Seismic data interpretation for hydrocarbon potential, for Safwa/Sabbar field, East Ghazalat onshore area, Abu Gharadig basin, Western Desert, Egypt

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A B S T R A C T

Safwa/Sabbar oil field located in the East Ghazalat Concession in the proven and prolific Abu Gharadig basin, Western Desert, Egypt, and about 250 km to the southwest of Cairo, it's located in the vicinity of several producing oil fields ranging from small to large size hydrocarbon accumulation, adjacent to the NW-SE trending major Abu Gharadig fault which is throwing to the Southwest.

All the geological, "structure and stratigraphic" elements, have been identified after interpreting the recent high quality 3D seismic survey for prospect generation, evaluation and their relation to the hydrocarbon exploration.

Synthetic seismograms have been carried out for all available wells to tie horizons to seismic data and to define the lateral variation characters of the beds.

The analysis has been done using the suitable seismic attributes to understand the characteristics of different types of the reservoir formations, type of trap system, identify channels and faults, and delineating the stratigraphic plays of good reservoirs such as Eocene Apollonia Limestone, AR "F", AR "G" members, Upper Bahariya, Jurassic Khatatba Sandstone, upper Safa and Lower Safa Sandstone.

The top Cenomanian Bahariya level is the main oil reservoir in the Study area, which consist of Sandstone, Siltstone and Shale, the thickness is varying from 1 to 50 ft along the study area.

In addition to Upper-Bahariya there are a good accessibility of hydrocarbon potential within the Jurassic Khatatba Sandstone and the Eocene Apollonia Limestone. More exploring of these reservoirs are important to increase productivity of Oil and/or Gas in the study area.

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1. Introduction

1.1. Location

The study area is geographically located onshore, within the south-eastern part of the northern portion of the Western Desert region of Egypt .The block is situated about 250 km to the west-south-west of Cairo and 200 km to the southwest of Alexandria, as shown in (Fig. 1).

It's located between latitudes 29°45″ and 30°05″N and longitudes 27°30″ and 28°10″E, in the vicinity of several producing oil fields ranging from small and large size hydrocarbon accumulation, Along the southern edge of the East Ghazalat concession, the map in (Fig. 1) shows multiple oil fields on either side of the concession.

East Ghazalat Concession is located in the proven and prolific Abu Gharadig Basin, North Western Desert, Egypt.

2. Western Desert General Geological History

The geologic history of the northern Western Desert is summarized as follows:

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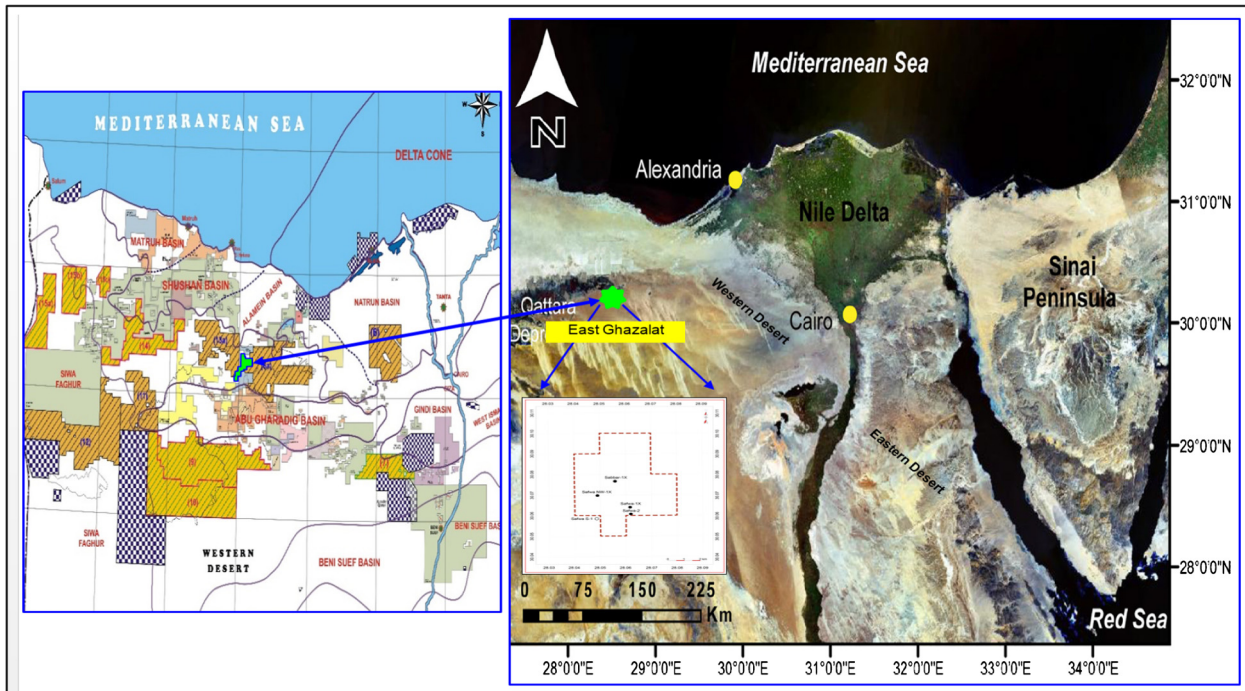 E-mail addresses: nrediny@yahoo.com, nrediny@petroamir.com (N.A. Hameed El Redini).

Fig. 1. Study area location map, Egypt, EGPC Western Desert concession map "2015".

– A shallow sea covered the central part of the Western Desert in Cambro-Ordovician time. A second transgression during the Carboniferous was restricted to the north.

– The Paleozoic sediments are more strongly folded than the overlying Mesozoic sediments, broad regional highs and lows may exist (ElShazly, 1977; Barakat, 1982). Khalil et al. (1983) mentioned that, there is a possible Paleozoic basin lies in the Abu Gharadig area, where 1300 m. of sediments were reached on drilling. A major disconformity is generally reported between the Paleozoic and Mesozoic (Beckman, 1967). No sediments of Permian age are known in Egypt (Orwig, 1982).

– The area above sea level was eroded at the end of the Paleozoic, i.e. Triassic sediments are missed.

– The area was subjected to emergence and local uplift (El Gezeery et al., 1972). This is represented by a widespread unconformity, which is recorded at the Jurassic-Cretaceous boundary.

– Lower Cretaceous transgression started from the north and northwest, then migrated to the east and possibly south. During Cenomanian, the deposition was affected by a major movement along the E-W faults crossing the central part of the study area.

– During Late Cretaceous, the sea continued to advance. It is represented by the wide transgression known in the geologic history of Egypt, which resulted in the extension of the Upper Cretaceous sediments extended beyond the limits of the other marine formations (Faris, 1956).

– Late Cretaceous-Early Tertiary diastrophism produced the major unconformities between Mesozoic and Tertiary sediments. Most obvious folds, which caused by the Laramide movements are the Syrian arcs, these started near the end of the Turonian (Salem, 1976), or during the Senonian (Beckman, 1967 and Barakat, 1982) and continued intermittently into the Paleozoic and locally to the end of the Eocene.

– At the end of Lower Eocene, a regional uplift or updoming occurred accompanied by a considerable block faulting along some old fault zones, with a partly NE-SW trend at least.

– During the Oligocene period, shaley Dabaa Formation had extended over most of the study area. Salem (1976) proposed a model for a series of NNW flowing rivers bringing those sediments to the Western Desert.

– During Early Miocene, the area received sandy fluvial-marine sedimentation reached the southern and western margins of it (Moghra Formation). Further transgression took place during the Middle Miocene and resulted in the deposition of the Marmarica Formation. From Late Miocene onwards, a general regression took place and most of the Western Desert was subjected to subarial erosion.

– Pliocene and Quaternary deposition is characterized by thin accumulation of clastics, with few calcareous interbeds across the area. Such deposition rests over the Middle Miocene or older sediments with a marked disconformity (Abdel Hamid, 1985).

2.1. Basin evolution

The prospectivity is related to several intra-basinal having NE-SW and E-W trends, forming structural highs and ridges. The main hydrocarbon play associated with stacked Cretaceous reservoirs, additional potential exists in platform area where Cretaceous and Jurassic and pre-Jurassic reservoirs are present at relatively shallow depth, the rocks are related to by both Cretaceous and Jurassic located in the basin and basin margins.

2.2. Structure

The structure of the study area is situated adjacent to the basin margin of Abu Al Gharadig Basin and with good accessibility to the hydrocarbons generated from the kitchen area where Cretaceous and Jurassic source rocks are capable of generating/expelling large volumes of oil and gas.

2.3. Reservoirs

The main reservoir interval comprises the successive Kharita Member (Albian), Bahariya Formation (Cenomanian) and Abu Roash Formation (Cenomanian-Santonian), with a mix of (mainly) clastic and carbonate reservoirs. Minor reserves are held in the Jurassic Khatatba Formation (mainly oil) and in the Upper Cretaceous Khoman Formation (gas only).

2.4. Stratigraphy of the North western Desert

See Fig. 2.

