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FULL LENGTH ARTICLE

# Structural interpretation of seismic data of Abu Rudeis-Sidri area, Northern Central Gulf of Suez, Egypt

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**Abstract** The 2D and 3D seismic data are interpreted to evaluate the subsurface geologic structures in the Abu Rudeis-Sidri area that occupy the northern central part of the Gulf of Suez. The 2D seismic data are used for determination of the structural configurations and the tectonic features which is analyzed through the study of interpretation with the available geologic data, in which the geo-seismic depth maps for the main interesting tops (Kareem, Nukhul, Matulla, Raha and Nubia Formations) are represented. Such maps reflect that, the Miocene structure of Abu Rudeis-Sidri area is an asymmetrical NW-SE trending anticlinal feature dissected by a set of NW-SE fault system (clysmic). Added, the Pre-Miocene structure of the studied area is very complex, where the area is of NE dip and affected by severe faulting through varying stratigraphic levels.
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## 1. Introduction

Abu Rudeis-Sidri oil field can be considered as one of the oldest oil fields occurred on the eastern coast of the Gulf of Suez, about 25 km north of Belayim land field, to the southeast of October and Ras Budran fields (Fig. 1). The concession occupies an area of almost 89 square kilometers. It was discovered in 1957 by Rudeis-2 well, where the oil was found in the Nukhul Formation. However, the exploration activity to test the Pre-Miocene potentialities started in 1978, by the drilling of ARS-1 well.

The Abu Rudeis field is producing an average of 2700 BOPD, mostly from the Nukhul reservoir, with smaller contributions from the Thebes Limestone, Matulla, Turonian and Nubia Sandstone. Ras Budran field is producing an average of 22,000 BOPD from the Raha and Nubia Sandstone. Also, the October field is producing about 170,000 (peak of production) from the Nubia Sandstone, Matulla, Nukhul and ASL sandstones.

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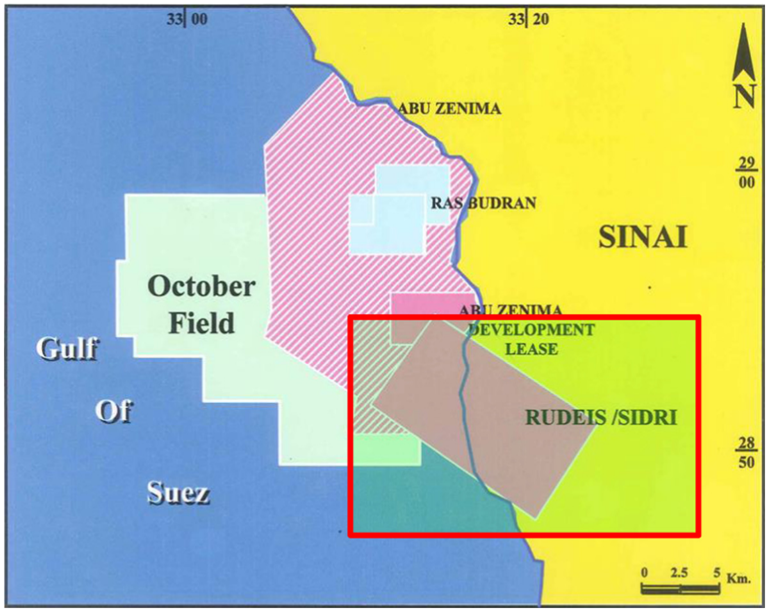


**Figure 1** Location map of the study area.

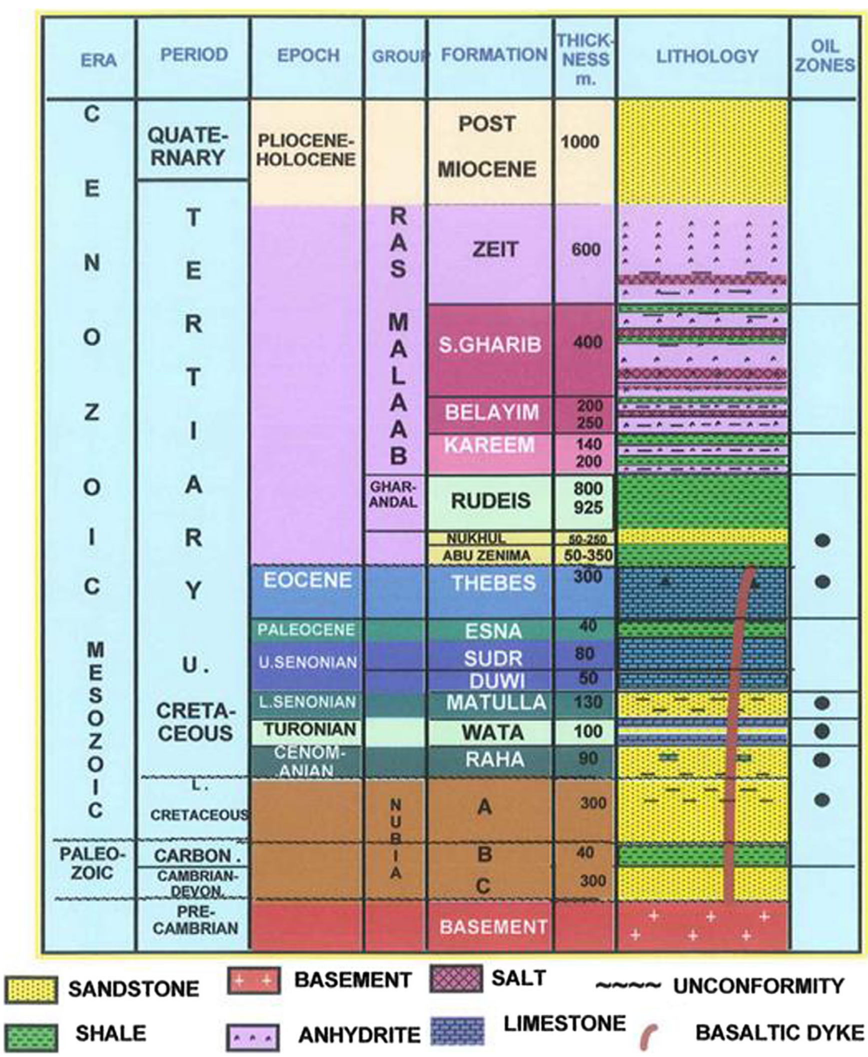


**Figure 2** Schematic stratigraphic column of Rudeis-Sidri area, Gulf of Suez.

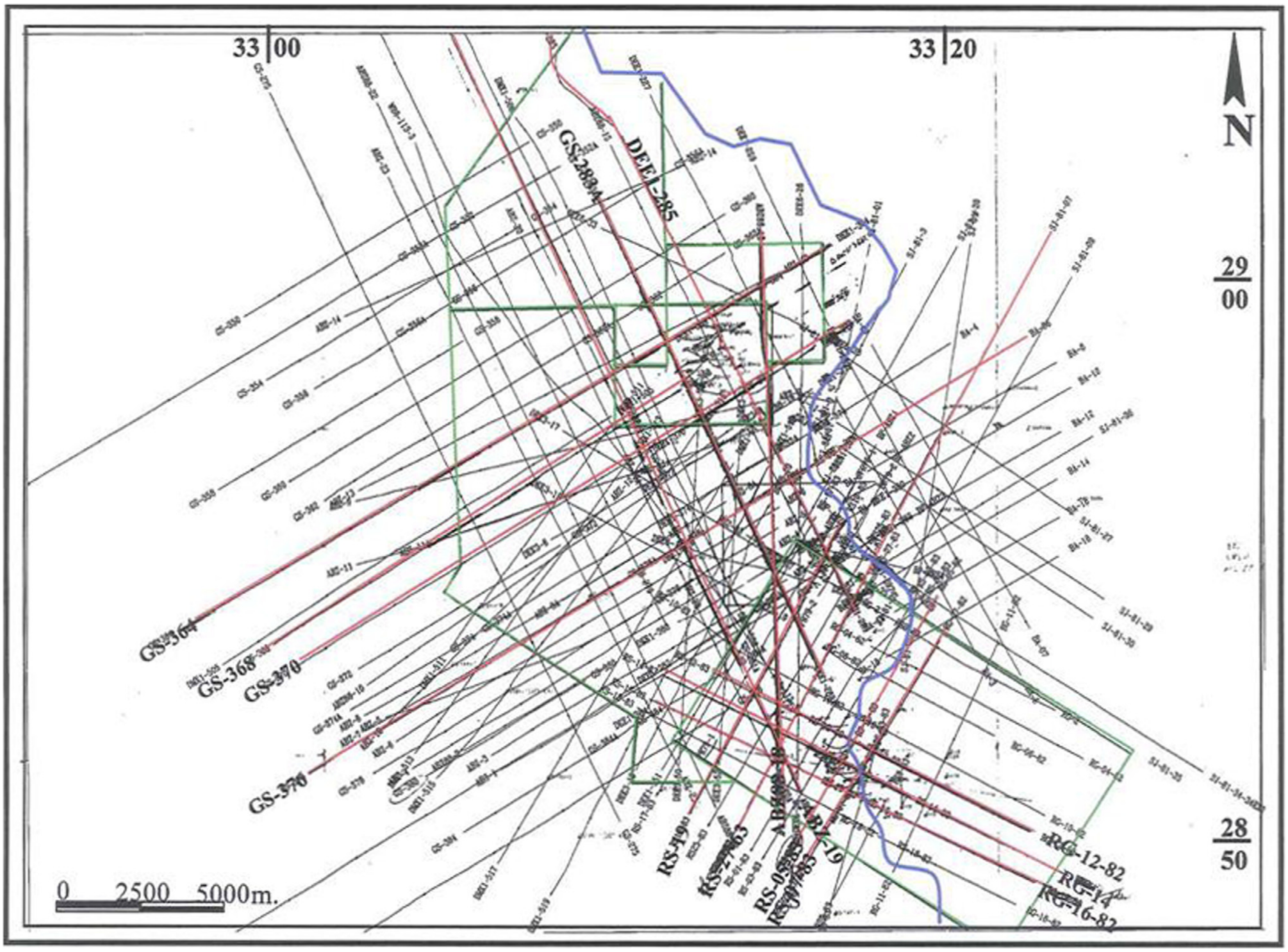


**Figure 3** 2D seismic base map covering the studied area, highlighted the interpreted seismic lines.

The 2D seismic data available in Rudeis-Sidri area were interpreted for a total coverage exceeding 1500 sq km. The current seismic grid results from merging the various regard old surveys with different seismic qualities and varying spacings. The whole seismic data set has been interpreted on an interactive workstation called Land Mark, Seisworks environment. The seismic data show good quality at the shallow horizons (Post-Miocene), whereas the quality of the Pre-Miocene seismic data is quite poor, due to the multiples events. The problem of multiple reflections affecting the seismic data in the entire range of the Gulf of Suez is well known. Its origin is due to the presence of the evaporites, in particular the Zeit and South Gharib Formations of the Late Miocene.

