Magnetic Interpretations For The Subsurface Geologic Conditions Of Halaib Area, South Eastern Desert Of Egypt

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ABSTRACT

The present study dealt with the geophysical processing and interpretation of the available magnetic data in the area of study. The extensions of the existing sedimentary ridges and basins and their relations to the operating swells and ridges of the basement, as well as delineated the workable tectonic deformations of the considered area. Multi-discipline system of interpretations has been executed utilizing several methods, not only in the space domain, but also in the frequency domain. Filtering and emphasizing the near-surface (local) anomalies on the expense of the deep-seated (regional) ones were done, using five orders polynomial surfaces and their corresponding residuals, as well as the low-pass and high-pass filters through out the moving average operator. The effective features, and the causative sources, as well as their corresponding depths were delineated through the first and second derivatives of the field data and their related complex gradients. Also, the strike filtering technique was applied at specific directional trend and five kms to remove the geologic noises cutting across the implications of interest through the enhancement and suppression processes. Moreover, the magnetic field was upwarded and downwarded at consecutive levels to follow the geologic signatures at the five kms. Finally, integration was done for the results of the fore-mentioned techniques to delineate the structural features and tectonic inferences characterizing the concerned area.

Key words: Geophysical processing, interpretation, magnetic, sedimentary

Introduction

The area under study is located in the southern part of the Eastern Desert and lies between latitudes 22°00’ & 22°45’ N and longitudes 34°30’ & 36°45’ E (Fig.1). The area is of sedimentary terrain, ranging in age from Late Cretaceous to Early Eocene and has limited subsurface information, this is because of the shortage in drill holes and few geological and geophysical studies. Therefore, it is aimed in this work to identify the subsurface structures affecting the basement complex and the overlying sedimentary cover.

The interpretation of the available magnetic data can be successfully employed, not only in the search for magnetic bodies, but also in locating buried structures including faults, intrusions and uplifts, that are associated with oil and gas fields. In this respect, such interpretation process can be executed qualitatively and quantitatively, as well as manually and automatically, to follow the susceptibility distributions of the evaluated sequences and to delineate the tectonic deformational inferences accompanying the hydrocarbon occurrences and products.

Fig. 1: Location map of the study area

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Magnetic Data:

The Magnetic anomaly map (Fig. 2) and R.T.P magnetic anomaly map of the study area (Fig. 3) shows magnetic belts trending in three major directions: N-S (or NNE-SSW to NNW-SSE), NW-SE and E-W. However, the south central part of Halaib area is occupied by a magnetic low belt trending NNE-SSW, followed westwardly by a magnetic high belt orienting NNW-SSE, floored to the east by NW-SE belts of magnetic anomalies and to the west by E-W belts of magnetic anomalies. The high and low magnetic belts may reveal comparable basement swells and troughs, as well as sedimentary ridges and basins. Intensive magnetic gradients may border and dissect the operating magnetic belts, giving rise to comparable linear structural elements bounding and crossing the implied magnetic trends and their anomaly-like magnetic features.

Fig. 2: Magnetic anomaly map of the study area

Analysis Of Magnetic Data:

The magnetic data, as represented by the R.T.P magnetic anomaly map (Fig. 3), are interpreted showing that, the implied RTP anomalies become more representative for the actual geologic conditions prevailing in the basement complex and the related sedimentary sequence. Furthermore, the bounding magnetic gradients become more intensive and steeper, giving rise to more resolution for both the encountered lithologic and structural inferences. This is followed by the application of certain separation techniques to isolate the shallower components from the deeper ones. Several potential filters can be applied in space and frequency domains to distinguish between the wanted geologic features from the unwanted ones.

A pair of programs has been utilized for the filtering of magnetic data in the aforementioned domains (Cooper, 1997). Grav. Map and Pf proc. programs have been used to carry out the basic filtering operations on the available map data sets.

