Analysis and Interpretation of Aeromagnetic Data for East of Nasser Lake Area, Aswan, Egypt

Eslam A. Elawadi, Ahmed A. Nigm, Mamdouh M. El Tarras and Mahmoud I. Mira
Nuclear Materials Authority, P. O. Box 530 El- Maadi, Cairo, Egypt
e_elawadi@yahoo.com

Received: 18/11/2006 Accepted: 18/3/2008

Abstract. The area of study is located to the south east of Aswan occupying part of Nasser Lake in its western section. Nasser Lake is contemplated as a source of tectonic instability and earthquake activities in Aswan region. Most of this activity was recorded in the western side of the lake, coincides with the intersections of the two major fault systems, trending in the NS and EW directions. Therefore, mapping the subsurface structures in the study area can shed more light on the structural setting of this zone of the lake and its relation to tectonic instability. This study presents the analysis and interpretation of aeromagnetic data to map the subsurface structural framework of the area around the Lake. Structural interpretation of the magnetic data was achieved through applying advanced interpretation techniques that provide automatic delineation and depth estimation of the magnetic structures. These techniques include Horizontal Gradient, Euler deconvolution and Local wave number. The structure locations and depths obtained from these methods were integrated to delineate the tectonic framework of the area. The mapped structures reveal that the area is affected by a set of faults trending mainly in the NW-SE, EW, NS and NE-SW directions. Moreover, the area is dissected by basement uplifts and troughs controlled mainly by the NW-SE faults.

Introduction

Nasser Lake lies in the extreme southern part of Egypt occupying a considerable area behind the Aswan High Dam. Due to the large area of
extent and the huge mass of water in this lake, it is the second largest artificial lake in the world. The lake is founded mainly on Precambrian granitic terrain and extends southward towards the Egyptian-Sudanese border. It was evident through previous geological and geophysical studies that Nasser Lake has, affected the tectonic stability of the Aswan region, since water penetration through open fractures and other tectonically weak zones in the submerged land has significantly contributed to further fracturing and reactivation of some pre-existing faults (Kamel and Elsirafe, 1993).

The area of study is located to the east of Nasser Lake between Latitudes 23° 00' & 23° 30' N and Longitudes 32° 45' & 33° 15' E (Fig. 1). This area is covered mainly with foreland sediments ranging in age from Quaternary to Cretaceous unconformably overlying Precambrian basement represented by younger granites (Conco map, 1987).

![Fig. 1. Location map of the study area with the major structure and seismicity (1981-2002) in Nasser Lake area (Awad and Kwiatek, 2005).](image)

The airborne survey of the study area was carried out by Aero-service Division, Western Geophysical Company of America in 1984. The data was acquired along parallel flight lines oriented in a NE-SW direction at one kilometer spacing, while the tie lines are spaced at 10 km directed in NW-SE direction. The flight altitude was at 120 m ground clearance (Aero-Service, 1984).
Regional Geology

The present area is mainly covered by foreland sediments which are represented by Cretaceous Nubian Sandstones and Quaternary deposits. The sedimentary cover is underlain by Precambrian rocks which are mainly younger granites (Fig.2). The Nubian Sandstones are unconformably overlying the basement rocks and can be classified into three units corresponding to the lithological and photogeological characteristics (El Tarras, 1995).

The granitic rocks are represented by three bodies outcropping in the central parts of the study area aligned in N-S direction. These granitic bodies possess sharp contacts with the surrounding rocks. Structurally the area is highly affected by NW-SE, NE-SW and ENE-WSW faults and fractures, where wadies and their tributaries run over these structural lineaments (Fig. 2).

The Nubian sandstone beds of the area show evidence of gentle folding, forming flat anticlines and synclines extending for long distance and having mostly a NNW direction (Attia 1955).

Fig. 2. Geologic map of the study area (after Conoco Inc. 1987).
Analysis Techniques

In this paper, three advanced techniques were used to analyze the magnetic data as a guide for structural interpretation. These methods are horizontal gradient (Cordell and Grauch, 1982, 1985; and Blakely and Simpson, 1986), Euler deconvolution (Thompson, 1982; and Reid et al., 1990), and local wave number (Thurston and Smith, 1997; and Smith et al., 1998). These methods are proven as efficient tools to map the location of magnetic structures such as faults and contacts. Moreover, the Euler and local wave number methods provide depth estimate to these structures, beside the horizontal location.