As far as the interpretation is concerned, the main problems were encountered in the imaging and definition of the Pre-Miocene horizons. All the pre-Miocene reflectors are completely obscured by over-migrated disturbs and often, especially in Abu Rudeis area. The seismic horizons appear to have an opposite inclination with respect to the interpretation of the well data. The seismic interpretation allowed the production, by means of the workstation based on Zycor software of the TWT contour maps. The well velocity data were used to execute the needed depth conversions.

The velocity survey data of the Miocene and Pre-Miocene rocks were detected from some drilled wells. Also, the reprocessing of seismic lines was done and achieved some improvement in the resolution of the Pre-Miocene horizons. As a result of the abovementioned steps, the picking of the pre-Miocene horizons in most of the seismic lines was controlled by the plotting of the Pre-Miocene well data. The Lower Senonion and Nubia horizons were picked and mapped.

## 2. Geologic setting

The stratigraphic sequence of the area under investigation represents an ideal succession of the central part of the Gulf of Suez. Such a succession is observed, not only on the surface outcrops at the different locations in the eastern side of the Gulf of Suez, but also in the drilled wells scattered in the area. A sedimentary sequence ranging in age from Paleozoic to Recent, with non-depositional and erosional hiatuses, was penetrated in the area of consideration. Fig. 2 shows the stratigraphic column of the study area, as well as the tectonic events, which affected the deposition of the various rock units composing the stratigraphic sequence of the Gulf of Suez province.

The Pre-Cambrian basement in Ras Budran field was penetrated in two wells (RB-A2 and EE85-7C) in a fault contacted with the sedimentary rocks and intruded by younger intrusives along the fault plane. Some wells in Sidri area, as well as in

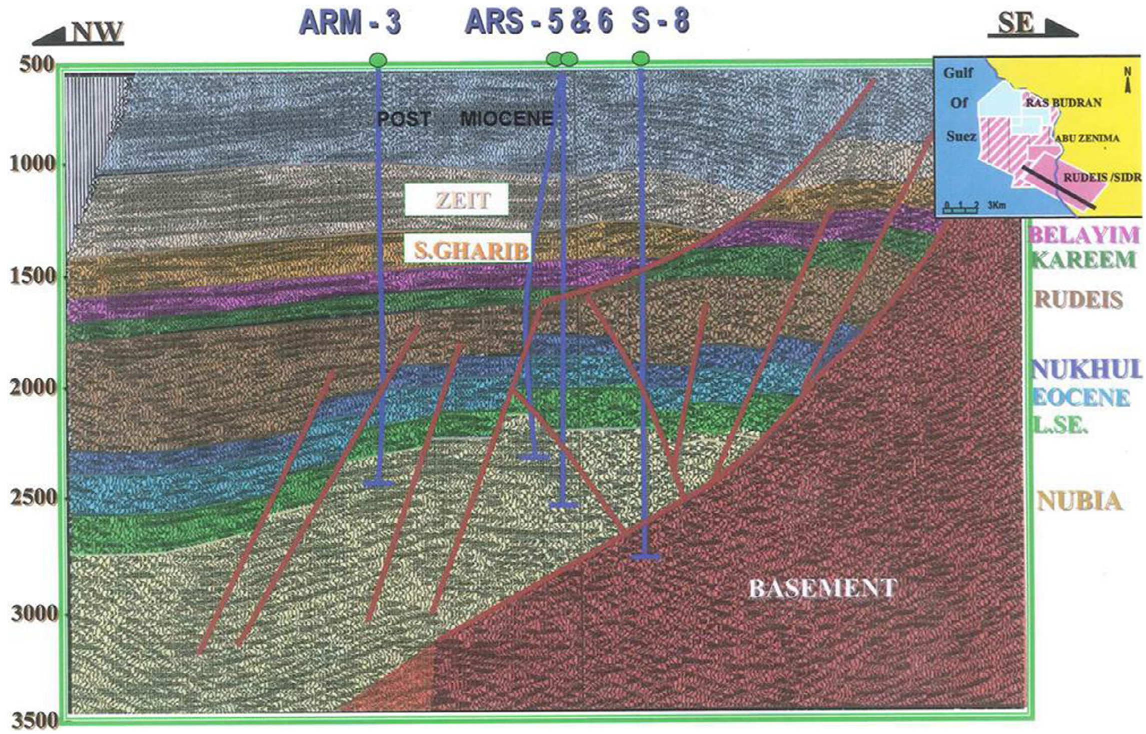


**Figure 4** Interpreted 2D seismic line (RG-16-82) showing the contact between the basement and sedimentary section.

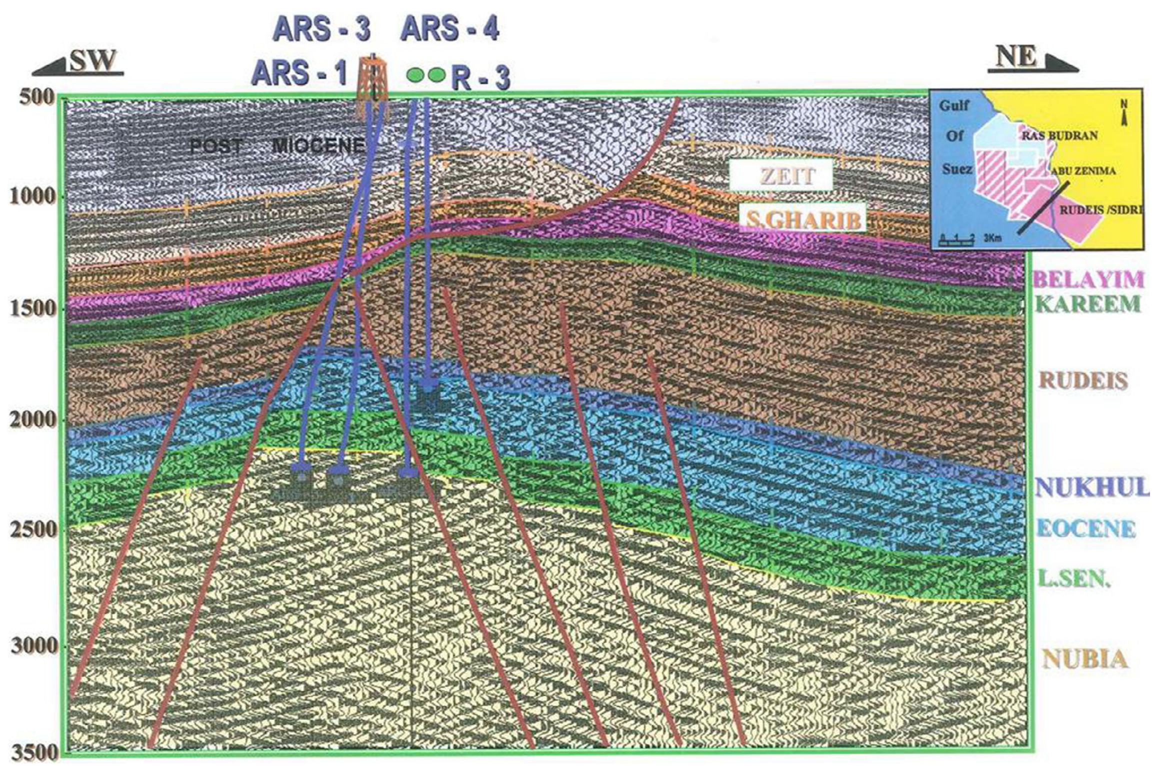


**Figure 5** Interpreted 2D seismic line (R6-05-82) showing the data quality along the listric fault.

Abu Zenima area, penetrated the basement at shallow depths (S-6, S-6R, Wadi El-Naqa, South Markha and South Zenima areas) along the main bounding fault. Sidri-8 and Sidri-4 wells hit the basement at deep depths (−3800 and −3570 m, respectively) as fault scarp relationships.

The Pre-Cambrian basement is unconformably overlain by the Paleozoic to Lower Cretaceous sediments (Nubia D, C, B and A at the top). The Paleozoic sandstones with thin shale layers (Nubia D, C, and B units) comprise the oldest section, that is partially penetrated by most wells in Ras Budran field,

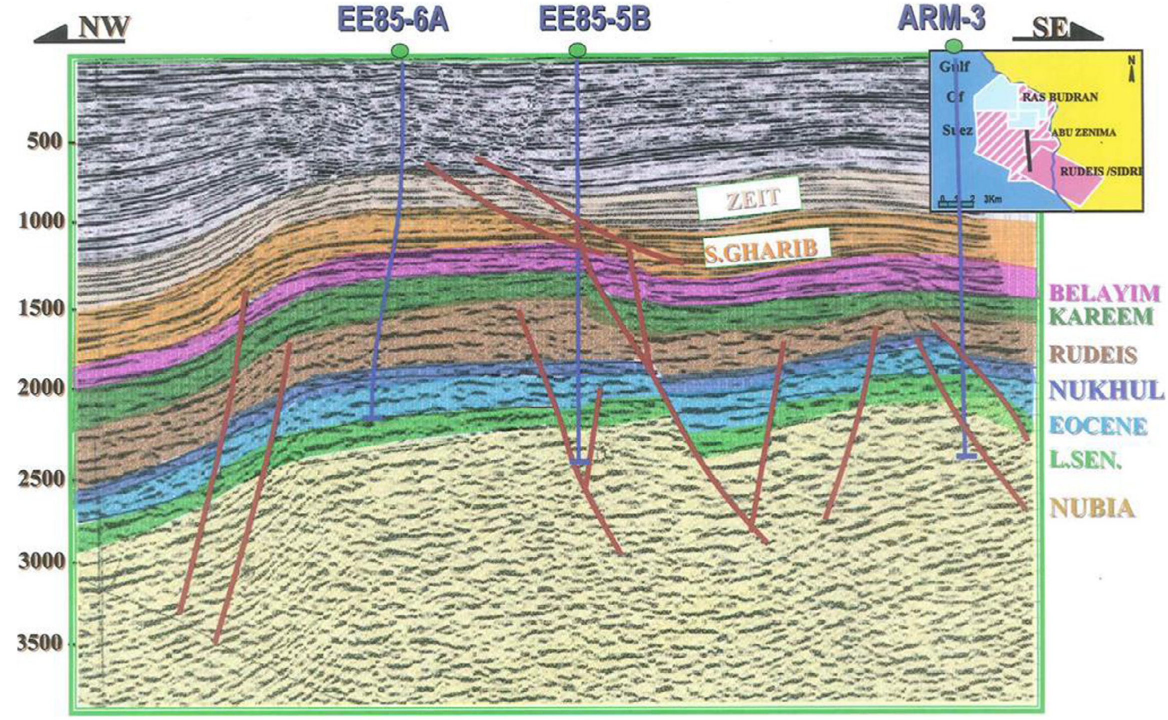


**Figure 6** Regional seismic line (ABZ-19) covering the western portion of the studied area in NW-SE direction. It shows the listric fault cuts.

