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FULL LENGTH ARTICLE

The improvements of three-dimensional seismic interpretation in comparison with the two-dimensional seismic interpretation in Al-Amal oil field, Gulf of Suez, Egypt

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Abstract Thirteen 2D seismic lines were interpreted with the help of well velocity and time-depth trace conversion to construct the structure-tectonic maps. This is to characterize the different stratigraphic tops of Al-Amal area, as well as to confirm the validity of the proposed structural model. Most of the available seismic data in Al-Amal area were investigated and reviewed to select the best quality set.

In order to study the detailed structural elements based on the 3D seismic lines; six depth structure contour maps were constructed on the tops of Zeit, South Gharib, Belayim, Kareem, Nukhul and Matulla formations from top downward. Interpretation was aided by the missing sections detected from the available well tops and dip-meter data as well. These maps indicate that, both of Miocene and Pre-Miocene formations in Al-Amal field were affected by elongated tilted graben blocks trending in the NW–SE directions and bounded by two sets of faults, which are down throwing toward the west and eastern directions.

1. Introduction

Al-Amal concession area is about 27 sq km in the offshore, southern province of the Gulf of Suez basin. It is located some 55 km from Ras Gharib city, about 15 km southwest from Morgan Oil field and about 15 km offshore from the western Gulf of Suez shoreline. Al-Amal field is located on a NW–SE faulted monocline, which has a SW dip, plunging due

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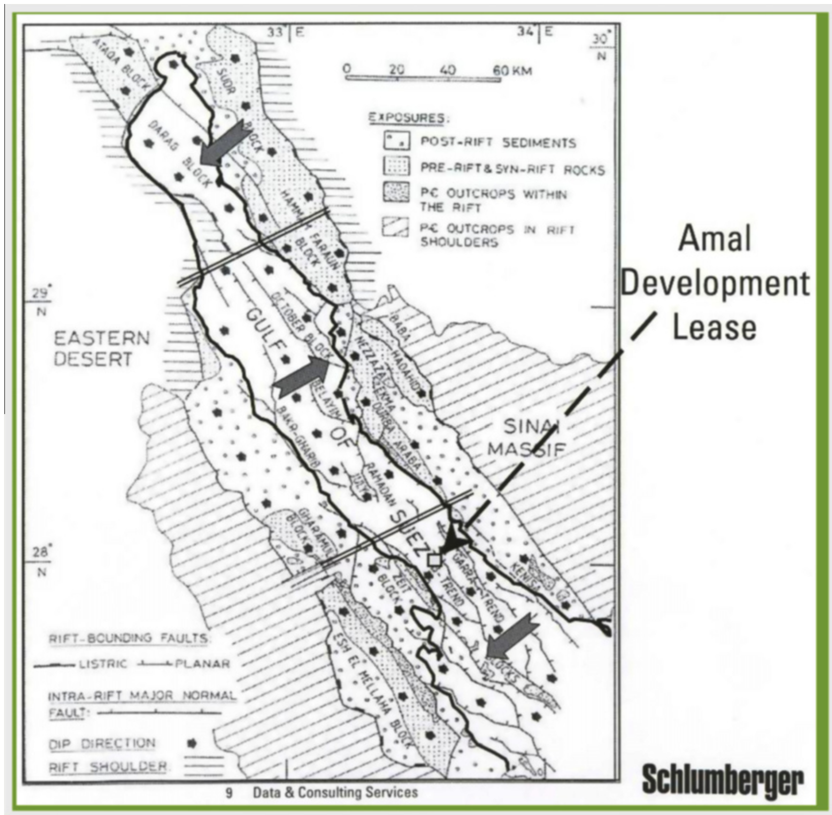

Figure 1 Amal field location map (After [1]).

NW and SE, sealed by clysmic faults and capped by Middle–Upper Miocene Evaporates (Fig. 1).

The field was discovered in 1988, started on November through five wells, producing hydrocarbons from the Lower-Middle Miocene reservoirs (Kareem and Rudeis formations), with a daily oil rate of 6500 BBL. This field is a byproduct of a complex positive structure located in the Gulf of Suez (southern province), which is characterized by a thin pre-Miocene section and high geothermal gradient with SW-dip regime.

The main productive reservoirs are Kareem and Rudeis ‘‘Middle and Lower Miocene’’. A total of 14 wells were drilled in the area and the field was declared commercially by the end of 1985. Five wells are currently in production, the production facilities were constructed onshore at Ras Dib area and the production started on November 29, 1988.

The first well was drilled on July 1966 by Pan American UAR Oil Company (now BP-AMOCO Egypt Oil Company) in the southwestern part of the structure, which was outlined by using the available seismic surveys and the surrounding geological data. The main objective was pre-Miocene reservoirs in addition to the Miocene-one.

Al-Amal oil field can be considered as one of the offshore oil fields, that occupies the southern part of the Gulf of Suez. The main issue of the present study deals essentially with the interpretation of the 2D and 3D seismic data of Al-Amal area in order to define the structural features intervening the area and their role in the evaluation of the petroleum system of this southern part of the Gulf of Suez province.

