Petroleum Res. J. Vol. 20 (2007); P. 21–34, 13 Figs.

# An Evaluation of the Waha Limestone South Al Jabal Field, Sirt Basin

Ali M. Massoud Elmesmari*

# تقييم الحجر الجيري (الواحة) جنوب حقل الجبل

علي م. مسعود المسماري

تأخذ بنية حقل الجبل الحالية تركيبة محدبة في اتجاه الشمال الشرقي-الجنوب الغربي، وهي بارزة المظهر نتيجة حدوث ارتفاع طبوغرافي في عصر ما قبل الكريتاسي الذي تم تحويره لاحقا بواسطة التصدع والتعرية والترسيب المتقدم إبان عصر الكريتاسي وبواسطة التصدع أثناء عصريْ الباليوسين والأيوسين، وهناك صدع كبير يحاذي هذا التركيب من جهة الغرب ويفصل بين غور الحقفة ومرتفع زلطن، كما يوجد صدعان آخران صغيران يميلان بعيدا عن الصدع الرئيسي ويقطعان التركيب البنيوي ومن المحتمل أن يغلقا التركيبة المحدبة للحقل من الغرب إلى الشمال الغربي.

يعتبر حجر الواحة الجيري التابع للكريتاسي العلوي الهدف الأول لصخور المكمن في منطقة رصيف زلتن، ويتراوح سمك صخور المكمن من الصفر عند ذروة التركيبة المحدبة إلى أكثر من 350 قدم عند الحواف، ويمكن ملاحظة بعض خواص المقاطع الزلزالية المنعكسة من خلال التنبؤ وموقع مكمن الواحة عند تواجد مقطع سميك منه، يولد تباين قوة مقاومة الصوت عند قمة الكلاش (فوق الواحة) والباهي/القرقاف (مباشرة تحت الواحة) انعكاسات تحدد معالم الغلاف الذي يوجد بداخله تكوين الواحة.

تم اكتشاف معظم المصايد النفطية بحقل الجبل اعتمادا على الدراسة الحقلية والمسح الزلزالي، ومنذ تأسيس الحقل فقد وصل الإنتاج حاليا مرحلة الاسترداد الثانية. قادت هذه الدراسة إلى البحث عن مصايد بنيوية صغيرة متواجدة مع هذا الحقل العملاق وخاصة في الجزء الجنوبي منه. وبالرغم من اعتبار أن هذه الظواهر الصغيرة قليلة المخاطر نسبيا، خاصة عند استعمال التقنية السيزمية، فإن موقع شاذات التركيبة المأمول قد تم التعرف عليها، ومن المحتمل أن تكون هدفا للحفر وهو ما يسمح للشركة من تحديد موضع قدم للنفط وتطوير الإنتاج في هذا الحقل.

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**Abstract:** *The present day structure of Al Jabal Field is a NE-SW trending anticline structure. The prominent shape of this structure is the product of a Pre-Cretaceous topographic high, which was modified by faulting, erosion and transgressive sedimentation during the Cretaceous and by faulting during the Palaeocene and Eocene. A major fault, bounding this structure on the west, defines Al Hagfah Trough/Zaltan Platform. Two other minor faults splay off from this major fault, cut the main structure and probably seal Al Jabal structural anticline from the west to the northwest.*

*The Upper Cretaceous Waha Limestone is a primary reservoir target on the Zaltan Platform. The reservoir ranges from zero thickness on the crests of topographic highs to over 350 feet on their flanks. Certain seismic reflection characteristics are noted in relation to the prediction and location of the Waha reservoir where a thick Waha section is usually present. Strong acoustic impedance contrasts at the top of the Kalash (above the Waha) and the Bahi/Gargaf (immediately below the Waha) generate*

* Sirte Oil Company.

*reflections that define the envelope in which the Waha exists.*

*Most of the traps were discovered in Al Jabal Field on the basis of geological fieldwork and seismic surveys since the field was established have now reached their secondary recovery stage. This study led the search for smaller satellite structures to be associated with this giant field, particularly in its southern part of the field. Although these small features are considered to be of relatively low risk, especially with using the seismic techniques, the locality of new prospective structure anomalies has been defined, and could be a drilling target, which would enable the company to spot the oil leg target and develop production in this field.*

## INTRODUCTION

Waha Formation in Al Jabal Field is the principle Upper Cretaceous producing formation, a saturated light oil reservoir with a gas cap and aquifer. The Waha Limestone varies in lithologic composition from sandstone to limestone and ranges in thickness from its depositional edge to over 350 feet in the northern part of the field (El Ghoul, 1996). This study focuses on prospective areas in the southern part of this field by looking for satellite structures and by analysing the effect of thickness variation of reservoir rock unit. Although there is minimum well data within studied area, the appearance of Waha Limestone elucidates fair distributed thickness to be a capable reservoir rock unit in this region. The identification of these potential structures could be useful with the prediction of production in Al Jabal Field.

### Location of the Study Area

Al Jabal Field is located in South Concession 6 on the updip edge of the Zaltan Platform in onshore Sirt Basin. Esso discovered this field in 1962 and drilled wildcat P1-6. Production of Al Jabal Field started in 1964, and a total of over 60 wells have been drilled to date (Wallace, 1988). The greatest part of the Concession 6 is located on the Zaltan Platform. This platform is bounded on the west by large scale syn-depositional faulting that separated the Zaltan Platform from Al Hagfah Trough to the west.

The area of study is located in the southern portion of Al Jabal Field (Fig. 1) between latitude N 28° 28‘36", N 28°41‘54", and longitude E 19° 49‘14", E 20° 01‘44".

### Petroleum System in Studied Area

#### *Source Rock*

The Sirte Shale is composed primarily of shale and some limestone. It is believed to be the hydrocarbon source rock that was deposited in Al

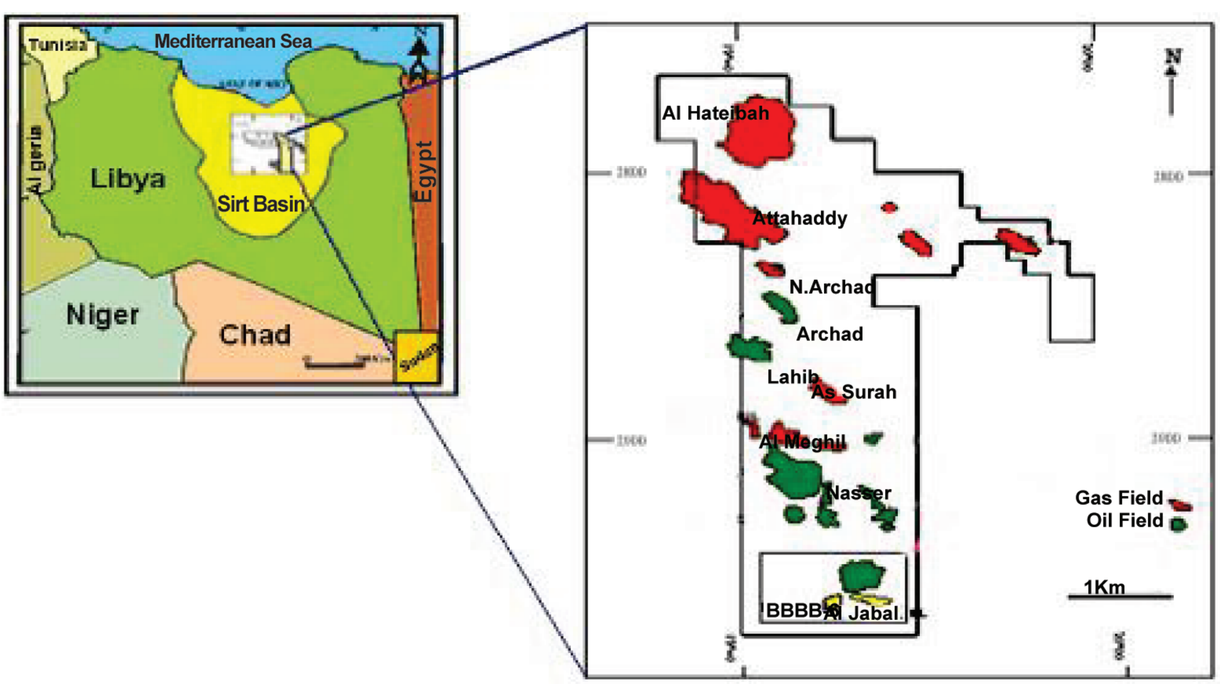


*Fig. 1.* Study area, locations map.

