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Implementation of Magnetic Technique to Delineate the Subsurface Tectonic Trends of Wadi Barqa Surrounding Area, Southeast of Sinai Peninsula, Egypt

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Abstract: *A detailed total intensity aeromagnetic survey was carried out in Wadi barqa, Southeastern of Sinai, Egypt; the magnetic data were corrected for the diurnal variations and reduced to the northern magnetic pole. The reduced to the magnetic pole map was qualitatively interpreted first through the magnetic separation by the 9-points Hanning filter into its regional and residual anomalies and second through the magnetic filtering in frequency domain into its low-pass and high-pass magnetic anomalies. The oldest tectonic trends seem to be rejuvenated and related to the opening of the Red Sea and the two gulfs. Furthermore, the reduced to the pole map was quantitatively interpreted first through the determination of the apparent magnetic intensity of the basement rocks, and through the basement depth determination by both the two-dimensional modeling and Euler deconvolution techniques. The basement relief map, according to either the step faults model or dikes and sills model reveals that the structural trend analyses have been applied for the shallow structural elements deduced from the observed and residual land magnetic data. The results of 2-D magnetic interpretation revealed that the depth of basement was ranging from 150 m to 1250 m .The interpreted fault and/or contact systems are statistically analyzed and plotted in the structure trends map. This map showed the major sets of trends, which are; (i) The NNW to SSE trends (Red Sea-Gulf of Suez trend) representing the most prevailing faulting direction in the studied area as the first order, and (ii) The NE to SW trend (Aqab trend) this trend is significance in the residual anomaly trend, (iii) The ENE-WSW trend (Aualitic) is the third order trend.*

Keywords: *Structural trend Map; Wadi Barqa; Southeast of Sinai; Egypt.*

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I. Introduction

Lately, the south of Sinai is facing a rise in population as well as extreme tourism for the glorious monasteries, the spectacular topographical landscape and the special geological and biological climate. The Magnetic data field of study is located in southeast of Sinai between two latitudes 27^{o} $45^{//}$ and 29^{o} and two longitudes 33^{o} $45^{//}$ and 34^{o} $45^{//}$ (Fig. 1)**.** In general, integrated geophysical tool, aeromagnetic technique is used to determine subsurface structures, basement depth, and sedimentary cover thickness. Many other authors used integrated geophysical tools in the southeastern region of Sinai.

The usage of magnetic their geophysical study on the southeastern part of Sinai Peninsula has been done by [1] to illustrate the structural trends and the sedimentary cover overlaying the basement using magnetic data analysis. A geophysical study on the southeastern and central parts of Sinai has been carried out by many researcher such as [2] using magnetic and geoelectric methods. This research demonstrated an incorporated geophysical study to approximate the depth of the basement complex and the geologic subsurface structures. The main objectives of this research are to define the regional structure and tectonic system of the study area by using magnetic as a potential field data, by defining the depths and patterns of the basement and its surface structures.

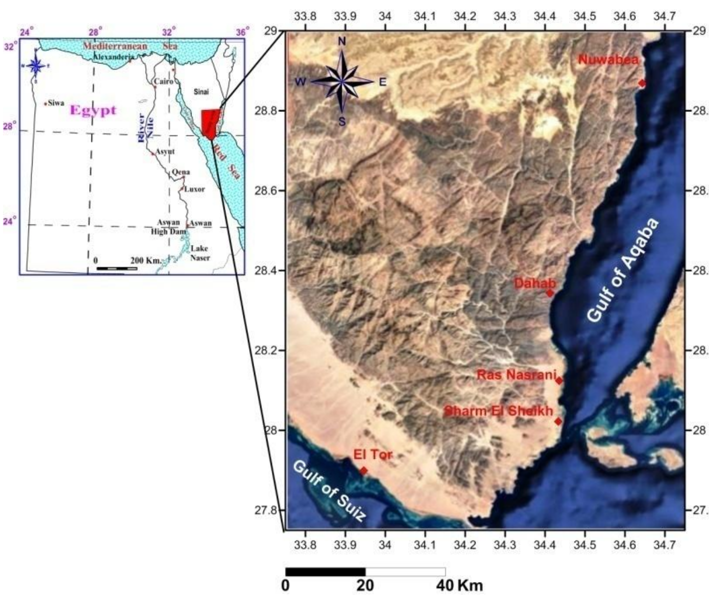

Figure (1): Location map of the study area.

