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Performance evaluation of spectral analysis and Werner deconvolution interpretation techniques in magnetic method

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ABSTRACT

Determining the depth of anomalous geological subsurface structure is an important parameter in any of geophysical methods. Though, numerous magnetic interpretation techniques are available in literature for locating depth to the causative source, no specific information is found on the performance of any of the techniques. Werner deconvolution and Spectral methods are widely used to determine the approximate depth to the causative sources, which are then used in modeling methods. An attempt has been made in this study to evaluate the performance of Werner and spectral methods. Synthetic magnetic anomalies are generated over sheet, dyke and fault models for different combinations of geometric dimensions of the bodies and magnetization angles. These anomalies were interpreted with the two methods: Werner deconvolution and Spectral analysis. The error percentages are calculated as the difference between the theoretical and interpreted values. In addition, the results are discussed for their performance. It is observed that Werner method yields more reasonable values for depth compared to spectral methods particularly when body widths are more and deep seated or faulting is deep. In case of dyke model, the Werner method determines width also reliably.

1. Introduction

The purpose of magnetic surveying is to investigate the anomalous subsurface geological features causing variations in the observed magnetic field. These magnetic field variations arise due to the differences in the magnetic properties of the underlying rocks. Many magnetic interpretation methods have been developed to determine the depth of the geologic structure of different geometric shapes. The methods are based on: i) graphical techniques using a few characteristic points on the magnetic profile (Koulomzine et al., 1970; Am, 1972; Subrahmanyam and Prakasa Rao, 2009) ii) nomograms (Prakasa Rao et al., 1986) iii) spectral analysis techniques (Bhattacharya, 1971; Bhattacharya and Leu, 1975; Sengupta and Das, 1975; Bhimasankaram et al., 1978), and iv) numerical techniques such as Werner deconvolution method (Hartman et al., 1971; Ku and Sharp, 1983), Euler deconvolution method (Thompson, 1982; Reid et al., 1990), and least-squares minimization approaches (McGrath and Hood, 1973; Silva, 1989; Dondurur and Pamukcu, 2003).

The large potential field data demands automatic interpretation techniques such as Euler method (Thompson, 1982) and Werner deconvolution (Werner, 1953). The Euler's interpretation technique is popular method of interpretation in magnetic data because it requires no information about the magnetization vector and only a little a priori knowledge about the magnetic source geometry (Barbosa et al., 2000). The Euler equation is solved in a nonlinear fashion using optimization technique (Dewangan et al., 2007). However, most of the approaches to nonlinear least-squares inverse problem rely on good initial estimates of the model parameters. Euler deconvolution has come into wide use as an aid to interpret profile or gridded magnetic survey data. Thompson (1982) further studied and implemented the method by applying Euler deconvolution to synthetic and real magnetic data along profiles. This method is used for rapid interpretation of potential field data and it belongs to automatic depth estimate methods which is designed to provide computer-assisted analysis on large volumes of magnetic and gravity data.

Estimation of the depth of magnetic source using different methods is preferably applied to profiles of large magnetic data sets. Kearey (2002) addressed that the interpretation of individual profiles is preferable for most geophysicists because they show fine sampling intervals, which generally lead to good understanding of the geology. There is no single method giving a unique solution for estimating the accurate depth because of the inherent ambiguity due to complex subsurface structures. There is no systematic performance evaluation except a few (Am, 1972; Prakasa Rao and Subtahmanyam, 1985; Subrahmanyam et al., 2013) for most of the methods. The professional geoscientist is at confusion as to which method among the many available would be

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better for his problem. A performance analysis of the methods will be of great use in such situations. Although there are many preliminary methods available in literature for determining depths to magnetic sources, Werner deconvolution and Spectral methods are widely used. Hence we thought a comprehensive analysis of these two methods is essential to know the performance levels when used for magnetic anomalies over different geometric shapes. The performance of spectral analysis and Werner deconvolution interpretation techniques are studied on the synthetic magnetic data for the 2D geological structures of sheet, dike and vertical fault (Fig. 1).

The application of power spectrum technique for analyzing aeromagnetic data was first used by Horton et al. (1964) and then activated by applying Fourier techniques by Spector and Bhattacharyya (1966). The theoretical basis of estimating the depth from Fourier spectra has been explained by many authors such as Spector and Grant (1970) and Hahn et al. (1976). The algorithm given by Spector and Grant (1970) directly estimates the depth of the causative source from the relationship between the logarithm of amplitudes and frequencies. For a single ensemble, the natural log of the power spectrum density as a function of wave number will have a linear slope approximately twice the maximum depth. Potential field anomalies analyzed by Spectral analysis display power spectrum on a natural logarithmic, show that much energy comes from large, deep sources (at a low wave number) and relatively small energy from shallow ones (high wave number) with an approximately exponential decay with wave number.

For multiple ensembles, one obtains linear slopes approximately twice the maximum depths to the various magnetic sources. The depth is to be estimated from the slope of the best linear fit. The deeper depth was estimated from the slope of the best fit of the low wave number portion, while the shallow depth was estimated from the slope of the linear best fit of the high wave number portion.

