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REVEALING AND INTERPRETING OF SUBSURFACE TECTONIC PATTERN OF THE AREA NORTH OF SIWA OASIS, WESTERN DESERT, EGYPT, USING BOUGUER GRAVITY DATA

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كشف وتفسير النموذج التركيبى التحتسطحى لمنطقة شمال واحة سيوة، الصحراء الغربية، مصر، باستخدام معطيات الجاذبية لبوجير

الخلاصة: تقع منطقة الدراسة فى الجزء الشمالى لواحة سيوة نحو الجزء الشمالى الغربى لمنخفض القطارة بالصحراء الغربية، مصر، بين خطى عرض ٢٩° ٣٠` و ٣٠° ٣٠` شمالاً وخطى طول ٢٥° ٠٠` و ٢٦° ٣٠` شرقاً بمساحة كلية ١٥٦٠٠كم٢ وتعتبر خريطة التثاقلية لبوجير هى أساس معطيات الجهد فى هذا البحث بجانب الدراسات الجيوفيزيقية والجيولوجية الأخرى كذلك المعطيات التحتسطحية من الآبار العميقة المحفورة داخل هذه المنطقة. تم تحليل هذه المعطيات لاستخراج معلومات عن التراكيب التحتسطحية العميقة والضحلة لكى تتعرف على الاتجاهات التكتونية الرئيسية السائدة فى المنطقة وتعيين الأعماق للصخور القاعدية فى منطقة الدراسة وكذلك نفسير طبيعة النموذج التكتونى التحتسطحى المستنتج وأيضاً الكشف عن المناطق الأكثر توقعاً للتراكمات الهيدروكربونية. ولإنجاز هذه الأهداف، تم تتبع خريطة التثاقلية لبوجير لرسم نموذج تركيبى تحتسطحى أولى لمنطقة الدراسة ثم تبع ذلك تطبيق تقنيات التحول التى تشمل تقنية Euler deconvolution وتقنية تحليل أطياف الطاقة power spectrum analysis لتعيين العمق إلى مصادر الشذوذ. وشملت أيضاً تقنية الفصل بين الشذوذ الاقليمية المحلية باستخدام تقنية الترشيح وتقنية المركبات الرأسية والأفقية وكذلك طرق استمرارية المجال . وتعتمد عملية التفسير الكمى على تطبيق تقنية Euler deconvolution وتحليل أطياف الطاقة وكذلك تقنية النماذج لسطح القاعدة ذات ٢,٥ بعد . وقد كشفت عملية تعيين الأعماق لصخور الركيزة القاعدية على أن العمق يتراوح بين ألفين وأربعة آلاف متر . وقد أوضحت خرائط الجاذبية المحلية أن المنطقة تحتوى على تتابعات كنتورية موجبة وسالبة لمجموعات صدعية مرتفعة (طيات وأخرى صدعية منخفضة (طيات مقعرة). تم رسم وتفسير الخريطة التركيبية التحتسطحية المستنتجة . وقد أوضحت الخريطة أن المنطقة غنية جداً بالأحواض الترسيبية العميقة والسمك الرسوبى الهائل منذ الباليوزوى إلى عصر المايوسين ذات الجهد الهيدروكربونى المرتفع. عملت العديد من شركات البترول بصورة مكثفة فى هذا الجزء لأجل البحث والتنقيب عن البترول ولذلك تمثل منطقة البحث مساحة واعدة للاستكشافات البترولية . وقد تحدد تداخل نارى مستقيم لأول مرة يفصل بين الأحواض الترسيبية الشمالية والجنوبية بطول حوالى ٩٠سم وعرض ٥ كيلومترات. وأمكن ترتيب الفوالق السائدة من الأقوى الى الأضعف: شرق – غرب ، شرق شمال شرق – غرب جنوب غرب ، شمال – جنوب ، شمال غرب – جنوب شرق وشمال شمال جنوب شرق – جنوب جنوب غرب.

ABSTRACT: *The studied area lies to the north of Siwa Oasis and to the west of Qattara Depression, western desert, Egypt, between lat. 29^o 30` and $30^o$ 30` N` and long. $25^o$ 00 and $26^o$ 30 E` with a total area of about 15600 km^2. The Bouguer gravity anomaly map is used in this study beside other geological and geophysical information data from deep drilled wells. The Bouguer gravity anomaly map of the studied area was interpreted to delineate the subsurface structural pattern. The gravity data are intensively analyzed to extract information about the shallow and deep seated subsurface structures, to identify the main prevailing tectonic trends, to determine the depth to the near surface and basement rocks of this area and to reveal the most prospective areas for hydrocarbon accumulations. The depth determination to the high density, shallower and deeper subsurface sources is carried out by applying transformation techniques which include Euler deconvolution technique and power spectrum analysis method. The Bouguer gravity anomalies are separated into their regional and residual components by filtration method, first derivative method, horizontal and tilt derivative methods and continuation method. For quantitative interpretation of these subsurface structures, the 2.5-D gravity modeling technique was also applied for determination the depth to the basement rocks and determination of average densities of sedimentary cover. The calculated depth ranges between 2000 and 4000 meters. The residual gravity map shows that the area consists of successive positive and negative anomaly groups of horsts (anticlines) and grabens (synclines) tectonic features. The prevailing fault patterns present are as follows from strong to weak; E-W, N-S, NW-SE, ENE-WSW and NNE-SSW. The interpreted subsurface shallow structural map shows that the area had suffered from faulting cutting the subsurface rocks in E-W and NW-SE trends constituting a great number of horsts and grabens while the deep faults cuts the area in ENE-WSW and N-S deep faults forming great E-W sedimentary basins with great thickness which encouraged many oil companies to carry out extensively deep drilling for seven wells for oil and gas exploration inside the studied area. The study revealed the presence of a very large sedimentary basin at the west of this area and also revealed a huge straight anticline or igneous intrusion cutting the northern part in E-W trend with 90 km length and 5 km width.*

INTRODUCTION

The studied area represents a part of the northwestern portion of the Western Desert Egypt, north of Siwa Oasis and west to the Qattara Depression, fig. (1).

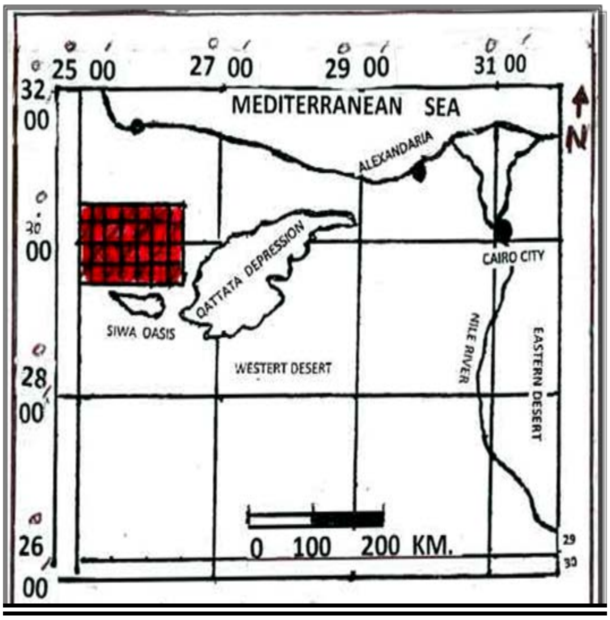

Fig. (1): Location map of the studied area.

