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Multi-deconvolution analysis of potential field data

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ABSTRACT

This paper presents a multi-deconvolution method for interpretation of potential-field data. The multi-deconvolution method used information from isolated anomalies and data transformations to produce functions forming a peak or a through above the center of a potential-field source. The proposed method can be applied to a wide range of potential field anomaly data as well as their total gradient (TG) and local wavenumber (LW) data. It allows the determination of the source depth and physical property of the source (susceptibility or density) from potential field data or their TG data if one assumes a source type. When applied to the local wavenumber of potential field data, it does not require information about the type of the source. Instead it enables the determination of both the depth and information about the nature of the source. The potential advantages of the method to estimate source parameters from gravity and magnetic data are illustrated using theoretical and field examples. The practical utility of the method is demonstrated using high-resolution data over dike-like bodies from Egypt.

1. Introduction

Various potential field anomalies of many simple bodies and their derivatives form a peak or a trough located directly above the source. The horizontal gradient (HG) over a vertical contact is one such peak function used for locating contacts and faults from gravity, pseudo-gravity, or reduced-to-pole (RTP) magnetic data (Cordell and Grauch, 1985; Roest and Pilkington, 1993). Other peak functions include the total gradient (TG) (commonly known as analytic signal, Nabighian, 1972), and local wavenumber (LW) (Thurston and Smith, 1997) over certain body shapes. This class of potential field functions is very useful for horizontal location of the sources, where the locations of the peaks or troughs of the fields can be identified easily.

Salem et al. (2004) used the symmetric function and its horizontal gradient of some potential field anomalies to provide depth and model type. Their method was applied to residual gravity data over spherical and cylindrical models and TG of magnetic data over 2D magnetic models. Phillips et al. (2007) used the curvature of the peak function to calculate the location of causative sources. Their method was applied to LW data over 2D magnetic models.

In this paper, I present a generalized deconvolution method for interpretation of peak functions in potential field data. It can be applied to a wide range of potential field anomaly data as well as their total gradient (TG) and local wavenumber (LW). The method is similar in some respects to Werner (Werner, 1953) and Euler (Thompson, 1982) methods, where potential field anomaly and total gradient (TG) data are transformed into information about source location parameters. However, the present method adds a significant advantage. First it can provide information about the location and physical property of the sources (susceptibility or density) from different data types, and hence it is named “multi-deconvolution”. Second it can provide information about the location and type of the sources when it is applied to LW data. Both Werner and Euler methods require assumptions about the type of the source.

2. Symmetric functions in potential field data

A function that presents a peak or trough over the source location (Salem et al., 2004), can be expressed as

$$f(x) = \frac{F}{(x^2 + h^2)^q} \tag{1}$$

where F is an amplitude factor, q is a shape factor characterizing the shape of the anomaly, x is the horizontal location of the observation point with respect to the source, and h is the depth. In potential field data, there are many model responses that are characterized by symmetric functions about the location of the source. Gravity fields of many simple bodies, for example, are symmetric about the location of the source (e.g., the gravity effect caused by simple models such as a sphere, an infinite horizontal cylinder, and a semi-finite vertical cylinder). The horizontal gradient of the gravity field (HG) of a horizontal sheet edge is also a symmetric function. TG and LW of the gravity field over models like the edge of a horizontal sheet, horizontal line mass and vertical line mass are symmetric. The magnetization direction and the direction of the Earth's magnetic field make the

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Table 1
Shape factor (q) and amplitude (F) of some symmetric functions of simple gravity sources. HG = horizontal gradient, TG = total gradient, LW = local wavenumber, γ = gravitational constant, m = density contrast times cross-sectional area, m_s = is the mass of the sphere, η is a value characterizing the source geometry (η=0 for a horizontal density sheet, 1 for vertical and horizontal cylinders).

Model	Gravity		HG		TG		LW	
	F	q	F	q	F	q	F	q
Horizontal density sheet			$2\gamma mh$	1	$2\gamma\|m\|$	0.5	$(\eta+1)h$	1
Vertical cylinder	γm	0.5			$\gamma\|m\|$	1	$(\eta+1)h$	1
Horizontal cylinder	$2\gamma mh$	1			$2\gamma\|m\|$	1	$(\eta+1)h$	1
Sphere	$\gamma m_s h$	1.5						

Table 2
Shape factor (q) and amplitude (F) of some symmetric functions of simple magnetic sources. RTP = reduced to the pole, HG_{rtp} = horizontal gradient of reduced to the pole, TG = total gradient, LW = local wavenumber, α = magnetization constant (see Nabighian, 1972), η is a value characterizing the source geometry (η=0 for a contact, 1 for a dyke, and 2 for *a* horizontal cylinder).

Model	RTP		HG_{RTP}		TG		LW	
	F	q	F	q	F	q	F	q
Contact			αh	1	α	0.5	$(\eta+1)h$	1
Dike	αh	1			α	1	$(\eta+1)h$	1
Horizontal cylinder					2α	1.5	$(\eta+1)h$	1

measured magnetic field asymmetric. However, RTP anomalies of some vertical models such as sheet edges are symmetric functions. TG and LW expressions of contacts, sheet edges, and horizontal cylinders are symmetric functions. Tables 1 and 2 summarize the amplitude and shape factors for symmetric functions in gravity and magnetic analysis.

