Petroleum Res. J. Vol. 12 (2000); P. 25–38, 12 Figs.

Estimated Generation Time and Migration Trends of Upper Cretaceous Source Rocks, Sirt Basin

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تقييم زمن تكوين وهجرة المواد الهيدروكربونية لصخور المصدر، التابعة للكريتاسي العلوي بحوض سرت الرسوبي

عبد الرحيم بن عاشور

تتناول هذه الدراسة الأوجه الجيوكيميائية وتطور الكيروجينات الموجودة في صخور المنشأ الكريتاسية العليا وتوزيعها الأفقي (حوض سرت الرسوبي). نوقش تطور الكيروجينات من الناحية الزمنية والعمق.

تشير التحاليل الجيوكيميائية أن صخور المصدر الفاعلة ونضوج الكيروجينات يقتصر وجودهما على المناطق الوسطى لمنخفضي زلة واجدابيا وكذلك المناطق الجنوبية من منخفض مرادة. ونتيجة لعدم الثقة، وبالتالي الاعتماد على درجات الحرارة المقاسة بالسرود، فقد استعمل عامل تصحيح بسيط لتعديل الأخطاء عند كل درجة حرارة مقاسة عند 13° ف، وتم إعداد خريطة توضح توزيع الحرارة الأرضية للحوض.

تم دمج درجات الحرارة المصححة وعمق الدفن بهدف التنبؤ بمستويات النضوج وزمنه بمنطقة الدراسة حيث يعتقد أن أوان النضوج الأصلي كان ما بين العصر الأيوسيني المتأخر إلى الميوسيني المتقدم والذي تم باستمرار عملية الترسيب والهبوط المصاحب بمنطقة تكوين المواد الهيدروكربونية. إن نطاق نافذة النفط قد اعتبر نطاقاً (حركياً متجاوباً) للتباين في معدلات الدفن والتعرية، ويعتقد بأن هجرة المواد الهيدروكربونية إلى التراكيب داخل المنخفض وإلى المرتفعات (المسطحات) المجاورة، كان إلى مسافات ليست بعيدة عن النشأة وأن الصدوع من أهم العوامل الموصلة بين المكامن وطبقات المنشأ.

Abstract: *Owing to a lack of confidence and reliability in measured log temperatures a simplified temperature correction was applied to compensate for the error at every measured temperature of about 13° F. Corrected temperatures and corrected burial depth were used to predict generation time for various locations and sites in Sirt Basin. Evaluation of collected data indicates that source rocks and maturation of the kerogens are restricted to central parts of Zallah, Al Kotlah, Hameimat, Ajdabiya and southern Al Hagfa troughs. Generation time is estimated to be late Eocene to early Miocene and progressed forward as subsidence and sedimentation continued. Generation and migration are closely related time-wise and faults are the main element that connected reservoirs to the source beds under consideration. Migration of hydrocarbon to the reservoirs within trough systems and to the adjacent platform is thought to be of short distance. Hydrocarbon accumulations prior to the late tilting (southeast) of the platforms of Sirt Basin reacted to the resulted structural configuration and formed the present accumulations.*

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INTRODUCTION

This study discusses the geochemical aspects and evolution of Upper Cretaceous source rocks present in the sedimentary section of Sirt Basin. It is based on geochemical data collected from the National Oil Corporation combined with geological background gained in the past century. Evolutions of Sirt Basin Upper Cretaceous source rocks are dealt with in time and depth that are directly related to temperature and duration of heat. Previous published studies, most related to this work are, those of Gumati and Kanes (1985) and El-Alami, *etal* (1989).

As is cited in the geochemical literature, maturation of kerogene in source Rocks are controlled primarily by temperature and duration of heat. Direct measurement of maturation is based on analysis of vitrinite reflectance and other kerogen and hydrocarbon constituents in samples of exploration wells that are mostly drilled on structural highs. On the other hand, presumably, more maturation of the organic constituents contained in the source rock is at lower structural levels in the basin, where drilling is not recommended by exploration geologists. Therefore, carrying out interpretation based on purely analytical data is most probably, misleading especially in Zallah-Ajdabiya troughs. Here, lack of dependence of maturation levels on depth position of source rock is encountered, which strongly suggest that elevated temperatures were maintained during the kerogen evolution.

To quantify the effect of time and temperature on the conversion of kerogen into petroleum and gas, the burial history of the basin should be established.

The proposed method by Magara (1976) for estimating maximum depth of burial for a given sedimentary section as well as a simplified method to correct bottom hole temperatures were employed to account for generation time and the dynamics of the oil windows of the Upper Cretaceous source rocks present in the sedimentary section of Sirt Basin.

GEOLOGY

A long list of investigators contributed to the description of the geology and structural evolution of Sirt Basin, including, Conant and Goudarzi (1967), Selley (1968), Barr and Weegar (1972), Van Houten (1980), Goudarzi (1980), and many others.

Two major hypotheses to the tectonic mechanism of forming the Sirt Basin were formulated. Van Houten (1980) attributed the opening of the Sirt Basin to the drift of north central Libya over a fixed mantle hot spot during early Cretaceous, whereas the second hypothesis suggests that the Sirt Basin formed in a failed spreading arm that extended southeast from the Tethyan spreading system to the north.

Following the Hercynian deformation, which ended Palaeozoic deposition, the Sirt Basin region underwent prolonged erosion before the beginning of sedimentation in the late Mesozoic. The floor of the basin is formed mainly of Precambrian rocks and the basin thus developed on the site of a deeply eroded high.

The general epierogenesis of the basin began late in the Mesozoic and continued well into the Holocene, (Selley, 1968). The subsidence kept pace with sedimentation and was locally fault controlled, with the result that considerable variation in thickness and facies exists in the contained sediments. The sediments are predominantly marine, mainly carbonates and shales, but with local thick developments of evaporates. Sandstones also occur, notably at the bottom and the top of succession. Stratigraphic variations within the individual units are largely regional in character and are controlled by position within the basin.

Sharp local variations also occur and these are most directly related to contemporaneous faulting. Most of the faults are normal faults and were active early in the development of the basin. Smaller numbers of normal faults are regional, and were generally active intermittently throughout the history of the basin and these had an important influence on the development of the basin into a series of horst and graben structural style with a NW-SE orientation, except the Al Kotlah trough that has a NE-SW alignment (Fig. 1). The oil producing structures of the basins are due to these faults and to the sedimentary drape over them. Hydrocarbons occur in commercial quantities at several stratigraphic levels within the basin.

1. In sandstones and quartzites of the pre-Upper Cretaceous units;
2. In sandstones and carbonates of the Upper Cretaceous;
3. In limestones, chalk and dolomites at various levels in the Palaeocene;
4. In sandstones of the Upper Eocene – Oligocene.

The overall distribution of oil in these reservoirs seems to be controlled by the regional facies variations within the major stratigraphic interval concerned.

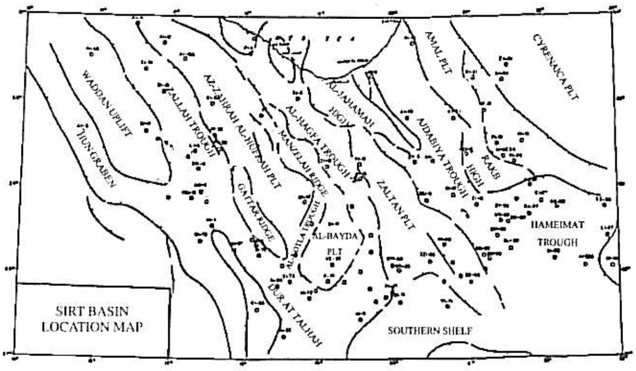


Fig. 1. Sirt Basin location map with well locations included in this study.

