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SUBSURFACE STRUCTURAL IMAGING AND ARCHITECTURE OF PRE-RIFT SEDIMENTS OF WEST HURGHADA DISTRICT, EGYPT.

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ABSTRACT

West Hurghada area is located on the Southern margin of the Gulf of Suez - Northern Red Sea rift system, Egypt. The present work represents an integrated analysis and interpretation of geophysical magnetic and seismic datasets and boreholes data in order to elucidate and delineate the subsurface structural imaging of prerift sediments of West Hurghada area. It was found that the main structural trends have the directions NE-SW, NW-SE to NNW-SSE and E-W. Results indicate that the calculated depths of the basement range from 5000 - 6000 feet on the Eastern side to 12000 feet depth on the Western basin of the area under investigation.

The seismic interpretation was integrated with the magnetic interpretations for West Hurghada Basin to study the depth configuration and structural framework of the basement and the overlying sedimentary section.

Two NNE-SSW and NNW-SSE trending profiles were forward. These profiles were situated along seismic lines. The tops of Basement surface, Nubia Formation, Matulla formations were interpreted through the integration of Magnetic and seismic data.

INTRODUCTION:

The study area of the West Hurghada basin is located on the Southern margin of the Gulf of Suez - Northern Red Sea rift system, Egypt, between latitudes 27°12′ 00″ to - 27°17′ 00″ N and longitudes 33°42′ 00″- 33°48′ 00″ E (Figure 1).

The penetrated stratigraphic column of the study area comprises Precambrian-Tertiary rock units. The Pre-rift sediments (Cretaceous sediments) represented by the Nubia sandstone and the post-Nubia sediments. They occupy the most parts of the study area, comprising rock units, known as Matulla, Sudr, Esna Shale, Thebes, Nukhul, Rudeis, Kareem, Belayim, South Gharib and Zeit formations.

The present work attempts to provide a better interpretation for the directions of subsurface structural trends in the area and the knowledge of the new prospective areas, which are interpreted from the ground magnetic and seismic interpretation. Also, using the structural attributes to enhancement the structures. The detection of the sedimentary basins of the West Hurghada and surrounding area based on the integration of magnetic data.

GEOLOGIC SETTING:

In the study area, the thick of the Upper Cretaceous sedimentary section is unexposed, overlying the Precambrian basement rocks, with a clear nonconformity. The Phanerozoic rocks ranges in age from Cretaceous to Post-rift sediments.

The oldest unit in the section is Nubia Formation, which rests unconformably over the Precambrian Basement in the most parts of the study area. The Post-rift (Post Miocene) formations are the youngest sedimentary unit in the study area, (Figure 2).

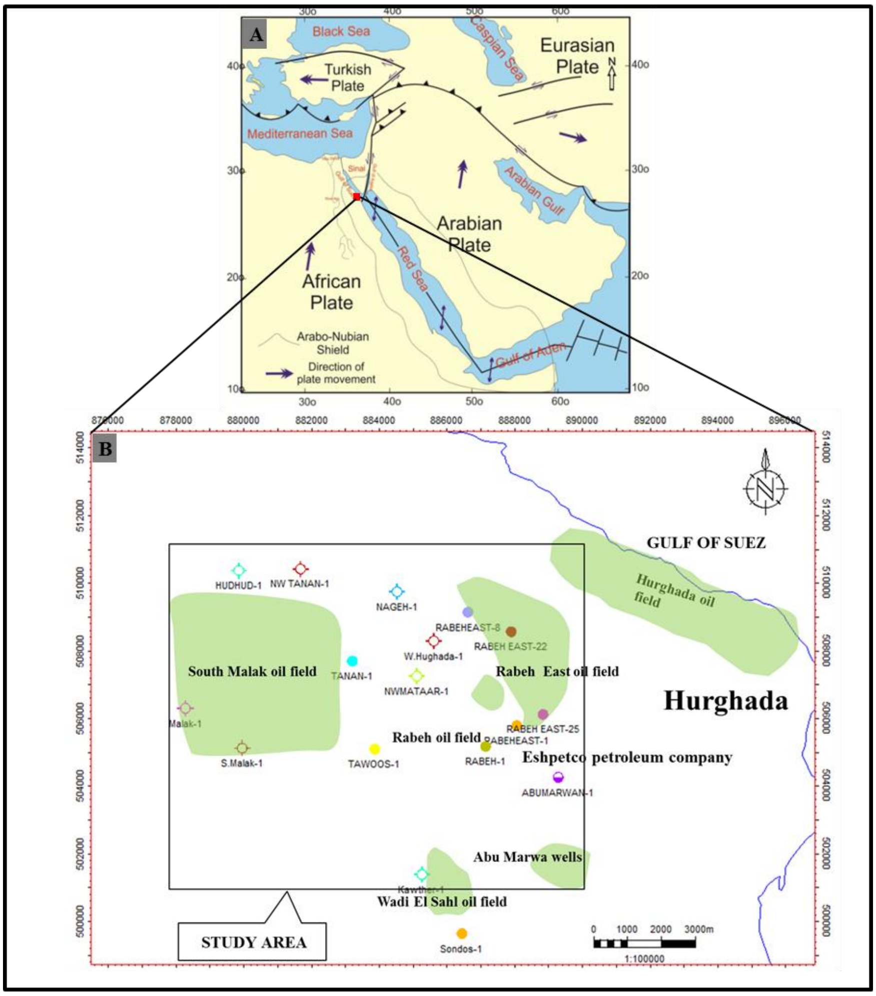

Figure 1: The location map of the study area shows the oil fields of West Hurghada, Egypt.

SUBSURFACE STRATIGRAPHY:

The cumulative stratigraphic sequence in the study area reaches about 12000 feet of sedimentary clastic successions, according to actual drilling wells that were drilled in the Western and southern parts of the study area by Esh El Mallaha, Wadi El Sahl, Aminex oil companies and reaches to 5000 - 6000 feet in the Eastern part of the area under study (At Rabeh and Rabeh East oil fields and concession of the Petromallaha Exploration Company, (Figure 2).

PRE-RIFT SEQUENCE:

This sequence stratigraphic is referring to the sedimentary section deposited prior to the Oligo - Miocene Gulf of Suez rifting (Robson, 1971, and National Stratigraphic Subcommittee, 1974). It had been penetrated at the point of study by some wells.

The basal part is characterized by stacked sandstone section, of Nubian faces, lying unconformably above the Precambrian granitic rocks. This section is known for the subsurface geologists as Nubia sandstone (Said, 1962). Although the Nubia sandstone is showing excellent reservoir properties, it is the first marine transgressive sequence is represented by the Cenomanian Raha Formation. It is composed of alternating clastics and carbonates of 80 to 100 meters thickness (Ghorab, 1961).