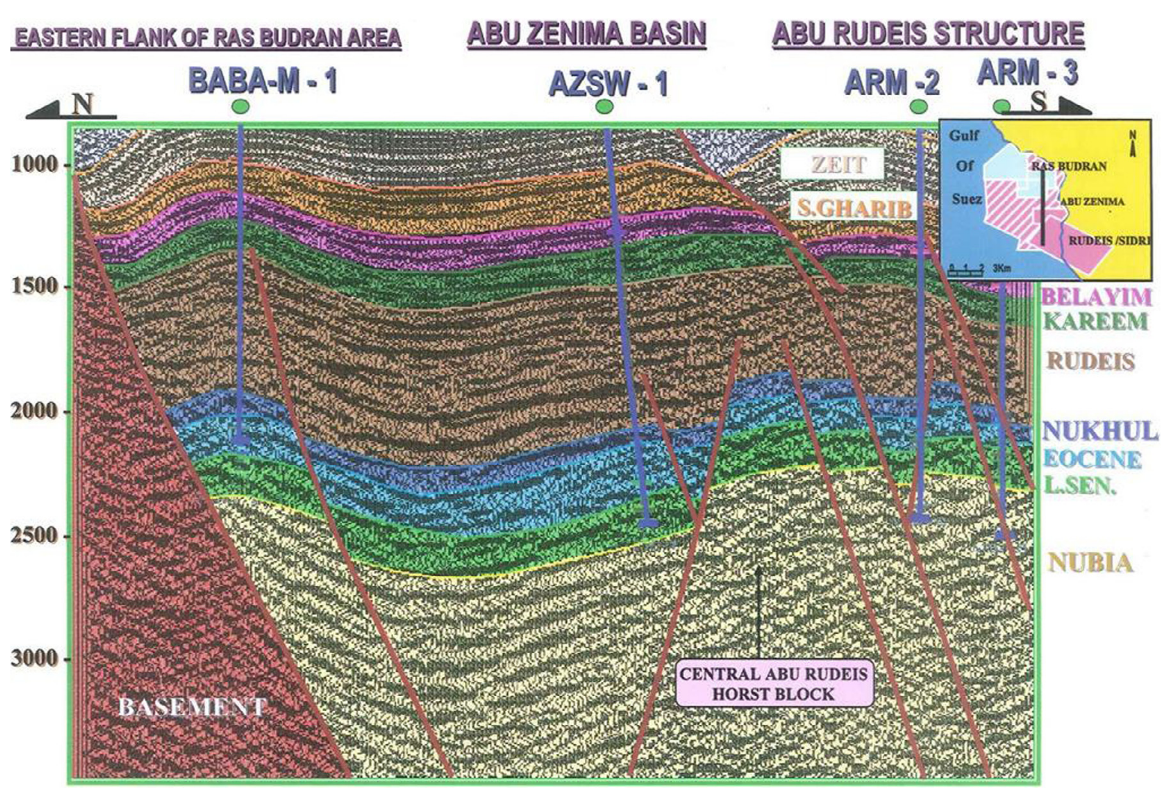


**Figure 7** Regional 2D seismic line (ABZ88-18) extends through Ras Budran-Abu Rudeis area.

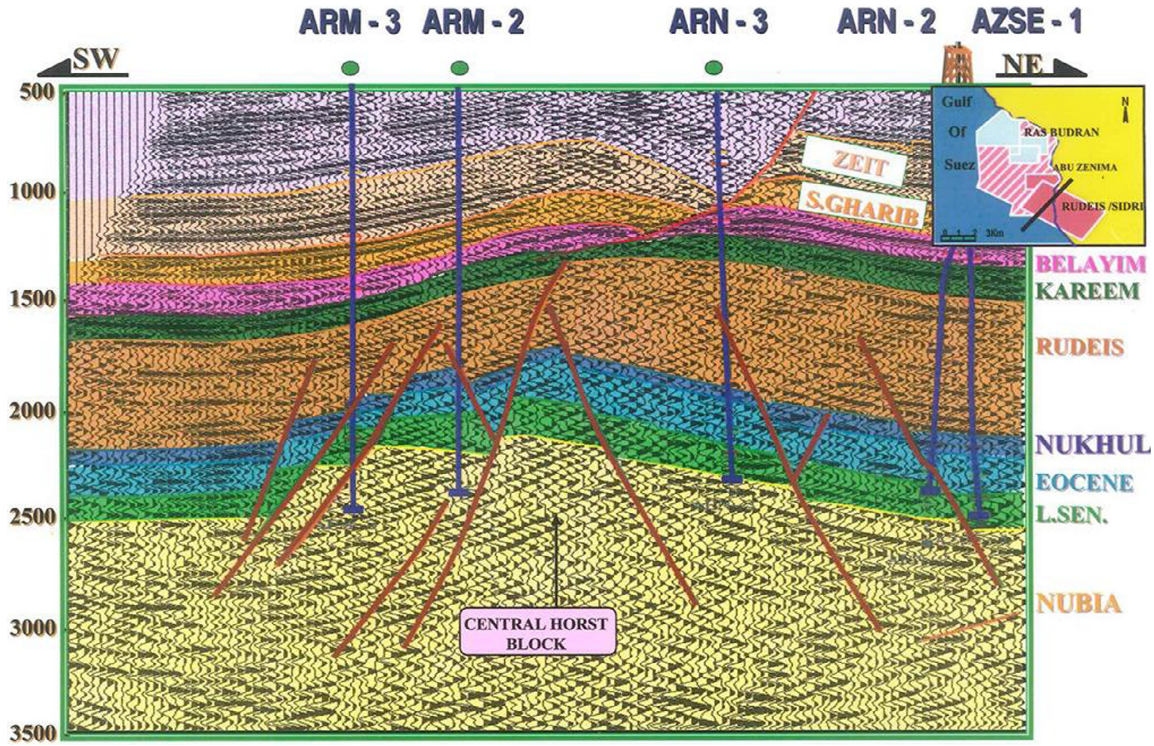


**Figure 8** Interpreted 2D seismic line (RS-27-83) showing the dip reversal on both sides of the central horst block.

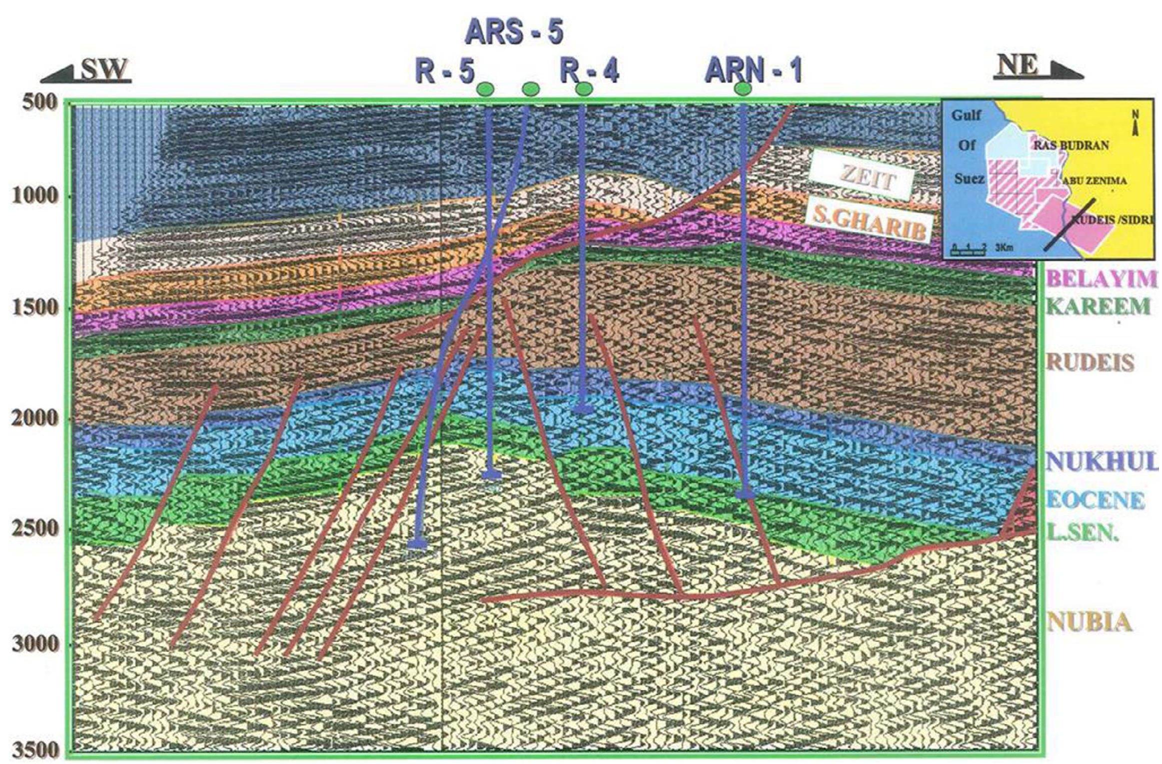


**Figure 9** Interpreted 2D seismic line (RG-07-83) showing the step clysmic faults on both sides of the central horst block.

but not penetrated by any well in Abu Rudeis-Sidri and Abu Zenima fields. Within this sequence, thus occured an unconformity between the Paleozoic and Cretaceous sediments (Fig. 2).

