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# STRUCTURAL AND SEISMIC MODELLING OF SARIR SANDSTONE RESERVOIR, MAJID AREA, SIRTE BASIN, LIBYA

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## ABSTRACT

The Lower Cretaceous Sarir Sandstone Formation is a prolific oil reservoir in Sirte basin (Libya), particularly in southeastern part with commercial quantities of hydrocarbons (around 9 billion barrels). The hydrocarbons were accumulated from the Nubia Formation from both structural and stratigraphic traps in giant oil fields. Classical exploration of the oil in the area, based on 2D seismic survey, led to several dry holes in the last decades. The present study, which was based on interpretation of acquired 3D seismic survey data, matched with available well logs, was used to construct a 3D model for the area to understand the complex structural setting of the area and is to understand the entrapment style of the implied hydrocarbon. Seismic interpretation has been achieved for reviewing structural configuration of the Majid area and illustrating the hydrocarbon potentialities (prospect and leads) by building 3D structure modelling by using borehole data and 2D seismic data. To achieve this work, three representative cross sections have been generated. These have been developed as a major input for a preliminary 3D geological model for determining the prospect and leads in the study area. Structure contour map (isochrochronous map, converted to depth map) was constructed for the top of Sarir Sandstone Formation. NE-SW dip-slip faults dipping to the southeast of the area and faulted fold (rollover faulted anticlines developed above the curved listric faults were identified in this map.

**Key Words**: Sirte Basin, Seismic Interpretation, 3D structural model, Sarir Reservoir, Structure Modelling

## 1. INTRODUCTION AND GEOLOGIC SETTING

The Majid oil field is one of the most promising areas in Southeastern part of Libya, which covered about 300 Km² and situated to the south of Benghazi in the southern part of Sirte basin (Fig. 1A). The Sirte Basin is divided into three lithostratigraphic sequences **(Barr and Weegar, 1972; Hallet, 2002)** (Fig. 2)**.** The lower sequence is the pre-rift sequence, which is represented by Hofra (Gargaf) Formation and the underlying Precambrian basement rocks. The Hofra (Gargaf) Formation is bound by unconformable boundaries, where it is overlain by the Sarir Formation and underlain by Precambrian Basement rocks **(Saheel *et al.*, 2010)**. The Hofra Formation is dominated by sandstone. The second sequence (synrift) is represented by the Late Cretaceous (except for the Sarir S.S. which is Pre-late Cretaceous) to Late Eocene sediments (Fig. 2). The Cretaceous sediments unconformably overlie the Hofra Formation (Fig. 2). The synrift sediments are represented from base to top by the Sarir, Bahi, Maragh, Lidam, Etel, Argub, Rachmat, Tagrifat, Sirte, Kalash, Satal, Waha, Hagfa, Beda, Khalifa, Zelten, Harash, Kheir, Al Gir, Gialo and Awjilah formations, respectively. The third sequence (post-rift) is represented by shallow marine carbonates (tidal to supra-tidal environment) related to the Oligocene – Miocene sediments. These sediments are represented by the Arida, Diba and Marada formations **(Barr and Weegar, 1972; Hallet, 2002)** (Fig. 2).

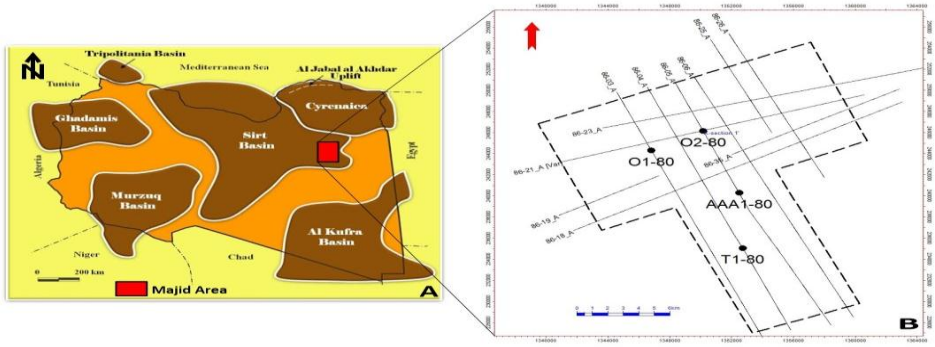


**Fig. 1. A)** Location map of the area. **B)** Seismic Lines and Well Location map.

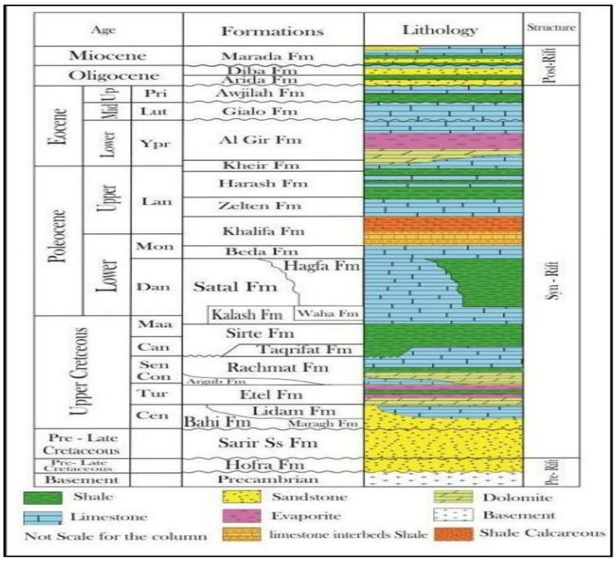


**Fig. 2.** Stratigraphic section in Eastern Sirte Basin (modified after **Barr and Weegar, 1972; Hallett, 2002**).

The Majid area is structurally formed as an elongated ridge crossed by four main faults running northeast-southwest and most of them dipping toward southeast. However, a fifth fault cut the ridge in parallel with the former faults dipping northwest. Series of normal secondary fault trending north- northwest and south-southeast cut the ridge perpendicular to the main former faults forming series of horsts and grabens. One of these horsts is dividing the Majid area into independent North and South blocks (Fig. 3). Due to intense erosion of Al-Jaghbub, Kalanshiyu, and Majid uplifts (Fig. 3), more than 2500 m of detrital sediments deposited to form a major sedimentary depocenter during the deposition of the Nubian sandstones, with braided fluvial systems entering the basin from all directions **(Van Houten and Karasek, 1981)**.