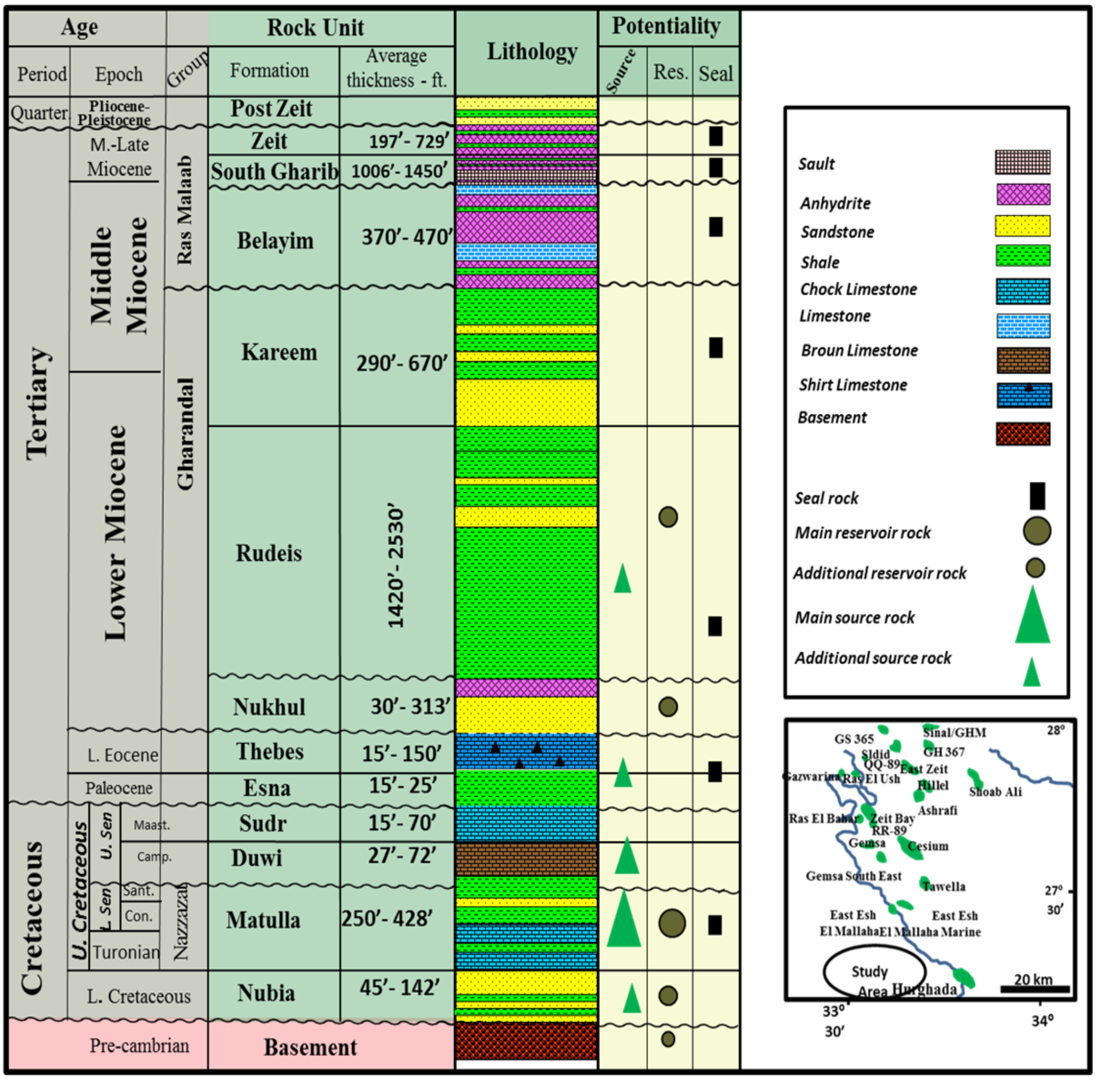

Figure 2: General Lithostratigraphic units based on well data at West Hurghada Basin area.

The Nubia Formation is a good hydrocarbon reservoir; also it was found oil bearing in the study area. It is followed by Lower Senonian marl and shale with sandstone and carbonates of Matulla Formation. The sandstone intervals within the Matulla Formation are one of the known reservoirs of moderate characteristics in the Central and Southern Gulf of Suez (e.g., Ramadan, Hilal and Geisum fields). The overlying section of carbonates is represented by the Upper Senonian Sudr Formation. The lower part of this formation (Campanian Brown Limestone) is commonly rich in organic content and regarded as the main source rock in the Gulf of Suez (Youssef, 1957; Ghorab, 1961, and Bosworth and McClay, 2001). West Hurghada trough compresses a sedimentary section of about 11900 feet. The pre- Miocene, Thebes, Esna shale, Sudr, Duwi and Matulla formations reached the phase of peak oil generation and expulsion recently from five maybe till present. In the study area, all sources have not reached a maturity level high enough to generate gasses, (Ellaboudy 2008). The Paleocene Esna shale rests unconformably above the Cretaceous section and followed by the cherty limestone of the Lower Eocene Thebes Formation. This carbonate section measures 230-300 feet and is known as a local reservoir rock, especially in the central dip province of the Gulf of Suez where it is getting thicker and fractured .

SYN-RIFTING SEQUENCE:

The Syn-rift is deposited in the sedimentary section during the phases of the Gulf of Suez rifting (Robson, 1971; Evans, 1988; Evans and Moxon, 1988, and Bosworth and McClay, 2001). This sequence is subdivided into seven formations represented in figure (2). The earlier lacustrine faces of the Red Beds of Abu Zenima Formation were locally deposited in the area and had been encountered in few wells. On the contrary, the surface exposures are not preserving this section. Nukhul Formation (Early Miocene) is the first rifting marine in the study area. It is composed of shallow marine deposits, which include calcareous conglomerates, sandstones and marl in its type section in Wadi Nukhul (central eastern part of the Gulf). In Gebel El Zeit area, the Nukhul Formation includes channelized submarine sandstones, near-shore chert cobble and conglomerates and various carbonate shelves and slope faces (Bosworth et al., 1998). The wells of West Hurghada had penetrated the sandstone of the Nukhul Formation occasionally interbedded with limestone and shale. In outcrops along the Esh El Mellaha Range; at the Western side of the Hurghada basin, the basal syn-rift conglomerates are sometimes referred to as the Abu Gerfan Formation (Ghorab and Marzouk, 1967; National Stratigraphic Subcommittee, 1974; Darwish and El Arabi, 1993, and Bosworth and McClay, 2001).

POST-RIFT SEQUENCE:

The Post Miocene stratigraphic sequence is deposited after the phases of Gulf of Suez rifting and during the Pliocene to Holocene. In marginal areas, this sequence is composed of sands and sandstone with shale predomination while limestone and clastics are forming the section in the offshore part of the Gulf of Suez. It is a variable thickness from 50 to greater than 5000 feet.

