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Structural Implications of the Miocene Sequence in Abu Darag Basin, North Gulf of Suez, Egypt, Using Seismic Reflection Data

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Abstract: Seismic reflection re-evaluation was attempted at the extreme northern offshore portion of the Gulf of Suez. Interpretation of the seismic data and the information extracted from bore-holes penetrated in Abu Darag basin had led to construct a number of structural and isopach maps for the Miocene formations, confirmed by two geologic cross sections. They reveal much of the structural set-up, as well as the lateral and vertical distributions within the study area. The structural analysis shows that, Abu Darag basin is a NW pre-Miocene/Miocene trending graben that is dipping steeply toward the southwest. The frequency curves on the tops of Miocene targets indicate that the basin was affected by a poly-cyclic rift stages. The peaks correlation suggests rejuvenation of the NW Clysmic and NE Syrian Arc trends, in consequence with the Gulf of Suez tectonics. The isopachs show a real thickening of the Miocene and post Miocene sections toward the southwestern part, due to the subsidence and tilting of the fault blocks. They exhibit a substantial thinning at the northern portion of the basin, as a result of the Cretaceous folding and uplifting. The cross sections confirm that, the Miocene clastics were controlled by the pre-Miocene structures. They suggest that, the basin is tectonically ceased since the Upper Miocene time, with minor deformations accompanied with syn-rift tectonics.

Key words: Abu Darag · Cross sections · Gulf of Suez · Isopach map · Seismic analysis · Structural map

INTRODUCTION

Abu Darag basin locates the northern part of the Gulf of Suez. It occupies the offshore part of the northern (Ataqa) province and extends for about 45 km long and an average width of 20 km in the NW-SE direction. The basin is stretched between Latitudes 29° 20′ & 30° 00′N and Longitudes 32° 20′ & 32° 50′E (Fig.1). The research aims to review the assessment of the local structural set-up and the regional conditions controlling Abu Darag basin. It is devoted to delineate the subsurface deformations and to define the extension and thickness variations of the time rock units. Ultimately, it tries to put new locations into mind favor for further explorations activities. The available data used in this study include a total of about 1050 km offshore seismic lines conducted through April 1976 for the Gulf of Suez Petroleum Company (GUPCO). Thirty-two seismic sections processed by GSI (Geophysical Service International) were incorporated with other nine lines recorded by Apache Company. These seismic lines cover

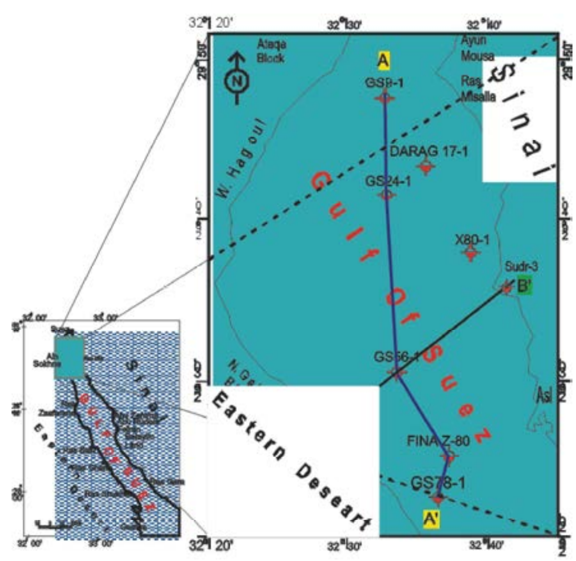

Fig. 1: Location map of the study area showing location of the drilled wells and cross section profiles (AA' & BB'

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the marine part and intersected with each other, forming a grid pattern. The first set consists of 24 lines, were oriented in the NE-SW dip direction. The second set of 17 lines, were oriented in the NW-SE strike direction. The sonic logs and well velocity surveys of Darag-1, GS 9-1, GS 24-1 and X 80-10 wells, as well as the synthetic seismogram of Fina Z-80-1A well were used as a source of the velocity measurements. The composite log and lithostratigraphic information were used to confirm the sonic logs correlations. All were integrated to establish the shape, structure and general dip of the reflecting horizons.

Relating the seismic reflections to the well velocity data, the upper and lower boundaries of the Miocene formations were identified. The deduced horizons were depth migrated on all sections and depth structural contour maps on the tops of these targets were satisfactorily worked. A structure contour map on the top of pre-Miocene section was obtained, as the deepest unreliable depth map. They focus the attention on the pre-Miocene highs and consequently the distribution of oil traps. As well, the structural maps on the tops of Nukhul, Rudeis and Kareem Formations throw more light on the faulting systems affecting of the Miocene clastics. A statistical study was carried out for the deduced faults on the different tops to follow up the tectonic setting of the area. In addition, based on the composite logs, isopach maps for these targets were constructed and tied with the seismically derived isopachs. They demonstrate the development of the basin depocenters through the rift stages. Moreover, two geologic cross sections were constructed, in parallel and cross to the Gulf of Suez feature, to confirm and throw more light on the basin structure.