Because these methods require the calculation of the first and second order derivatives of the magnetic field, they are very susceptible to noise in the data. It is usually necessary to improve the signal-to-noise ratio of the data by filtering or upward continuation prior to calculation of the derivatives. In this paper these methods were applied to the filtered regional and residual magnetic components after removing of the noise to improve the signal-to-noise ratio.

1) Filtering of the Magnetic Data

Filtering the magnetic data is an essential process prior to analysis and interpretation. The objective of the filter is to condition the data set and to render the resulting presentation in such a way as to make it is easier to interpret the significance of anomalies in terms of their geological sources (Bird, 1997). Therefore, the most effective way to filter the data is with an understanding of the geologic control and the desired filtered results. Several filtering techniques can be performed in the frequency domain. However, one of the most traditional filters, used in the potential field, is the separation of long (deep) and short (shallow) wavelength anomalies. The success of this technique depends on the proper choice of cut-off wavelength used in the filter design. The cut-off wavelengths and information about the contribution of the short and long wavelengths in the spectrum can be obtained from the calculated radially-averaged power spectrum of the data.

Two-dimensional power spectrum curve of the present RTP data (Fig. 3) shows two linear segments related to long and short wavelength components with frequency bands ranges from 0.0 to 0.3 and from 0.3 to 0.95 wave numbers, respectively (Fig. 4). Following Spector and Grant (1970), the slope of these two linear segments was used to estimate the average depth (≈2.0 and ≈1.0 km) to the top of the deep-seated and near-surface magnetic source, respectively. These depths are average
estimates for the entire area and do not reflect a resolved and quantitative topography of the basement surface. The frequency bands corresponding to these linear segments were used through the band pass filter technique to produce the regional and residual magnetic component maps. Meanwhile, the higher frequency signal, beyond these segments, was considered as noise and was eliminated from the data to enhance the signal to noise ratio.

Fig. 3. RTP total magnetic intensity map.

Fig. 4. Power spectrum of the RTP magnetic map (Fig.3).
2) Horizontal Gradient (HG)

Horizontal gradient is a simple approach to locate linear structures such as contacts and faults from potential field data. For magnetic field \( M(x,y) \), the horizontal gradient magnitude \( HG(x,y) \) is given by (Cordell and Grauch, 1982, 1985).

\[
HG(x, y) = \sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial y}\right)^2}
\]

(1)

This function peak over magnetic contacts is under certain assumptions: (1) the magnetic field and source magnetization are vertical, (2) the contact is vertical and (3) the sources are thick (Phillips, 2000). Violation of the first two assumptions leads to shift the peaks away from the contact location. Violation of the third assumption, leads to secondary peaks parallel to the contacts. In order to partially satisfy the first two assumptions, the method was applied to the regional component of the reduced to the pole magnetic data. When these assumptions are satisfied, the method is effective in detecting lineaments that may correspond to basement faults and contacts. Moreover, the method is less susceptible to noise in the data, because it only requires calculation of the two first-order horizontal derivatives of the magnetic field.

3) Euler Deconvolution

Euler deconvolution is an automatic technique used for locating the source of potential field based on both their amplitudes and gradients. The method was developed by Thompson (1982) to interpret 2D magnetic anomalies and extended by Reid et al. (1990) to be used on grid-based data. Magnetic field \( M \) and its spatial derivatives satisfy Euler’s equation of homogeneity.

\[
(x - x_0) \frac{\partial M}{\partial x} + (y - y_0) \frac{\partial M}{\partial y} + (z - z_0) \frac{\partial M}{\partial z} = -NM,
\]

(2)