Werner (1953) has introduced a method of interpreting magnetic anomalies of two-dimensional sheet like bodies, in which the anomalies and distances of observation points along a profile are arranged to form a linear equation, with its coefficients related to the parameters of the sheet. Rao et al. (1973) observed that anomaly, or its horizontal derivative, of a large number of geophysical models can be arranged in the form of a linear equations. Werner deconvolution technique, when compared to conventional methods such as the characteristic curves, is expected to provide more rapid and reliable results, since all the available data on the profile is used in interpretation (Sudhakar et al., 2004). Another advantage of this technique is that it can be applied to horizontal gradient data of the anomaly also, so that we get two parameters one from anomaly and another value from its horizontal gradient.

The Werner's method does not require any initial values of the parameters. There has been an increasing tendency to apply the Werner deconvolution method to trace basement structures (Ku and Sharp, 1983; Malleswara Rao et al., 1983; Thakur et al., 2000) based on clusters of fictitious positions at the locations of sheets. Radhakrishna Murty et al. (2000) pointed that clusters are confined to contacts and faults in the basements only when they are wide apart and very steep. For moderately dipping, close, not very shallow and smooth edged structures, the Werner's method does not provide any reliable interpretation. This technique is based on the assumption that the source is vertical thin dike, but it can be applied for other type of bodies as well assuming that the body consists of several thin dikes. The method is simple, fast and reliable, when it is confined to interpret the anomalies of isolated simple geometric bodies. The depth estimates obtained from these methods could be used as initial guess values for modeling techniques.

Hence, the main objective in the present study is to present the performance evaluation of Spectral and Werner deconvolution interpretation techniques over 2D tabular bodies of sheet, dike and vertical fault model. The spectral method does not require any knowledge on the geometry of the causative structure whereas Werner techniques assumes a sheet or dyke like body and inverts magnetic anomalies. However, the interpreter need not specify any model for input. We have applied these

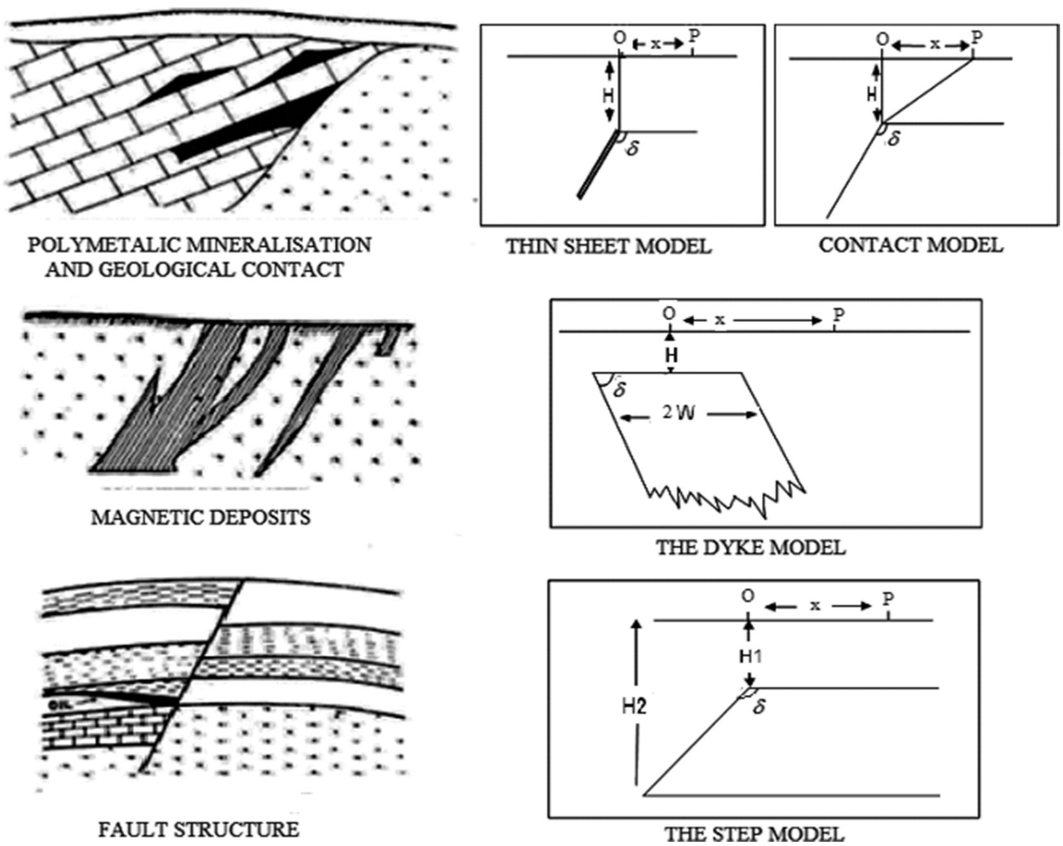

Fig. 1. Geometries of different geological models (after Fekadu 2013).