Many Oil Companies working in Egypt were drilled eight deep wells inside and surround the studied area. These eight drilled wells are penetrated the sedimentary sections of the studied area for oil exploration. These deep wells are: Faghour-1 well (northwestern corner), Basour well, (at the center of the studied area), Kohla-1 and Kohla-2 (below the Basour well), Gib Afia-1 and Gib Afia-2 wells (near the southeastern part of the area), Safa well (at the center of western border of the area). Ghazalat-1 well, (outside the studied area and lies at the northeastern corner). The thickness of sedimentary sections of these wells range between 2225 to 3900 m, (El Shamma, et al., 2012).The great thickness of sediments may be due to a very long time of geological sedimentation between Cambrian and Middle Miocene times.

The studied area has been intensively investigated by various Oil Companies as Sahara, Philips, Shell Oil Companies, Western Desert Operating Petroleum Company, (WEPC) and Gulf of Suez Petroleum Company (GUPCO) and other petroleum companies.

THE GEOLOGICAL SETTING

The studied area sites to the west of Abu Gharadig Basin which lies inside the northwestern part of Egypt. The geological map of this area is shown at fig. (2).

Where the different geological units from the Eocene rocks to Recent salt dunes are represented. The structural elements are illustrated as a surface faults of NW-SE trend. The studied area and the northwestern part of Egypt has been intensively studied by many authors, (Said, 1962, Meshrif, 1982, 1990, Schlumberger, 1984, 1995; General Petroleum Company, (1986), Fawzy and El- DAHI, 1992, Bayoumi, (1996), El-Badrawy and Soliman, 1997, Awad, 2008, William et al., 2011 and El-Shamma, et al., 2012 and Rabeh, 2012).

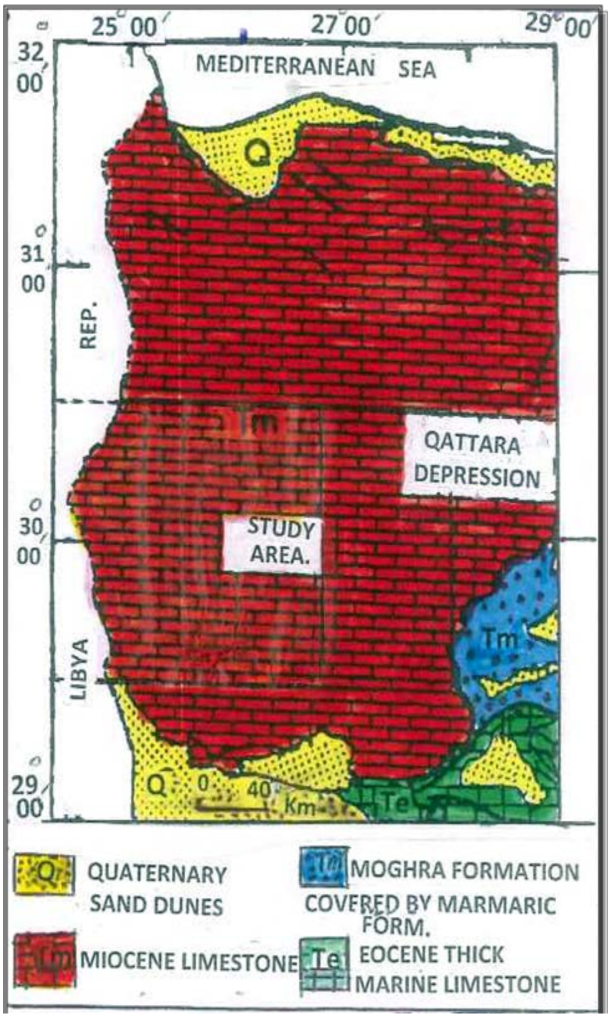

Fig. (2): The geological map of the studied area.

According to Said,1962, Egypt can be broadly divided into four structural divisions. These are the Hinge zone and the Unstable Shelf in the north, and the stable shelf and the Nubian/ Arabian Cratons, in the South. The Hinge zone occupies nearly the coastal area of Egypt, while the central portion of the Western Desert is covered by the transition zone between stable and unstable zones.

According to Paleoservices Ltd.; 1986, the Paleozoic section for the north Western Desert was classified into the following:

1-Siwa Group; of Early Middle Cambrian to late Silurian, which include the following formations :

1- **Shifa** Formation; (Middle- Cambrian- Mid-Ordovician).

2- **Kohla** Formation; (Landoverian-Ludlovian).

3 **- Basour** Formation; (Middle-Late Ludovian).

2 - Faghur Group; (Late Permian to Early Jurassic)

According to Meshrif, 1982 and 1990; the basement rocks of northern Egypt had affected by a northern compression force at Upper Paleozoic – Early Jurassic ages leading to the folding and faulting of basement rocks with major E-W (Tethyan or

Mediterranean) trend The northwestern part of Egypt had occupied by a great Ghiarabub- Siwa Paleozoic Basin; which extends from north by Mamura basin and to south of Siwa Oasis, (Fawzy and Dahi, 1992).

The Generalized Lithostratigraphic Column of north Western Desert , Egypt, fig. (3) was prepared by the Schlumberger Oil Company, in 984, 1996 , where, the different geological ages of different eras ,the various rock units, the lithology of geological formations and the corresponding thickness of each formations are represented.

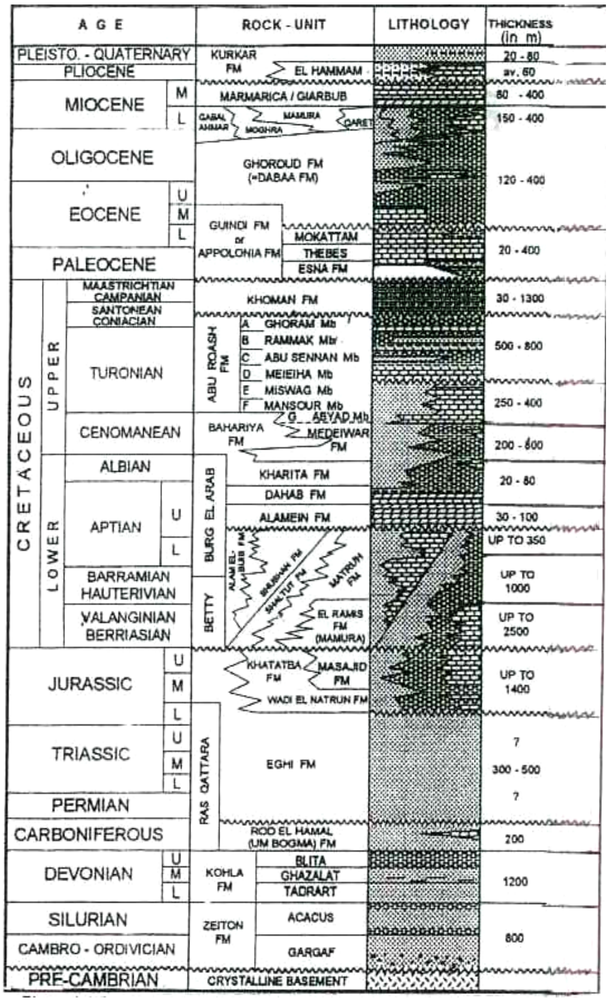

Fig. (3): Generalized lithostratigraphic column of north western desert, Egypt (Schlumberger, 1984, 1996).

