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SEISMIC STRUCTURAL INTERPRETATION FOR TAREK FIELD IN MATRUH BASIN, NORTH WESTERN DESERT, EGYPT

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التفسير السيزمى التركيبى لحقل طارق في حوض مطروح ، الصحراء الغربية الشمالية ، مصر

الخلاصة: برزت الصحراء الغربية المصرية كمقاطعة هيدروكربونية رئيسية في شمال أفريقيا. وقد ركزت معظم شركات النفط استكشاف الهيدروكربونات في الصحراء الغربية على خزانات العصر الطباشيري. في السنوات الأخيرة تم اكتشاف حقول عملاقة في الطبقات الجوراسية ، ولكن هناك موارد كبيرة لا تزال موجودة في الخزان الطباشيري. المصايد التركيبية كانت ولا تزال هي النوع الرئيسي في الصحراء الغربية الشمالية. تمثل الطيات المشكلة بسبب انعكاس الحوض المصدية التركيبية السائدة في الصحراء الغربية الشمالية التي هي في شكل إغلاق ثلاثي الاتجاه ورباعى الاتجاه. تمثل كتل الأنماط المائلة أيضا نوعا آخر من المصيدة التركيبية في الصحراء الغربية الشمالية. وقد استخدمت البيانات السيزمية الثنائى الأبعاد لتسليط الضوء على الوضع التركيبي تحت سطح الأرض وأصطياد الهيدروكربونات في حقل طارق بالصحراء الغربية المصرية. ويتحقق ذلك من خلال الدراسات الجيولوجية السابقة المتضمنة لفهم طبيعة منطقة الدراسة (حقل طارق). بعد ذلك ، يتم إجراء التحليل السيزمى التركيبي من خلال تتبع عاكسات مختلفة على طول الأجزاء السيزمية وبناء خرائط كنتورية تركيبية لهذه العاكسات. في نهاية المطاف ، يظهر عرض الهيكلية الثلاثى الأبعاد النمط التركيبي لمنطقة الدراسة. تتأثر المنطقة من شمال NNE-SSW وNW-SE بميول صدعية. وأدى عكس منطقة الدراسة في وقت العصر الطباشيري المبكر إلى إعادة تنشيط الصدوع القديمة فى الاتجاه NNE-SSW عن طريق الانزلاق العكسي. وقد أدى الانتشار المتصاعد للصدوع من خلال الرواسب ما بعد الصدع إلى تطوير خطوط غير متناظرة متجاوزة ذات نسق NNE-SSW ، تمثل طيات انتشار للصدوع وهياكل متراكمة. قد تشكل هذه الهياكل المصايد الهيدروكربونية ممتازة، كما هو الحال في منطقة الدراسة.

ABSTRACT: *Egyptian Western Desert has been emerged as a major hydrocarbon province in North Africa. Most oil companies have concentrated exploration for hydrocarbons in the Western Desert on the Cretaceous reservoirs. In recent years, giant fields have been discovered in the Jurassic strata, but significant resources continue to be found in the Cretaceous reservoirs.Structural traps have been and still are the main type of traps in the northern Western Desert. Folds formed due to basin inversion represent the common structural trap in the northern Western Desert that are in the form of 3-way and 4-way dip closures. Tilted fault blocks also represent another type of structural trap in the northern Western Desert . 2D seismic data have been used to shed light on the subsurface structural setting and the hydrocarbons entrapment styles in the Tarek field of the Egyptian Western Desert. This is achieved through integrated previous geological studies to understand the nature of the study area (Tarek Field). Then, structural seismic interpretation isaccomplished through tracing different reflectors along the seismic sections and construction of structural contour maps for these reflectors. Finally, 3D structural display shows the structural pattern of the study area. The area is affected by NNE-SSW and NW-SE fault trends. The inversion of the study area in the Late Cretaceous-Early Tertiary time resulted in reactivation of the old NNE-SSW oriented normal faults by reverse slip. Upward propagation of the faults through the post-rift sediments led to the development of NNE-SSW oriented asymmetric, doubly plunging anticlines, which represent fault propagation folds and roll-over structures. These structures may form excellent hydrocarbon traps, as in the study area.*

INTRODUCTION

The Western Desert covers a total surface area of 681.000 km², which is two-thirds of the entire Egypt (Younes, 2012), this area lies between latitudes 22°00'-26°30'N and longitudes 28°30'-33°00'E (Zaher, 2009), and its medium altitude is 500 m above mean sea level “MSL”.Geomorphologically, it is stone desert plateau with numerous large, deep and closed topographic depressions.

The area under investigation (Tarek Field) is located in the northeastern side of Matruh Basin. Tarek Field is located 51 km away from Mersa Matruh city and 27.5 km from shore line bounded by latitudes 30º 53' 02'' N and 30º 59' 22'' N and longitudes 27º 31' 17'' E and 27º 36' 59'' E Figure (1). It covers an area of approximately 106 square kilometers. Actually, it is a small block located at East Khalda concession.Matruh Basin lies in the NW part of the Western Desert and has a NNE-SSW orientation (Moustafa et al., 2002).

Tarek Field was discovered by Tarek-01X exploratory well, its primary targets were the Bahariya sands and the Alam El-Bueib (3A, 3D, 3E) sand members. While its secondary target was lower the Alam El-Bueib sands (5 and 6). No significant hydrocarbon shows were reported at the primary objectives, while oil shows appear at the secondary target. Tarek-01X well is abandoned and plugged, as a gas condensate well. The field was appraised by three other wells that are Tarek-02 X, Tarek-03 and Tarek-04.

The main objective of this study is to image the subsurface structures that play important roles for hydrocarbon traps in the study area. This is achieved through integrating pervious geological studies, to understand the nature of the study area (Tarek Field). The structural seismic interpretation is accomplished through tracing different reflectors along the seismic sections and constructing of structural contour maps for these interseted reflectors namely; top Baharia Formation, Top Alam El-Bueib-1 Member and Top Alam El-Bueib-6 Member. Finaly, a 3D display shows the structural pattern of the study area and defines hydrocarbon traps affecting Alam El-Bueib Reservoir.

GEOLOGIC SETTING

Stratigraphically, the sedimentary section of the northern Western Desert ranges from LowerPaleozoic to Recent Figure (2). It is thick and includes most of the sedimentary successions from Recent to pre-Cambrian basement complex (Hegazy, 1995). It can be subdivided into four major regressive cycles, each terminated by a marine transgression (Sultan and Halim, 1988).

