ANALYSIS

11(25), March 1, 2014

ISSN 2278–5469 EISSN 2278–5450

Discovery

Fault blocks of Abu Darag Basin, Northern Gulf of Suez, Egypt, as deduced from potential field data interpretation

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Publication History
Received: 04 January 2014
Accepted: 08 February 2014
Published: 1 March 2014

Citation
Ahmad A Azab, Ahmed A El-Khafeef. Fault blocks of Abu Darag Basin, Northern Gulf of Suez, Egypt, as deduced from potential field data interpretation. *Discovery*, 2014, 11(25), 9-19

ABSTRACT

Herein, an integrated approaches to image the main fault blocks and related structures that characterize "AbuDarag Basin" at the extreme northern part of the Gulf of Suez. The potential field data were analyzed qualitatively and quantitatively for identifying and locating the gravity and magnetic lineaments including faults and/or contacts. The Bouguer and RTP aeromagnetic anomalies were implemented and emphasized using different techniques, concerning anomaly resolution, fault locations and trend analysis. As well, the interpreted structure was supported and refined by constructing 2.5-Dgravity/magnetic joint models, invented and guided by available drilled wells. All outcomes were incorporated to construct a structural map for the basement surface. The structural elements map illustrates that the basement relief is dominated by low and high tectonic features of NW orientation, with some significant structural discontinuity to the NE. The conjugate NW and NE faults divided the basin floor into a number of basement blocks of different tilts. These two main fault systems control the internal structure and impose the blocks orientation to the main structural axis of the gulf. Joint models indicate very complex rift geometry inserted in a fairly heterogeneous basement rocks. The basement surface is highly affected by the gulf-trending and cross-gulf normal faults, forming a number of swells and troughs. They reveal many tilted fault blocks of SW regional dip regime with thickening the sedimentary section towards the west and south. The complexity reaches maximum at the western borders where the basement rocks are vertically offset by more than 3 km, along a major east-throwing bounding fault.

Keywords: Abu Darag, Gulf of Suez, Tilt derivative, Joint modeling, Horizontal Gradient

1. INTRODUCTION

The main exploration difficulty in and around the study area (Figure 1), as a part of Gulf of Suez, is the complexity of the basement structure and the overlying pre Miocene/Miocene rocks. In such areas, the traditional seismic interpretation is often uncertain because of the upper Miocene-Pliocene evaporitic sequence conceals the deep signals or masks the seismic energy. The multiple reflections from the evaporite layers makes tracing the tops of the basement and pre-Miocene horizons are rather difficult. Hence, the interpretation of potential field data for deep prospects has proven its efficiency. The gravity and magnetic data have been extensively used to reveal the internal basin geometry, based on the contrasts of density and magnetic susceptibility between the sedimentary rocks and their crystalline basement (Talwani et al., 1959; Blakelyet al., 1999; de Castro et al., 2007). In view of that, potential mapping on the basement surface was essential to understand the role of reactivated Precambrian structures and major geological units in the development of Abu Darag Basin. The present study depends on the Bouguer gravity and RTP aeromagnetic maps as a main source of data. The Bouguer gravity map was compiles by General Petroleum Company, (GPC) 1984, with scale 1:100000 and contour interval 1mGal. The RTP aeromagnetic map was prepared by Pan American Company, compiled by GUPCO, 1982 with scale1:100000 and contour interval 5 nT.

The objective of this study is in delineating and mapping the structural element on basement surface. The interpretation better defines deep prospects primarily major basement blocks and associated fault locations, trends, and depths at the extreme northern part of Gulf of Suez. To overcome these limitations, several interpretational techniques were carried out. Decomposition of the Bouguer and RTP anomalies was applied utilizing second vertical derivative (Rosenbach, 1953) to resolute the observed gravity and magnetic anomalies resulted from the upper crustal sources. The optimum filter was used to delineate the edges and minor structures that are not easily seen in the original image. Maximum enhancement of the anomalous features due to sources in part the basement complex was achieved by the application of tilt derivative methods. The calculation of the curvature and horizontal gradient techniquesaided in defining the location of linear features which in turn are related to the trend of the main faults in the area. Faults/contacts were traced easily along these linear features. All filtered maps worked together in harmony in order to highlight the most effective features and trends. Besides, statistical analyses were executed for the different gravity and magnetic filtered maps using the successive overlap technique. It was used to outline the main tectonic trends responsible for the prominent structure that characterized deep prospects. In addition, three2.5-D joint models were constructed through integration all above geophysical experiments and constrained by the available geologic information. The obtained results had been incorporated for constructing a structural elements map including fault blocks and associated fault patterns and trends on basement surface which not reached by seismic investigation.

2. GEOLOGIC SETTING

The Gulf of Suez is an area of subsidence within the northern part of Nubian-Arabian Shield. It was formed originally during Early Paleozoic time as a narrow embayment of the Tethys and intensively rejuvenated during the rifting phase of the great East African Rift System in Lower to Middle Tertiary time. Great accumulations of sediments (Paleozoic-Quaternary) from this fast subsiding depression, was interrupted at times by a general and regional uplift with subsequent erosion. As the subsurface geology and drill-hole information (Table 1), indicated that the study area is characterized by a thick sedimentary section unconformable overlying the basement crystalline rocks. The generalized stratigraphic section (Figure 2) of the Gulf of Suez (Khalil and Meshref, 1988) ranges in age from Precambrian basement complex to recent. It is classified into three successions including the pre-rift (Precambrian to Late Eocene), syn-rift (Miocene), and post-Miocene rocks. Commonly, the exploration of hydrocarbon reservoirs in northern gulf of Suez region has led to numerous geological and geophysical investigations (Robson, 1971; Hagras, 1976; Wasfi and Azazi, 1979; Kulke, 1982; Scotte and Govean, 1984; Abdel Gawad, 1970; Meshref et al. 1976; Bayoumi, 1983; Evans, 1988; Moustafa, 1992; El-Khadragy et al. 1999; Winn et al. 2001).

Table 1
Parameters of the Drilled wells in the study area

WELL	Lat	Long	TD (ft)	TD (Fm)	Status/Remarks
DARAG-1	29 21 56.000	32 41 07.900	10790	NUBIA	P & A
GS 78-1	29 22 50.100	32 36 44.100	7290	PALEOZOIC	P & A
NEBWI 81-1	29 24 01.600	32 45 59.700	10177	EOCENE	P & A
FINA Z80-1	29 25 22.300	32 37 24.900	12333	BASEMENT	P & A
GS 56-1	29 30 31.700	32 33 53.700	15526	EOCENE	P & A
RAD-1 "st2"	29 33 09.260	32 30 35.719	16344	Wata	Stuck
DARAG 23-1	29 37 16.000	32 40 01.000	6586	NUBIA	P & A
X 80-1	29 37 49.300	32 38 57.600	6200	JURASSIC	P & A
GS 24-1	29 41 28.200	32 33 21.700	9405	JURASSIC	P & A

DARAG 17-1A	29 43 16.900	32 35 53.300	7890	UPPER JURASSIC	P & A
W 78-1	29 44 28.800	32 25 58.400	9140	PALEOZOIC	P & A
N.DARAG-2	29 45 18.400	32 31 57.400	5250	JURASSIC	OIL PRODUCER MIOCENE NUKHUL DISCOVERY
N.DARAG-3	29 45 42.000	32 32 24.100	4849	JURASSIC	OIL PRODUCER MIOCENE NUKHUL DISCOVERY
N.DARAG-1	29 45 46.300	32 30 53.900	5799	JURASSIC	OIL PRODUCER MIOCENE NUKHUL DISCOVERY
GS-9	29 47 34.300	32 32 57.400	8302	BASEMENT	P & A
N.SUDR-3	29 39 38.500	32 42 38.300	4918	UPPER CRETACEOUS	P & A WITH OIL SHOWS IN THE MIOCENE