The main source rocks in the area are the Campanian Brown limestone and Lower Eocene Thebes Formation, (Figure 3). The Miocene shale of Kareem and Belayim formations are being at shallow burial and found immature source rocks, while the Early-Middle Miocene shale of Nukhul and Rudeis formations are found mature source rocks.

The hydrocarbon bearing reservoir in the area is represented by the sandstone intervals of Pre-rift (Nubia and Matulla) sediments. These intervals were representing the pay zones in oil fields in the West of Hurghada district. These thicker sandstone intervals exist in the stratigraphic column and are showing better reservoir characteristics and they were found oil bearing,(Figure 3). The thick salt and anhydrite section of the Late Miocene, South Gharib, and Zeit formations are the regional cap rock in the entire Gulf of Suez (Figure 2). On the local scale, the well distributed shale and marl in the stratigraphic section are providing the top and lateral seal for the thin pay zones in the study area.

STRUCTURES AND TECTONICS:

Kröner (1984) and El-Bayoumi and Greiling (1984) believed that the Pan-African belt was created by a compression from an Easterly direction, while Shackleton et al. (1980), Ries et al. (1983), and Habeib et al. (1985) considered that the direction of tectonic transport was towards the NNW.

The basin of the study area is bounded by two major faults striking NNW, the Northeast one is downtown to the southeast (F1), Also the SSW bounding fault is downtown to the Southeast (F10), creating a major Graben, (Figure 5). All these structural segments are good evidence for an ideal rift system configuration.

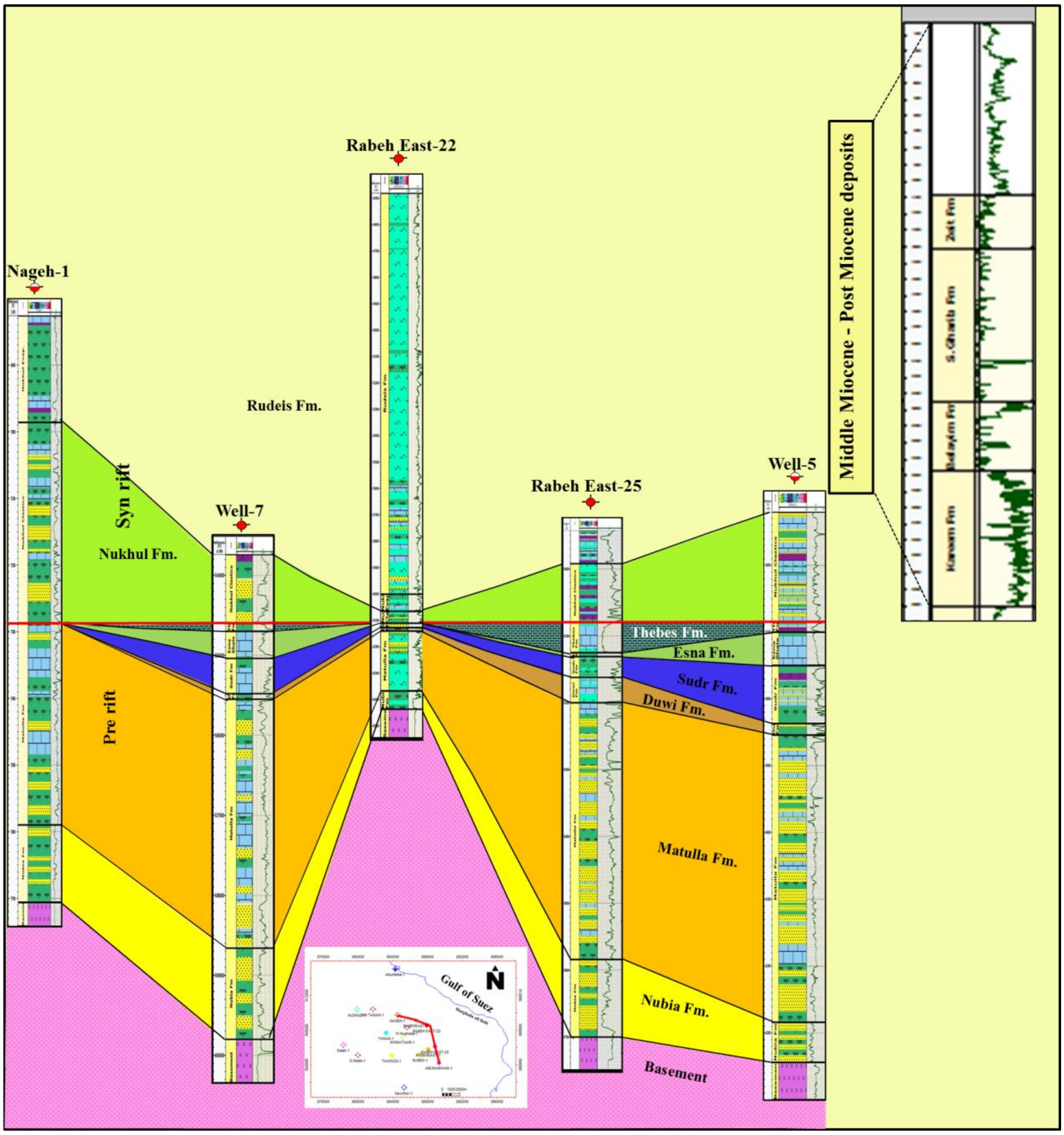

Figure 3: punching out of Pre-rift (Early Cretaceous to Early Eocene) sediments, shows decrease thickness of Pre-rift formations in Rabeh East oil field and increases in two western and eastern sides of the study area.

THE AVAILABLE DATA:

The available information used for the present study includes ground magnetic, seismic and borehole data (Figures 3 & 5). This research work focuses on the interpretation of the structures of Pre-rift Formations of West Hurghada area, as being deduced from the integrated geophysical data (magnetic and seismic).

THE METHODOLOGY:

The ground Magnetic survey covering the entire Southern Gulf of Suez province were acquired by Penzoil, 1998 to produce magnetic maps in support of geological research and exploration. The main objective of such survey is to be used for petroleum exploration and to delineate the main structural trend in this study area.

This pattern of a magnetic anomaly in the study area represents zones of the high magnetic level, (Figure 3). This high magnetic level is exposed in the Eastern and Central parts of the study area. This level is distinguished by pink to yellow color and intensities from 120 nT to 230 nT. This anomaly indicates that there is highly magnetic rock source underneath this location and due to the thin thickness of the crust. It has an elongated shape in the NW-SE to NNW-SSW direction that may represent the most dominant structure in the study area striking in the same trend of Clysmic fault.