The earliest cycle consists of clastic facies forms the oldest sedimentary rocks and includes the Paleozoic and Lower Jurassic Formations. These non-marine clastics are overlainedby marine deposits of Khatatba Formation, which deposited during the Middle and Late Jurassic. The maximum transgression occurred in the

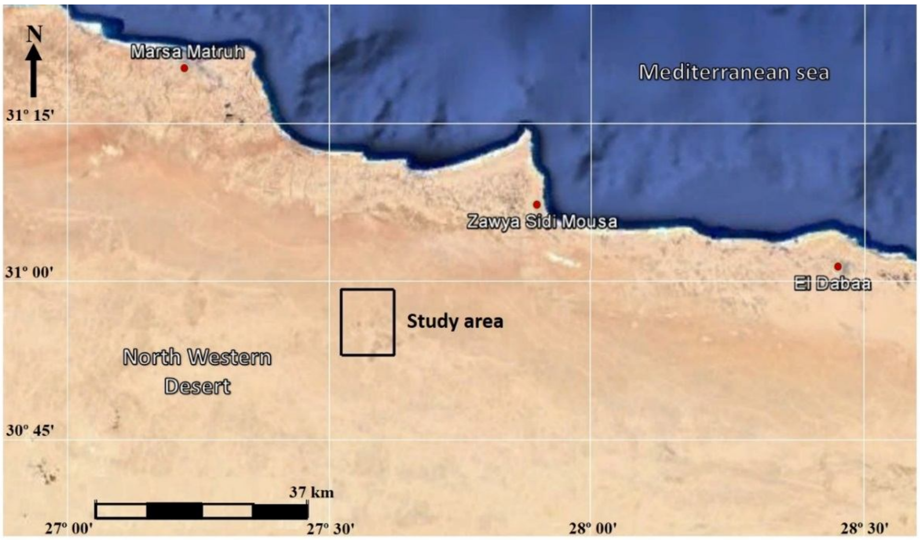

Figure (1): Location Map of the study area.

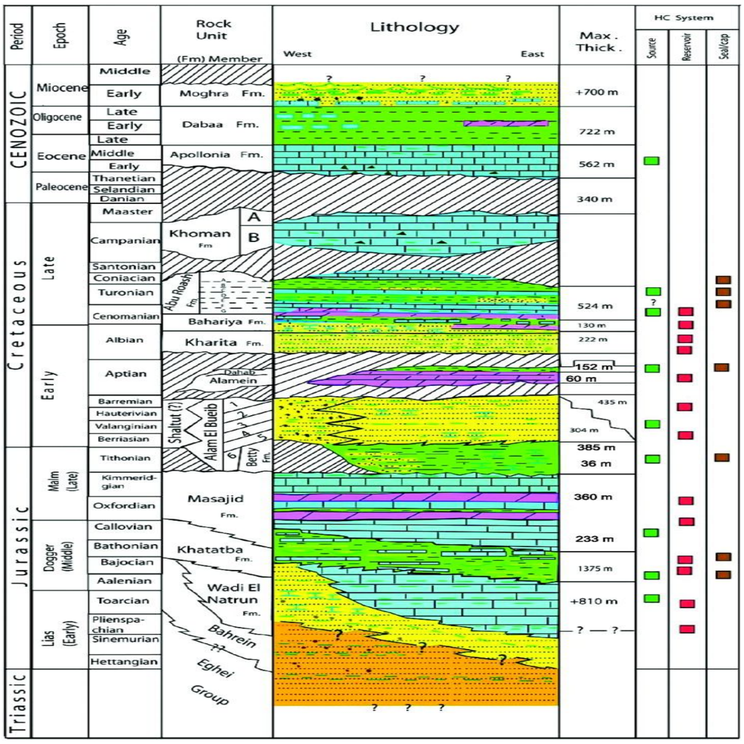

Figure (2): Generalized litho-stratigraphic column of the northern Western Desert.

Jurassic is represented by the marine carbonates of Masajid Formation that deposited during the Late Callovian.

A great unconformity separates between Masajid Formation and Alam El Bueib Formation that deposited during the Early Cretaceous, followed by Dahab Shales during the Aptian.

Another unconformity separates Dahab Shale from the shallow marine Kharita clastics that deposited during the Albian, while Bahariya Formation deposited during the Early Cenomanian representing a regression period.

The last cycle represents a transgression stage depositing marine non-clastics from the Upper Cenomanian until the Lower Miocene such as Khoman, Apolonia, Dabaa, and Moghra Formations thst overlain by the Marmarica Limestone, representing the top of the geologic succession.

The Western Desert can be divided into a number of large-scale structural provinces, which developed along lines of weakness in the African basement, in response to lateral movements between Europe and Africa (Hegazy, 1995). In general, the Western Desert is characterized by a northwestward thickening Paleozoic section and northward thickening of the Mesozoic and Tertiary,which is interrupted by the major east-west trending Sharib-Sheiba high. This regional uplift separates the Abu Gharadig basin to the south from the coastal basins (Matruh, Shushan, Dahab and Natrun basins).

A number of diverse basins and structural features make up the Western Desert Figure (3). Specifically in the northern Western Desert, five mega-structural zone affecting the basement have been identified. They have a strong influence on localization and orientation of the main sedimentary basins in the area and on their tectonic and sedimentary evolutions(Said, 1990).

- **Bahariya-Diyur high:** it is located in the south, where the sediments cover above the basement has a thickness of not more than 3 km (except Guindi basin, 5 km).
- **Gib-Afia high:**it is oriented with a NE-SW direction, from the western part of the Siwa oasis.
- **Sharib-Sheiba high:** it extends with E-W direction, from the western part of the Gib-Afia high to the intersection with the Kattaniya High eastward.
- **Kattaniya high:** it's a raised block bounded by faults with NE-SW direction.
- **Abu Gharadig basin:** The oldest and deepest basin in the area. Its sedimentary sequence reaches up to 13 km of thickness in its depocentre (Deaf, 2009), while according to (Abu EL-Ata, 1985) thickness reaches up to only 7 km.

The northern Western Desert structures are dominated by steep normal faults and most have a long history of growth. These faults were probably related to the plate tectonics during the Jurassic and Late cretaceous. Strike slip movements affected the orientation of many of the fold axes (Hantar, 1990).

Abu El-Ata (1981 and 1988) delineated six systems of regional structural deformations in the subsurface. The oldest of them is the Meridian system of folds (Precambrian-Early Paleozoic) has NNW-SSE trend. Then, the Atlas system of folds and fractures (Late Paleozoic-Early Mesozoic) has NNE-SSW trend. The third is the Syrian arc system of folds and faults (Middle Mesozoic-Late Mesozoic) has a NE-SW trend. The fourth is the Red Sea system of faults and folds (Early Tertiary) has a NW-SE trend. The fifth is the Mediterranean Sea system of faults and folds (Late Tertiary) has an E-W trend. Then, the sixth is the Aqaba system of faults (Quaternary), which is of N-S trend.

Matruh Basin (at which the study area is located) lies at the NW part of the Western Desert and has a NNE-SSW (Moustafa et al., 2002). The basin history shows an early rifting phase during the Jurassic and Early Cretaceous. The basin was inverted in the Late Cretaceous-Early Tertiary time, leading to the development of NNE oriented fault-propagation folds dissected by NW-oriented normal faults. These folds form excellent hydrocarbon traps, as in Tarek Field (Moustafa, 2008).

Matruh Basin was inverted in the Late Cretaceous-Early Tertiary time, where the old NNE-SSW oriented normal faults were reactivated by reverse slip. Upward propagation of the faults through the post-rift sediments led to the development of roll-over structures and NNE-SSW oriented asymmetric, doubly plunging anticlines that represent fault propagation folds. A large number of NW-SE oriented normal faults dissected the folded Cretaceous rocks. Basin inversion ended before the deposition of the Upper Eocene-Oligocene sediments of the Dabaa Formation. Post-inversion sediments include the Dabaa, Moghra and Marmarica Formations.