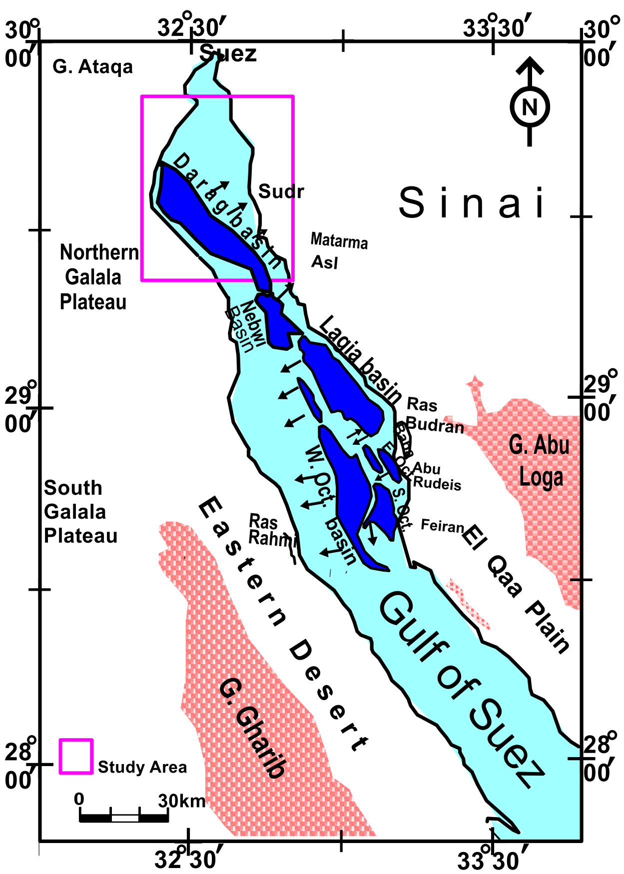

Figure 1

Location map of the study area

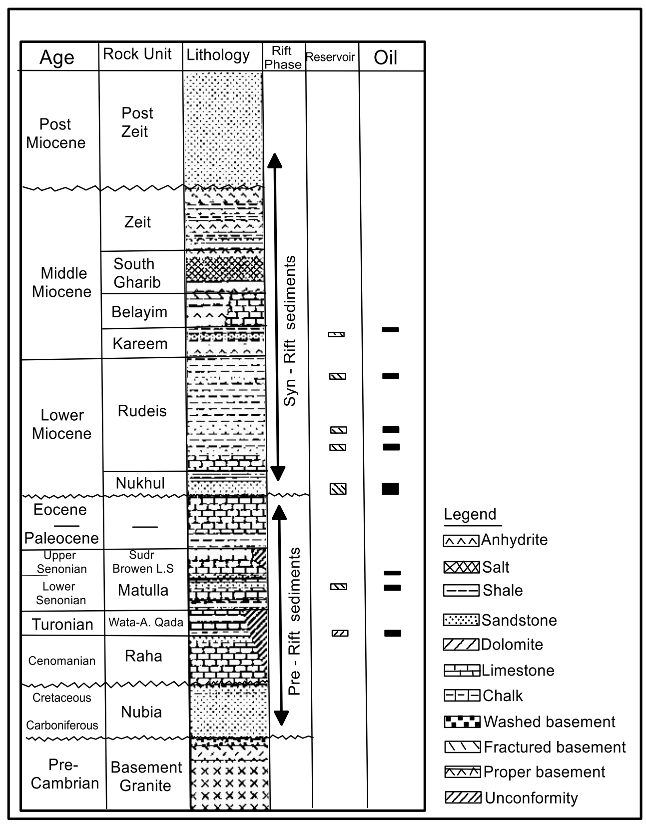

Figure 2

Generalized lithology of the rock units in the Gulg of Suez, Egypt (After Khalil and Meshref, 1988)

Structurally, Abu Darag basin considered as a deep NE-SW oriented asymmetric graben, consists of a number of SW down-faulted structural blocks. It is developed preferentially along pre-existing lines of weakness in the basement in response to geotectonic lateral movements (Nazih, 1988; Zahran and Meshref, 1988). The sedimentary section is overprinted by the NW trending sub-basins, cut by the NE trending normal faults. The western margin of this basin is marked by a major border fault zone which up throws the basement to about 2km forming the NorthGalala plateau. The significant thickening of the Nubia formation, observed on seismic and well logging data, provides an evidence for Paleozoic-Early Mesozoic initiation (may be Hercynian) of Darag basin (El-Gezeery et al., 2006). The major faults as well as the hydrocarbon accumulations in the northern gulf are mostly associated with the NE-SW trend or the NW-SE trend.

Tectonically, the subsequent plate movements provide an overall framework for understanding the evolution of the Gulf of Suez area (Vander Ploeg, 1953; Colletta et al. 1988 and hence the Abu Darag Basin). Mostafa (1992) divided the Gulf of Suez into three tectonic provinces according to the dip regime; separated by two hinge zones (Figure 3). The repeatedly reactivated basement trends modified the regional structure of the area, creating extensional and compressional tectonic cycles due to several continental plate collision phases. These cycles are separated by regional unconformity surfaces that represent orogenic breaks associated with tectonic erosion. The development of Darag basin is closely linked with major structural features in north Gulf of Suez including AyunMousa block, Araba block, N.Galala Plateau and Mokattam Block.

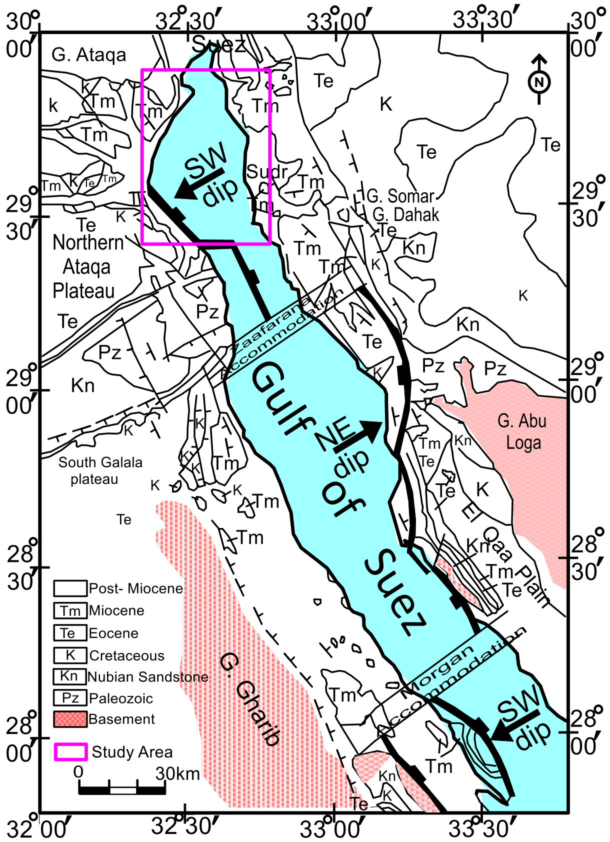

Figure 3

Three tectonic provinces of the Gulf of Suez (after Moustafa, 1992)