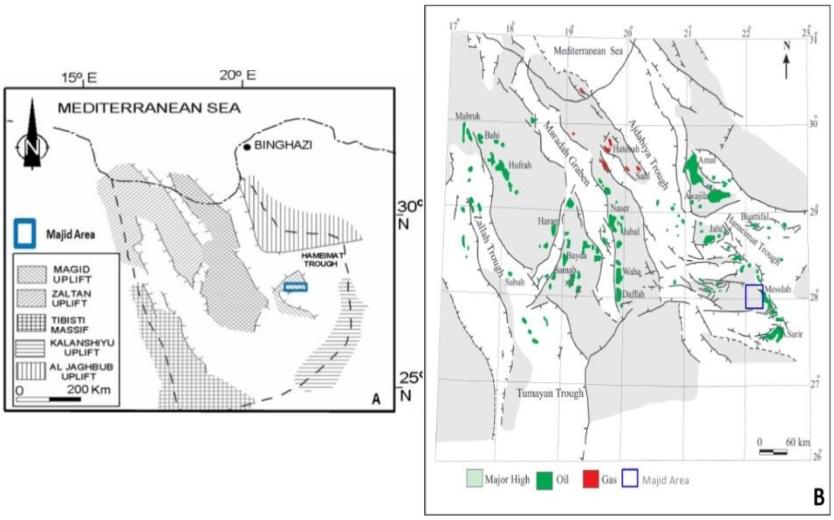


**Fig. 3.** Stratigraphic correlation flattened on top Aguila Formation through Majid Area.

The main objective of this paper was to build a 3D structure geological model for Sarir sandstone reservoir. This model will be achieved by studying four selective wells (O1-80, O2-80, AAA-1 and T1-80) in Majid oil field (Figs. 1, 4). This study includes structural model (structural maps), well correlations and cross-section in different directions for reviewing the potentiality of developing this promising oil field. In this study, well correlation has been applied as a relatively easy method to give an idea and allow simple visualization of the changes in the thickness within Majid area from South to North, especially through Sarir Sandstone.

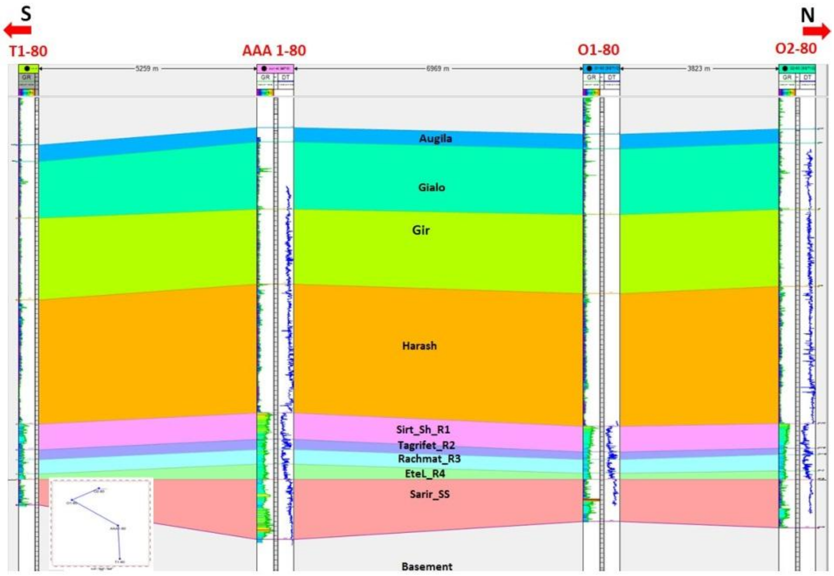


**Fig. 4. A)** Tectonic map of the Sirt Basin, showing oil and gas distribution and its relationship to major structural elements in the Sirt Basin ( modified after **Rusk 2001**). **B)** Uplifts distribution within Sirte basin and around studied Hameimat Trough (modified after **Van Houten and Karasek, 1981**).

## 2. DATA AND AVAILABLE TECHNIQUES

The context of this work is shown in the seismic lines at four wells that can be shown on the location map (Fig. 1B). The available data include two-way travel time (TWT) 2D seismic sections from Arabian Gulf Oil Company, which include eleven individual 2D onshore seismic sections in different directions, located in Majid Area. Logging data of four onshore wells and the available E-logs contain Gamma Logs as well as Sonic logs. Two Well velocity surveys as check shot were studied in detail.