3. Methodology

The methodology used to model Upper-Bahariya reservoir includes: Well-log editing and pseudo-log generation, tying a
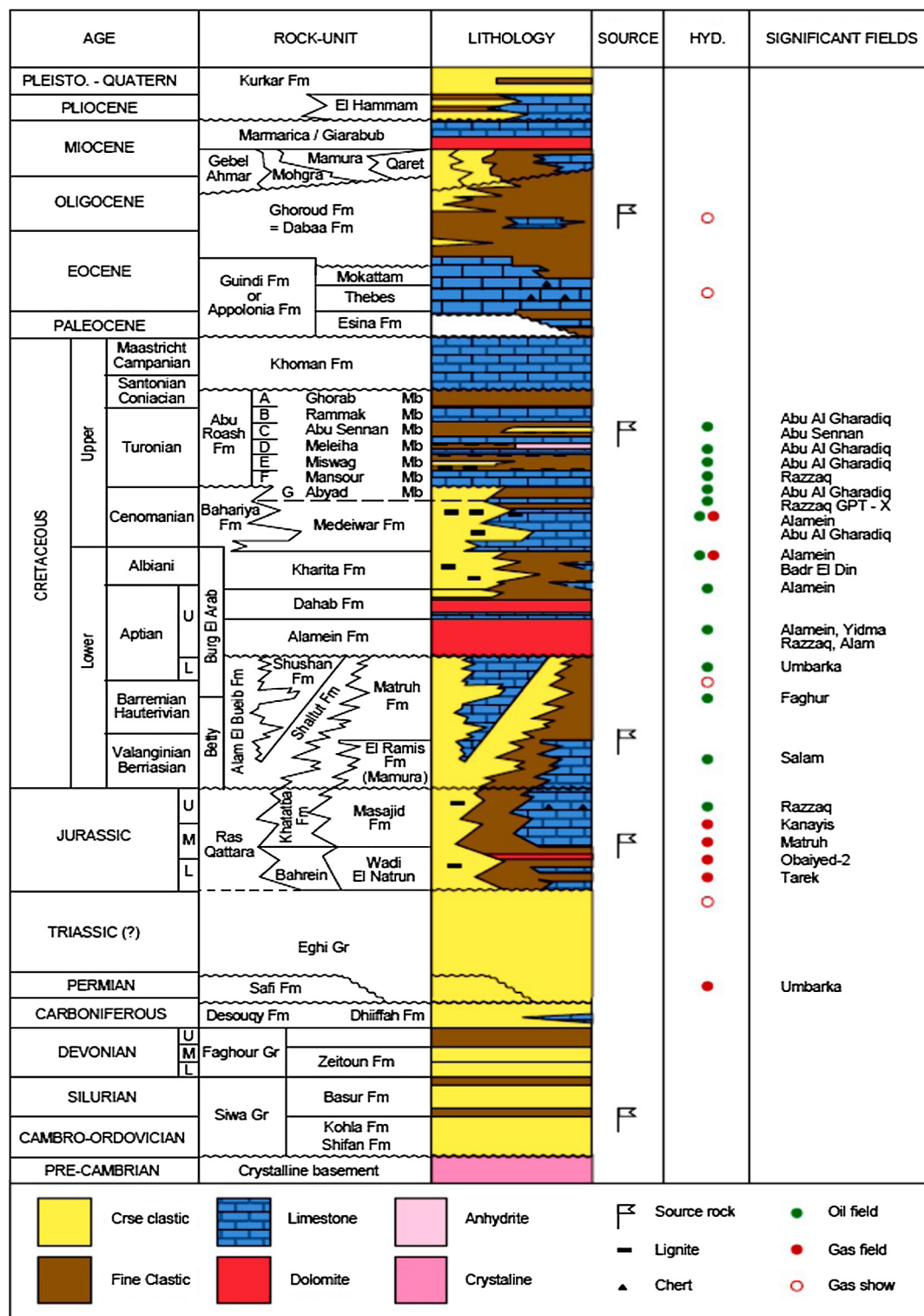

Fig. 2. Generalized stratigraphic column of the North Western Desert. (modified from WEC Egypt, Schlumberger,1984; EGPC Western desert, Oil and Gasfields,1992; and Shaarawy, GUPCO in Abdel Halim, EGPC,1994).
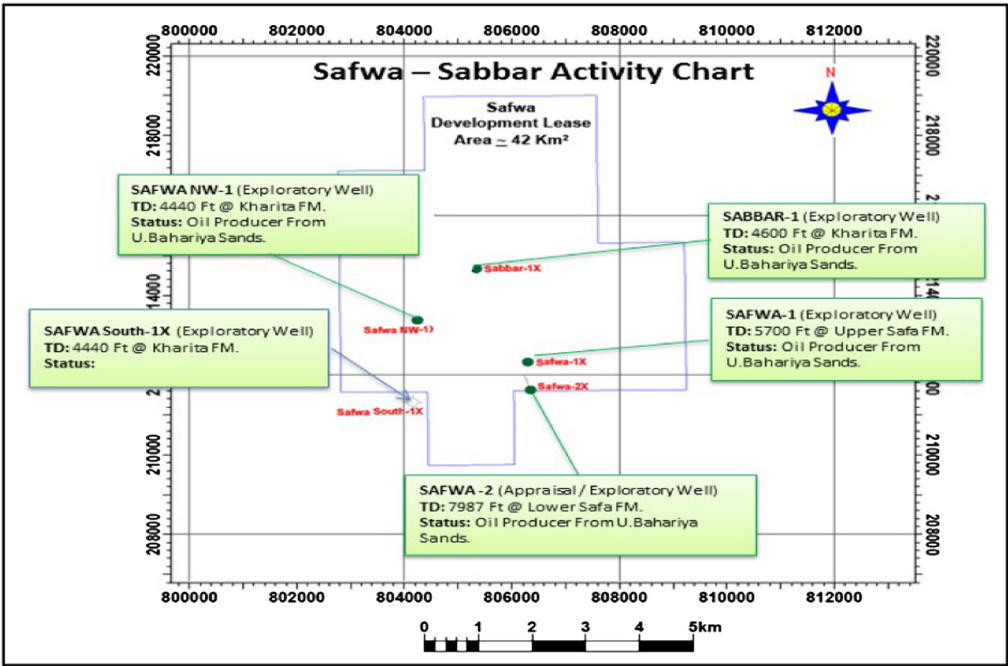
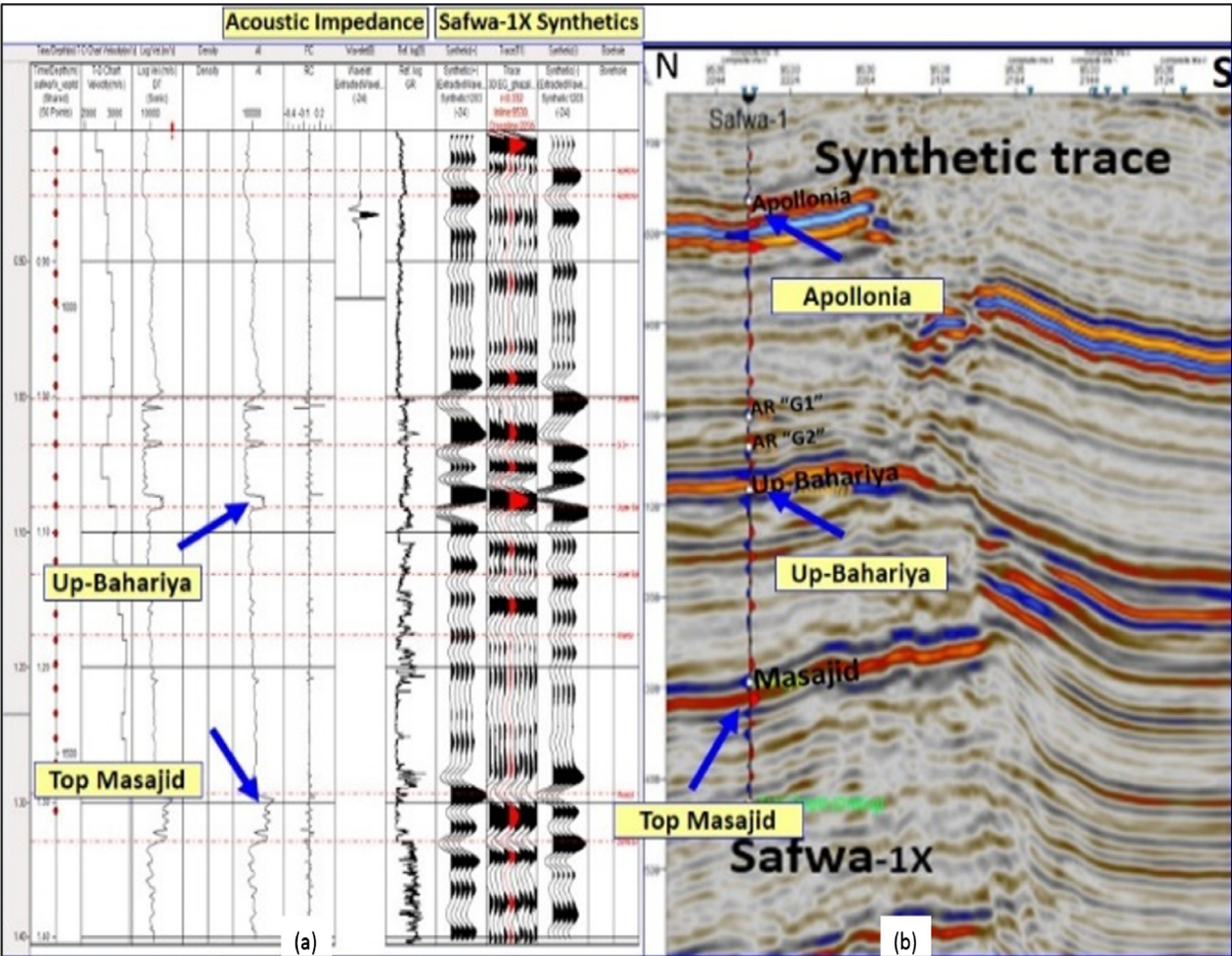**Fig. 3.** Regional location map for "Safwa-Sabbar" study area.