Grav. Map program takes data values from the scattered locations (magnetic stations), grids and contours to produce a map. This map may then be filtered using the polynomial surface fitting and downward continuation. PF proc program operates in a similar manner to the Grav. Map program, in which the filters that may be applied to the data are the moving average low and high pass filters, vertical derivatives and strike filtering (enhanced and suppressed).

1- Polynomial surface fitting:

The performance of the orthogonal polynomial technique of the filtration of regional and residual anomalies has been evaluated through its application on the available magnetic data. However, the advantage of the orthogonal over the non-orthogonal polynomials is their ability to estimate an optimum order of polynomial to represent the predominant regional trend in the data (Agarwall and Sivaji, 1992), then establishing the residual one. This can be attained through successive polynomial surfaces until reaching the fitted one. By this way, five polynomial trend surfaces fitted to the magnetic data are executed to belong to the most fitted regional order, as well as the comparable residual one. Three regional maps and the associating residual ones (first, third and fifth) are selected for representation in this work (Figs. 4, 5, 6, 7, 8 and 9). In this respect, the first order polynomial trend of regional and residual anomalies (Figs. 4 and 5) show primitive features, while those of the third order polynomial trend (Figs. 6 and 7) exhibit closer pattern, and those of the fifth order (Figs. 8 and 9) are more expressive for both the regional and local geologic (stratigraphic and structural) inferences.
Fig. 3: Total Intensity Magnetic Map Reduced To The Magnetic Pole (Geosoft, 1994)

Fig. 4: First-Order Polynomial Trend Surface Fitted To The R.T.P. DATA

Fig. 5: Residual Map of The First-Order Polynomial Trend Surface Fitted To The R.T.P. DATA.

Fig. 6: Third-Order Polynomial Trend Surface Fitted To The R.T.P. DATA.
Fig. 7: Residual Map of Theird-Order Polynomial Trend Surface To The R.T.P. DATA

Fig. 8: Fivth-Order Polynomial Trend Surface Fitted To The R.T.P. DATA

Fig. 9: Residual Map of the Fivth-Order Polynomial Trend Surface of The R.T.P. DATA.

2- Moving average low and high-pass filtering:

The moving average option replaces each grid point of the gridding map with its average of the eight neighboring grid cells as a low-pass filter. The resultant high-pass of the filtered map is merely the difference between the original R.T.P map and the low-pass filtered map. However, the produced low-pass filtered map (Fig. 10) reveals the predominant magnetic belts, that characterized the deep-seated basement rocks with their regional anomalies and the bordering magnetic gradients of the major structural deformations. The corresponding high-pass filtered map (Fig. 11) reflects the prevailing magnetic anomalies, that characterize of the shallow-seated sedimentary rocks with their local features and the bounding magnetic gradients, particularly at the central, southern, western and southeastern parts of the map area. The later residual anomalies represent the combined effect of lithologic effect represents the intra-basement lithologic contacts and supra-basement are those of the structural features as sewlls and troughs and structural (folding in the form of basement swells and troughs, and sedimentary anticlines and synclines, as well as faulting in the form of dip-slip and strike-slip faults) variations.
3- Vertical derivative operator:

The derivatives may delineate qualitatively the position of potential lineaments, where the lineament (fault, contact ... etc) lies at the maximum rate (gradient) of change of the anomalies. Furthermore, the second vertical derivative has a great value emphasizing the local components (residuals) of the field and is considered a sound tool for focusing the hidden bodies in the subsurface, particularly with increasing depth. The vertical derivatives can be regarded as a type of high-pass filters, that enhance the anomalies caused by small features, while suppressing the longer wavelength regional trends.

