Estimate of upper cretaceous Source rock G1- NC 98 southeastern of sirte basin north-central part of Libya.

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الملخص

تتكون صخور المصدر الرئيسية لتجمعات النفط في الخليج الشرقي من صخور الطين الغنية بالمواد العضوية (Organic-rich shale) والموجودة في تكوينات صخورالرشمات وسرت (Rachmat and Sirt Shale formations) من العصر الكريتاسي العلوي (من الكونياك إلى الكامباني) والتي تم دفنها بما يكفي لتوليد النفط على نطاق واسع جداً. تشير التحليلات الجيوكيميائية للبئر الرئيسيG1 - NC 98 ، الذي يمثل الجزء العلوي من حوض سيرت السفلي إلى وجود قيمة عالية لمؤشر الهيدروجين مع مؤشر أكسجين منخفض مما يشير إلى إمكانات هيدروكربونية كبيرة تشير إلى وجود نفط من النوع الثاني من الكيروجين فيما يتعلق بالنضج. على النقيض من ذلك، يتميز الجزء السفلي من حوض سرت السفلي بقيم متوسطة لمؤشر الهيدروجين مع قيم عالية تشير إلى وجود غاز من النوع الثالث من الكيروجين

Abstract

The main source kitchens for the petroleum accumulations of the Eastern Embayment are composed of organic-rich shales present in the Rachmat and Sirt Shale formations of the Upper Cretaceous (Coniacian to Campanian) which have been buried sufficiently for oil generation on a very large scale. the geochemical analyses of the key Well G1 – NC 98, represents the upper part of Lower Sirt basin Succession have high value of Hydrogen Index with low Oxygen Index indicate that the significant hydrocarbon potentiality which indicates Kerogen Type II Oil prone with respect maturity. In Contrast the Lower Part of the Lower Sirt basin Succession characterized by medium values of Hydrogen Index with high (OI) values indicate Kerogen Type III Gas prone.

Introduction

The Sirt Basin is the most prolific oil province in North Africa, with original reserves comparable to those of the entire North Sea petroleum province. The oils are generally sweet, with sulphur content between 0.15% and 0.66%, and with relatively little gas. Sixteen of the twenty- one major oilfields are under-saturated Most of the oil in the Sirt Basin was derived from the Campanian Sirt Shale, a rich and thick source rock with excellent characteristics. Unlike the thinner Tanzuft hot shale of western Libya, the effective thickness of the Sirt Shale source rock in the Sirt Basin is frequently over 800 ft, and in places reaches 2,200 ft. The Sirt Shale is a dark-brown to black laminated organic shale, rich in planktonic foraminifera. This implies that the upper water layers were not anoxic, but the subsiding troughs in which the shales accumulated may have been separated from the open sea by sills which led to water stratification and anoxic conditions on the stagnant floor of the troughs. The lack of bioturbation in the Sirt Shale supports the idea that the Campanian sea floor was an unfavourable environment for burrowing organisms. In the eastern Sirt Basin the lower part of the Sirt Shale passes into a dark-brown, argillaceous micritic limestone, the Taqrifat Limestone, which also provides evidence of an oxygen-deficient, low-energy environment, but with limited areal extent. It is an interesting question to what extent the environment of deposition of the Sirt Shale mirrored that of the Tanzuft Shale or indeed the Jurassic Kimmeridge Clay of the North Sea rift system. Obviously the temperatures were very different between the post-glacial Tanzuft and the warm Cretaceous seas of Libya but the circumstances leading to anoxia may have similarities. Some have noted the similarities of the Jurassic rifts of the North Sea and the Cretaceous rifts of the Sirt Basin. Baird et al. pointed out the interesting fact that the Sirt Shale does not fall into any of the six stratigraphic intervals which account for 90% of the world’s oil, and is therefore an unusual source rock in global terms.

TOC values average between 2% and 5%, but occasionally exceed 10%. The determination of a suitable TOC cut-off for the definition of effective source rock varies between authors from 1% to 3%.

The Sirt Shale is thin or absent over the platform areas. El Alami et al. have shown that the shale in these platform areas is dominated by non-productive type IV kerogen. Kerogen type grades from type III around the trough margins, to type II in the centre of the troughs. Type I kerogen has not been found in the Sirt Shale.

Source Rock and Source Kitchens

The main source kitchens for the petroleum accumulations of the Eastern Embayment are composed of organic-rich shales present in the Rachmat and Sirt Shale formations of the Upper Cretaceous (Coniacian to Campanian) which have been buried sufficiently for oil generation on a very large scale both in the Hameimat and Ajdabiya troughs. The Rachmat and Sirt shales are excellent source rocks and they are very well developed in the Hameimat Trough where the succession includes over 300 ft of source rock with greater than 2% TOC. Kerogen within these shales is type II and maturity in the deepest part of the trough ranges from early to mid-mature for the Sirt Shale, to peak to late-mature for the Rachmat Formation. The Sirt-Rachmat sequence has been largely oil generative in the Hameimat Basin, the relatively few gas accumulations being attributed to older and deeper sources. TOC for these Upper Cretaceous shales ranges from 2% to 6% with an average of 3.5%.