## 3. RESULTS AND DISCUSSION

### 3.1. The Sarir Sandstone reservoir

The Sarir Sandstone is of Late Jurassic to Early Cretaceous age and is composed mostly of continental siliciclastic sediments deposited in a variety of environments including braided fluvial, braid plain, deltaic, meandering fluvial, alluvial fan, fan-delta, aeolian, coastal plain, sabkha and lagoonal-lacustrine **(Viterbo, 1969; Bonnefous, 1972; Ambrose, 2000).** The Sarir Sandstone was divided into four lithostratigraphic members, which can be correlated regionally (Fig. 5). The lowermost member of Sarir Sandstone, which is the main reservoir of the field, is divided into the lower Sarir Sandstone and the overlaying Red Shale. This basal member unconformably overlies the pre-rift basement. In general, it is composed of coarse-grained quartz arenites and conglomerates deposited in proximal alluvial fan and braid plain environments, and is genetically related to, and interfingers with, the Red Shale **(Ambrose, 2000).**

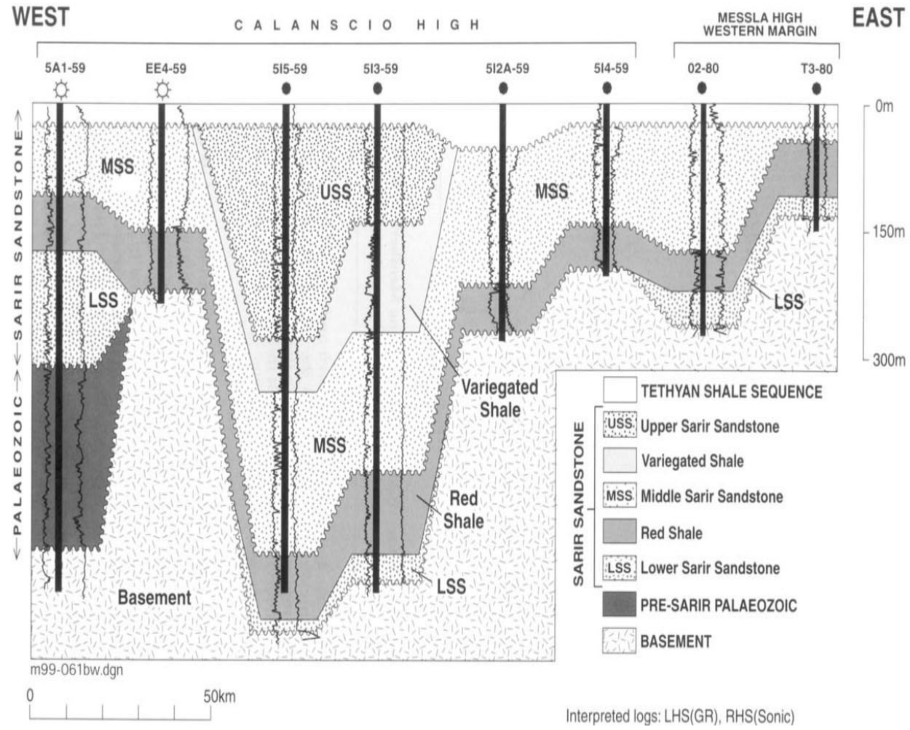


**Fig. 5.** West-east structural section across the Calanscio High to the western margin of the Messla High. Faulting has variably eroded the Sarir Sandstone along the High (after **Ambrose, 2000**).

The thickness of the basal sandstone varies considerably from 463 to 2061 ft (141 to 628 m). The overall variation results from a combination of three main factors: internal thickness variation within the individual members, the severity of the post depositional erosion, and the initial configuration of the basement surface. The variation in thickness ranged from 527 ft at T1-80 well to 997 ft at O2-80 well through Majid area with increasing in thickness in NE direction (Fig. 6).