Hagfah Trough for the Waha, Bahi and Gargaf reservoirs (Fig. 2). This figure shows the total and minimum petroleum system in Concession 6 (El Ghoul, 1996).

### *Reservoir Rock*

The main primary producing reservoir in Al Jabal Field is the Upper Cretaceous Waha Limestone in the southern part of Concession 6 (Fig. 2). The Waha is composed primarily of skeletal limestone and calcarenite sands. It represents deposition in the high-energy zone at or near wave base as the first Cretaceous seas on-lapped the Zaltan Platform (Barr and Weegar, 1972). The best Waha oil reservoirs are usually on the old highs where Sirte Shale was not present. Waha Limestone ranges in thickness from its depositional edge to over 350 feet (Waha Limestone thickness in well 4B2-6 is 11 feet, and 357 feet in well P1-6).

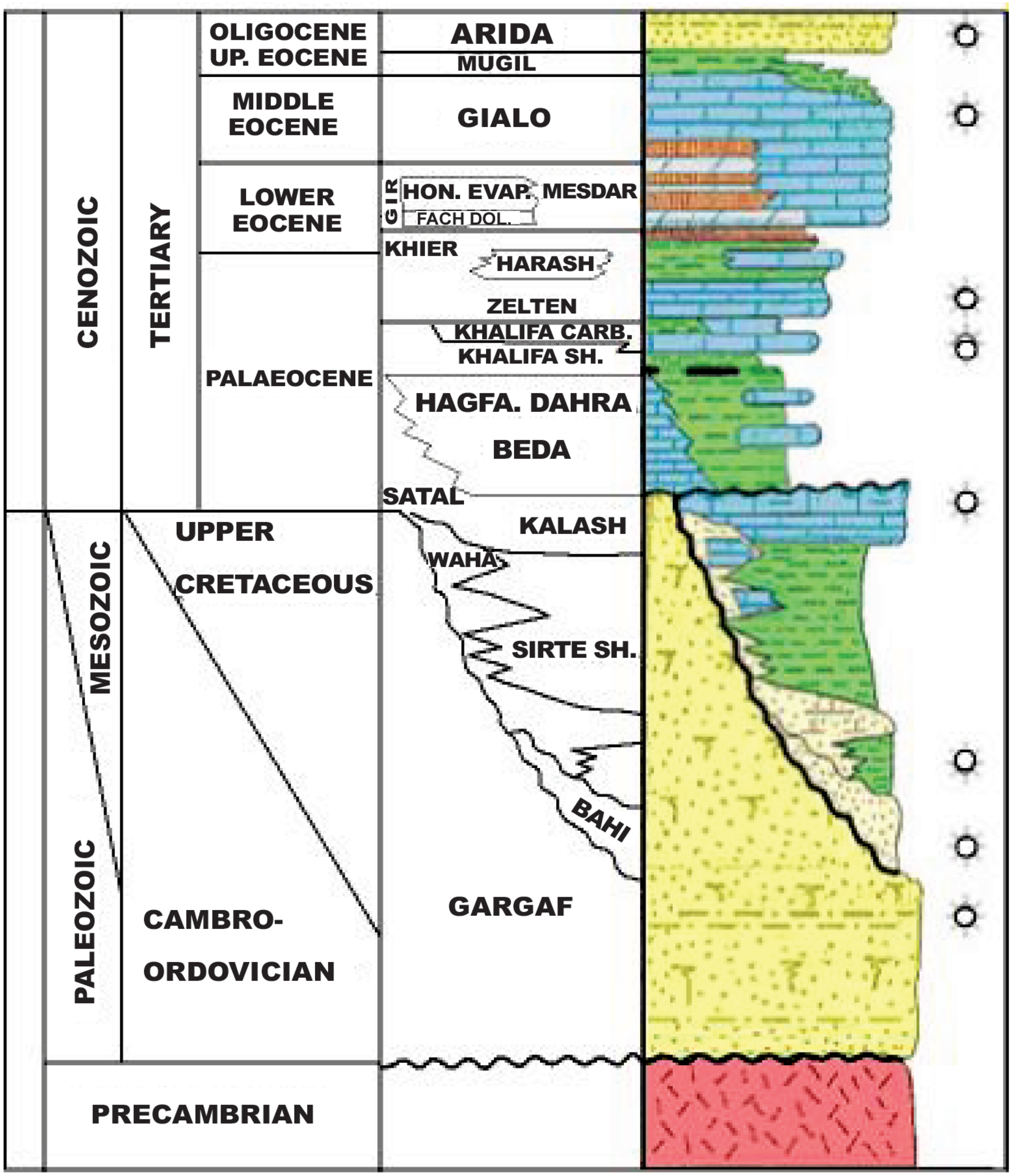


*Fig. 2.* Generalized columnar stratigraphic section of Concession 6.

***Seal Rock***

The Kalash Limestone is the most widespread Cretaceous sediments unit and covers all of the Concession 6 (McDowell, 1988), both the Zaltan Platform and the Al Hagfah Trough. It is a tight micritic limestone and represents deep water carbonates deposition (Barr and Weegar, 1972), and it is not normally a reservoir. The Kalash Limestone is supported by massive shale (Hagfa Shale), which acts as a seal for Upper Cretaceous reservoir rock in the Zaltan Platform (Fig. 2). Hagfa Shale is widespread in central and western Sirt Basin. It is Lower Palaeocene (Danian) in age, and consists mainly of a shale sequence with occasional thin limestone interbeds.

***Trap Style***

The trap style in Al Jabal Field is a combination of stratigraphic and structural traps. The anticline at Al Jabal is a NE-SW trending feature with faults on the western and northwestern flanks of the field. In addition, major unconformities, bounding the Waha reservoir at the top and base contribute to the complexity of the reservoir sequence at Al Jabal (Wallace, 1988). The field illustrates an excellent example of a combination of a stratigraphic-structural trap in many Libyan oil fields.

***Oil Migration***

The Sirt Basin is an example of a dominant vertical migrated petroleum system, wherein Upper Cretaceous oil charges multiple reservoirs along fault zones adjacent to horsts and grabens (Ahlbrandt, 2001).

## OBJECTIVES

Most palaeotopographic giant structural traps were discovered in the early stage of exploration in the Al Jabal Field, with the aim of developing production of this field as its secondary stage of recovery by looking for new localities of potential satellite structures and constructing time and thickness maps for seal and reservoir layers in the South Al Jabal Field.

The purpose of this study involves evaluating the Waha Limestone as a reservoir unit, and Kalash Limestone, which is a widespread Upper Cretaceous sedimentary unit in Concession 6. Additionally as an excellent mappable seismic reflector, and fairly easy to follow as it is overlain by massive shale of Hagfa Shale that on certain seismic reflection shows strong acoustic impedance contrasts at the top of Kalash enabling calculating of the thickness of Waha reservoir and seal rocks. Mapping the shallower formation, which is (the Middle Eocene Gialo) can illustrate the general, and overall structural picture of the studied area.

## AVAILABLE DATA

### Seismic Database

All seismic data provided is vibroseis and covered the southern part of the Al Jabal Field. These data, the last proposed on this field, were shot in years 2000 and 2001, associated with previous seismic proposed in the recent years, which were shot in years 1998 and 1999. The seismic data used in this study includes 15 lines of migrated 2D and consist of 302 km. Six out of 15 seismic lines are strike lines and 9 of them are dip. The strike lines orientate in NW-SE direction whereas the dip lines in NE-SW (Fig. 3). A seismic base map with a scale of 1:50,000 have been used.