Fig. 4. (a) Shows the well logs and synthetic seismogram correlation for the well Safwa-1X, (b) is the seismic well tie correlation section of inline 9500 passing through the Safwa-1X well.
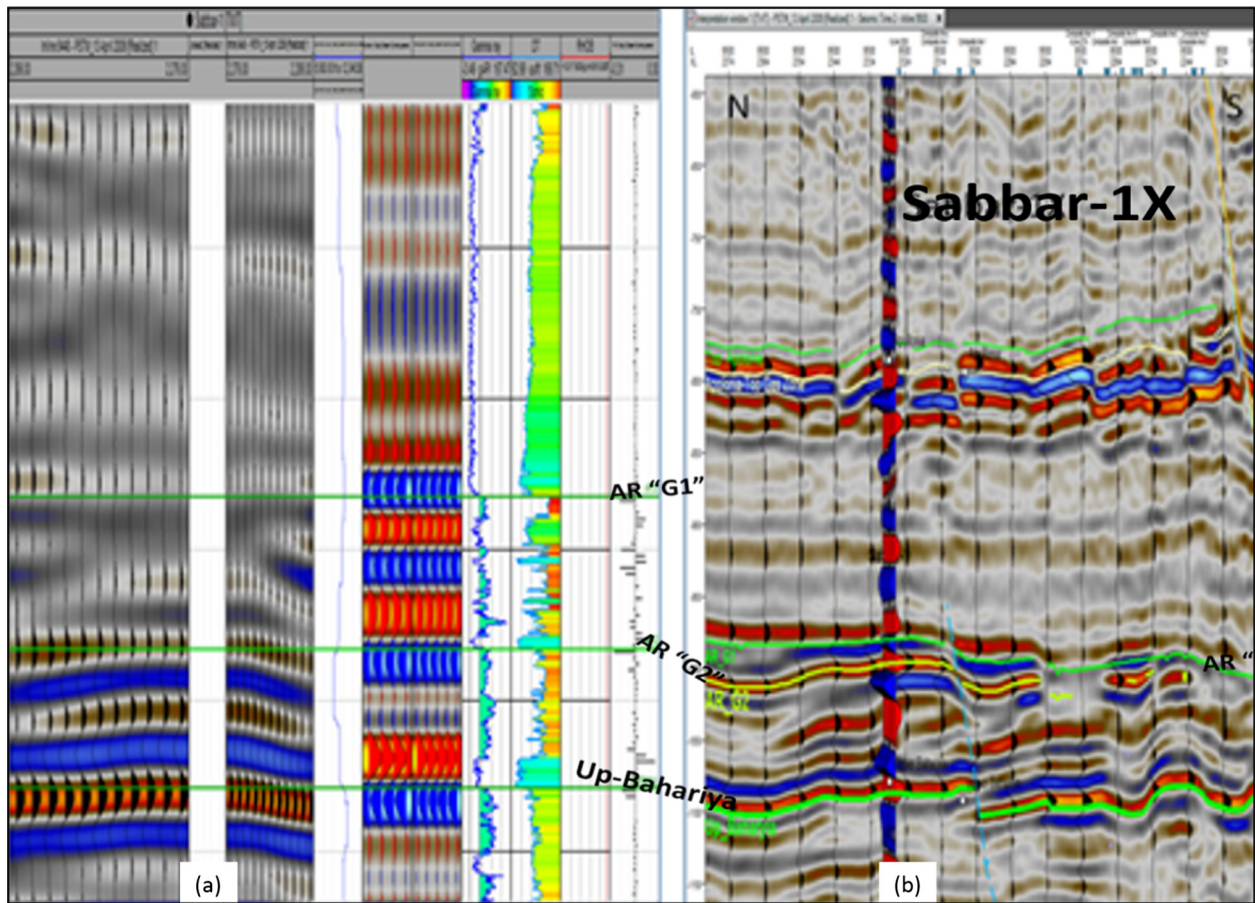
Fig. 5. (a) Shows the well logs and synthetic seismogram correlation for the well Sabbar-1X, (b) Shows the Seismic well tie correlation.
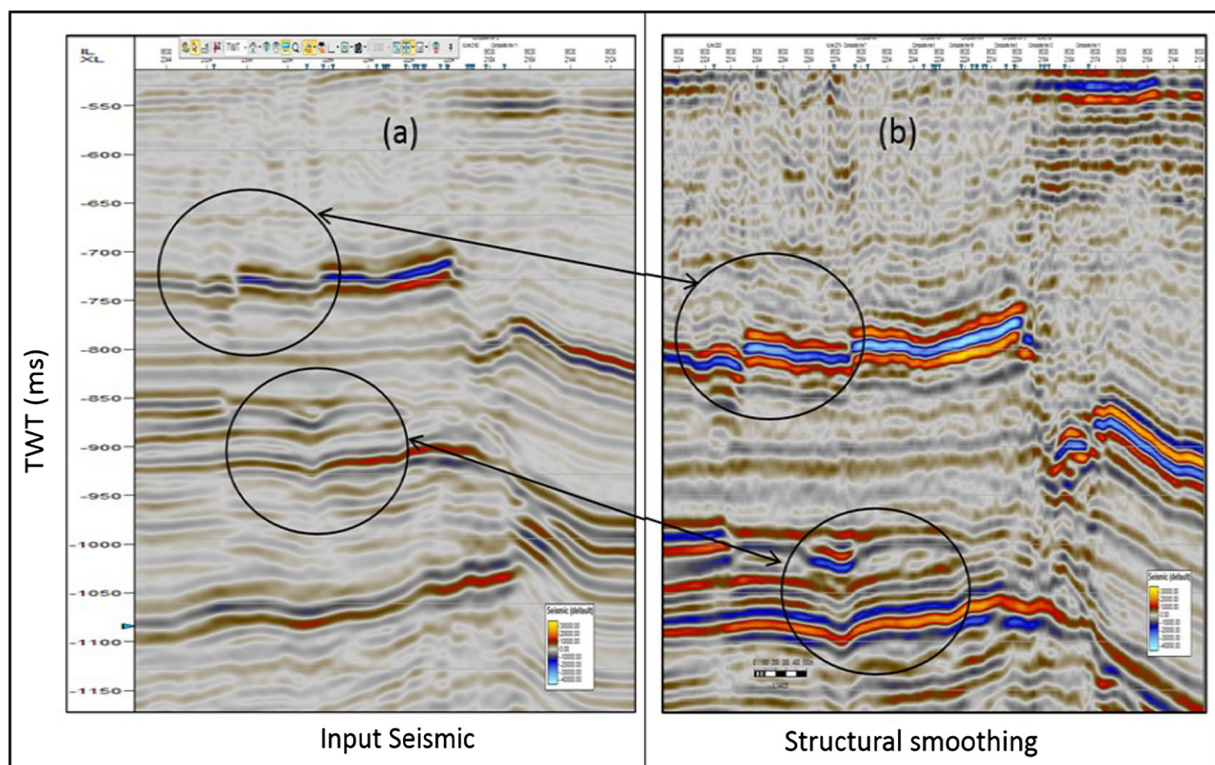