The second pattern of a magnetic anomaly in the study area represents a zone of intermediate to low magnetic level. This level is distinguished by green to blue color and varies in their magnetic values from 50 to 110 nT. This level is exposed in Northern part of the study area. Most of these anomalies trends in the NE-SW to NNE-SSW direction that may be represent a second major fault striking in the same trend of Aqaba faults.

The 3D seismic program included about 90 km2 of firm seismic lines that were acquired using Vibroseis. However, there is a limited agricultural area plus some other rough areas, where dynamite was an optional solution. Acquired 90 km² of Q-land 3D seismic acquisition in August 2006 by Western Geco, processed and interpreted for Esh El Mallaha Oil Company. It is more quality than 1994 Q-land 3D.

DESCRIPTION OF GEOPHYSICAL DATA: (RTP GROUND AND SEISMIC MAPS):

The inspection of the RTP ground magnetic anomaly map (Figure 3b) reveals that the most striking criterion of the anomalies in the study area is the NE-SW magnetic high. The main high is separated from a low by a steep magnetic gradient with a shallow basement rock.

This steep gradient indicates that the study area is structurally controlled by a fault having a major axis in the NNW-SSE direction. This part reflects very strong magnetic anomalies with steep gradients and high amplitudes at the Northeastern and Southwestern sides.

The most conspicuous anomalous features of the Northwestern platform that have a magnetic low and extends in the NW-SE direction, are represented by incomplete negative magnetic anomalies of limited areal extent and characterized mainly by their relatively low amplitudes, low frequencies, and moderate gradients.

These almost negative magnetic anomalies may be interpreted, as structural lows or down-faulted basement blocks.

The RTP aeromagnetic anomaly map (Figure 4b) is characterized by the dominance of negative magnetic anomalies in the Central part of the study area. The Northern and Southern parts are characterized by intense positive magnetic anomalies constituting several peaks of high amplitudes.

These peaks reflect very high magnetic susceptibilities and may be attributed to the occurrence of subsurface basic intrusions of high magnetic contents at different depths. In addition, the differences in magnetic relief between each of the two adjacent magnetic highs and lows suggest a comparable variation of lithology.

This map also shows that the local magnetic anomalies are superimposed on the regional magnetic field. These anomalies are most probably related to the basement faulting structural highs and lows.

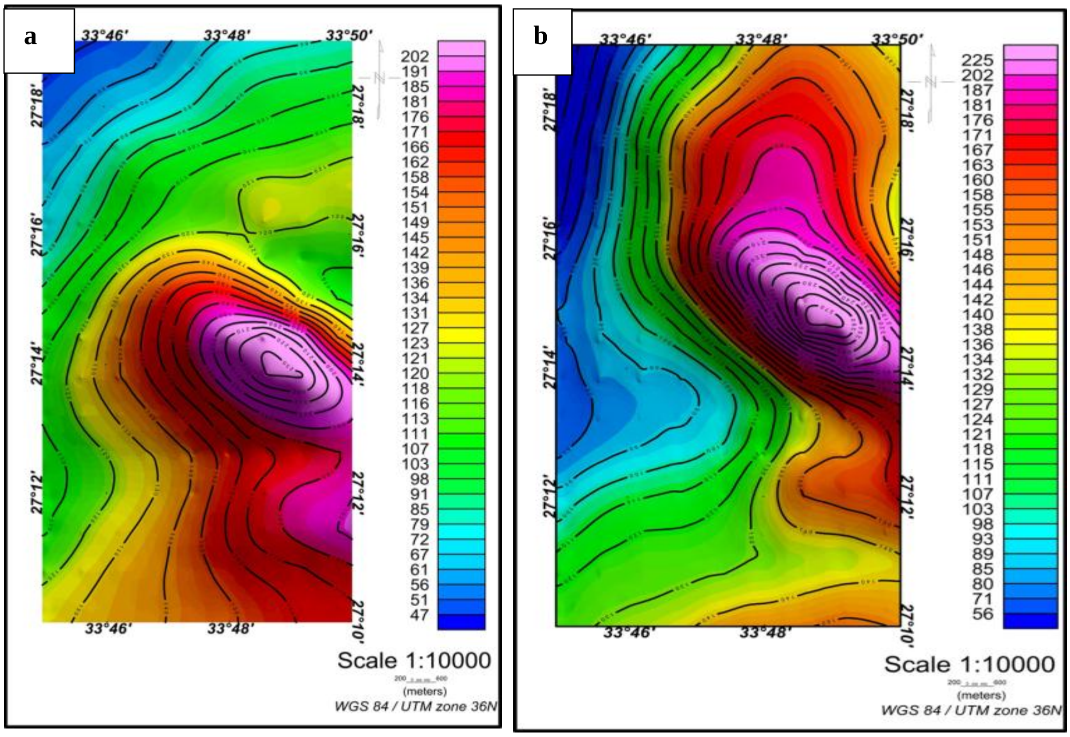

Figure: 4 The Reduced to the North magnetic pole (TMI) ground total magnetic field intensity map (a), and (b) Reduced to the north magnetic pole (RTP) airborne total magnetic field intensity.

DISCUSSION AND ANALYSIS OF STRUCTURAL ELEMENTS:

Analysis of the ground magnetic and seismic interpretation considerably anatomized network of faults across the study area on the basement level and within the overlying sedimentary section (Figures 4, 5, 6). Many elements, lineaments, a line or discontinuities representing the probable fault, of these following magnetic are of dip-slip nature and others of probable strike-slip nature. The four trends of predominant faults across the study area are of, NNW-SSE (bounding faults), NW-SE and N-S. All of these trends were dissected by ENE-WSW. The ENE-WSW crosscutting trend is represented in the sedimentary fault network in the most parts of the study area and another one, lying in its Northwestern part. These faults are interpreted as probable transfer faults and extend across the full width of the basin. These faults appear to mediate shallow saddle regions that separate narrower sub-basins in the central, from broader sub-basin developed in the Northeastern and Southeastern parts of the study area. This feature may be of comparable regional significance, especially as evidenced by its presence in the magnetic data, (Figure 4).

USE OF ATTRIBUTES TO ENHANCE STRUCTURAL INTERPRETATION:

In this study, we used the Coherence attributes technique based on 3D seismic data which showed trends of faults in the area when talked more one-time slice noted the structure changed from time slice to another time slice. Seismic coherence is a measure of lateral changes in the seismic response caused by variation in structure, stratigraphy, lithology, porosity, and the presence of hydrocarbons. Based on these attributes we noted the main trend of faults, (Figure 5).