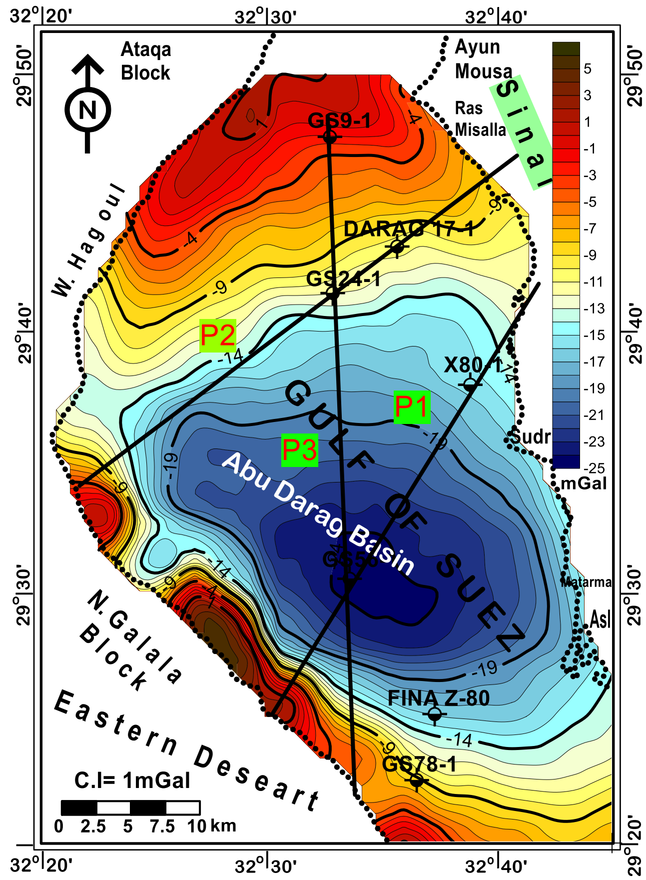

Fig. (4): Bouguer anomaly map of the study area (after, GUPCO, 1974)

3. THE AVAILABLE MATERIALS

3.1. Bouguer Gravity Map

Visual inspection of the Bouguer map (Figure 4) shows clearly that Abu Darag basin is distinguished by a regional gravity low occupies the offshore area of the Gulf of Suez. It is distinguished by a broad negative anomalous feature that strikes in the WNW direction. The anomaly's gradient decrease inward reaching about -30 mGal at GS56-1 well (~ 4733 m)and grade up outwards into positive values (>15 mGal). This asymmetrical shape dips steeply to the SW which may be the expression of the basement down fault forming the deep area from Ras Sudr in the east to Wadi Araba in the west. Generally, the gravity minimum is bounded by steep gravity gradients which are associated with shallow basement rocks. Westward, the synclinal are aside limited by a linear feature (zone of condensed contours) that marks an imperical fault of great throw separating the uplifted blocks (Galala Plateau) from the down faulted ones. The northern portion is also marked by a northeasterly trending belt and high relief. This in-complete gravity anomaly can be correlated with basement rocks of Ayun Mousa uplift.

3.2. RTP Aeromagnetic Map

The RTP map is generally characterized by a complex anomaly pattern over Abu Darag basin if compared with the Bouguer map. It comprises various northwest and northeast trending anomalies of varying frequencies and amplitudes. The broad and low frequency anomalies are resulting from relatively deeper and older structures, whereas high frequency local anomalies reflect shallow tectonic features on basement surface. Visually, the basin is bounded from west by a strong northwest linear anomaly patterns where the gradient of contours became intensive (>125 nT) along the borders of the gulf. This sharp magnetic gradient is well correlated with high gravity gradient that most probably terminates against a major fault zone (Figure 5). The northern part exhibits a high magnetic belt (>50 nT) presumably caused by near-surface basement rocks (depth of basement at GS-9 well is 2530m). This zone is delineated by a WNW steep gradient which may defines location of a major block fault. Alternatively, the southern portion is evidenced by a low magnetic trend where the negative value attains -180 nT at the southeast corner. Such rapid magnetic decrease is essentially attributed to low topography of Nebwei basin. To a great extent, the magnetic and gravity signatures of the study area show more or less good agreement.

4. DATA ENHANCEMENT

4.1. Second Vertical Derivative

In fact, most of low amplitudes either negative or positive anomalies in the study area had been masked by the strong regional effect and broad gravity/magnetic minimum of Gulf of Suez basin. It is preferable to remove the effects of such regional dip, to help emphasizing small-scale features that might be associated with small-scale faults and structures. Consequently, a number of SVD gravity and magnetic anomalies maps were produced to follow up the near surface anomalies at different depths. Rosenbach (1953) method was chosen to obtain best illustration and presentation. The calculated values of correlation coefficient (Table 2) between successive SVD maps of different radii were determined using Abdelrahman et al. (1988). The deduced coefficients indicate that the optimum level for separation in the area of study is represented by the fourth order surface (S=4 km) for the gravity data. Meanwhile, magnetic separation on basement surface is represented by radius S=3 km.

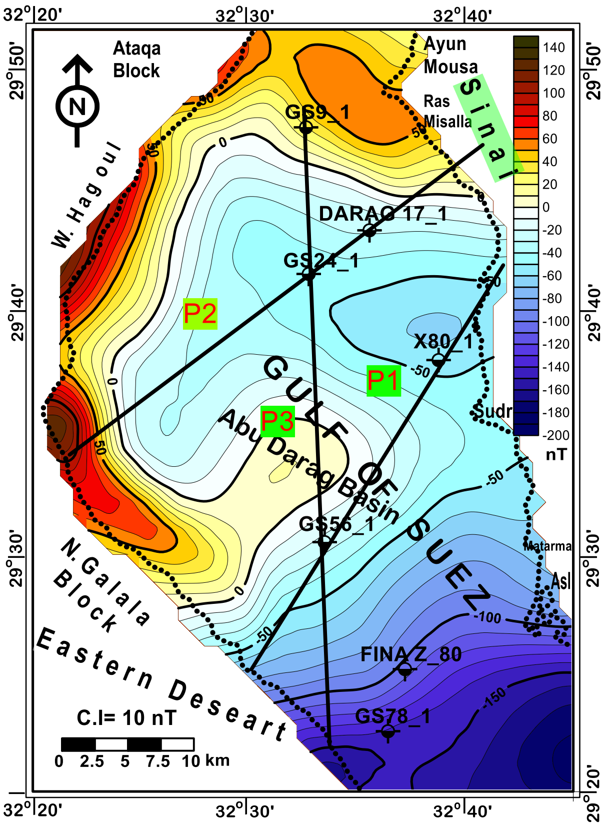

Fig. (5): RTP magetic map of the study area

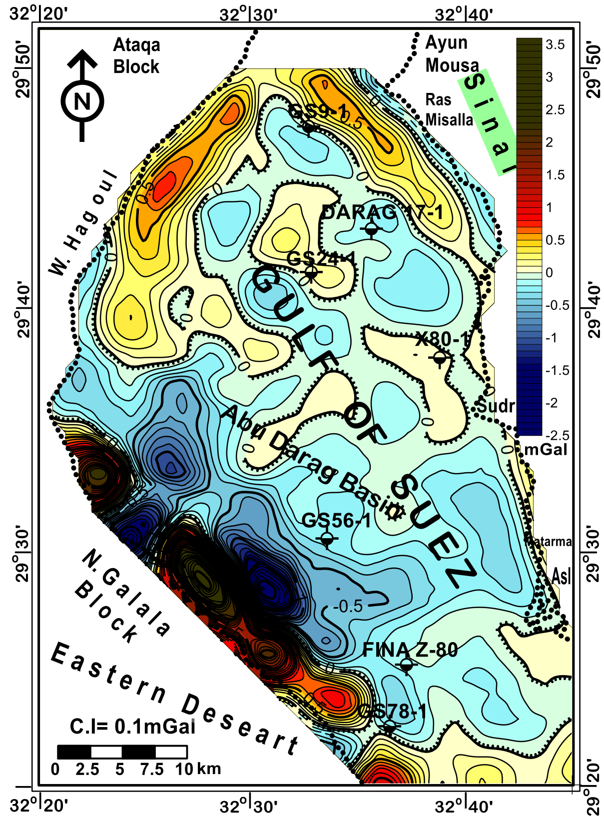

Fig. (6): SVD gravity map of the study area S=4km

Table 2

Correlation Coefficient results for residuals of Second Vertical Derivative

	r_{12}	r_{23}	r_{34}	r_{45}	r_{56}
Magnetic	0.704147	0.741301	0.**703045**	0.748168	0.681737
Gravity	0.685764	0.753204	0.787785	**0.946504**	0.755955

In contrast to the Bouguer anomalies which are totally negative across the offshore area, the SVD gravity map (Figure 6) contains positive values that could be interpreted as horst structures or ridges of crystalline basement. The axial trends of most anomalies are regularly aligned in the NE and NW directions, reflecting two different tectonic events. The boundaries of the basin are evidenced by high gradient and high frequency liner anomalies where faults could be interpreted at zones of zero lines (Rosenbach, 1954). The SVD map indicates a southwestern decrease in the gravity values where the sedimentary section thickens from Sudr toward Galala Platea u occurs.

