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Interpretation of Aeromagnetic Data to Locate Buried Faults in North of Zanjan Province, Iran

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Abstract

Zanjan Province is located in the North of Iran and known for its great mineral exploratory interest in zinc, lead and Fe, among others. In the years of 2011 and 2012, the geological survey of Iran performed an airborne magnetic survey over the whole of the province for the geological purposes. The horizontal gradients and the 3-D Euler deconvolution have been applied to the aeromagnetic data from the North part of the Province to delineate the subsurface lineaments. Determination of the magnitude maxima of the horizontal gradients of the residual magnetic intensity field allowed the production of a structural map showing the fault systems for the study area. The suggested source depths are in the range of 800 to 4000 m. These results reveal deep tectonic features, which up to date were unknown. This work emphasizes the importance of the role of the magnetic method and analysis to better understand the geological structures.

Keywords: Aeromagnetic data; Euler; Fault; Horizontal gradient; Zanjan

Introduction

The magnetic method is one of the most commonly used geophysical tools. This stems from the fact that magnetic observations are obtained relatively easily and cheaply and few corrections must be applied to the observations. Despite these obvious advantages, like the gravitational methods, interpretations of magnetic observations suffer from a lack of uniqueness. Aeromagnetic data have consistently been used in mineral exploration and geological mapping such as faults since the early 1960s [1,2].

This paper presented the results of aeromagnetic interpretation for purpose the identifying of the major faults over the North part of Zanjan province in the North of Iran (Figure 1). The study area is very importance for its great mineral exploratory, thus more geological information extracted by aeromagnetic data will be useful in the future prospecting in the area.

Figure 1 shows the position of the study area in Iran with a satellite picture and a large scale geological map. The study area in geological aspect is a member of Zanjan quadrangle which is located in small part of western Alborz zone and in Tarom Mountains which most it has complicated features in geology (stratigraphy, geomorphology and tectonic) viewpoint. One of the prominent features of magmatic highlands in north of Zanjan province is the existence of large granitic and granodioritic bodies, which have been penetrated into the Eocene pyroclastic rocks (Karaj formation). They represent post Eocene intrusive bodies of Pyrneeanorogenic phase intruding via direction of very deep fundamental faulted zones in Tarom mountain ranges. Various halos in volcano-clastic rocks of Eocene are one of the characteristics consequences of these intrusive events. Mineralization of gold, copper, lead-zinc and kaolin are associated with these hydrothermal alteration halos (Geological Survey of Iran: GSI).

In north Tarom piedmont in a NW-SE trend there is sequence of marl, conglomerate and sandstone. The set of these rocks have been located under influence of folding and tectonic after Eocene, especially lore phase of Alpian phase and it rehears dominant morphology of the region. The main trend of contact and faults are in the NW-SE direction.

Aeromagnetic Data and Reductions

The keycomponent of this study involved image enhancement of the existing aeromagnetic datasets acquired by the Geological Survey of Iran (GSI) in 2011. Aeromagnetic surveys were flown with a flight height of 150 m and a nominal flight line spacing of 500 m in direction NE-SW, perpendicular to the dominant trend of geology in the area. After applied the preliminary corrections of the measurements, the observed magnetic field data of the study area reduced for diurnal variation over the study area. To obtain magnetic anomalies associated with local magnetic variations of rocks, it is necessary to remove the normal geomagnetic field of the study area from the data. The normal geomagnetic field used for the reduction was the International Geomagnetic Reference Field (IGRF) computed by GEOMAG program [3] for our data.

After necessary data corrections, the data was interpolated using a minimum curvature gridding algorithm (available in the Geosoft Oasis Montaj 6.4.2 software), with a grid cell size of 200 m and internal tension of 0.5. The isolation of the anomaly from the regional contribution used a first order trend surface calculated by the least squares fitting for all the values in the grid. Subsequently, it was performed the reduction of the magnetic pole (RTP) transformation of an anomaly in the Fourier domain through the algorithms of Baranov [4] available at the Geosoft Oasis Montaj® software. The inclination and declination angles of the ambient field were taken as 55.5° and 4.7°, respectively in the center of the region for the year of 2011 according to IGRF.The resulting magnetic anomaly (residual magnetic map) has been represented in