Fig. 6. (a) Original seismic section, (b) structural Smoothing attribute seismic section, shows the continuity of the seismic events.
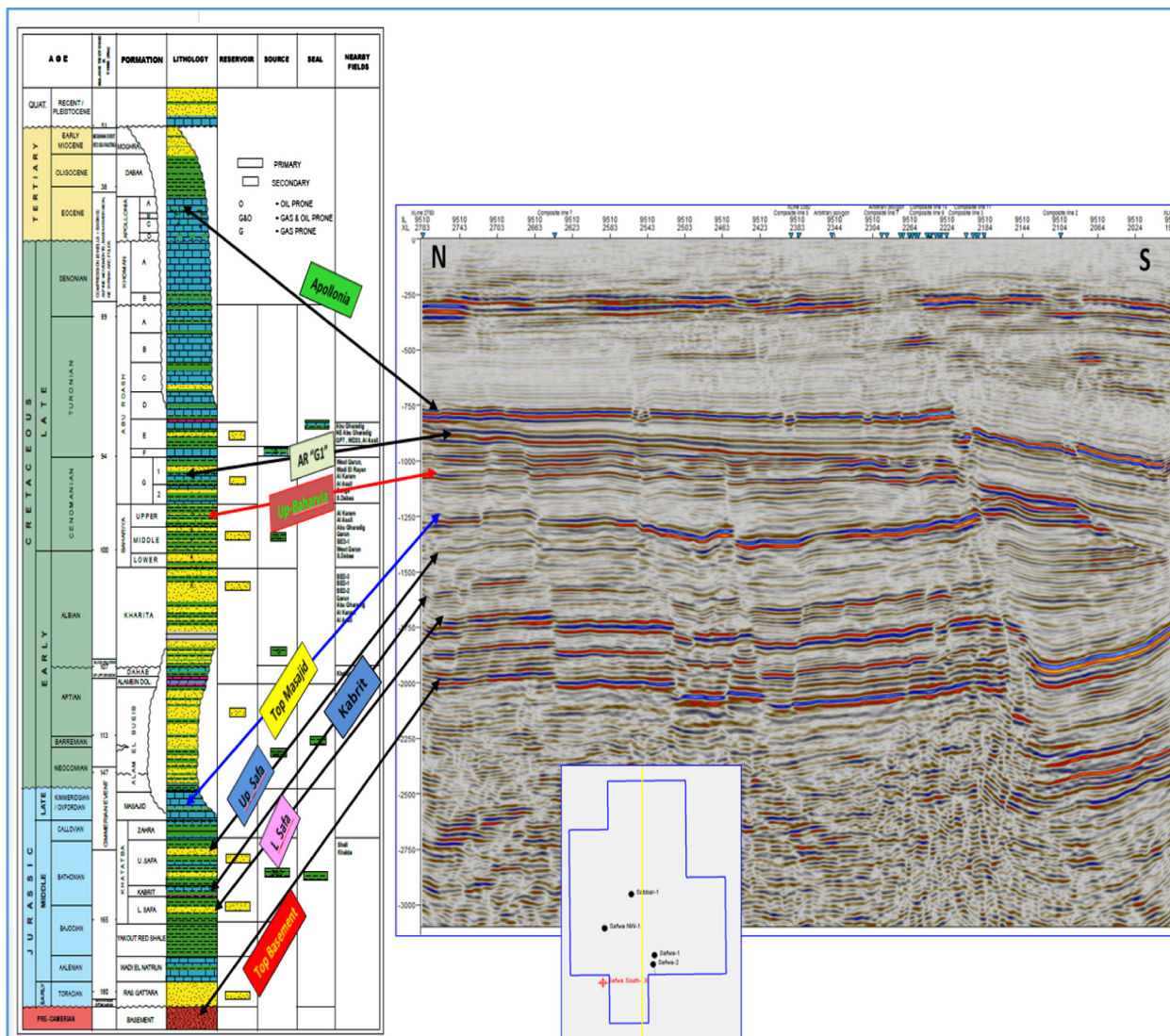
Fig. 7. Correlate the Seismic data and structural features.

synthetic model to a surface seismic data, interpreting the recent high quality 3D seismic survey for prospect generation, evaluation and their relation to the hydrocarbon exploration, and using the suitable attributes analysis which may have a great support in delineating the geometry and trend of stratigraphic features to understand the characteristics of different types of the reservoir formations.

3.1. Well data

The study utilizes data from four producing wells, Safwa-1X, Safwa NW-1, Sabbar-1X and Safwa-2X, one dry well Safwa South-1X. Some wells in the area are penetrating and testing the deep Jurassic section such as Safwa-1X and Safwa-2X as shown in Fig. 3.

↻ Safwa south-1X "DRY" where the MUD LOG No Oil Shows and based on chromatogram no good indication for presence of hydrocarbon, more over the Wireline interpretation confirm absence of any hydrocarbon (Oil/ Or Gas).

3.2. Seismic data

About 42 km² of 3D-Sesimic Data Safwa/Sabbar Development Lease (study area) was shot in 2008 using a combination of Vibro-

seis and Dynamite waves. The obtained seismic were processed by PGS in 2008 and fully processed PSTM survey available (25 × 25 m), the seismic volume indicated a very high quality data, Seismic in-line (265 Iline) through X-direction (E-W), Seismic cross-line (350 Xline) through Y-direction (N-S).

4. Synthetic seismograms

Well log data is very important for, creating synthetic seismogram for seismic to well tie. Also log data is very important in determination of different formation tops and reservoir properties such as porosity, permeability and water-hydrocarbon saturation using set of composite logs such as Gamma Ray, Resistivity and Porosity (Density and Neutron, Sonic logs) as well as cores data.

The rock property are identified such as acoustic impedance which can be easily recognized using the velocity derived from sonic or VSP well log and the density from density log. It can be integrated with the results of attributes in a powerful way for identify the possible hydrocarbon reservoirs and confirm the seismic data.

The log data of four wells with high resolution and quality, where the data had been corrected for the environmental and hole conditions were used in both well petrophysical evaluations.
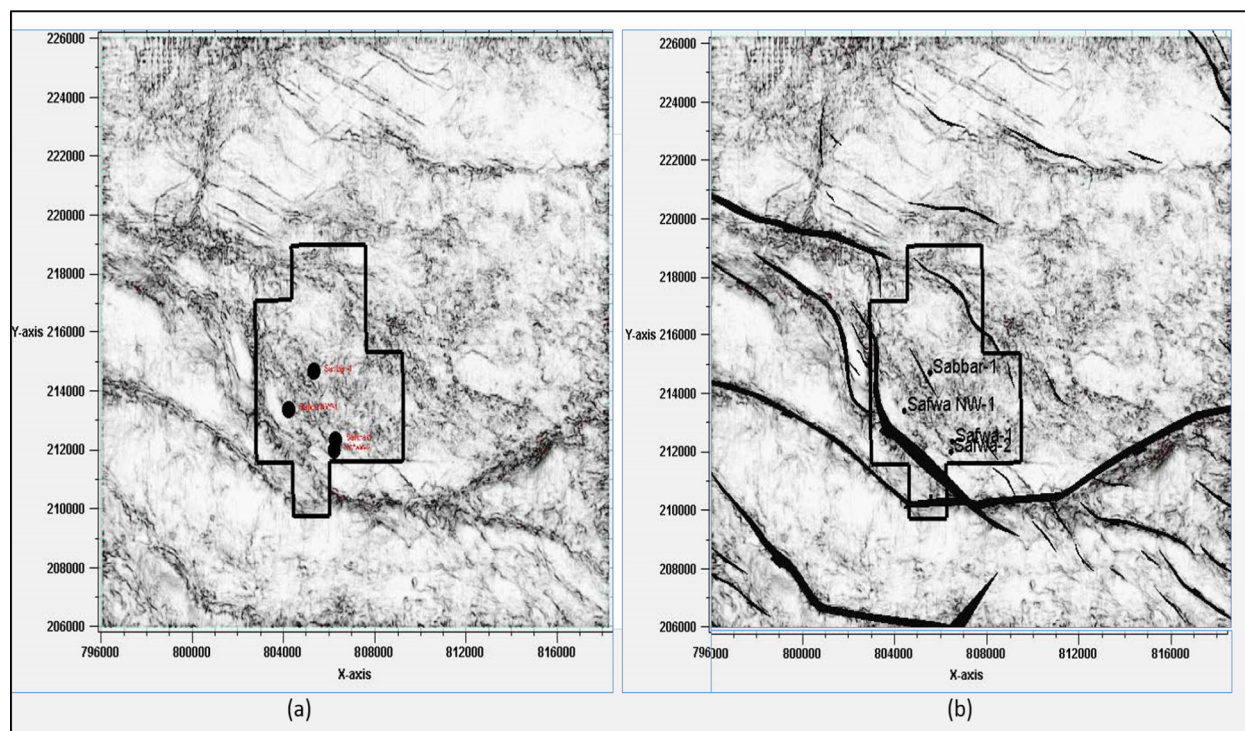
Fig. 8. (a) Time slices show the fault continuity correlates with seismic variance attribute at the Upper-Bahariya level, (b) fault polygon set.
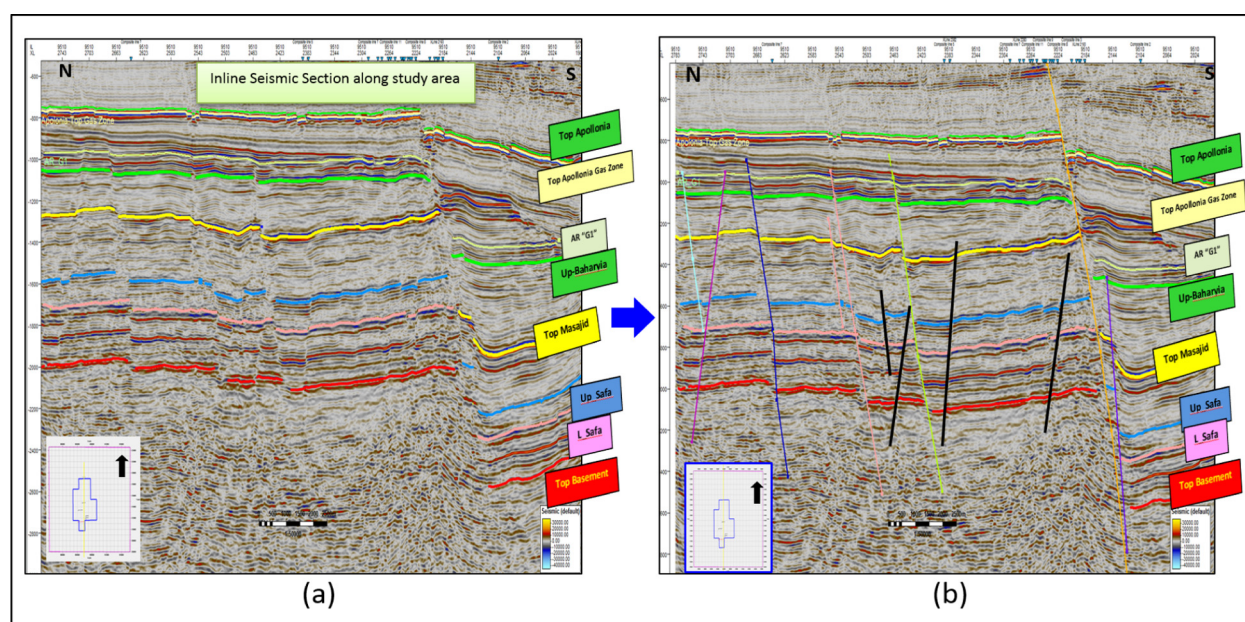