### Well Database

The well data used in this study have been collected from 17 wells that were drilled below Kalash level, in Al Jabal Field (Fig. 3). Well data information includes composite logs containing spontaneous potential (SP), gamma ray (GR), resistivity (LLD), and sonic logs.

## METHODOLOGY

A seismic programme of 302 km has been selected from the database of Sirte Oil Company (SOC) in Al Jabal Field to determine the main seismic reflectors in the area of study and the presence of potential hydrocarbon traps. Synthetic seismograms were used from 12 wells to tie the well data with seismic profiles. The main seismic marker in the area is the Upper Cretaceous Kalash Limestone, being the strongest and continuous reflector and an excellent mappable seismic marker. The Kalash Limestone is believed to be a good seismic reflector marker for the Waha

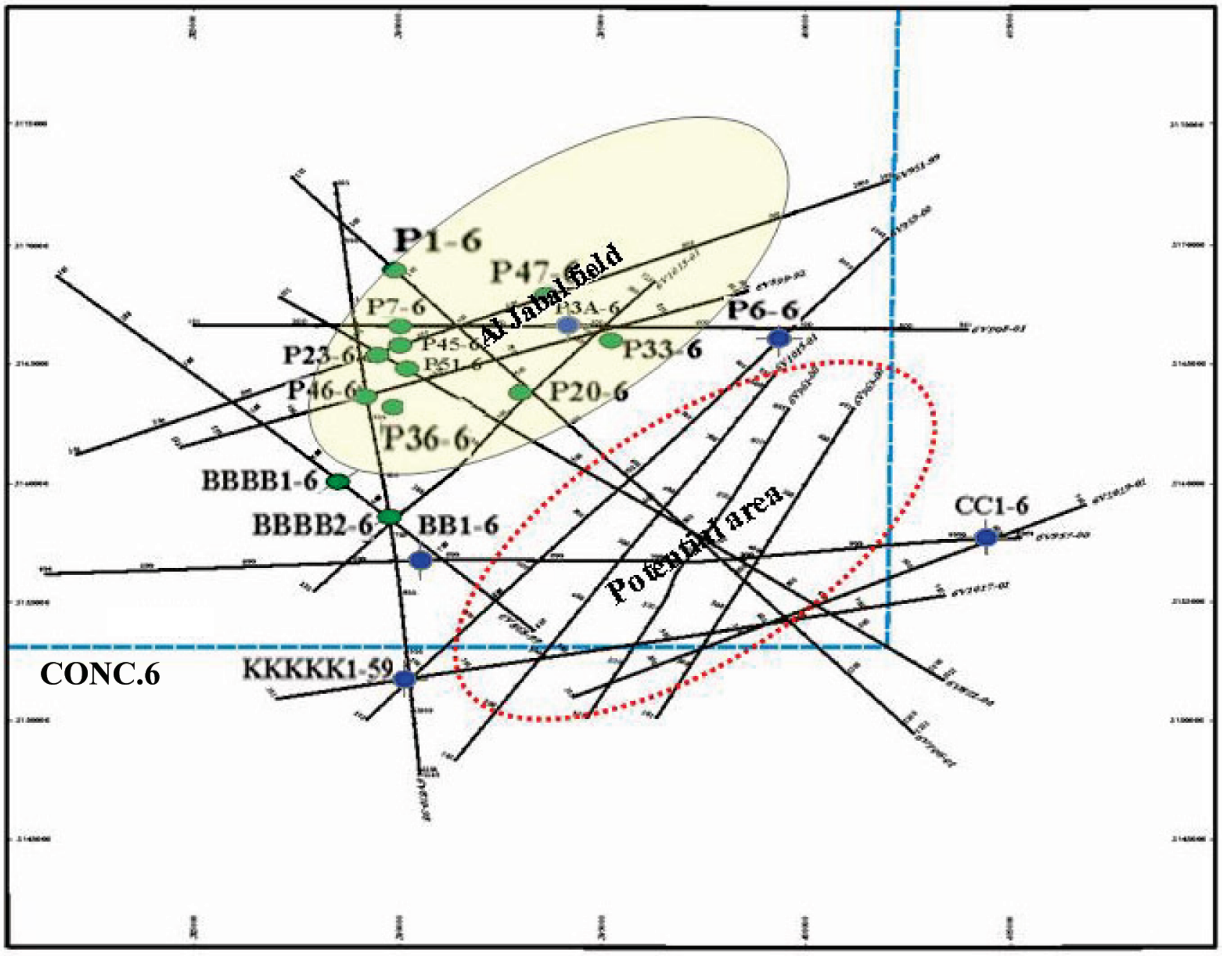


*Fig. 3.* Base map Al Jabal Field.

Limestone reservoir that contacts the Kalash with the Waha, which has a minor variation in acoustic impedance contrast.

Two-way time structure map was generated for the top of Kalash posted on a base map every 40 shot points by using 20 (ms) as a contour interval, and another two-way time structure map was generated for the top of Gialo Limestone, demonstrating the general structure of the area, and could illustrate new shallower structures.

Two cross-sections were generated across the field in two different directions by using sub sea depth at (-6600 ft) as a datum within Hagfa Shale that overlies the Kalash Limestone.

Well data information was used also to illustrate the distribution of the formations' thicknesses. Two isopach maps in vertical sequence succession were generated for Kalash, and Waha limestones.

## SEISMIC INTERPRETATION

The purpose of the seismic interpretation was to define and map the south part of Al Jabal Field and track any possible structure for development, outpost or exploration drilling. Basic procedures for seismic interpretation were followed involving the identification of strong and continuous seismic reflector. This achieved by tying well data to seismic profiles and tracking the marker horizons. Eleven seismic markers have been traced during the course of this work to verify the presence of hydrocarbon traps within the studied area.

### *Tying Well Data*

Interpretation was started by picking horizons that were displayed on the seismograms from twelve wells in this area. The seismograms generated by using sonic logs to determine the formation tops.

Two seismic lines were used as key lines since they intersect with the most lines in this study. Line 6V957-00 shot in year 2000, extends for approximately 24 km in a W-E direction as a strike line and ties two wells, BB1-6 in the west at shot point 475, and CC1-6 in the east at shot point 1035

(Fig. 4). The second line is 6V872-00, which extends for approximately 23 km in a NW-SE direction as a strike line as well and crosses over well P51-6 (Fig. 5).

The second stage involved the interpretation of all seismic lines used to correlate and tie at every intersection between these lines, closing loops of seismic grid by correlating the recognized horizons on the two key lines and follow them on the other seismic profiles.