SOURCE ROCK

In Sirt Basin, geochemical analyses have indicated several stratigraphic units to be rich in organic content. However, maturity is restricted to sediments of middle Nubian shales and Upper Cretaceous (Rakb Group) Sirte, Rachmat and Tagrifet Limestone. Targrifet Limestone is restricted to the Ajdabiya and Hameimat troughs, which with Sirte Shale give a combined thickness of average 1,500 ft, while Rachmat Formation (shale) has a widespread distribution in the other troughs of the basin with Sirte Shale both make an average thickness of about 1,300 ft in Al Hagfa, 1.200 ft in Zallah and 800 ft in Al Kotlah areas. Total organic content ranges from 0.5% to 5% and heigher and the amorphous kerogen types derived from land plant materials were detected from the Upper Cretaceous source rock.

Delineation of the areas of Upper Cretaceous source rocks in Sirt Basin was based on S_1, S_2, P.I. and T.O.C. data classification (Fig. 2). The scarcity of data in the northern parts of Al Hagfa and Ajdabiya troughs hinders satisfactory rating of source rock potentiality in those parts of the basin, although early exploration has indicated mostly disappointing results of hydrocarbon accumulation discoveries.

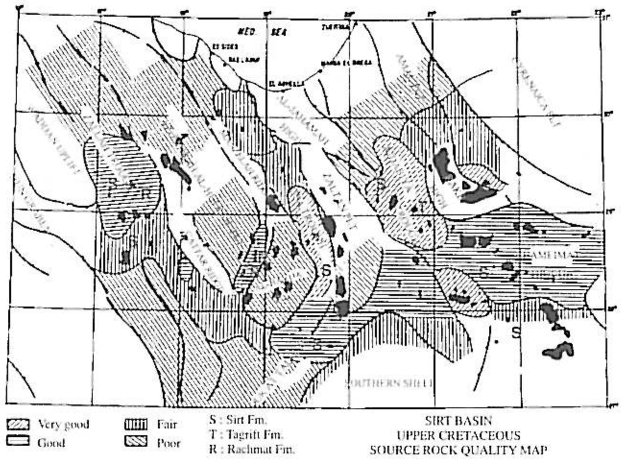


Fig. 2. Source rock quality map, Upper Cretaceous Sirt Basin.

ESTIMATED REMOVED STRATIGRAPHIC SECTIONS

Geologic evidence indicates that considerable parts of the stratigraphic section are missing from the exposed outcrops in the Sirt Basin. Lower Eocene rocks are exposed at the surface in some western parts of the basin, Oligocene outcrops in the central areas of the basin, while east central and eastern regions include Miocene and younger outcrops. The missing stratigraphic cover in the western Sirt Basin (Zallah trough) must have been comparable with those preserved in the eastern Sirt Basin. This large difference in removed stratigraphic section will have a major influence

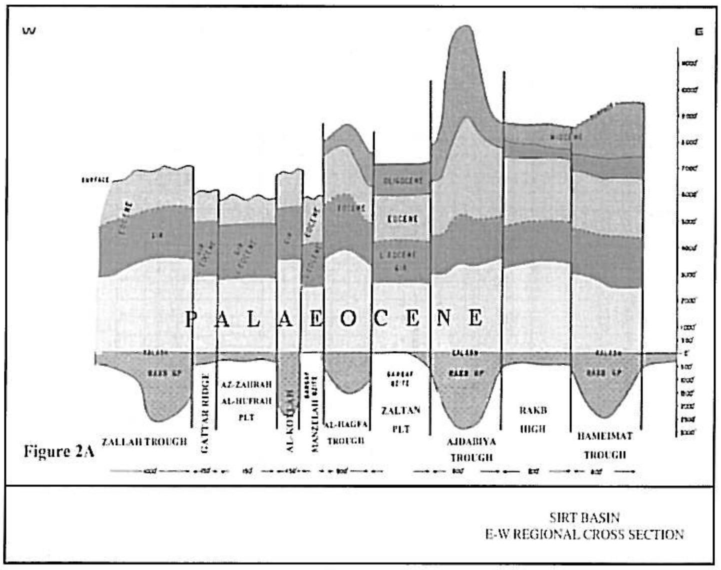
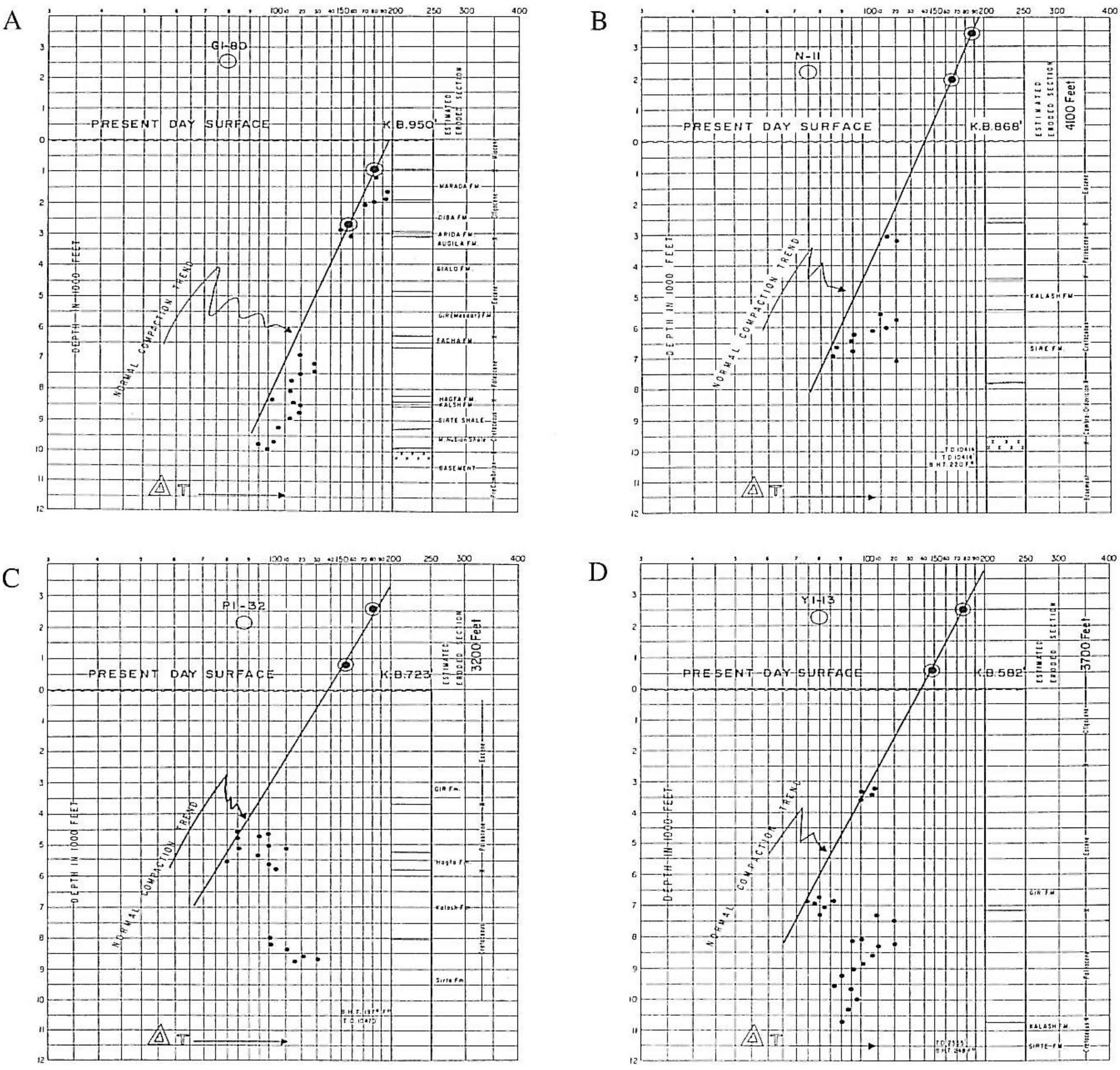