Geologic Setting: The Gulf of Suez Rift is a continental rift zone, that was active between the Late Oligocene (ca. 28Ma) and the end of the Miocene (ca. 5 Ma) [1]. It represented a continuation of the Red Sea Rift [2, 3] until the break-up occurred in the Middle Miocene, with most of the displacement on the newly developed Red Sea spreading centre, being accommodated by the Dead Sea Transform. During its brief post-rift history, the part of the remnant rift topography has been filled by the sea, creating the Gulf of Suez. North of the Gulf of Suez, the rift becomes indistinct and its exact geometry uncertain, linking eventually to the Manzala riftbeneath the [4]. Stratigraphically, the information derived from the drilled wells in the study area indicated that, the area is characterized by a thick sedimentary section unconformably overlying the basement rocks of theArabian-Nubian Shield. The stratigraphic column in the study area (Fig. 2) ranges in age from Precambrian basement complex to recent [5, 6]. It includes several major and local unconformities, as indicated from the composite logs of the drilled wells. Abu El-Ataand Helal [7] explained and discussed the criteria for the recognition of strike-slip faults on the seismic data as indicators of shearing deformations, along the western coast of the Gulf of Suez. Figure 3 shows the main tectonic features of the northern Gulf of Suez [8].

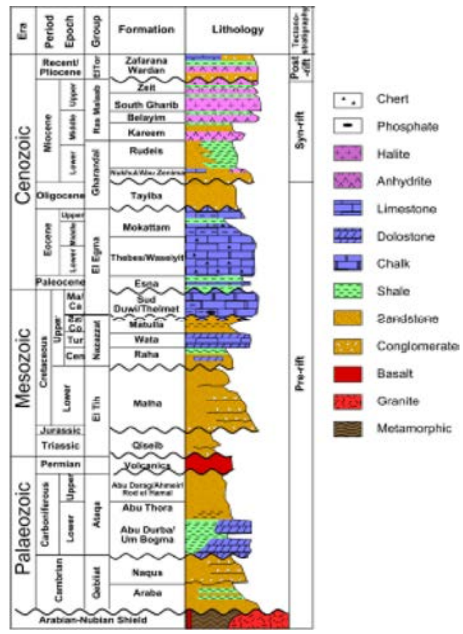

Fig. 2: Regional stratigraphy of the Gulf of Suez (after Darwish and El Araby [5]).

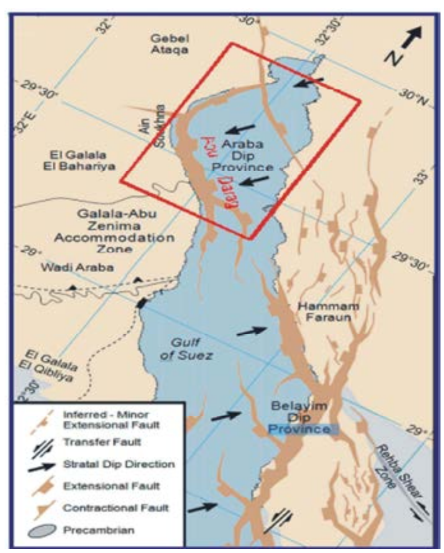

Fig. 3: Tectonic map of the northern Gulf of Suez Rift (after Bosworth and McClay[8]).

Velocity Analysis: The average and interval velocities, as well as the comparable times for GS 56-1, GS24-1, Darag17-1A and X60-1 wells were determined and plotted versus depth (Figs. 4-7) to define the vertical velocity variations. The average velocity ($V_{av} = Z/t$) is simply defined as the velocity over certain reflecting surface below the seismic reference datum [9]. The average velocity down to the tops of different formations has been determined from the well-velocity data using the depth-velocity relations utilizing the simple equation of Dobrin [10]. Figures 4-7 show that, the average velocity increased generally with the depth, particularly those corresponding to the pre-Miocene formations (clastic sequence). The interval velocity represents the velocity of a wave front travelling through a single homogeneous rock unit. It depends mainly on the lithology of the formations, in addition to the depth, temperature and pressure. Mathematically, it can be calculated from the simple equation according Dix [9]. ($V_{int} = Z_2–Z_1/ t_2–t_1$). Figures 4-7 show low interval velocities for the Miocene and post-Miocene formations, with respect to the pre-Miocene formations velocities. They also show that, the interval velocity of Nukhul Fm. always have high values than those of Rudeis and Kareem Fms. This may indicate the presence of high content of hard carbonates and anhydrite in the Nukhul Fm. with respect to the Rudeis and Kareem Fms. This may also reflect that, the Nukhul Fm. was deposited in maritime environment, may be deeper than those of Rudeis and Kareem Fms.