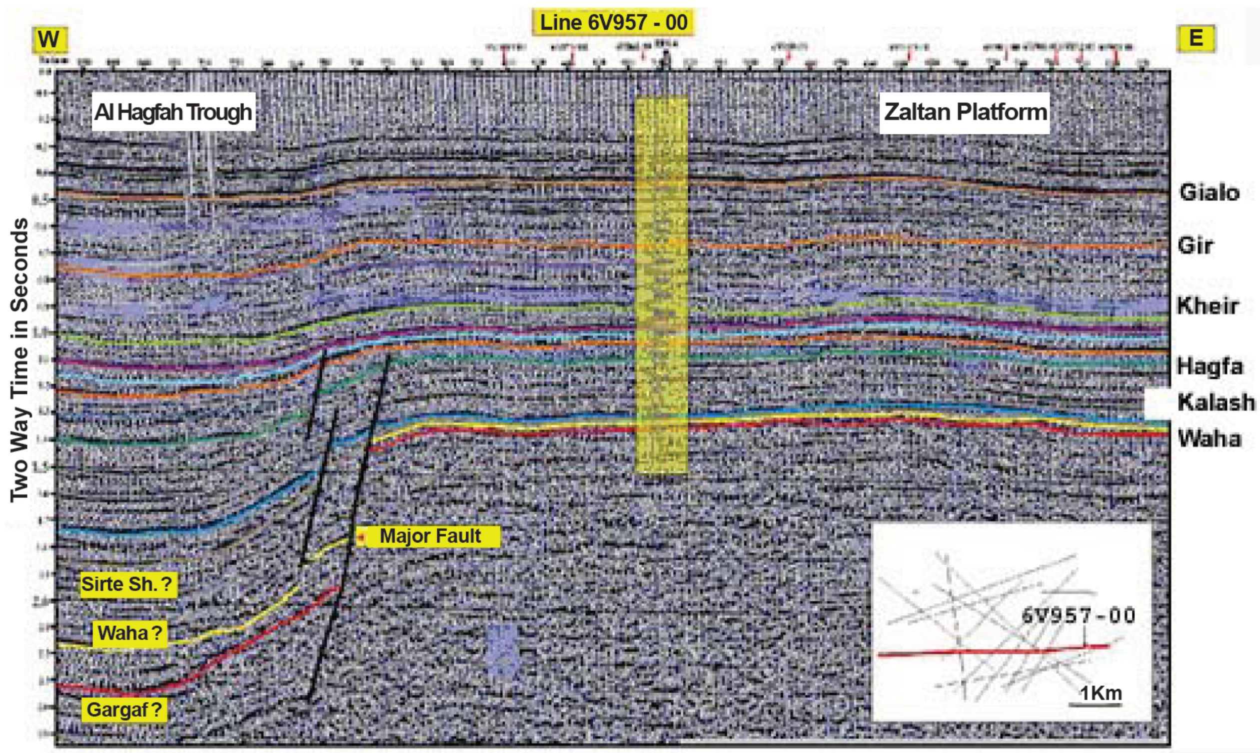


*Fig. 4.* Seismic profile of line 6V957-00.

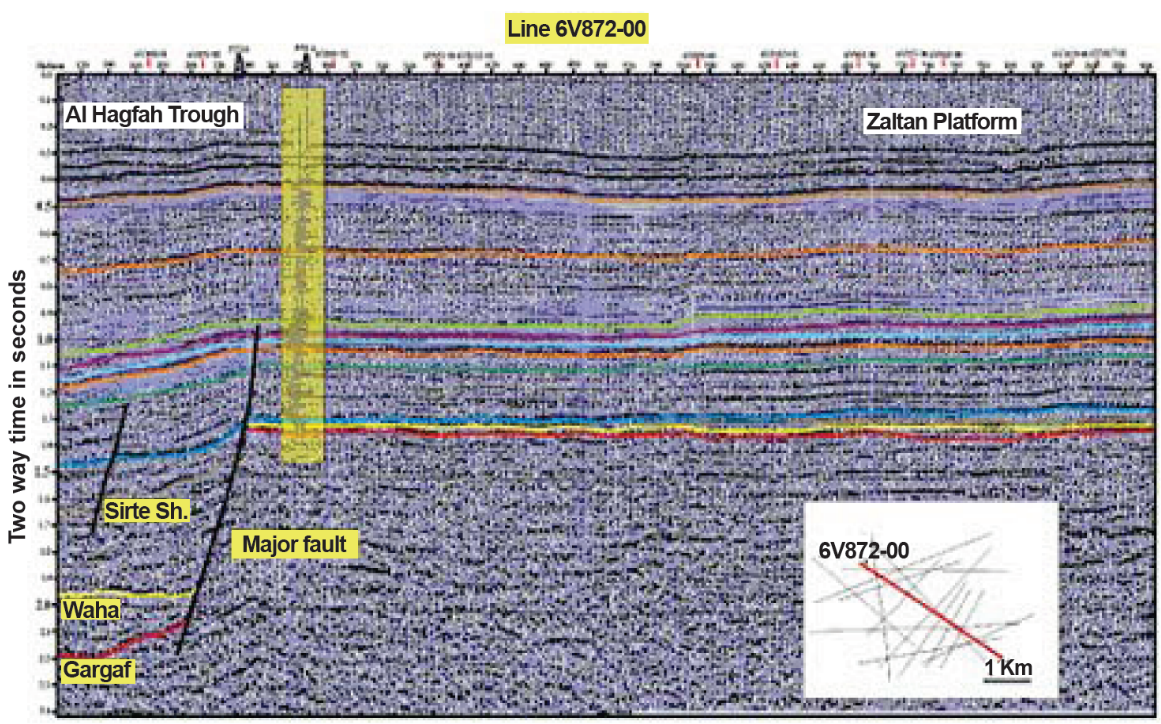


*Fig. 5.* Seismic profile of line 6V872-00.

### *Structural Interpretation and Mapping*

This phase of interpretation involved the production of satisfactory time structure maps for target horizons to illustrate the general structural picture in the vicinity of Al Jabal Field. Verification of the presence of hydrocarbon traps within the area of study was achieved through the construction of two-way time maps, which may be considered to represent a new mapped structural configuration of the top of the reflector (Kalash). Mapping time values are utilized for the identification of many untested structurally high features that may indicate new Waha sweet spots.

The interpretation enabled the production of time structure maps that were generated on a scale of 1:50,000 for inclusion in this study:

- A time structure map of Top Gialo Middle Eocene (Fig. 6) was generated, because Gialo map illustrates the general and overall picture of the structure of the area. This horizon appears almost flat and it is not disrupted by any tectonic events, which is reasonably undisturbed. A smooth gently dipping Gialo surface was constructed. This surface was then modified as the standard from which all other events were compared.

- A time structure map of Top Kalash Upper Cretaceous (Fig. 7) was generated, since mapping of the Kalash seismic horizon indicates the Waha reservoir. Seismically, top Kalash surface has proved to be an excellent mappable event. This peak is due to the strong acoustic impedance contrasts at the top of Kalash. The Kalash horizon is gentle dipping to the northeast, and in the west most of the Kalash surface has been affected by the major fault and a number of complex normal faults system situated to the west of Al Jabal Field. These faults are trending to the north south towards and downthrown into Al Hagfah Trough. The map can be utilized for identification of many untested structurally high features located in the South Al Jabal Field on the Zaltan Platform.

The Kalash time structure map has clarified some satellite structures; it demonstrates a crest of anticline structure traps. The most interesting structural high anomalies that have been interpreted are on seismic profiles of line 6V957-00, which extends in a W-E direction showing a typical anticline sitting on this line (Fig. 8), and the time computed for this closure is 1.22 sec. Second seismic profile of line 6V1019-01 extends in a SW-NE direction relocates another typical anticline sitting on this line of computed time