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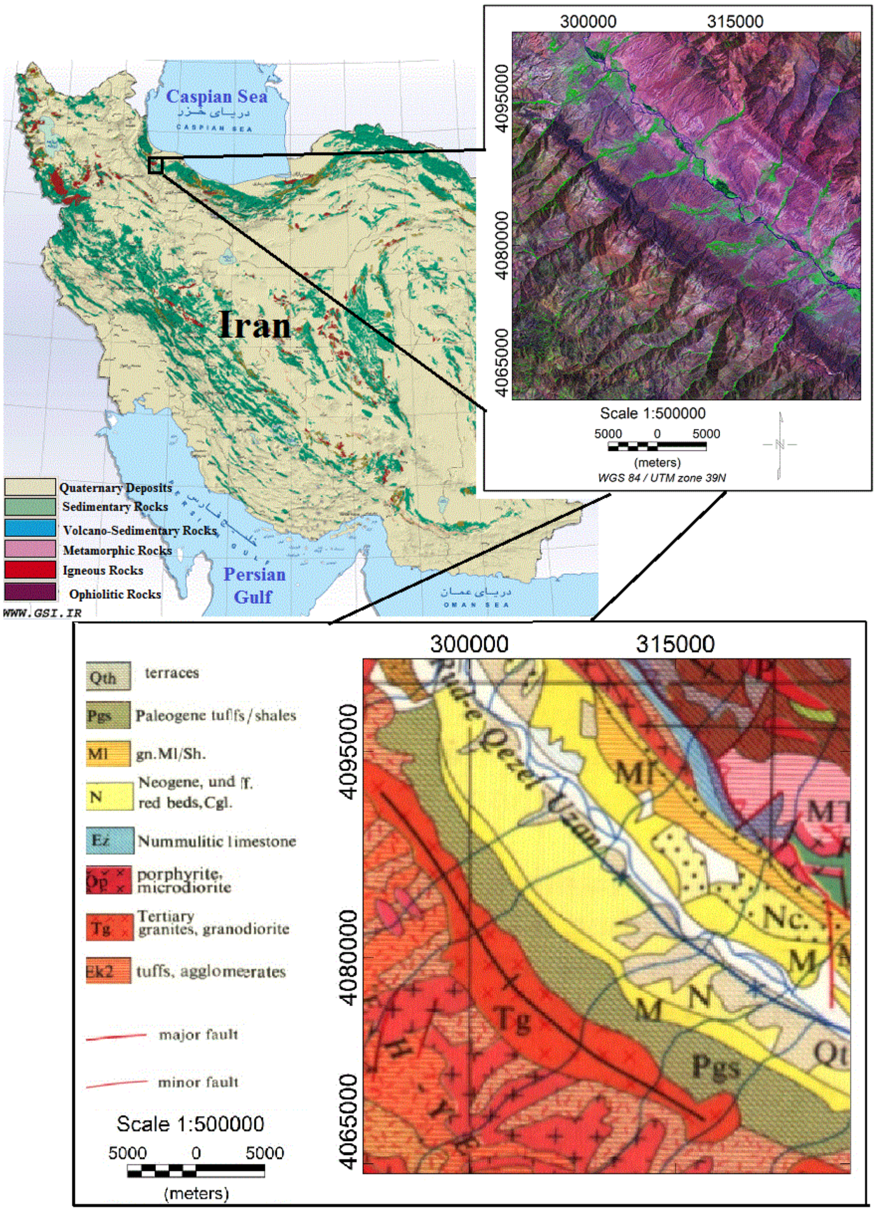

Figure 1: Study area in the Zanjan province in Iran with a satellite picture and a large scale geological map.

Figure 2. The magnetic anomalies are indicated by color shaded grid. The map (Figure 2) is characterized by high magnetic anomalies of NW-SE trending direction. This configuration may be attributed to relatively deep-seated low relief basement structures with the igneous rocks composition. In fact, according geology map in Figure 1, the igneous rocks intrude to the sedimentary host rocks in the south-west margin of Alborz zone. In the mineral exploratory point view, the mentioned mechanism have been caused a good mine mineralization such as zinc, lead and Fe in the whole of the study area.

Among the geophysical method, aeromagnetic survey is a most popular and an economical method for the investigation of geological structures with the goal of mineral exploration. Therefore the results of this paper can be very important for the future mineral exploration as well other purposes in the study area.

Data Interpretation

In this paper, we are applied two methods over aeromagnetic data to locate buried faults in the study area: horizontal gradient and 3D Euler deconvolution. The first is a robust method in edges/faults detection and the second is most popular and rapidly making depth estimation from potential data.