According to El-Badrawy and Soliman (1997), Siwa Oasis forms a portion of the Shoushan Basin that was constructed along E-W deep Jurassic fault dividing the Oasis itself into northern and southern parts. According to Awad (2008), most of the studied area constitutes a part of Shoushan Basin of Marmarica Formation of Middle Miocene age and it is restricted from north by a plateau that bounded from the north by Mamura basin. He added that, the Western Desert of Egypt has a complex poly- phase tectonic history starting in the Mesozoic with Jurassic rifting. Early Jurassic extension event occurred during the separation of North- African and European plates and resulted in a broad zone of rift basins cutting across the Pre-Cambrian basement and in some areas, pre-existing Paleozoic Basins .

The following is a brief description of some large and deep sedimentary basins located in and around the studied area, at the northwestern part of Western Desert, Egypt, according to the Egyptian General Petroleum Corporation,1992; see fig. (4).

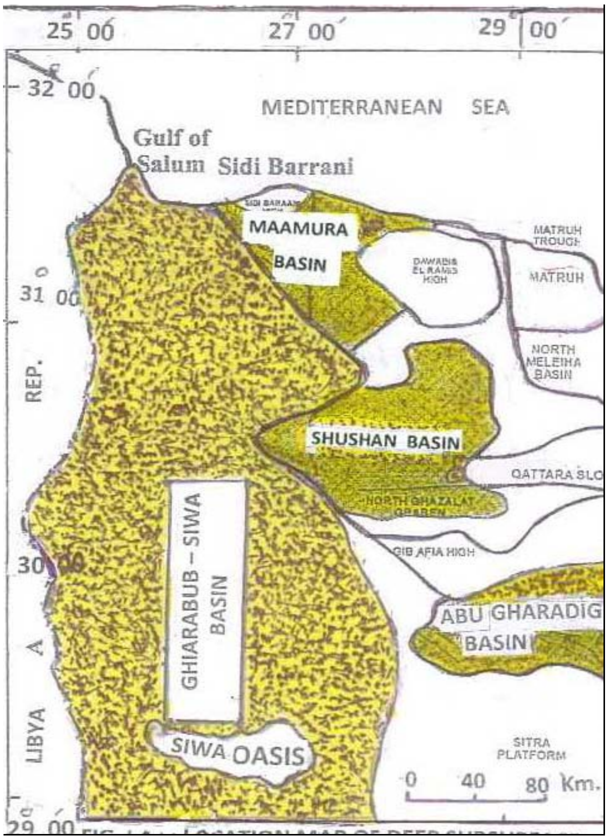

Fig. (4): Location map of the sedimentary basins lies at the northwestern part of western desert, Egypt.

Faghour-Siwa: This area was not properly a basin as it represents the erosion remnants of a great Paleozoic Basin, developed some surprisingly large numbers, primarily because of its size. Estimated total recoverable Oil and gas are 319 MMBO (Million Million Barrels of oil) and 0.592 TCFG p (Trillion Cubic Feet Gas).

Siwa Basin: The Siwa Basin is a northeast continuation of the Kufra Basin in Libya , its thickness increases westward into the Kufra basin. The Siwa Basin is a Paleozoic basin formed by gentle crustal downward and faulting as a result of Hercynian Orogeny resulting in the erosion of uppermost Paleozoic section. The maximum thickness of Paleozoic age is over 9000 f south, west and northward thickening occurs from the Western Desert into the Siwa basin depocenter in Libya .

Ghazalat Basin: The Ghazalat basin shows only gas from the Paleozoic in relatively small quantities 0.66 (TCFG), Trillion cubic feet gas. This basin suffers from a lack of control. Surrounding wells are either basin flank or inter basin wells.

Shushan Basin: The Shushan Basin has an estimated 871 MMBO (million million barrel of oil) and 2- 2.3 TCFG (Trillion Cubic Foot Gas) recoverable. Most of the oil is from the Lower Cretaceous (48%) and Jurassic (37%) rocks. 70% of the gas is from Jurassic and the rest comes from Lower Cretaceous and Paleozoic rocks. This basin has reserves of 82 MMBO and 0.132 TCFG.

Matruh Basin: The total recoverable resource calculated in 4MMBO and 0.15 TCFG. This basin could possibly be fed by richer source rocks offshore to the north.

Abu Gharadig Basin: This deep basin area is almost bifurcated into northern and southern sub- basin by an east-west trending positive features of horsts. The southern sub- basin may have an excess of 15000 f. of sedimentary section and the northern basin may have as much as 35000 f. Abu Gharadig basin is a deep east-west oriented a symmetrical graben. It has a reserves of oil and gas reaches of 207 BBO (Billion Barrels Oil) and 3.6 TCFG. The oil comes entirely from Upper Cretaceous rocks and gas comes from Upper Cretaceous, Paleozoic, Jurassic and lower Cretaceous rocks; (EGPC, 1992).

USED DATA AND METHODOLOGY

The northwestern part of the Western Desert of Egypt was sufficiently treated by many authors such as Zein, et al., 1991; El-Awady, et al. 1998; Soliman, 1999, Awad, 2008; El-Khadragy et al., 2010, William, et al., 2011.Abu El-Ata, et al., 2012, Rabeh, 2012, El- Shamma, et al., 2012 and Zahra, 2013.

The Bouguer gravity data of any area reflects lateral variations in the densities of the Earth's crust which is very important for geophysical explorations. The Bouguer gravity anomaly is the difference between the observed gravity values (gob).controlled by the algebraic sum at all necessary corrections and that of a base station (gbase). The variation of the Bouguer anomaly should reflects the lateral changes in density such that a high- density feature in low- density medium that gives positive gravity anomaly and that feature of lower- density than surrounding medium giving lower gravity anomalies.

The Bouguer gravity data of the studied area was intensively analyzed into their residual and regional components using different geophysical methods and Software Programs using filtration methods, first vertical derivative method, total horizontal derivative and tilt horizontal derivative methods; for enhancement the residual gravity component at the expense of regional component and to clearly detect the edges and ridges of subsurface structures. Upward and downward continuation methods; are applied at various depth's levels as a separation filter for removing the undesired potential component.

1: Bouguer Gravity Anomaly Map :

The Bouguer gravity map of the studied area, fig. (5) scale of 1: 100.000 and 1 mGal contour interval was prepared by the General Petroleum Company (G.P.C.), (1986).

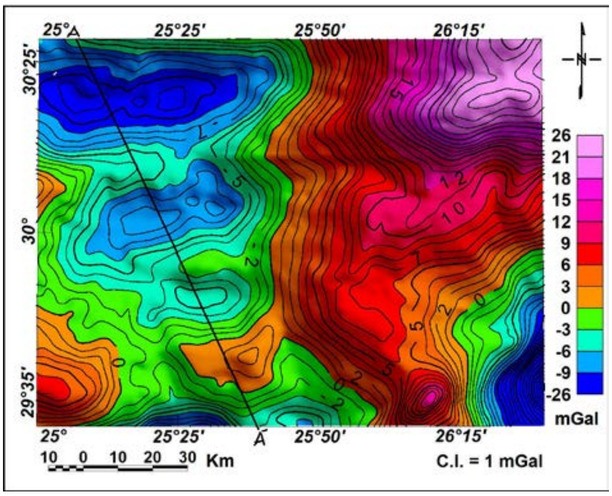

Fig. (5): The Bouguer Gravity Anomaly map of the Studied area.