In other words, the work is a trail to shed lights on the seismic techniques for both 2D and 3D seismic interpretations in order to give chances for enhancing the oil prospecting and exploration in the Gulf of Suez oil province in Egypt. Therefore, we believed that, the detected structural elements and their types and genesis (faults and folds) in this study are controlling, to a great extent, the distribution of the hydrocarbon accumulation and trapping styles in Al-Amal oil field.

Seismic surveys, gravimetric and aeromagnetic data were conducted, from which the major structural elements were delineated, while about 1800 km coverage of seismic surveys was available on Al-Amal area. These data were acquired throughout 19 campaigns through the following phases:

- Acquisition from trading around the block,
- The 3D-seismic profiles done by CGG, 1980 (TPO own acquisition),
- The 2D-seismic lines done by GSI, 1982 (TPO own acquisition.

The 2D seismic interpretation is achieved in a parallel manner with the geological interpretation. Several seismic, geo-seismic and geological maps were constructed and interpreted. Some 3D lines have been checked to confirm the previous 2D works done in this area. Using the velocity surveys of a lot of available boreholes, the geological well-data and the picked and mapped seismic horizons have been calibrated, transferred and contoured in terms of depth structure contour maps on specific formational tops.

2. Methodology

Using different seismic data processing softwares, the 2D and 3D seismic interpretations have been made. By searching on the internet at different sites, especially the programs and softwares which concern with seismic interpretation, we used some of them for the interpretation of the 2D seismic lines, putting the wells on the sections, also the mentioned formations(South Gharib, Belayim, Kareem and Rudies) from the top downward. Thereinafter, the depth structure contour maps were accomplished by the surfer program, which is very helpful in contouring.

In 3D seismic interpretation, by searching on the internet web sites we found a useable interpretation program which can be used by training for 30 days, so we use it and installed the 3D seismic volume, then preserve all the wells which are at the study area, mentioned the formations on the seismic traces by the velocity analysis data, depth and thickness, then interpreted the studied formations on the sections, interpreted the possible faults cutting these formations in the seismic lines, and putting the names of the mentioned horizons or formation and name of wells, and type of the faults .

The 3D seismic sections are arranged according to the dip and strike trend or orientation so it consists of x-lines and in-lines 3D seismic volume, Thereinafter structure fault polygon (fault pattern) map is constructed for each formation in the study area. Then collecting all polygons was performed for each formation in a depth structural contour map for seismic sections of the study area.

3. Results of 2d seismic interpretation

Amal field is considered as a complex positive structure located in the Gulf of Suez southern province, which is characterized by a thin pre-Miocene section, SW dip regime with high geothermal gradient. The structural elements of the Gulf of Suez have been discussed by many authors, such as; [2–5]. The most significant contributions, however, are those by [6–18].

Thirteen reprocessed seismic lines by TPO in 1989 were selected (eleven 2D lines and two 3D lines), where the data reprocessing was carried out by the pre-stack depth migration technique (MIGPACK). The thirteen seismic lines (Fig. 2) included eight oriented NE–SW and the rest were directed NW–SE crossing each others.

Some of these depth migrated seismic lines are reasonably reliable, while other lines are ranked between poor to fair. Well data matching with seismic events showed that the last seismic section is deeper than the actual one with about 80 m static shift. In general, it represents the best quality of seismic data in the Al-Amal area, but the interpretation of different important horizons needs additional lines for better mapping.

The preliminary 3D seismic data of TOTAL-1980, prestack depth migrated with the available well control data were used for constructing depth map on top Kareem Formation. Post-Stack Depth Migration of both TOTAL 1980 and GUPCO 1993/94 were not used for the interpretation due to its poor quality, i.e. gap area for this type of processing. Two seismic surveys were acquired by GUPCO 1993/94, where a gap area in the recorded surveys was encountered, because of the non-accessibility to conduct the survey nearby Al-Amal platform.

For 2D seismic interpretation, the applied procedures were executed for some selected good seismic sections. The markers start from Zeit Formation down to the Thebes and Matulla