Fig. 2 (a). East–west regional cross-section.

on estimates of the maximum temperature attained by kerogen-bearing rocks mainly in the Zallah trough. (Fig. 2A)

Magara (1976) established a method for estimating the maximum depth of burial for a given sedimentary section. His method was based on the fact that porosity in shales decreases exponentially with increasing depth because porosity is linearly related to sonic transit time. Therefore the transit time through a shale section should decrease exponentially with depth of burial. If transit time (ΔT) of a shale section is plotted on a logarithmic scale against depth plotted on a linear scale, the plot should be a straight line. Since clay on the modern day sea floor has a transit time of approximately 200 m sec/ft, a straight-line extrapolation to the 200 m sec/ft point should give an estimate of the maximum depth of burial. Magara's technique was employed here to estimate the thickness of the eroded overburden and hence maximum burial depth of Upper Cretaceous source rocks of Sirt Basin.

For the calculation of eroded stratigraphic sections estimates, well G1-80, where it is believed that not much erosion of overburden has occurred, was used as a standard normal compaction trend for areas in Sirt Basin where subsequent removal of stratigraphic sections is believed to have taken place. (Fig.3, A, B, C. and D). The average



Fig, 3. A, B, C, and D normal compaction trends, G1-80, N1-11, P1-32, Y1- 13.

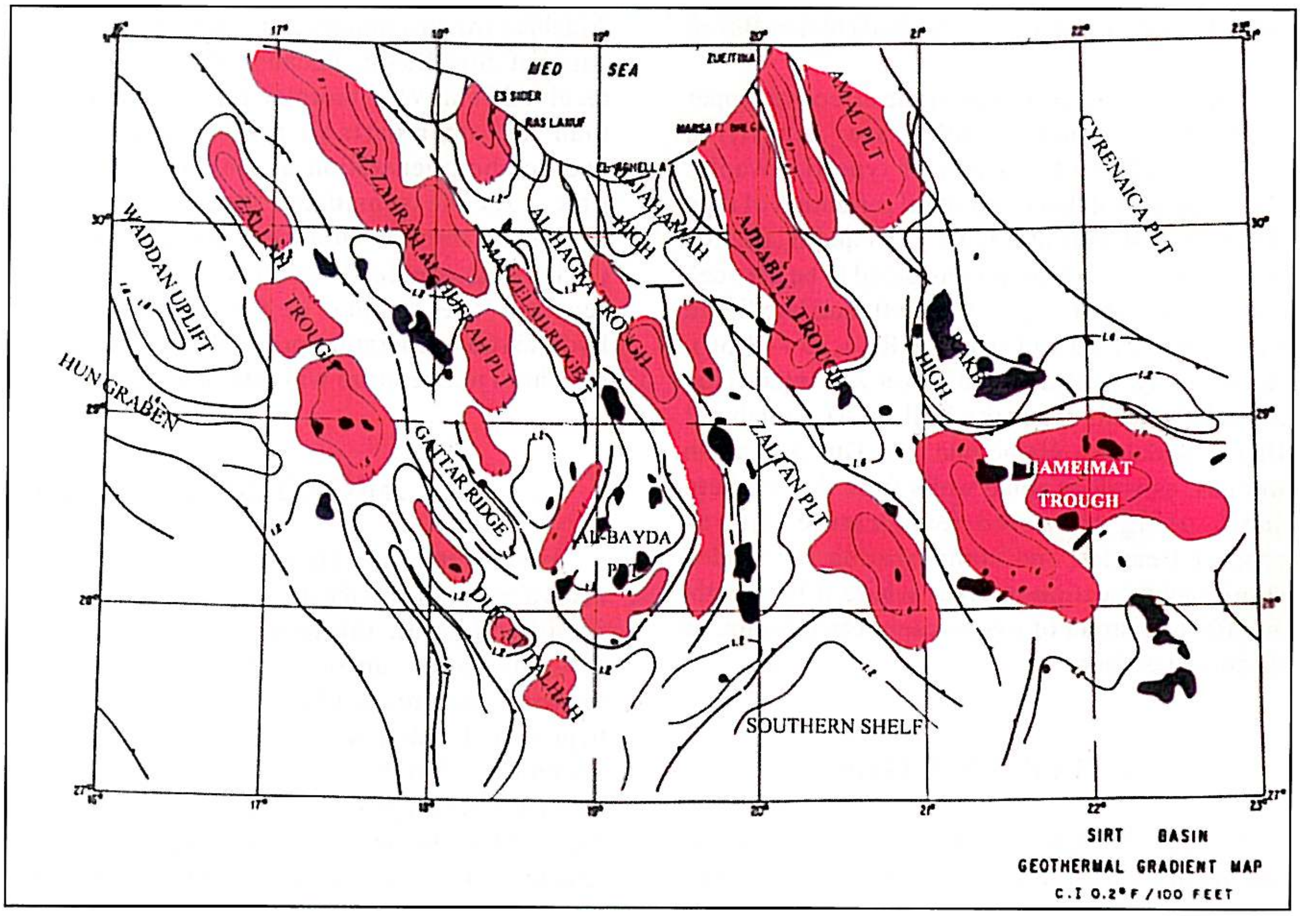
estimated missing thickness of overburden in the indicated areas that has affected the present geothermal gradient is calculated in the order of 3,200 to 4,000 ft of sediments.

TEMPERATURE AND MATURATION HISTORIES

The measured log temperatures are systematically lower than stabilised subsurface temperatures. They are inaccurate for analysis of geothermal gradients owing to insufficient knowledge of mud circulation time prior to logging, difference in borehole size, friction and compression during DST's and time needed to reach formation temperature equilibrium during shut-in periods. Scarcity of accurate measured temperatures limits the use of many proposed bottom hole temperatures correction methods and the Horner plot, in particular, requires at least two accurate temperature measurements at the same depth for any correction to be made. Since it is almost impossible to meet the requirement set for correction of measured log temperatures, it is assumed that the error in equilibrium thermal temperature estimates is unlikely to be more than 10°C and certainly greater than 1°C (Denning and Chapman, 1988). The error involved in surface temperature is in the order of 2°C to 3°C. Accordingly, the error of any one equilibrium temperature is estimated to be in the order of 7°C (13°F) which is used as correction value added to measured temperature data involved in this study.

The calculated geothermal gradients, on the basis set forth earlier (Fig. 4), are superimposed on a tectonic map compiled by Mouzughi and Taleb (1981). High geothermal gradients occur over the platform whereas lower geothermal gradients exist over the trough regions. As the geothermal gradient is the rate of increase of temperature with depth, so the high geothermal gradients are not necessarily obtained from wells of high temperature but possibly of shallow depth.

The geothermal gradient map patterns also indicate that high geothermal gradient values are



Fig, 4. Geothermal gradient map, Sirt Basin.

to the north (1.8°F/100 ft) whereas the southern region is characterized by relatively lower geothermal gradient with an average of 1.2° F/100 ft, with some local anomalies. The Palaeocene producing horizons in the central and eastern oil fields are within the range of 5,000 ft below sea level. Converting geothermal gradients to temperatures at a common depth of 5,000 ft in much of the Sirt Basin gives a figure of 150 ° F. While in the western Sirt Basin 150 ° F is reached at a shallower depth.