II. Geological Settings

Sinai is placed at the center of the African, Arab and Anatolian plates [3], [4], and [5]. It contains a subset of the Levant and Eastern Mediterranean [6] and [7]. The middle of the peninsula consists of sub-horizontal deposits of Mesozoic and Tertiary which form the shield of thin sediments. The southeastern portion of Sinai is inhabited by igneous and metamorphic pre-Cambrian rocks that comprise the northern tip of the Arabian-Nubian Shield [8] (Fig. 2a). The surface of the shield dips softly towards the north with overlying sediments, ranging from Cambrian to Recent age. They thicken towards the north [9].

These land-forms are classified in the Gulf of Aqaba area into seven geo-morphological units [10]. These land-forms are categorized into seven geo-morphological units in the Gulf of Aqaba as the following: (1) Basement mountains, (2) Tableland (El Egma–ElTih), (3) Dissected hilly area, (4) Inland (alluvial hammadah) plains,(5) Coastal plains, (6) Alluvial fans (deltas), (7) Hydrographic basins (Fig. 2b).

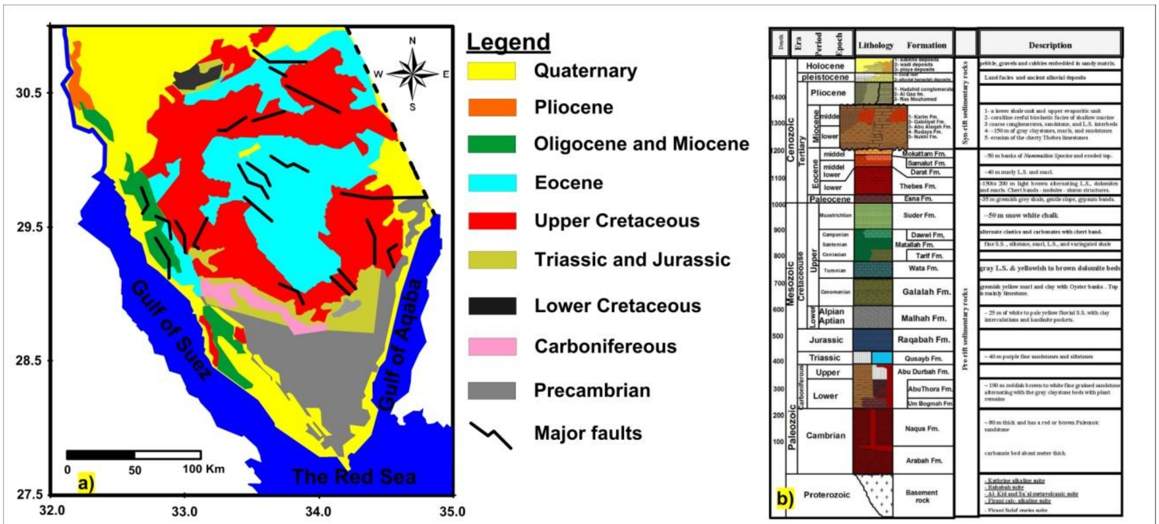

Figure (2): a) Geology map of the study area (after [11]), **b)** Stratigraphic column of southern Sinai and its description, Egypt (after [11]).