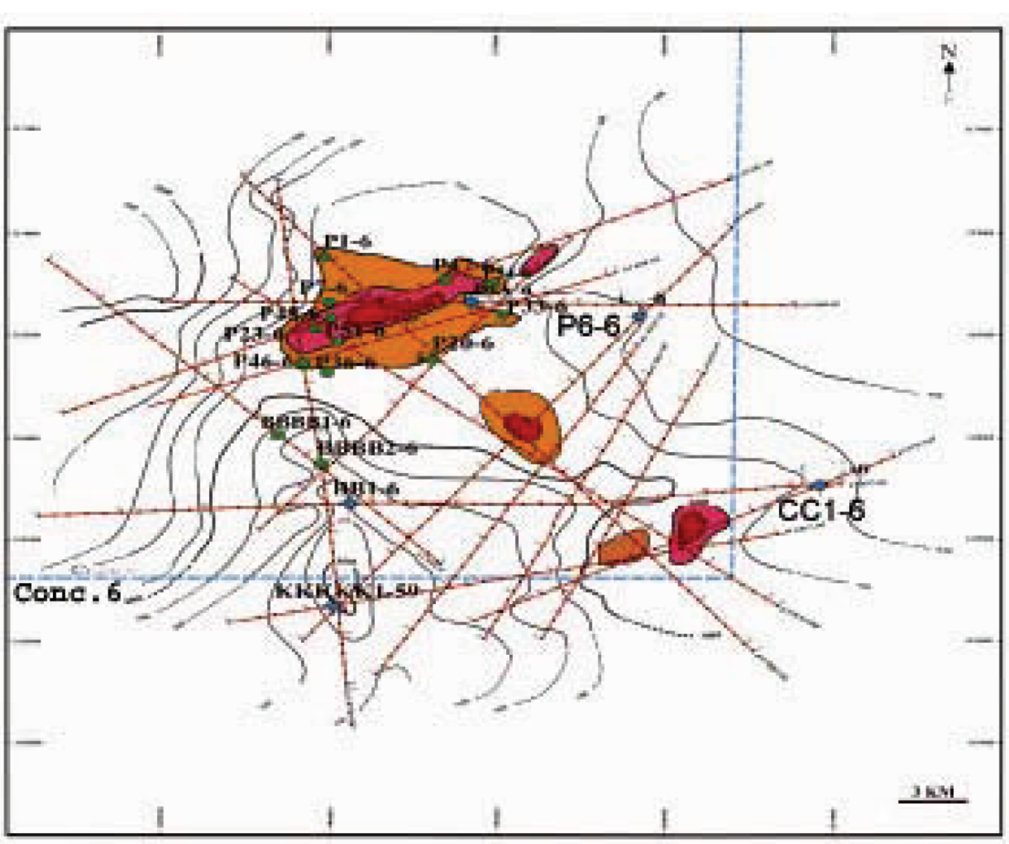


*Fig. 6.* Time structure map of top Gialo, contour interval (20 ms).

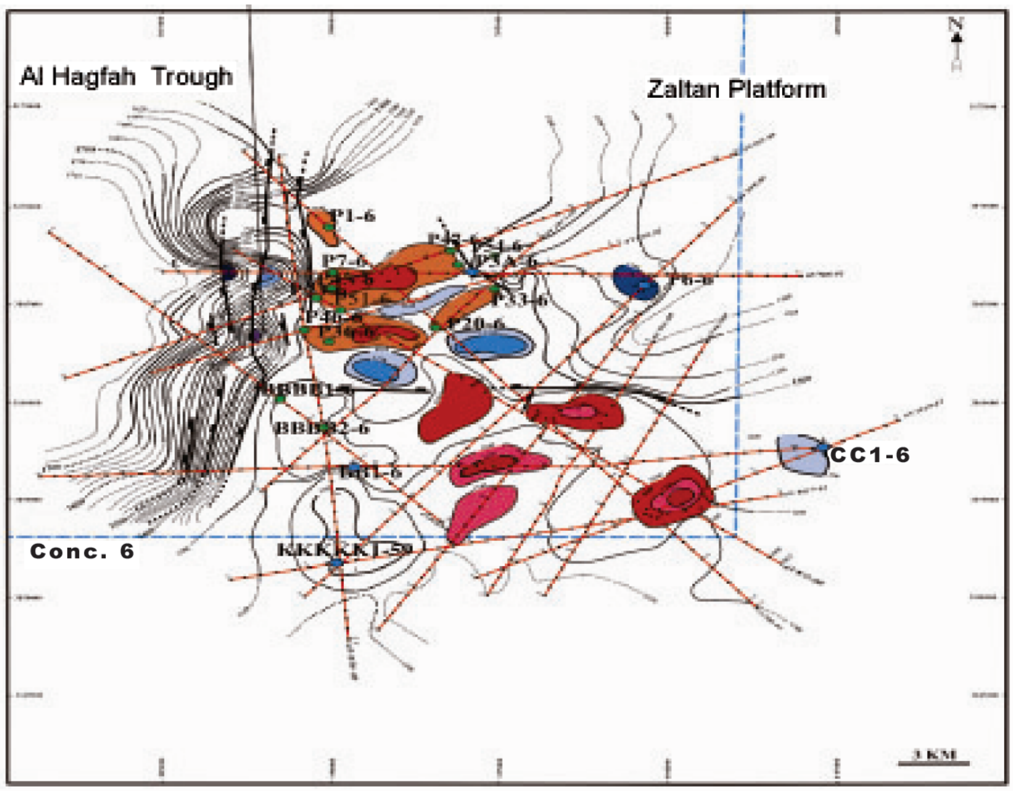


*Fig. 7.* Time structure map of Kalash, contour interval (20 ms).

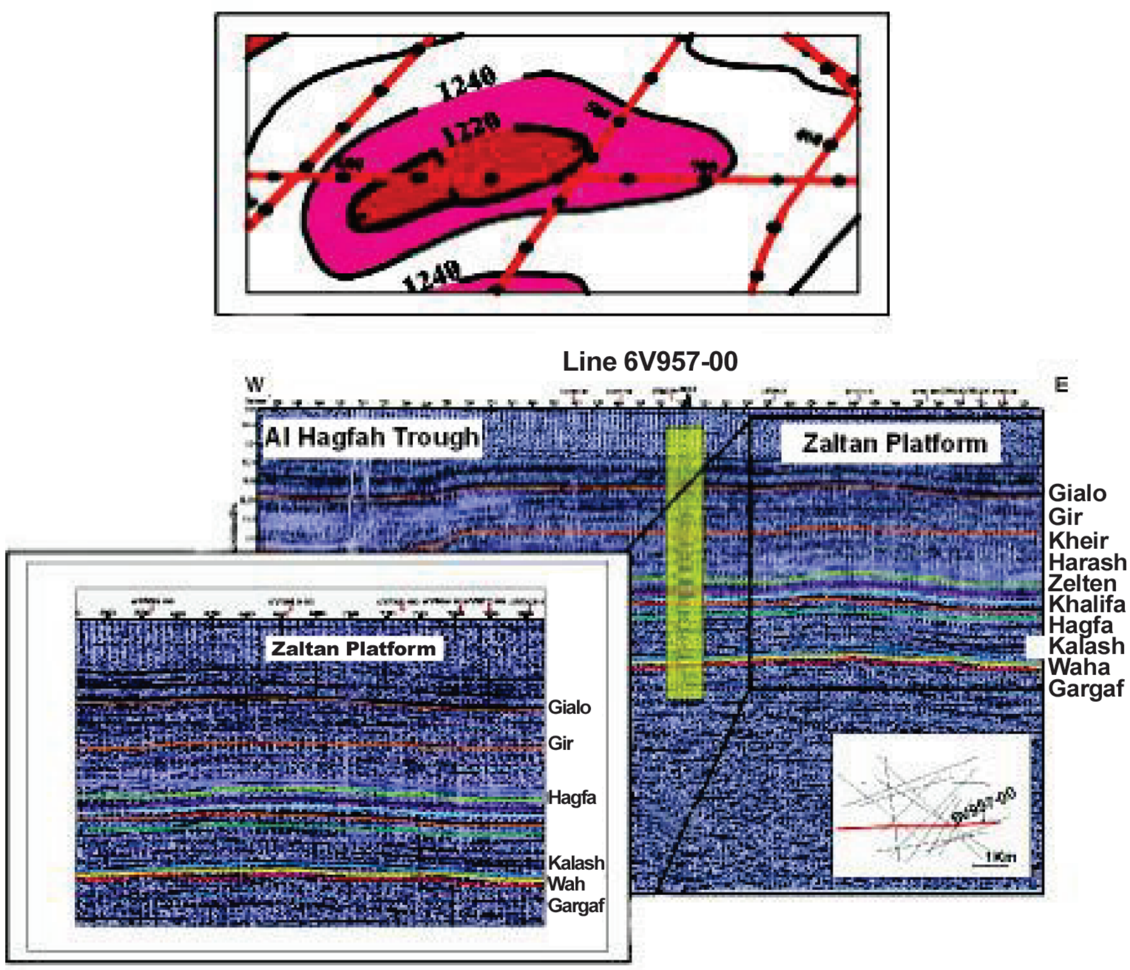


*Fig. 8.* Enlarged portion along seismic profile of line 6V957-00, showing anticline structure.

1.22 sec as well in the south part of Al Jabal Field in the Zaltan Platform (Fig. 9).

## WELL LOGS ANALYSIS

### *Well Status*

The well data information that has been used in this study was collected from 17 wells. Five wells are dry (BB1-6, CC1-6, KKKKK1-95, P3A-6, P6-6) and two are abandoned (BBBB1-6, BBBB2-6). The reasons for dry wells will be discussed later in the text.