Tarek Field lies on the northern margin of the Matruh Basin, where the early rift detritus were deposited mainly in the low parts of the rift flexure area that represents the main reservoir. NNE-SSW oriented faults played a major role in the structural and tectonic evolution of the Matruh basin. These faults dissect only the deeper stratigraphic units in the Matruh basin. They are clear at the Jurassic and Alam El-Bueib levels, but do not extend upward to dissect the Abu Roash Formation. These faults die out at the base of the Kharita Formation or at the top of the Alam El-Bueib Formation, and divided the area into a number of NNE-SSW oriented rectangular blocks.

Structural inversion occurs when the basin-controlling extensional faults reverse their movement during thecompressional tectonics, and, to varying degrees, basins are turned out to become positive features. The result is that individual faults may retain net extension at depth and show net contraction associated with anticline growth in their upper portions Figure (4).

DATASET AND METHODOLOGY

The available seismic data for the present study is ashot-point location map of the study area Figure (5); twenty seismic lines are selected from the seismic cube (10 in-lines of 9087 mlength and 10 cross-lines of

11635 mlength) and velocity measurements, in the form of vertical seismic profiles (VSP) for four wells (Tarek-01X, Tarek-02X, Tarek-03 and Tarek-04). The used data are permitted and obtained from Khalda Petroleum Company.

In order to achieve the objectives of this study, the following steps are achieved:

1. Creating synthetic seismograms for tying between the seismic sections and wells Figure (6).
2. Enhancing the quality of seismic data by making Amplitude Gain Control(AGC)attribute for the lines that help in horizon picking and also by creating Coherence/Variance attribute to aid in following the structural development (fault locations) of the study area.

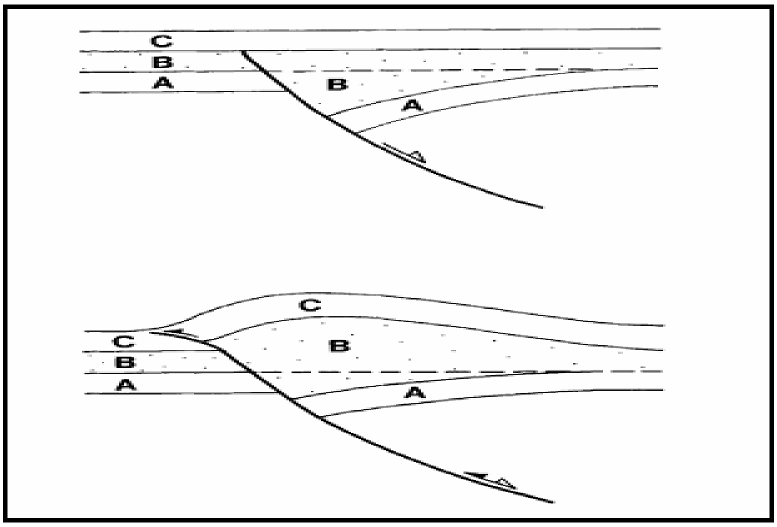

Figure (4): Schematic diagram of a classic positive inversion structure. A, B and C are stratigraphic sequences. A is prerift; B is synrift; C is postrift sequence (after Williams et al., 1989)

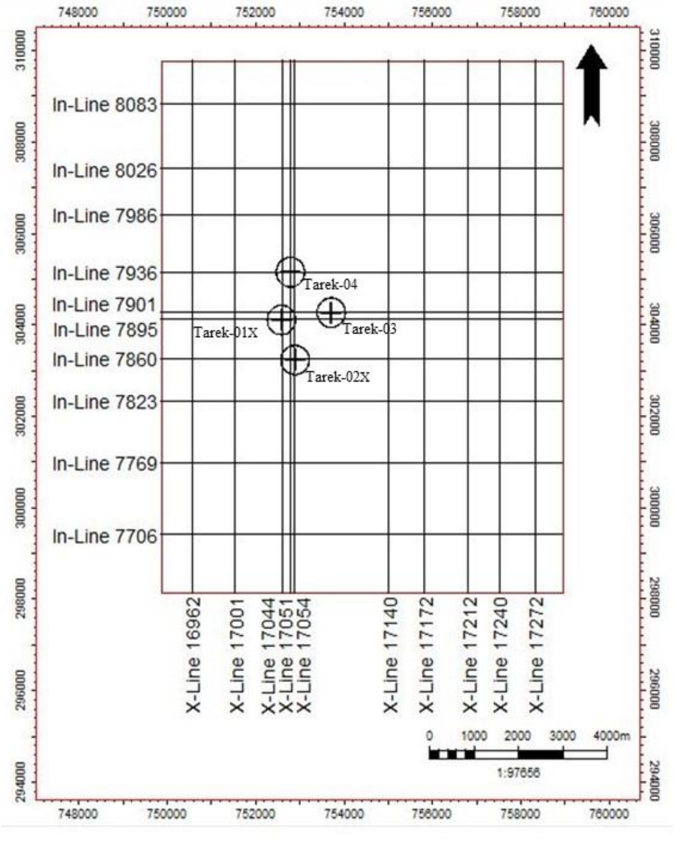

Figure (5): The Base map showing the in-lines; cross-lines directions and the well locations in the study area.

3. Interpret twenty seismic sections by identifying reflector tops on wells, picking up and tying them through the whole seismic lines by using PETREL2009 software developed by Schlumberger Services Company.
4. Constructingstructural maps on the tops of the interesting formations to illustrate the subsurface structural features.

ENHANCING THE QUALITY OF SEISMIC DATA:

The quality of the seismic data was bad in the study area and the continuity of the reflectors was weak along the sections. So, certain seismic processes and attribute extraction should be applied on the seismic data to increase its quality (continuity). From these processesamplitude gain control (AGC) and structure smoothing, they enhances the trace amplitudes and flatten them, making the events more clear, bright and continuous.

Trace AGC (Amplitude Gain Control) scales the instantaneous amplitude value with the normalized RMS amplitude (root mean square) over a specified window. Trace AGC(t) = f(t) * (1.5 - RMS/(max)), where (max) is computed over the entire survey. Figure (7) shows the enhancements of the continuity of the reflectors along the seismic sections

The sedimentary structures manifest themselves as lateral changes in the seismic response along the horizons, and can be recognized by their morphology. Faults manifest themselves in the seismic images, as discontinuities in the layered structure. Faults and fractures are the main factors building the hydrocarbon traps and affecting their behavior. These faults may not appear so clear on normal seismic sections .So, it is preferred to use seismic attributes, such as Coherence/Variance attribute. Since the attributes are useful in getting a better insight into the fault and fracture systems and their relationships (Neves et al., 2004).