The tectonic floor of Barqa is dominated by the rocks in the basement, while the sedimentary rocks dominate its central part. Sedimentary rocks contain Cambrian-age Arabah Sandstone and Galalah formation of Cenomanian age, while the wadi base consists of the latest deposits. The Rift of the Red Sea is subdivided into two branches which demarcate southern Sinai. First branch is the Suez Gulf, which has the same pattern as the initial red sea rift (N30 W). Second branch is the Gulf of Aqaba rift (N30 E to N-S) which reflects the southern portion of the Dead Sea rift (1100 km long) that stretches along Aqaba, Dead Sea and Jordan Valley and Taurus

Mountain Chain [12]. Two key factors, which profoundly affect the geological environment and ultimately the hydrogeological conditions in the region, govern the structural setting of the Gulf of Aqaba. The Tertiary Magmatism (dykes) and the faulting mechanism are these cases. In the region of Barqa there are three main tectonic patterns, namely Aqaba (NE-SW), Clysmic (NW-SE) and Syrian arc (W-E) [13].

III. Methodology

In this study, the geophysical techniques was carried out in the field of study, including aeromagnetic data prepared and collected by [11] as aeromagnetic map to assess the subsurface structures in the region under analysis.

The magnetic technique has been one of the geophysical methods used often to explore the Earth's subsurface. It can be extended to a wide range of sub-surface discovery challenges from horizontal magnetic differences from the base of Earth's crust to the upper part meters of surface. This differences create irregularities in the standard magnetic field on Earth which are traced using the magnetic method [14]. The magnetic examination depends on changes in the earth's magnetic field, which are extracted from horizontal variations in subsurface magnetization [14].

IV. Potential field data interpretation

1. The reduced to the north magnetic pole (RTP) map

According to the total intensity aeromagnetic map (Fig. 3a) and the RTP aeromagnetic map (Fig. 3b), these map show a collection of negative and positive magnetic anomalies as well as linear sharp gradients representing the shallow and or near surface structural features affecting this. These anomalies have different shapes, polarities and reliefs. The general magnetic trends patterns of this field are NNW-SSE, NE-SW, and E-W. The middle and west parts of the studied area is characterized by relatively low magnetic anomalies with short wave length magnetic of positive values closures, it is representing shallow basement and/or basic nature in the composition of the underlying basement. On the other hand, low magnetic relief reflecting relatively deeper basement characterizes in these parts. In the northeastern part, two small sized low anomalies of circular shape are noticed and interpreted to be small basic intrusions having low polarization. Another low magnetic anomaly appears in the western part. The high anomalies appear in the south and southwestern parts of the study area, these relatively high anomalies reflect shallower basements with intrusion as mountains [15], [16] and [17].

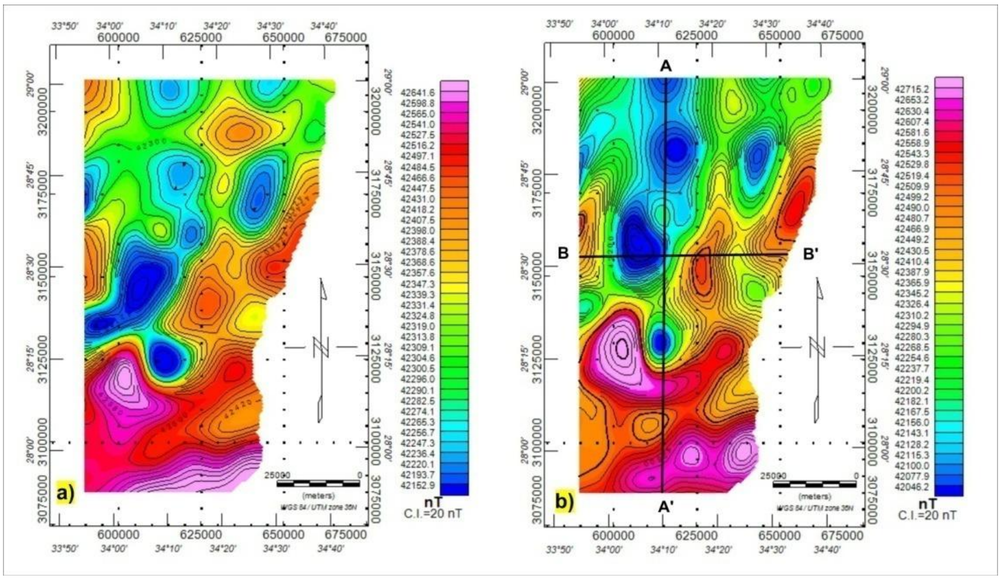

Figure (3): a) Total Magnetic Intensity map of the study area, **b)** RTP magnetic map of the study area.