Naggar and El-Hilaly (1985), believed that, this unconformity is at the base of the shale unit (due to some criteria):

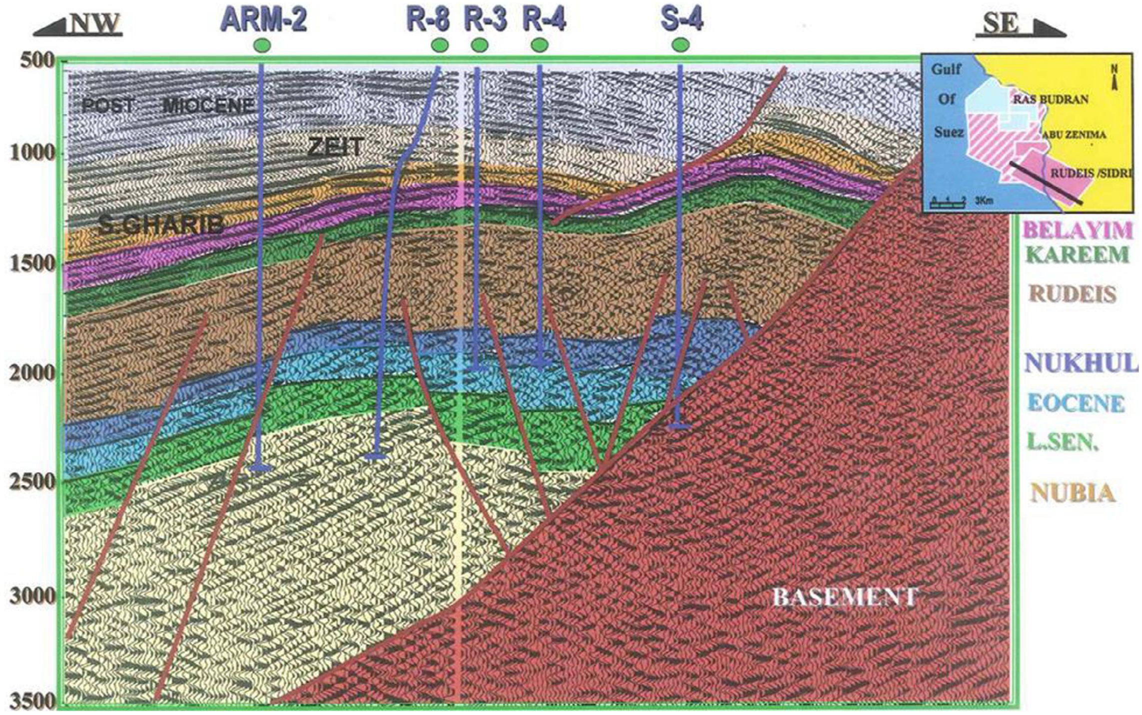


**Figure 10** Interpreted 2D seismic line (RG-12-82) which is running in Rudeis-Sidri field and showing the contact between the basement and the sedimentary section along the eastern main bounding fault.

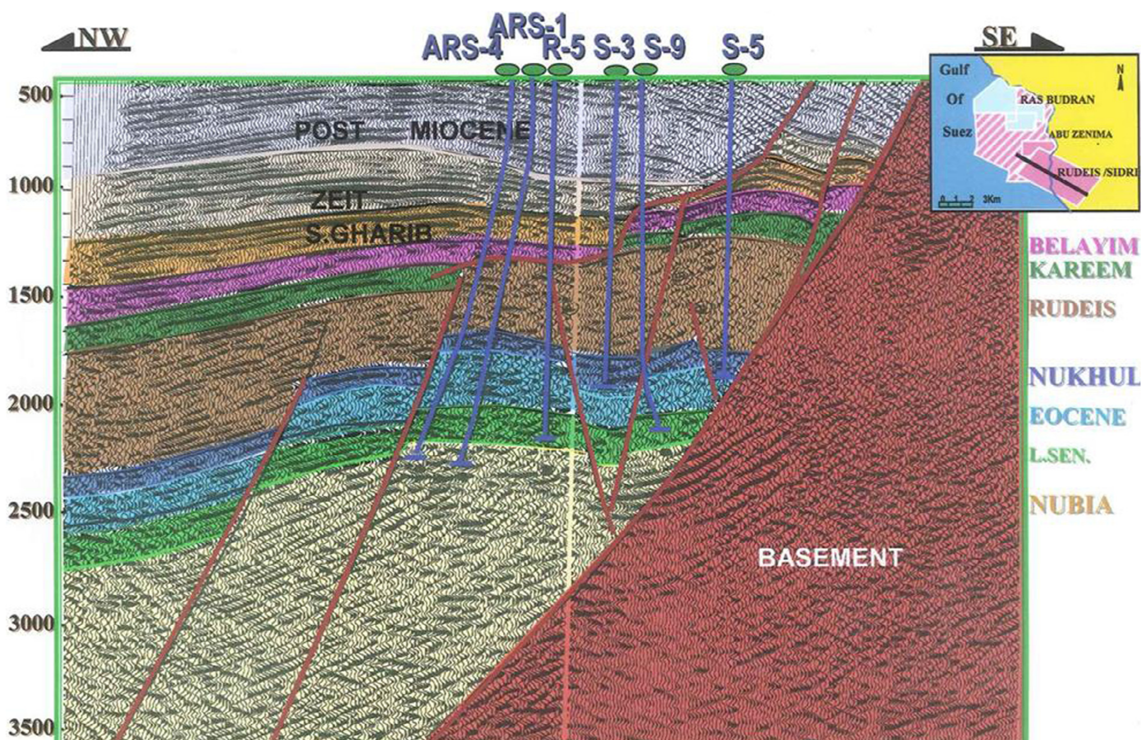


**Figure 11** Seismic line (RG-14-82) showing the structural configuration of Rudeis-Sidri field.

(a) The shale unit is thinner on the high relief structure and increases in thickness on the peripheries.

(b) Lithologically, the sandstones of the Nubia C and D are highly kaolinitic and differ from the sandstone layers within the shale unit, as in most of Ras Budran wells.

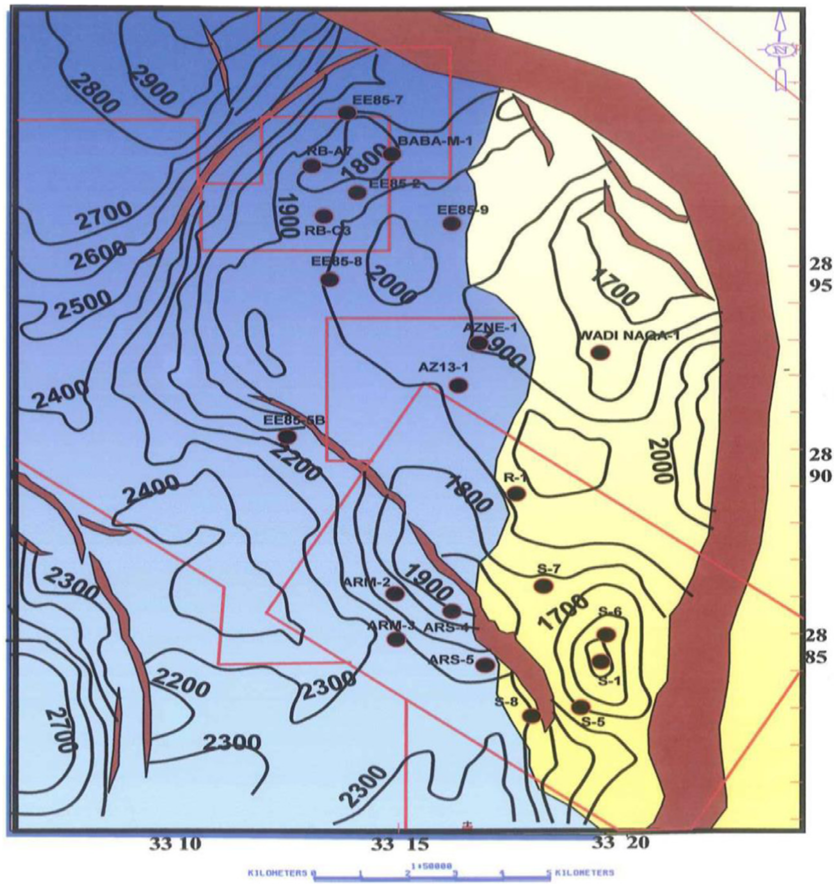


**Figure 12** Depth structure contour map on top Kareem.

(c) The presence of layers of hematitic sandstone within the sandstone of the Nubia C & D and their absence in the overlying shale unit.

The shale unit is overlain by the sandstones of Nubia "A" Formation which is dated to Cretaceous of Albian to Cenomanian age. These sediments were the first fossiliferous strata laid down on the shale unit. Based on the detailed peak to peak correlation of log markers within the Nubia A sandstone, it is concluded that, these sediments were deposited as sheet-like sands. The Nubia A Member is hit in most of the drilled wells in the area under investigation with an average thickness ranging from 200 m to 300 m (Fig. 2). It represents the most interesting reservoir in the central part of the Gulf of Suez (Belayim, Abu Rudeis, October and Ras Budran fields).

The general structural pattern of the area is mainly determined by a swarm of faults, which dissect the area into several blocks. The description of these fault trends has been the subject of many publications. Abdel Gawad (1969) classified the fault system of the gulf into five intersecting trends: two of them are oriented parallel with and perpendicular to the gulf, NW-SE and NE-SW and two other systems are diagonals to the gulf, N-S and NNW-SSE. The fifth trend is E-W, which cuts across Sinai Peninsula.

Abdel Magid (1976) made a regional study across the Gulf of Suez and referred to the presence of two dominant fault trends, the northwest trend with greater throw and the northeast trend, along which trans-current movements take place.

Sultan and Schutz (1984) mentioned that, the major faults at the graben shoulders and inside the Gulf of Suez basin form NNW-SSE trend. However, these major faults are not long continuous features, but are composed of a complex of faults, which follow a pre-existing structural pattern (e.g. a pre-existing fault pattern); a 120° angle of intersection between these trends is common.

From the geological aspects of Ras Budran field (Naggar and El-Hilaly, 1985), the Miocene structure is a NW-SE trending anticlinal feature, while the Pre-Miocene is highly faulted, and these faults are mainly due to the intra-Rudeis severe tectonic movements.

Zahran (1986), studied the geology of October field and concluded that the structure of the area can be considered as the northwesterly extension of Gebel Nezzazat structure, where an elongated northwest-southeast trending fault block extends offshore from Gebel Nezzazat for a distance of 30 km through October field area.