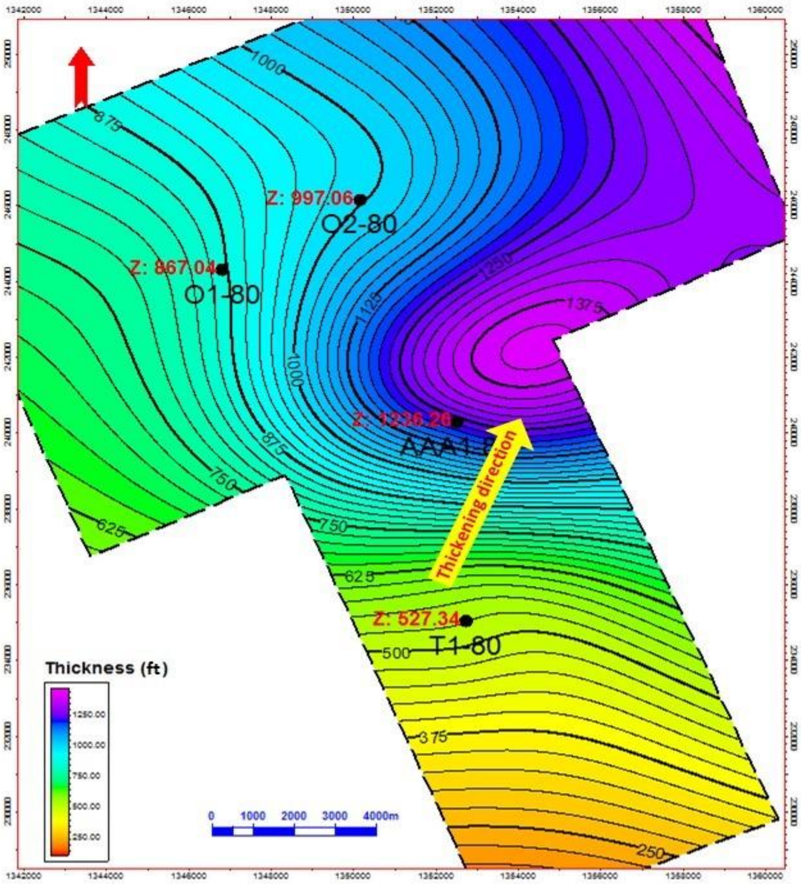


**Fig. 6.** Regional Isopach map for Sarir Sandstone through Majid area.

### 3.2. Well Velocity Survey and Seismic Well Tie

The vertical change of velocities with depth is helpful to identify reflectors representing the tops and the bottoms of the different boundaries (Fig. 7). Through this method, it shows the time depth curves in the O2-80 well (Fig. 7). These curves show the maximum and the minimum values of interval velocity against different formations making use of the plots correlating velocity data (average and interval velocities) with respect to the TWT. The low interval velocities correspond to elastic shale and sandstone, while the high interval velocity is limestone. It is observed that interval velocity discontinuities correspond to the geological boundaries where the maximum interval velocity is observed close to geological discontinuities **(Garotta, 1971)**.

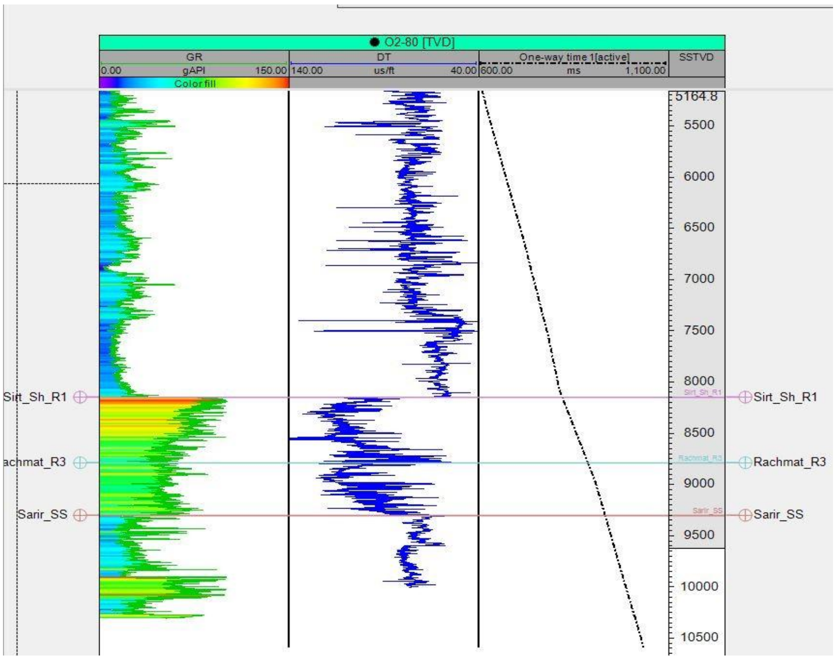


**Fig. 7.** A plot of survey check shot travelling time against depth of Sarir Sandstone.

From the studied seismic lines, two chronostratigraphic boundaries have been identified from the youngest to the oldest: the Sirt Sh-R1 and the Sarir Sandstone. The two horizons were picked both on the post stack volumes within the time interval of 1550 m and 1830 m (Figs. 8, 9).

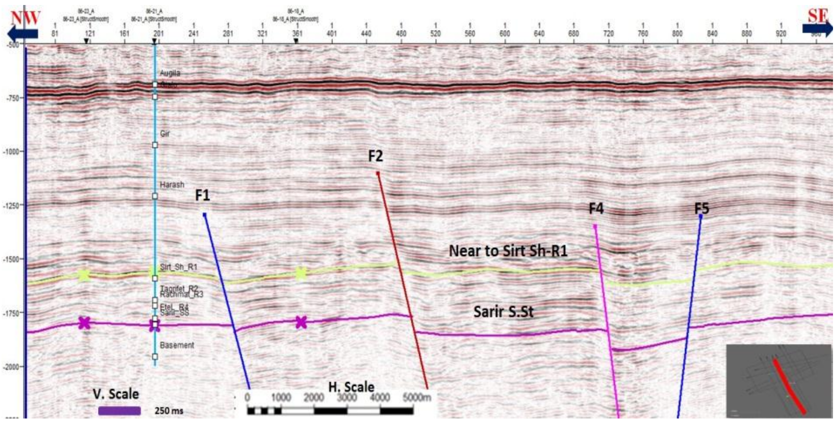


**Fig. 8.** The seismic boundaries discovered in the study area (In-line-68-05-A).

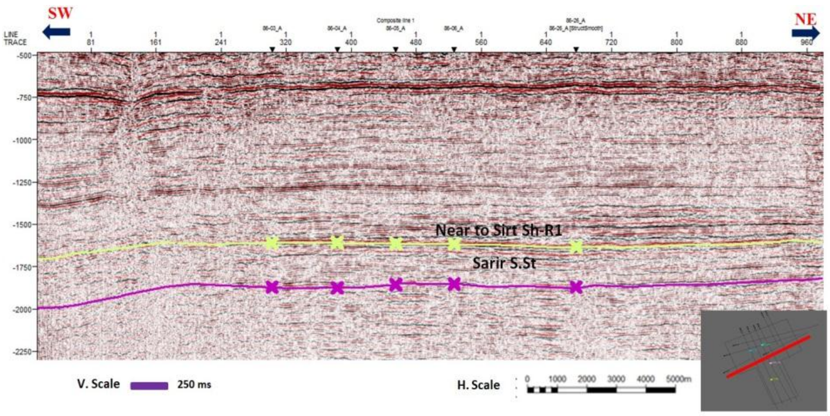


**Fig. 9.** The seismic boundaries discovered in the study area (Cross-line-68-18-A).

### 3.3. Structural analysis

Mapping 3D seismic lines for exploratory purposes normally requires a good understanding of the basin's structural framework and seismic facies analysis. In contrast, mapping in developed fields is usually initiated by connecting production results to the regions of interest. Such mapping entails the interpretation and correlation of existing wells in the vicinity and tying the zones of interest from the logs to the seismic data **(Oyedele, 2005)**. In this work, the study of structural setting has been achieved after mapping the Sarir Sandstone top of pay zone Time, Velocity and Depth maps.