2. Radially Averaged Power Spectrum Technique

The radially averaged power spectrum technique is used to determine the depths of the surface layers, the intricate basement and the geological formations below. Many researchers, such as [18], [19], [20] and [21] clarified the technique of spectral analysis. It depends on the spectral analysis map and its device conjugate using the Fourier Transform to evaluate the magnetic data. It is a wavelength function, both in the X and Y directions. In the current study, to measure the energy continuum, we used the Fast Fourier transformation (FFT) on both RTP aeromagnetic data. The technique of 2-D radially distributed power spectrum was applied to calculate the average depth range of the magnetic source in the field tested. In our study, using magnetic data, such methodology was implemented [22]. The radially power spectrum diagrams obtained show the average mean depth ranges to the shallow and deep depth segments existing in the field of study. Figure (4) reveals that the average depth of the deeper source is about 1250 m and the shallow one is about 150 m. The implementation of this technique provides a detailed picture for the depth of the digitized magnetic data in two dimensions.

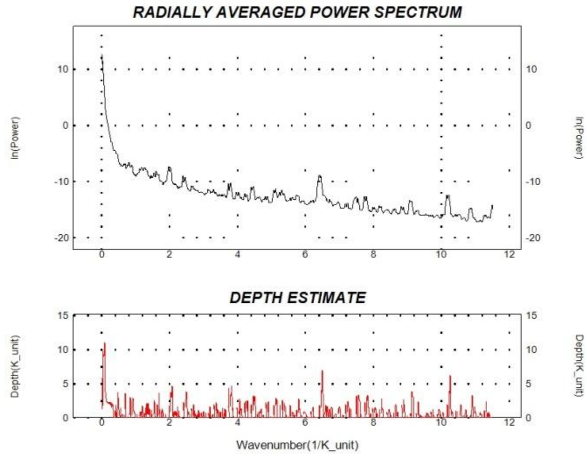

Figure (4): Radially Power Spectrum diagram along RTP magnetic map.

3. Filtering techniques

The key purpose of the filtering techniques is to isolate the differences between various wavelengths. The shallow sources anomalies, especially the local ones, lead to anomalies of short wavelengths or high frequencies. Although, these anomalies localized deep-source anomalies lead to long wavelengths or low frequencies.

The 2-D filtering on the RTP aeromagnetic maps was done in the current analysis; map the lineation bases on dislocations in the basement rocks or structural faults at different depths. In this analysis, the filtering technique is carried out by using the frequency spectrum from 0.015 cycle / unit to 0.0275 cycle / unit data.

Filtered Map with an effective cutoff wavelength of 0.015 cycle / unit shows the low pass technique (Fig. 5a). The magnetic field rises with the influential patterns in the northeast and southwest is NE-SW and NW-SE. The RTP magnetic map also shows the influential structure patterns in the low pass filtered map. This represents the tectonic character of these faults and sub-surface systems that range from shallow depths and even from considerable heights. The high pass filtering implemented to the observed field map with efficient 0.015 cycle / unit cutoff wavelength points to a short wavelength location and high frequency like magnetic anomalies (Fig.5b). These maps are interpreted as residual components situated in southeastern and southwestern locations in the studied area.

On the other hand, the dominant patterns of magnetic map are NE-SW and NW-SE is also present on the highly filtered map, suggesting that the predominant tendencies are faulting. RTP map extended to deeper depths in the subsurface of the sample area. In addition, the sporadic patterns of small-scale anomalies indicate that various stresses of the modern tectonics have dissected the shallow subsurface portion, which should not have influenced it.