Moustafa (1987) made a detailed study on the drape folding in the Baba-Sidri area and concluded that, this model is applicable to several other surface and subsurface parts in the Suez rift.

Moustafa and khalil (1987), from their study on the Durba-Araba fault, concluded that, the Gebel Abu Durba block is bounded to the East by a spoon fault, that caused its rotation. This spoon fault has a strike - slip segment (Durba-Araba fault) and a dip-slip segment (a N-NW, Clysmic fault).

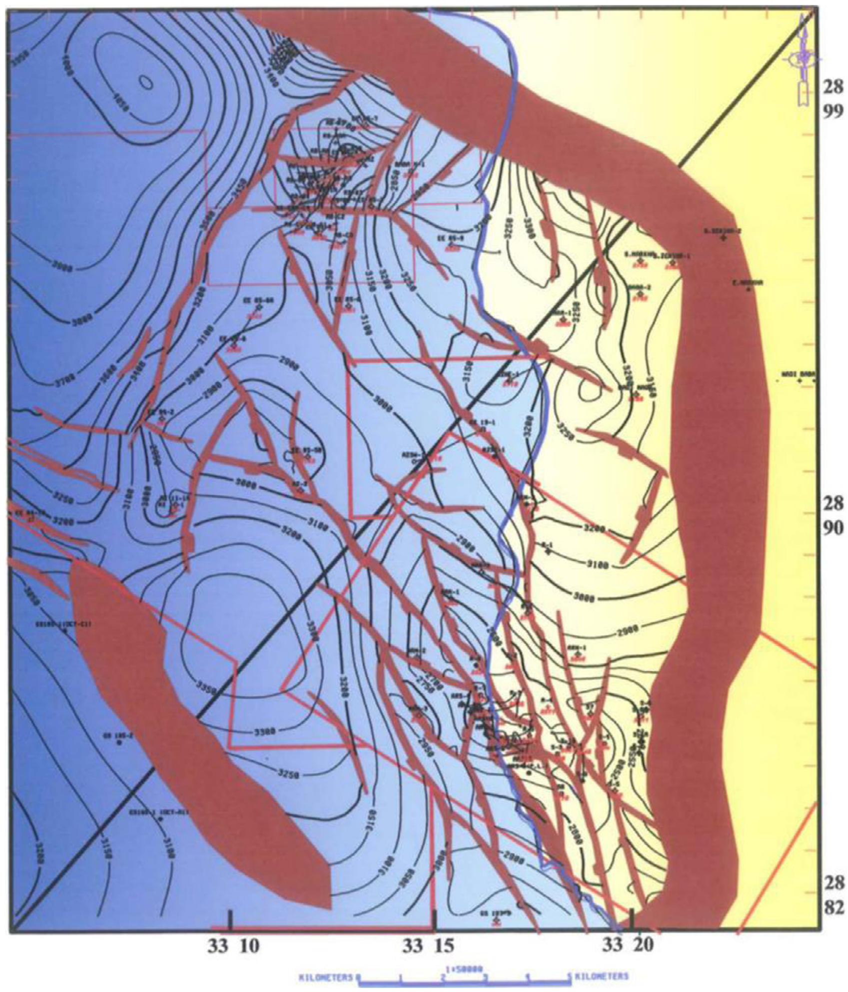


**Figure 13** Depth structure contour map on top Nukhul.

Perry and Schamel (1990) made a study on the role of low-angle normal faulting in the evolution of the Suez rift. They suggested that, the early movement over the low-angle detachments and accompanying isostatic response may play an important role in localizing the deformations within the rift, and are probably critical elements in the early formation of the passive margins.

Moustafa (1992) made a regional study on the Feiran tilted block as an example of a synthetic transfer zone. He indicated that, the bifurcation of the major faults and the decrease in throw of the branching faults could lead to the development of the transfer zones within the half grabens of the rift basins.

Abu Karamat and Meshrcf (2002), from their study on the reverse fault geometry in the Gulf of Suez rift basin, suggested that, the apparent reverse faults observed in the southern gulf are the result of interaction between the pre-rift (oblique trend) and the superimposed early and syn-rift northwest trending (clysmic) normal fault system. Also they believed that, this model is applicable for the Gulf of Suez subsurface geologic interpretation.

Sultan (2002) in his study on the Gulf of Suez/Red Sea structural evaluation, shows that, the main structural trends of NE-SW to NNE-SSW and NW-SE are significant and most of the hydrocarbon accumulations are directly or indirectly related to the intersections of these structural elements. Also, the NE-SW trending structural elements are cross-faults, along which the Gulf of Suez and the Red Sea have been opened.

## 3. Seismic data of Abu Rudeis-Sidri area

The seismic data were used in evaluating the Abu Rudeis-Sidri field (Fig. 3). The land survey was carried out by Geosource Company (Cayman) from December, 1981 to January, 1982, using the Vibroseis, as an energy source. The shallow marine survey was carried out by Seismograph Service Limited Company (S.S.L.) from January, 1983 to May, 1983, using the Geoflex and Dynamite, as energy sources.

Previous surveys were earned out by Western Geophysical Company, using the Vibroseis, as an energy source, through 24-fold land coverage, deep marine and 24-fold telesis lines. The land lines were reprocessed by Geophysical Service Incorporation (G.S.I.), in an attempt to enhance the deep reflections. Many velocity survey data of the Miocene and pre-Miocene sections were detected from the wells: Wadi El-Naqa-1, AZ-13-1, EE85-5A, ARM-1, ARM-2, ARM-3, ARS-1, ARS-5, ARS-6, ARN-1, R-5, S-8, S-7 and ARN-2. Such data were used for controlling the interpretation of the Miocene and pre-Miocene horizons.

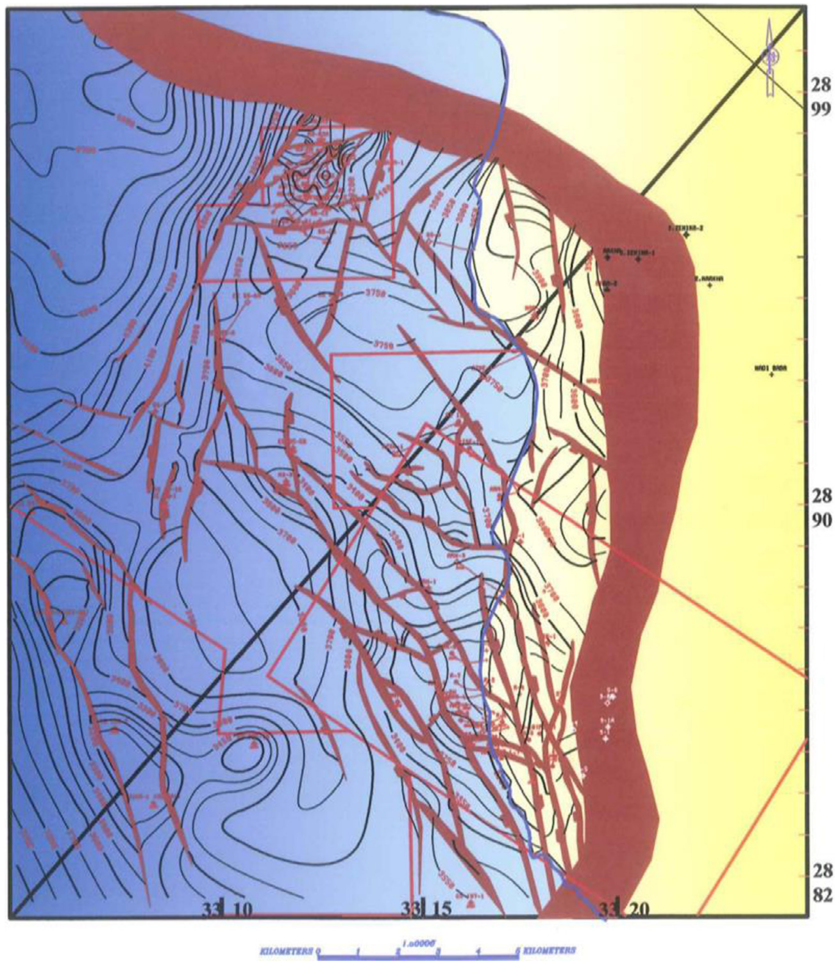


**Figure 14** Depth structure contour map on top Lower Senonian.

As a result, the contact between the Miocene strata and the basement rocks is not clear, even the migrated sections. The dimensions of this shallow basement block are not easy to determine and the continuity of the reflectors is not consistent (Fig. 4). In addition, in the areas, which are affected by the listric faults, the quality is fair. Distortions and scattered noises originated from the fault plane affected the data quality above it, while the multiples affected the data quality below it (Fig. 5).

Also, the quality of the Pre-Miocene horizons is sometimes fair and in other times quite poor, due to the following reasons:

1. Thick evaporite section occurred in the Zeit, South Gharib and Belayim Formations, which is responsible for the attenuation and absorption of seismic energy.
2. Multiple reflections came from the Post-Miocene and Miocene evaporites, especially the Zeit and South Gharib Formations, which masked the weak reflections from the Pre-Miocene interfaces and in most cases superimposed the true reflections.
3. Dip reversals observed in the Miocene strata, which have different dips in all directions, affected the data acquired and velocity analysis interpretation.
4. The thickness of Rudeis Formation (which is composed of shale and marls), reaches in some parts to one thousand meters, causing absorption and scattering of both the down going and reflected energies, and hence reveals lack of penetration of the seismic energy.
5. Closed space faults caused a lot of diffraction and scattered noises, which may be interfered and stacked giving pseudo reflections of indefinite trends.

The reprocessing of some lines was done and achieved some improvement in the resolution of the Pre-Miocene horizons (Lower Senonian and Nubia horizons), that were controlled by the interpretation of the Miocene and Pre-Miocene well data.

## 4. Seismic data interpretation

### 4.1. Seismic line ABZ-19

This line strikes toward the NW-SE direction (Fig. 6) and extends from Abu Rudeis and Abu Zenima areas to the western part of Ras Budran area. The wells: ARM-3, EE85-5B and EE85-6A are located on this line. Aquick look on the southern part of the section shows the horst block of ARM-3 well. Going to the central part, the listric fault affecting the area exists and cuts at shallow Miocene levels. Toward the north, a major fault bounds Ras Budran area to the west.