This map reveals three distinctive anomalies for three different parts, which are, the eastern, the central and the western parts. The eastern part of the Bouguer map characterizes by a highly positive gravity values (+ 24 mGals) with nearly E-W closured contour. This part may reflects either a high density of subsurface structures or thinning in the Earth's Crust or a large subsurface anticline structures. The southeastern part of the map shows strongly negative gravity values (- 25 mGal) in the form of perfect negative gravity closure reflecting great sedimentary thickness of Abu Gharadig Basin, which represents a great source of Oil and Gas in Egypt. To the west of this basin structure, there is a highly positive (+12 mGAl) semicircular gravity anomaly that may reflects near-surface (or highly dense) subsurface structure. The central part of the eastern side has positive linear gravity anomaly with NE- SW trend reflecting Gib-Afia-High. The western side of the Bouguer gravity map refers to the presence of several elongated negative gravity closures with E-W trend. These negative gravity contours (-5 and -11 mGals) reflect the presence of low density sedimentary basins that may be important for oil accumulation. The most southwest corner of this map is occupied by an elongated uplifted (E-W) positive gravity contours (+ 6 mGals). The central part of the Bouguer map seems to be a large natural uplifted barrier structure with nearly N-S high density values and looks like to separate between two different types of subsurface rocks of the studied area.

The preliminary tracing of the Bouguer gravity contour map for delineating the boundaries between different structures and detecting the probable faults led to creation an interpreted subsurface structures map of the area, fig. (6), showing trends, positions, and lengths of these structures. Euler deconvolution technique was applied for determination the depth of shallow and deep – seated faults along five's depth levels (every 1000 m) with their locations and clustering. which illustrates the relation between subsurface rock boundaries and the positions of these faults.

2 : Interpreted Subsurface Structures:

Figure (6) shows the interpreted subsurface structures deduced from the Bouguer gravity map of the studied area. These subsurface structural elements include, different faults with their throws directions, horsts (anticlines), grabens (sedimentary basins) with their axes and igneous ridges. The studied area seems to be affected by several tectonic movements along very long geological time, since Paleozoic to Middle Miocene eras. This area had suffered from more than one tectonic movements leading to formation of a groups of deep, intermediate and shallow faults taking different trends and strengths. The first strongest tectonic movement had come from north with little shifting toward the west leading to formation of E-W (Upper Paleozoic-Early Mesozoic eras) deep faults. The second set of subsurface faults are represented by N-S central faults which may be a huge igneous instruction separating the eastern part from the western one of the studied area, that may be related to East African Rift movement with Upper Jurassic age due to E-W compression tectonic movement. The third group of subsurface faults is illustrated by ENE-WSW (Syrian Arc) tectonic faults of Upper Cretaceous age due to tectonic movement with NNW-SSE compression force. The fourth subsurface tectonic elements has NNW-SSE (Gulf of Suez trend) that cut across the older faults . This tectonic set may be related to Gulf of Suez faulting process of Oligocene age which intersected with the older ENE-WSW tectonic movement of Cretaceous age. The fifth and most weakest tectonic movement has NNE-SSW of Gulf of Aqaba trend of Late Oligocene-Early Miocene time which may be represented by small little faults at the eastern part only. This latest set may be happened during Late Oligocene time (fig. 6).

3: Depth Determination

Euler Deconvolution technique was applied for determination the depths and clusters of shallow and deep-seated faults in the studied area. This technique illustrates the relation between boundaries of subsurface rocks and the locations of subsurface faults.

3.1: Euler Deconvolution Technique

The Euler homogeneity relation (according to Thompson 1982) can be expressed as:

$$(X-X_0)\, df/dx + (y-y0)\, df/dy + (Z-Z0)\, df/dz = N \quad (1)$$

Where; (X0, y0, Z0) marks the position of the source that creates the potential field (f) measured at the point (x, y, z). (N) expresses the degree of homogeneity that may be interpreted as a structural index, (SI) which is a measure of the rate of change with the distance of a field. The structural index (N) for various simple bodies may be derived by direct solution of Euler equation.

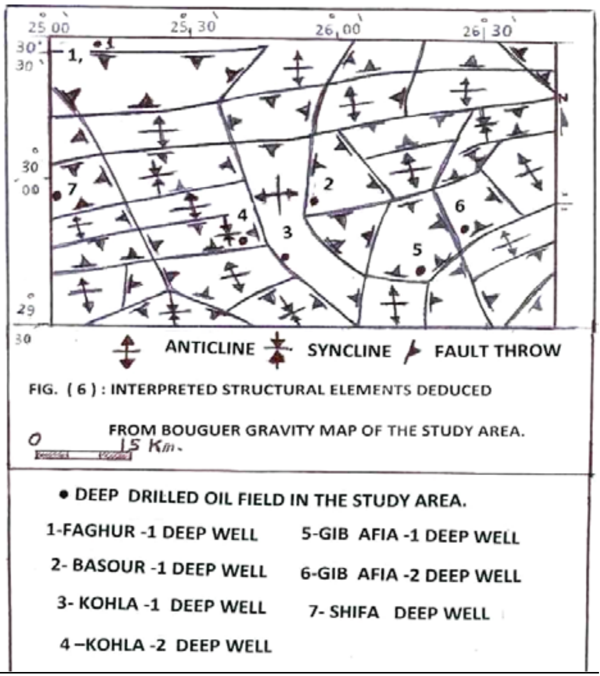

Fig. (6): Interpreted structural elements deduced from Bouguer gravity map of the studied area.

Thomson, (1982) and Reid et al., (1990) revealed that a structural index (SI) of 1.0 provided the best image of the crustal structure boundaries. The locations of the causative structures, with a depth level are calculated by the Euler method, the technique could be expected to work on gravity data by showing that Euler's equation was approximately obeyed by gravity anomaly over a finite step using a SI = 1.0.

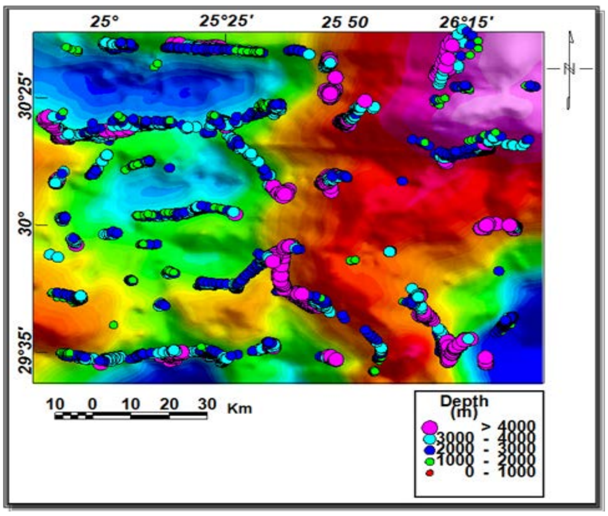

Fig. (7): Euler deconvolution map of the studied area.