This technique is applied on the available R.T.P magnetic anomaly map through two depths in the subsurface, giving rise to the first and second vertical derivative maps (Figs. 12 and 13). The first vertical derivative map (Fig. 12) clears the local anomalies occurred in the shallow section, subdivides some other anomalies and outlines the gradients surrounding both. The second vertical derivative map (Fig.13) bifurcates the residual anomalies into smaller ones, intensifies the gradients bounding them through certain preferred orientations reflecting the operating structural deformations and clarifies the lithologic heterogeneities at depth.
4- Strike filtering technique:

This type of filtering can be used to selectively suppress anomalies, that having preferred azimuthal orientation and enhances the anomalies of another trend. This is often useful to remove geological noises, such as dyke anomalies cutting across a feature of directional filter, that tends to exaggerate and enhance trends in some chosen directions. In this respect, trends and alignments, that are discovered in the data set by the use of such filters must be verified by referring back to the original data set (Dobrin, 1988). The filter direction must be defined from the north with severity levels at consecutive depths in the subsurface.

Accordingly, the angle 60° clockwise from the north is taken as a filter direction and three severity levels (1, 3 and 5 kms) are selected for the application of this filter in both enhancements for some anomalies and suppression for the others. By this way, the resulted enhanced strike filtering features laying at angle 60° clockwise from the north and at the three fore-mentioned severity levels (1, 3 and 5 kms) of the magnetic data were displayed in (Figs. 14, 15 and 16). In a comparable way of representation, the resulted suppressed strike filtering features laying at angle 60° clockwise from the north and at the three severity levels (1, 3 and 5 kms) of the magnetic data were illustrated in (Figs. 17, 18 and 19).

The effect of the enhanced strike filtering for the chosen angle and severity levels is represented in the forward attenuation of some spot-like anomalies and the suppression of the minor noising in the anomalies contour lines, giving rise to their smoothness, low reliefs and gentle gradients between them, consequently good indication about the regional configuration, as we go from Fig. (14) to Fig. (16). Also, the effect of the suppressed strike filtering for the same angle and severity levels is exhibited by analogous style, where it is normally suppressing the unwanted geologic noises from the significant local ones of shallower depth, as we go from Fig. (17) to Fig. (19) and as shown in the central, southern and western parts.

![Image](image.png)

**Fig. 13:** Second Vertical Derivative Map, As Derived From The R.T.P. DATA

![Image](image.png)

**Fig. 14:** Enhanced Strike Filtering Features Laying at angle 60 Clockwise From The North and at 1Km In R.T.P. DATA
Fig. 15: Enhanced Strike Filtering Features Laying at angle 60 Clockwise From The North and at 3Km In R.T.P. DATA

Fig. 16: Enhanced Strike Filtering Features Laying at angle 60 Clockwise From The North and at 5Km In R.T.P. DATA

Fig. 17: Suppressed Strike Filtering Features Laying at angle 300 Clockwise From The North and at 4Km In R.T.P. DATA
Fig. 18: Suppressed Strike Filtering Features Laying at angle 300 Clockwise From The North and at 3Km In R.T.P. DATA

Fig. 19: Suppressed Strike Filtering Features Laying at angle 300 Clockwise From The North and at 5Km In R.T.P. DATA

5-Vertical continuation Transform:

Upward continuation is the process of transforming potential-field especially magnetic data measured on one surface to some other higher surfaces. No assumptions are required about specific sources. Because the data are being “moved” away from sources, this procedure is generally stable mathematically. So, the upward continuation has the effect of something the data and attenuates the local anomalies. Downward continuation means, the transforming of data to some lower surfaces, is extremely unstable; however, because moving nearer the source amplifies the shorter wavelength information (including the noise). So, the downward continuation increases detail, but also makes the map more noisy, as well as emphasizes the local component and suppressed the regional one.

Upward-downward continuations orders:

It is generally a useful and physically meaningful filtering operation. It allows smoothing the field and eliminating the small anomalies in the form of noises from the near- surface objects. The upward continuation of the reduced to the pole data to an altitude above the measurements level will eliminate the effects of possible near- surface noises, that may result in misleading responses. In the same time, upward-continued maps to 2. 3 .4 and 5 kms. Figs.(19,20,21 and 22) reflect the general configuration of the main sources of the magnetic anomalies, which are mainly the surface of basement rocks. This will, definitely, reduce the resolution of the magnetic anomalies.