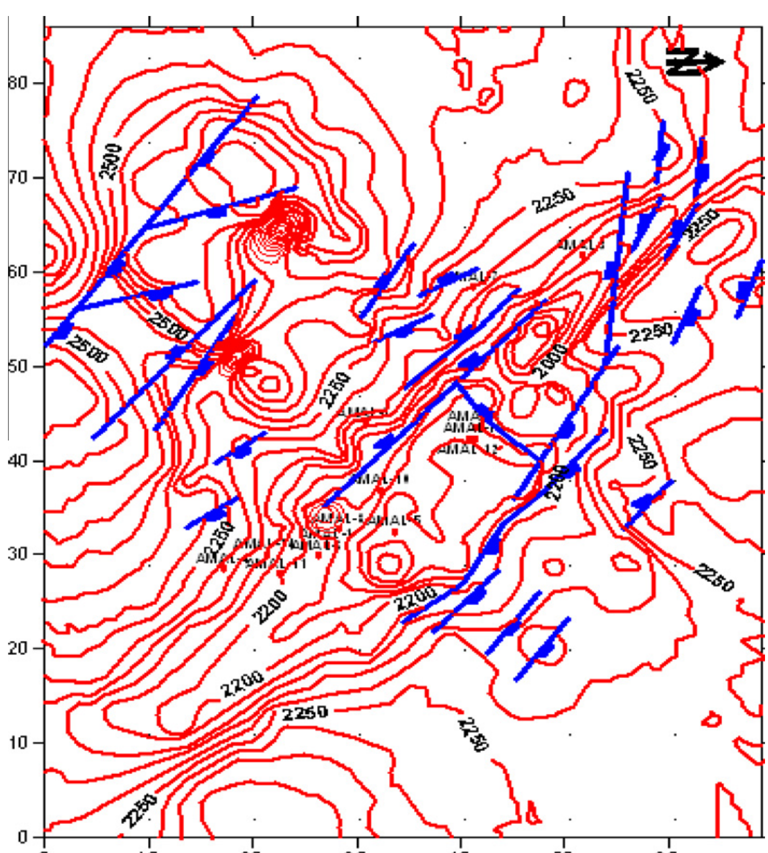

Figure 2 Depth structure map on top of Kareem Formation, Al-Amal field, Gulf of Suez, Egypt.

reflectors, then the results confirmed and checked by the 3D seismic data interpretations. The second target is the outlining of the most important blocks (horsts, grabens and step blocks), then following and recognizing them, especially in the dip direction. The interpretation of about one hundred forty five kilometers of 2D seismic sections (using the filtered stacks and migrated stacks) was carried out in Amal area. The interpretation was made at the Miocene (Kareem and Rudeis formations) and the pre-Miocene (Thebes and Matulla formations) sequences.

As an example for the mentioned works (Fig. 2) reveals that, the depth structure contour of Kareem Formation decreases toward the central part of the study area, recording the minimum value of 2000 m at the up thrown side of the horst (faulted anticline) at the central part and at the shoulders recording the values of 2200 and 2250 m. On the other hand, the depth increases at the up thrown side of the dip-slip faults (faulted synclines) at the southern and southwestern parts, recording the maximum value of 2500 m. Also, the depth increases at the up thrown side of the strike-slip faults (faulted synclines) in the southern and southeastern parts, recording the maximum value of 2250 m.

Fig. 2, shows that, structures are very clear, while, strike-slip faults are conspicuous the southwestern, northwestern, southern and northeastern parts of the study area. Dip-slip faults are clear at the central part of the study area; oblique faults are obvious at the southern part. Folds are relevant as anticlines at the central part, as synclines at the northeastern, southeastern, and southwestern parts. At the central parts there is a big salt intrusion lied between two down lifted features at the northwestern and southeastern parts.

Fig. 3 reflects that, the basins are located at the northwestern part in depths ranging between 600 and 1100 m below the surface. It also shows that, the depth structure contour map of Rudies Formation decreases toward the central part of the study area, recording the minimum value of 2000 m at the up thrown side of a horst (faulted anticline) occurred at the central part and at the shoulders recording the value of 2250 m. On the other hand, the depth increases at the up thrown side of the oblique-slip faults at the southwestern part, recording the maximum value of 2750 m, and at the south recording the value of 2500 m. Also, the depth increases at the up thrown side of the oblique-slip faults at the southeastern part, recording values ranging between 2250 and 2500 m. Structures are very clear in this section, faults like strike-slip fault are clear at the southwestern, northwestern, southern and northeastern parts Dip-slip faults are clear at the central part of the study area, while oblique slip faults occurred at the central part. Folds are clear as anticlines at the central, southwestern, northeastern, and southeastern parts, as synclines at the northwestern part. At the central part there is a big salt intrusion dome between two basins at the northwestern, southeastern parts.

Fig. 4 shows that, the seismic section TAL-82-111; passes near the middle part of the field, where there are moderate erosions at the front of the field. On this line, AMAL-1 and AMAL-6 wells were drilled on the front edge of the field, where it passes from South Gharib to Thebes formations. This case was interpreted as unconformity surface that can criticize the up-thrown side. But the analyses of the geological and dipmeter data led to explaining it as a fault scarp relation, which opened the chance for the exploration on its up-thrown side. This assumption was tested on the up-edge with positive results which clarifies the location of the well reference to the fault scarp. This line extends from southeast to northwest direction crossing the central part of the field. In the southeastern part, there are step-like faults and then there are three grabens toward northwestern part. Added, there are two shallow down lifted features occupying the upper part of the section.