Horizontal gradients

The horizontal gradient of the magnetic field in a given direction enhances lateral changes in the magnetic field and attenuates its regional trend along that direction [5]. The derivative will reach a maximum/minimum in areas where the magnetic susceptibility contrast is higher, thus highlighting discontinuities perpendicular to the direction of derivation and defining more clearly the faults and the

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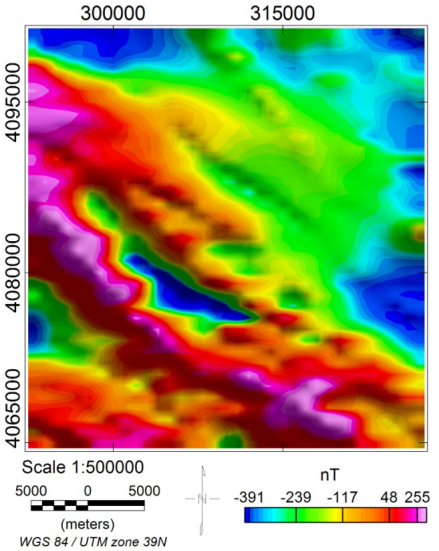

Figure 2: Residual magnetic map of the study area.

edges of structures. In the other words, the horizontal gradient method is in many ways the simplest approach to estimate contact locations of the bodies at depths. The importance advantage of the horizontal gradient method is its low sensitivity to the noise in the data because it only requires calculations of the two first-order horizontal derivatives of the field [6]. If M is the magnetic field then the horizontal gradient magnitude (HGM) is given by:

$$HGM = \sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial y}\right)^2} \qquad (1)$$

This function gives a peak anomaly above magnetic contacts under the following assumptions [6]: (1) the regional magnetic field is vertical, (2) the magnetizations are vertical, (3) the contacts are vertical, (4) the contacts are isolated, and (5) the sources are thick. Violations of the first four assumptions can lead to shifts of the peaks away from the contacts. Violations of the fifth assumption can lead to secondary peaks parallel to the contacts. In order to partially satisfy the first two assumptions, it is usually necessary to perform a standard phase shift operation known as Reduction-to-Pole (RTP) on the observed magnetic field. Crests in the horizontal gradient magnitude grid can be located by passing a small window over the HGM grid and searching for maxima [7].

Considering the direction of the main faults found in the area, two maps of horizontal directional gradient were calculated, one along the direction NS, to enhance the structures in the direction of almost WE (Figure 3a), and another along the direction WE to reveal the system of faults in the direction of almost NS (Figure 3b).

The maps show clearly the importance of the main lineaments, the faults system that controls the evolution of the sedimentary host rocks in Alborz zone. Considering the geological map (Figure 1) and the magnetic signatures (Figure 2), it is clearly that main faults and contacts are in NW-SE direction, therefore they are well recognized in both horizontal gradient maps as shown in Figure 3. In this figure, black lines (full line) are charted faults and white lines are faults/ discontinuities identified using the horizontal gradient maps.

Euler depth estimation

The standard Euler deconvolution uses three orthogonal gradients of any potential quantity to estimate the location of a source body. 3D form of Euler's equation can be defined [8] as

$$x\frac{\partial T}{\partial x} + y\frac{\partial T}{\partial y} + z\frac{\partial T}{\partial z} + NT = x_0\frac{\partial T}{\partial x} + y_0\frac{\partial T}{\partial y} + z_0\frac{\partial T}{\partial z} + NB \qquad (2),$$

where (x0, y0, z0) are the coordinates of a magnetic source, ∂T/∂x, ∂T/∂y and ∂T/∂z are the derivatives of the total field versus x, y and z, respectively, N indicates the structural index (SI) and relates the rate of change of a potential field with distance and B is a local background representing the "regional" field within a sliding window with adjustable size.

Eq. (1) can be solved in a window centered on a given grid point to find the unknown source point (x0, y0, z0) and the regional field [8]. This approach introduces a nonlinear relation between the SI and the unknown regional field. By specifying the SI, Euler's equation is solved using a linear least-squares method [8] The SI depends on the source geometry and its range is between 0 to 3 for the magnetic sources (and 0 to 2 for the gravity sources). Stavrev and Reid [9] show that the SI depends on the type and physical parameters of the potential field providing an excellent overview on the properties of Euler's homogeneity equation in general and the SI in particular.