3. The multi-deconvolution method

Since the horizontal location of the source can be estimated at the location of the peak or the trough of the symmetric function, our goal now is to determine the unknown parameters (depth and amplitude factor). With a simple rearrangement of Eq. (1), we obtain

$$x^2(f(x))^{1/q} = -(f(x))^{1/q}h^2 + (F)^{1/q} \quad (2)$$

The above equation has a form similar to the Werner deconvolution (Werner, 1953) and Euler's equation (Thompson, 1982). It is a linear function in the squared depth (h^2) and $F^{1/q}$. These two parameters can be obtained using any of the conventional methods of linear inversion. For example, in matrix notation, Eq. (2) can be written as

$$\overline{d} = \mathbf{G}\overline{m} \quad (3)$$

where $\overline{d}$ is a vector of N elements given by $\overline{d_i = x_i^2[f(x_i)]^{1/q}}$, G is a matrix ($N \times 2$) whose elements of the ith row are: $g_{i1} = -[f(x_i)]^{1/q}$ and $g_{i2} = 1$, and $\overline{m}$ is a vector of the unknown parameters (h^2 and $F^{1/q}$, respectively).

Fig. 1 shows two flow charts demonstrating the implementation of the method. Right one is applied when the source type is known. In this case, the deconvolution is applied to the symmetric functions in the potential field data, or to their horizontal or total gradient, with Eq. (3) cast using the value of q depending on the type of data and type of the model (see Tables 1 and 2). The left chart is applied when information about the model type is not available. In this case, the deconvolution is applied to the LW data and Eq. (3) is cast using the value of $q = 1$ (all gravity and magnetic models in this case have the same q). This means that deconvolution of LW data is model-independent, and the estimate of the amplitude factor (F) and depth (h) can help characterize the nature of the source because the model type (η), commonly known as structural index (See the capture of Tables 1 and 2 for η each model type), can be estimated using the following equation

$$\eta = (F/h) - 1 \quad (4)$$

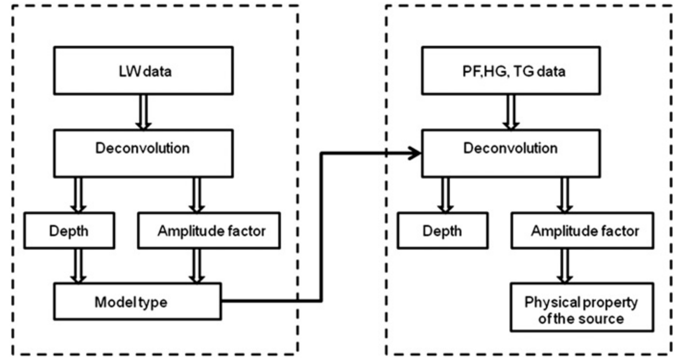

Fig. 1. Flow charts for implementing the multi-deconvolution analysis of potential field data. Left chart for application of the method to Local wavenumber (LW) data when the source type is not known. Right chart for the application of the method to symmetric functions in potential field (pf), horizontal gradient (HG), and/or total gradient (TG) when the source type is known.

For both cases, the anomalies are first identified using the peak or trough of the symmetric anomaly. Locating the peaks or troughs can be done using the procedure described by Blakely and Simpson (1986). Then the method is applied to a data window around the peak or trough, where the signal-to-noise ratio of the symmetric function is relatively high. The choice of the number of selected data points is based on the quality of the data and interference of nearby sources. The optimum data area (window size) should be small enough to see only a single anomaly but large enough to include the complete variation of the anomaly (Reid et al., 1990).

4. Synthetic example

To demonstrate the feasibility of the present approach, I tested the method using a NS profile of synthetic local wavenumber of magnetic anomaly data over a 2D basement block intruded by a thin dike (Fig. 2a). The basement block has two edges. The shallower one is located at a distance of 1000 m and at a depth of 30 m. The deeper edge is located at a distance of 3000 m and at a depth of 80 m. The dike is placed at the center of the profile with its top at a depth of 55 m. The basement block has a susceptibility contrast of 0.001 SI. The dike has a susceptibility contrast of 0.1 SI. Both bodies have induced magnetization only, generated by a magnetic field of strength 40,000 nT, effective declination 0° and inclination 40°. The synthetic magnetic anomaly values (Fig. 2b) were calculated at an interval of 10 m. In this example, I used a conventional FFT technique to calculate the requisite gradients for the local wavenumber data. Fig. 2c shows the local wavenumber over the basement block and the intruded dike. The proposed deconvolution method was applied to the local wavenumber data to estimate the depth and amplitude factor. Fig. 2d and e shows the estimate of the depth and structural index from the local wavenumber data. It can be seen that the present method estimated the correct locations and types of the magnetic sources.

Since the present method uses the location of the peak or the trough as the horizontal location of the source, a noise induced error in the peak or trough location may lead to errors in the results of the present method when dealing with real data. To assess the effect of such errors, deconvolution was applied to the TG anomaly data of the