P114 INTERPRETATION OF ISOLATED GRAVITY ANOMALIES USING EULER DECONVOLUTION

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Abstract

We have developed a simple approach to determine simultaneously the horizontal location, depth and structural index of simple geometrical structures from isolated gravity anomalies based on Euler's homogeneity equation. The horizontal location is determined using conventional Euler method applying approximated structural index value. Using the determined horizontal location parameters as constant values, Euler's equation can be written as a linear relation between the depth and the structural index for each observation point. Plotting this relation for a number of observation points produce a set of intersecting lines. The common intersection of these lines reveals the solution for the depth and structural index of the causative body. This approach can be applied to either profile or grid-based data. The proposed method was tested using synthetic data and the correct depth and structural index of the source were obtained. The efficiency of the method was also evaluated using two field examples. The estimated location and structural index were in accordance with the drilling results and the results reported in the literature.

Introduction

Interpretation of gravity anomaly aims essentially to estimate the location, depth and the geometry of the causative source. Since the observed anomaly can be adequately explained by different distributions of anomalous masses, such interpretations are never unique (Skeels 1947). However, a unique solution can be obtained by incorporating certain a priori information such as assigning a simple geometry of the source (Roy et al., 2000). Assuming fixed source geometry, several methods have been developed to interpret gravity data. Several attempts have been also made to identify the source geometry, beside the source location, from the observed anomaly. A brief review of these methods is given by Roy et al. (2000). Among these methods, Euler deconvolution is probably the most popular; it forms a linear inverse problem that can be easily implemented to determine the source location and depth. In earlier works, the solutions of Euler method for horizontal location and depth were computed in a moving window for some pre-assigned structural indices. The value of structural index yielding the best cluster of solutions for horizontal location and depth was used to characterize the source geometry (Thompson 1982; Reid 1990). Recently, two techniques have been proposed to estimate the structural index, based on the correlation between the estimated background and the total-field anomaly (Barbosa et al., 1999), and based on the misfit between the anomaly simulated from the determined parameters and the total-field anomaly (Roy et al., 2000).

In the present work, Euler deconvolution has been employed to determine the location, depth and structural index for simple sources, simultaneously, from isolated gravity anomalies. The horizontal location is determined using conventional Euler method applying approximated structural index value. At a fixed horizontal location, Euler's equation can be adapted as a linear relationship between the depth and the structural index. Plotting this relationship for some observation points generate a set of intersecting lines that cross at the solution of the depth and structural index of the causative body.

Theory

The generalized gravity anomaly $g(x,y,z)$ over different idealized sources can be expressed by (Roy et al, 2000)

$$g(x,y,z) = K / r^N , \qquad (1)$$

where $r^2 = (x - x_\circ)^2 + (y - y_\circ)^2 + (z - z_\circ)^2$, $(x_\circ, y_\circ, z_\circ)$ denotes the position of the source centroid/top, K is a constant, and N assumes different integer values of 0,1,2,… , depends on the source geometry. It has been found that (1) is homogenous of order -N and satisfies Euler's equation. The Euler's homogeneity equation corresponding to (1) can be written as (Thompson, 1982)

$$(x - x_{\circ})\partial g / \partial x + (y - y_{\circ})\partial g / \partial y + (z - z_{\circ})\partial g / \partial z = -Ng \,, \qquad (2)$$

where $\partial g / \partial x, \partial g / \partial y$ and $\partial g / \partial z$ represent first-order derivative of the observed gravity anomaly along the *x, y* and *z* directions, respectively, ***N,*** known as structural index (SI), is related to the nature of the gravity source. For example, ***N***=2 for a point of mass, ***N***=1 for an infinite horizontal and semi-infinite vertical line of masses, ***N***=1 to 2 for horizontal and vertical line of masses, ***N***=0 to 1 for 2D vertical ribbon, and ***N***= -1 for a semi-infinite contact (Stavrev, 1997). Equation (2) can be rearranged and written as

$$x_{\circ}\partial g / \partial x + y_{\circ}\partial g / \partial y + z_{\circ}\partial g / \partial z - Ng = x\partial g / \partial x + y\partial g / \partial y + z\partial g / \partial z \,. \qquad (3)$$

Assigning the structural index (***N***) and using the known values of the gravity anomaly and its first-order derivatives for at least four points, a system of linear equations can be obtained and solved for the unknown parameters. Within a moving window containing more than four points, it becomes an over-determined problem that can be solved using the least squares method to obtain the three unknowns (x_o, y_o, z_o) and their uncertainties (standard deviations). Moving the window over large grid can result in many solutions. Good solutions are considered to be those that group well and have small standard deviations.