Description and Geology of NC98 Field-W aha-Sirte Basin

NC98 is one of Waha Oil Company fields that are located in the southeastern section of sirte basin that is found in the north-central part of Libya. Sirte basin is the newest developed basin in Libya with the largest petroleum reserve. The producible quantity of the hydrocarbon in this basin is estimated at 45 billion bbl of oil and 33 trillion ft3 of gas. Geologically, the source rocks of the Sirte basin are Upper Cretaceous Rachmat and Sirte shale. The lithology of Gialo - NC98 field is clearly shown in (Fig.1).

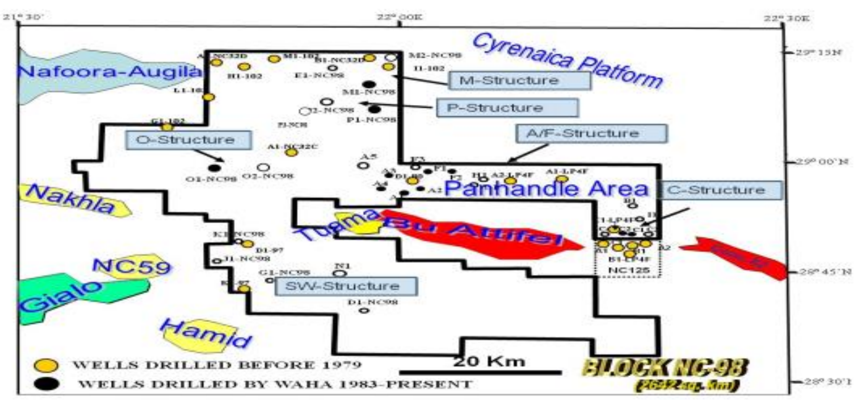


Fig. 1. NC98 Field-Waha-Sirte Basin

1.1 Study area

Block NC98 is located in the Mar Trough between the Cyrenaica Platform and the Gialo-Sarir High in the southeastern part of the Sirte Basin between latitudes 28° 30' to 29° 15'N and longitudes 21° 25' to 22° 25'E . WOC has ranked Block NC98 as having the highest exploration potential for hydrocarbon resources.

1.2 Objectives

This work attempts to apply petroleum geochemistry on source rocks of the Upper cretaceous and Sirt Shale Formation in the NC 98 Concession, Sirt Basin, Libya to:

1. Characterize the organic matter using organic geochemical data.
2. Assess and investigate the hydrocarbon generation potential of the studied source rocks.
3. Identify the sedimentary environment in which organic matter was produced and preserved.

1.3 Material and methodology

Eight samples were registered from exploratory well from different depth intervals within the Sirt Shale Formation in the G1 – NC98 Central Libya. In order to evaluate the geochemical results of the Rock-Eval 6 pyrolysis of this formation. In order to assess the hydrocarbon potential and organic geochemical signature of this formation.

Methods adopted here in are discussed as follow:

1.3.1 Pyrolysis analysis

Pyrolysis is the decomposition of organic matter by heating in the absence of oxygen to yield organic compounds (Peters, 1986). Organic geochemists use pyrolysis to measure richness, quality and maturity of potential source rocks. The most widely used pyrolysis technique is the Rock-Eval.

1.3.2. Rock-Eval pyrolysis

The purpose of Rock-Eval pyrolysis (Fig. 2) is to quickly obtain information on hydrocarbon generation potential, presence or absence of non-indigenous hydrocarbons, organic matter type and thermal maturity of a rock.

Rock-Eval pyrolysis was performed on 70 mg pulverized whole rock samples using a Rock-Eval 6 apparatus. In order to determine these parameters: TOC= Total organic carbon, wt % / Tmax = Temperature at maximum / HI: Hydrogen index / OI= Oxygen index, PI= Production index. (Table I). With S1, S2, S3, PP, that we not used in this study.

Fig. 2. Illustrative picture showing the Rock-Eval 6 apparatus

All these parameters are explaining and interpreting in Table I.

1. **Total Organic Carbon Content, TOC% Weight of rock**

Very Poor	Poor	Fair	Rich	Very Rich
0.01-0.20	0.21-0.5	0.51-1.0	1.01-3.00	Over 3

2. **Petroleum Potential (PP), S1+S2, mg/g of rock**

Very Poor	Poor	Fair	Rich	Very Rich
0.01-0.5	0.51-2.0	2.01-5.0	5.01-20.0	Over 20.0

3. Hydrogen Index (HI), S2/TOC*100

Very Low	Low	Medium	High	Very High
0-50	50-100	101-300	301-600	Over 600

4. Oxygen Index (OI), S3/TOC*100

Very Low	Low	Medium	High	Very High

0-50	50-100	101-200	201-400	Over 400

5. S1, mg/g

Poor	Fair	Good	Very Good
0 - 0.5	0.5 – 1.0	1.0- 2.0	Over 2.0

6. S2, mg/g

Poor	Fair	Good	Very Good
0 – 2.5	2.5-5.0	5.0 – 10	Over 10.0

7. Hydrocarbon Generative Potential in Terms of HI:

Type	Gas	Gas and Oil	Oil
HI	0 - 150	150 – 300	Over 300

Thermal Maturation Levels:

Parameter	Immature	Mature	Over-mature
Tmax, deg. C	Below 430	430-470	Over 470
PI=S1/S1+S2.	Below 0.1	0.1 – 0.4	Over 0.4

(Ref: After Beicip, 1991; K.E Peters, 1986).