Fig. 9. (a), Inline seismic section display main interpreted horizons, (b) The same Inline seismic section shows horizons and faults interpretation.

4.1. Well-to-seismic tie

Log data from the area under study, Safwa-1X, Safwa-NW-1X, Sabbar-1X and Safwa-2X wells and the 3D seismic lines were used for the synthetic-to-surface seismic tie.

A wavelet extracted from the surface data around the target reservoirs and the edited well logs was used to generate the zero-offset synthetic seismogram necessary to tie surface seismic data at the well locations. The synthetic-to-surface seismic ties at the wells are shown (Figs. 4 and 5), the tie is very good and suggested that the Apollonia, Upper-Bahariya and Masajid zones should be picked started at 378 ms and ended at 1399 ms two-way time in the Safwa-1X well consequently, started at 732 ms and ended at 1750 Ms. in the Safwa-2X well, started at 382 ms and ended at 1194 ms in the Safwa NW-1X well, and stared at 334 ms and ended at 1230 ms in the Sabbar-1X well.
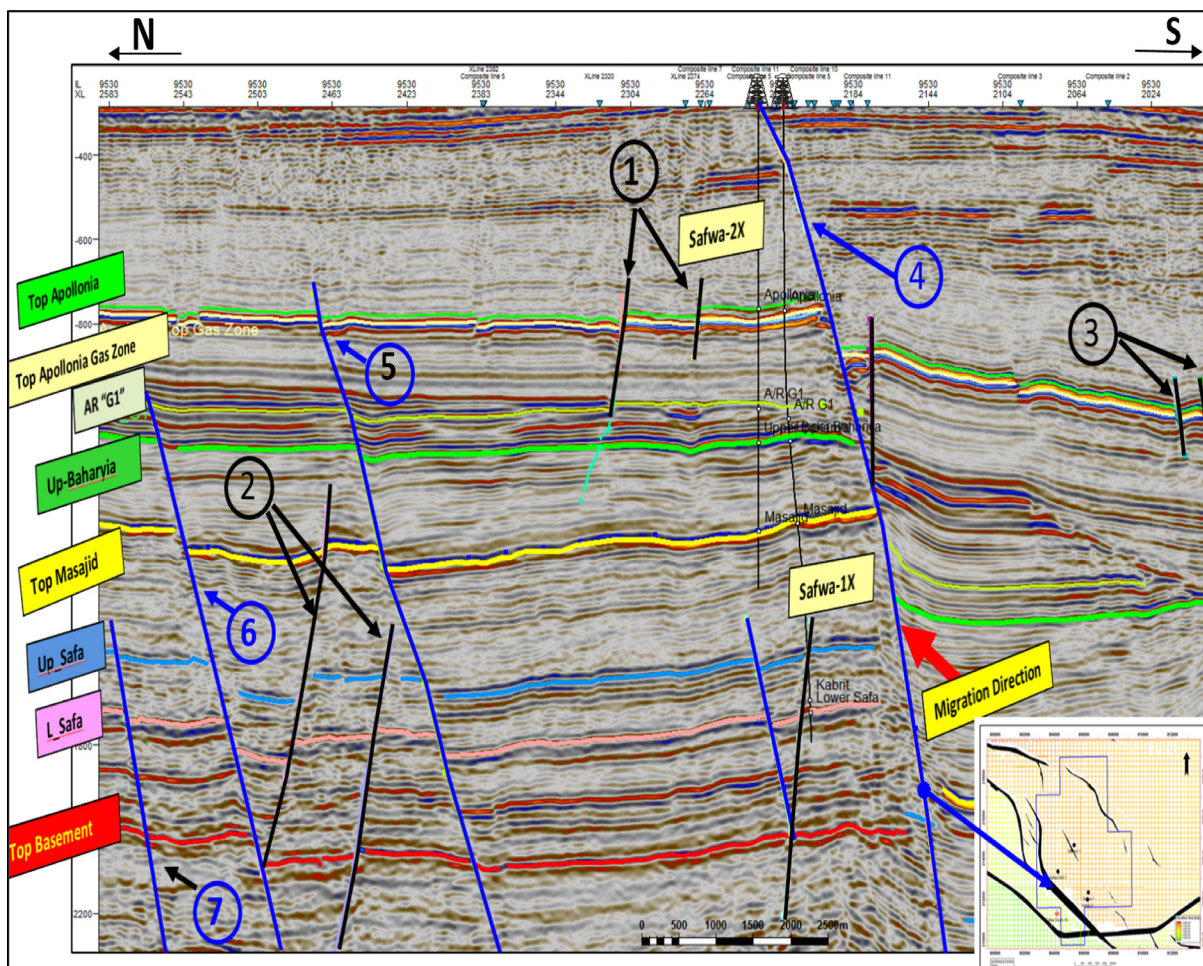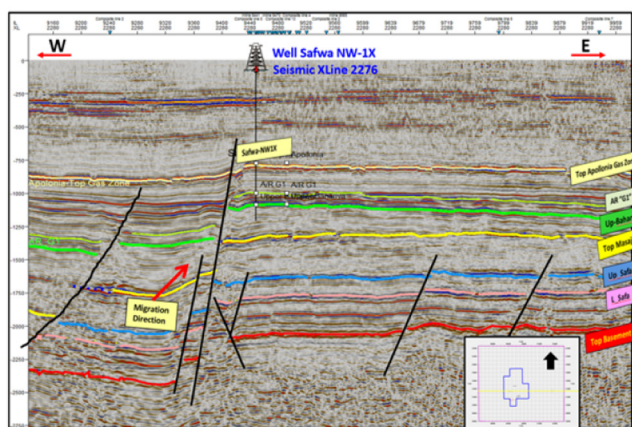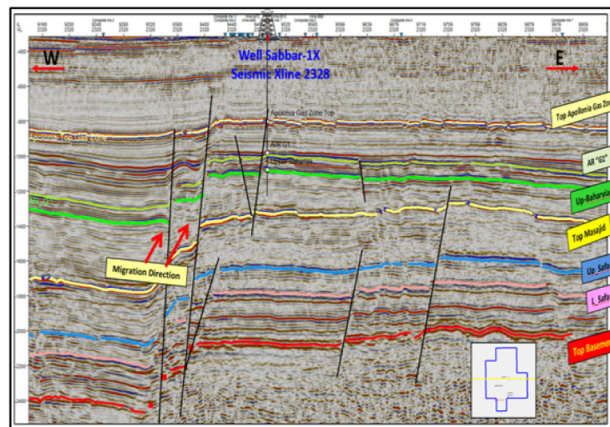
Fig. 10. Shows normal fault as 4, 5, 6 & 7 and minor reverse fault as 1, 2 & 3.

Fig. 11. (a and b): Xline Seismic section display main interpreted horizons and faults, Safwa-NW-1X and Sabbar-1X Wells.

Examples for synthetic seismogram generation Safwa-1X and Sabbar-1X, Logs from Safwa-1X well and 3D seismic data were used for the synthetic-to-surface seismic tie, (Fig. 4) showing, Upper-Bahariya and Masajid zones the same polarity, indicates that no change are observed within the Upper-Bahariya unit in the study area, the blue arrows indicated a good quality reservoirs located within the Upper-Bahariya and Jurassic, the Upper-Bahariya reservoirs contain hydrocarbons.

Fig. 4 shows the GR, Sonic logs and synthetic seismogram correlation for the well Safwa-1X.