Seismic traces cut by a fault surface have a different seismic response than the other regions of neighboring traces. This causes a sharp discontinuity in the local trace-to-trace coherence. Calculating the coherence for each point along the seismic section results in lineaments of low coherence along the faults. By repeating this process for a series of seismic sections, these lineaments form fault surfaces, even if these fault plane reflections have not been recorded (Bahorich and Farmer, 1995).

Coherence is the measure of the similarity in appearance and shape of waveforms from trace to trace while variance is mathematically expressed as one minus the coherence value, so if all traces are equal the coherence value is 1.0 and the variance is 0.0 (Chopra and Marfurt, 2007).

These variance sections help in picking fault stick locations through the study area besides the original seismic sections.Figure (8) showsinline 7823 seismic section and itsvariance section. The main use of variance is to create an intuitive display that allows an interpretation task to be performed both more efficiently and more effectively.

Seismic structural interpretation:

Seismic Sections Interpretation:

Some interpreted seismic lines are selected, in order to show the picking of the horizons and the structural features in the study area. Four seismic sections are selected for representation; two sections in the in-line direction (N-S) and two others in the cross-line direction (E-W).

The interpreted seismic section (In-line 7936) is located nearly at the central part of the study area, passing through Tarek-04 wellFigure (9). It is oriented in theEast-West direction. This line shows the major fault (F1) strikingin the northeast-southwest direction through the area with a dip direction northwest ward. Three other normal faults (F3, F4 and F7) are located west of the major fault, as antithetic faults, they are oriented in the same direction and dipping southeast ward. Another normal fault (F8) is shown on the section at the eastern side, striking northwest-southeast with a dip direction southwest ward.

All these faults are dissecting the whole shallower succession, from Bahariya Formation till Alam El-Bueib-6 Member and even deeper, while the main fault (F1) is extended through the deeper succession till the Jurassic formations.

The main fault (F1) appears as a normal fault at the deeper successions, while at shallower parts appears as a reverse fault. This is due to the geologic inversion occurred where the forces inverted from tension to compression, causing rejuvenation of the main fault and forming roll-over structures (forming good oil traps) on its hanging wall. Also the bed thickening appears clearly on the hanging wall at the western side of the section.

The interpreted seismic section (In-line 7895) is located at the central part of the study area, passing through Tarek-01X wellFigure (10). It is oriented in theEast-West direction. The line shows the same structural regime and the same fault trends, but two new normal faults (F2 and F6) have been appeared on the foot wall of the main fault, as antithetic faults on it, at the eastern side of the section. These range of faults forms a flower structure, which is common at the northern Western Desert, because of the Syrian arc system. Well and seismic data ensure the regional uplift occurred in the study area.

The interpreted seismic section (Cross-line 17140) is located nearly at the central part of the study area. Figure (11). It is oriented in theNorth-South direction. The line shows three normal faults (F8, F9 and F10) striking in the northwest-southeast direction and dippingsouthwestward, and a normal fault (F11) is oriented northeast-southwest, with dip direction northwest ward, located at the far southern side of the section. These faults bisect the shallower part of the section only.

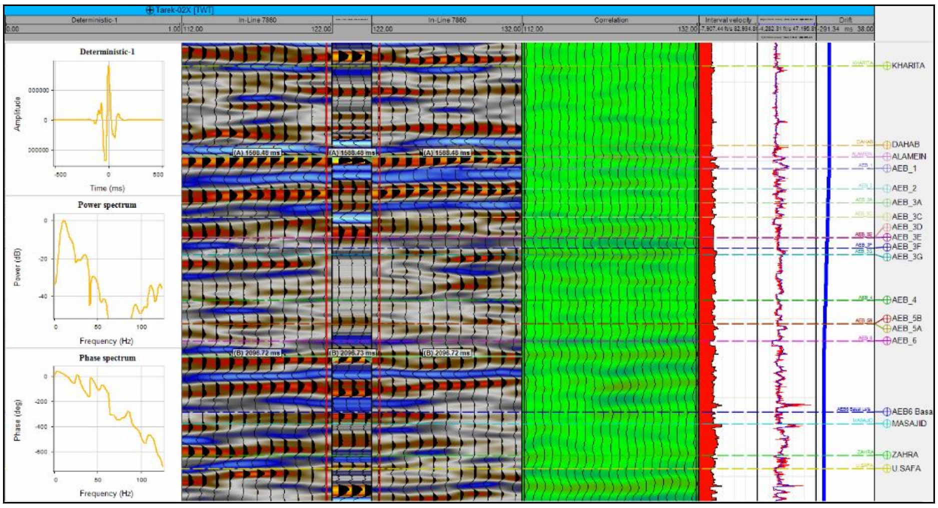

Figure (6): Synthetic seismogram of Tarek-02X well.

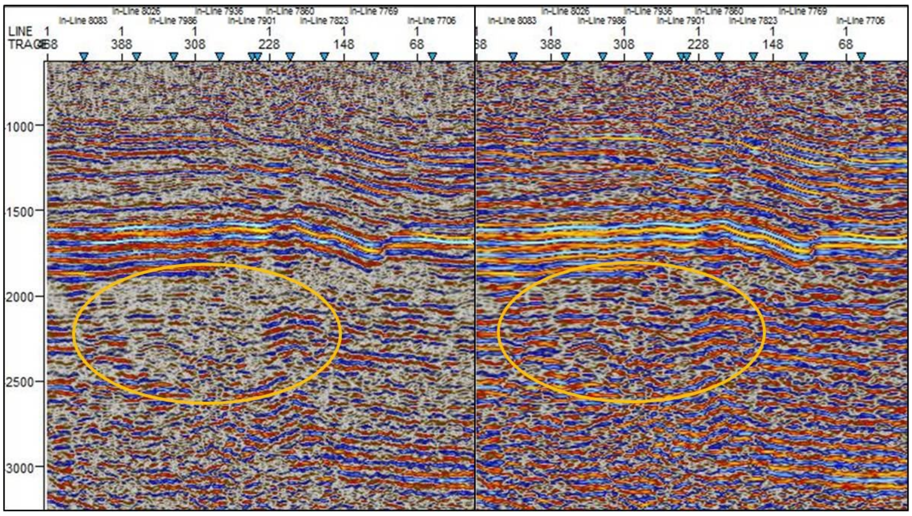

Figure (7): Seismic line 17044 and its AGC section (at the right).

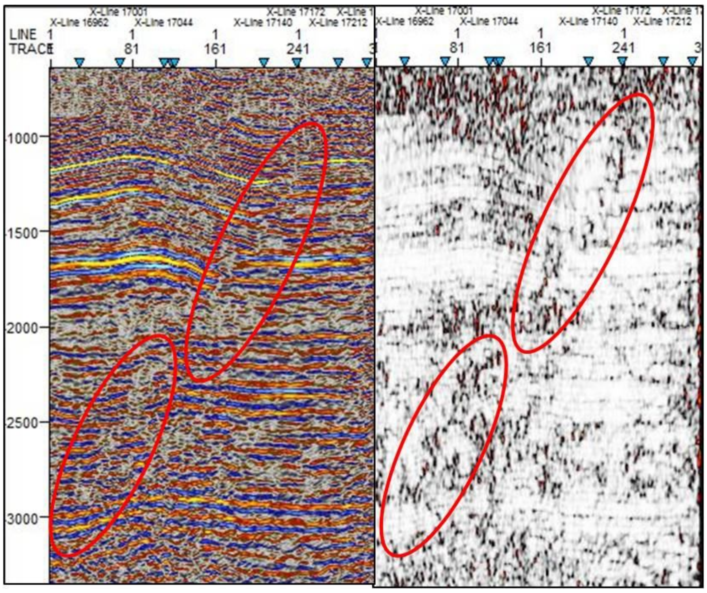

Figure (8): inline 7823 Seismic section and itsvariance section (at the right).