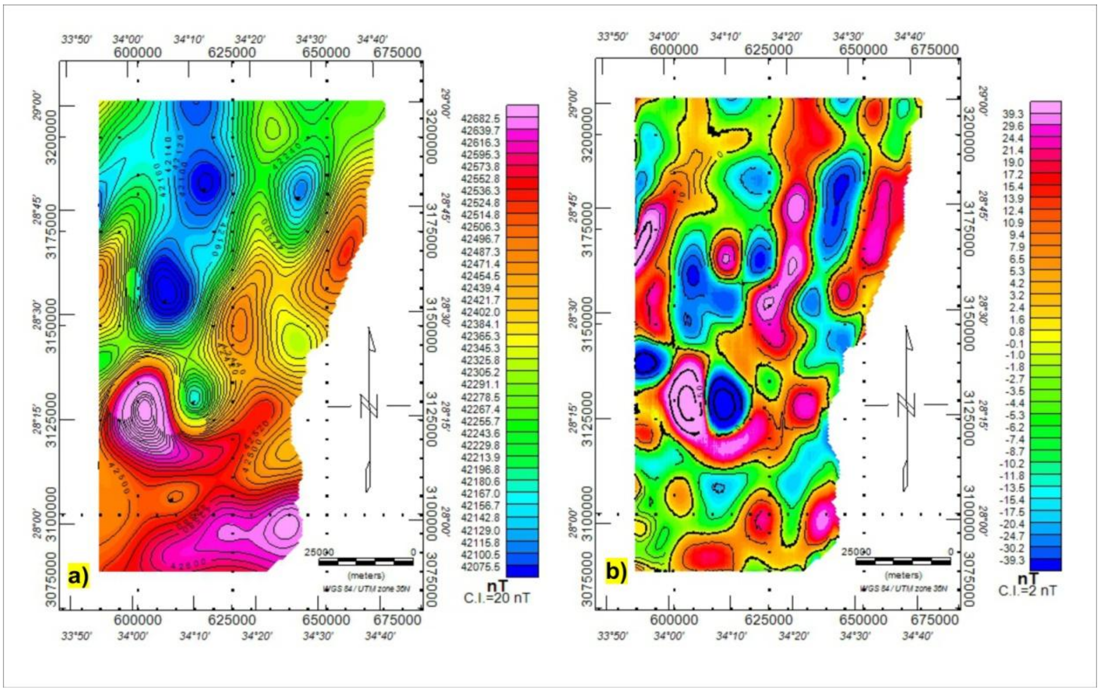

Figure (5): a) The regional magnetic anomaly map, **b)** The Residual magnetic anomaly map (as average values using radially averaged power spectrum technique).

4. Depth estimation

4.1. Euler deconvolution

The Euler deconvolution method was first proposed for fourier domain data on the profile data by [23] and later advanced by [24]. For certain linear subsurface features such as (dikes, sills, cliffs lineaments and geological contacts), The Euler deconvolution technique enables the determination of positions and depths. Thus, details about the form and function of the complaint investigation of subsurface bodies that can be obtained by specifying the structural index is necessary [25]. In addition, the structural index can even be described as the field change rate, based on the geometry of the source. In this study, the technique of 2-D Euler deconvolution was applied to both magnetic field data to detect the positions and depth values of the various lineaments and faults in the study site.

The magnetic map solution obtained for Euler deconvolution is seen in (Fig. 6). The Euler methods are extended to the field analyzed using the RTP magnetic map in assistance of [22]. The structural index added to the RTP map in the present analysis is 0, 1, 2, and 3 to pick the best solution. SI= 0, SI= 1, SI= 2, and SI= 3 by using RTP magnetic map. The structural index SI = 0 provides decent responses than the structural index 1, 2, and 3 since the data are clustered at certain locations in the research region not spread as SI= 1, SI= 2 and SI= 3 in the sector.