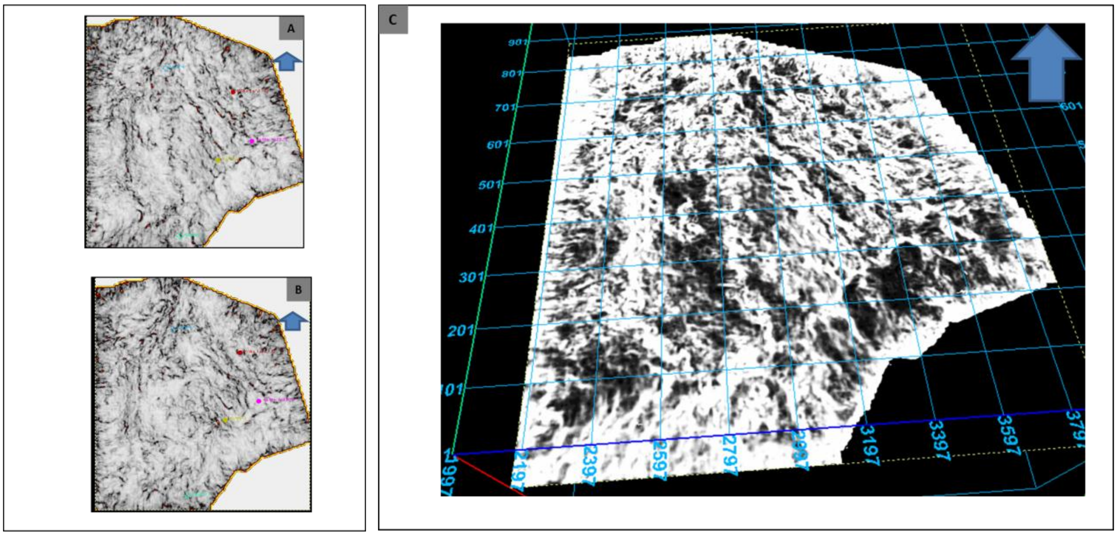

Figure5:Variance seismic attribute map on near top Basement at 1600 msc. (A) and on near top Nubia at 1300 msc. (B) to enhance structural interpretation of the study area on top Basement and Nubia, Coherence seismic attributes map in 3D view on near top Basement at 1600 msc. (C).

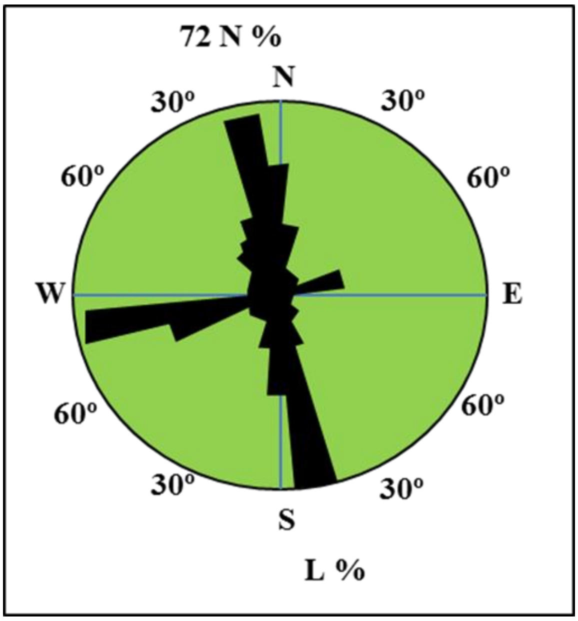

Figure 6: Rose diagram showing fault strike in the study area in total numbers and the total length of the structural trend of the Pre-rift (Basement, Nubia, and Matulla).

THE INTERPRETATION OF STRUCTURAL TRENDS:

In this study, major trends of ground magnetic, structural attributes, and seismic maps were traced and analyzed. The results are plotted as rose diagrams for the counted number, in percent (N, %) and the measured length, in percent (L, %). The major trends can be summarized as follows:

The Major trends are ENE-WSW and NNW-SSE in a decreasing order. Meanwhile, major trends measured in length are the same and directed towards E-W and NNW-SSE in a decreasing order.
The results of trend analysis of structural attribute data are plotted on (Figure 5). Major trends are E-W and NW-SE in a decreasing order. Meanwhile, major trends in length are E-W, NW-SE, and NNE-SSW in a decreasing order, (Table 1).

The results of trend analysis of seismic data are plotted as a rose diagram (Figure 6). Major trends, counted in number percent (N, %) are NNW-SSE, E-W, and NE-SW in a decreasing order. Meanwhile, major trends measured in length follow the same directions, in a decreasing order, (Table 1).

BASEMENT DEPTH DETERMINATION:

In this study, depth determinations were carried out based on 3-D Euler Deconvolution methods. The 3D Euler deconvolution technique was carried out on the magnetic data. For interpreting fault types, the magnetic data structural index SI = 0.5 (for magnetic fault, Reid et al., 1990) was used. According to the 3D Euler Deconvolution method, the depths of the basement in the study area were found to be widely variable. The recorded depth values range from about 12000 feet (M. S. L.) in the deepest location on the Southwestern part, to 5000 feet in the shallowest ones in the Eastern and Southeastern parts of the study area (Figure 7).

DEPTH STRUCTURAL CONTOUR MAPS BASED ON 3D SEISMIC DATA:

DEPTH STRUCTURAL CONTOUR MAP ON THE TOP OF BASEMENT:

The depth structural contour map on top of Basement, based on 3D seismic data, (Figure 7), shows two main structural lineaments (fault) trends, directed towards the NNW- SSE (F1, F2, F3, and F10).

The NNE-SNW (F5,F6,F7, and F9) trend appears to represent the dominant one. The variation in basement depth is structurally controlled. The interpreted depth values range from 12000 feet at the deepest location to about 6000 feet in the shallow one. The faults are normal, the trend towards the NW-SE direction and throw towards the Eastern and Western directions forming graben structures and step faults. These faults dissected by the trnsfere faults (cross element) in ENE – WSW trend and represented by FA,FB,FC,FD and FE where based on seismic interpretation in the study area.

The locations of sub - basins, during the deposition of this sequence, are mainly located in the northwestern, southeastern and southern portions of the central part of the study area. The Precambrian structural (fault) trends in the Basement are of NW-SE direction that is a result of the Clysmic system (Precambrian) orogeny, inherited in Basement rocks.