Methodology

Barbosa et al. (1999) proved analytically that even in the case that ***N***=0, and as far as $\partial g / \partial x$ and $\partial g / \partial y$ are not too small, determination of the horizontal location of the source is unique and stable problem and independent of ***N***. Accordingly equation (2) can be written as

$$(z - z_{\circ}) = aN + b \,, \qquad (4)$$

which is a liner equation illustrating the relationship between (z - z_o) and ***N*** for each measuring point with constants $a = -g / \dfrac{\partial g}{\partial z}$ and $b = -\left[(x - x_{\circ})\dfrac{\partial g}{\partial x} + (y - y_{\circ})\dfrac{\partial g}{\partial y} \right] / \dfrac{\partial g}{\partial z}$.

Drawing this linear relation for different measurement locations produce intersecting lines that cross at a point represents the true depth and structural index of the source. The procedure can be applied as follow.

(1) Using an approximated structural index value, determine the horizontal location parameters (x_o, y_o) of the source under consideration by conventional Euler method for different windows and select those parameters of the lowest standard deviations.

(2) Calculate the constants ***a*** and ***b***, for some observation points, at and around the determined location (x_o, y_o), and calculate (z - z_o) versus different *N* values using equation (4).

(3) Drawing these linear relations will produce intersecting lines that should cross at the point of the correct depth and structural index. Theoretically, any two lines associated with two data points are enough to simultaneously determine (z - z_o) and *N*. In practice more than two lines are required because of the presence of noise. The procedure can be easily applied to profile data by excluding the term $(y - y_{\circ})\partial g / \partial y$ from equation (4).

Application to synthetic data

Two models (cylindrical and point mass) are used to test the validity of the proposed method using line and gridded data, respectively. The data profile has 35 points for the case of the cylinder, and the grid has 25×25 points for the case of the sphere. In both cases, the observations are separated by 1.0 m interval and symmetrically distributed about the anomalous source. The synthetic data are calculated using a code given by Blakly (1995) and the horizontal and vertical derivatives are calculated in the frequency domain using covenantal Fast Fourier Transform technique (FFT).

Following the proposed procedure for the cylindrical example (Fig. 1a), the horizontal location is determined applying Euler method with10 points moving window and 0.5 structural index. The correct horizontal location x_o=15m is obtained as the solution giving the lowest standard deviation from the different windows positions. Using equation (4), the depth values were calculated for tentative values of structural index at successive 7 points meddled by the estimated horizontal location. Figure 1b shows the plot of the relations between the depth and the structural index, giving the correct solution, z_o=5m and *N*=1.0 at the intersection.

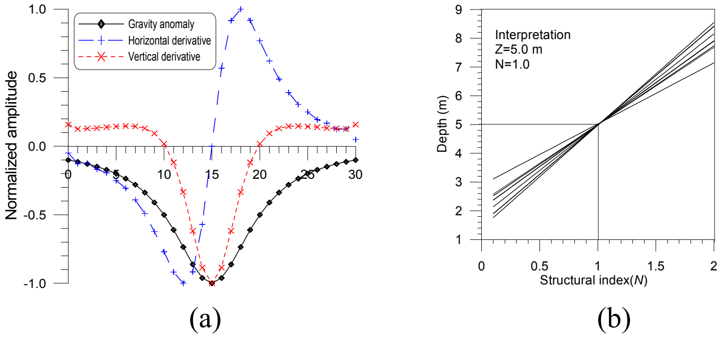
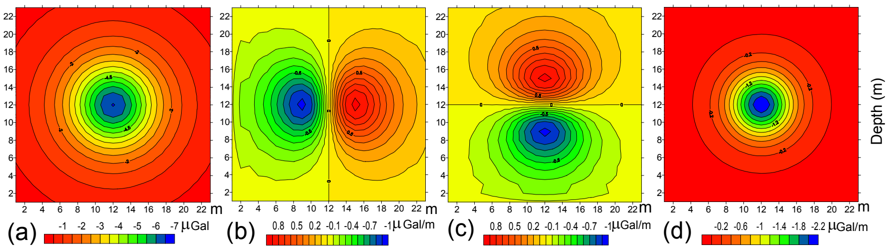


Fig.1. Normalized gravity anomaly and its firs-order derivatives of a horizontal cylinder located at x_o =15m and z_o=5m depth (a), and a plot of linear relations between depth and structural index, showing the correct solution at the intersection (b).

Figure 2 (a to d) shows the gravity anomaly due to the spherical example and its first-order derivatives. Applying Euler method with a 12×12 moving window and 0.5 structural index, the correct horizontal location x_o=12m, y_o=12m is obtained. The correct solution for z_o=6m and N=2.0 occurs at the intersection of the linear relations calculated using equation (4) for 8 points around the estimated horizontal location (Fig. 2e).