### *Well Correlations*

Two geological structural cross-sections were constructed from the well logs for comparison with the interpreted seismic data to achieve the best geological model. These cross-sections were generated using well logs across the studied area in two different directions to elucidate the distribution of thickness and map the tops of the seal and reservoir layers by using sub sea depth measurements at -6600 ft as a datum for both cross-sections within the Hagfa Shale.

The first cross-section A-A' was based on seven wells (P1-6 to BB1-6) extending north-

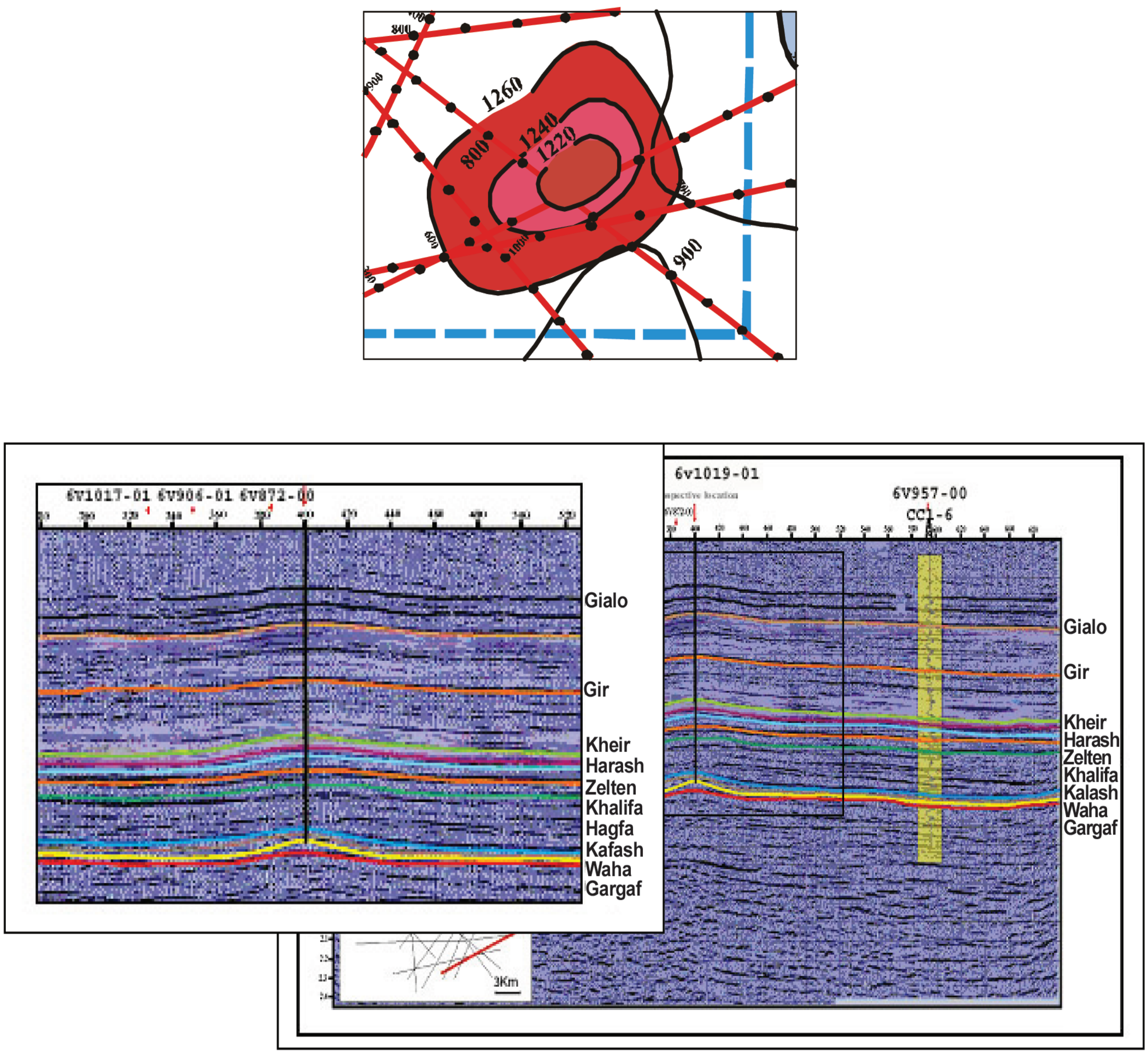


*Fig. 9.* Enlarged portion along seismic profile of line 6V1019-01, showing anticline structure.

south across the southern area of the field (Fig. 10). In this cross-section well BB1-6 is located at the southern part in the field. This well was drilled in 1964 and it was dry. The results of drilling were three oil shows in the upper section in the Gialo Limestone that tested tight and no significant shows were encountered in the Cretaceous section (Wallace, 1988).

The well BBBB2-6 located about 5 km south of Al Jabal Field was drilled in 1984. This well was abandoned because the results demonstrated tight show in Gialo Limestone and only 11 feet of wet Waha that gave up fresh water (Wallace, 1988).

The second cross-section B-B‘ was based on six wells (P7-6 to CC1-6) extending west- east across three dry wells in the southern part of the field (Fig. 11). Well CC1-6 drilled in 1964, located to the southeast side of the field. No shows in the target section of this well and the test showed salt water.

Well P3A-6, located to the north of the study area, was drilled in 1963, on a high structure, but the reservoir thickness was only 17 feet, and there were no shows in Waha Limestone. The third well in this cross-section is P6-6 located to the south east of well P3A-6. It was drilled in 1963 and it was proposed to drill on a seismic structure of the southeast the field. The well bottomed in metamorphosed igneous basement and no shows were established (Wallace, 1988).

These two cross-sections showed how the thickness of Waha reservoir varies; it attains its maximum thickness up to 357 feet in well P1-6 in the north and reduces to 11 feet in well BBBB2-6 in the southwest.

The Upper Cretaceous Waha Limestone is capped by the chalky Upper Cretaceous Kalash Limestone and generally on-lapped the eroded quartzite highs of the Cambro-Ordovician Gargaf. The thickness variations are discussed below for each formation. Although minimum well data was available for the studied area, these two sections show a fair distributed thickness to be a capable reservoir unit in this region.

**Formations' thickness Distribution**

Two isopach maps were generated from well data to calculate the thickness of the lower layers in the