Visual inspection of the SVD magnetic map (Figure 7) reveals several minima and maxima over Abu Darag basin. The negative anomalies were believed to be associated with the down faulted basement blocks, whereas positive anomalies seem to be linked with uplifted ones. The characteristic feature on the SVD magnetic map is the steep gradients which run more or less parallel to the shore lines. The linear anomalies, either negative or positive became, sharp and clear along borders of the rift, particularly the western side. The linear structures on both SVD gravity and magnetic maps in coordination with geologic information suggest presence of major fault zones, in parallel to the shoreline.

4.2. Curvature Method

Because of the SVD is non-unique and the sources in lower crust may produce wavelengths that may be still included in its residuals. A more elaborated technique such as curvature was helped. Curvature is a surface-derived attribute that is computed from the surface itself and is closely related to its second derivative. It has been used for analysis of seismic data (Roberts, 2001) and was also successfully tested on potential field data (Ottetal. 2002; Schmidt et al., 2003). The results are highly sensitive to the input data density and gridding method used. Dip curvature is a second derivative type of surface derived attribute. It is defined in the maximum dip direction as a measure of the rate of change of dip (Roberts, 2001). It is useful to improve detection of the linear features (elongated features like faults). It can be considered as one of the most important edge-detection filter. The directional derivative (Curvature) is a measure of the rate of change of the inclination angle of tangential planes on a profile line defined by the surface along a specified direction. Curvature is reported as the absolute value of the rate of change and is, therefore, a positive number. The directional curvature is the absolute value of the rate of change, in a specified direction, of the inclination angle of the tangent plane.

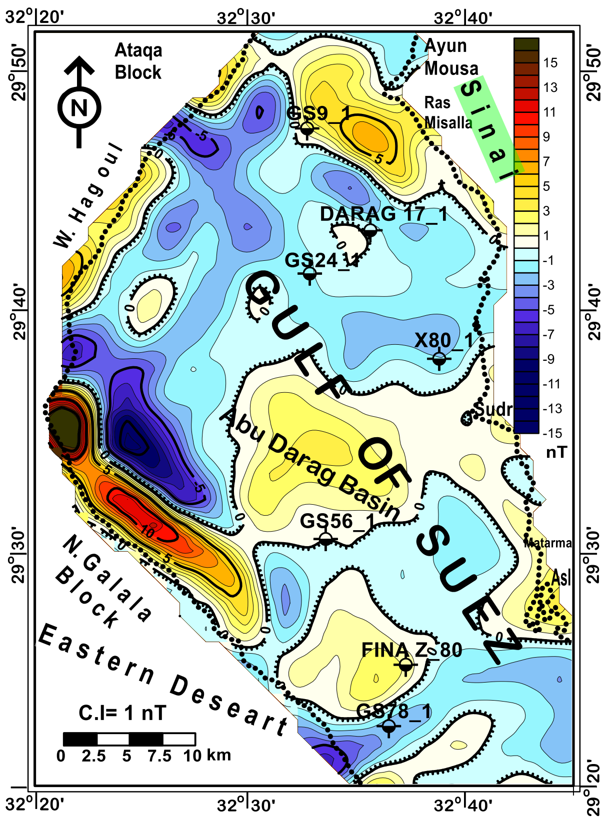

Fig. (7): SVD magnetic map of the study area S=3km

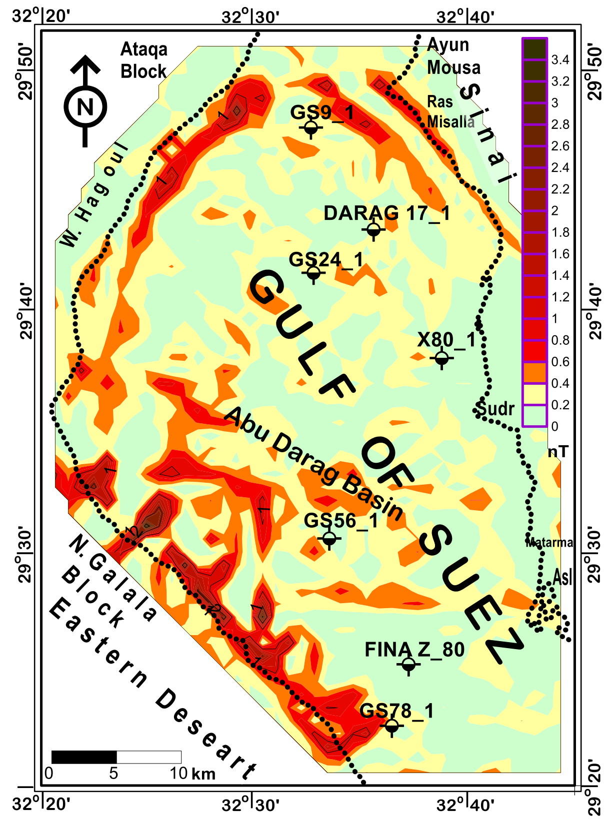

Fig. (8): Curvature map of Bouguer gravity data

The mathematical formula for the directional curvature of a surface f(x,y) in a direction defined by s is:

$$K_s = \frac{\frac{d^2f}{ds^2}}{\left[1+\left(\frac{df}{ds}\right)^2\right]^{3/2}} \qquad (1)$$

$$K_\propto = \frac{\left|\frac{d^2f}{dx^2}.\text{Cos}^2(\propto)+\frac{d^2f}{dxdy}.\text{Cos}(\propto)\text{Sin}(\propto)+\frac{d^2f}{dy^2}.\text{Sin}^2(\propto)\right|}{\left[1+\left(\frac{df}{dx}.\text{Cos}(\propto)+\frac{df}{dy}.\text{Sin}(\propto)\right)^2\right]^{\frac{3}{2}}} \qquad (2)$$

The obtained maxima and minima deduced from the gravity and magnetic curvature maps (Figures 8 and 9) displays two main trend patterns strike nearly in parallel and perpendicular to the Gulf of Suez rift. The linear features shown on Figures8 and 9indicate that the NW and NE trend patterns are the most prominent. The intersection of these two trend systems divided the area into a number of blocks in the northwestern and northeastern directions. The strong NW gravity/magnetic associations along marginal areas indicate that the basin was initially controlled by the Clysmic tectonics.

4.3. Horizontal Gradient Method

The horizontal gradient method is another pre-view method to outline the general framework of the offshore area "Abu Darag basin". It is considered as a simplest approach to estimate the contact locations. The greatest advantage of the horizontal gradient method is that, it is lease susceptible to noise in the data, because it is only requires the two first-order horizontal derivatives of the potential field (Phillips, 2000). Indeed, the superposition of the maxima determined buildings on various scales will make it possible to highlight the different contacts present on the horizontal gradient map. The method is robust for delineating both the shallow and deep sources, in comparison with the vertical method, which is useful only in identifying the shallower structures. The amplitude of the horizontal gradient is expressed as:

$$HG_g = \sqrt{\left(\frac{\partial g}{\partial x}\right)^2 + \left(\frac{\partial g}{\partial y}\right)^2} \qquad (3)$$

where: ($\partial g/\partial x$) and ($\partial g/\partial y$) are the horizontal derivatives of the gravity field in the x & y directions. Grauch and Cordell (1987) discussed the limitations of the horizontal gradient method from a position directly over the boundaries, if the boundaries are not near-vertical and close to each other.