Euler deconvolution method (fig. 7) is carried out to the gridded data which can measure the gradients, locate the square windows within the grids of gradient values and field and locate the structural windows. The results are plotted in its plan (x, y) position using a symbol size proportional to depth Z. Reid et al.; 1990 and Yaghoobian et al., 1992 and depending on the reselected structural indices (S.I.) which identifies the rate of changes of the potential field with distance, showed that, for gravity data, the S.I. = 0 (for probable faults) can be applied.

3.2: The power spectrum analysis:

The fast Fourier Transformation was carried out on the Bouguer gravity data for estimating the energy spectrum curves and calculating the average depth to the shallow (residual) and deep (regional) causative sources. The filter depends on the cut-off frequencies that pass or reject certain frequency values and pass or reject a definite frequency bands. This technique distinguishes between the two linear segments, one characterizes by low frequency (long wave lengths), steep slopes and high amplitude that refers to deep sources and the other linear segment represents a high frequency (short wave lengths), low amplitude with gentle slope referring to near surface local structures. The analysis of the Bouguer gravity data of the studied area by power spectrum technique is shown at Fig. (8) where the average depths to the regional and residual components was calculated using the Geosoft Oasis Montaj (2007).

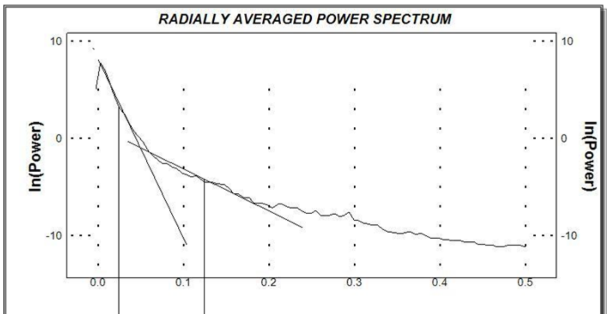

Fig. (8): Power spectrum technique for depth determination.

4: Gravity anomaly separation:

4.1: Filtration technique:

Filtration technique is introduced as a way to remove the long-wave length component. Filtering is applied to the functions of distance and time. In this case, spatial frequency or wave number (number of waveform cycle/ unit distance replaces (Keary and Brooks, 1994).

Wavelength linear filtering was done to the Bouguer gravity map of the studied area. The Fourier Transformation technique was performed using two types of filtration: the first type is the low- cut (low pass) filtering to isolate the regional component from the residual one, i.e. separation of low frequency, long wavelengths, regional and deep-seated structures from short wavelengths, high frequency, local and shallow-seated structures. The high cut (high pass) filtering is another type of filtration used to isolate high frequency, short wavelengths, local and near surface geologic structures of residual anomaly from regional component.

High cut (high pass) filtering process was carried out on the Bouguer gravity map of the studied area to obtain the residual anomaly map (fig. 9).

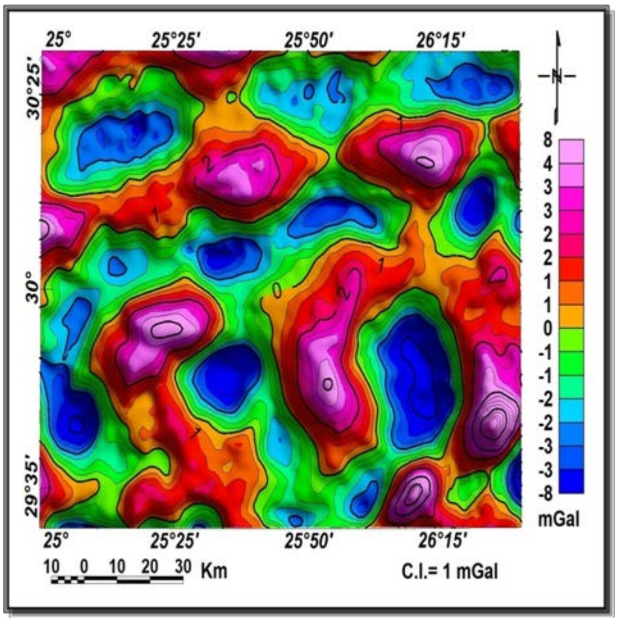

Fig. (9): High pass filtered gravity map of the studied area at 30 km.

This figure reflects the near surface positive and negative anomalies that express the shallow horsts (anticlines) and grabens (sedimentary basins). At the northern half of the area, these basins and horsts are aligned at E-W trend , while at the southern half both these structures are trend at NW-SE .

Low cut (low pass) filtering was carried out on the Bouguer anomaly map to isolate the regional component from residual one. Fig. (10) expresses the deep- seated regional structures present in the studied area. From this map, it can say that the regional contours at the eastern part of the studied area expresses the presence of a very huge anticline structure with NW to NNE axis plane while the western part of this area contains three large sedimentary basins filled by a very thick sediments with E-W axial planes . The southeastern corner has very low negative values of low density sediments and refers to the Abu Gharadig Basin.

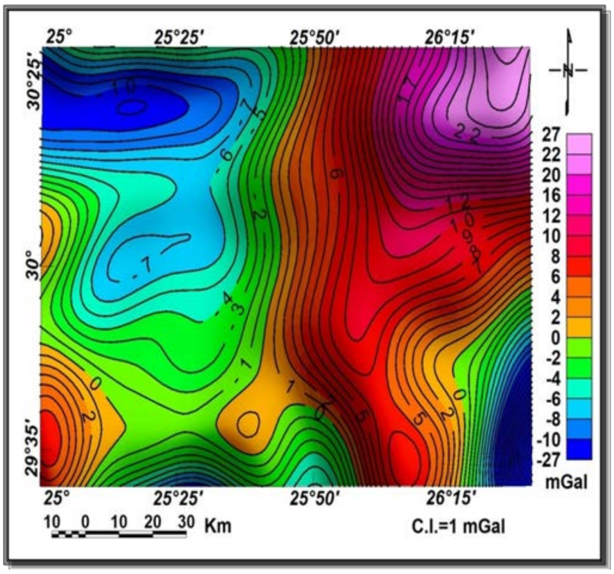

Fig. (10): Low pass filtered gravity map of the studied area at 30 km.

All of these regional features may be very prospective locations for oil foundation.

4.2: Derivatives methods (data enhancement):

Data enhancement techniques are used to increase the perceptibility of the gravity anomalies that may be associated with near- surface interested structures. This technique is very useful for strength weak gravity anomalies related to small, local and shallow structures.

The residual gravity anomalies have a small amplitudes and are easily obscured by regional gravity effects. The most important techniques are derivative methods. The most commonly used derivatives are the first vertical derivative (gradient) (Elkins, 1951) (Fajklewicz, 1976; Butler, 1984, a, b), second vertical derivative (curvature) which are analytically calculated from a Bouguer gravity anomaly grid.