Thompson [10] exhibited different values of SI for some geological geometry. Table 1 shows those values. Note that a zero index implies that the field is constant regardless of distance from the source. These solutions are physically impossible for the real data, and a zero index represents a physical limit which can only be approached as the so-called 'infinite' dimensions of the real source increases. In practice, an index of 0.5 can often be used to obtain reasonable results when an index of zero would be indicated otherwise. To obtain reliable results, the structural index and the window size must be carefully selected.

The window size determines the area in grid cells used to perform Euler deconvolution. All points within the window are used to solve Euler's equation for source location. It should be large enough to incorporate the entire anomaly being interpreted and small enough to avoid significant effects from adjacent or multiple sources [11]. In case of anomalies caused by close sources considered included in a given

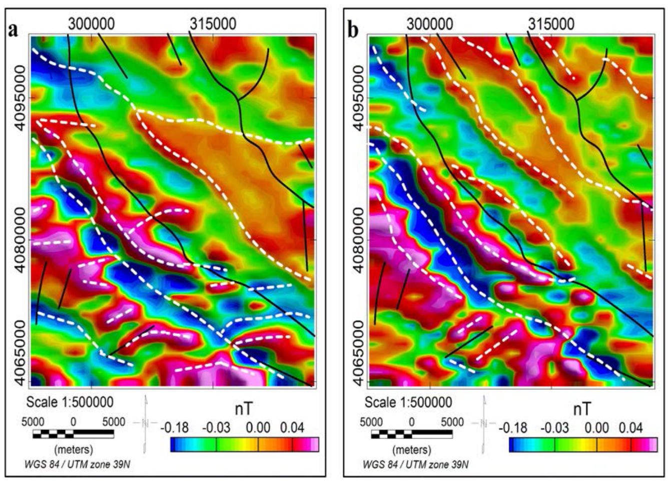

Figure 3: Horizontal gradients along the directions of NS (a-left) and EW (b-right). Black lines are confirmed faults (full lines) and White lines are faults identified using the horizontal gradient map.

Geological model	N
Horizontal contact with infinite dimensions	0
Vertical contact	0-0.5
Dyke-Amorphoussill	1
Vertical cylinder	2
Amorphous cylinder	2.5
Horizontal cylinder	2-2.75
Point dipole- Sphere	3

Table 1: Structural indexes (SI) for some geological models (Thompson [10]).

window, the uncertainty of the solution will increase.

In order to apply the Euler method on the data, we used the package of Geosoft Oasis Montaj® software. After preparing the data grid, we applied magnetic field derivatives in three directions of x, y and z which are necessary for Euler deconvolution process. SI and window sizes have been selected appropriately. To achieve the best SI, different values were tested. Since we had no good imagination about the geometry of the source of the main magnetic anomaly , we tested structural indices from 1 (SI for dyke) to 3 (SI for sphere) by steps of 0.1. Finally, an appropriate SI was estimated between 1.6 and 1.9 for the main anomaly. The SIs in this range suggested the best clustering and regularity in the solutions, therefore, we considered a value of 1.75 for the SI as an average. Then the Euler method was applied to the residual data by moving different window sizes. The best results were attained by a window size of 400 m × 400 m while SI was fixed equal to 1.75.

The following criteria are used in the presented algorithm to discriminate between solutions after Beiki .

1- The estimated source locations with standard deviation to estimated depth ratio greater than a predefined threshold were rejected.

2- Only those solutions with horizontal coordinates located within the window were accepted.

3- Solutions with estimated depths greater than a predefined threshold are rejected.

4- Solutions with unreliable estimated structural indices were rejected.

Fig. 4 shows Euler depth estimation solutions on the residual magnetic field by using the SI of 1.75. According to Table 1, the source was resolved nearly as a vertical cylinder. Thus our suggested model based on the SI value of 1.75 is an igneous intrusive almost like a vertical cylinder.

The Euler solutions on the residual map in Figure 4, shows different depths. So the estimated depths in the W to the E-NE direction over the main anomaly gradually increase. In other words, the depth of the top of the intrusive body is different on the main anomaly, so most probably it is located at about 1000 m depth (black circles on the main anomaly in Figure 4 with a regular increasing to about 1500 m toward E-NE (blue circles on the main anomaly in Figure 4. Moreover, the short wave anomalies in the north above the main positive anomaly are due to the granite and granodiorite at the surface or at levels shallower than the main source.

Depth estimation by Euler deconvolution technique was used for delineating geologic contacts where usually faults occur. This technique provides automatic estimates of source location and depth. Therefore, Euler deconvolution is both a boundary finder and depth estimation method. Euler deconvolution is commonly employed in magnetic interpretation because it requires only a little prior knowledge about the magnetic source geometry, and more importantly, it requires no information about the magnetization vector [8,10].