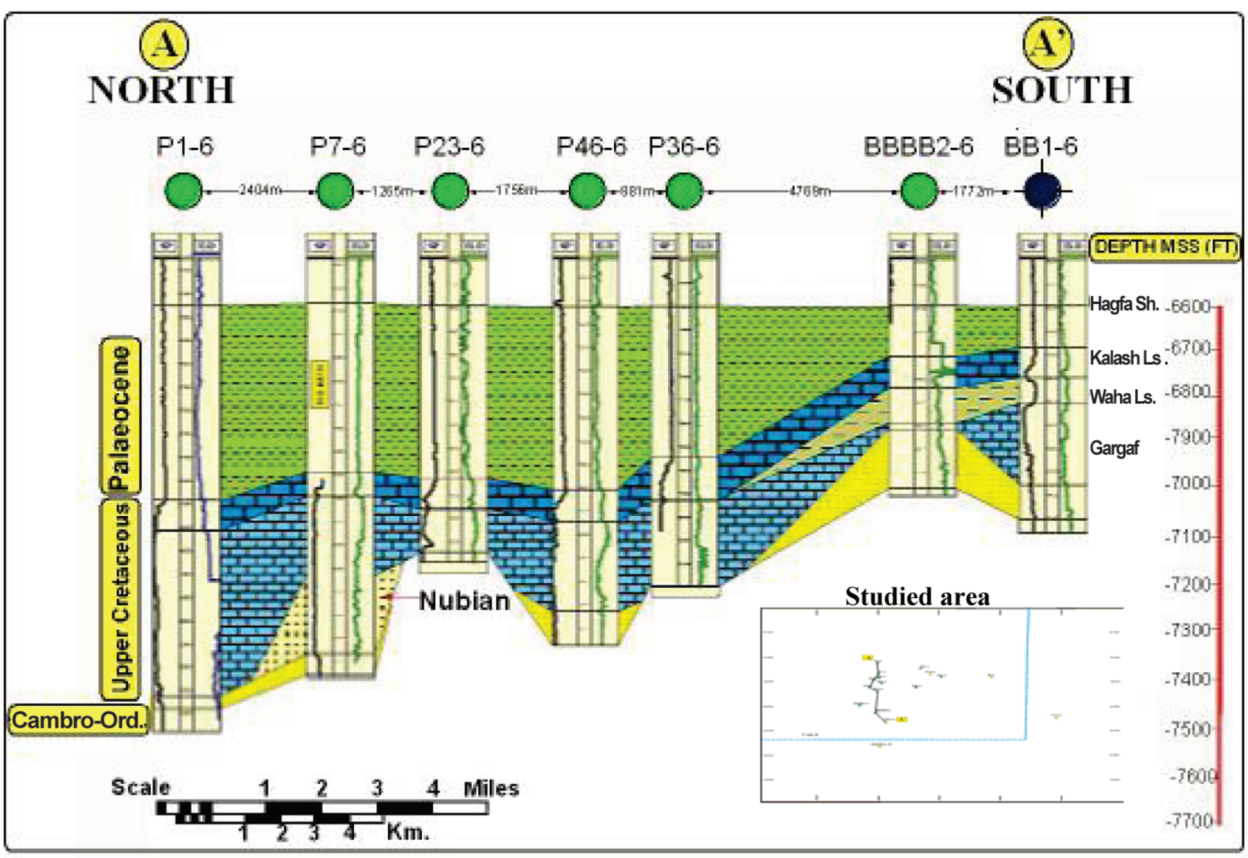


*Fig. 10.* Geological structural cross-section (A-A‘).

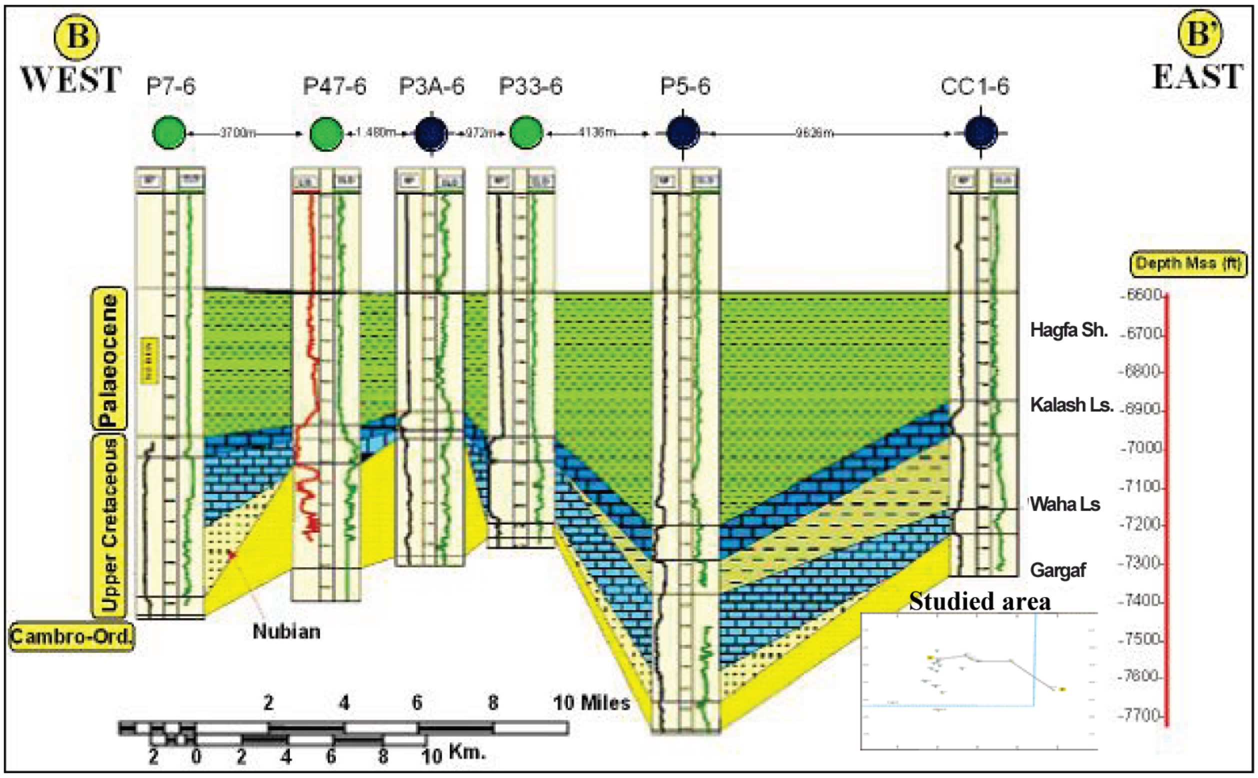


*Fig. 11.* Geological structural cross-section (B-B').

area of study (Table 1). The following analysis covers the formations' thickness consecutively:

### *Kalash Limestone*

An isopach map of the Kalash was generated, using 10 feet as a contour interval (Fig. 12). This map illustrates the seal rock thickness that is supported by Hagfa Shale in Al Jabal Field. It is evident that Kalash Limestone is widespread in this area, and reasonably sufficient to deduce that the Kalash is an excellent indicator for Waha reservoir in the area of interest. This map shows some reduction in thickness towards the north as it reaches the crest of Al Jabal structure and increases to the south.

The Kalash thickness ranges from 37 feet to the northeast in well P47-6 up to 92 feet in the southwest in well P36-6 (Table 1).

### *Waha Limestone*

An isopach map was produced to estimate the gross thickness using an interval contour of 25 feet for the Waha Limestone in the southern part of the field (Fig. 13). The Waha map clarifies several important trends:

**Table 1. Formations' thickness of the lower section in the study area.**

| Well name | Hagfa Sh (ft) | Kalash (ft) | Waha (ft) |
|---|---|---|---|
| BB1-6 | 1110 | 65 | 170 |
| 4B1-6 | 1106 | 70 | 38 |
| 4B2-6 | 1094 | 72 | 11 |
| CC1-6 | 1117 | 86 | 64 |
| 5K1-59 | 962 | 46 | 184 |
| P1-6 | 1111 | 66 | 357 |
| P3A-6 | 1034 | 44 | 17 |
| P6-6 | 1107 | 89 | 185 |
| P7-6 | 1113 | 50 | 179 |
| P20-6 | 1078 | 90 | 100 |
| P23-6 | 1005 | 60 | 91 |
| P33-6 | 1056 | 62 | 145 |
| P36-6 | 1033 | 92 | 90 |
| P45-6 | 1049 | 55 | 295 |
| P46-6 | 1051 | 70 | 192 |
| P47-6 | 1022 | 37 | 59 |
| P51-6 | 1063 | 59 | 207 |

First, stratigraphic thinning onto the structure is quite evident. This trend agrees with the regional structural and stratigraphic history of the Sirt Basin during the Upper Cretaceous. Secondly, the western flank of the field illustrates rapid thickening as one moves further away from the structure crest.