Where, \( \frac{\partial M}{\partial x}, \frac{\partial M}{\partial y} \) and \( \frac{\partial M}{\partial z} \) represent first-order derivative of the magnetic field along the x-, y- and z- directions, respectively, \( N \) is known as a structural index and related to the geometry of the magnetic source. For example, \( N=3 \) for sphere, \( N=2 \) for pipe, \( N=1 \) for thin dike and \( N=0 \).
for magnetic contact (Reid et al., 1990). Taking into account a base level for the regional magnetic field (B), equation (1) can be rearranged and written as:

\[
x \frac{\partial M}{\partial x} + y \frac{\partial M}{\partial y} + z \frac{\partial M}{\partial z} + NB = x \frac{\partial M}{\partial x} + y \frac{\partial M}{\partial y} + z \frac{\partial M}{\partial z} + NM,\tag{3}
\]

Assigning the structural index \((N)\), a system of linear equations can be obtained and solved for estimating the location and depth of the magnetic body. Using a moving window, multiple solutions from the same source can be obtained. Good solutions are considered to be those that cluster well and have small standard deviations (Thompson 1982; Reid et al., 1990). Selection of the appropriate structural index is very important to obtain the correct depth solutions. However, the estimated horizontal location is independent of the structural index (Barbosa et al., 1999), which means that there is no ambiguity with regard to the structural location. In this paper we applied the method using the structural index \((SI \approx 0)\) of contact or step (Thompson, 1982 and Reid et al., 1990), since the main objective is to map the faults and contacts. Despite of generating scattered solutions, using structural index very near to zero is the way for better estimation of depth and location of the contact/fault. The estimated depths and locations using Euler methods were compared with that estimated using the SPI methods and the consistent solutions get the highest consideration in the interpretation.

4) Local Wave Number (SPI) Method

Local wave number is a technique based on the extension of complex analytical signal to estimate magnetic depths. The original SPI method (Thurston and Smith, 1997) works for two models: a 2-D sloping contact or a 2-D dipping thin-sheet. For the magnetic field \(M\), the local wave number (Thurston and Smith, 1997) is given by:

\[
k = \frac{\partial^2 M \cdot \partial M}{\partial x \partial z} \cdot \frac{\partial^2 M \cdot \partial M}{\partial x^2 \partial z} = \left( \frac{\partial M}{\partial x} \right)^2 + \left( \frac{\partial M}{\partial z} \right)^2 \tag{4}
\]

For the dipping contact, the maxima of \(k\) are located directly over the isolated contact edges and are independent of the magnetic inclination, declination, dip, strike and any remanent magnetization. The depth is
estimated at the source edge from the reciprocal of the local wavenumber.

\[ Depth_{(x=0)} = \frac{1}{k_{\text{max}}} \]  

(5)

One more advantage of this method is that the interference of anomaly features is reducible, since the method uses the second-order derivatives.

In practice, the method is used on gridded data by first estimating the direction at each grid point. The vertical gradient is computed in the frequency domain, and the horizontal derivatives are computed in the direction perpendicular to the strike using the least-squares method.

**Results for Synthetic Test Model**

To demonstrate the applicability of the analysis methods to delineate the fault-like structures, these methods were applied to a synthetic test model (Fig. 5). This model was designed to represent basement uplift and troughs controlled by faults with different dip angles. The model consists of one uplifted block with 10 m depth bounded by two down-faulted blocks located at depths of 20 and 30 m depths. The dips of the bounded faults are 45° and 60° respectively.

![Fig. 5. Vertical cross-section of the synthetic test model.](image)

The magnetic response of the model has been calculated with inclination 45° and declination 2° and total field of 42000 nT. The data was then reduced to the north magnetic pole (Fig. 6) to simulate the real data used in this study.

The analysis methods were applied to the synthetic model and the resulting location and depth of the faults were mapped (Fig. 6 a, b and c). The methods show similar efficiency in locating the vertical contacts. For the dipping contacts the HG method (Fig. 6 a) could trace the location of
the contact with offset depends on the dip angle. Meanwhile, the Euler solutions (Fig. 6 b) disperse over the dipping contacts according to the dip angle. In contrast, the SPI method (Fig. 6 c) shows the best resolution in locating the dipping contacts regardless the dip angle. Concerning the depth to the contact, the SPI method shows higher accuracy in the depth estimation than the Euler method especially in the deeper blocks.