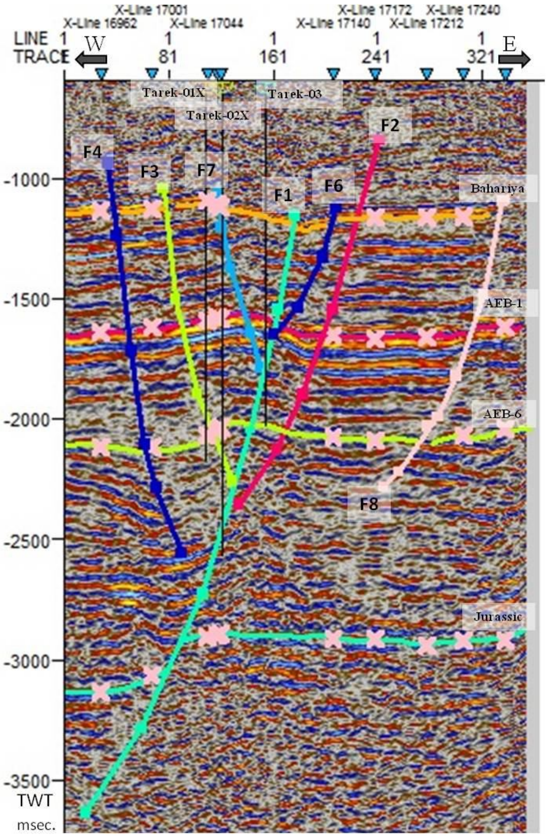

Figure (9): In-line 7936interpreted seismic section.

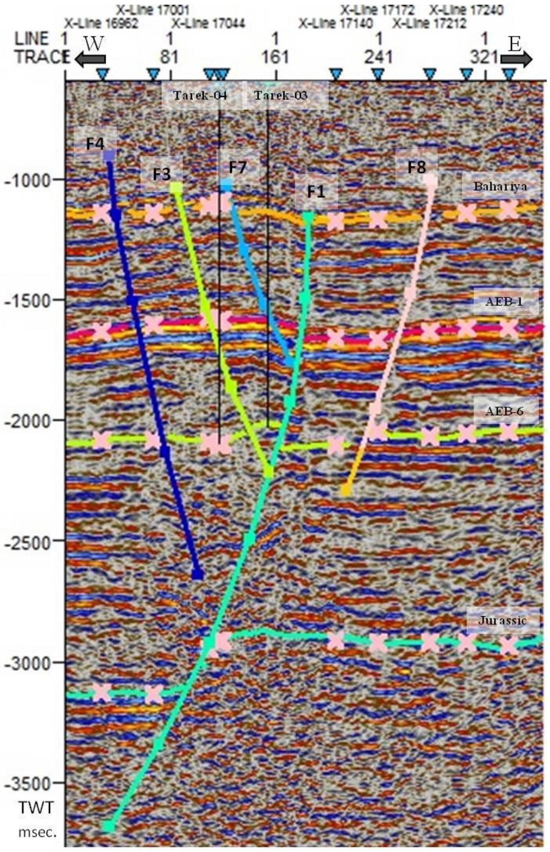

Figure (10): In-line 7895 interpreted seismic section.

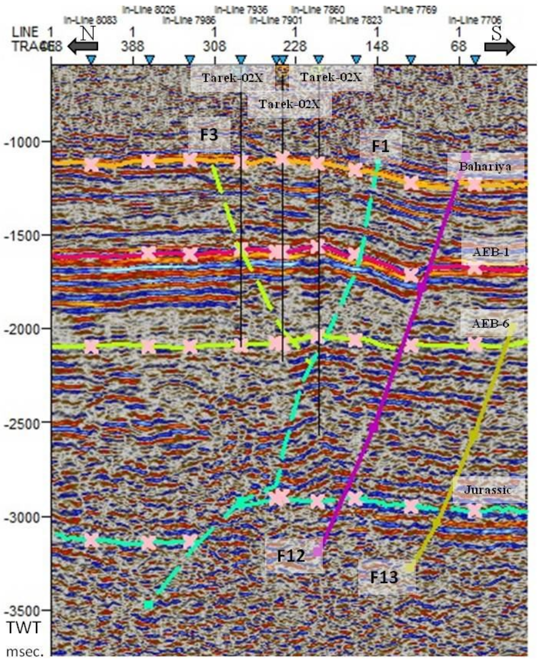

Figure (11): Cross-line 17140 interpreted seismic section.

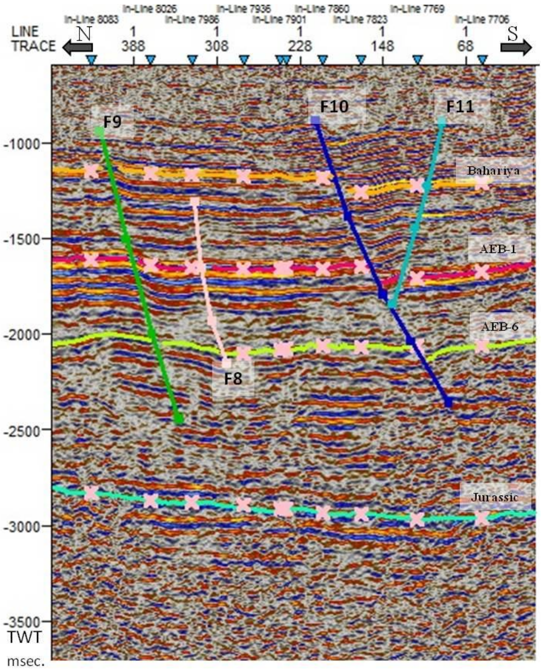

Figure (12): Cross-line 17044 interpreted seismic section.

The interpreted seismic section (Cross-line 17044) is located at the western side of the study area. Figure (12). It is oriented in the North-South direction. The line shows two normal faults (F12 and F13)striking in the northwest-southeast direction and dipping northeast. Also, it shows the projection of the major fault (F1) plane and an antithetic fault (F3) on it picked through the in-lines, emphasizing the structural regime of the area.

CONSTRUCTION AND INTERPRETATION OF THE STRUCTURAL CONTOUR MAPS

Some geological information could be understood by just looking at the interpreted seismic sections. But to represent the geological features,which are deduced from the seismic sections in the three dimensions clearly, it is required to map these information to clarify the high and low anomalies and the structural trends existing in the area of interest. Three types of maps are constructed at the top of the required formations (Bahariya Formation, Alam El-Bueib-1 and Alam El-Bueib-6 members), which are the Two-way time (TWT) structure maps, average velocity gradient maps, and depth structure maps.