Euler deconvolution is based on solving Euler's homogeneity equation (2) [8]:

$$(x-x_0)\frac{\partial M}{\partial x}+(y-y_0)\frac{\partial M}{\partial y}+(z-z_0)\frac{\partial M}{\partial z}=N(B-M) \quad (3)$$

where B is the regional value of the total magnetic field and (x_0,y_0,z_0) is the position of the magnetic source, which produces the total magnetic field M measured at (x,y,z). N is so called structural index. For each position of the moving window, on overestimated system of linear equations is solved for the position and depth of the sources [8,10].

The most critical parameter in the Euler deconvolution is the structural index, N [10]. This is a homogeneity factor relating the magnetic field and its gradient components to the location of the source. Essentially, N measures the rate of change of the fields with distance from the source (fall-off-rate) and is directly related to the source dimensions. Therefore, by changing N, we can estimate the geometry and depth of the magnetic sources. Stavrev and Reid [9] show that the SI depends on the type and physical parameters of the potential field providing an excellent overview on the properties of Euler's homogeneity equation in general and the N in particular.

A poor choice of the structural index has been shown to cause a diffuse solution of source locations and serious biases in depth estimation. Thompson and Reid et al. [8,10] suggested that a correct N gives the tightest clustering of the Euler solutions around the geologic structure of interest. For magnetic data, N values range from 0 to 3. The magnetic field of a point dipole falls off as the inverse cube, giving an index of 3, while an effective vertical line source such as a narrow, vertical pipe gives rise to an inverse square field fall-off and an index of 2. Values less than zero imply a field strength that increases with distance from the source (and is infinite at infinity).

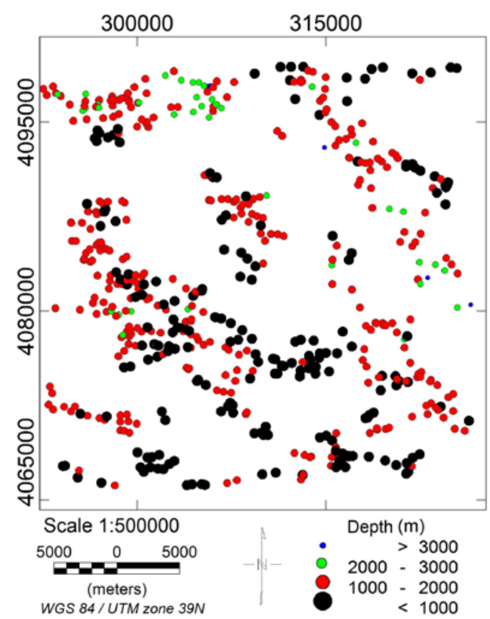

Figure 4: 3D Euler solutions from analysis aeromagnetic data over the study area. The color circles represented the depth of anomaly source.

The window size determines the area in grid cells used to perform Euler deconvolution. All points within the window are used to solve Euler's equation for source location. It should be large enough to incorporate the entire anomaly being interpreted and small enough to avoid significant effects from adjacent or multiple sources [11]. In case of anomalies caused by close sources considered included in a given window, the uncertainty of the solution will increase.

After preparing the data grid, we applied magnetic field derivatives in three directions of x, y and z which are input grids for Euler deconvolution process. N and window sizes have been selected appropriately.

Figure 4 shows the results of Euler solution on the residual magnetic map. According color legend circles, source depth of anomalies is between 800 m and 4000 m approximately.

Results of two methods

Magnetic lineaments were traced by the maxima of the horizontal gradients along the direction NS (Figure 3a) and EW (Figure 3b) in addition to Euler solutions. Horizontal gradient of magnetic data along the direction of NS/EW is able to detect every magnetic lineament and fault that across this direction. White color lines in Figure 3 are detected faults using this method. To attain a map with whole of faults, we merged results of two directional horizontal gradients and showed in Figure 5. This figure shows both faults of pre-known and newly detected faults in the study area.

Also, in order to attain knowledge about the depth of faults, we applied 3D Euler deconvolution method over the aeromagnetic data. The results of this method have been showed in Figure 4. Based these depth estimation, the depth of faults are less than 4000 m. Also, according this figure, the depth of magnetic source is varies from southwest of the study area where exist the igneous rocks toward northeast of area where exist sedimentary rocks (Alborz zone). The depth of magnetic anomaly increase along this direction gradually. Change lithology is reason of this increase in the source depth.