The time structure contour map of top of Pay zone from Sarir Sandstone formation based on 2D seismic data (Fig.10) shows one main set of faults (1, 2, 3, 4 and 5) trend (NE-SW). It is composed of three-way dip closure distributed in the study area while the minimum value of TWT 1810 m at the center (second compartment) and the maximum value 2020 m was recorded away from the structure.

The produced time and depth maps which created on top pay of Sarir Sandstone (Pay Zone) give a general idea about the present day structures affecting the Majid Oil Field is created by group of faults trending from NE to SW directions, which is the dominant one with stratigraphically three-way dip closure distributed in the study area stepped into four compartments from North to South with variety in depths ranges from -9100 ft. in the North structure and -10200 ft in South structures which represent down thrown of NE to SW fault trend (Fig. 11).

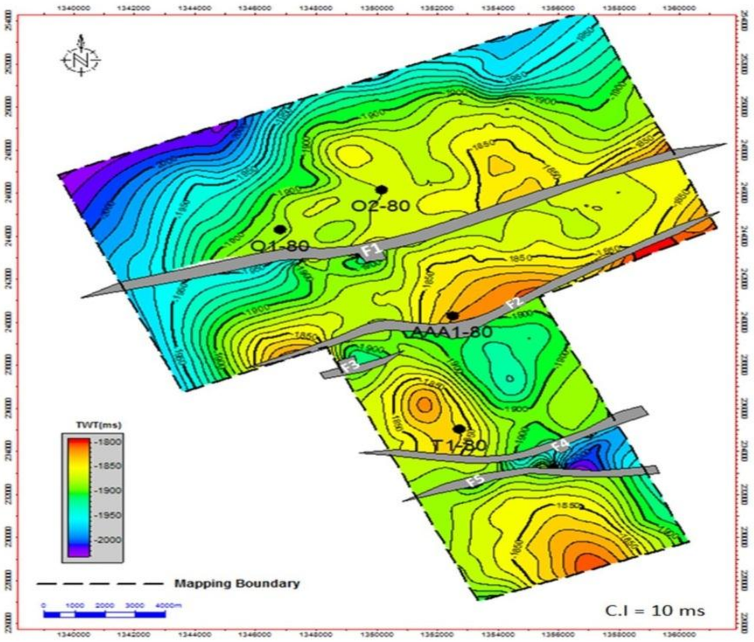


**Fig. 10.** Regional Time structure map for Top Sarir Sandstone Zone through Majid area.

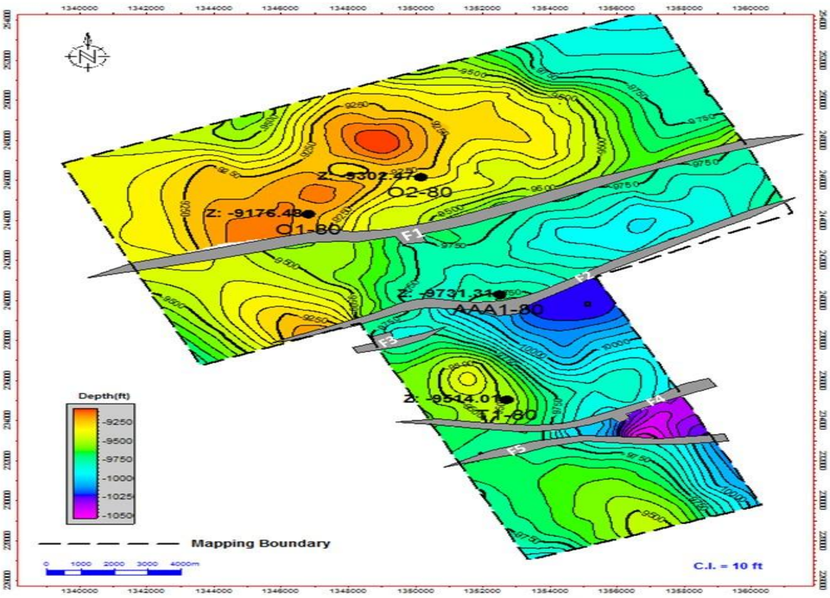


**Fig. 11.** Regional Depth structure map for Top Sarir Sandstone through Majid area.

## 3.4. Structure Modelling

### 3.4.1. Fault modelling

The process of fault modelling defines the faults in the geological model, which will form the basis for generating the 3D grid. These faults will define breaks in the grid; lines along which the horizons are inserted can be recompensated later. The recorded offset was entirely dependent upon the input data. The purpose of this step was to define the shape of each fault that should be modeled. This was done by generating "key pillars" which describe the fault. In this study the faults interpreted on seismic lines can easily be converted to fault modeling with vertical normal faults as Cretaceous horizons in the normal case. However, it was very difficult to convert the faults interpreted to fault modeling according to the type and the relation of the faults, which coded from F1 to F5 (Fig. 12). In the studied area, the recorded normal faults extend in two or three lines in the same plane with controlled shape points (Fig. 13).

