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New improved formulas for gravity anomalies interpretation

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We present a new formula for the calculation of gravity anomalies from a cylinder model representing a geological body. Compared to conventional methods, this new development allows the cylinder to be freely oriented in space, consequently, more variables are considered, such as the dip angle, the strike direction, the size, depth to top and the density of the cylinder. Those parameters are often important in the determination of the drilling direction. Based on a series of forward modeling using the new formula, a multiple linear regression system has been developed. Using this linear relationship, the user can quickly estimate the cylinder's parameters from several key attributes of the gravity anomaly observed at the surface.

1 Introduction

We can access information on the internal structure of the earth from surface observations. To do this, we often need to solve inverse problems by building subsurface models, which can be

validated by their ability to adequately reproduce observations. Nonlinear problems are typically solved numerically by iteration following a given optimization algorithm (Wang 2007, references therein). Some examples are genetic algorithms and simulated annealing (Smith, Scales, and Fischer, 1992; Sen and Stoffa, 1995; Yao, et al, 2003; Shi and Wang 2007), Marquardt inversion (Chakravarthi and Sundararajan, 2005), as well as the Monte Carlo inversion method (Cary and Chapman, 1988; Wang, 2007). More recently, there is a growing interest in the use of artificial neural networks to solve inverse problems (Sen and Stoffa, 1995; Shi, et al., 2004). In the case of multivariable problems such as ours, multiple linear regression would be a suitable method to use. It is a common statistical tool for petroleum geologists (Wendt, Sakurai, & Neson, 1986), and had been used to predict shear wave velocity (Eskandari, Rezaee & Mohammadnia, 2004), for trap quality evaluation in western China (Shi, et al., 2004), and for detection and classification of airborne time-domain electromagnetic anomalies (Claprood, et al., 2008). With the develpment of numerical approximation methods and increasing computer power we can perform more than more complex calculations in geophysical data interpretation, but the basic goal is to find out the relationship between what we observed and the estimated anomaly causative source.

2 New formula of calculation

For mineral exploration, simple physical models are useful to make quick interpretations of geophysical field observations. Conventional methods

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calculate the geophysical response along a profile passing over the centre of an inclined body, assuming that the body dip lies within the profile plane. Since the variation in shape of a geophysical anomaly has complex implications on the geological structure of its source, in order to improve the method of field data interpretation, we choose a cylinder model as the starting point of development. we improved the convention formula for the calculation of the gravity response by letting the cylinder have a free orientation in space. Ultimately, we use the multiple linear regression method to mathematically relate variations in the gravity field to the most significant parameters that define the cylinder. This linear relationship allows the user to quickly quantify the likely structure of a cylinder from surface gravity observations.New improved formulas please consult :Http://www.sciencedirect.com/science/article/pii/S092698511200119X.

3 Gravity forward modeling

Using the solution of new improved formula, we performed a series of forward modeling experiments based on different values of density, depth to the top, dip extent, dip angle, strike angle, and radius of the cylinder. The depth to the top of the cylinder is always at least two times larger than its radius. The length of the cylinder varies from 100m to 500m and, the dip angle changes from horizontal (0^o) to vertical (90^o), and we choose the strike angle to lie in all 4 quadrants.

4 Gravity inverse problem

Supposing that the shape as well the amplitude of the gravity anomaly will change with the changes of cylinder occurrence. We use the multiple linear regression to examine if there is a linear relationship between each parameter of the cylinder and a series of attributes from the gravity anomaly.

It may be expected that the regression equations should include as many independent variables as possible, so that the regression equation can better fit the observations. Nevertheless, in order to simplify the regression equations, and due to the difficulties in obtaining information on a large number of independent variables, the equations should be optimized and the number of independent variables is usually restricted to a minimum number. Therefore, it is essential to determine the number of variables to be used in the regression equations. Initially, we have considered all the inflection points on an anomaly curve and the distance between them, and have chosen 14 attributs from the gravity anomaly. We used this stepwise regression procedure to determine the most significant attributes to each parameter of cylinder.

5 Application to survey data

We applied the new method to an area in the Abitibi greenstone belt (Québec, Canada), where there are many synvolcanic intrusions. We focus on the zone where there are three well closed Bouguer anomalies (I, II and III).

Since we have no information on the occurrence of those intrusions at the depth, we took more than one profile along different directions over each anomaly region in order to estimate source parameters of the three intrusions.

For intrusion I, we used the 7 attributes of the gravity anomaly described above from 9 profiles (red lines on the Figure) to calculate the density, depth, dip extent, dip angle, strike angle, and radius of the cylindrical source. The estimated values given by those 9 profiles are shown in Table. The same exercice was repeated for intrusions II and III. According to the results, intrusion I is less dense than intrusions II and III. The density of intrusions II and III is within the range of felsic rocks. The estimated strike angles correlate with the long axis direction of the anomalies, respectively 47.49^o for intrusion I (oriented NE-SW), $232.52\ ^o$ for intrusion II (oriented SW- NE), and $282.35\ ^o$ for intrusion III (oriented NW-SE). All of them extend to more than one kilometre in depth, and intrusion I is the deepest. Intrusion I dips to the NE at 71 degrees, intrusion II has a flat angle of about 43 degrees dipping to the SW, and the tilt of intrusion III is about 76 degrees to the NW. From this case study we show the advantage of the new formula: to be able to give an estimation of the dip angle and the dip direction (strike angle) simultaneously. Those are very important variables when planning drill hole position and inclination in mineral exploration.

6 Conclusion

The new formula improved the method of calculation for gravity by letting the cylinder model freedom oriented. Starting from a series of forward models using the newly developed formula, we assessed the variability of a gravity anomaly as a function of the source occurrence. We identified the six most significant parameters of a cylinder-like body, namely its density, depth to the top, dip extent, dip angle, strike angle and radius, who influence the shape of the gravity anomaly as well its intensity.

The multiple linear regression method relates the variations in the gravity anomaly to changes in the source parameters, therefore, using the multiple linear regression method we can estimate the source parameters of a cylinder model, and interpret circular gravity anomalies. We build up a linear regression system that contains six linear relationships between the six most significant parameters of a cylinder-like body and seven attributes from the gravity anomaly. Those equation allow the user to estimate the multiple parameters of an elongated geological body simultaneously under the constraint of gravity observations. Integrating those calculations into gravity surveys, it is help of making drilling decision.

Key words: Forward modeling, Inversion, Multiple Linear Regression.

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