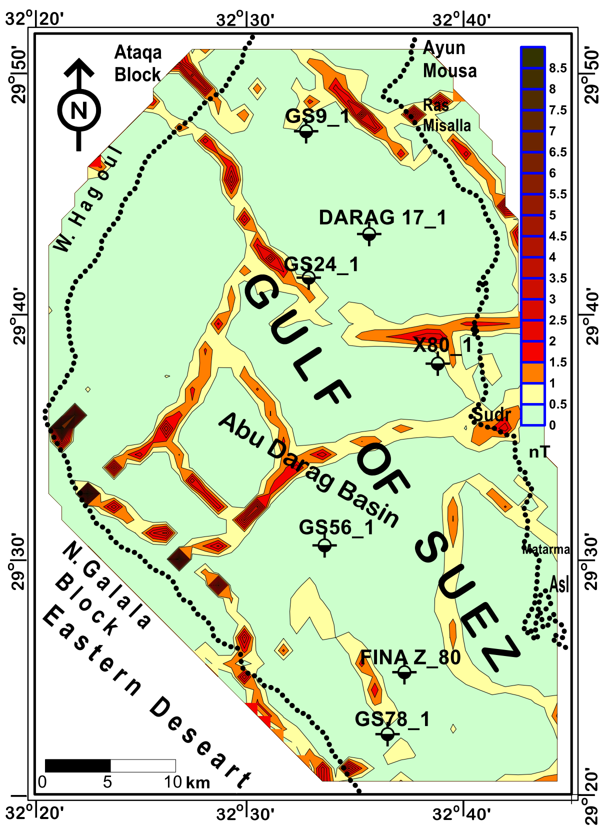

Fig. (9): Curvature map of RTP magetic data

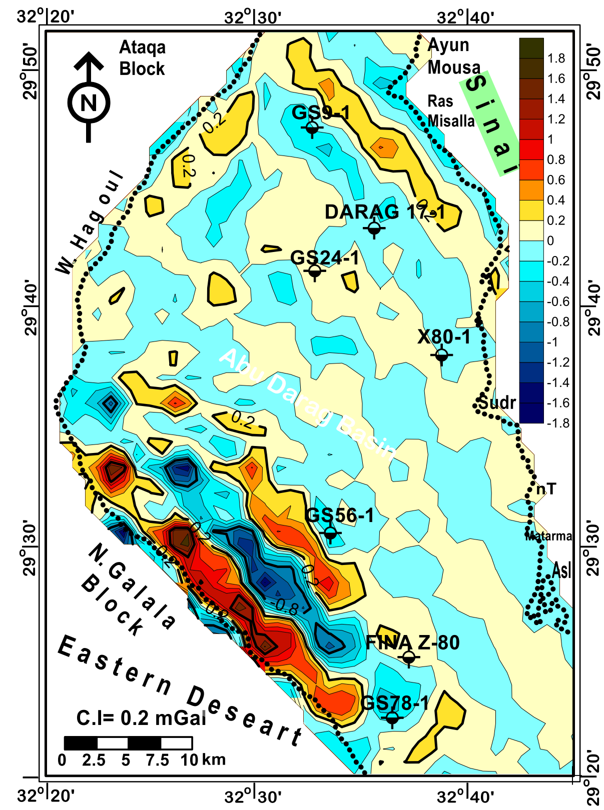

Fig. (10): Enhanced horizontal gradient of Bouguer gravity map

For the magnetic data, the same principle can be applied after transforming the data into a form, which is mathematically similar to the gravity data, called pseudo-gravity or on RTP magnetic data (Baranov, 1957). Local peaks (or ridges) in the magnitude of the horizontal gradient of pseudo-gravity give the locations of the steepest gradients, intuitively similar to taking the first derivative of a curve. A modification of the method, which isolates the horizontal-gradient associated with the short-wavelength anomalies (Grauch and Johnston, 2002), was applied to the gravity and pseudo-gravity data and or the RTP magnetic data.

Once the horizontal gradient maps are calculated, the data were upward continued analytically for the optimum depth interval 4km (separation filter). Then the difference between upward continued data and the original horizontal gradient is calculated. The output result is considered as enhancement horizontal gradient maps in which the linear anomalies could be observed clearly and the faults/contacts also could be traced along the edges of the anomalies.

Enhanced horizontal gradient maps for the gravity and RTP magnetic data were essentially used to indicate areas of considerable density/susceptibility contrast and consequently to visualize features such as faults and contacts which are depicted as lineaments. These filtered maps are characterized by pronounced pairs of alternated positive and negative values. They show a number of linear anomalies which are associated with tilted basement blocks. The gradients surrounding these rectangular features suggest boundaries and could be used to trace easily the faults/contacts that characterized the area (Figures 10 and 11). The zero line from east and west can be taken as the best location for Gulf of Suez trending faults on the basement surface. Meanwhile north and south boundaries could be denote locations of cross elements (cross-gulf trending faults). The lineaments as well as trends identify from a combination of gravity/magnetic images nearly have the same prediction of the edges of the sources. The direct correlation of these structural segments on both the magnetic and gravity maps is easily to determine. They may indicate that the NW down-faulted structural blocks of Abu Darag basin, were developed preferentially along pre-existing lines of weakness in the basement in response to the major geotectonic movements of the Gulf of Suez.

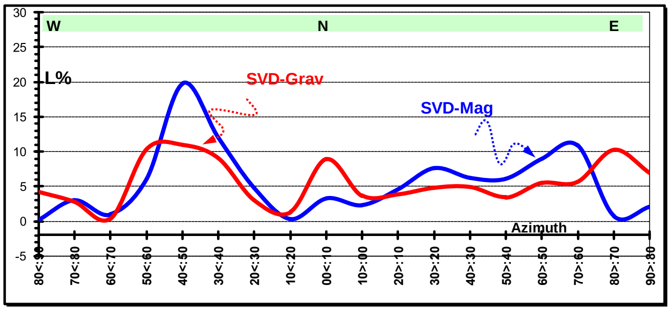

Fig.(12): Frequency distribution curves of the tectonic trends of SVD gravity and magnetic lineaments

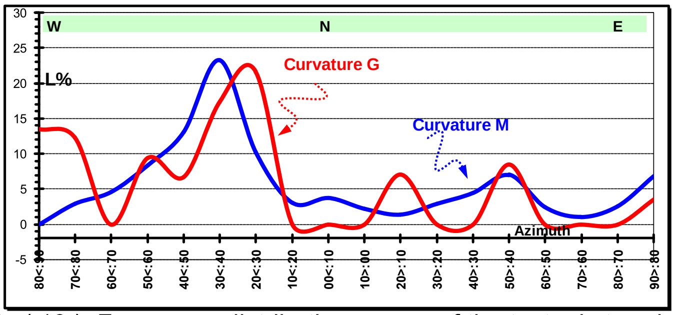

Fig.(13): Frequency distribution curves of the tectonic trends of gravity and magnetic curvature lineaments

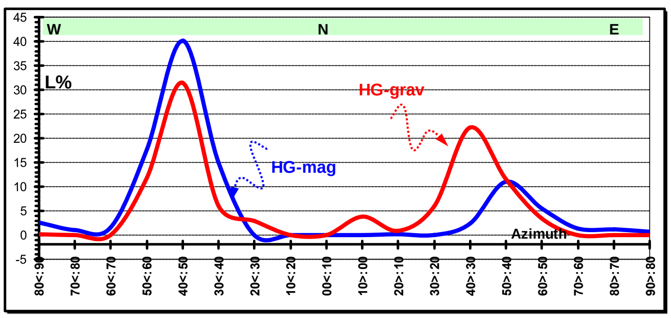

Fig.(14): Frequency distribution curves of the tectonic trends of horizontal gradient gravity and magnetic lineaments