The main points extracted from seismogram are:

The main reflectors are very close to the reservoir facies, such as Upper-Bahariya which is the main reservoir in the area, Kharita
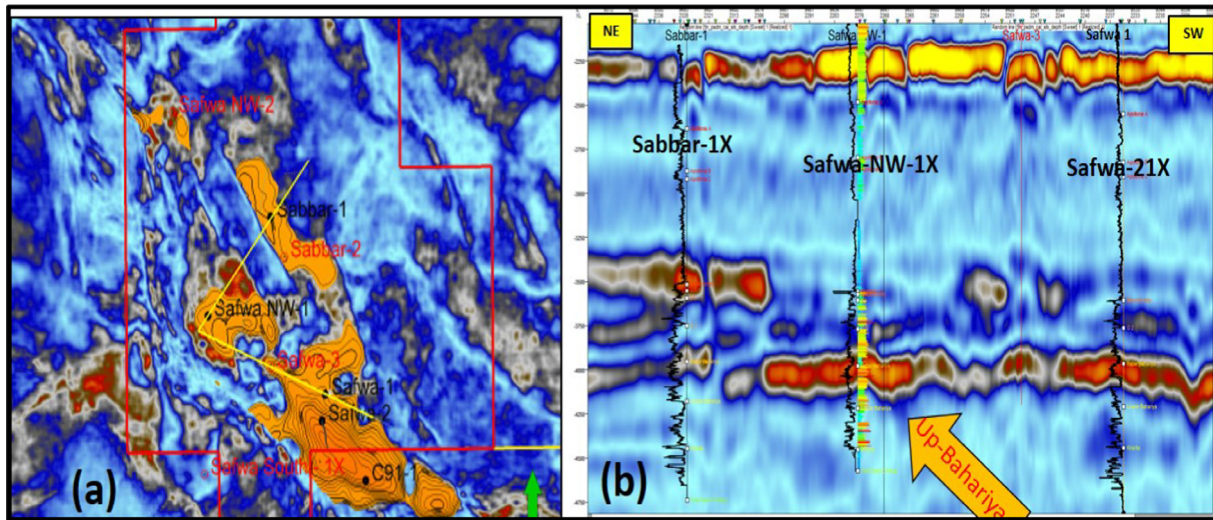
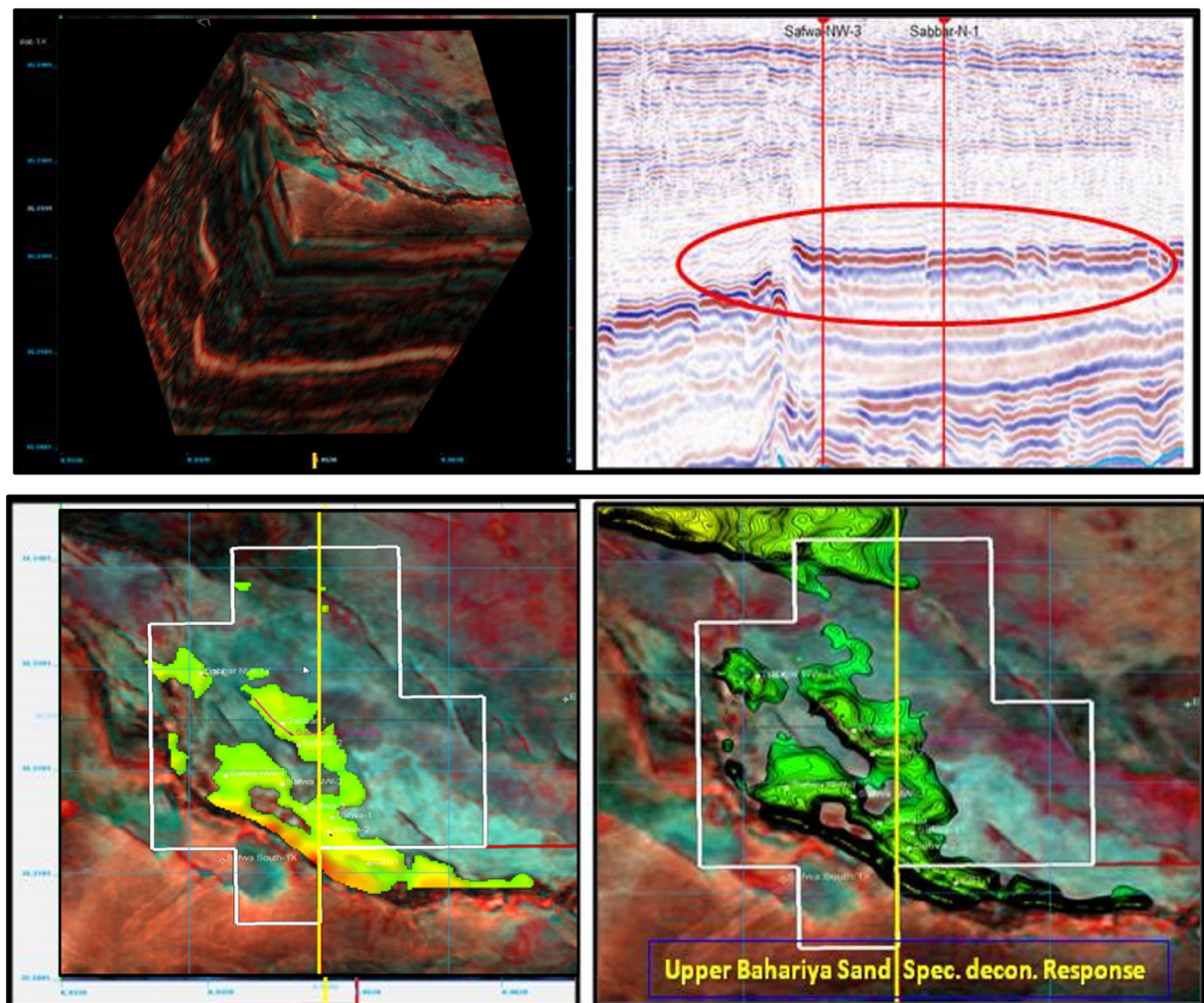**Fig. 12.** (a) Sweetness Base map at Upper-Bahariya attribute, (b) Composite Seismic section.

Fig. 13. Upper Bahariya Spectral decomposition Response, the channel, indicated by the green color.
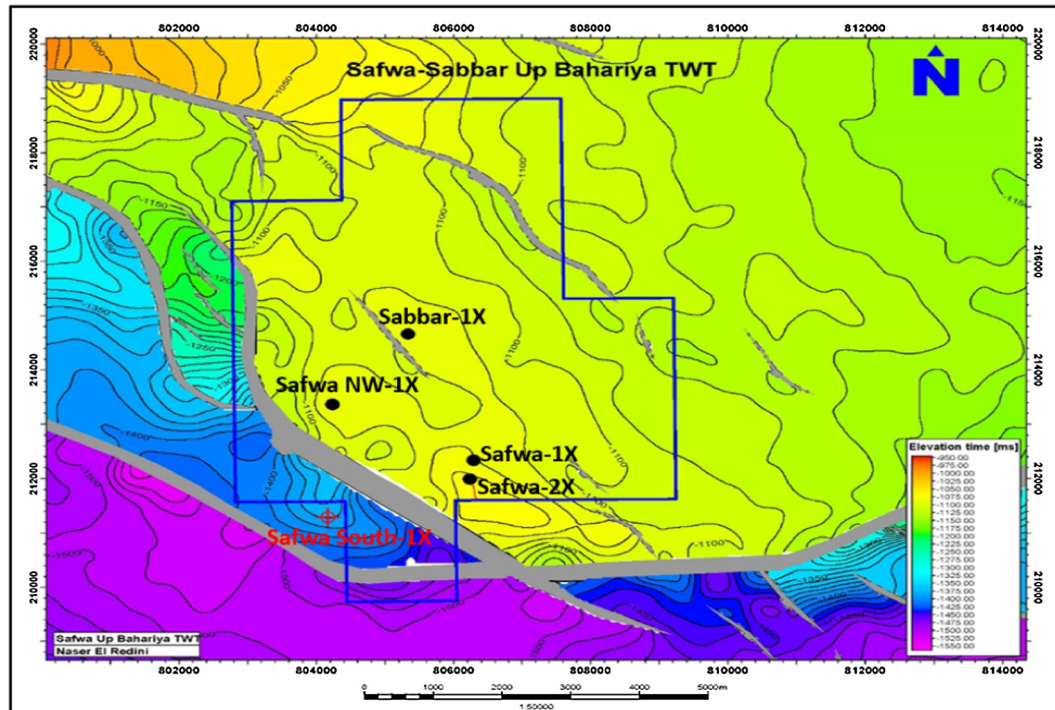
Fig. 14. Two way time (m.sec) structural contour map on Upper Bahariya.

which is possible reservoir and Masajid lime stone which is very close to Khatatba reservoir.

There is no possible lateral change of the lithology in the area under study and in case of lateral change it will be very small.

5. Use of Seismic attributes to infer reservoir features

Seismic attributes are very useful in the characterization of faults and fractures in 3D seismic data volumes. Decomposition coherence algorithms are designed not to be sensitive to dip; rather, they provide maps of lateral changes in waveform. Mathematically independent, coherence and curvature images are often coupled through the underlying geology. "Satinder Chopra 2007".