During the course of this study, it was recognized that the depth of burial seems to be the controlling element for maturation of kerogens in the Upper Cretaceous source rock based on the discrepancies among the maturity levels reported and stratigraphic position of source rock samples. Therefore, interpretations based on purely analytical data are most probably misleading, especially in Zallah trough. Here lack of dependence of maturation levels and depth position of source rock is encountered, which strongly suggests that elevated temperatures were maintained during the kerogen evolution present in the Upper Cretaceous source beds of Sirt Basin.

The identified kerogens of the effective Upper Cretaceous source rocks are classified geochemically to be mainly of type II. Waples (1985) proposed that onset of oil formation of type II kerogens begins at TTI (3 – 10) and R_0 (0.50 – 0.60), whereas its peak is considered to be between TTI (20) and (50), R_0 (0.70 – 0.90) and late liquid stage ends at TTI (180) and R_0(1.35 – 1.50). Accordingly, maturity evaluation was interpreted to include wells from the Zallah, Al Kotlah, Al Hagfa, Ajdabiya, Hameimat and Dur At Talhah troughs, as well as some wells from the southern shelf, using corrected temperature data as proposed earlier, and compensating for eroded stratigraphic section in areas where it is thought an effective strata of overburden was missing, as discussed earlier.

GENERATION TIME

Connan (1974) has stated that in a continuously subsiding basin the generation time at the threshold temperature is the time elapsed since source rocks reached the corresponding depth of burial, and it correlates with the age of the geologic formation, although chemical reaction of organic matter was in process at a much earlier state before the threshold temperature was reached. In Sirt Basin, where sedimentation and subsidence are believed to be uninterrupted since the deposition of the Upper Cretaceous sequences, and at least till the Miocene time. An average geothermal gradient of 1.4°F/100 ft and calculated estimated depth of 9,000 to 10,000 ft. was the required depth of burial to reach the threshold point for initial hydrocarbons generation. As sedimentation continues, obviously overburden thickness will increase and maturation levels proceed forward to reach peak and late maturation levels. A series of regional isopach maps were constructed (Figs. 5,6 and 7) to establish overburden thickness that affected the effective source rock sediments under consideration. A montage of those maps with the Upper Cretaceous source rock quality map (Fig. 8), and tracing the (10,000 feet) thickness of overburden, would result in the delineation of areas that attained the required burial depth for initial time of hydrocarbons generation (Fig. 9). Generation of hydrocarbons in the center of Ajdabiya trough commenced earlier than the other parts of Sirt Basin, because this region has received relatively more sediments, time-wise, than the other parts of the basin that led to hydrocarbon generation at the close of Eocene time. As the subsidence and sedimentation continued, through Oligocene time, other Upper Cretaceous source rocks in Sirt Basin troughs reached the proper depth of burial, and hydrocarbon generation proceeded as soon as the threshold temperature was attained.

MIGRATION

Avenues and paths are a product of rock fatigue and deformation, and the movement of hydrocarbons is either lateral, through bedding plains and permeable layers, and/or vertical, through faults and the hairy fractures resulting from rock fatigue due to pressure build-up in the walls of the hydrocarbon generating chambers, Meissner (1978). These passage ways for gas and oil generated from source rocks led to the accumulation of hydrocarbons in structural and stratigraphic reservoirs present at the time, within the troughs and the adjacent platforms in Sirt Basin.

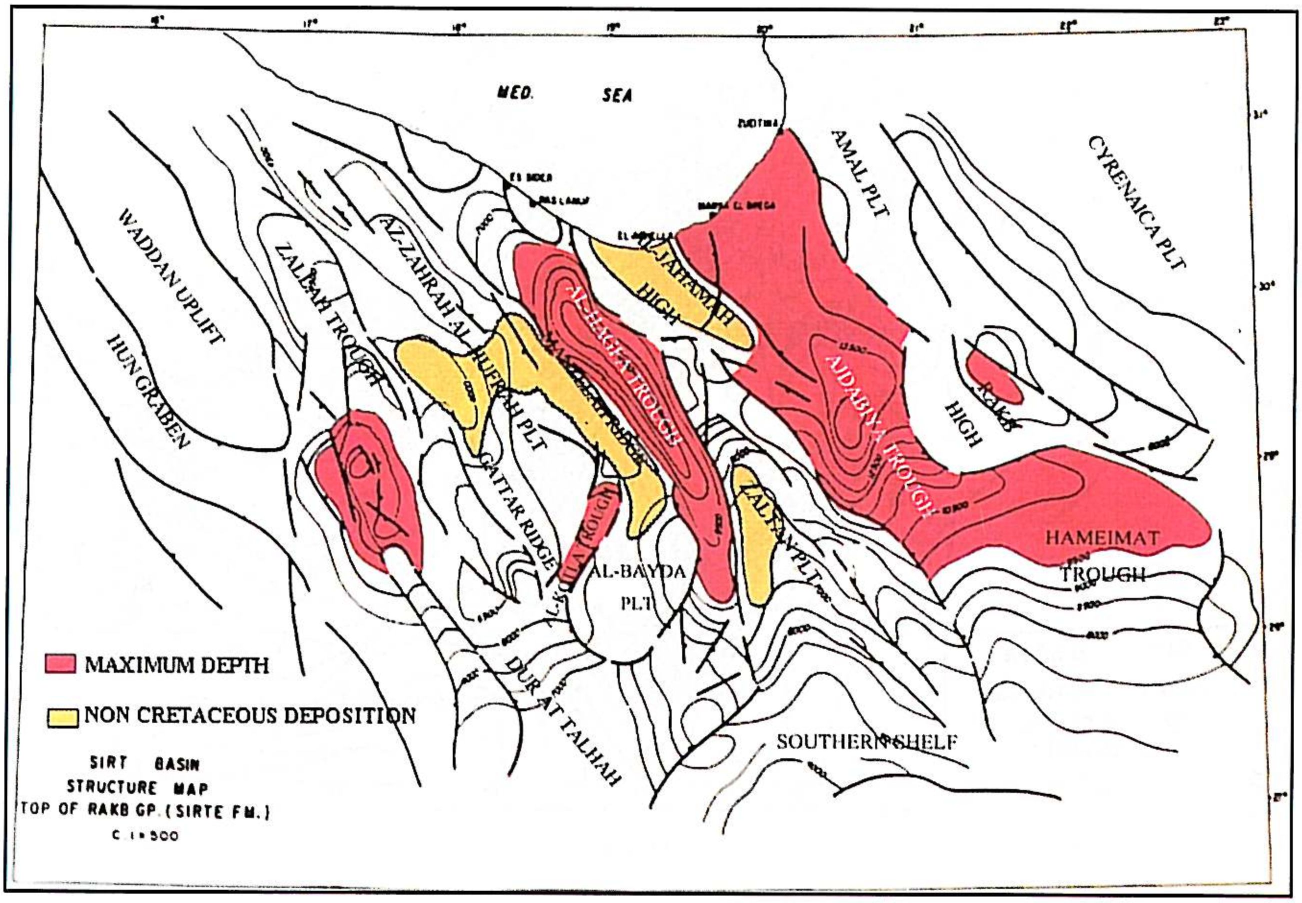


Fig. 5. Structure map top of Rakb Group (Sirte Formation).