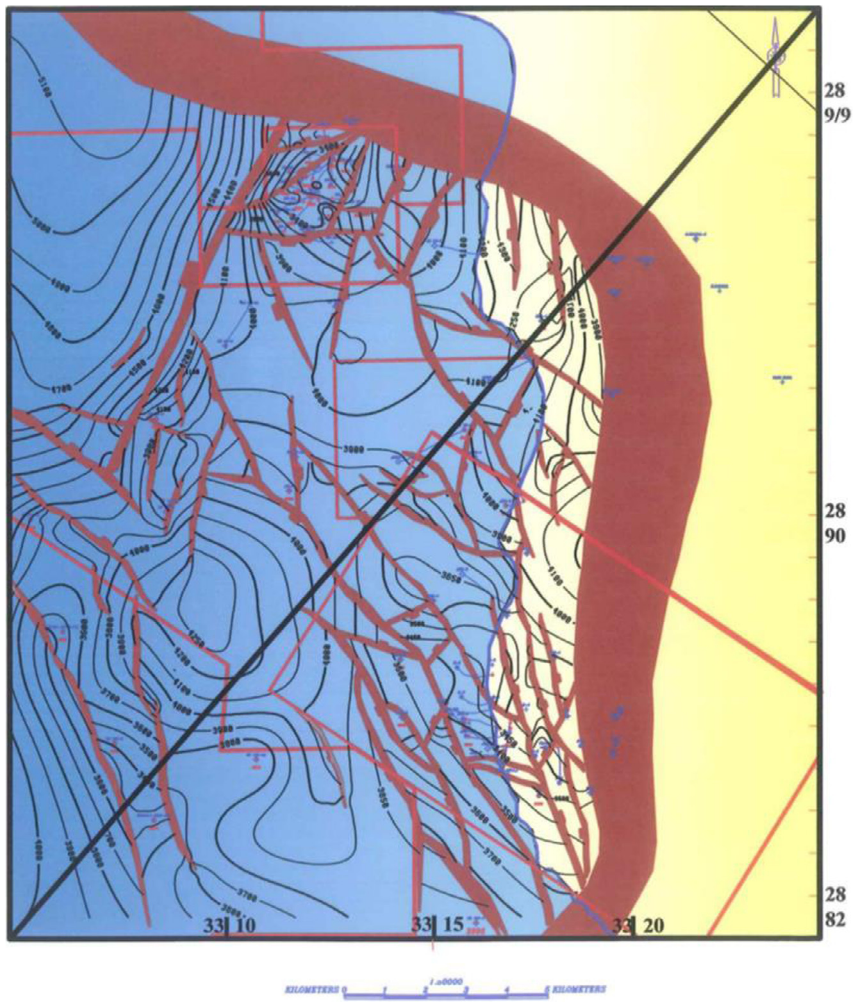


**Figure 15** Depth structure contour map on top Nubia.

*4.2. Seismic line ABZ-88-18*

It extends from Abu Rudeis area to Ras Budran area (Fig. 7) in the N-S direction. The wells: ARM-3, ARM-2, AZSW-1 and Baba-M-l are projected on the line. The central horst, which is running in clysmic trend and extends from Abu Rudeis area to Abu Zenima area, can be illustrated. In addition, the listric fault, which cuts at shallow Miocene levels, is obvious. The graben of Abu Zenima basin, which occurred between Abu Rudeis area and Ras Budran area to the north, is demonstrated.

*4.3. Seismic line RS-27-83*

This line is located in the NW portion of Abu Rudeis area (Fig. 8) and extends in the NE direction. The wells: AZSE-1, ARN-2, ARN-3, ARM-2 and ARM-3 are located on this line. The middle part of this line illustrates the central horst block, which separated the northern part of Abu Rudeis area from the southern one. The dip reversal on both sides of this horst block is clear, added to the listric fault affecting the area and cuts at shallow Miocene targets.

*4.4. Seismic line RS-07-83*

This line crosses the central part of Abu Rudeis area (Fig. 9) in the NE direction. The step clysmic faults down-stepping toward the north (above the central horst block), besides the clysmic faults down-stepping toward the south (below the central horst block) can be distinguished. The listric fault cutting most of Abu Rudeis wells (in the central part) is clearly appeared.

*4.5. Seismic line RG-12-82*

This line extends in the NW direction (Fig. 10) crossing the northern part of Abu Rudeis area. The wells: S-4, R-4, R-3, R-8 and ARM-2 are located on this section. The main bounding fault to the east, and the contact between the basement rocks and the Miocene section can be established. The extension of the central horst and the abrupt change along its two sides is clear. The clysmic faults in the southern part of the section are down-stepping to the east, and on the other hand, another fault occurred in the northern part is down-stepping to the west. This proves the existence of dip reversal along this

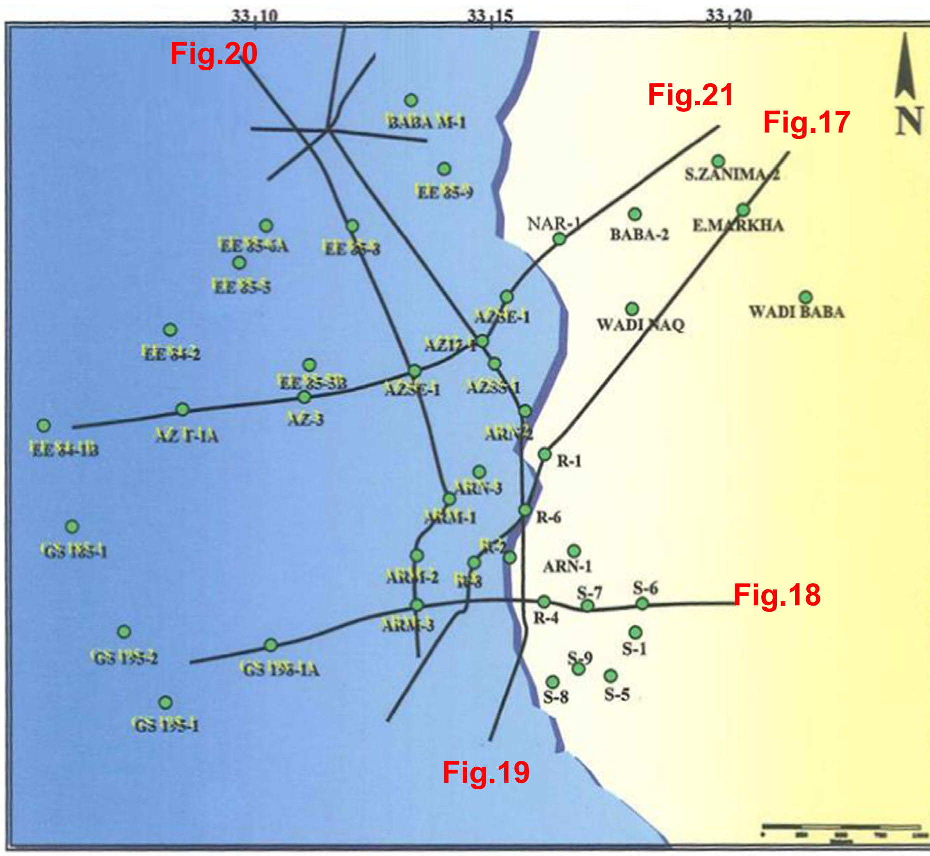


Figure 16 Base map of the studied area, showing the locations of geological cross sections.

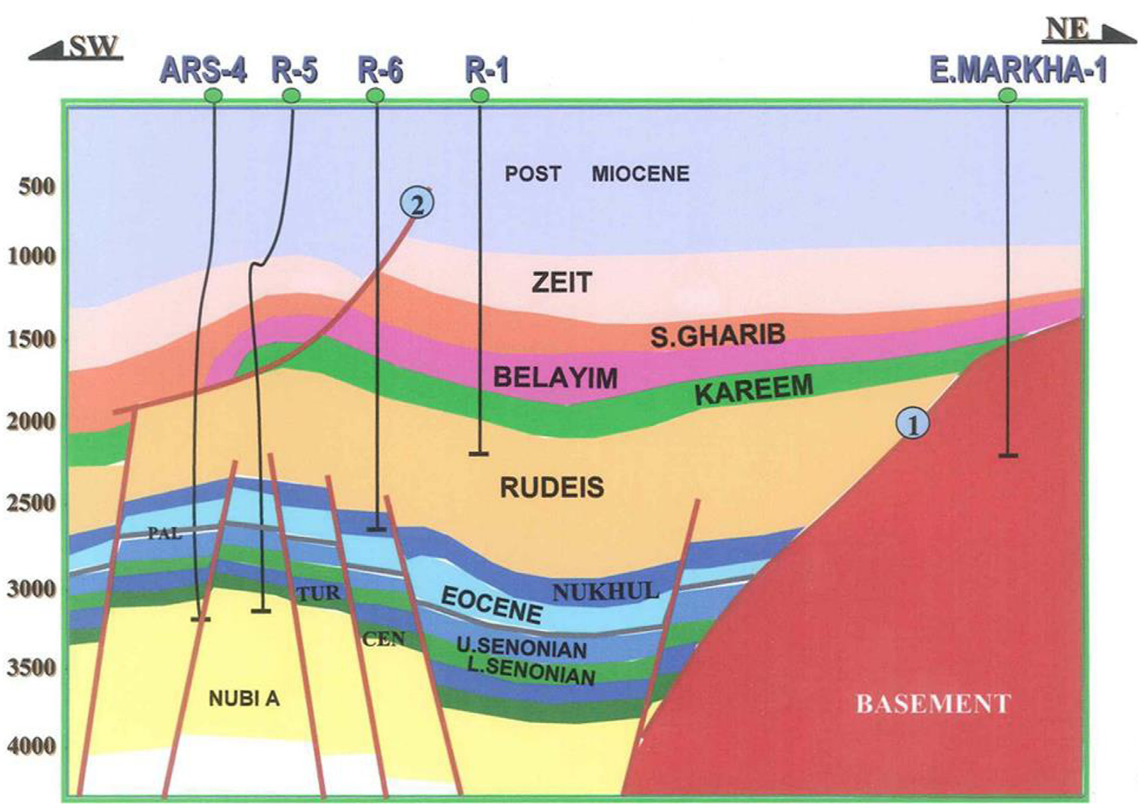


**Figure 17** Geological cross section clarifies: 1 - the eastern main bounding fault, 2 - listric fault affecting the miocene section of Rudeis/Sidri field.