5.1. Structural attributes

5.1.1. Structural smoothing

The structural smoothing attribute was used in the area under study, enhanced the seismic event continuity parallel to the estimated bedding orientation and option is available to enhance edges (faults) during the smoothing operation, as shown in (Fig. 6). (a) showing the original seismic data, and (b) showing the seismic data after generating a new structural smoothing seismic volume, with good resolution and continuity of the seismic events, helps to remove the background noise and enhance the appearance of seismic events (Fig. 6).

5.1.2. Seismic data and structural features

Seismic data are sometimes interpreted in terms of structural features or as indicators of hydrocarbons. In (Fig. 7) five regional movements control the tectonic development of Western Desert basin during the different times of their geologic development. Missing different formation in different areas and strata's.

Prospect Safwa at near top Cenomanian Abu Roash "G" horizon is interpreted as a three way tilted block dipping to the NE and

bounded by a NW-SE trending major fault throwing to the SW. The structure is a low relief type structure. The maximum area extent of prospect Safwa, as identified at near top Cenomanian Abu Roash "G" horizon and which reflects the geometry both Bahariya and Kharita sandstone objectives, amounts to some 16 km^2 and a vertical relief of 150 ft.

5.1.3. Variance attribute

The Variance attribute was used in the area under study, to basically measures the horizontal continuity of the amplitude, and in other words, variance cube is identify channels and faults (Vav Bemmel and Pepper, 2000).

6. Seismic Data Interpretation and Mapping

The high-filtered stack-migrated signal enhancement version was used in this part of the present study for the structural interpretations of the Safwa/Sabbar oil field, and allows easy identifications of good reflector that can be followed and traced from line to line with good trusts. The analysis of seismic data includes major confidence factor, namely reflectors identification, picking and correlation of reflectors, fault location, closing loops, constructing geoseismic cross-sections, construction of the isochronous and structural contour maps, and time-to-depth conversion.

6.1. Horizons interpretation

The horizons were picked along all seismic grids by correlating the seismic events and tying their times, the Upper-Bahariya (top Lower Cenomanian) and top Masajid horizons (top Middle Jurassic) were easily started picking along the study area, and in addition to Upper-Bahariya and Top Masajid, interpreted the other horizons such as: (The Eocene) Apollonia Formation, Top Abu Roash "F" and "G", Jurassic sandstones of the Upper Safa, Intra Khatatba - Lower Safa and Near Top Basement) as shown in the (Fig. 9).
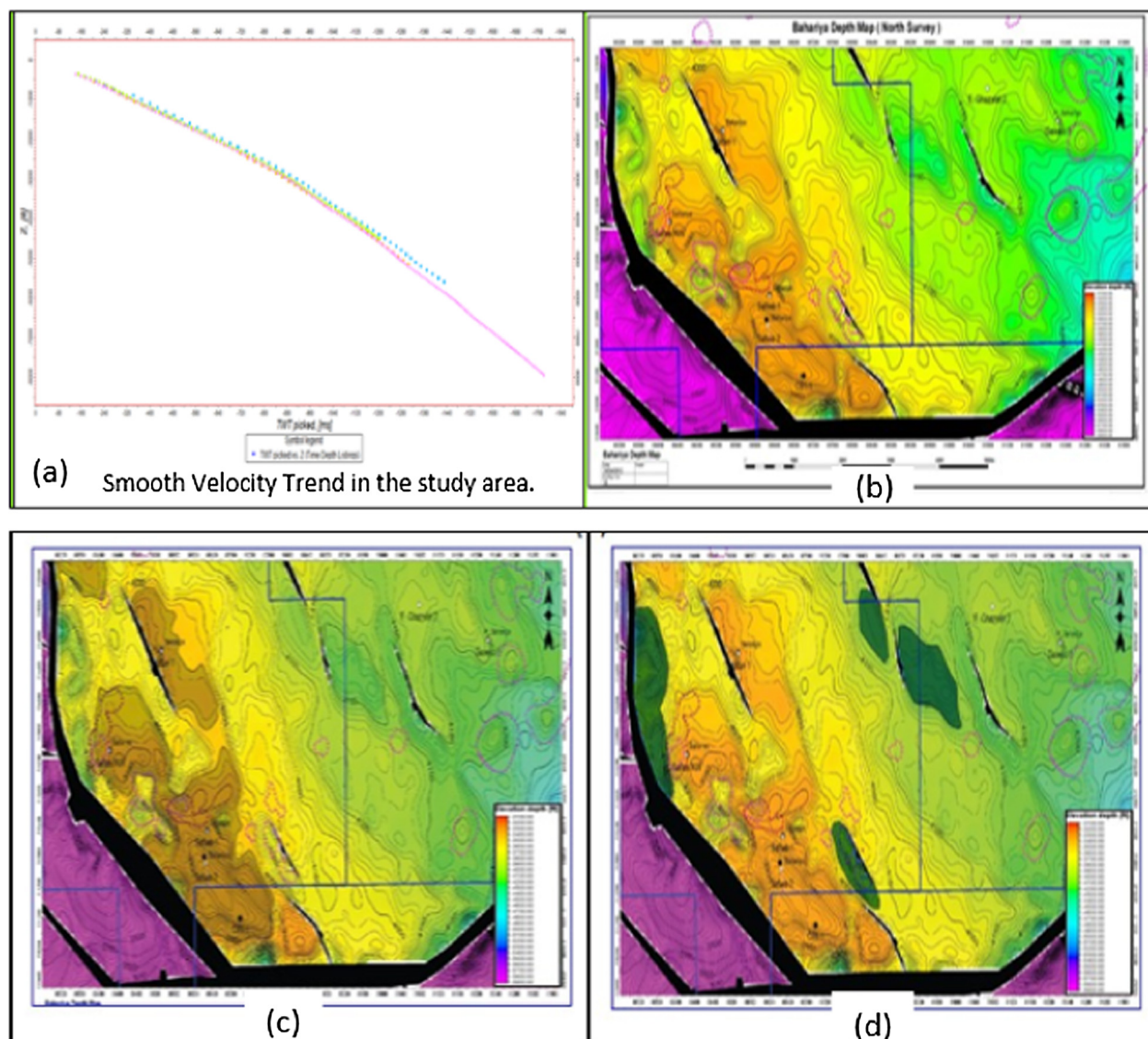
Fig. 15. Safwa/Sabbar Dev. Lease, (a) Depth structure contour map on Upper Bahariya, (b) Closure around Safwa-Sabbar wells, (c) Closure around Safwa-Sabbar area with no wells.

6.2. Fault Location detection and interpretation

In general and from well data of western desert it is considered that the timing of the Khatatba and lower part of Alam El Bueib formations has been able to generate oil during Late Cretaceous. The largest area of potential source rocks did not enter the oil generation phase until Early Tertiary, in addition, the generation of gas did not begin until Late Tertiary (Abd El Halim, 1992).

The types of faults in the study area, are normal growth faults, with possible occurrence of small reverse faults as showed from variance cube as indicated on the previous figures.

As showed in (Fig. 8), variance attribute time slice map, (Fig. 10), the black arrows refer to the minor reverse fault as 1, 2 & 3 and the blue arrows refer to the gross normal fault as 4, 5, 6 & 7 and, the faults and seismic processing are probable cause of concave and convex Processing artifact.

This figure also shows the main horizons and faults interpretation, major horizons (Apollonia, Top Abu Roash, Top Bahariya, Top Masajid and upper, Lower Safa), the two main majors normal faults (No's 4 & 5) and runs parallel to the main faults (No. 6), also shows the migration occurred probably vertically from source rock to the reservoirs, and the time of migration was Khoman deposition time

of Late Cretaceous age, the red arrows refer to migration direction (see Fig. 11).

6.3. Stratigraphic Attributes

6.3.1. Sweetness Attributes

The seismic Sweetness and Spectral decomposition attributes were used in study area, the Sweetness attribute map of the Upper-Bahariya (Fig. 12), is the combination of envelope (reflection strength) divided by the square root of instantaneous frequency can sometimes help in delineating discontinuities, also can be used for channel development especially when channels appear as sand bodies in shale, in hydrocarbon indicator it is a classical attribute for hydrocarbon sand detection (highly correlated with envelope).

Passing through Safaw-1X, Safwa-NW-1X and Sabbar-1X wells for Bahariya Reservoir, arrow refer to the Upper-Bahariya horizon.