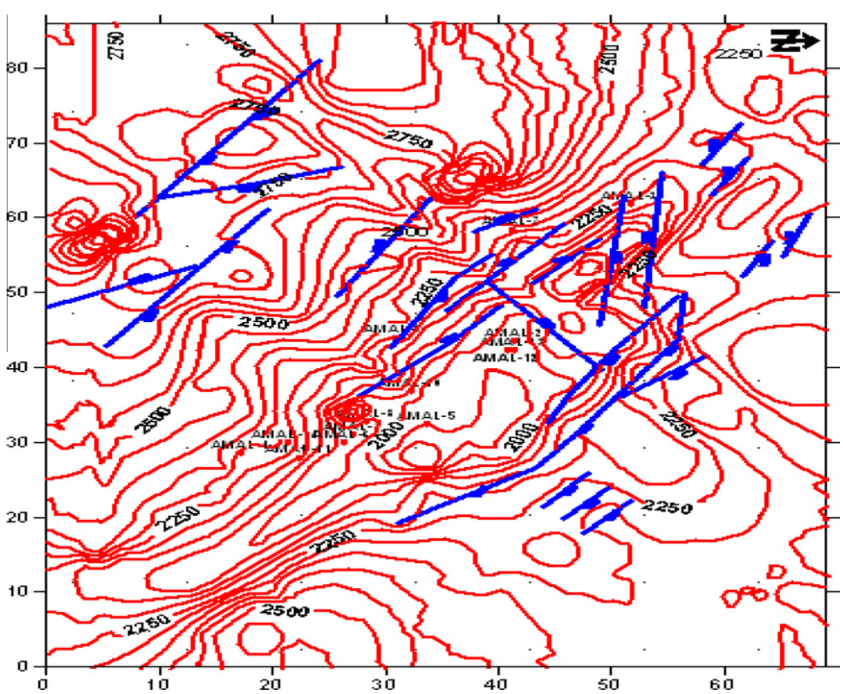

Figure 3 Depth structure map on top of Rudeis Formation, Amal field, Gulf of Suez, Egypt.

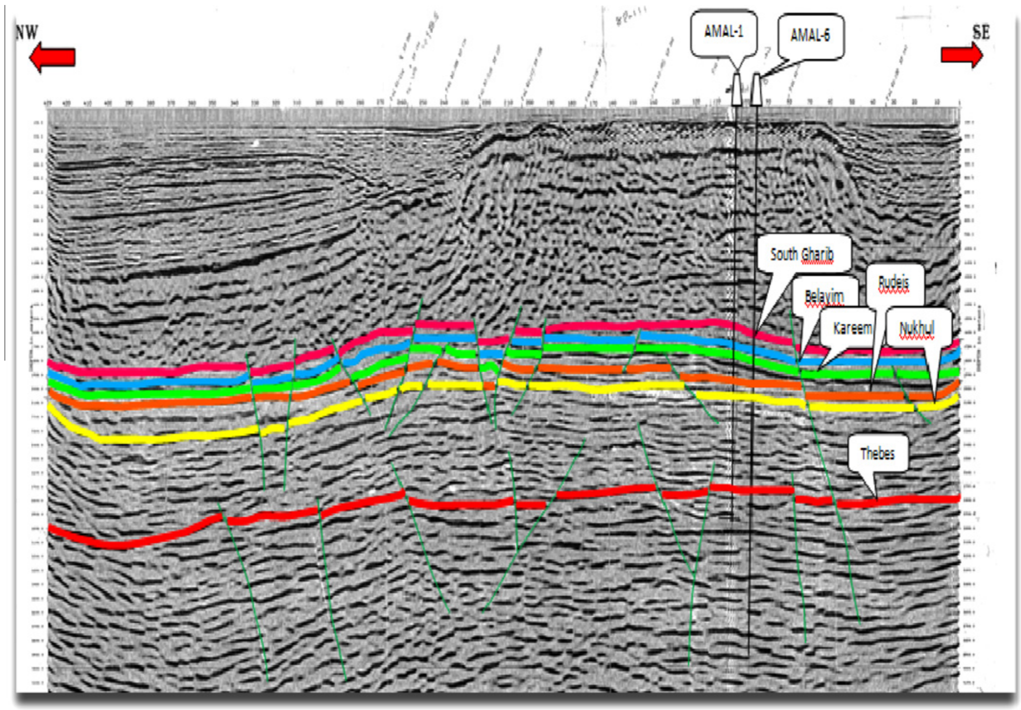

Figure 4 NW–SE interpreted 2D seismic line passing through wells AMAL-5 and AMAL-1. The line shows six horizons were picked and simple graben and horst structure bounded by some clysmic trending fault. Line TAL-82-111.