The first type of these maps is the time structural contour map which shows the subsurface structural features of the horizons, as a function of the two-way reflection time Figures (13, 14 and 15). What makes these time maps reliable and effective is that the time values are plotted directly from the interpreted horizon grid to construct the surface map representing the actual data obtained.

The second type of the maps is the average velocity gradient maps. The average velocity is calculated from the time-depth curves of the vertical seismic profiles (VSP) that recorded for the wells drilled in the study area. These values are contoured at each rock unit top to give the average velocity map Figures (16, 17 and 18), whichis used later in producing the depth structural contour map for the chosen formation tops.

The third type of these maps is the depth structural contour map. These maps are usually preferred rather than time maps, particularly if there are much changes in velocity related to the layer heterogeneity,where the structure shown on a time map will differ from the structure shown on depth maps.

Depth structural maps reflect more detailed subsurface structural picture than these derived from the time maps at each rock unit top.These maps are based on the conversion of the two-way time maps into depth structural contour maps using the average velocity gradient map at the top of each formation. A Depth structural contour map is established by contouring the calculated depth values, taking into account the position of the faults.They are similar to the time maps with the exception of a slight variation due to lateral change in the velocity. Figures (19, 20 and 21) show the depth structure maps of Bahariya Formation, Alam El-Bueib-1 and Alam El-Bueib-6 Members, respectively.

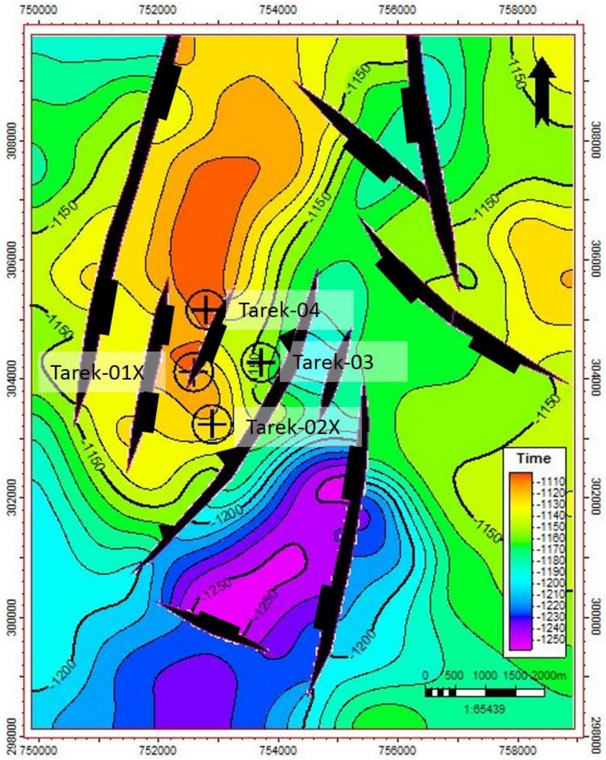

Figure (13): Two-way time structural contour map on top Bahariya Formation.

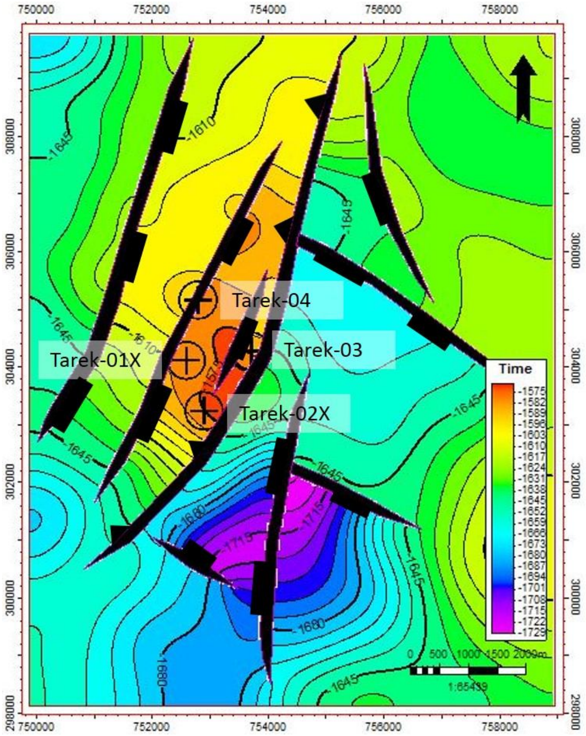

Figure (14): Two-way time structural contour map on topAlam El-Bueib-1 Member.

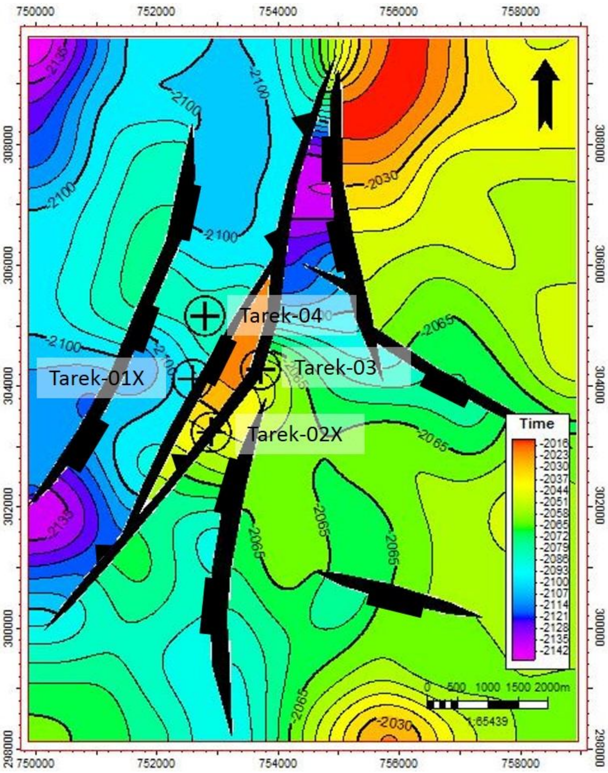

Figure (15): Two-way time structural contour map on top Alam El-Bueib-6 Member.

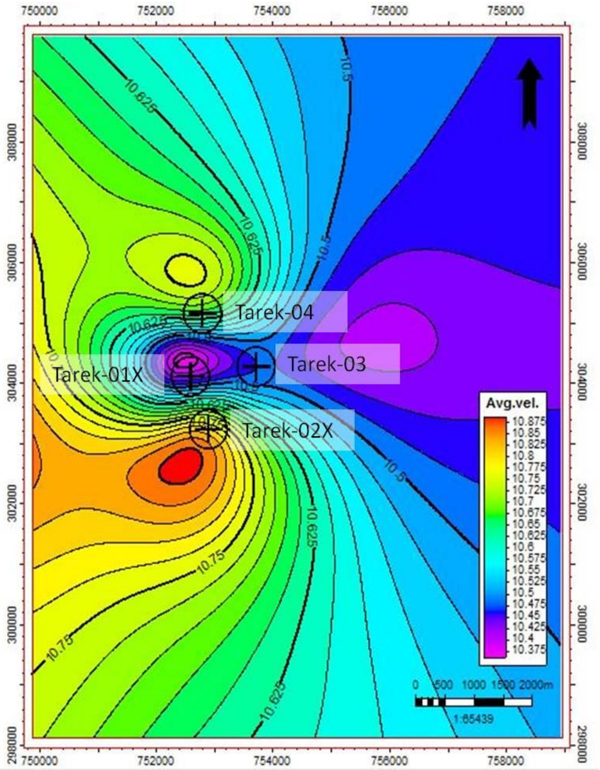

Figure (16): Velocity gradient map on top Bahariya Formation.