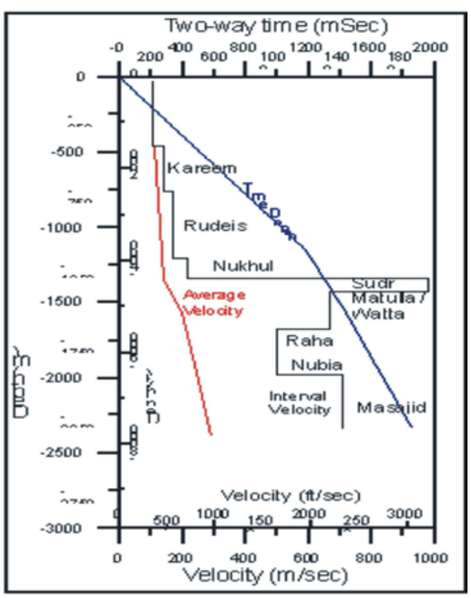

Fig 4: Time and velocity measurements versus depth of GS17-1well.

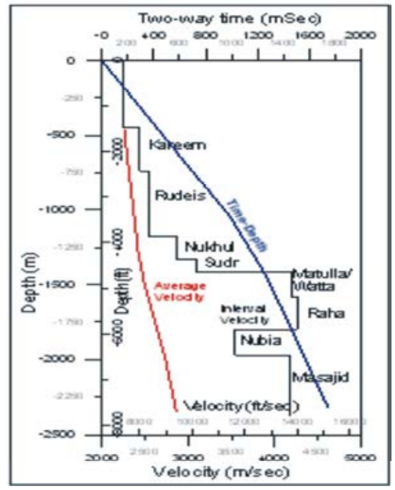

Fig 5: Time and velocity measurements versus depth of GS9-1well.

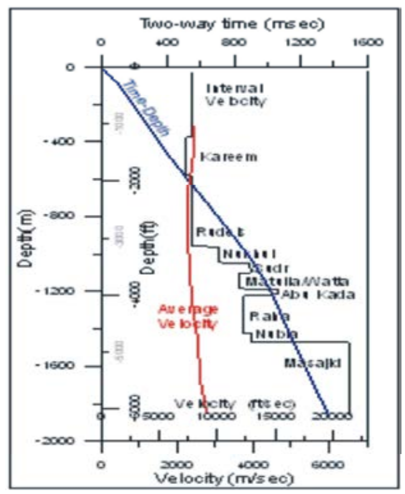

Fig 6: Time and velocity measurements versus depth of GS24-1well.

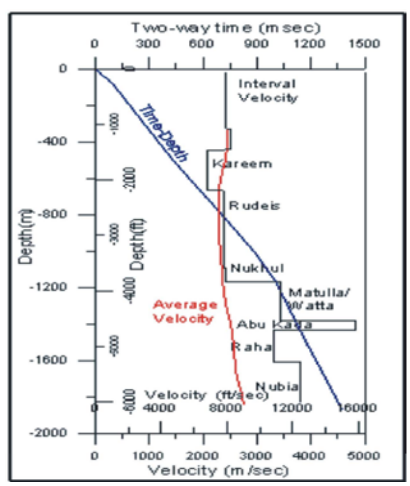

Fig 7: Time and velocity measurements versus depth of X80-1well.

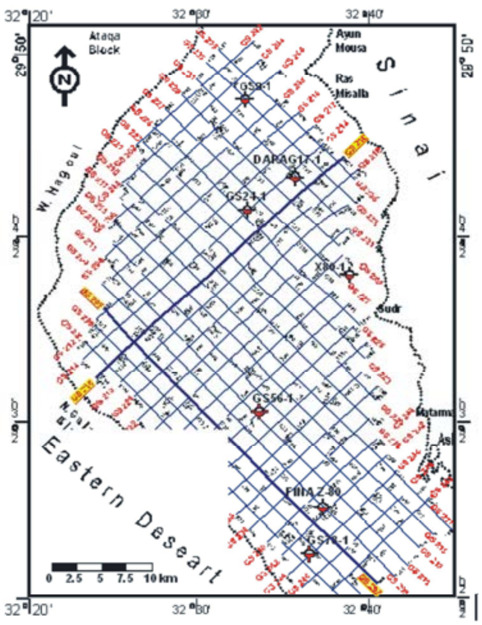

Fig 8: Shot-points location map of the study area.