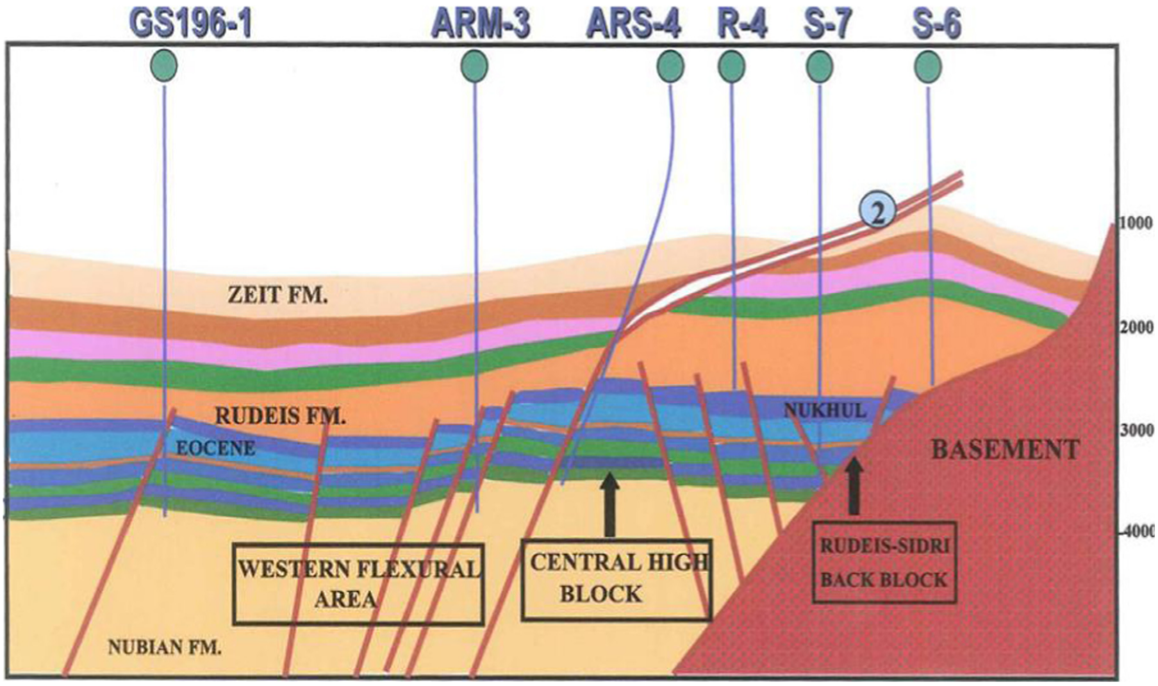


**Figure 18** Geological cross section in the central part of Rudeis-Sidri fields showing: (1) western flexural area, (2) listric fault, (3) central high block, (4) Abu Rudeis back block.

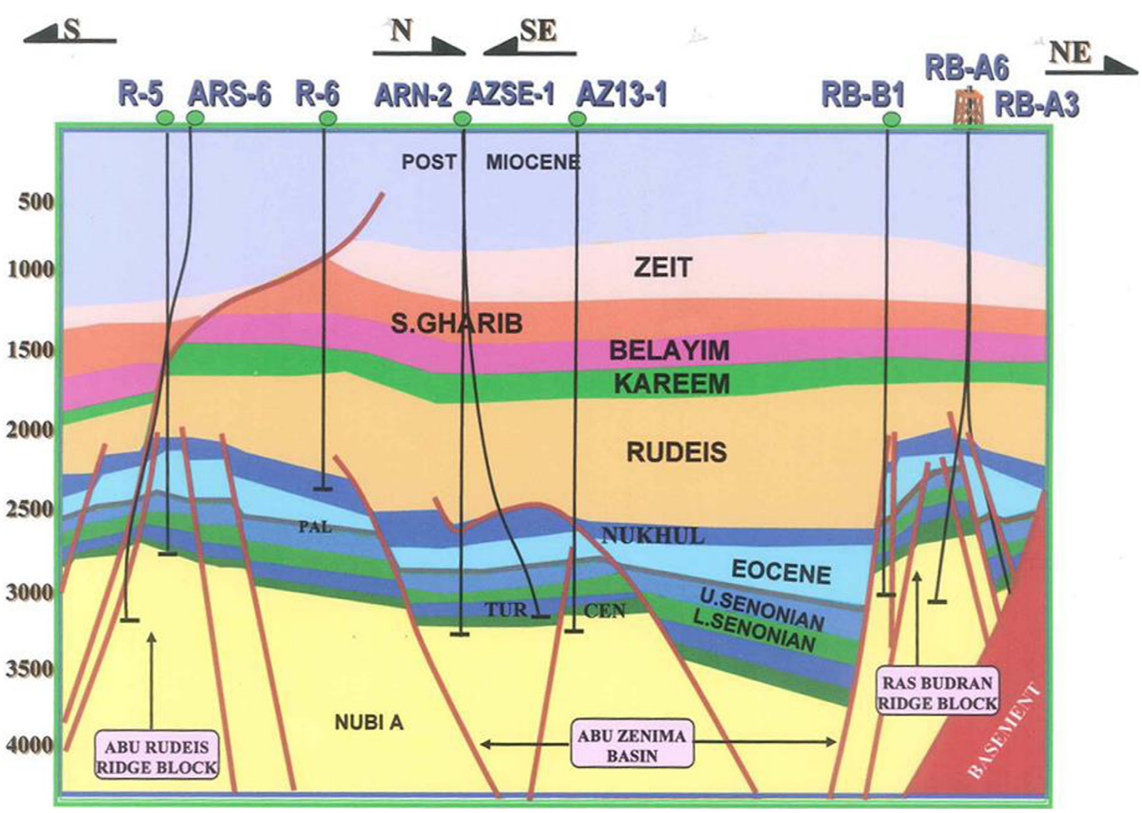


**Figure 19** Geological cross section extended from Rudeis-Sidri to Ras Budran field, showing the two ridges of Abu Rudeis, Ras Budran and Abu Zenima basin between them.