Table 1: Results of trend analyses of seismic data of West Hurghada area

Trend	N	L (km)	N %	L %
NNE – SSW	5	8.4	6.94	5.6
ENE – WSW	7	20.7	9.72	13.8
NNW - SSE	28	45.5	39.44	33
N-S	21	39	28.16	26.7
E-W	6	30.2	8.33	20.13
NW-SE	5	5.1	6.94	3.4
Total	72	150	100	100

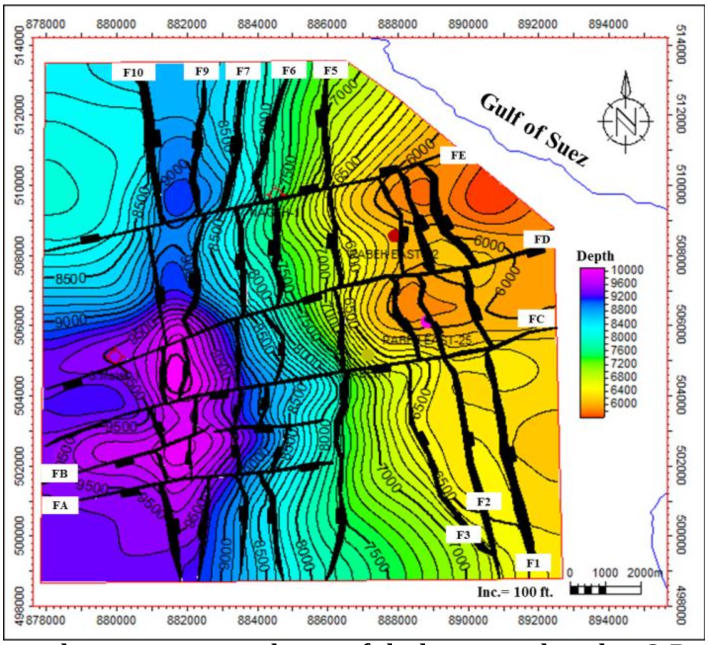

Figure 7: Depth structural contour map on the top of the basement, based on 3-D seismic data.

DEPTH STRUCTURE CONTOUR MAP ON TOP OF NUBIA:

The depth structural contour map on the top of Nubia based on 3D seismic data (Figure 8). The main fault trends, NNW-SSE bounded faults (F1, F2, F3, and F10) and NNE-SSW (F5,F6,F7, and F9),to ENE-WSW transfer faults (FA,FB,FC,FD, and FE) where the former trend appears to represent the dominant one. The general configuration of Nubia is also structurally controlled. The interpreted depth values range from 9600 feet in its deepest location to 5400 feet in its shallowest one. The locations of sub-basins, during the deposition of this sequence, are mainly located in the Northwestern, Southeastern and Southern portions of the central part of the study area. The trend of Nubia is mainly of the NW-SE direction that is the result of the Clysmic system, whereas it represents the source and reservoir rocks in the study area, as indicated from the drilled wells.

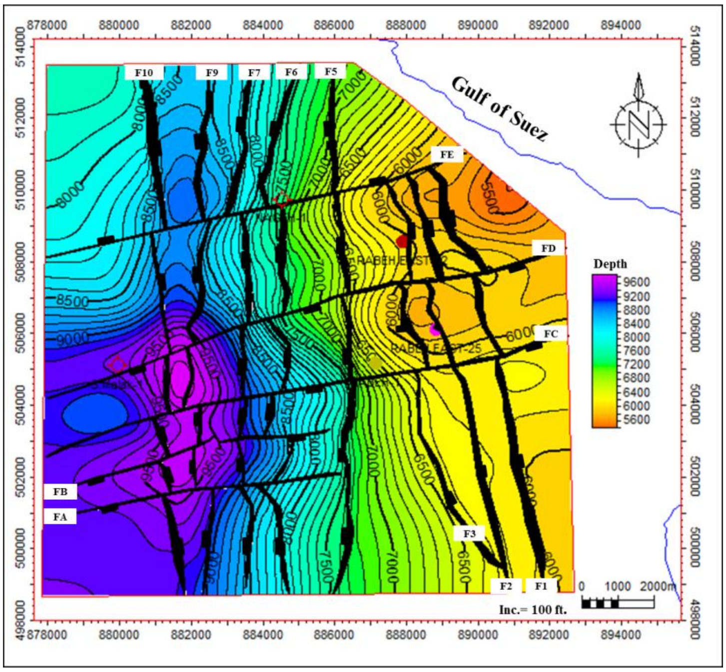

Figure 8: Depth structural contour map on the top of Nubia, based on 3D-seismic data.

DEPTH STRUCTURE CONTOUR MAP ON TOP OF MATULLA:

The depth contour map from the top of Nubia to the top of Matulla (Figure 9) shows variable thicknesses ranging between 250 feet to 430 feet. The maximum thickness of Matulla is encountered in its Southwestern and Southeastern parts of the study area. Meanwhile, it exhibits its minimum thickness in the Eastern part of the study area.

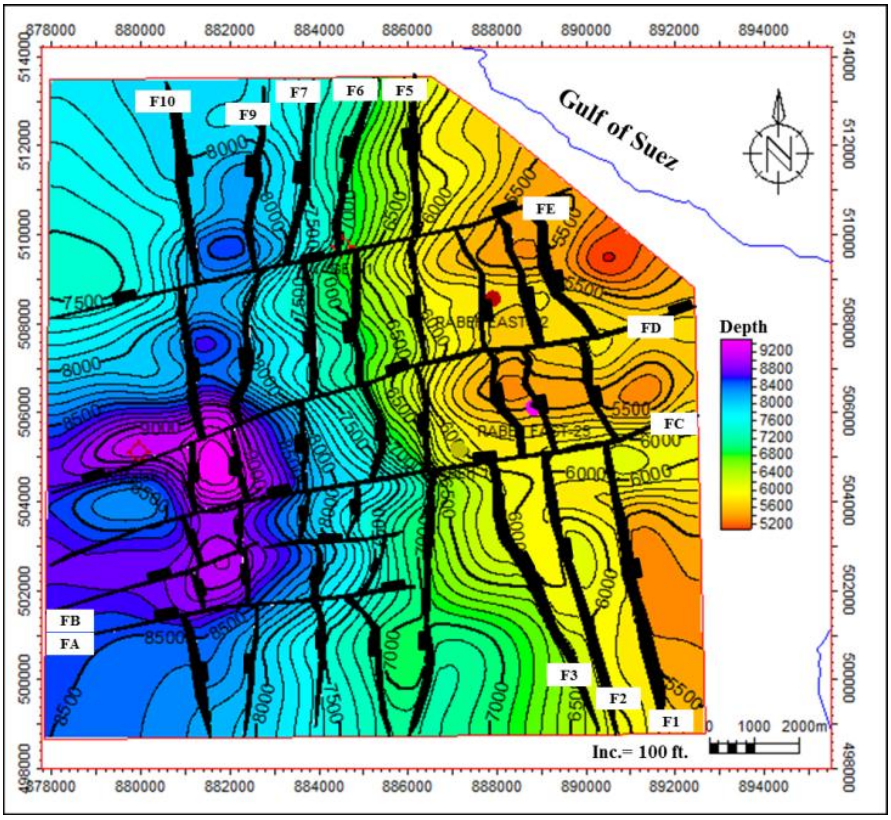

Figure 9: Depth structural contour map on the top of Matulla, based on 3D-seismic data.