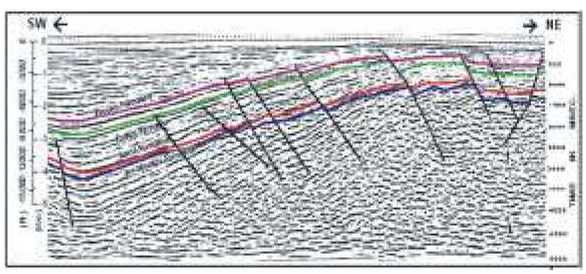

Fig 9: Interpreted seismic section GS-216, with NE-SW (dip) direction.

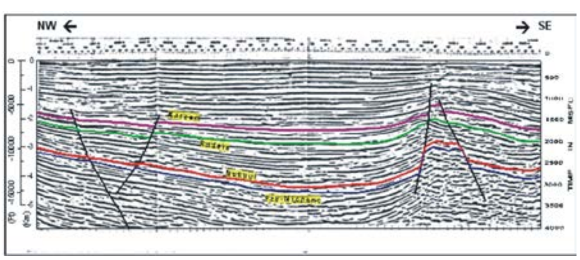

Fig 10: Interpreted seismic section GS-207, with NW-SE (strike) direction

Seismic Lines Interpretation: Two samples of the seismic lines named GS-207 and GS-216 were interpreted with the structural elements expected and by migration of the interpreted time intervals to depths through the well known velocities across the various rock units. The locations of these two lines are shown in the shot-points location map (Fig. 8). The first seismic section GS-216 (Fig. 9) was acquired in the dip direction (NE-SW), that parallel to the cross-gulf elements. It highlights many of the longitudinal faults and the widths of the tilted fault blocks. The structure along this trend is characterized by a general dipping of the sedimentary strata towards the SW, with thickening of the sedimentary section as a whole. It clearly reveals wedging of the post-Miocene sediments toward the northeastern direction. The structural elements exhibit the presence of nine normal faults with downthrown sides mostly northeastward. They show that, most of the faults were activated from the basement surface, extending upwardly into the overlying sedimentary sequences, including the pre-Miocene and Lower Miocene rock units. The structures indicate that, the deduced faults do not affect the Quaternary and younger rocks. This suggests that the basin almost tectonically ceased since the Upper Miocene time, with minor faulting accompanied with the recent tectonics. The second seismic section GS-207 (Fig. 10) is trending in the NW-SE (strike) direction that may help in mapping the cross-gulf elements. The reflectors picked in this line show a gentle southeastern dip regime. In fact, it is difficult to recognize the faulting, folding and uplifting as those defined in the dip lines. The structure is evidenced by a few faults that almost originated in the basement surface and terminated through the Middle Miocene before reaching the surface. This may explain the fact that, the study area is recently stable like those adjacent areas in Northern Egypt. The southern portion exhibits a substantial thinning of the sedimentary section, as a result of the local folding and uplifting. Commonly, these two examples reflect the effect of pre-Miocene structures on the Miocene clastics. They indicate that, the cross fault elements, either the NW or NE were originated in the pre-rift series.

Structure Contour Maps: The interpretation has been traced four reflectors on the tops of the pre-Miocene and Lower Miocene unit, Nukhul, Rudeis and Kareem Fms. The structure contour maps were constructed through converting the reflection times (TWT) into depth by using the average velocity. The structure contour map on the top of pre-Miocene sequence (Fig.11) shows the most complicated pattern of fractures. The contours are dipping steeply down toward the SW, where the maximum depth exceeds 5000m, while the minimum depth reaches 1500m at the northern portion. The structure shows the dominance of NW-SE fault system, particularly along the coast lines of the gulf. The boundary faults extend over long distances and seem to have larger throws than the entire ones. Basinward, the longitudinal faults were traversed by smaller faults of NE to E-W orientations and

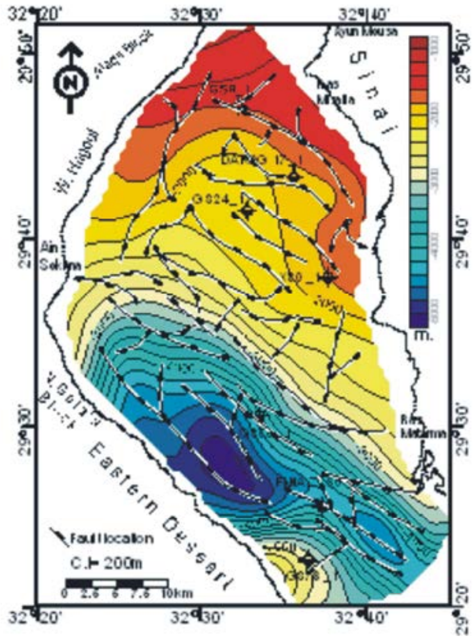

Fig. 11: Structure contour map on the top of pre-Miocene sequence.