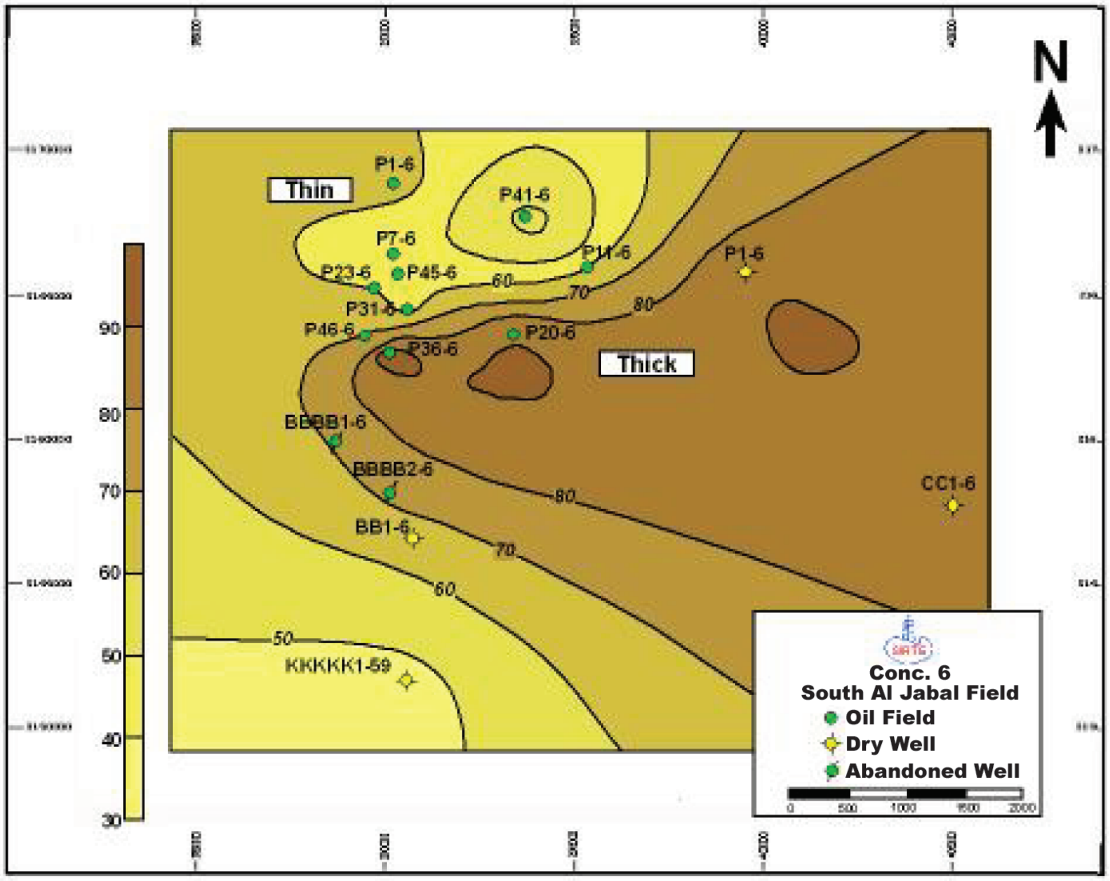


*Fig. 12.* Isopach map of Kalash, contour interval (10 feet).

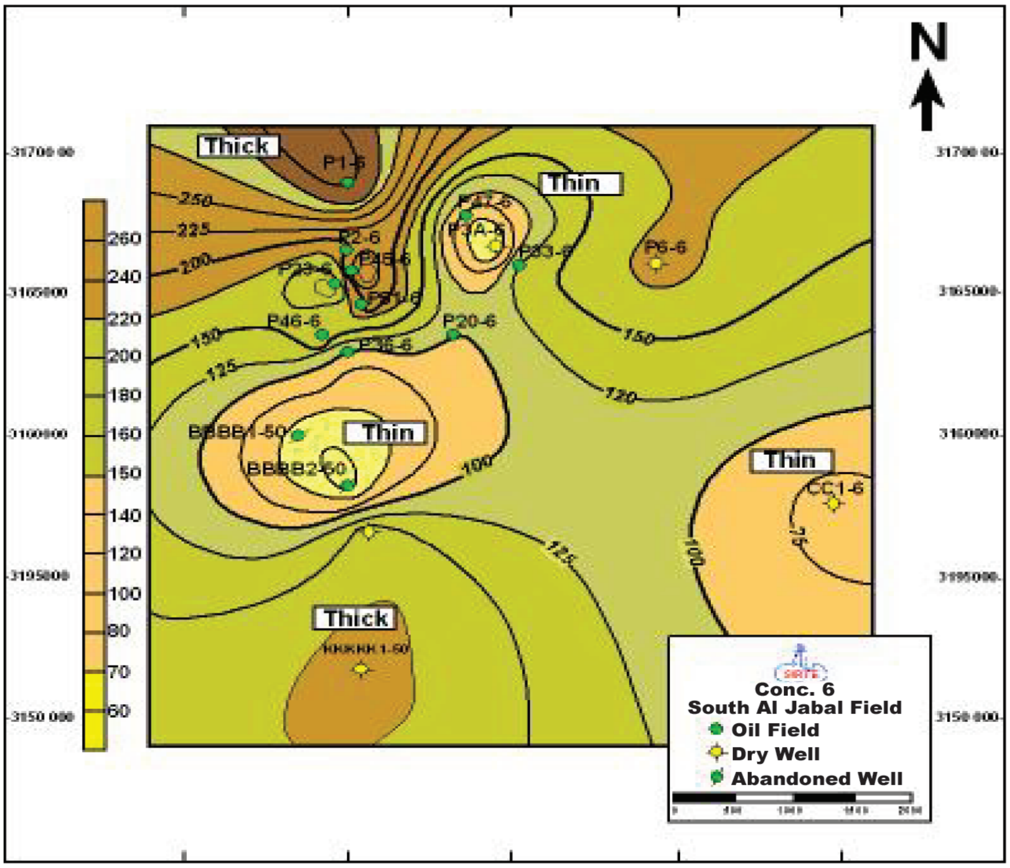


*Fig. 13.* Isopach map of Waha, contour interval (25 feet).

## SUMMARY

Most palaeotopographic structural traps were discovered in Al Jabal Field, so as a secondary recovery stage by focusing on these prospective areas, we can enhance the production in Al Jabal Field.

The results of the Top Kalash two-way time structure illustrated areas of prospectivity, which are in the southern part of the Jabal Field. The time computed for the closure of the crest is 1.22 (sec), and the low contour is 1.26 (sec). These anomalies are considered to be of relatively low risk, especially when using seismic techniques to locate new drilling targets that could develop the production in this field.

The Upper Cretaceous Waha as a reservoir target ranges from 0 on the crest of palaeohighs to over 350 feet on their flanks as it moves away from these palaeohighs, so on these flanks Waha Limestone is almost present.

## CONCLUSIONS

1. The anticlinal structure at Al Jabal, Field is in a NE-SW trending feature, with a sealing major fault on the western and northwestern flanks of the field. Two additional faults trend parallel to sub parallel with the major basement faulting at Al Jabal Field.

2. The Upper Cretaceous Waha Limestone in Al Jabal Field is the principal producing formation for Cretaceous sediment units, a saturated light oil reservoir with a gas cap and aquifer. The Waha Limestone varies in lithologic composition from calcarenite to limestone and ranges in thickness from its depositional edge to over 350 feet in the northern part of the field. It is at a depth of 7,000 feet subsea.

3. The Upper Cretaceous Kalash Limestone that is the most widespread Cretaceous sediments unit overlies the Waha Limestone reservoir. It covers all of Concession 6, both the Zaltan Platform and Al Hagfah Trough. It is a tight micritic, and it is believed to be a seal for the Upper Cretaceous reservoir rock supported by massive Hagfa Shale in the Zaltan Platform.

4. The dominant source rock is the Sirte Shale, which is composed primarily of shales and some limestone. These are source rocks for the Waha, Bahi and Gargaf reservoirs and were deposited in Al Hagfah Trough.

5. Several untested significant anomalies, for some satellite structures, have been identified in the southern portion of the field, which could suggest to company to spot the oil leg target and develop the production in this field.

6. Although low control on well data within studied area, the appearance of Waha Limestone shows fair distributed thickness to be a capable reservoir rock unit in this region.

## RECOMMENDATION

3D seismic is proposed to re-evaluate discovered leads in the studied area. This new 3D survey would present the opportunity to construct one data set, which will resolve problems related to any seismic mis-tie issues, and make changes for improved stratigraphic resolution in Kalash. This seismic technique should assist in resolving the critical reservoir thickness and build a consistent depth map for reservoir unit.

## ACKNOWLEDGEMENT

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