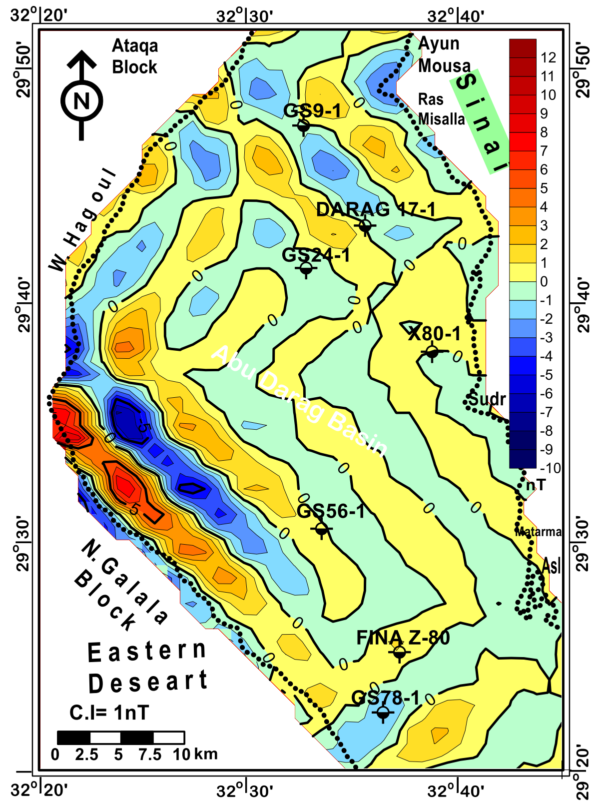

Fig. (11): Enhanced horizontal gradient of RTP magnetic map

4.4. Trend Analysis

The simple and standard method for portraying two dimensional trend patterns is to construct a frequency plot showing the number of elements lying in various direction ranges (Miller and Khan, 1962). The lengths and trends for each lineament detected on the different maps were measured clockwise from the north, regarding the map scale. The deduced faults/contacts for the different directions were grouped every 10° around the north for their length percentage (L%). These statistical calculations were applied on the SVD, curvature and horizontal gradient maps.

The results are presented as frequency curve. Accordingly, the trend analysis of the SVD gravity and RTP magnetic maps shows a relative strength of the NW-SE and NE-SW azimuth as represented by high magnitudes and lengths. The statistical peaks show that the key-structures are generally oriented in the NW and NE directions, while a small number is oriented in the ENE and E-W directions. As well as, the statistical analysis for the orientation of the Gulf of Suez trending and cross-faults was done as traced from the enhanced horizontal gravity and RTP magnetic maps. They reveal that the structure is dominated and highly influenced by the Gulf of Suez tectonic events (Figures 12 to 14).

Therefore, the Abu Darag basin is related to the Gulf of Suez-Red Sea rift tectonics and highly affected by northern Egypt wrench tectonics. They collectively show that the NW to WNW and NE to ENE tectonic trends are by the far the strongest and most widely observed trends in the study area. The first trend is an old Precambrian trend and can be considered as structural grains and old fabrics along which rejuvenations took place during the geologic times. The second trend is considered to be due to Syrian arc system, which uplifted the northern part of the Gulf of Suez since the Late Mesozoic times. These figures show that the Aqaba trend (north 15°–25°east), north–south and E–W direction is hardly found.

4.5. 2.5-D Forward Modeling

The 2.5dimensional modeling was performed using GM-sys, Geosoft, (2007) along three selected gravity-magnetic profiles. Potential field data over Abu Darag basin are reinterpreted primarily for attributing the causative source and to delineate the geometry of the structural framework. The system is based on an interactive forward modeling procedure, where the calculated gravity/magnetic effect of the modeled structures is compared to the observed ones. To match the observed and theoretical anomalies, as accurately as possible, it is found to break up the basement into a set of prisms or rectangular blocks whose contributions are calculated separately. Each separate polygon in the lower part is assigned a certain density and susceptibility value. A reasonable fit were obtained by modifying the configuration of the assumed bodies. It was stand on using as much geologic control from wells data, with special emphasis on the wells that reached basement or close to it. In the present models, we assumed the sedimentary formations as one layer with an average density of 2.38 g/c^3. However, the actual density of the subsurface is not as simple as we assumed. The density of the sediments is varied laterally and vertically, affecting the fitness of the modeled profiles.

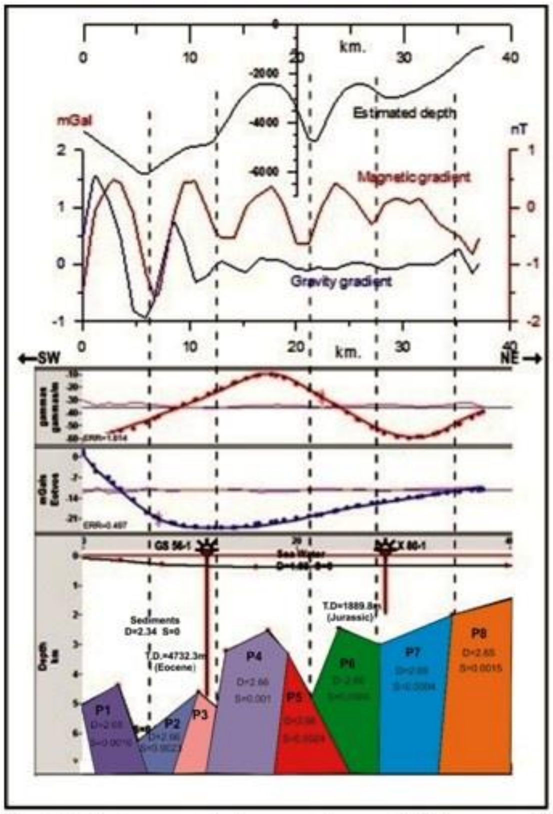

Fig.(15):Joint gravity/magnetic model along profile P1

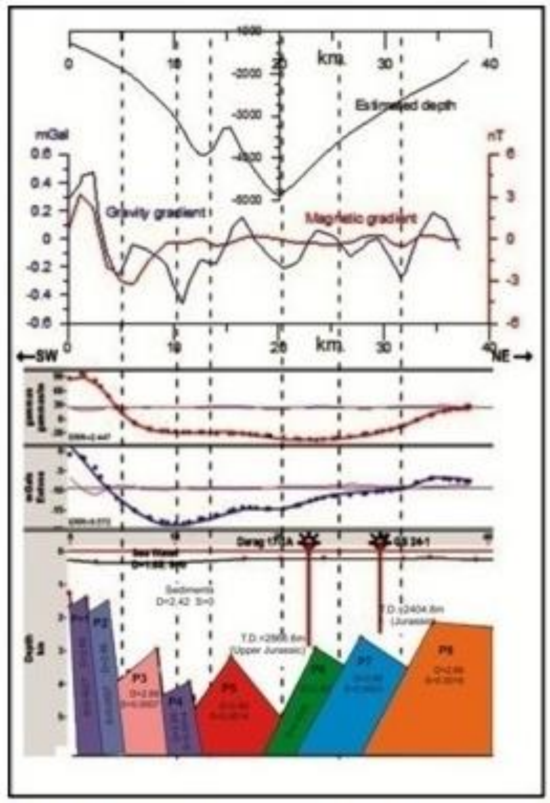

Fig.(16):Joint gravity/maqgnetic model along profile P2

Profile A-A' (Figure 15) was taken at right angle to the main trend of the Gulf of Suez. It cuts laterally across the major synclinal feature in the SW-NE direction from Ras Sudrin the east to Galala plateau at west. The profile extends more than 40km long passes through GS56-1 and X80-1 wells which control the geometry and physical parameters of the basement blocks. The model reveals that, the subsurface basement structure is complicated by several normal faults of different dips and throws forming local horsts and grabens. The model along this transect highlights the NW-SE trending faults of Gulf of Suez tectonics. It reveals that these fault systems significantly control the structure and to large extent the magnitude of anomalies. The central part seems to be uplifted where the basement blocks (p4 & p5) arelocallyshallower in depth than the surroundings, contributing the regional magnetic gradient.