Downward continuation highlights the high frequency content of a gridded magnetic data set, just as if the data had been acquired at a lower survey height.
Theoretically, the field can also be continued downwards until the continuation level does not cross any field sources. However, it has been proved that, this operation is unstable because it greatly magnifies the existing noises and makes the field unusable.

To deal with this problem; some relaxation (regularization) techniques can be used. In the current study, that can be done through the use of Tikhnonov regularization parameter.

The Tikhonov regularization parameter $\beta$ (Tikhonov and Arsenin, 1977) is important in the optimization process. Kristofer and Yaoguo, (2007) explained that, in order to find the optimal data misfit, a Tikhonov's parameter, $\beta$, is chosen based on the optimal model weighting. The regularization parameter is chosen, so the optimal solution is neither over- smoothing nor under-smoothing the data (i.e. fitting the noises or the signals). Several values for this parameter were tried to find the best for the data under study.

This parameter was chosen such that the resulted data using the selected parameter's value show some sort of similarity (in its overall representation) to the pattern of the original data to be downwardly-continued.

The reduced-to-pole data are subjected to the downward continuation, with Tikhonov regularization parameter of $10^{-4}$, to transform the studied data to be as taken at lower levels.

Downward continued data to a relatively shallow depth will emphasize the residual components (of shallower sources) making the map noisier.

The downward continuation of the magnetic data transforms the available data to some lower surfaces extremely unstable with depth in the subsurface. This is because their moving nearer the source amplifies the shorter wavelength information. Such a condition is attained when reaching the basement complex, in which afterward the magnetic field became oscillating, giving rise to lower values compared to the steadily increasing magnetic values through the sedimentary section and before getting the basement surface.

In the present study, the magnetic data are downwarded to 1, 2, 3, 4 and 5 kms (Figs. 20, 21, 22, 23 and 24). However, the downward continued magnetic map at level 2 kms (Fig. 21) reflects a similarity in the distribution of the produced anomalies (lithologic belts) and the intervening gradients (structural discontinuities). When we move from level 3 kms downwardly to level 5 kms, through level 4 kms, the magnetic contours became more crowded and the magnetic gradients became more intensive at some parts, as well as complexed, more condensed and noisy magnetic anomalies, with their inherited magnetic gradients at the other parts. Also, the Red sea coast is stretching from long. 35° 30' at the upper boundary of the map to long. 37° 00' at the lower boundary of the map, subdivides the studied area into two parts, northeastern with noisy contours and southwestern with steady contours this reflects shallower basement complex (thinner sedimentary section) for the northeastern part and deeper basement (thicker sedimentary section) for the southwestern part. Moreover, the east-west and northwest-southeast trends of the magnetic anomalies, belts and gradients that characterize the shallower levels (2 and 3 kms) are replaced by the north northeast-south southwest and north northwest- south southwest trends of the anomalies, belts and gradients, that characterize the deeper levels (4 and 5 kms).

![Fig. 20: Downward Continued R.T.P. Map at Level 1Km](image-url)
Fig. 21: Downward Continued R.T.P. Map at Level 2Km

Fig. 22: Downward Continued R.T.P. Map at Level 3Km

Fig. 23: Downward Continued R.T.P. Map at Level 4Km
In the same time, upward-continued maps to 1, 3, and 5 kms. Figs.(25, 26 and 27) reflect the general configuration of the main sources of the magnetic anomalies, which are mainly the surface of basement rocks. This will, definitely, reduce the resolution of the magnetic anomalies.
6- Sun Shading Enhancement:

Another technique for enhancing the directional features of maps. It considers the map (RTP for total intensity) as if they are 3D topographic surface. Then calculating the lengths of the shadows, that would be cast by sun, when occupied a specific elevation and azimuth. In the present study, sun shading enhancement applied for RTP magnetic data at 20 elevation from the horizon and directions 90°, 180° and 270° clockwise from the north as represented in (Figs. 28, 29 and 30).

