_x, k_y, k_z. Taking the derivative of the 3D Euler equation in the x, y, z directions, they obtain a simple linear equation: $k_x x_0 + k_y y_0 + k_z z_0 = k_x x + k_y y + k_z z$

where (x_0, y_0, z_0) is the position of a magnetic source whose total field f is measured at (x, y, z).

This equation is similar to the 3D Euler equation and does not require any prior information about the source geometry. Using a standard progressively moving window approach to the magnetic anomaly, where each window has n data points with known locations x, y, z and tilt angle derivatives k_x, k_y, k_z (accepting those solutions that satisfy some selection criteria), the above equation can be transformed to a matrix equation which is solved in a least square sense to determine the 3D vector of the unknown source locations (x_0, y_0, z_0) at n points. Once the source location is obtained the value for the structural index is estimated using the derivatives of the Euler equation. Thus Salem et al (2008) demonstrate the possibility of using this method for determining both the source location and the source type. They demonstrate the practical utility of the method using high resolution aeromagnetic field data from Namibia which contains the Erindi gold prospect. The data are collected at a flight altitude of 80m and flight line spacing of 200m and they used a digital grid cell size of 50m. The results of their method do show broad correlation with previous published results using interactive forward modeling. Thus we find that the tilt derivative method not only estimates the source location and depth but it is also able to resolve sources at different depths and, with some modification, it can also resolve the type of the magnetic source.

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