Qualitatively, the model show good fitness between the observed and calculated gravity / magnetic anomalies. It was obtained by assuming eight polygons of different parameters and attitudes. The polygons distribution reveals that the basement relief is rough, and generally slopes westwards. Crests of these tilted blocks could be considered a good trap for the pre-rift or syn-rift oil migrations. Maximum depth to the basement at the western depression reaches 6100m (p3). The apparent susceptibility of the basement rocks ranges from 0.001 to 0.022 cgs, while the density ranges between 2.63 and 2.71 g/cc.

Profile B-B' (Figure 16) is oriented in the SW-NE direction and attains about forty kilometers in the northern part of the basin. The observed gravity and magnetic profiles exhibit broad minima underlain by a thick sedimentary cover (2.5 to 5.1 km). The lower part of the model indicates presence of a deep basin area lies between two uplifted belts on both sides of the gulf. The basement surface was break down by a number of normal faults that have different dips and throws forming a system of step-fault patterns. The profile reveals the strong effect of the NW trending faults of the Gulf of Suez in this direction. It displays a series of major downthrown-east faults along the western side and downthrown-west faults along eastern side of the gulf. The steepness of the gravity and magnetic gradients along edges confer the amount of great throw and dip of the faults. Commonly, the western boundary-faults seem to be of greater displacement resulting in a regional southwest dip regime for the tilted fault blocks. The western rift-bounding faults are of larger throws (>2.5km) and high angles as compared to the eastern ones. Generally, the upper part of this profile shows good fitting between the calculated and the observed curves.The narrow range of the density values (2.65-2.71 g/c3)and susceptibility (0.0003-0.002 cgs-unit) of the basement blocks are enough to explain the gravity/magnetic anomalies.

Profile C-C' (Figure 17) was taken vertically cutting across the study area from north to south and passing through three drilled wells (GS56-1, GS24-1, and GS9-1) that were used for constraining the model and crossing the profile A-A' at GS56-1 well and profile B-B' at

GS24-1 well. The model shows a low relief graben structure interposed with normal faults of different amount of dips and throws. It display a number of tilted fault blocks with a regional dip toward the south. Commonly, the model along this trend clarifies the NE-SW cross-gulf elements that resulted in discontinuity of the NW (Clysmic) trending elements. Thickening of the stratigraphic section has good correspondence with the gravity low in the upper part. Meanwhile, the uplifted basement blocks north of GS56-1 well are much signified by the observed magnetic anomaly. Qualitatively, the profile shows good fittings between the observed and calculated anomalies. The proposed polygons revealed that the Precambrian basement complex vary greatly in depth from north to south. The depth to the basement surface ranges between 2.5 and 3km in the north and exceeds southward to reach about 5.5 km south of GS56-1. The parameter sofblocks assumed normal susceptibility/density values along this transect with slight increase to the north.

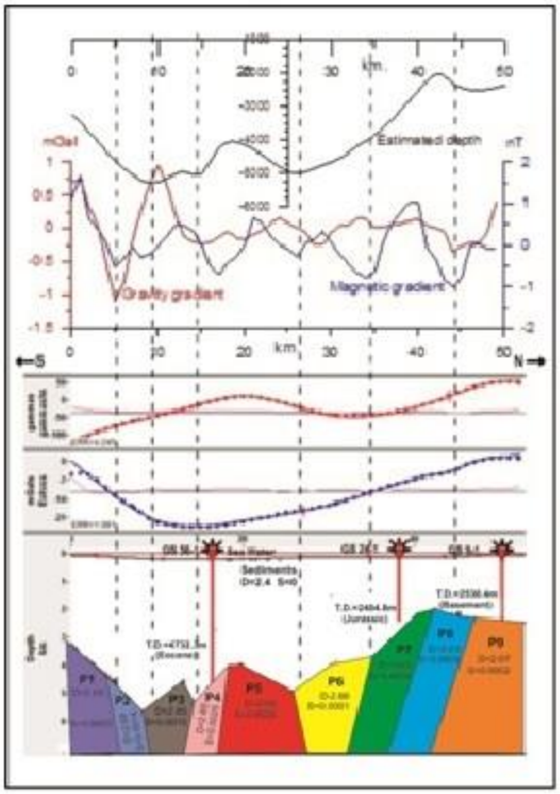

Fig.(17):Joint gravity/magnetic model along profile P3

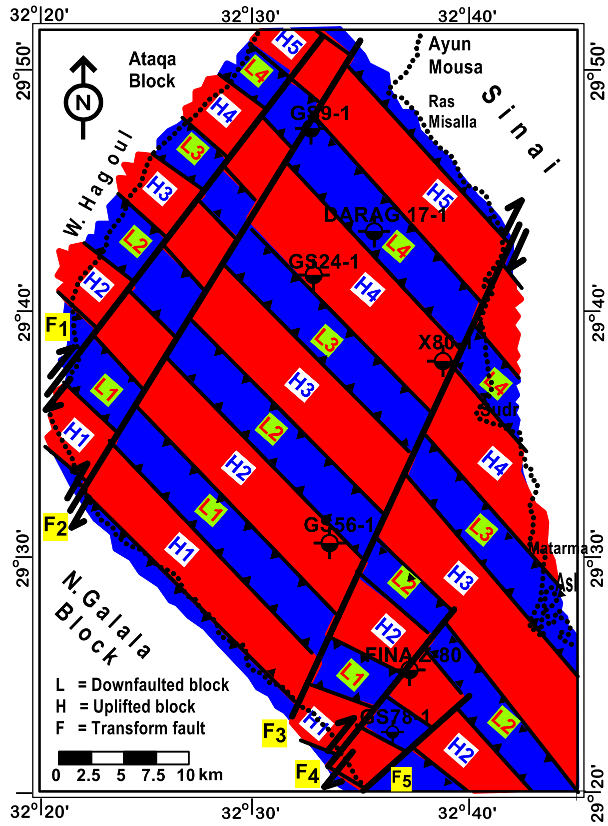

Fig. (18): Interpreted structural elements as deduced from tilt derivative filtered maps

4.6. Tentative Basement Structure Map

The interpreted tentative structure map (Figure 18) on basement surface of the study area was constructed through integrating all results obtained from the conduct experiment as well as geological knowledge. It illustrates the block faulting and approximates some of the structural details of the Precambrian basement rocks. These uplifted and down faulted blocks occur in alternated manner and were bounded from all sides by faults. The NW linear structures represent the major trend which be initiated with the Clysmic event of rifting. They were dissected into segments by cross faults trending approximately in the NE direction, bounding the structures from north and south.

The uplifted blocks of basement complex were labeled (H1 – H5) are alternated with down faulted blocks (L1 – L4). The trend of swells and troughs are oriented in the NW direction parallels to the Gulf of Suez trend. These block structures are principally formed by a number of longitudinal faults. The NW-SE trend has suffered by later and younger system of traverse faulting that cut across the gulf forming several numbers of northeasterly rising and sinking blocks. These two dominant trends represent the interaction between the compression and extensional tectonics.

The northern and southern parts show some discontinuities separating the NW linear structures. These discontinuities or offsets mark locations of transform faults (F1-F5) which represent planes of differential horizontal extension across the Gulf of Suez trend. The NE-SW transform faults represent fracture zones and considered to be right lateral displacement. The interpreted structures were constrained by available drilled wells and relevant works (Elgezeery et al., 2007).