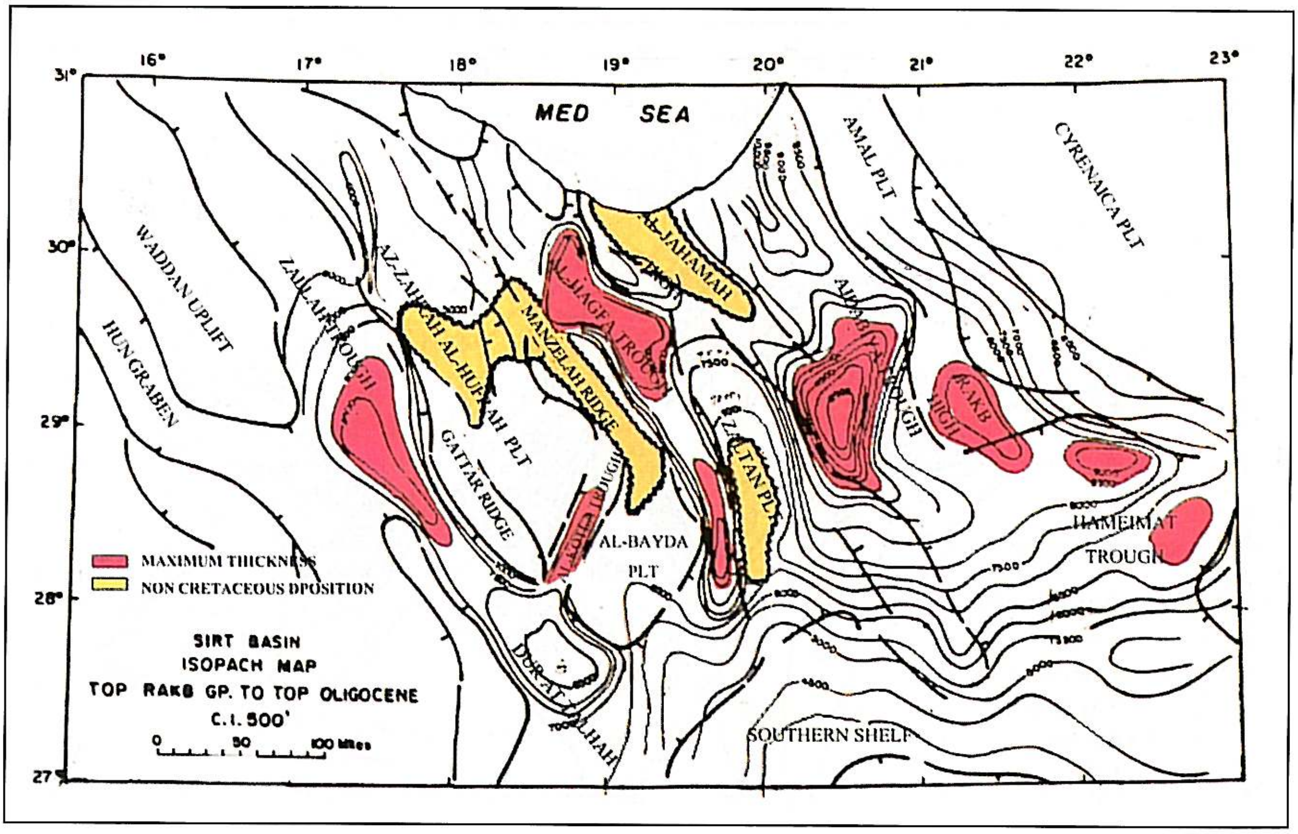


Fig. 6. Regional isopach map – top of Rakb Group – top of Eocene.

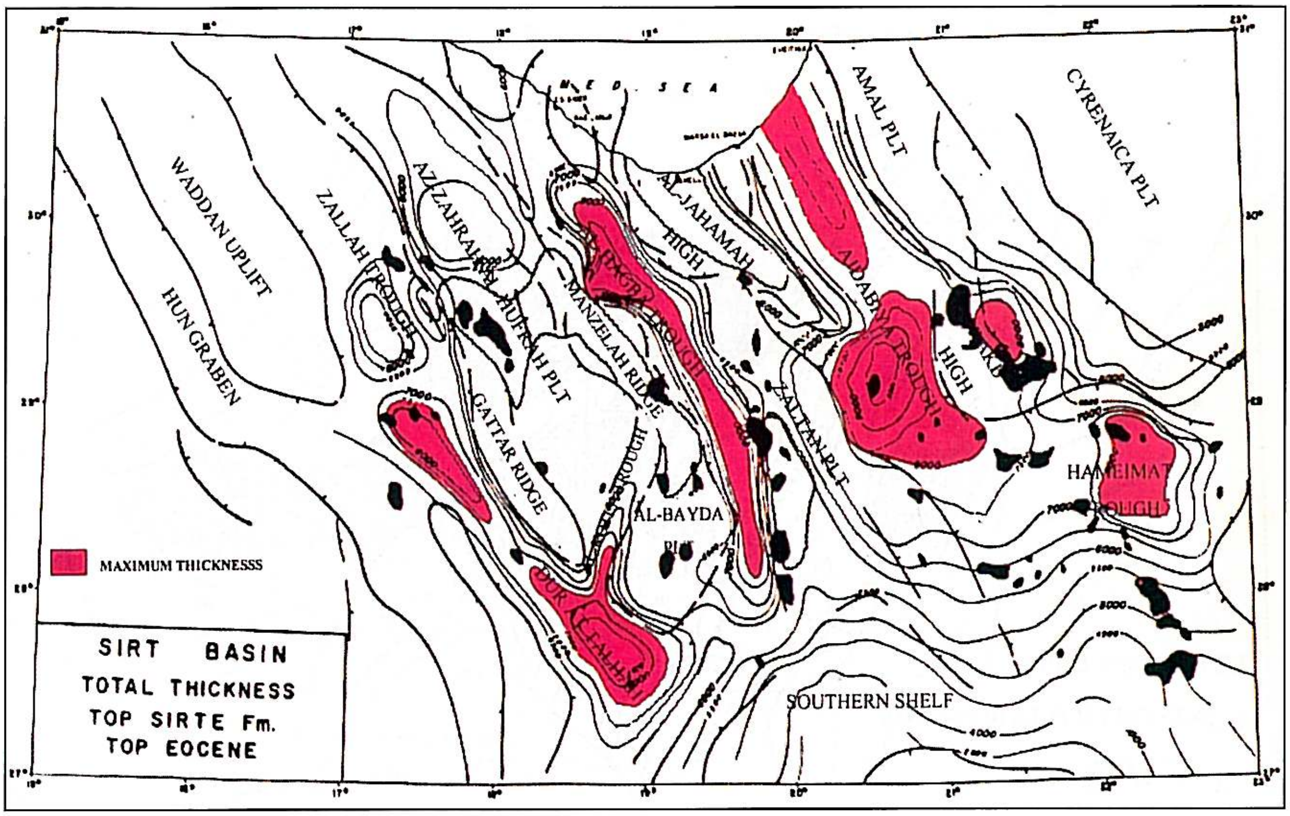


Fig. 7. Regional isopach map – top of Rakb Group – top of Oligocene.