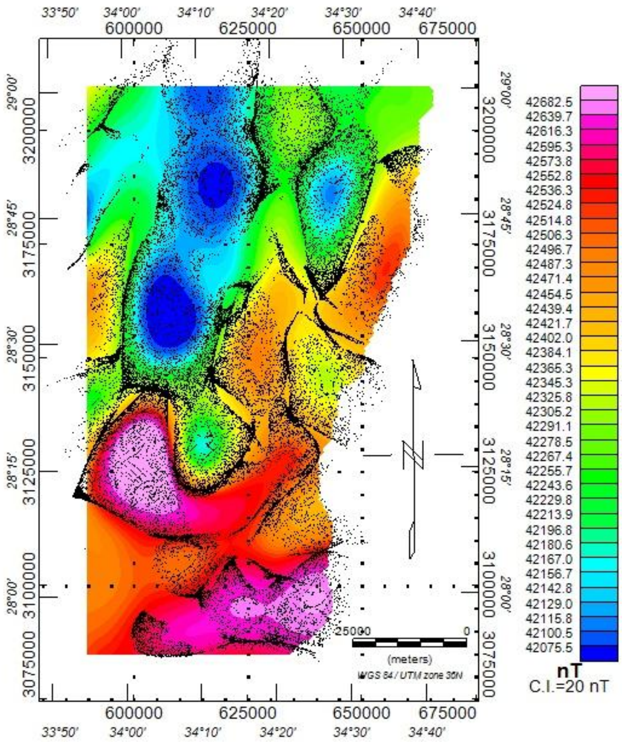

Figure (6): Euler Deconvolution magnetic map of the study area.

Clearly, the depth values of the fault structures or interaction structures derived from both Euler deconvolution of magnetic data in the study region varying from a minimum depth of less than 150 m to a maximum depth of more than 1250 m. The subsurface trend lines and fault systems are directed in various directions, such as NNW-SSE, NE-SW and E-W, taking the patterns of the Suez Gulf, the Aqaba Gulf and the Syrian arc folding system as well as the Mediterranean offshore coastal region.

4.2. Two Dimensions Magnetic Modeling

In the study area, by applying the magnetic data, the two-dimensional magnetic modeling was done by applying more than ten iterations to reach the fit between the measured magnetic data, which was calculated with an error rate of less than 0.5 percent (Fig. 7a and b). The two main parts of the final two-dimensional magnetic modeling are shown that the topographic surface appears and the upper crust or the depth to the surface of the base rocks.

1. The depth reaching the topographic surface ranges from 150 m in the northern parts to 1250 m in the central and southwestern regions of the study area, which indicates high topographical characteristics.

2. The surface of the upper crust (depth to the basement rocks) appears as a result of the depth analysis of the study area, which indicates that the depth of the shallow basement surface is located in the northeastern and western parts and decreases in the central areas of the study area and may reach about 2.5 km below sea level. While the depths of the deep basement surface were concentrated in the southern parts, the southeastern and western corners, as well as the northeastern parts of the study area, by a proportion of 3 km.

Using the previous interpreted results, it can be concluded that the thickness of the sedimentary cover ranges between 2.5 km in the northeast, western and central parts, while it ranges to 3 km in the southeastern and southwestern corners. In general, the thickness of the lower layers appears to increase towards the southern part of the study area.