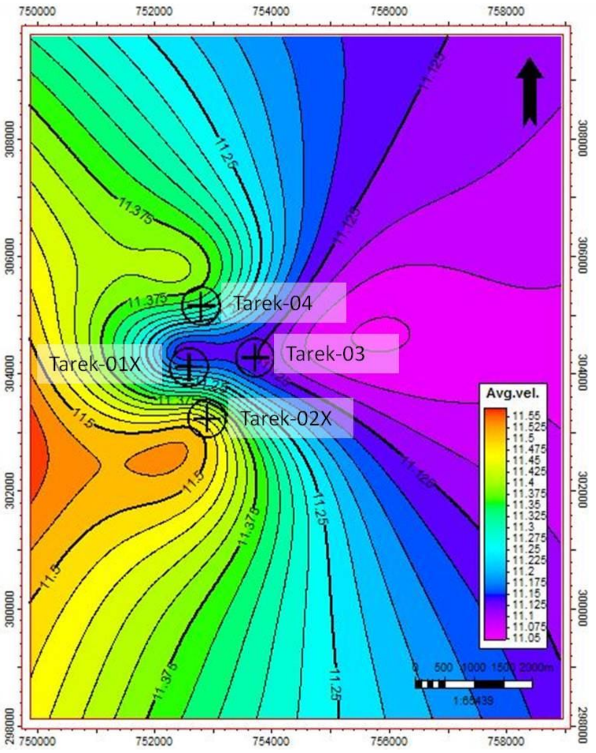

Figure (17): Velocity gradient map on top Alam El-Bueib-1 Member.

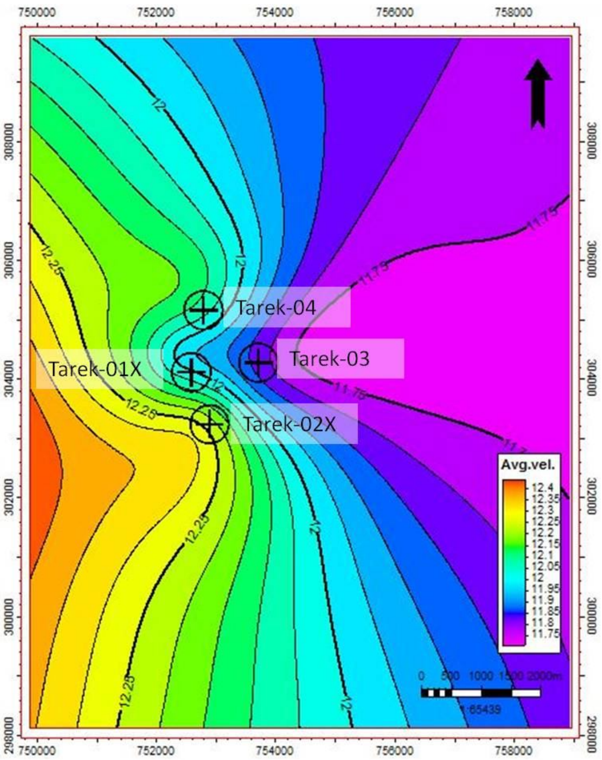

Figure (18): Velocity gradient map on top Alam El-Bueib-6 Member.

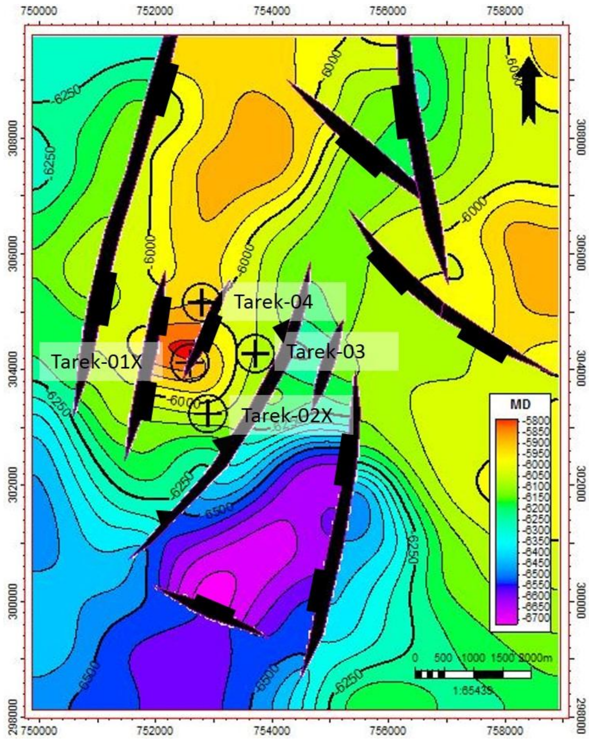

Figure (19): Depth structural contour map on top Bahariya Formation.

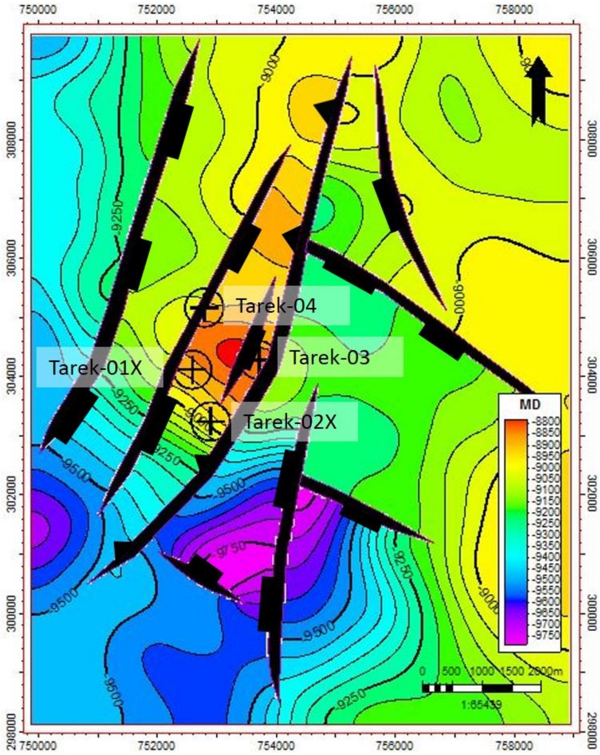

Figure (20): Depth structural contour map on top Alam El-Bueib-1 Member.