Fig. 6. Locating magnetic contacts using the HG (a), Euler deconvolution (b), and SPI (c) methods of the synthetic test model with RTP map in the background.

Results for the Magnetic Data of the Study Area

The methods were applied to the regional and residual components of the magnetic data to map the deep-seated and near-surface structures of the study area. The peaks of the HG and SPI functions were traced by passing a small 3 by 3 window over the grid data and searching for maxima (Blakely and Simpson, 1986). Euler solutions were filtered using the criteria of Reid et al., 1990 to remove the solutions of low certainty. The traced structures were plotted over a background of the magnetic components (Fig. 7, 8 and 9).

The maxima of the HG function could map the deep-seated and near-surface magnetic structure of the study area (Fig. 7a and b). These structures are trending mainly in NW, NNW, NE, and NS directions.

The Euler solutions (Fig. 8a and b) show good clustering along linear segments trending in NW, NNW, EW, and NS directions. Moreover, the Euler solutions provide depth estimation to these structures. These depths range from 1.5 km to 2.5 km for the deep-seated structures with general increase toward the west. Meanwhile, the depths estimated for the near-surface structures range from 300 to 1200m.
Fig. 7. The picked maxima of the horizontal gradient function over the regional (a) and residual (b) magnetic component maps.
Fig. 8. Euler solutions of the regional (a) and residual (b) magnetic component maps assigning structural index of contact (SI=0).
The SPI method (Fig. 9 a and b) could map the linear structures in both magnetic components with higher resolutions. The structures are trending in NW, EW, NS, and NE directions. The SPI depth estimates from the regional magnetic component shows deeper values compared to the Euler method. However, these depths agree with that obtained from Euler depths in the relative depths to the structures. On the other hand, the SPI depths estimated for the residual magnetic component are closed to those obtained from the Euler method. The SPI method could delineate the axis of the major basement trough of the study area associated with the largest depth values. This basement trough is located at the southwestern part of the study area and trending mainly in NW direction.

**Interpreted Structure Map**

The results (locations and depths) obtained from the analysis methods were compared and integrated to construct the basement tectonic map (Fig. 10). The deep-seated structures, interpreted from the regional map, are displayed in bold black lines. Most of these structures are traced in confirmation by the three analysis methods. However, some structures were interpreted following the disruption and discontinuity of the method's solutions.

The near-surface lineaments, shown in red dashed lines, were traced by the application of the analysis methods to the residual component map. These lineaments show good agreement with the geologically mapped linear features and main valleys cut across the area (Fig. 2). Accordingly, these lineaments might reveal top basement and intra-sediment structures.

Close inspection of the interpreted structure map (Fig.10) reveals that, the area is affected by four sets of deep-seated and near-surface structural lineaments oriented in NW-SE, E-W, N-S and NE-SW directions. The NW-SE (Red Sea) trend is more strongly developed than the other identified trends. It represents the prevailing tectonic trend in the area, and played an important role in the formation of its tectonic framework. It was noticed that this trend is greatly responsible for the formation of the major basin that trends in the same direction and occupies the western and southwestern parts of the area. Kamel and Elsirafe (1993) stated that the NW and N-S trends represent the prevalent directional orientations of the surface structural lineaments in north Nasser lake area.
Fig. 9. SPI solutions of the regional (a) and residual (b) magnetic component maps.
The E-W (Tethyan) and N-S (Nubian) trends come in the second priority as deep-seated and near-surface structures in the study area. These two trends have been proved from interpretation of gravity survey data (Abdelrahman et al., 1991) to be the deepest and oldest Precambrian tectonic trends in south Egypt. The E-W trend is represented by boundaries of uplifted and subsided blocks. The N-S trend is represented by strike slip faults affecting the central and eastern parts of the area and dislocating the E-W trending structures. This fault system is well identified in the area and extended for long distance northward controlling the primary extent of Nasser Lake and Nile valley in Upper Egypt. These tectonic trends have been shown to have a significant control on the distribution of seismic activity in the Aswan region. Most of the recorded earthquake activities in the western side of Nasser Lake are associated with the intersections of these two trends (El Shazly and Abdel Hady 1984, Kebeasy et al. 1987 and Kamel & Elsirafe 1993).