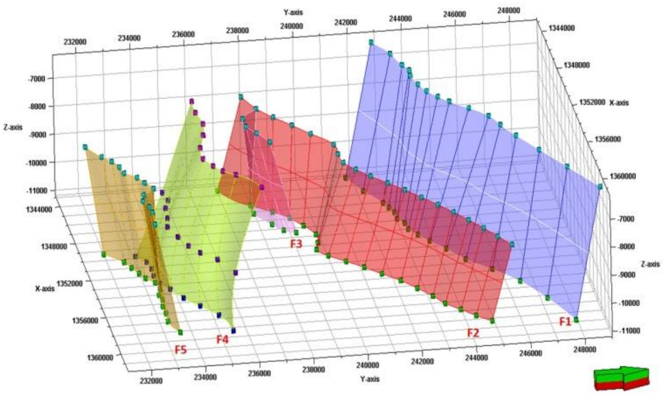


**Fig. 12.** All Faults sticks displayed in a 3D window before fault modeling.

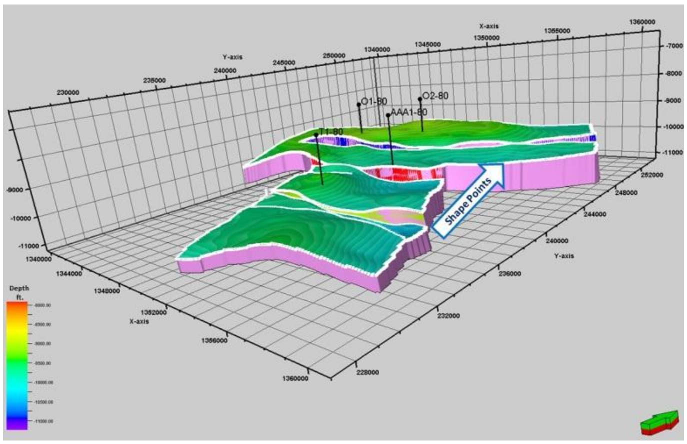


**Fig. 13.** The Maximum shape points control the major normal faults in the Majid area.

The generation of structural models was done in a process called pillar gridding. Pillar gridding is a unique concept in Petrel where the faults in the fault model are used as a basis for generating the 3D grid. Several options are available to customize the 3D grid for either geo-modelling or flow-simulation purposes. Pillar gridding is the process of making the ‘skeleton framework’ or 2D grid. The skeleton is a grid consisting of a top, a mid and base skeleton grid, each attached to the top, the mid and the base points of the key pillars (Fig. 14). In addition to the three skeleton grids, there are pillars connecting every corner of every grid cell to their corresponding corners on the adjacent skeleton grid (Fig. 14). The pillar grid used in the area was 100 m X 100 m (Fig. 15).

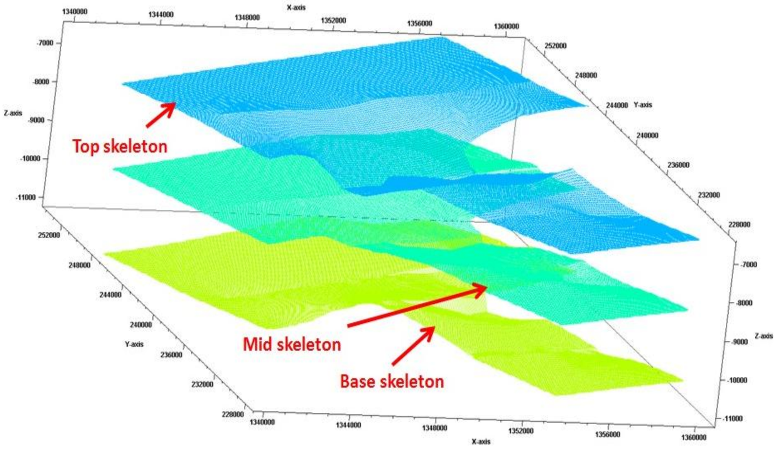


**Fig. 14.** Skeleton framework of the Majid area.

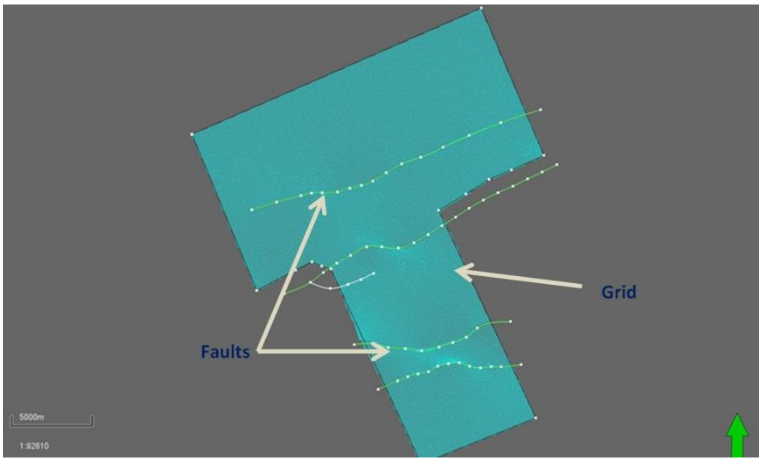


**Fig. 15.** Pillar gridding increments (100 m x 100 m) within the Majid area.

Making horizons is the final step in structural modeling. This process is a fully automatic procedure once the input data and some settings have been specified such as the relationships between the surfaces considered (erosion, discontinuity or conformable). To put stratigraphic horizons in the model, the first step was to make horizons, which honor the grid increment, and the faults defined in previous steps.