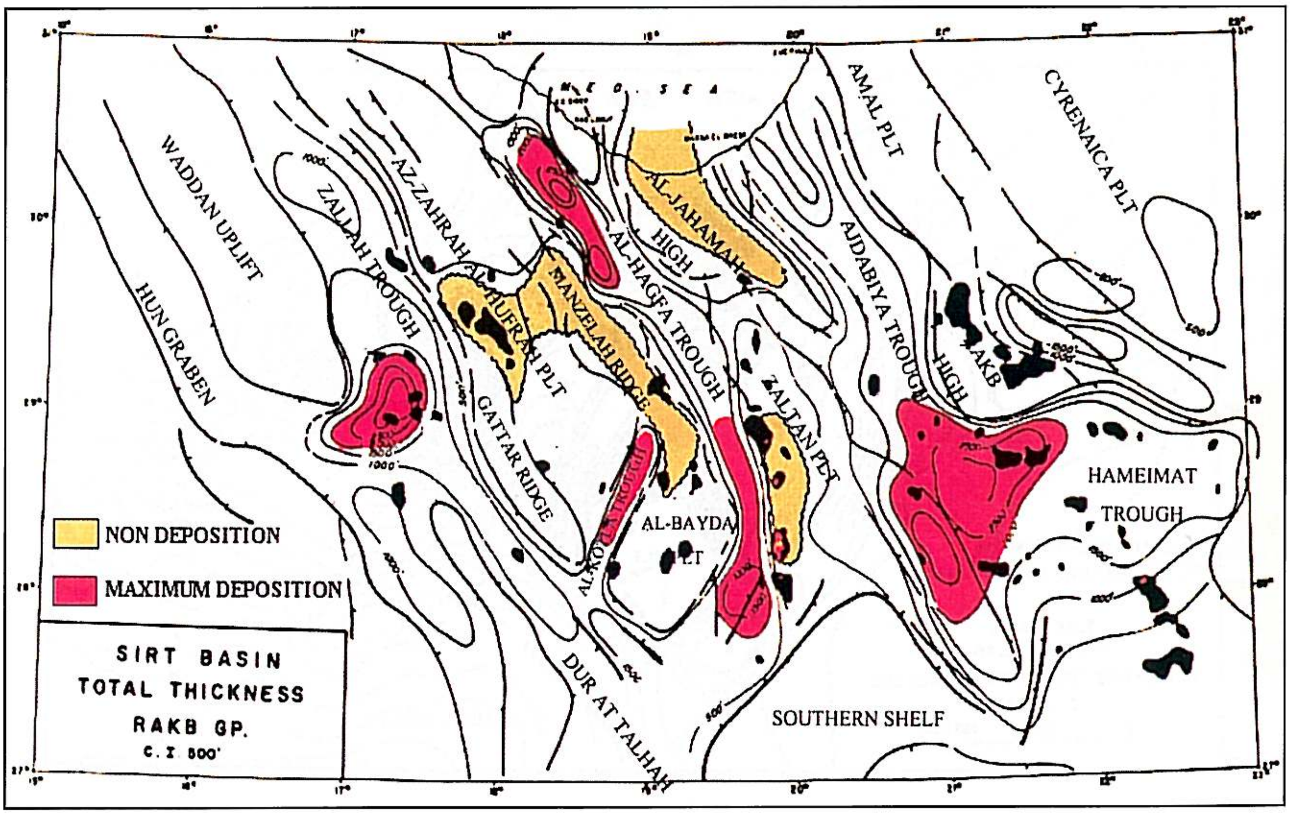


Fig. 8. Isopach map total thickness of Rakb Group.

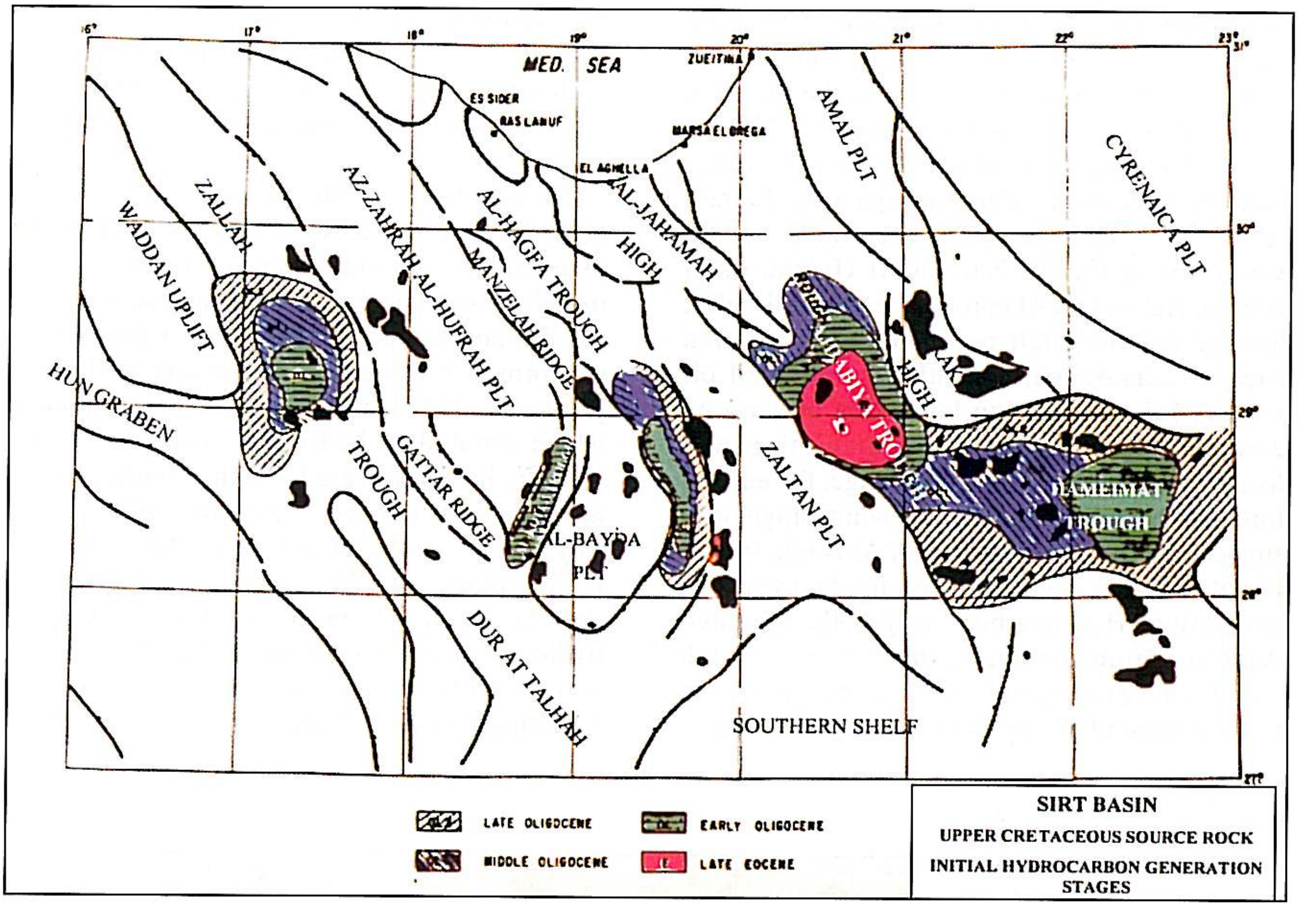


Fig. 9. Initial hydrocarbon generation stages map (Upper Cretaceous source rocks).

The migration of hydrocarbons in Sirt Basin is closely related to the progressive rate of generation, as subsidence and sedimentation progressed, since the close of the Eocene times. As it was indicated earlier, generation of oil and gas in Sirt Basin from Upper Cretaceous source rock initially started in the epi-centre of Ajdabiya trough and continued to include the surrounding potential areas. The yielded hydrocarbons moved to fill reservoirs within the trough and the adjacent Amal platform. As the generation proceeded in Ajdabiya trough, kerogens in the southern Al Hagfa trough reached the required depth of burial and threshold temperature, and the generated petroleum migrated to accumulate within the trough reservoirs and in the bordering reservoir rocks (Al Bayda, Zaltan, Az Zahrah-Al Hufrah platforms). Simultaneously, relative to other troughs of Sirt Basin, the generated petroleum in depo-centre of Zallah trough was migrating to fill the reservoirs within the trough proper and reservoir in the western Az Zahrah-Al Hufrah platforms. Also, probably hydrocarbons generated in the central Zallah trough have found their way through faults to the Waddan uplift, that were not preserved, most likely because it was eroded as a result of the intense period of erosion.