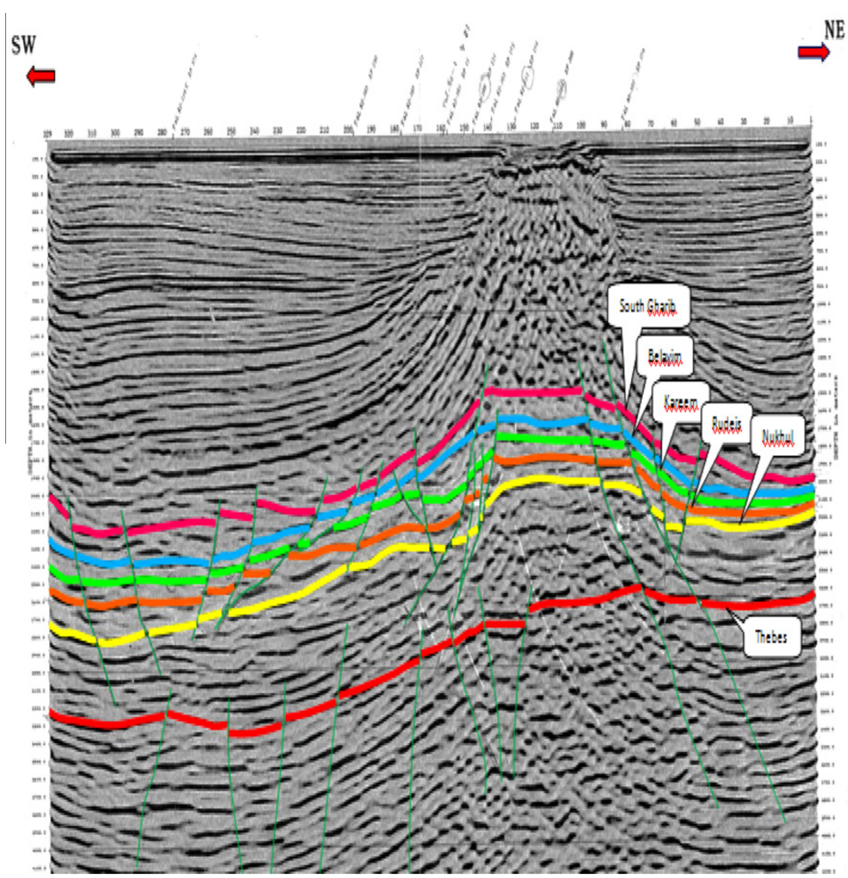

Figure 5 SW–NE interpreted 2D seismic line. The line shows six horizons were picked and simple graben and horst structure bounded by some clysmic trending faults. Line TAL-82-118.

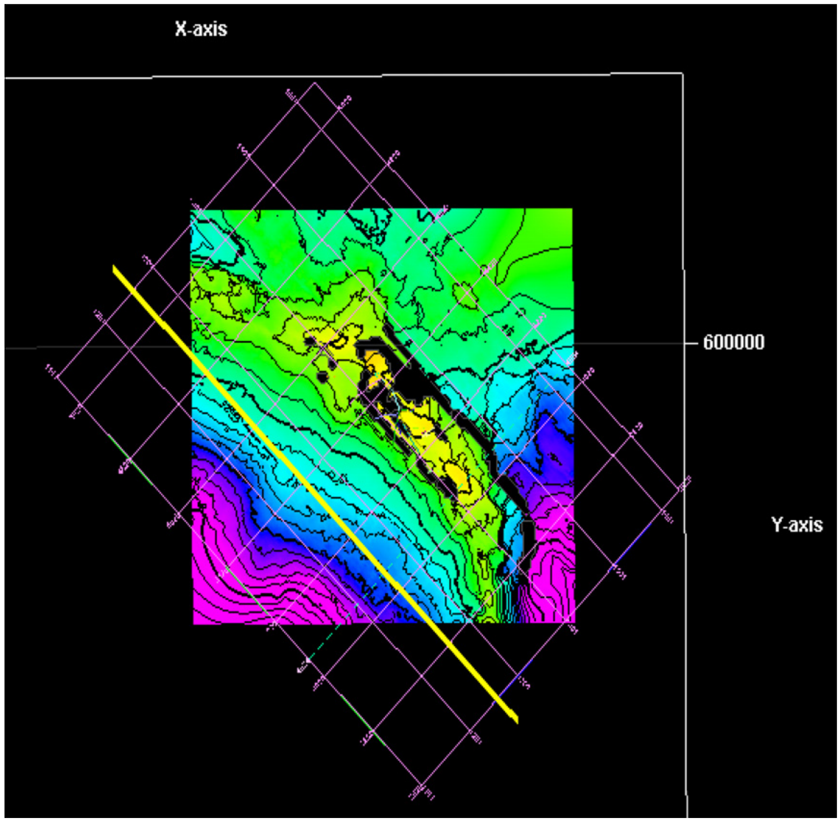

Figure 6 Depth map on top Kareem Formation, Al-Amal field, Gulf of Suez, Egypt.

Fig. 5 exhibits the seismic section TAL-82-118, while it was shot in the northeastern to southwestern direction .On the pass of this line, there are some faults. From the northeast there is a graben, and then step-like faults, then a big horst in the central part, then some strike-slip faults and grabens through the sequence extended from South Gharib Formation at the top to Nukhul and Thebes formations at the base.

4. Results of 3d seismic interpretation

A 3D seismic survey profile of 834 km seismic coverage was acquired and processed by CGG, 1980 (TPO own acquisition).The 3D seismic lines in the study area are classified into two sets, the dip oriented NE–SW In-lines and the strike oriented NW–SE cross-lines, and together they form a closed grid pattern, which has been used to highlight the detailed structural and stratigraphic elements in the study area.