The study the depth configuration and structural framework of the Basement and the overlying Pre-rift sedimentary section (Nubia and Matulla), two NNW-SSE and dissected by ENE-WSW trending profiles were forwardly and inversely modeled in terms of magnetic and seismic data.

STRUCTURE ARCHITECTURE OF WEST HURGHADA:

The two profiles are situated along two seismic lines.The cross line and inline of seismic data was made in E-W and N-S, based on regional knowledge, integration of well data was provided. The Figures (10&11) show the structure model section along the tow seismic lines. The results of modeling, after fitting of Basement surface, using well data integrated. These two figures also show the modeling on the two profiles, containing the two seismic lines 900 and 2791 respectively.

The two cross sections profiles show that the study area is characterized by uplifting structures, affecting Basement rocks, located towards the Northeastern and Southwestern parts of the study area. From the two geological cross sections in NW-SE and SW-NE trends, the Basement rocks form depressions in the Western side and Southwestern part of the study area. These uplifting and down-thrown structures (horsts, grabens, and step faulting) affect the overlying sedimentary section. The Basement depth reaches about 12000 feet in the Southwestern of the block and becomes shallower to the East and Northeastern part of the study area (about 5000-6000 feet, (Figures 12&13).

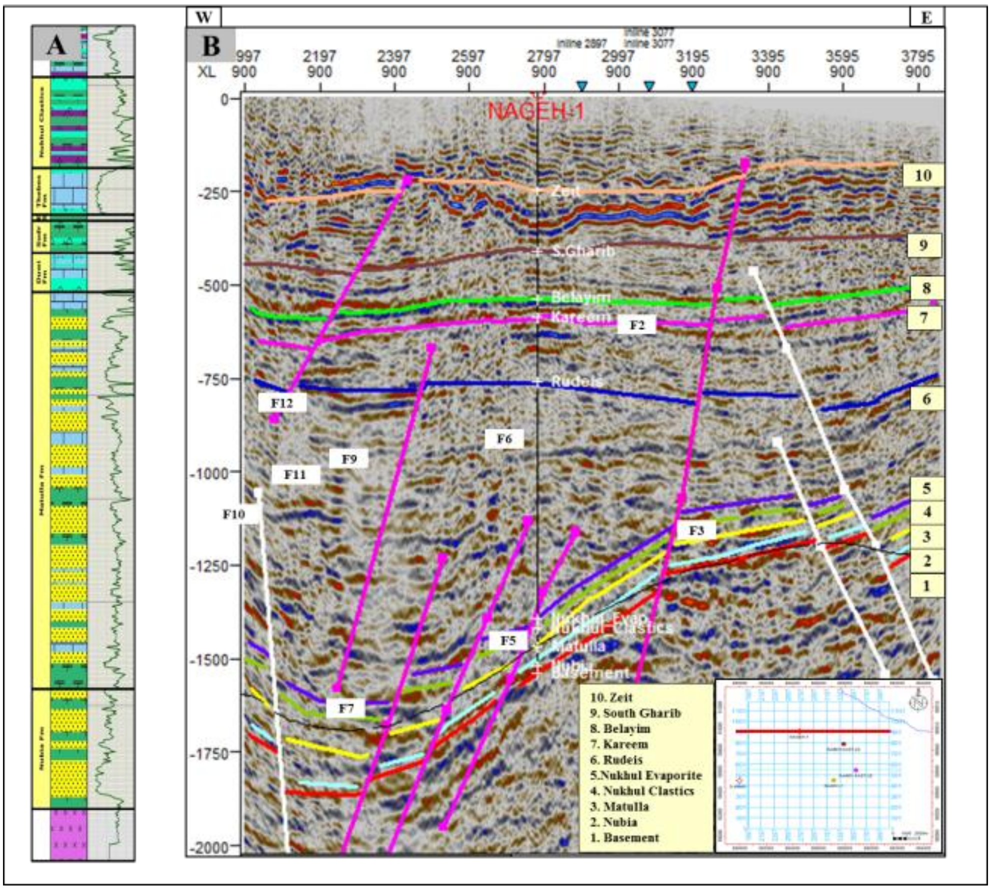

Figure 10: Stratigraphic boundaries and well log data of Nageh well show Pre-rift and Syn-rift formations (A). And E-W Seismic section (cross line 900) showing the identified faults (B).

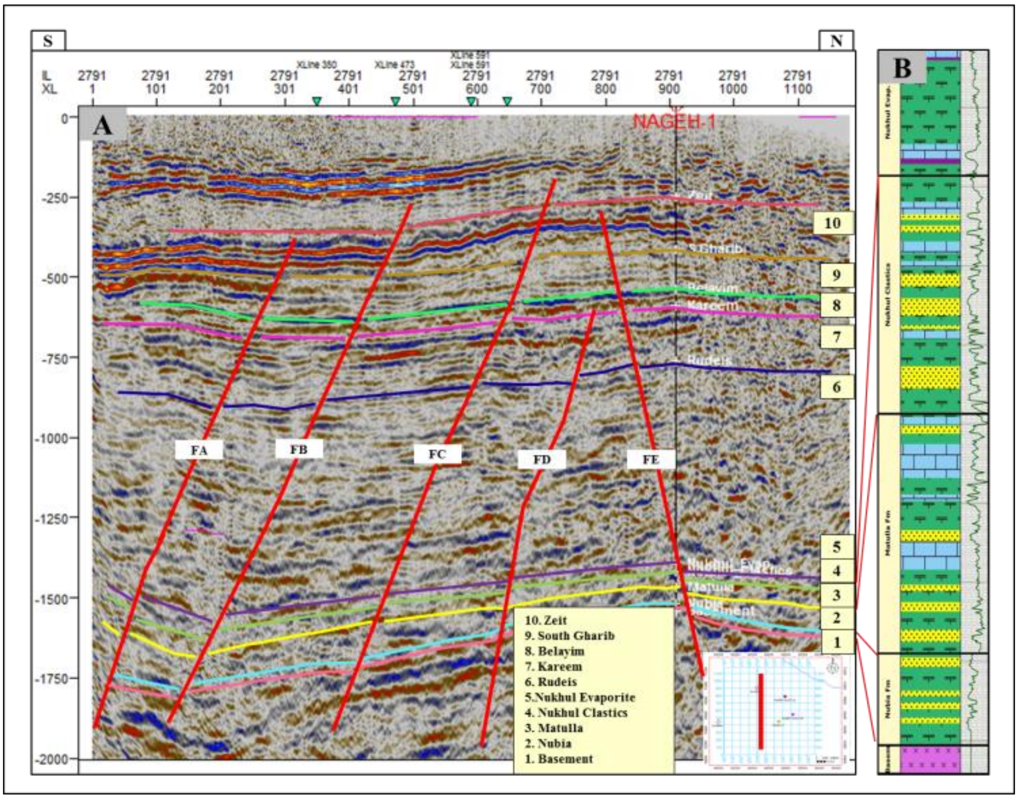

Figure11: Seismic section (inline 2791) showing the identified faults and picked reflectors (A). And stratigraphic boundaries and log response of pre-rift and Syn-rift formations of Nageh-1 well (B).