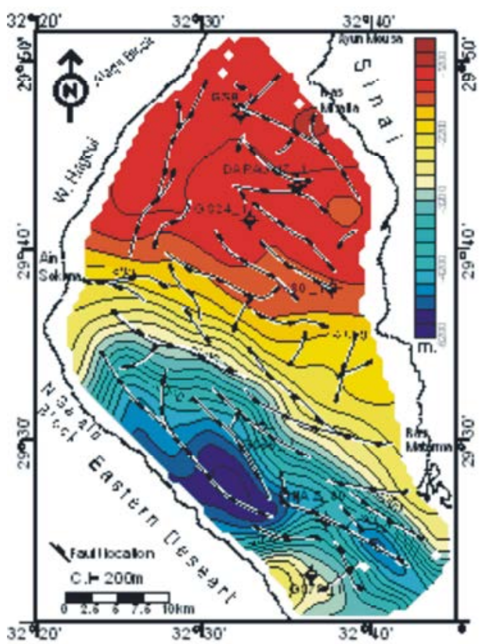

Fig. 12: Structure contour map on the top of Nukhul Formation.

gave rise to different closures that may act as good leads in case of sealing the hydrocarbons upwarding from the basin. The interaction between these two sets of fractures has resulted in the dissection of the pre-Miocene package into northwesterly trending fault blocks. The structure contour map on top of the Nukhul Fm. (Fig. 12) nearly reflects the same numbers and locations of faults, as well as the closures were observed on the top of pre-Miocene. This may indicate that, the Lower Miocene clastics were affected by the high and low structures of the pre-rift tectonics. The basin is westerly delimited by east-throwing faults, which strike parallel to the shoreline. The formation shows a great variation in depth from the northeast to the southwest, where it ranges from 1350 to 4800m, respectively. The structure reveals an ENE trending belt at the extreme northern part of the basin.

The structure map on the top of Rudeis Fm. (Fig. 13) still reveals the distributions of most deformation systems that were active during the pre-Miocene age. It shows similar structural distribution pattern with decreasing numbers and lengths of the faults affecting this top. Rudeis basin is characterized by a wide extension and a southwest dip regime. The contours show significant variations in depth to the top of Rudeis Fm., from northeast (1000m) to southwest (3500m). This large variation is certainly a consequence to the regional SW dipping of the northern (Ataqa) province of the gulf. The structure contour map constructed on the top of Kareem Fm. (Fig. 14) also illustrates a regional dipping to the southwest. The map reveals lesser complexity in the structures, where the fault density is a minimum. The lowest portion of Kareem Fm. is restricted to the western side (from 2500 to 2800m), while the highest part is found at the northern side (from 400 to 600m). The structure is thus overprinted by the rejuvenation of some marginal faults, particularly along the western side.

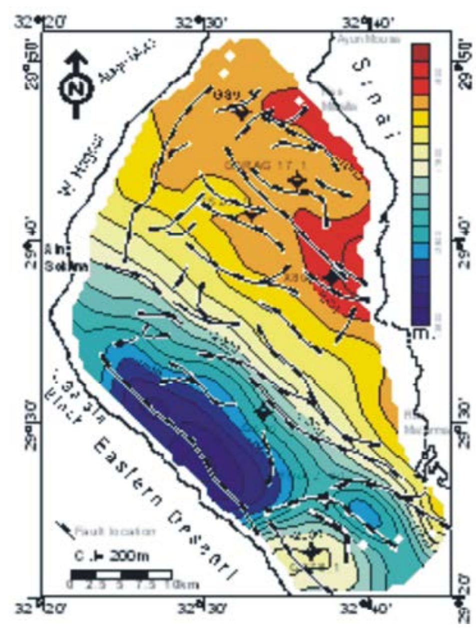

Fig. 13: Structure contour map on the top of Rudeis Formation.

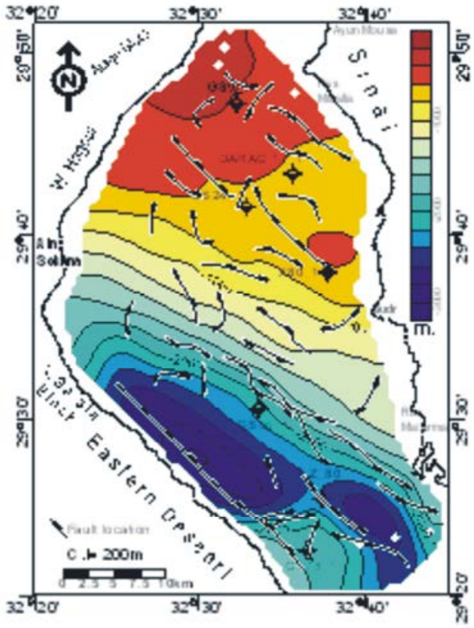

Fig. 14: Structure contour map on the top of Kareem Formation.