Preliminary 3D seismic pre-stack depth migration data (Total, 1980), which was conducted by Paradigm Geophysical, with the available well control data, were used for more details to construct depth map on top of Kareem Formation. Post-Stack Depth Migration of both TOTAL 1980 and GUPCO 1993/94 surveys, were not used for this interpretation; due to the poor quality data.

Middle and pre-Miocene formations are represented here at the top from Zeit, South Gharib, Belayim, Kareem, Nukhul and Matulla formations. This section clarifies that the field is represented by tilted faulted blocks, affected by the faults f1, then (F1 and F3), which form the central graben. These features affected mainly the first five rock units from Zeit Formation at the top until Kareem Formation at the base, then there are some faults (f1, f2, f3, f4, f5 and f4*) affected Nukhul and Matulla formations generating structural graben and horst faulted blocks.

It is most probably due to the insufficient data i.e. gap area, for this type of processing. (Two seismic surveys were acquired by GUPCO 1993/94, where a gap area, in the recorded surveys was encountered, because of the non-accessibility to conduct the survey nearby the Amal platform.

Signal processing has been applied to the data for the removal of coherent noises and multiples attenuation has been applied post migration. Data quality seems to be good and well information was checked carefully throughout layers and updated to correlate with the output depth volume. 3D pre-stack depth migration data give us a better image of the subsurface geology and also the results are enhanced in the geologic model of the field. Stacking velocities play an important role to transfer the pre-stack time migrated 3D volume to the pre-stack depth migrated 3D volume.

The 2D seismic surveys did not cover the off-shore area of the field, so an interpretation was carried out for the available (PSDM) 3D seismic volume, and incorporating these data with the available well data to follow up Amal field structure. Six horizons were selected and picked. Geological well data, gravity and magnetic field data sets were integrated into the seismic interpretation.

For example, for 3D seismic interpretation results Figs. 6 and 7, the depth structure contour map on top Kareem Formation reveals that, the depth of Kareem Formation decreases toward the central part of the study area, recording the mini-

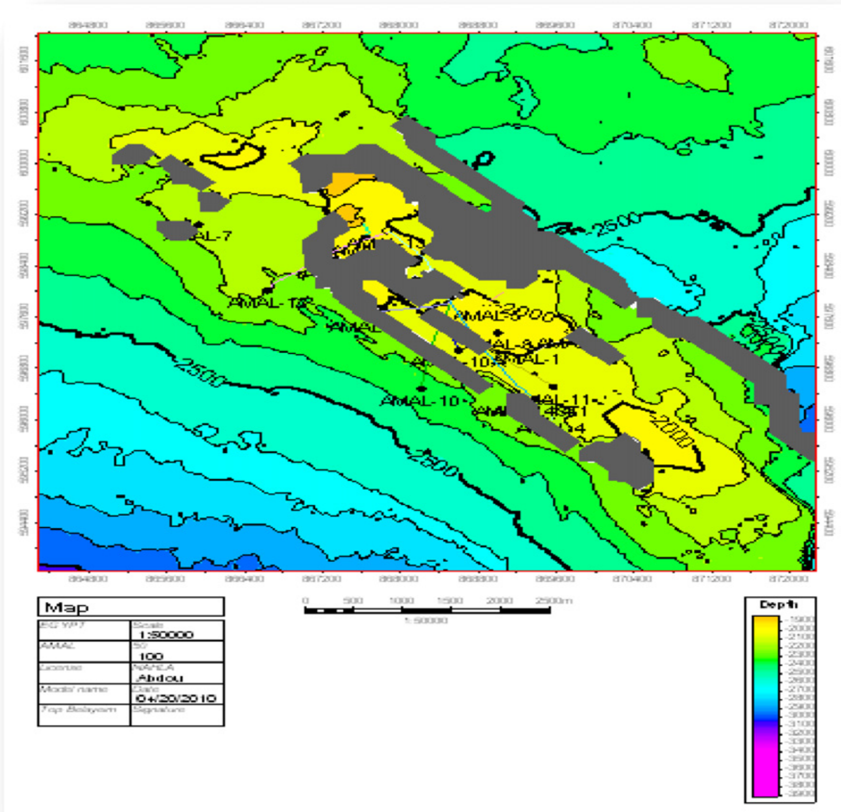

Figure 7 Depth polygon structure contour map on top Kareem Formation, Al-Amal field, Gulf of Suez, Egypt.

mum value of 2000 m at the up thrown side of the horst located at the central part and at the shoulders forming faulted anticline and recording the value of 2500 m. On the other hand, the depth increases toward the up thrown side of the oblique-slip faults in the south central part, forming faulted syncline and recording values more than 2500 m, added at the southeastern part, the depths recorded the value of 2500 m, and increases toward the up-thrown side of the dip-slip faults at the northwestern and northern parts, forming faulted syncline and recording values ranging between 2250 and 2500 m.