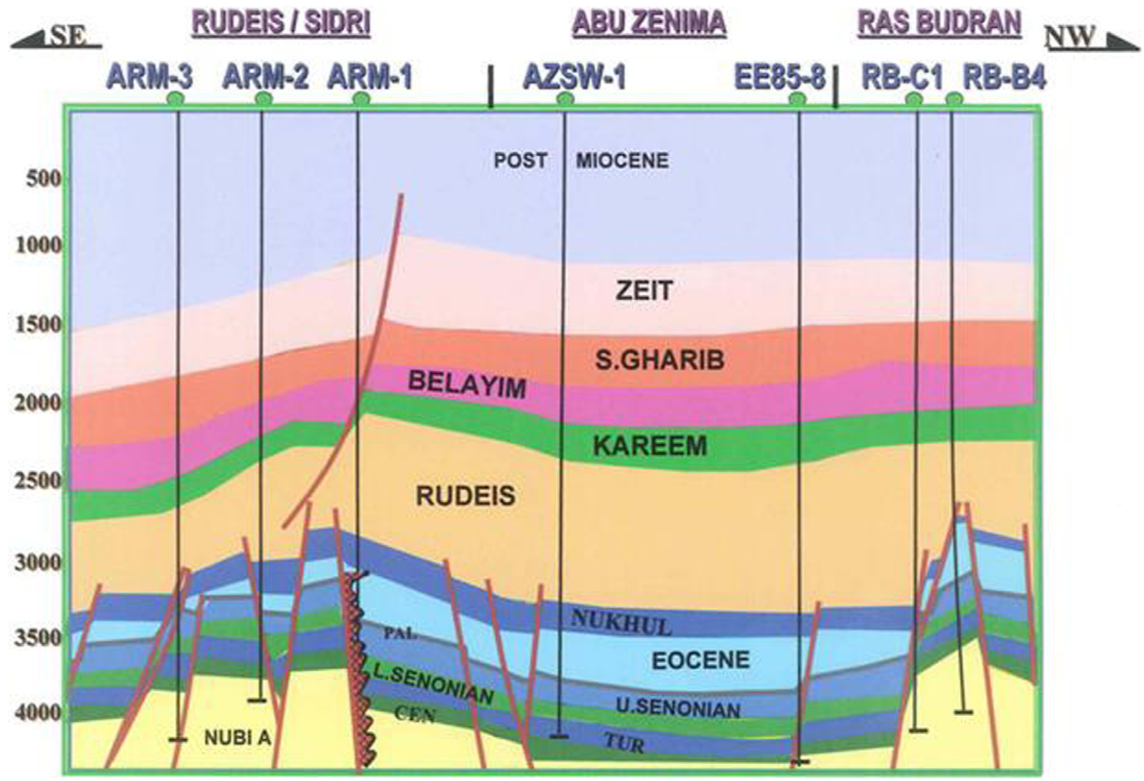


**Figure 20** Regional geological cross section between Ras Budran Abu Zenima and Abu Rudeis/Sidri areas.

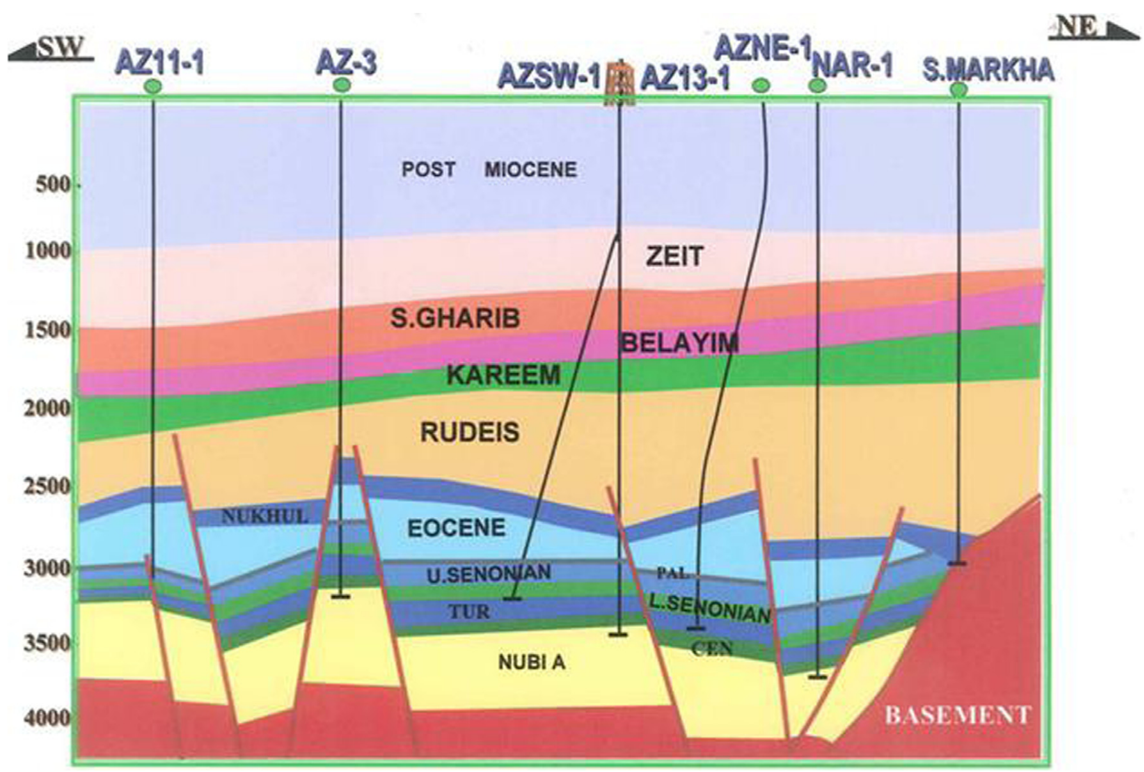


**Figure 21** Geological cross section showing the structural configuration within Abu Zenima basin.

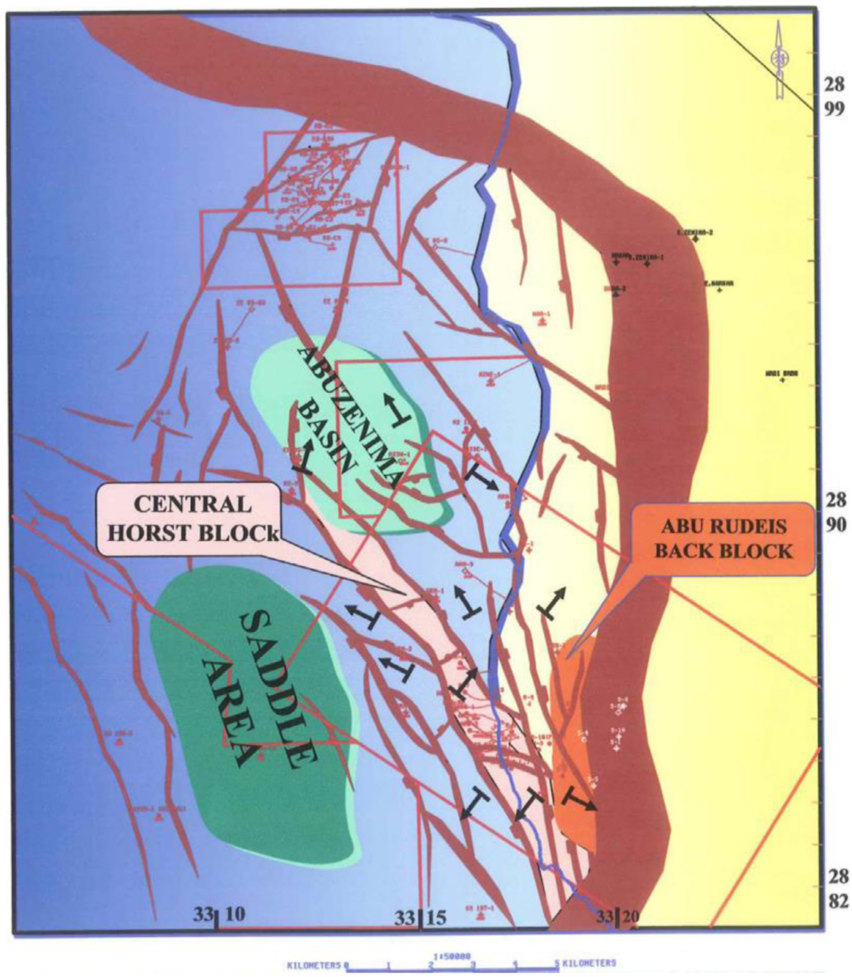


**Figure 22** Lower senonian fault pattern and dipmeter interpretation showing the block rotation.

horst block. Also, the change along the listric fault affected the area is obvious.

*4.6. Seismic line RG-14-82*

This line crosses the central part of Abu Rudeis area (Fig. 11) in the NW direction. This line reflects the main structural configuration of Abu Rudeis area.

## 5. Structural configuration of Rudeis-Sidri area

As an end product of the interpreted seismic data and the geologic integration, the faults and structural patterns were depicted to illustrate the tectonic features characterizing the area. Accordingly, the geo-seismic regional depth maps were constructed for the main interesting levels of Kareem, Nukhul, Matulla (Lower Senonian), and Nubia Formations (Figs. 12–15), in addition to a number of geologic cross sections (Fig. 16).

The dominant fault system is the NW-SE longitudinal faults (Clysmic trend), that run subparallel to the field axis prolongation with a general NE dip, which constitutes the prevailing tectonic feature. This trend is associated with an oblique fault system, that has varying degrees of deviations from the main NE-SW trend. In addition, the eastern margin of the area is characterized by a major rift border fault, which has a considerable throw (+5000 m.) and get the Miocene and Pre-Miocene sections in juxtaposition with the basement complex (Fig. 17). On the other hand, the western side of the area has distinctly flexural character with a number of faults, each has a relative small throw (Fig. 18). In this dip domain, the anti-dip faults (faults throwing to the west) are the main linear structures controlling the oil entrapments.

Besides, the structural pattern of the area reveals two main ridges characterizing Rudeis-Sidri and Ras Budran areas, added to a wide basin between them called Abu Zenima basin. This basin, in turn, is affected by many fault systems dissecting this basin into small horsts, grabens and step-faulted blocks (Figs. 19–21).

Finally, the structural configuration of the area under study is implicated by two structural features superimposing each other, the Miocene (Rift sequence), where the faults trend in a NW direction (Clysmic) and the Pre-Miocene (Pre-Rift sequence), where the faults trend in a NNE to N-S (oblique) direction.

*5.1. Miocene structures*

The Miocene structures of Abu Rudeis-Sidri area, as declared on the top of Nukhul Formation (Fig. 13), are an asymmetrical NW-SE trending anticlinal feature dissected by a set of

NW-SE fault system (Clysmic) into several parallel blocks. The Miocene strata exhibit a gentle dip with an average of 6–15°. As a result, the two limbs of that structure are represented by one dipping to the east and the other tilting to the west with a steep dip. The inflection zone between the two dips is manifested by a gentle dip.

The throws of these clysmic faults range from 50 to 200 m. The dips of these clysmic faults vary from 25 to about 50° in the Pre-Miocene. Also, the dips of such faults are changed, due to the deposition of the Miocene shale and evaporites, to low angle (listric) slump faults with 20–25°, in a way affecting the Zeit, South Gharib, Belayim and Kareem Formations (Figs. 12, 17 and 18). The Miocene structural axis of Abu Rudeis-Sidri field is parallel to that of October field, and is separated from it by a large saddle occurred between them.

### 5.2. Pre-Miocene structures

The structural configuration of the Pre-Miocene section is shown in Figs. 14–21. The Pre-Miocene structures of Abu Rudeis-Sidri area, as seen from the geoseismic depth maps of the tops Matulla and Nubia Formations (Figs. 14 and 15), are very complex and implicated by severe faulting at different stratigraphic levels. Such complexity is continued up to the top Nukhul Formation (Fig. 13). Most of the faults were rejuvenated in the Miocene section and die out upwardly within the Rudeis Formation (Figs. 17–21).

The structural pattern of such a field is affected by two major tectonic phases: Pre-rift (Pre-Miocene) phase, where the faults trend in the NNE to N-S direction (Aqaba trend) and a Syn-rift (Miocene) phase, where the faults trend in the NW direction (clysmic trend). The Pre-Miocene blocks exhibit NE dip ranging from 7 to 12° and split into several blocks by a system of intervening faults. The cross elements affected the area, giving rise to dip reversal, as shown in the area of S-8, ARM-3, ARN-2 and AZSE-1 wells (Fig. 22). The magnitudes of throw of these faults range between 50 and 200 m. Basaltic intrusions were observed along these fault planes (Fig. 20), in a way affecting the reservoir characteristics and oil potentialities of the main field and extended their occurrences in the eastern flank of October field.

The Clysmic fault system, together with the cross elements, has broken Abu Rudeis area into different blocks, each block has its varying reservoir regime. Fig. 22 shows these main blocks: Abu Rudeis back block, in which the Miocene section faces the Basement complex along the eastern main bounding fault; the central horst block, which causes dip reversal on both its sides and characterized by the main production of the field; and Abu Zenima basin in the northern part, which separates Abu Rudeis area from Ras Budran area; the western flank of Abu Rudeis field.

## 6. Summary and conclusions

The present study deals with the interpretation and evaluation of the seismic data of Abu Rudeis-Sidri Fields in the north central part of the Gulf of Suez, in terms of subsurface geologic structures and tectonic pattern characterizing the area.

The seismic reflection data (2D and 3D), integrated with the geologic data, are worked to define the structural configuration of the area, through a set of structural maps for varying time horizons.

The Miocene geoseismic depth maps for Rudeis-Sidri Fields reflect an asymmetrical NW trending anticlinal feature dissected by a set of NW-SE fault elements (Clysmic). Moreover, the pre-Miocene geoseismic depth maps for Rudeis-Sidri Field show a complex structure with NE dip and affected by severe faulting at consecutive stratigraphic levels. Most of these faults die out at the top of Kareem Fm. The structural complexity of the studied area is enhanced by the presence of two major erosional unconformities in the stratigraphic section: One is of Post - Eocene and the second is of Intra-Rudeis, added to the Post - Carboniferous unconformity.

The analysis of the fault systems detected from the structural maps for the studied area, reflects four main fault trends: NNW-SSE (older trend), that formed during the Early Paleozoic and rejuvenated in the Oligocene time (rifting phase), NE-SW (Syrian arc) during the Middle Mesozoic-Late Mesozoic time, NW-SE (clysmic) during the Early Tertiary and NNE-SSW (Aqaba), that formed during the Quaternary time.

The geologic history of the area illustrated that, Abu Rudeis structure is formed during the late Oligocene-Early Miocene time (rifting phase).

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