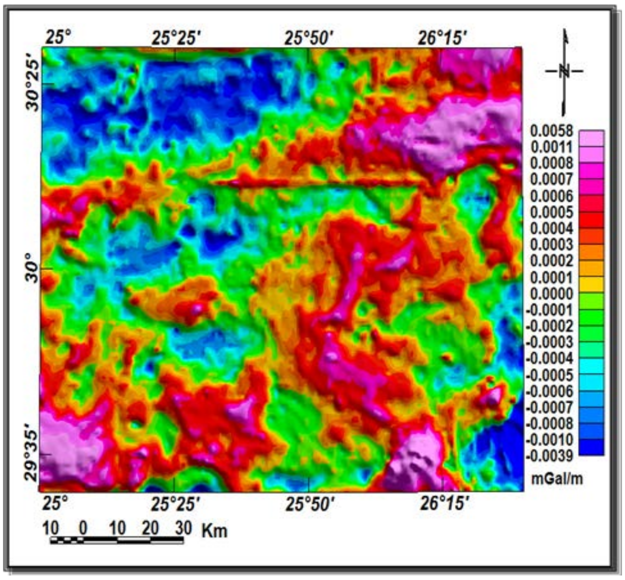

Fig. (11): First vertical derivative (fvd) gravity map of the studied area.

The first vertical derivative (FVD) method enhances the residual anomaly component of smaller near- surface structures at the expense of regional component reflecting effects of deep-seated elements and much more responsive to local effects than the regional one and so tends to give sharper figure than the Bouguer gravity map. The first vertical derivative (FVD) indeed, is used to delineate high frequency, small sources more clearly in large amplitude low frequency anomalies.

The application of (FVD) method is very important for enhancement of gravity or/ and magnetic anomalies associated with faults and other structural discontinuities, and to emphasize the effects of geological contacts., (Dobrin and Savit, 1988; Telford et al. 1990).

This (FVD) technique was applied on the gravity map of the studied area, (fig. 11), in which, it shows the edges and contacts between different small geological units, separating the positive and negative contour areas and occupying the apex amplitude between them. It refers to the presence of a straight, large structural ridge cutting the northern part of the studied area with E-W trend. This ridge has about 90 km length and 5 km width which acting as a natural barrier between northern and southern basins. This igneous ridge appears in residual and regional maps and this proves that , its origin lies at very deep depth. The second vertical derivatives (SVD) map shows great distortion between different structural boundaries so, it does not represented.

The total horizontal derivative (THDR) and tilt horizontal derivative (TDR) methods are another effective techniques that are applied on the gravity potential data as a powerful tools for delineating the edges, ridges and boundaries of geologic structures .

The resulted maps are shown in figs. (12) and (13) that refer to a clear boundaries between different faulted blocks.

The edges of the high-density structures have been delineated by applying horizontal derivatives of the potential data. The total horizontal derivative (THDR) method peaks over the edges and is near zero over the body (Miller and Singh, 1994).Total horizontal derivative magnitude of the gravity data was calculated using the standard formula (Verduzco et al., 2004).

$$THDR = \sqrt{\left(\left(\frac{dt}{dx}\right)^2 + \left(\frac{dt}{dy}\right)\right)^2} \qquad (2)$$

where, T is the Bouguer gravity or magnetic intensity field data.

In this map we can see clearly the good picture of the edges separating between positive and negative anomalies and showing very well the contacts between different blocks and also illustrating the northern edge of E-W-trend.

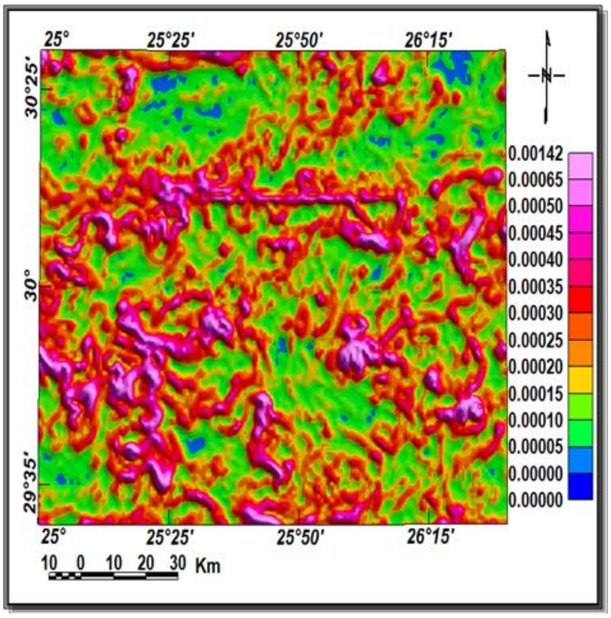

Fig. (12): The total horizontal deivative gravity map of the studied area.

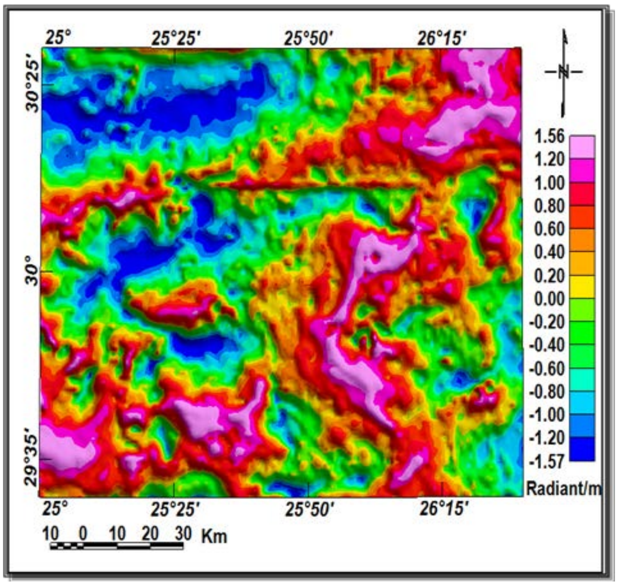

Fig. (13): Tilt horizontal derivative gravity map of the studied area.

The tilt derivative technique can be defined as the ratio of the first vertical derivative to the total horizontal derivative of the potential field. This technique delineates the sources in areas at low gradient. In contrast to the total horizontal derivative, the tilt derivative has high positive value over the source body, close to zero values near the edge; and a negative value outside the source region (Miller and Singh, 1994). Salem et al., (2007) used the zero contour to locate the magnetic body edges and also calculated the depth to the magnetic body by measuring the distance between the zero contour and + 45 or -45 contour lines.

The map shows clearly the edges between different blocks and the contour line over the edge has positive value in contrast to the total horizontal derivative map in which the edge has zero intensity. The contact between various blocks are very good represented.

4.3: Continuation methods:

Downward continuation technique:

Downward continuation of gravity field is a method used for anomaly separation, depend on emphasizing small effects at the measured surfaces. If such effects are present from shallow sources and are continued below their depth, contribute large false components to the continued field, for this reason, the downward continuation has more application in magnetic than in gravity interpretation, because airborne magnetic survey make at- higher elevations above ground surface and therefore flight away far from these surface effects of small sizes (Nettleton 1976). The application of this technique illustrates clear pictures about subsurface sources as it measures above it, and also can compute the actual depth of anomalous sources and basement complex. It calculates the depths of sources along several, horizontal depth's levels. In the present work, the downward continuation of gravity field was calculated at a depth 1000 meters,

Fig. (14) which shows very clear the locations, trends, and polarities of subsurface structures with clear boundaries between different geological blocks.