Fig. 8 shows the In-line 1380 seismic section. It was shot in the northeast-southwest direction; there are some wells (AMAL-7, AMAL-9, AMAL-4, AMAL-12, AMAL-11, AMAL-14, AMAL-10 & AMAL-10A) were drilled on the pass of this line. The structural features along this line indicate some faults affecting this area in the form of graben, horst and step-like faults. Some of them are of NW–SE trend, while, others are of SE–NW trend.

Fig. 9 shows the cross-line 4340 seismic section. It was shot in the northwest-southeast direction. On the pass of the line, there are some wells (AMAL-1, AMAL-13, AMAL-4, AMAL-10A, AMAL-10, AMAL-5, AMAL-8, & AMAL-9) that were drilled through this line. The structural features along this line are some faults that affect this area in the form of horst, graben and step-slip fault. Some of these faults are of NW–SE trend, while others are of SE–NW trend. Middle and pre-Miocene rock units are represented here at the top downward from Zeit, South Gharib, Belayim, Kareem, Nukhul and Matulla formations. This section clarifies that the field is represented by tilted faulted blocks, affected by the faults (F2 & F3*) which form the central horst, and (F5 & F4*), which form the second horst, faults (F1** and F2) form a graben and faults (F3* and F4*) which form another graben, these features affected mainly the six units from Zeit Formation at the top down to Nukhul and Matulla formations.

5. Hydrocarbon implications

The main productive reservoirs in the Al-Amal oil field are the Kareem and Rudies formations of the Middle and Early Miocene age. A total of 14 boreholes were drilled in the area, while the oil field was declared commercially by the end of 1985, five boreholes are currently on production, while the production facilities were constructed onshore at Ras-Dib area and the serious oil production hasstarted on November 29, 1988. According to the experience, only three types of hydrocarbon traps are dominating in the Gulf of Suez. They are: structural, stratigraphic and combined traps. About two thirds of the oil discoveries are from the structural traps and one third from the others.

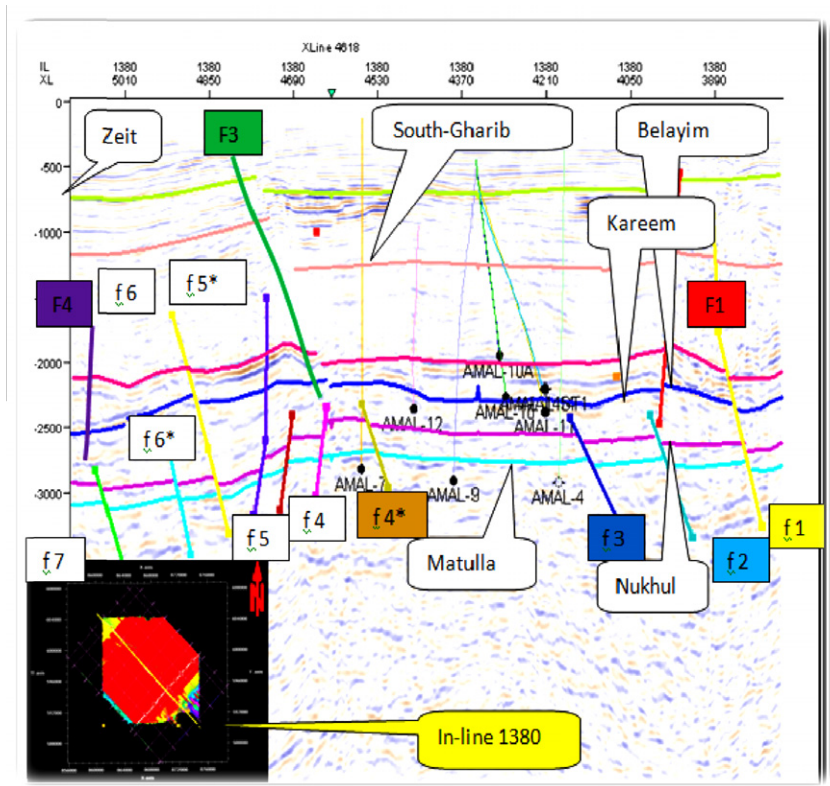

Figure 8 NE–SW interpreted 3D seismic inline, passing through AMAL-7, AMAL-9, AMAL-4, AMAL-11, AMAL-12, AMAL-10A & AMAL-14.Al-Amal field, Gulf of Suez, Egypt.