After the constriction of the 3D structural modeling in time, the conversion based on the seismic data directly can be established (Fig. 16). The important stage is the depth conversion to increase the certainty of the model based on the velocity model. The final 3D depth model will then be utilized to place a plan for exploring drill wells according to the structure framework.

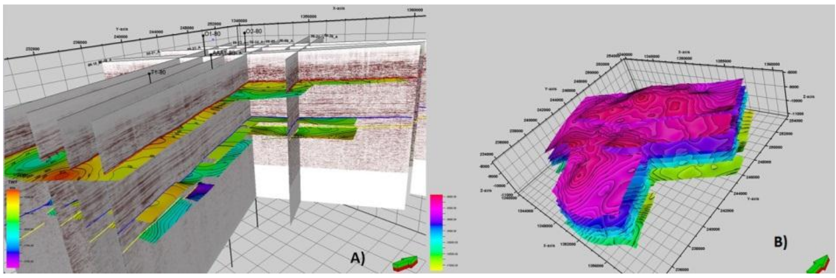


**Fig. 16.** Two views of the 3D model constructed from structure time maps in the study area A) Horizons with seismic lines. B) Horizons without seismic lines.

### 3.4.2. 3D Structural Model

As exploration concentrates along the seismic interpretation, the need develops for an analysis, which derives structure without relying on the seismic section as a photographic image. This need is satisfied by the role of seismic modeling. In the last years, with the advent of powerful computer workstations, the ability to perform interactive 3D modeling has become commonplace throughout the petroleum industry. This change in modeling capability represents a profound expansion of the modeler's ability to comprehend the seismic response to complex structure. The advantage of 3D modeling lies in its capability to allow the interpreter to view and evaluate a structure model by displaying a cross-section along any line of section and through any well control.

The 3D structure model of the study area had been done using Petrel software, which represents a complex structural pattern. The structural elements were subdivided into faults and faulted folds. The configuration of the study area is controlled by NE-SW trends. Most of these faults are dipping to the southeast. Also, folding plays a minor role in the definition of the structural setting. Rollover faulted anticlines developed above the curved listric faults.

### 3.4.3. Cross Sections

Three cross-sections were built from structure model, the first one along line 86-05-A, passing through O2-80 and AAA-80 wells, which reconstructed in south-north direction of the model and represent the main structure in the study area (Fig. 17). The second cross-section along line 86-06-A was constructed in NW to SE direction (Fig. 18). While the third one was built along cross line 86-21-A which passes through O2-80 well (Fig. 19).

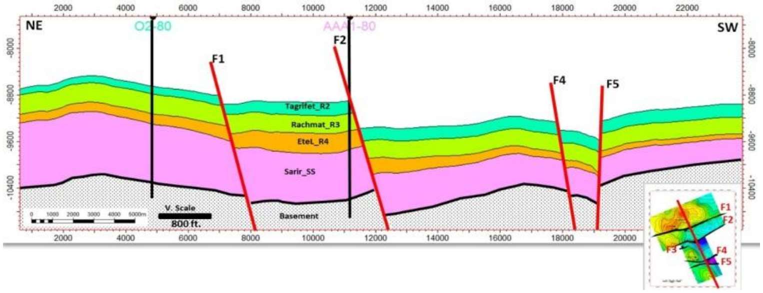


**Fig. 17.** Cross section along In-line 86-05-A from NW to SE.

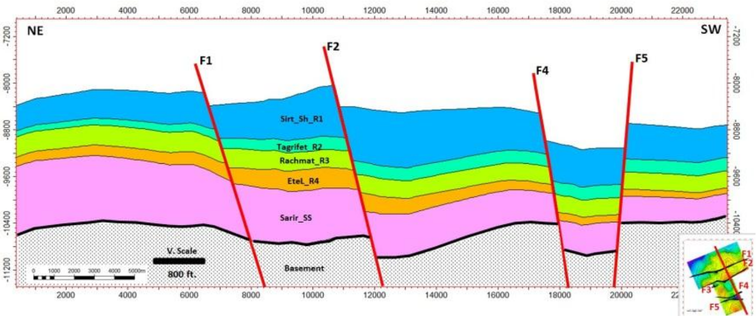


**Fig. 18.** Cross section along In-line 86-06-A from NW to SE.

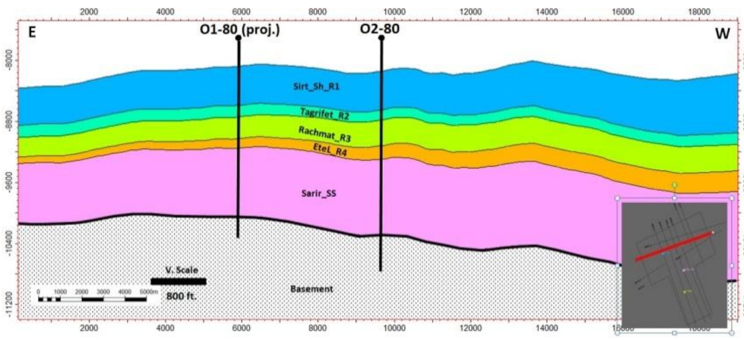


**Fig. 19.** Cross section along Cross-line 86-21-A from NE to SW.

### 3.4.4. Recommendations

As a result of the Majid Field evaluation, it is recommended to drill about five wells to increase productivity of the field at least three development wells and two exploration wells as follows:

Location # 1: The up dip from O1-80 in the SW direction to test Sarir sand penetrated in the offset well (O1-80) (Fig. 20).