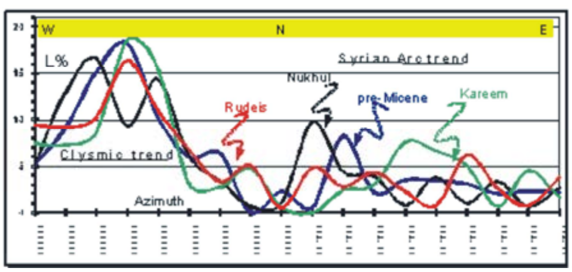

Fig. 15: Frequency distribution curves of the tectonic trends on the tops of the evaluated formations.

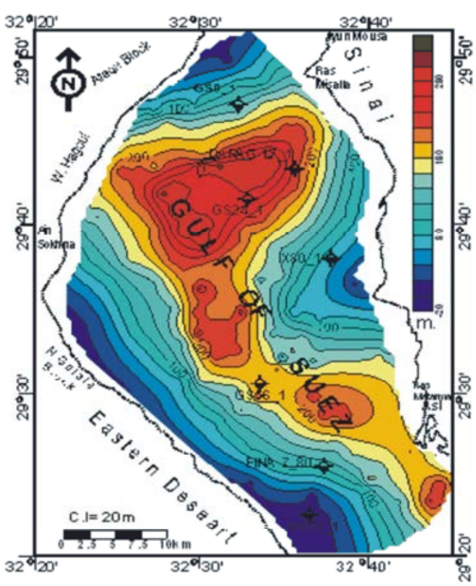

Fig. 16: Regional isopach map of Nukhul Formation.

Statistical trend analysis was established on the tops of pre-Miocene rock units, as well as the Nukhul, Rudeis and Kareem Fms. The results deduced on these tops were inferred from the frequency curves in (Fig. 15). They indicate that, the target formations were heavily affected and structurally controlled by the wide azimuth of the NW Clysmic trend, which was rejuvenated during the tectonic movements of the Gulf of Suez shear and rift phases. It was traversed by cross faults having the NE to ENE direction that can be attributed to reactivation cycles of the Syrian arc trend in northern Sinai and/or Gulf of Aqaba tectonics. The peaks on (Fig. 15) suggest that, the fault density decreases from the bottom (pre-Miocene) to the top (Kareem) and from west to east.

Isopach Maps: Depending on the composite logs of the drilled wells in the study area and the interpreted seismic sections, three isopach maps were constructed for Nukhul and Rudeis (reservoirs), as well as Kareem (cap-rock) Fms. The isopach map of Nukhul Fm. (Fig. 16) shows a broad basinal area extends from Wadi Hagoul in the west to Asl in the east. The distribution of Nukhul sediments shows two main depocentres. The axial trough of the northern depocentres strikes approximately northeast-southwest, while the southern one (Nebwi basin) is oriented in the northwest direction. The central offshore area seems to have been the most subsiding, where the Nukhul sediments reach about 300m around GS 24-1 well, while attain 100m at the margins. Nukhul Fm. was deposited unconformably over the Turonian (Wata Fm.) and Eocene sediments. This suggests a Late Cretaceous to Eocene/Oligocene erosion, followed by the deposition of Nukhul deposits (mainly L.S, Shale and S.S). During the Early Miocene rift phase, the Northern Galala and Wadi Araba were uplifted, actively eroded and established a site for sand supply, particularly at their scarps facing the gulf [11]. The isopach map of the Lower Miocene Rudeis Fm. (Fig. 17) is evidenced by a major sediment accumulation (>2500m) at the southwestern part, parallel to Gulf of Suez boundaries. It suggests a widespreading marine transgression over Abu Darag area. Southwestern thickening of Rudeis Fm. may reflect a great tectonic subsidence at the end of Nukhul Fm. Time associated with uplifting of the northern part. Commonly, the deepening of the rift is significantly recorded by the Lower Miocene Rudeis Fm, since it considered the most important and prospective syn-rift reservoir in the northern gulf. The presence of basement uplifts to the east and west of the study area is believed to be the main supply of these clastics. The Rudeis sediments are reduced in thickness at the extreme northern portion (<150m).