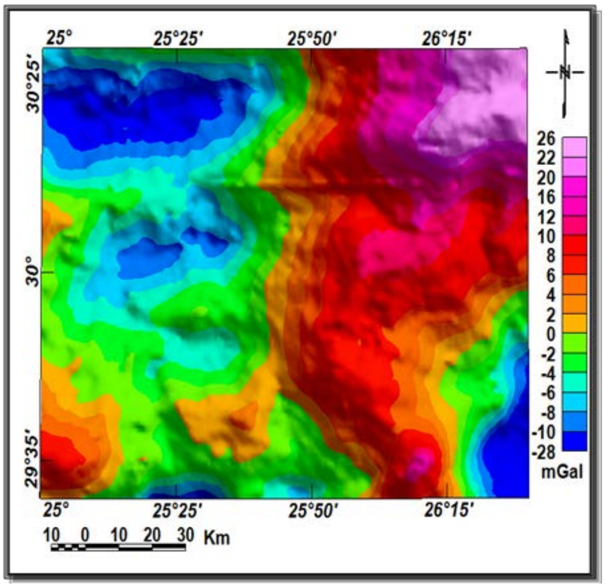

Fig. (14): Downward continuation of gravity field at 1000 m depth's level of the studied area.

Upward continuation technique:

The upward continuation is the process by which the potential field data are analytically projected from one data in surface upward to a different level surface above the original datum. This is commonly achieved by using continuation operators consisting of a number of coefficients operating upon uniformly gridded field data. The advantage of this technique as a prospective tool comes from viewing a filed at different levels that are widely considered as a useful in interpreting subsurface anomaly sources (Telford et al., 1990).

The continuation coefficients are calculated using upward continuation in the frequency domain of Bouguer gravity data using the coefficients by numerical evaluation of the Fourier transformation in the frequency domain (Oasis Montage, V. 5.1.7).

The results of this application on the Bouguer gravity data of the studied area are represented by Fig. (15). which illustrates one example of the application of upward continuation method at 5 kilometers. This map mainly shows the distribution of different subsurface blocks that range from highly- density subsurface rocks that occupying the north- east and southwest parts of the studied area. The extremely southeast and northwestern parts of the studied area show a strongly negative density values that may be related to sedimentary basins with real thickness, which represents an important zones for hydrocarbon accumulation.

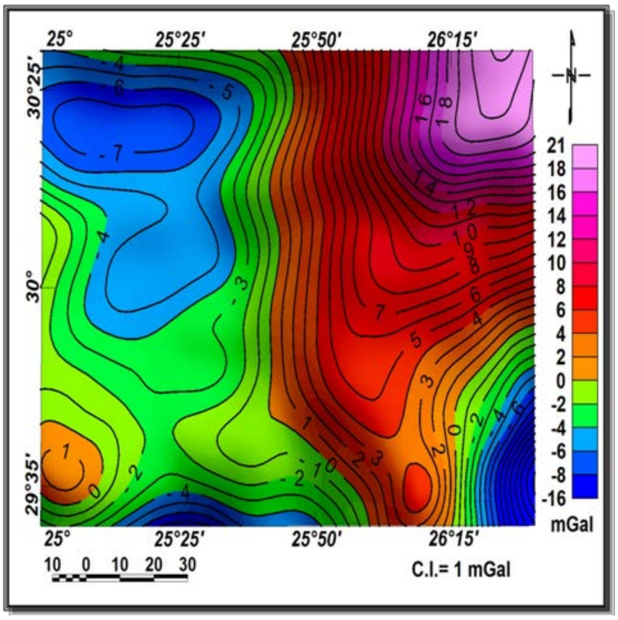

Fig. (15): Upward continuation of gravity field to 5 km. of the studied area

QUANTITATIVE INTERPRETATION

1- The 2.5-D modeling:

The quantitative interpretation of the studied area depends on the obtained results of depth determination to the basement surface and the average densities of both sedimentary cover and igneous rocks, Fig. (16).The quantitative interpretation used a 2.5-D gravity modeling package running on GM-SYS Software, (1999). The 2.5-D modeling technique was applied along profile (A-A) taken on the Bouguer gravity map of the studied area near to the western side to show the depth, surface average configuration and densities of constructed subsurface formations.

The profile A-A` was taken on the Bouguer gravity map of the studied area and the observed gravity field was calculated along it as an observed curve and that field was determined for the 2.5-D model of subsurface structures as a calculated curve. A good fitting between two profiles must be done to conform the proposed model parameters of subsurface structures.

The average density of the upper most layers of sedimentary cover is 2.2 g/cc while that of the underlying sedimentary rocks reaches to 2.6 g/c.c. and the average density of basement rocks refers to 2.7 g /c^3 or acidic igneous rocks. This section covers about 113 km length and cutting across the western side of the studied area passing near to two deep drilled wells which are, Faghour-1 and Kohla-2 over major and minor subsurface features. In general the surface configuration of the deep anomalous structures obtained from 2.5-D model technique illustrates that, the main depth of the basement rocks increased from south to north . The basement surface seems to be faulted in E-W trend constituting a group of horsts (anticlines) and grabens (sedimentary basins) with various basement depth. The calculated depth values to the igneous surface from the 2.5-D modeling agree well with that depth obtained from deep drilled wells by oil companies, where the recorded depth range from 2 to 4 km.

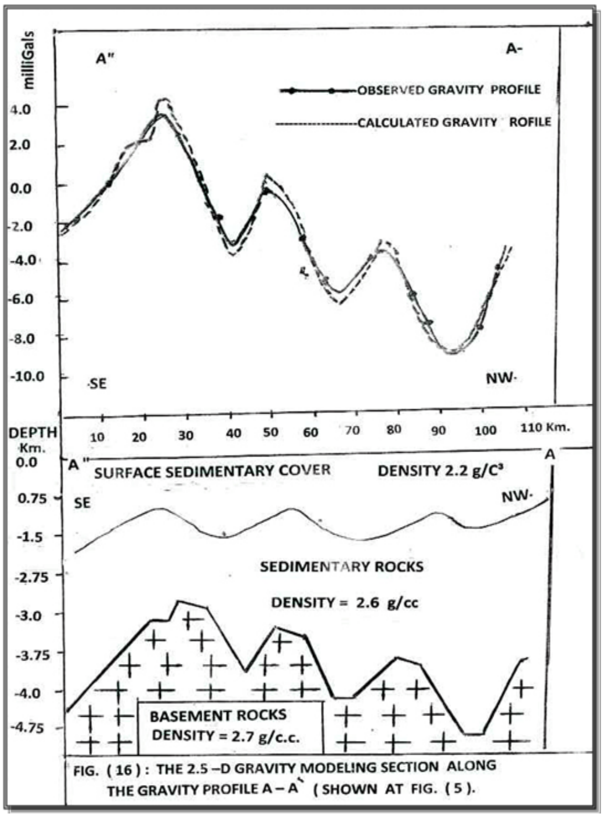

fig. (16): The 2.5-D gravity model of subsurface rocks of the studied area.