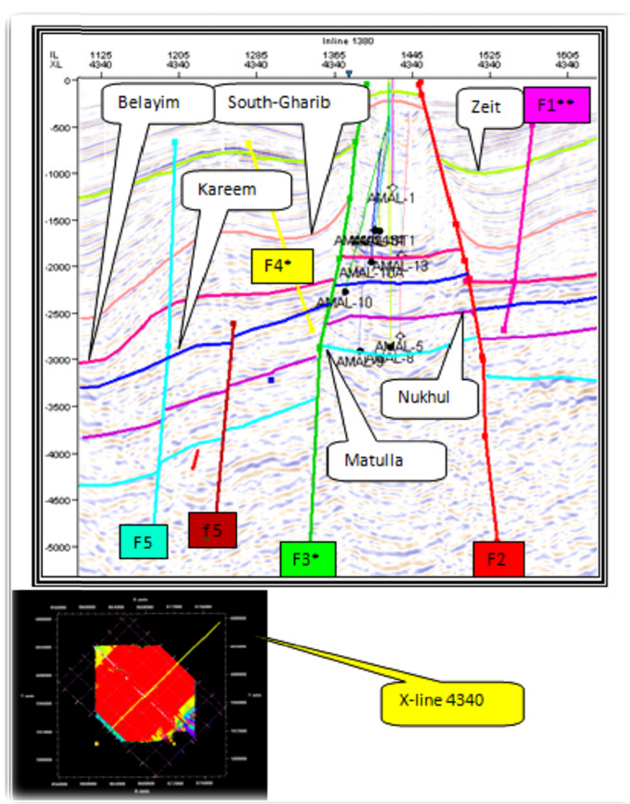

Figure 9 NW–SE interpreted 3D seismic cross-line-6. Seismic section cross-line 4340, Al-Amal field, Gulf of Suez, Egypt.

Charged Pre-Miocene reservoir rocks are in general widely distributed, while their reservoir characteristics are mainly depending on the intensity of rock fracturing and leaching (secondary permeability) rather than lithologic facies changes. On the other hand, the Miocene deposits were influenced and controlled by block faulting, block rotation and syn-sedimentary fault movements (growth faults). The sediments were deposited on irregular Pre-Miocene relief, thus resulting in rapid sedimentary thickness and facies changes.

6. Summary and conclusions

1. Al-Amal concession area is about 27 km^2 in the offshore, southern province of the Gulf of Suez basin. It is located some 55 km from ‘‘Ras Gharib city’’ about 15 km south west from the Morgan Oil field and about 15 km offshore from Western Gulf of Suez shore line .The Al-Amal oil field is located on a NW–SE faulted monocline, which has a SW dip, plunging NW and SE, bounded by the clysmic faults and sealed by the Middle–Late Miocene evaporates.
2. The field was discovered in 1988, started on November through five wells, producing hydrocarbons from the Lower-Middle Miocene reservoirs (Kareem and Rudies formations) with, a daily oil rate of 6500 BBL. This field is a byproduct of complex positive structure located in the Gulf of Suez (southern province), which is characterized by thin pre-Miocene section and high geothermal gradient with SW-dip regime.

3. Al-Amal oil field can be considered as one of the offshore oil fields that occupies the southern part of the Gulf of Suez. The main issue of the study deals essentially with the interpretation of the 2D and 3D seismic data of the Al-Amal area to define the structural features intervening the studied area and their role in the evaluation of the petroleum system of this southern part of the Gulf of Suez, Egypt.
4. Several seismic lines were selected, in the present work, reprocessed and interpreted with the help of well velocity and time-depth trace conversion to construct the structural-tectonic maps characterizing the different levels of the concerned area, as well as to confirm the validity of the proposed structural model. Most of the available seismic data in the Al-Amal area were investigated and reviewed to select the best quality set.
5. The 2D seismic interpretation is achieved in a parallel manner with the geological interpretation. Several seismic, geoseismic and geological maps were constructed and interpreted. Some 3D lines have been checked to confirm the previous 2D seismic work done in this area. Using the velocity surveys of a lot of available boreholes, the geological well data, and the picked and mapped seismic horizons have been calibrated, transferred and contoured in terms of depth structure contour maps on specific formational tops.
6. The sediments were deposited on irregular Pre-Miocene relief, thus resulting in rapid sedimentary thickness and facies changes. The Pre-Miocene shales and organic carbonates act as good source rocks. Also the sediments of the Lower Miocene in some deep basins act as source rocks.
7. Charged Pre-Miocene reservoir rocks are, in general, widely distributed, while their reservoir characteristics are mainly depending on the intensity of rock fracturing and leaching (secondary permeability) rather than lithologic facies changes. On the other hand, the Miocene deposits were influenced and controlled by block faulting, block rotation and syn-sedimentary fault movements (growth faults).
8. The Middle-Upper Miocene evaporates play a very important role for hydrocarbon trapping in the Early and Middle Miocene reservoirs. The Pre-Miocene reservoirs are generally covered by the shale of the Early Miocene age. The Pre-Miocene carbonates are capped and sealed directly by the Miocene evaporates.
9. The main productive reservoirs in the Amal oil field are the Kareem and the Rudies formations of the Middle and Early Miocene age. A total of 14 boreholes were drilled in the area, while the oil field was declared commercially by the end of 1985, five boreholes are currently on production, while the production facilities were constructed onshore at Ras-El Dib area and the serious oil production have been started on November 29, 1988. According to our experience, only three types of hydrocarbon traps are dominating in the Gulf of Suez. They are: structural, stratigraphic and combined traps. About two thirds of the oil discoveries are from the structural traps and one third from the others.

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