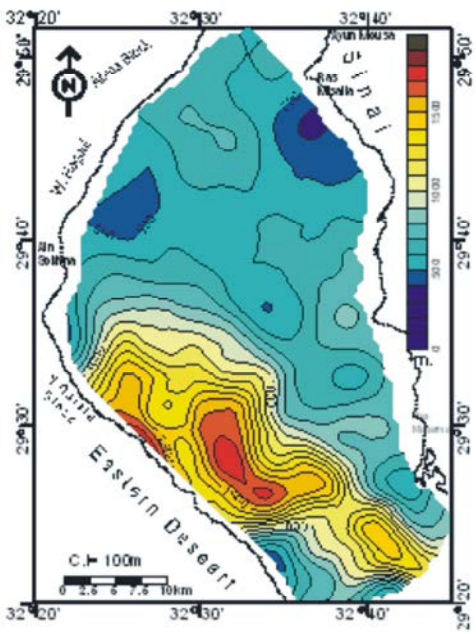

Fig. 17: Regional isopach map of Rudeis Formation.

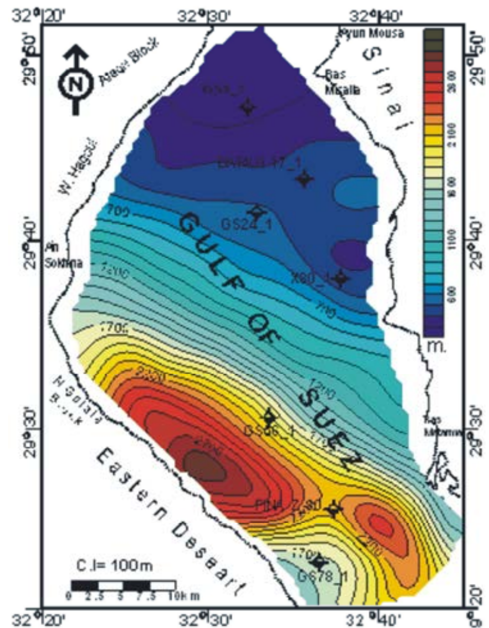

Fig. 19: Regional isopach map of post-Miocene section.

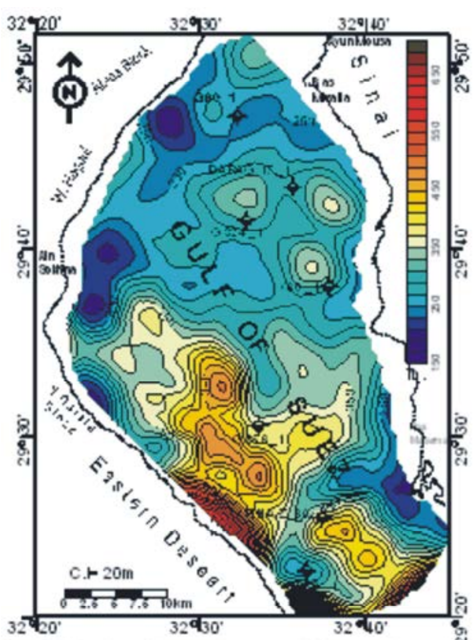

Fig. 18: Regional isopach map of Kareem Formation.

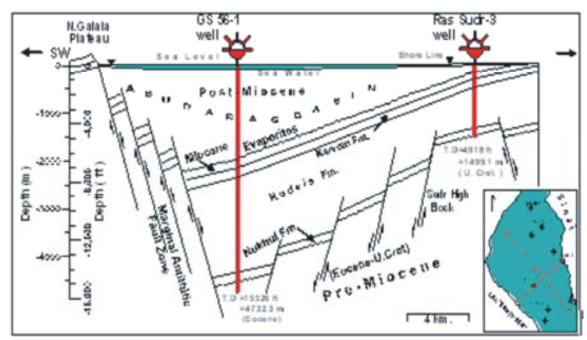

Fig. 20: Geologic cross section along the SW-NE trend.

Isopach map of Kareem Formation (Fig. 18) comprises two smaller sub-basins on the down thrown side of the major boundary faults, with the NW-SE trending depocenters. The sediments attain their maximum thickness at the western low (>600m) and reaches the minimum at the northern high (100-200 m). The Kareem Formation witnessed the first development of evaporites, indicating basin restriction. The sediments seem to be structurally controlled by the Miocene tilting and rotation. Isopach map of post Kareem (Fig. 19) is well developed in the western and southern parts, forming two depocentres with NW-SE axial troughs. The post Kareem sediments were heavily deposited parallel to the western shoreline, to the east of Wadi Hagoul and Northern Galalla, where it attains about 3000m in thickness. Northward, the formation sediments gets thinner, where it reaches about 200m. The distribution of the sediments suggests a southwest rotation, associated with westerly subsidence at that time (post Miocene).