The NE trend is common in the interpreted near-surface structure in good agreement with the geologic map (Fig. 2). However, this trend is relatively scarce in the interpreted deep-seated structure.
Conclusions

Three analysis techniques were applied to airborne magnetic data to map the location and depth of the magnetic source edges as an aid to structural interpretation. These techniques are the Horizontal Gradient, The Euler Deconvolution and the local Wave number. The methods were applied to synthetic test model to demonstrate its efficiency and accuracy in mapping the source edges. The methods show similar efficiency in locating the vertical contacts. On the other hand, the SPI method shows superior accuracy over the other two methods in mapping the dipping contacts. The SPI method shows higher accuracy in the depth estimation than the Euler method especially in the deeper blocks.

These methods were then applied to the regional and residual components of the magnetic data of the study area. The HG method could map the deep-seated and near-surface magnetic structure of the study area. The Euler solutions provide tracing of linear segments and the depth to these features. These depths range from 1.5 km to 2.5 km for the deep-seated structures with general increase toward the west. Meanwhile, the depths estimated for the near-surface structures range from 300 to 1200m. The SPI method could map the linear structures in both magnetic components with higher resolutions. The depths estimated using SPI method show comparable values to the Euler results. The SPI method could delineate the axis of the major basement trough of the study area associated with the highest depth values. Integration of the results obtained from these methods facilitates mapping the interpreted basement tectonic map of the area. This map shows that the area is affected by sets of faults trending in NW-SE, E-W, N-S and NE-SW directions. Moreover, the area is dissected by a set of basement uplifts and troughs controlled mainly by the NW-SE faults.

References


تحليل وتفسير المعطيات المغناطيسية الجوية لمنطقة شرق بحيرة ناصر، أسوان، مصر

إسلام أحمد العوضي، وأحمد عاتير نجم، وممدوح محمد التراس ومحمود السيد ميرة

هيئة المواد النووية، ص. ب. 360 المعادي، القاهرة، مصر

المستخلص: تقع منطقة الدراسة إلى الجنوب الشرقي من مدينة أسوان وتحتل جزءاً من بحيرة ناصر في قسمها الغربي. تعتبر بحيرة ناصر مصدرًا لأنشطة الزلازل وعدم الاستقرار في منطقة أسوان. أغلب هذا النشاط سجل في الجانب الغربي للبحيرة، حيث يتطابق مع تقاطعات نظامين للصدوع الرئيسية باتجاهات شمالي – جنوب، و شرق - غرب. لذا، فإن تخريج التركيب تحت السطحية في منطقة الدراسة يمكن أن يسلط المزيد من الضوء على الوضع التركيبی لهذا الجزء من البحيرة وعلاقته بعدم الاستقرار التكتوني.

تُقدِّم هذه الدراسة التحليل وتفسير بيانات المسح المغناطيسی الجوى لرسم الإطار الگتربی تحت السطحی للمنطقة حول البحيرة. إن التفسير الگتربی للبيانات المغناطيسیة قد أُجزِر من خلال تطبيق تقنيات التفسير المتقدمة التي تمكننا من التحديد التفصیلى، ومقدِّر عمق الگتربی المغناطیسیة. تتضمن هذه التقنيات المشتقة الأفقیة معادلة تجانس أوبرلو والعدد الموجي الموضعي. لقد أدى التكامل بين تطبيق هذه التقنيات الثلاثة، إلى التوصول إلى مواقع وأبعاد الگتربی، لتحديد الإطار التكتوني للمنطقة. إن الگتربی التي تم تحديدها بالمنطقة أثبتت أنها متأثرة بمجموعة من الصدوع ذات
الاتجاهات الرئيسية شمال غرب - جنوب شرق، وشرق - غرب، وشمال شرق - جنوب غرب. علاوة على ذلك، فإن المنطقة غنية بمناطق الارتفاعات والانخفاضات في صخور الركيزة المعقدة التي يغلب عليها الصدوع ذات الاتجاه شمال غرب - جنوب شرق.