Structural-Tectonic Interpretation:

The integrated interpretation of the fore-mentioned processed and transformed magnetic data, through the polynomial surface fitting, moving average filtering, vertical derivatives, strike filtering and downward continuation approaches structural-wise, is revealed in Fig.(31).
The structures are diversified into folds (swells and troughs capping the basement complex, as well as basins and ridges implicating the overlying sedimentary section) and faults (dip-slip faults, strike-slip faults and diagonal-slip faults). Also, some of them are majors in scale, while the others are minors. Moreover, they are of varying depths and directions, intersecting with each other, and forming blocks of varying polarities and directions of movements.

By this way, the south central part of the study area is characterized by a NNE-SSW graben and a NNW-SSE horst intervened by diagonal-slip faults of right-lateral and left-lateral movements, which are continued to the NNW-SSE blocks. Eastward and westward of these meridional blocks to a zone of ENE-WSW and WNW-ESE grabens and horsts truncated also by strike-slip faults of varying trends. Northward, northeastward and northwestward of the later zone, there are numerous elongated blocks (horsts, grabens and step-like features) of NW-SE and NE-SW trends. However, the older NNE-SSW and NNW-SSE blocks are crossed by the NE-SW blocks, that are further complicated by the NW-SE blocks, that finally interrupted by the younger E-W (ENE-WSW and WNW-ESE) blocks.

Accordingly, the complexity of structural regime of the fault system, that bound the encountered fold system, reflects a comparable diversity of the operating tectonic deformations with time. As shown by Abu El-Ata(1988), the NNE-SSW and NNW-SSE faults are of Precambrian and Paleozoic times, while the NE-SW faults are of Mesozoic time, the NW-SE faults are of Tertiary time, and the E-W (ENE-WSW and WNW-ESE)
faults are of Quaternary time. The crossing relationships of these structural-tectonic elements emphasize the 
fore-mentioned deductions of their timing, trend-wise. Rejuvenation of the older features through the younger 
elements are synchronous to the Red sea rifting and tectonics.

Summary And Conclusions:

The present work is devoted to study the configurations of the existing sedimentary ridges and basins, as 
well as the related swells and troughs of the basement complex. In addition, to give a reasonable picture about 
both of shallow and deep seated structures which is the main target of magnetic interpretation that intervening 
their rocks. The magnetic data were subjected to several transformations and enhancement operations, in order 
to be in more interpretable forms for the needed targets. Moreover, the resulted data have been contoured and 
interpreted in terms of geological features.

Fig. 31: Structural tectonic map of The study area.

The available magnetic anomaly map is first resolved into its regional and residual maps through the five-
order polynomial surface fitting, and the low-pass and high-pass filtering using the moving average operator. 
Also, the shorter wavelengths of local nature are enhanced, the anomalies caused by small features are focused 
and the longer wavelengths of regional trends are suppressed through the two-order vertical derivatives. Added, 
the geological noises created from the dyke anomalies cutting across the features of interest have been removed 
utilizing the strike filtering transform, through enhancement and suppression. Moreover, these magnetic data are 
upwarded and downwarded to five kms, to follow the prominent geologic elements through the sedimentary 
section down to the basement complex.

Besides, the major and minor structural deformations dissecting the sedimentary section and the related 
basement complex are delineated, based on the integrated interpretations of the fore-mentioned maps of the 
various enhancement and transformation techniques. These structural elements are diversified into NNE-SSW 
graben and NNW-SSE horst belts, interveled by ENE-WSW and WNW-ESE grabens and horsts. Also, NW-SE 
and NE-SW horsts, grabens and step-like features are complicated the other fault trends. These fault trends are 
bordering the comparable fold features of positive and negative polarities characterizing both the sedimentary 
section and the underlying basement complex. The initiative tectonics standing behind the synthesis of these 
structures are established too.

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