6.3.2. Spectral decomposition attribute

The seismic Spectral decomposition attribute of the reservoir is a common geophysical method for imaging and mapping bed thickness and geologic discontinuities in 3D seismic volumes (Schlumberger, Seismic Attributes). This process is based on the
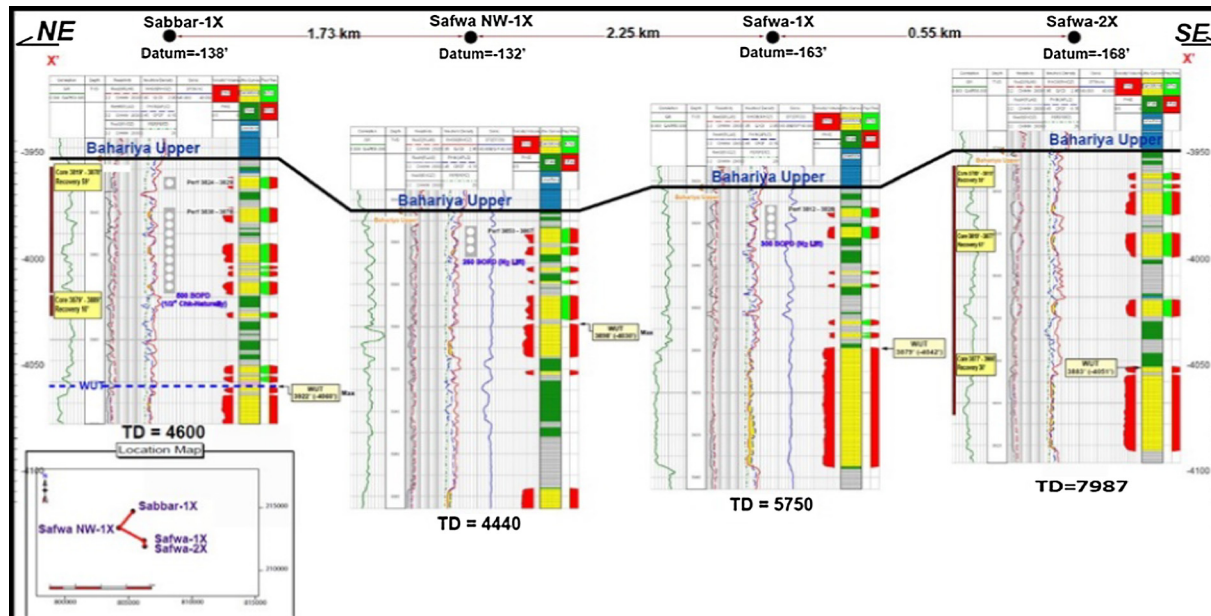
Fig. 16. Structural well correlation X X′ - Upper Bahariya section through the wells of the study area.
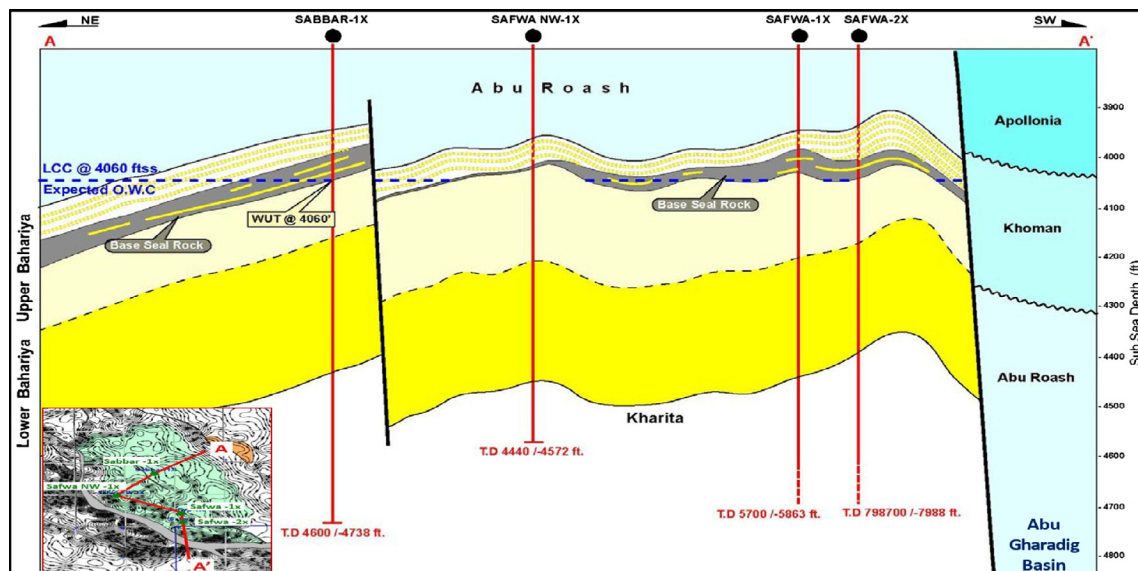

Fig. 17. East Ghazalat, Concession Safwa-Sabbar Discovery Bahariya Structure Profile (A A′).

conversion of seismic data to the frequency domain; the amplitude response at different frequencies tunes into a specific bed thickness, which helps highlight stratigraphic features such as channels and complex faulted areas.

Fig. 13, the objective of conducting spectral decomposition was to highlight stratigraphic features and test the idea that detailed reservoir characterization could benefit from using different attributes.

Using spectral decomposition, it was concluded that most of the channel belts are located in Bahariya Formation.

6.4. Safwa/Sabbar time maps

The Safwa-Sabbar prospect is a low relief type structure mapped as a three way tilted fault block dipping to the NE and bounded by a NW-SE trending major Abu Gharadig fault which is

throwing to the southwest. Seven regional time maps "Top Apollonia, AR "F", AR "G1", Up-Bahariya, Top Masajid, Upper and Lower Safa", were produced in the study area, one Jurassic half graben is defined, and this half graben could work as the local basin for hydrocarbon generation.

Fig. 14: shows the Upper-Bahariya time map which is the main reservoir in the Safwa/Sabbar study area, the major fault that caused the local basin, can be inferred from the variance cubes as indicated on the previous image.

7. Depth conversion and mapping

Depth conversion were done for most interpreted horizons using the equation $V = V_O + KZ$, (both Vo and K independent of location coordinates X and Y), time against Depth relation showing simple relation and recommending simple Time to depth

conversion, the final depth surface was calibrated to the wells formation tops.

Time against Depth relation showing simple relation and recommending simple Time to depth conversion (Fig. 15(a)).

The depth conversion were carried for the Top Apollonia, Near Top Cenomanian Abu Roash "F" and "G" horizon, Top Bahariya and Top Jurassic (Masajid Formation).

The Bahariya formation in study area is hydrocarbon bearing and represent the main reservoir not only in the study area but also within all western desert fields, three-way dip closure closing against ENE –WSW normal fault (Fig. 15), This fault is the boundary of the Abu Gharadig basin which is originated in the late Triassic - early Jurassic structure.

The location of the closure is very close to the supply of hydrocarbon and also more hydrocarbon could fill the far closures in the area.

8. Safwa/Sabbar structural correlation and structural cross section

8.1. Structural correlation

The correlation through the wells in the area based in well logs data, Sonic, GR, Resistivity, and SP logs displayed along with well Up-Bahariya Formation tops (Fig. 16). The hydrocarbon interval is nearly constant in the area, the deeper part of the formation is better in facies than the upper and composed mainly of thick sand stone.

8.2. Structural cross section

The structure comprises four culminations enclosed in a common lowest closing contour defined at 4060 FTSS (Fig. 17). The four culminations mapped were caused by inversion of normal faults in response to a compressive regime, to the south, the structure is juxtaposed against the tight limestones of the Khoman formation which form the lateral seal. This is the southern boundary of the culmination, and the border to the productive Abu Gharadig basin (likely kitchen area).

9. Conclusions

– Qualitative interpretation has been carried out for 42 km², 3-Data after runs Gaussian smoothing (Structural Smoothing), Sweetness, Variance, 3D Curvature, were calculated and clearly inferred that the main old NE-SW (Jurassic fault) and may NW-SE Cretan and younger faults.

– Synthetic seismogram were created for four wells and all typically shows very good tie without any shift of a seismic data. Apollonia, AR "G", Upper-Bahariya.

– Seismic interpreted for Top Apollonia, AR "F", AR "G1", Upper-Bahariya and deep old reflectors Masajid, Upper Safa & Lower Safa.

– The NE-SW deep old fault represents the conduit for hydrocarbon migration from southern basin to younger Crest Beds, more than two new leads are clearly resulted.

– The time to depth modeling includes two algorithms, both ensured that no velocity anomaly is present, so depth conversion was a straight forward.

– The resultant depth map has almost same structural features as the time maps.

– Structural Smoothing and Variance attributes were used to detect better pictures for the structural elements (Faults, formation dip...).

– Sweetness and Spectral decomposition volume attributes at Upper-Bahariya level showed the channel axis trending which matched with well data suggesting that could represent a new future target.

– After finishing seismic interpretation of the area it is clear that the area of study still have a good features to be explored.

10. Results

– It is recommended to apply the different types of attribute analysis, structure and stratigraphic, on the other available fields in the E-Ghazalat area for explore the possible reservoirs to increase the production over all the area.

– It is recommended to drill more wells for increase the productivity from Upper Bahariya Sands reservoir in Safwa/Sabbar Field depending on attributes analysis results of 3D curvature and Iso-frequency attributes to the SE direction of Safwa-NW1 well, SE direction of Safwa-1X and NW direction of Sabbar-1X to increase productivity of Up. Bahariya Sands reservoir in Safwa/Sabbar Field.

– It is recommended to drill more wells for increase the productivity from Top Apollonia Formation and top Apollonia gas zone Limestone in Safwa/Sabbar Field depending on a new study using different attributes analysis and good closures from the structure contour maps.

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