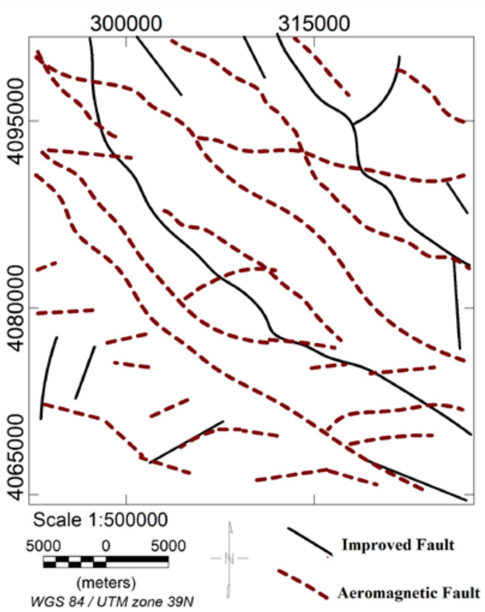

Figure 5: Structure map of the study area. The dashed lines are detected faults from horizontal gradient maxima and full lines are pre-known faults.

Aeromagnetic lineaments/faults suggest that the area has been subjected to an important regional field stress. The predominant NW-SE faults trend affecting thearea among which are faults extend from southeast of the study area to the extreme northwest part. The regional field stress associated with the predominant trending of magnetic lineaments is in accordance with Pyrneeanorogeny trend and would so have played an essential role in the control of the geodynamic evolution of the region.

Conclusion

This work presents the analysis of a regional aeromagnetic survey to identifying new geological structures over the north of Zanjan province. The horizontal gradients map shows that most of the anomalies observed are associated with major faults and contact zones of different lithologies. The main tectonic structures, both improved and new recognized faults, have a strong expression in the NW–SE dominant lineament orientation, observed in the residual anomaly map, and especially in the horizontal gradients maps.

These faults do not seem to be reflected in the surface but the high values of the anomalies suggest that they could have expression in depth and that they may represent important discontinuities in lithology. Depth estimation using Euler deconvolution shows the depth of 800 to 4000 m for the identified faults.

The new structural map derived from the interpretation of the gravity data, when combined with other geological, geophysical, Hydro geochemical and numerical models, provides an effective tool for analyzing potential geothermal system and subsurface structure in study area.

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References

1. Hood PJ (1967) Detectability of diabase dykes by aeromagnetic surveys. Geological Survey of Canada, Report of Activities, Part B: 3-9.
2. Jespersen A (1964) Aeromagnetic interpretationof the Globe-Miami copper district, Gila and Pinal counties, Arizona. GeologicalSurvey Research, US Geological Survey Professional Paper, D70-75.
3. National Geophysical Data Centre (2010) GEOMAG Computer Program and the 1990 Coefficients for IGRF Model, World Data Centre-A for Solid Earth Geophysics, NOAA, E/GCI, 325 Broadway, Boulder, CO 80304, USA.
4. Baranov V (1957) A new method for interpretation of aeromagnetic maps: pseudogravimetric anomalies. Geophysics 22: 359-383.
5. Blakely RJ (1995) Potential theory in gravity and magnetic applications, (1stedn) Cambridge Univ. Press, Cambridge.
6. Phillips JD (1998) Processing and Interpretation of Aeromagnetic Data for the Santa Cruz Basin - Patahonia Mountains Area, South-Central Arizona. U.S. Geological Survey Open-File Report, Arizona, 02-98.
7. Blakely RJ, Simpson RW (1986) Approximating edges of source bodies from magnetic or gravity anomalies.Geophysics 51: 1494-1498.
8. Reid AB, Allsop JM, Granser H, Millett AJ, Somerton IW (1990) Magnetic interpretation in three dimensions using Euler deconvolution. Geophysics 55: 80-90.
9. Stavrev P, Reid A (2007) Degrees of homogeneity of potential fields and structural indices of Euler deconvolution. Geophysics 72: L1-L12.
10. Thompson DT (1982) EULDPH: A new technique for making computer-assisted depth estimates from magnetic data. Geophysics 47: 31-37.
11. Bournas N, Galdeano A, Hamoudi M, Baker H (2003) Interpretation of the aeromagnetic map of Eastern Hoggar (Algeria) using the Euler deconvolution, analytic signal and local wavenumber methods. J Afr Earth Sci 37: 191-205.