2- Interpretation of subsurface structures:

The aim of this study is to reveal and interpret the subsurface structural pattern of the studied area. For this purpose, the previous geological and geophysical work, and the deep- drilled wells data are collected. The Bouguer gravity anomaly map of the studied area was intensively analyzed using different methods and techniques for anomaly separation into regional residual anomalies, depth determination using Euler deconvolution and power spectrum analysis techniques for depth determination to the shallow and deep-seated structures . 2.5-D modeling technique was also applied for giving a clear picture about the densities of subsurface rocks and the nature of subsurface configuration.

2-1- Shallow- Seated Structural Features:

This local- structural map is shown at Fig. (17) which illustrates the nature of subsurface faults affecting the studied area. This map illustrates the distribution of shallow seated faults, their trends, locations, down throw sides and their types. This map shows that, the subsurface rocks of this area had affected by two main types of faults which are E-W and NNW-SSE faults. The E-W (Tethyan Trend) faults had formed as a result of a N-S tectonic movement

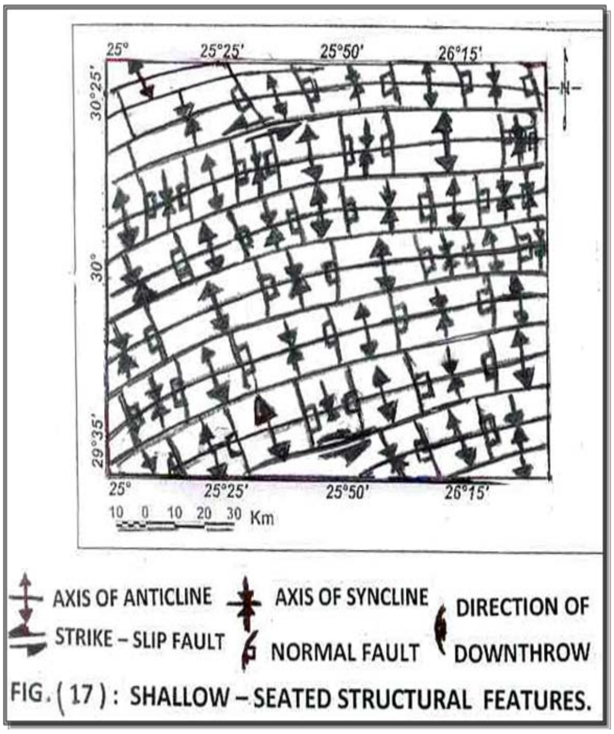

Fig. (17): The shallow seated structural map of the studied area.

During the Late Paleozoic-Early Mesozoic age. These faults are considered as a strike –slip type constitute in between a great number of parallel anticlines and synclines folds. The second type has NNW-SSE (Gulf of Suez) trend . This set of faults runs nearly parallel and had deformed the subsurface rocks constituting an alternation of horsts and grabens with east –west axes trend . These represented horsts and grabens are considered very important for hydrocarbons accumulation especially in the presence of a large thicknesses of Paleozoic and Mesozoic sediments.

2-2- Deep seated structural elements:

The deep seated various rocks of the studied area seem to be affected by a deep ENE-WSW and N-S faults. Fig (18), illustrates the deep faults, their locations, distribution and down throw side directions. The ENE-WSW faults have a strike-slip characteristics; while the N-S deep faults have normal type. Both of previous faults interest with each other forming a great number of parallel horsts (anticlines) and grabens (sedimentary basins) of highly economically importance . The eastern part of the studied area characterizes by the presence of a huge anticline structure with N-S axis and westward dipping trend. The western part of the area under investigation looks like a great syncline structure or a great sedimentary basin with a N-S with axis trend.

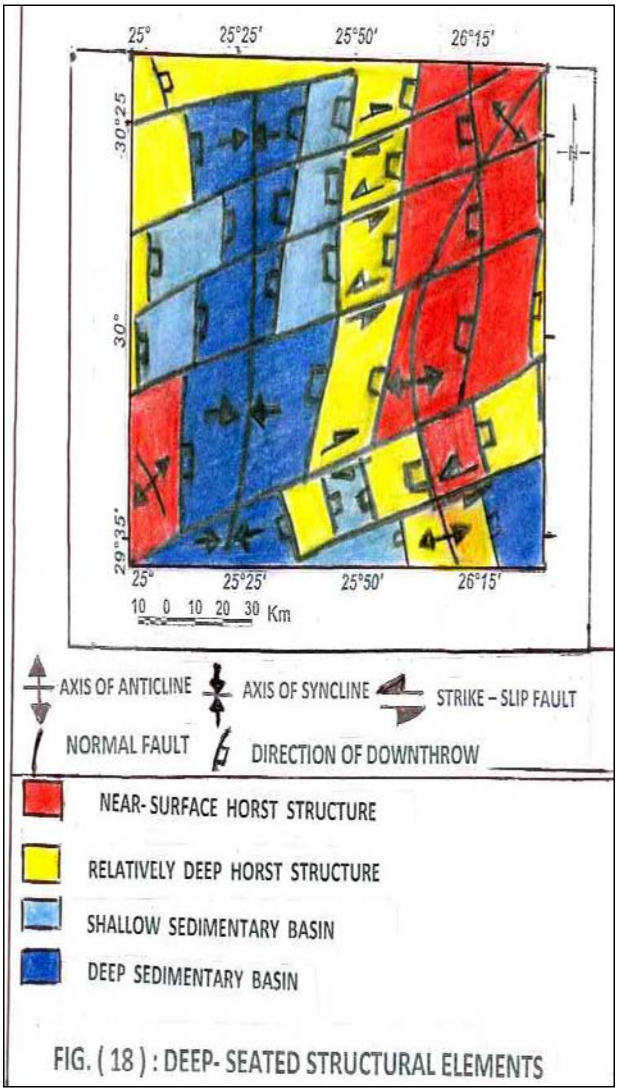

Fig. (18): The deep seated structural map of the studied area.

CONCLUSION

The studied area constitutes a part of the northwestern side of Egypt and lies in and around a great number of sedimentary basins as Ghiarabub, Shushan, Ghazalat-1, Mamura, Matruh and Abu Gharadig Basins. The age of sedimentary basins ranges between Paleozoic to Early Tertiary time with sedimentary thickness between 2220 and 3000 meters. The studied area had affected by many tectonic movements as the Late Paleozoic to Early Mesozoic age, the Late Permian Early Jurassic, the Upper Cretaceous and the Oligocene movements leading to the formation of various subsurface faults as: E-W, N-S, ENE-WSW, NNW-SSE and NNE-SSW faults respectively.

The subsurface rocks had suffered from the previous faults constituting a great number of horsts and grabens with different down throw sides. The eastern part of the studied area is represented by a huge anticline structure runs from northwest to northeast trend while the western part of the area characterizes by a very large synclinal structure forming a great sedimentary basin with north-south axis. This obtained results conform my point of view that the eastern part differs from the western side of the studied area.

Both the obtained regional, residual and vertical derivative gravity anomaly maps show, for first time, the presence of a straight, intrusive and huge ridge cutting the northern part of the area with E-W trend, with 90 km. length and 5 km. width and acts as a natural barrier between sedimentary basins. The thickness of sedimentary rocks is recorded by deep drilled wells which ranges from 2220 to 2995 m. and this thickness was calculated by Euler deconvolution as 4000 m. while that determined by 2.5-D modeling gives about 4000 m. So, the presence of a large thickness of sediments plays an important role hydrocarbon accumulation.

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