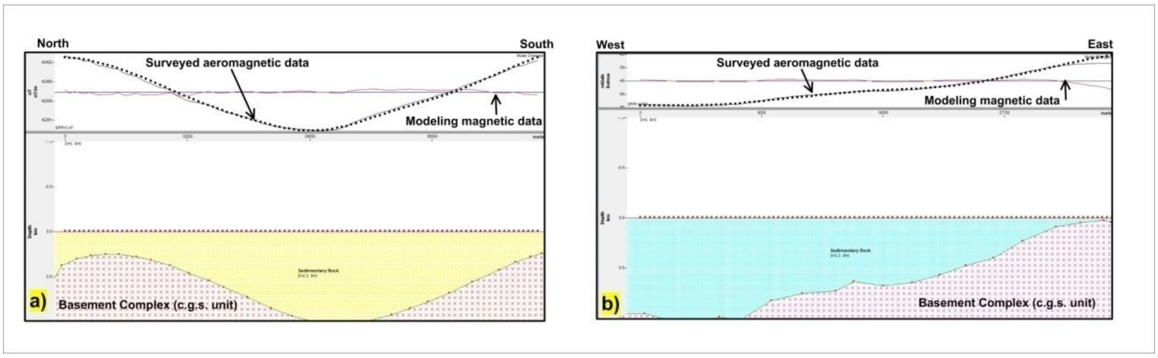

Figure (7): 2-D magnetic model along **a)** profile A-A' and **b)** profile B-B'.

V. Structural analysis

By applying [26] method, the RTP aeromagnetic map and filtered magnetic anomaly maps were used to evaluate the general structural trends in the studied region (Figs. 3b, 5b, and 6). [26] claimed that identifying structural patterns by observing magnetic contour lineage constitutes the most valuable geological techniques of magnetic survey. In certain cases the lineation represents the strike lines of extended disruptive structures or broad fault surfaces mirrored in the topography of the basement. These characteristics are covered beneath sedimentary deposits, and only exist on magnetic charts.

The structural derived maps reflect the region that dissects the fault zone. For their length percentage L point, the deducted fault planes of the various directions are clustered around the north every 10 and described by Rose diagram. From all magnetic maps and filtered magnetic anomaly maps, the findings of the fault system are depicted in the form of a rose diagram as seen in figure (8).

The findings show that, according to its features, most of the prevalent directions are N 45 E, this first trend is the most prominent in the region under investigation allowing a mean strike of N 45 E. This trend is closely linked to observations derived from both map of Total magnetic Intensity and RTP magnetic. The second prevailing trend is N 45 W linked to structural trend in the Suez Gulf. The third prevailing trend is the factor of N 15 E referring to the River-Nile system. The least prevalent is the E-W trend pertaining to tectonics in the Mediterranean. It can be seen that the region was primarily influenced by the Gulf of Aqaba, or even the tectonics of the Gulf of Suez and the Syrian Arc.

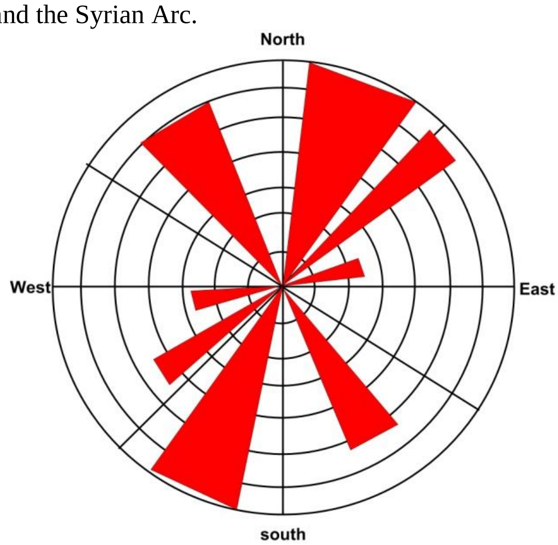

Figure (8): Rose Diagram shows the main trends in the study area.

VI. Discussion

This research aims at determining the systemic aspect that influenced the field of analysis. Interpretation of magnetic data is used to assess the subsurface structures and to describe the depth of the basement rocks. The trends of inferred fault components from the RTP and filtered magnetic maps are combined with the Euler deconvolution findings. The interpretations of the magnetic data show that the Euler depth solutions are rising towards the middle and northeast regions of the study area (Fig. 9). The central and northeastern areas show high depths, the magnetic analysis findings using Euler solutions suggest that the basement depth varies from 150 m to 1250 m (Fig. 10).