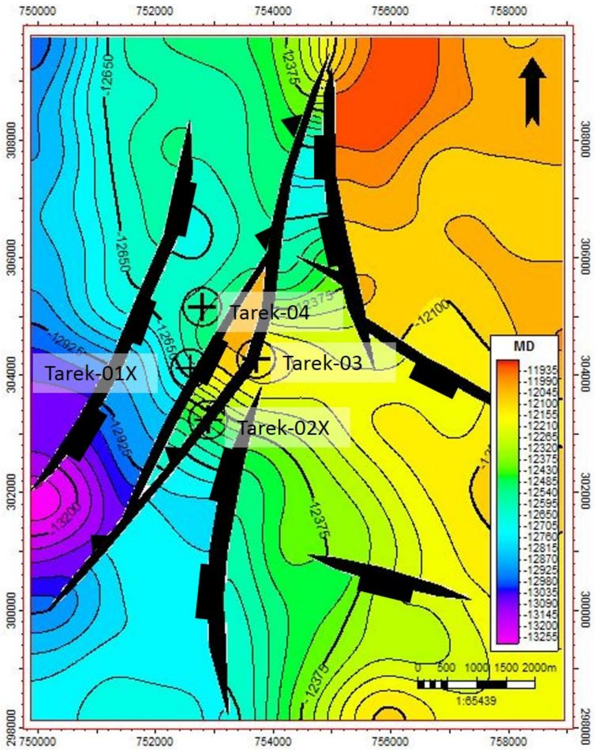

Figure (21): Depth structural contour map on top Alam El-Bueib-6 Member.

Generally, the depth structural contour maps at the studied formation tops reveal the following:

- The folding system plays a major role in the tectonic framework of the studied area. The main fold trend axis is the E-W direction and NE-SW direction. Reflects the Syrian Arc tectonics.
- The folds either anticlines or synclines are bounded and dissected by a group of fault elementsmost of them oriented in the NE-SW direction.
- The first set of faults trend represents the NNE-SSW direction which is older than the second set of NW-SE direction. Most of these faults are throwing towards the north-western direction, while the others throw towards the south-eastern direction, and they form together a pattern of grabens, horstsand step-like blocks.
- The structural settings in the studied area are suitable for hydrocarbon accumulations due to the availability of several structural high closures in the form of anticlinal folds and horst blocks.
- The velocity is not affecting much in the area, where the depth maps have the same anomalies of those in the two-way time maps withfew deviations. Velocity control points (wells) are concentrated at the central part of the map, so the velocity values at the rest of the map are not accurate enough (extrapolation).

The depth values reach to the maximum at the southern and south-western parts of the study area, while the minimum values occurred at the north-eastern and central parts with closed contour lines. The central closure reveal probable prospect which is of high chance of hydrocarbon accumulation.

RESULTS AND CONCLUSIONS

The integrated seismic data interpretation represented in the form of the interpreted seismic sections, structural contour maps; (times and depths) of the studied formations and 3D structural display show the prevalence of structural tectonic trends. These trends of local structures are produced as a result of different systems of regional tectonic deformations affecting the surrounding regions. Figure (22) shows the flower structure clearly in a 3D display for the fault planes occurred in the study area, while Figure (23) shows the 3D structure display of the four interpreted horizons; (Bahariya, Alam El-Bueib-1, Alam El-Bueib-6 and Jurassic) and the main fault planes in the study area. The subsurface structural features are summarized as follow:

- NNE-SSW oriented faults played a major role in the structural and tectonic evolution of the study area. These faults dissect only the deeper stratigraphic units in the area. They are clear at the Jurassic and Alam El-Bueib levels, but do not extend upward to dissect the Abu Roash Formation. These faults die out at the base of the Kharita Formation or at the top of the Alam El-Bueib Formation, and divide the area into a number of NNE-SSW oriented rectangular blocks. Also, minor faults of N-S trend are known in the study area.
- The inversion of the study area in the Late Cretaceous-Early Tertiary time resulted in reactivation of the old NNE-SSW oriented normal faults by reverse slip. Upward propagation of the faults through the post-rift sediments led to the development of NNE-SSW oriented asymmetric, doubly plunging anticlines that represent fault propagation folds. These folds form excellent hydrocarbon traps as in the study area.
- A large number of NW-SE oriented normal faults dissected the folded Cretaceous rocks. Basin inversion ended before the deposition of the Upper Eocene Oligocene sediments of the Dabaa Formation. Post-inversion sediments include the Dabaa, Moghra and Marmarica Formations.
- The flower structure clearly appears in the 3D structural display for the fault planes occurred in the study area.

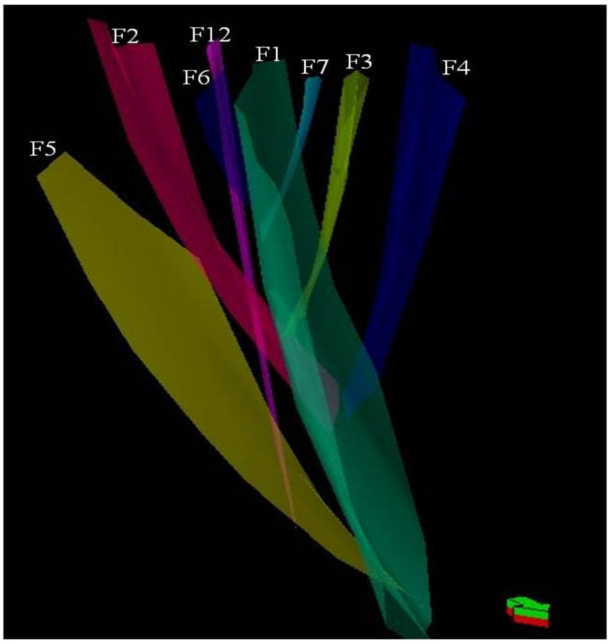

Figure (22): A 3-D model for the fault plains, showing the flower structure.

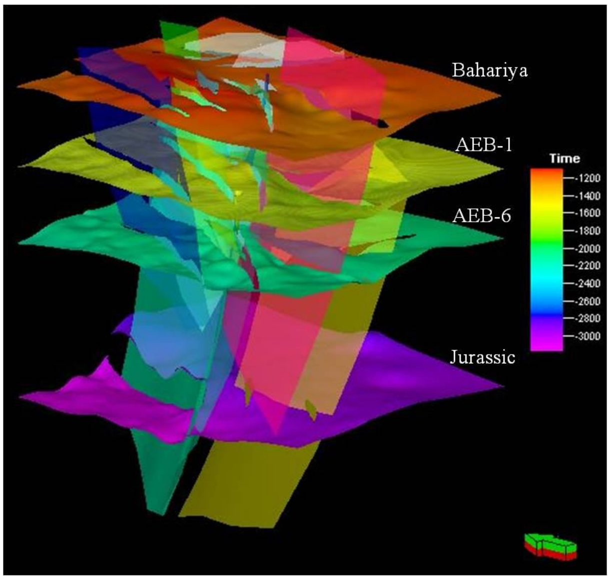

Figure (23): A 3-D structural model for the fault plains and the interpreted tops in the area of study.

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