Oil fields that are located on the western flanks of Az Zahrah-Al Hufrah platforms would not have taken their source from Zallah trough, if the present day structural configuration of north-north east dipping of strata had prevailed since Eocene times. (Fig. 10). However, synthesis of the structural development of these platforms using several east-west cross-sections perpendicular to the strike (Fig. 11) indicated almost unified thickness distribution of sediments, continuous sedimentation and south-southwest dipping of strata since Eocene through Miocene times. Therefore, generated hydrocarbons in central Zallah trough have migrated eastward up dip to Az Zahrah-Al Hufrah platform during Oligocene and Miocene times, as soon as maturation levels of kerogens in this trough were reached. The migrated hydrocarbons probably reached distances further east in the Az Zahrah-Al Hufrah platform to fill the existed reservoirs. When the NE tilting of the platform occurred and as a response to the new NE dip direction, hydrocarbons, which originally migrated from central Zallah trough to Az Zahrah-Al Hufrah platform, were regrouped up dip westward in the Az Zahrah-Al Hufrah giant (Dahra, Hufra) Um Al Faroud and other oil fields, leaving behind small petroleum accumulation such as Almas, Ali, and other single-well oil fields. This explanation holds true because no commercial hydrocarbon accumulation was located so far in the Menzellah ridge, the eastern limits of the platform, (Fig. 12) which might also suggest that the northern half of Al Hagfa trough is not a highly potential area for hydrocarbon generation. Hydrocarbons originally migrated eastward from the southern Al Hagfa trough (south Z1-13) to occupy the existing reservoirs in the Zaltan platform, prior to the NE tilting of the platform reacting to the adjustment in the regional NE dip direction that prevailed to the present, forming large hydrocarbon accumulations at the western edge of the platform.

In addition to the migration condition proposed and discussed previously, a possible hydrocarbon sourcing occurred from Ajdabiya trough to areas at the far north and southeast of the Zaltan platform after the NE tilting of the platform as the regional adjustment of the area proceeded. Other large volumes of hydrocarbons, which matured in the southern half of Al Hagfa trough, have migrated south, southeast and northeastward to charge reservoirs of eastern Al Bayda and southeast corner of Az Zahrah-Al Hufrah platforms. The matured source rocks of the Al Kotlah trough are the source for hydrocarbon accumulations in the reservoirs of western Al Bayda and southeastern flanks of the Az Zahrah-Al Hufrah platforms.

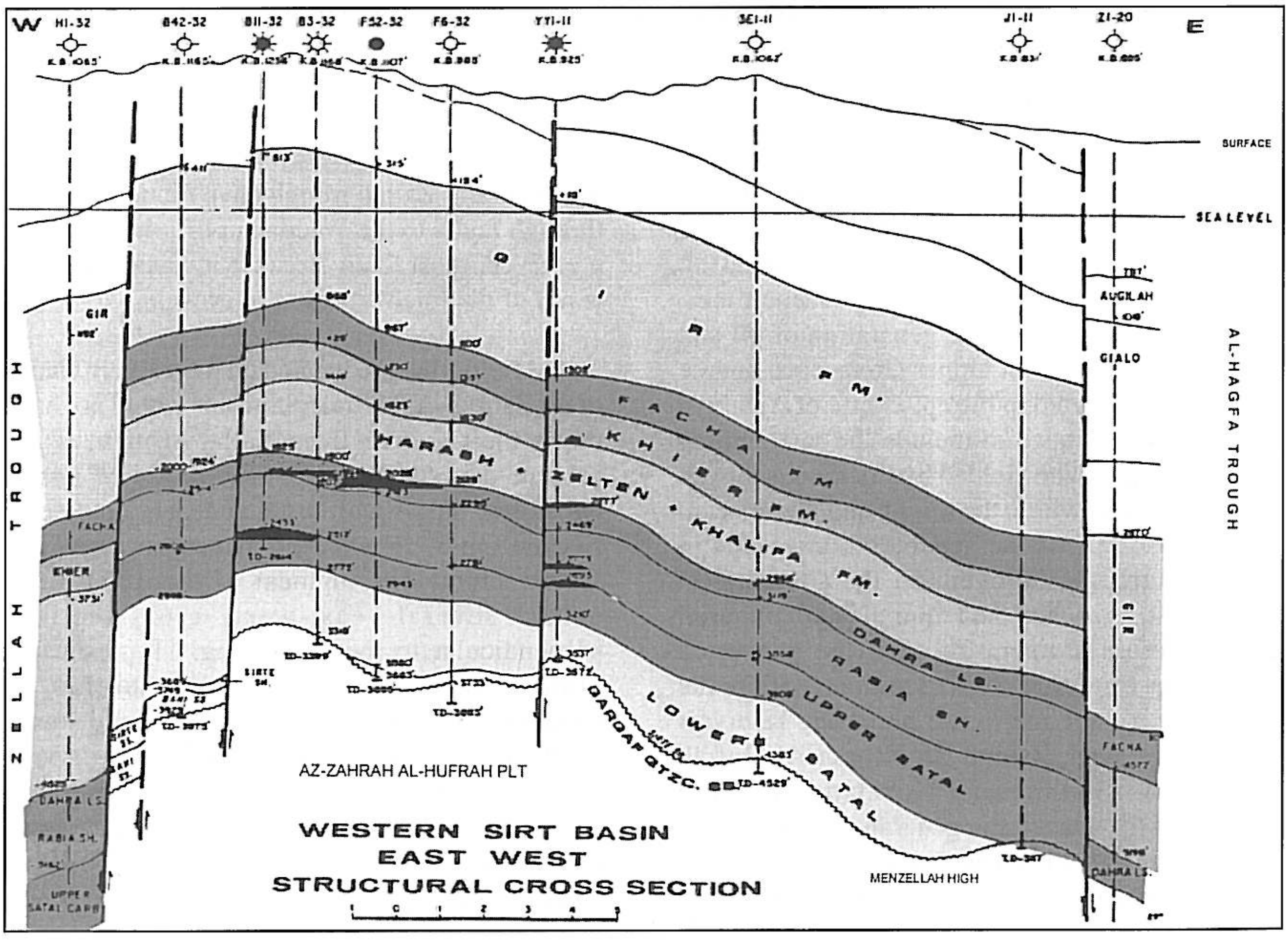


Fig. 10. Western Sirt Basin east –west structural cross – section.