There is a strong steadiness between the magnetic 2-D findings and modeling simulation. The 2-D magnetic modeling findings indicate strong compatibility between observed and measured data. The 2-D magnetic simulation result even shows the location of the various layers.

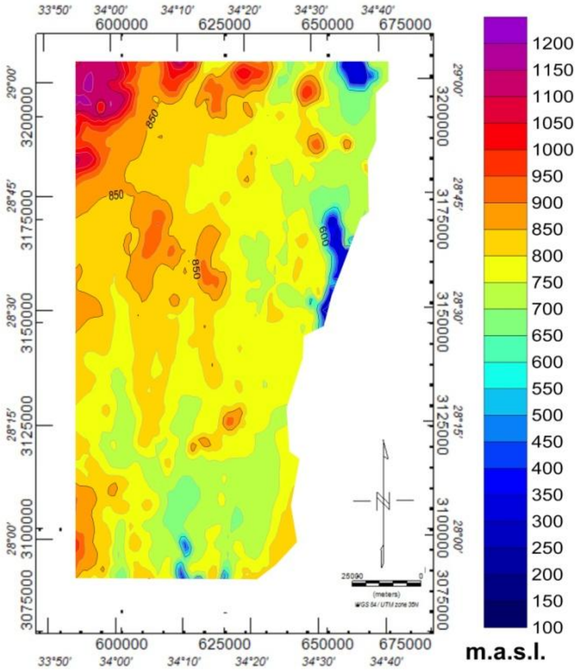

Figure (9): Basement relief of the study area.

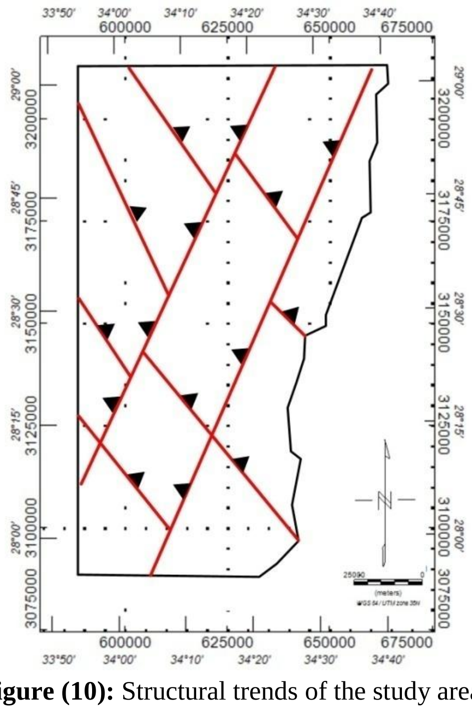

Figure (10): Structural trends of the study area.

VII. Conclusions

The purpose of this paper is to estimate the tectonic structure of the subsurface, and to experiment the relief of the basement and its tectonics in the region under study. In this study, the most relevant results obtained are:

- ❖ From the RTP aeromagnetic anomaly map of the region under study, the southern, northwestern and northeastern parts have a dense sedimentary cover and an immense depth of the rocks.
- ❖ Depth of the basement rocks in the area under study is ranging from 150 m to 1250 m.

❖ The Euler deconvolution technique has been also useful for the grided magnetic data to calculate approximately the basement depth in addition to its structural trends. The obtained Euler anomalies depths range from <150 m to >1250 m.

❖ The intrinsic and analyzed structural elements that examined the study area are directed in three key directions, for instance NE-SW, NW-SE and E-W. It is noticeable that the study area was clearly and mainly affected by the directions of the structures in the Gulf of Aqaba, as well as in the Gulf of Suez, and also by the tectonics of the Syrian arc.

❖ In the end, it can be said that the results obtained from the study and interpretation of geophysical measurement can contribute to the understanding of the topography of the base, tectonic and sub-surface structural settings in the southeastern Sinai region.

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