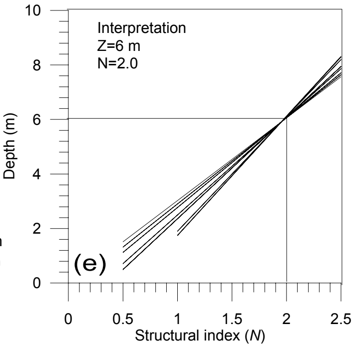
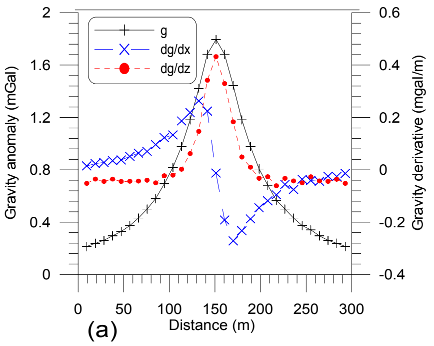


Fig.2. Gravity anomaly of a spherical body located at x_o=12m, y_o=12m and z_o=6m depth (a). In (b), (c) and (d) the first-order derivative of (a) are shown, (e) is a plot of linear relations between z_o and N, showing the correct solution at the intersection.

Field examples

The applicability of the present method is evaluated using two field examples, representing the profile and grid-based data. The first example is from residual gravity data measured over a sulphide deposit, Noranda, Quebec (Grant and West, 1965). Roy (2001) identifies the shape of this body as a 2D ribbon of finite depth extent, according to combined interpretation of the structural index and the shape factor. Accordingly, a profile-based data over this body is digitized (from Roy et al., 2000) at an interval of 9.45 m and interpreted using the present method. Figure 3a shows the digitized anomaly and its first order derivatives. Figure 3b shows the liner relations calculated for 7 points around the estimated horizontal location (x_o=150 m). The common intersection depicts the solution (z_o=29.0 m and N=0.73). The estimated parameters are in good agreement with the drilling result (30 m depth) and the results published by Roy et al., 2000 (z_o=29.44m and N=0.77).



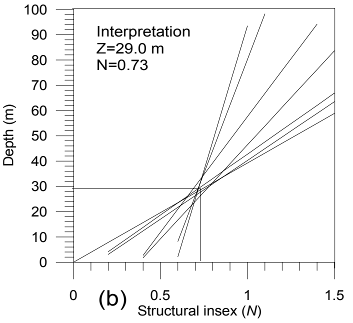


Fig. 3(a). Residual gravity anomaly, and its derivatives, over a sulphide deposit, Noranda, Quebec (after Grant and West, 1965), (b) is a plot of linear relations between z_o and N, showing the interpreted solution at the common intersection.

The second example is from residual gravity data measured over a Medford cave site, Florida USA (Butler, 1983). The gravity data over a known cavity (Fig. 4a) has been digitized at a grid interval of 1m and interpreted by the proposed method. Figure 4b shows the liner relations calculated for 6 points around the estimated horizontal location (x_o=67 and y_o=68 m). The common intersection can be interpreted at a point where the depth is about 3.7m and structural index N=1.85. The estimated parameters agree well with the drilling result (about 3.6m depth) and the interpretation published by Elawadi et al., 2001 (z_o=4.6m suggesting spherical shape).

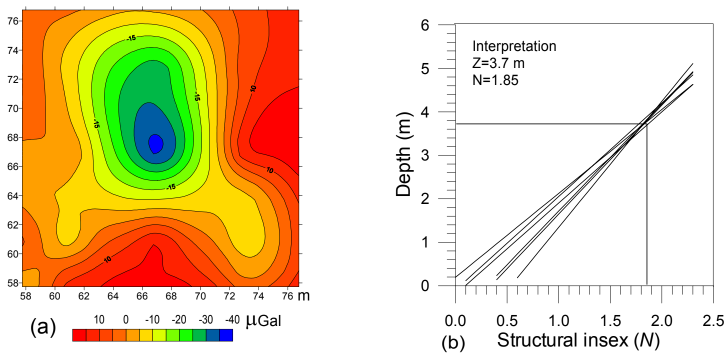


Fig. 4(a). Residual gravity anomaly map over Medford cave site, USA (Butler, 1983), (b) a plot of linear relations between z_o and N, showing the interpreted solution at the common intersection.

Conclusion

Euler deconvolution is employed to estimate the location and structural index of simple sources, simultaneously, from isolated gravity anomaly. The horizontal location is determined using approximated structural index value. Depth and structural index can be, then, determined at the intersection of the linear relations between depth and structural index for different observation points around the estimated horizontal location. The method is tested using synthetic data and could estimate the exact parameters. The applicability of the method is demonstrated using two published field examples. The results agree well with drill-hole results and previous interpretations.

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