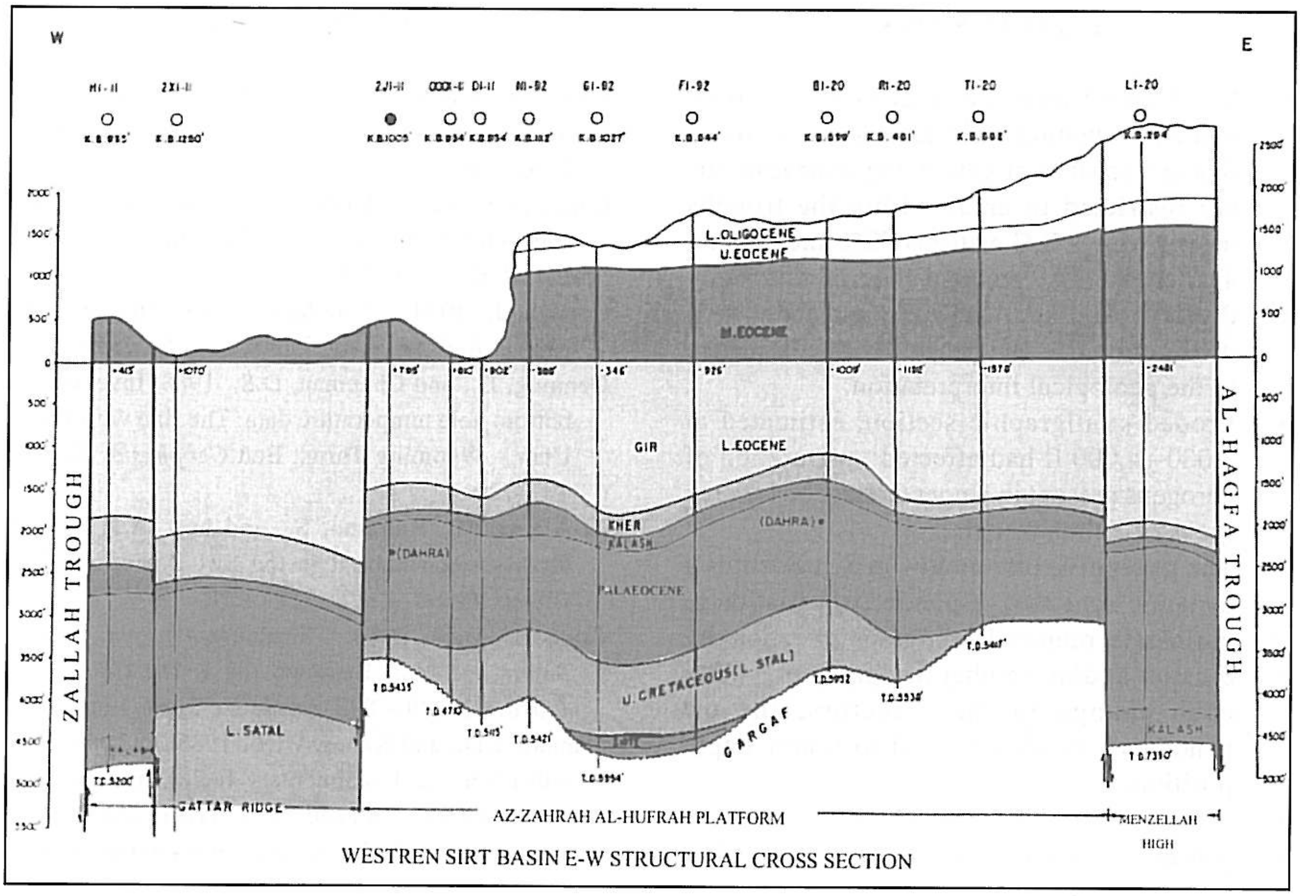


Fig. 11. Western Sirt Basin east – west structural cross section using top of Gir Formation datum line.

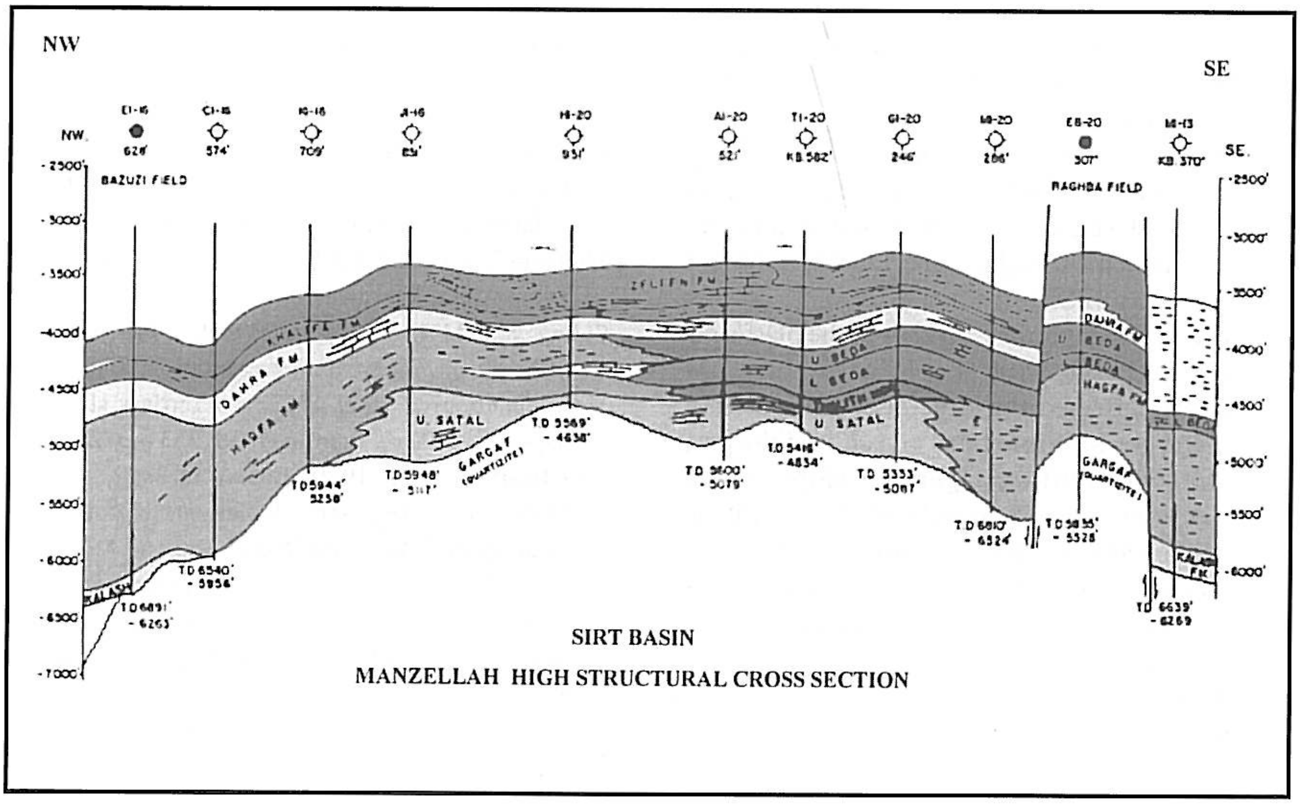


Fig. 12. Northwest –southeast structural cross-section along western Al Hagfa trough (Menzellah ridge).

CONCLUSIONS

- Sirt Basin Upper Cretaceous source rock quality evaluation indicates that source rocks that are capable of generating hydrocarbons are restricted to areas within the troughs proper with T.O.C. values of 2% and greater.
- The geothermal gradient map of this study displays first-hand information about heat distribution that can be used with confidence in the geological interpretation.
- Eroded stratigraphic section, estimated at 3,000– 4,000 ft had affected maturation of kerogens present in Upper Cretaceous source rocks of Zallah trough.
- The generative oil window in Sirt Basin is a dynamic zone that responded to variation in burial rate, removed stratigraphic sections by erosion and/or geothermal gradient. With each change in these factors, the oil generative window moved to a new depth position.
- The initial time of hydrocarbon generation in Sirt Basin Upper Cretaceous is estimated to be late Eocene-Oligocene, and continued as generation stages proceeded to cover the outer flanks of the generating sites of the troughs.
- The northern parts of Al Hagfa, trough probably did not contribute hydrocarbons to the reservoirs of Sirt Basin owing to the lack of proper source rocks in its sediments.
- Hydrocarbon migration was principally through the fault systems that connect matured source beds with the reservoirs present in the troughs proper, and the adjacent platforms of Sirt Basin.
- The regional northeast tilting of the platforms of Sirt Basin since post-Miocene time has greatly affected the structural configuration of the pre-Miocene traps and shifted the pre-Miocene southwest general slope of the platforms to the east-southeast slope, until the structural conditions of present day were reached. Simultaneously, hydrocarbons occupying the pre-Miocene traps responded to the new structural conditions and migrated up-dip westward to accumulate in the newly formed traps.

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