5. CONCLUSION

In view of the foregoing results obtained from interpretation of the gravity and magnetic anomalies, the following items can be summarized: Structurally, the tentative structural elements map revealsthat the area is dominated by the northwesterly trending structures of uplifted and down faulted blocks that were bounded from all sides by faults. It reveals two main types of possible fault systems are controlling the tectonic subsidence of the Abu Darag Basin; the longitudinal NW–SE faults and the traverse NE-SW fault pattern. The most conspicuous of all is the major boundary faults bordering the basin, parallel to the shoreline. It also exhibits five transform faults cut across the Gulf of Suez trend structures. Modeled profiles provide a complex view of the geometry of the basement attitude. They show that the synclinal structure of Abu Darag is complicated by smaller structures in a form of tilted fault blocks. They reveal a regional southwest dip regime where the basement at the eastern side is shallower in depth (about 2.5km) than the western side (about 6.1 km). The models show relatively low susceptibility (0.0001 - 0.003 cgs) and normal density (2.63-2.7 g/c^3) for the basement blocks of the basin. Statistically, the Gulf of Suez and Syrian arc trends are the two main fracture systems that strongly affect the Precambrian basement of the study area. The Clysmic trend plays the most important role in the structure of the area, as well as the Syrian arc trend which cuts across the Gulf of Suez trend. Tectonically, in view of the rifting, the development of Abu Darag basin is closely linked with major structural features and tectonics of the Gulf of Suez. The repeatedly reactivated basement trends modified the regional structure of the basin. Concerning the hydrocarbon traps, it could be expect that oil and gas pools are locate towards the NE direction opposite to the regional dip, where it may be trapped in the NE corner of the up dip of tilted fault blocks. Also, it may also accumulate on the higher block sides or crests where cross-gulf faults cut off Clysmic faults.

REFERENCE

1. Abdel Gawad M**.** The Gulf of Suez, a brief review of Stratigraphy and structure. *Phil. Trans. Roy. Soc. Lond. A.,* 1970, 267, 23-40
2. Abdelrahman EM, El-Araby HM. Determination of optimum second derivative coefficient, set for various grid systems. E. G. S. Proc. of the 6th Ann. Meeting, 1988, 44-53
3. Bayoumi AI. Tectonic origin of the Gulf of Suez, Egypt, as deduced from gravity data CRC. Handbook of Geophysical Explor. USA, 1983, 417-432
4. Blakely RJ, Jachens RC, Calzia JP, Langenheim VE. Cenozoic Basins of the Death Valley Extended Terrane as Reflected in Regional-scale Gravity Anomalies. Geological Society of America, 1999, 333, 16
5. Colleta B, Le Qelle P, Letouzey I, Moretti LI. Longitudinal evaluation of the Suez rift structure. Egypt. T*ectonophysics*, 1988, 153, 221-233
6. El Gezeery R, Ghoneimi A, El Khadragy A, Saada S. Structures and tectonics of lower Miocene formations of the northern offshore part of gulf of Suez, as deduced from seismic reflection data. *J. appl. Geophys*., 2006, 5, 247-267
7. El Khadragy A, Hammouda H, Gabr A. Construction of the basement relief map of the western side of the Gulf of Suez, using aeromagnetic and gravity data.E.G.S., 17th annual meeting, 1999, 303-334
8. Evans A. Neogene tectonic and stratigraphic events in the Gulf of Suez rift, Egypt. *Techtonophysics*, 1988, 153, 235-247
9. Geosoft Program (Oasis Montaj), Geosoft Mapping and Application System, Inc, Suit 500, Richmond St. West Toronto, ON Canada N5SIV6, 2007
10. Götze HJ, Ebbing J, Hese F, Kollersberger T, Schmidt S, Rybakov M, Hassouneh M, Hrasha M, El-Kelani R. Gravity field analysis and 3D density modeling of the lithosphere along the Dead Sea Transform. *Eos Trans. AGU*, 2003, 83(47), Fall Meet. Suppl., Abstract S61A-1105
11. GPC. Bouguer Gravity map of Egypt. Ciro, ARE, 1984
12. Grauch VJS, Cordell, L. Short note, Limitation of determining density or magnetic boundaries from horizontal gradient of gravity o pseudo gravity data. *Geophysics*, 1987, 52, 118-121
13. Grauch VJS, Johnston CS. Gradient window method: A simple way to isolate regional from local horizontal gradients in potential-field gridded data: 72nd Annual International Meeting, Society of Exploration Geophysicists, 2002, Expanded Abstracts
14. GUPCO. A high sensitivity aeromagnetic survey, by Aero-service Division, Western Geophysical Company of America, for GUPCO, 1981
15. Hagras MA. The distribution and nature of Miocene sediments in the Gulf of Suez.5thExplor.Semin., EGPC., Cairo. 1976, 12p
16. Khalil BA, Meshref WM. Hydrocarbon occurrences and structural style of the southern Suez rift basin. 9th E.G.P.C., Exploration Seminar, 1988, Cairo
17. Meshref WM, Refai EM, Abdel Baki SM. Structural interpretation of the Gulf of Suez and its oil potentialities. EGPC., 5th Petrol Explor. Semin., Cairo, 1976, 21p
18. Miller RL, Khan JS. Statistical analysis in the geological sciences, Khan Wiley and Sona, Inc., N.Y. 1962, 469p
19. Moustafa AM. Rifting under sediment loading in the Gulf of Suez, Egypt. 11th Petrol Expl.Proj. Co., Cairo, 1992, 1, 1-5
20. Nazih T. An exploration outlook on the northern gulf of Suez, Egypt .the 9th petroleum exploration and production conference, field trip 24-26th, Sinai peninsula ,1988. 26p
21. Ott N, Götze HJ, Schmidt S, Burger H, Alten M. Meta Geo-information System facilitates Use of Complex Data for Study of Central Andes. *EOS, Trans. Amer. Geophys. U.*, 2002, 83, 367
22. Phillips JD. Locating magnetic contacts: a comparison of the horizontal gradient, analytic signal, and local wave number methods. Society of Exploration Geophysicists, 2000, Calgary/2000 Technical Program Expanded Abstracts CD-ROM
23. Roberts A. Curvature attributes and their application to 3D interpreted horizons, EAGE, First Break, 2001, 19
24. Robson DA. The structure of Gulf of Suez Clysmic rift with special reference to the eastern side. *Jour. Geol. Soc., London*, 1971, 127, 274-276
25. Rosenbach O. A contribution to the computation of the "second derivative" from gravity data. *Geophys*., 1953, 18(4), 894-912
26. Rosenbach O. qualitative studies concerning the vertical gradient interpretation. *Geophys*., 1954, 2, 128-138
27. Schmidt S, Götze HJ. Pre-interpretation of potential fields by the aid of curvature attributes. *Geophysical Research Abstracts*, 2003, 5
28. Scott RW, Govean FM. Early depositional history of a rift basin: Miocene in the western Sinai EGPC, 1stExplor. Semin., Cairo, 1984, 15p
29. Smith RP, Grauch VJS, Blackwell DD. Preliminary Results of a High Resolution Aeromagnetic Survey to Identify Buried Faults at Dixie Valley, Nevada: Geothermal Resources Council Transactions, 2002, 26, 543-546
30. Talwani M, Worel JL, Landisman M. Rapid gravity computations for twodimensionalbodies with application to the Mendocino submarine fracture zone. *Journal of Geophysical Research*, 1959, 64, 49-59
31. Vander Ploeg P. Egypt, In: V.C. Illing (Edit.) , the world's oil fields, The Eastern Hemisphere. Sci. Petrol., Oxford, Univ. Press, London, England, 1953, Vol. 6, Part 1, pp. 151-157
32. Wasfi S, Azazi G. Stratigraphy of the northern Gulf of Suez. *Ann. of the Geol. Surv. Egypt*, 1979, 9, 308-321
33. Winn R, Crevello P, Bosworth W. Lower Miocene Nukhul Formation, Gebel el Zeit, Egypt: Model for structural control on early synrift strata and reservoirs. *Gulf of Suez. AAPG Bulletin*, 2001, 85(10), 1871-1890
34. Zahran ME, Meshref W. The northern Gulf of Suez basin evolution, stratigraphy and facies relationship. The 9th petroleum exploration and production conference, 1988, field trip 24-26th, Sinai peninsula, 30p