Location # 2: The location is about 2000 m from O2-80 well in the North direction the depth of Sarir reservoir could be 240 ft higher than O2-80 (Fig. 20).

Locations # 3: To explore the tilted fault block West of AAA-1 well for all reservoir (Fig. 20).

Location # 4: The location is about 1400 m from T1-80 well in the Northwest direction the depth of Sarir reservoir could be 130 ft higher than T1-80 well (Fig. 20).

Locations # 5: To explore the tilted fault block South of T1-80 well, but this location needs to acquire more lines or a denser grid of 2D lines and to be able to do ranking for future drilling (Fig. 20).

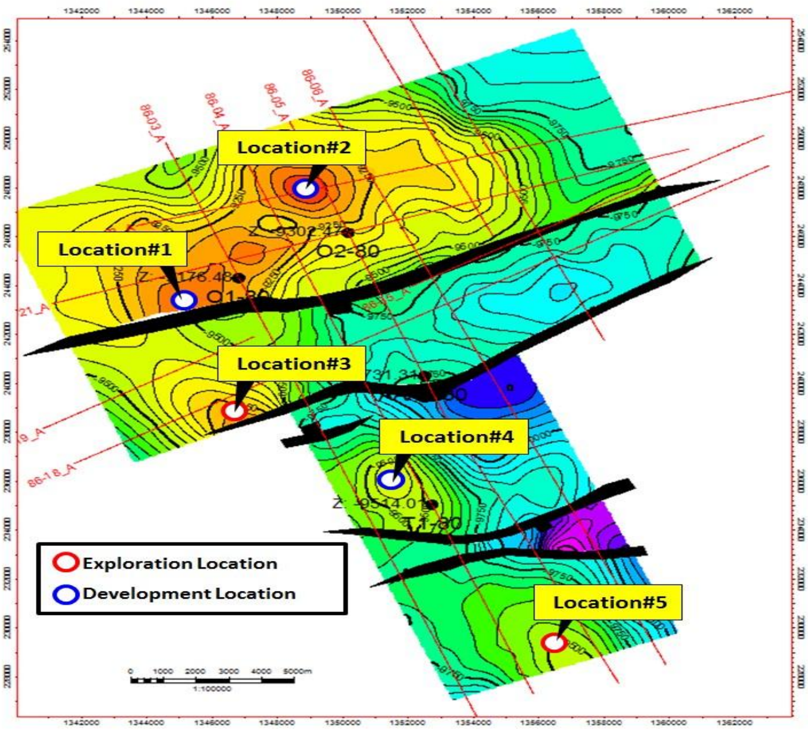


**Fig. 20.** Proposed Drilling Location Map Sarir Depth Map.

## CONCLUSION

The structural pattern of the area is dominated by NE-SW oriented faults. The structure depth contour map, which was constructed on top of the Sarir Sandstone based on ten 2D Seismic lines, showed that the structural closures formed in this study area were mainly three-way closure type. 3D seismic model is recommended to improve the structural and facial understanding of the area according to the economic consideration, plus resolving the time/depth reversal that could be attributed at the reservoir levels.

## ACKNOWLEDGMENTS

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## النمذجة البنائية والسيزمية لخزان الحجر الرملي السريري، منطقة ماجد، حوض سرت، ليبيا

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يعد مكون "سرير الرملي" ذو العصر الطباشيري السفلي خزان نفطي غزير الانتاج في حوض سرت ليبيا، وخاصة في الجزء الجنوبي الشرقي بكميات تجارية من الهيدروكربونات (حوالي 9 مليار برميل). تراكمت تلك الهيدروكربونات من تكوين النوبة من كل من المصائد التركيبية والطباقية في حقول النفط العملاقة. أدى الاستكشاف الكلاسيكي للنفط في المنطقة، بناءً على المسح الزلزالي ثنائي الأبعاد، إلى العديد من الآبار الجافة في العقود الماضية. تُستخدم الدراسة الحالية، التي استندت إلى تفسير بيانات المسح الزلزالي ثلاثي الأبعاد المكتسبة، ومطابقتها مع سجلات الآبار المتاحة، لبناء نموذج ثلاثي الأبعاد للمنطقة لفهم البيئة التركيبية المعقدة للمنطقة وفهم نمط احتجاز الهيدروكربون الضمني. تم تحقيق التفسير الزلزالي لمراجعة التكوين البنائي لمنطقة ماجد (منطقة الدراسة) وتوضيح إمكانات الهيدروكربون (الاحتمالات والخطوط العريضة) من خلال بناء نمذجة تركيبية ثلاثية الأبعاد باستخدام بيانات الآبار وبيانات المسح الزلزالي ثنائي الأبعاد. ولتحقيق هذا العمل، تم إنشاء ثلاثة مقاطع عرضية تمثيلية. طُوِّرت هذه البيانات كمدخل رئيسي لنموذج جيولوجي ثلاثي الأبعاد أولي لتحديد التوقعات والخطوط الرئيسية في منطقة الدراسة. رُسمت خريطة كونتور تركيبية جيولوجية (خريطة متزامنة، حُوّلت إلى خريطة عمق) لقمة مكون سرير الرملي. وحُدّدت في هذه الخريطة صدوع انزلاقية مائلة من الشمال الشرقي إلى الجنوب الغربي، تمتد إلى الجنوب الشرقي من المنطقة، وطيات صدعية (طيات صدعية متدحرجة) تكوّنت فوق الصدوع الليسترية المنحنية.