Cross Sections: Two geologic cross sections were constructed using the available wells data, to confirm and throw more light on the regional structures of the study area. The first geologic cross section AA' (Fig. 20) shows a number of pre-Miocene down-faulted blocks oriented in the NW-SE direction. They indicate a southwestern regional dip regime, with extensive thickening of the

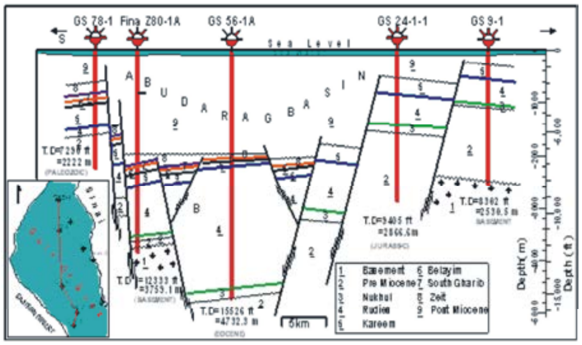

Fig 21: Geologic cross section along the S-N trend.

sedimentary cover as a whole in this direction. The structure exhibits a number of normal faults of different throws in a step-like form. Most of these faults penetrate the syn-Miocene sediments, while no ones can be traced in the post-Miocene rocks. The western borders are marked by a large fault zone of considerable throw, where the Miocene formations are directly in contact with the basement rocks. The structure suggests that, the basin is tectonically ceased since the Middle Miocene, with minor faulting accompanied with the Pliocene tectonics. The second cross section (Fig. 21) exhibits a number of northeast block faults, forming a deep basinal area around GS56-1 well (~5500m). The tectonic faults were developed preferentially along the pre-existing lines of weakness in the basement surface and die out through the Middle Miocene. The dense fractures led to the presence of some unconformities and missing of some formations, as recorded at GS 78-1, GS 24-1, GS 56-1 and GS 9-1 wells. Some of deduced faults are of growth or branching type as indicated by the great structural variation in the thickness of formations from one borehole to another. The depocentres lay either on the down-thrown side of the NW-SE Clysmic faults or on the down-dip flank of the blocked structures.

Summary and Conclusions: Our structural implications in view of the foregoing results obtained from the seismic data analysis, could be summarized as follows:

- The geology of the basin provides structural and stratigraphic conditions for hydrocarbon trapping, since they consist of complex fault blocks (horsts/grabens), unconformably overlain by a thick sedimentary series containing anhydrite layers.
- The seismic records show very strong reflections from the relatively shallow part of the subsurface and lake of information from the deeper parts. The strong reflections are actually corresponding to the high velocity and high density evaporites of the Upper Miocene and Pliocene, as verified by the wells data. Alternatively, the continuity of the seismic events in the deeper subsurface was markedly bad, which are related to the stratigraphic variations. Thus, the pre-Miocene reflectors neither mapped out nor aligned lineups along the seismic lines.
- The seismic evidence for the structure of Abu Darag basin shows the subsurface to be composed of a sharp relief graben structure interposed with faults of large throw, particularly along the western borders. The maximum thickness of the sedimentary cover reaches ~6.5 km at the extreme southwestern portion of the basin. Meanwhile, the minimum depth to the basement attains 2.4 km at the northern part.
- The structure exhibits two main types of faults that are controlling the tectonic subsidence of Darag basin these are; the major NW–SE longitudinal dip-slip faults and the traverse NE-SW strike-slip fault pattern. The structure suggests that, the gulf (NW) and cross-gulf (NE) trending faults are thought to be pre-rift structural fabric. They seem to be effectively rejuvenated during the Tertiary rifting phases (Oligocene and Early Miocene) along lines of weakness.
- Close correlation of the isopach maps reveals that, the main depositional areas were developed in the western part, where a high rate of prolonged subsidence and sedimentation took place. The Miocene clastics were derived from the uplifted and updip Precambrian and Early Paleozoic rocks at the eastern and western shoulders of the Gulf of Suez. The structural relationship between the North Galala plateau and the offshore gulf controls the distribution and accumulation of these sediments.
- The depocentres of the lower Miocene sediments suggest a little southwest tilting and blocks rotation. This was evidenced by the thick Miocene clastics, in particular, the Rudeis Fm. (~2500m). During the Middle Miocene-recent depositional time, a great southwest blocks rotation and severe subsidence took place with a continuous down movement, forming a westerly located deep basinal area of the Pliocene sediments (>3000m). Further to the north, the post Miocene sediments have reduced their thickness.
- Concerning the hydrocarbon traps that may be found in the buried structures, crests of the tilted blocks could be considered a good trap for the pre-rift or syn-rift oil migration. It was expected on the higher block sides, where the cross-gulf faults cut through

the Clysmic faults and where the oil migration and entrapment was controlled by the regional dip direction.

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