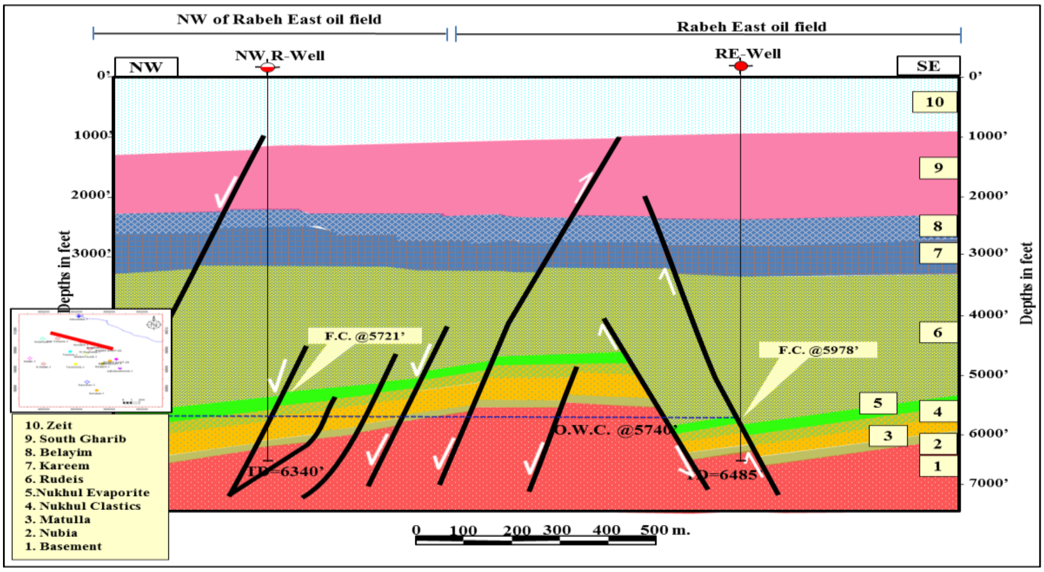

Figure 12: Regional structural cross section along the northwest Rabeh East and Rabeh East oil field, shows the identified structures of the West Hurghada area.

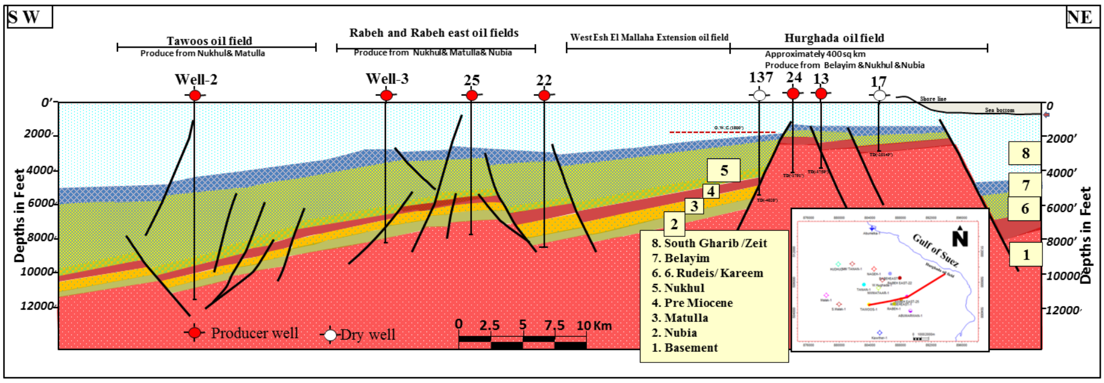

Figure 13: Regional Structural Cross Section along the study area and across the West Hurghada basin and shows the pinching out of Pre-rift and Syn-rift sidiments.

Table 2: Results of trend analyses of geological data of West Hurghada area, Southern GOS.

Structural attributes	Ground magnetic data	Seismic data
ENE– WSW	E – W	NNW – SSE
NW – SE	NNE-SSW	NNE-SSW
NNW-SSW	NNW – SSE	N-S
NNE-SSW	ENE-WSW	ENE – WSW
N – S	N-S	E-W

SUMMARY AND CONCLUSIONS:

The area under investigation is bounded by two major faults (F1 &F10) striking in the NW-SE to NNW-SSE trend; both of them are downthrown to the Southeast, while the others faults between these bounding faults are downthrown to the Southwest, creating a major graben.

This graben is separated from another major one by an accommodation horst of eastern part of the study. All these structural segments are good evidence for an ideal rift system configuration.

The magnetic and seismic data of the study area were analyzed through the application of some conventional frequency-domain filtering operations.The seismic data were used to realize and integrate the goals of this study, including 3Dseismic data sets and well data, which include Vertical Seismic Profile (VSP).

The study area is characterized mainly by the presence of main structural trends (Table 1) such as; E-W, NW-SE, NNW-SSE, NE-SW, NNE-SSW and N-S. Then all of these faults were dissected by the ENE-WSW extensional faults which perpendiculars on the Clysmic trend of the Gulf of Suez refitting.

In the study area, the detailed interpretation and integration of the ground magnetic, structural attributes and seismic data showed:

The NW-SE to NNW-SSE and NE-SW to NNE-SSW structural trends are confirmed by these geophysical techniques in the magnetic and seismic beside the structural attributes, (Table 2). This trend is parallel to the rift bounding faults of the Red Sea-Gulf of Suez (Clysmic or Erythrean faults). It is dissected by another structural trend (ENE-WSW) of Trans-African that is confirmed from the magnetic and seismic data.

The N-S meridional trend is a fault, that is indicated only from geophysical methods(Magnitic and seismic methods). The estimated average depth, from magnetic and seismic data, for the regional (deep-seated) sources.The depths of basement complex, Nubia, and Matulla formations range from12000 feet to 9600 feet, 9200 feet at the Western side and 6000 feet to 5600 feet and 5200 at the Eastern side respectively. The thickness of the top of basement complex to the Matulla shows variable thicknesses of that interval and range between 300 feet to 600feet.Two of the seismic profiles, controlled by the drilled wells, were modeled through the integration the magnetic and seismic data.

ACKNOWLEDGMENTS:

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من اهم نتائج البحث توضيح ودراسة الوضع الجيولوجي وتحليلات الصدوع الموروثة وأحداث التصدع في الهامش الجنوبي الغربي من صدع خليج السويس. عموما، وتولى الدراسة الحالية اهتمام خاص لصخور ما قبل العصر الميوسيني من قبل الدراسة المطروحة وكذلك من قبل شركات النفط العاملة بمنطقة الدراسة.

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