2. Geologic setting

Libya is located on the Mediterranean coast of North Africa, and has an area of about 1,775,500 square kilometers. It extends about 1,525 kilometers east and west and as much as 1,450 kilometers north and south, except for the northernmost parts, where the country lies entirely within the Sahara.

Libya is divided into three Palaeozoic, and two Mesozoic-Cenozoic basins (Gumati et al., 1996). These basins in order of importance are as follows: the Sirte Basin (Mesozoic-Cenozoic), the Ghadames and Murzuq basins (Palaeozoic), Tripolitana Basin (Mesozoic-Cenozoic), and the unexplored Kufra Basin (Palaeozoic) (Fig.3).

The Murzuq and Kufra basins cover large areas in the south-west and southeast of Libya extending across the border into adjacent countries. The Ghadames Basin covers the NW part of Libya, whereas the Sirte Basin is located in the north central part of Libya and the Tripolitana Basin is situated in the northwest, offshore Libya.

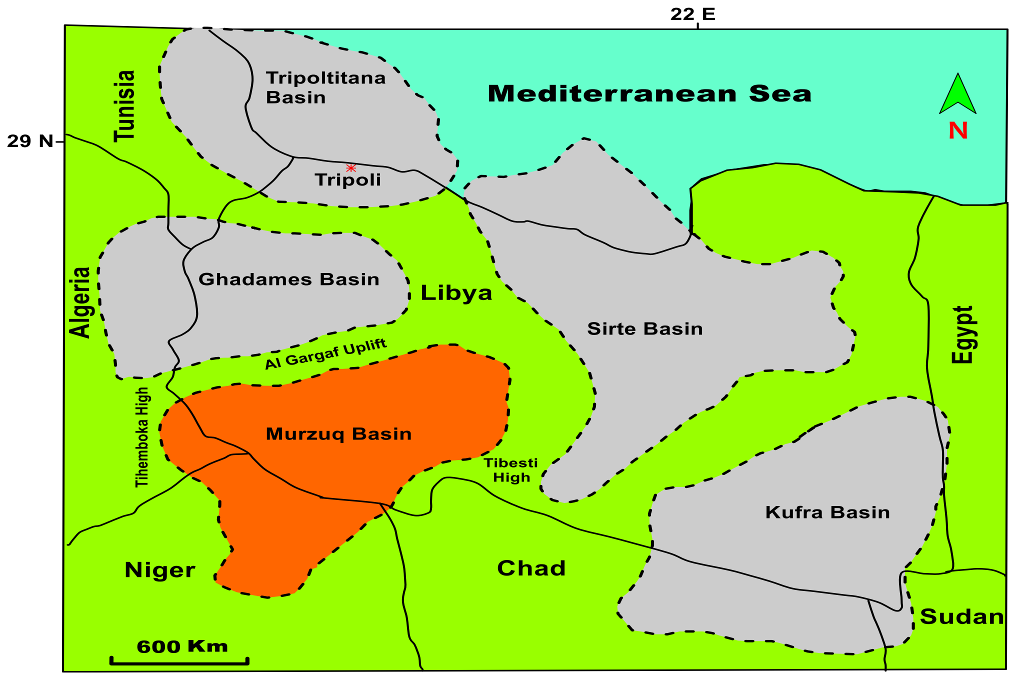


Figure 3. The geological basins of Libya (Gumati et al., 1996)

2.1 Sirt Basin

2.1.1 Stratigraphic succession of the Sirt Basin

Maragh Formation

In the eastern Sirt Basin the equivalent of the Bahi Formation has been named the Maragh Formation with a type section on the Amal field. The formation comprises a basal conglomerate with quartzitic and volcanic pebbles in a clay matrix containing glauconite. The conglomerate is overlain by a poorly-sorted, friable sandstone containing glauconite, hematite, and dolomite. The thickness in the type well is 140 ft. the presence of several age-diagnostic palynomorphs which give a Cenomanian to early Turonian age.

Etel Formation

To the south and east, the time equivalent of the Argub Formation is a sequence of thin-bedded dolomites, anhydrites, shales and siltstones named the Etel Formation. It is notable for containing thick evaporites in several of the trough areas. The dolomites are often brown, very finely crystalline or with a sucrosic texture. The type section was defined in the O2-59 well, on the south-east margin of Al Bayda Platform. Here the formation has a thickness of 530 ft. It has a sharp contact with the underlying Lidam Formation, and in other areas it rests unconformably on the Bahi Formation or on pre-Upper Cretaceous rocks. The contact with the overlying Rachmat Formation is disconformable. It has a widespread distribution in the south-central Sirt Basin, but is absent over the Zahrah-Hufrah, Zaltan and Amal platforms. The formation is assigned a Turonian age on the basis of stratigraphic position.

Rakhmat Formation

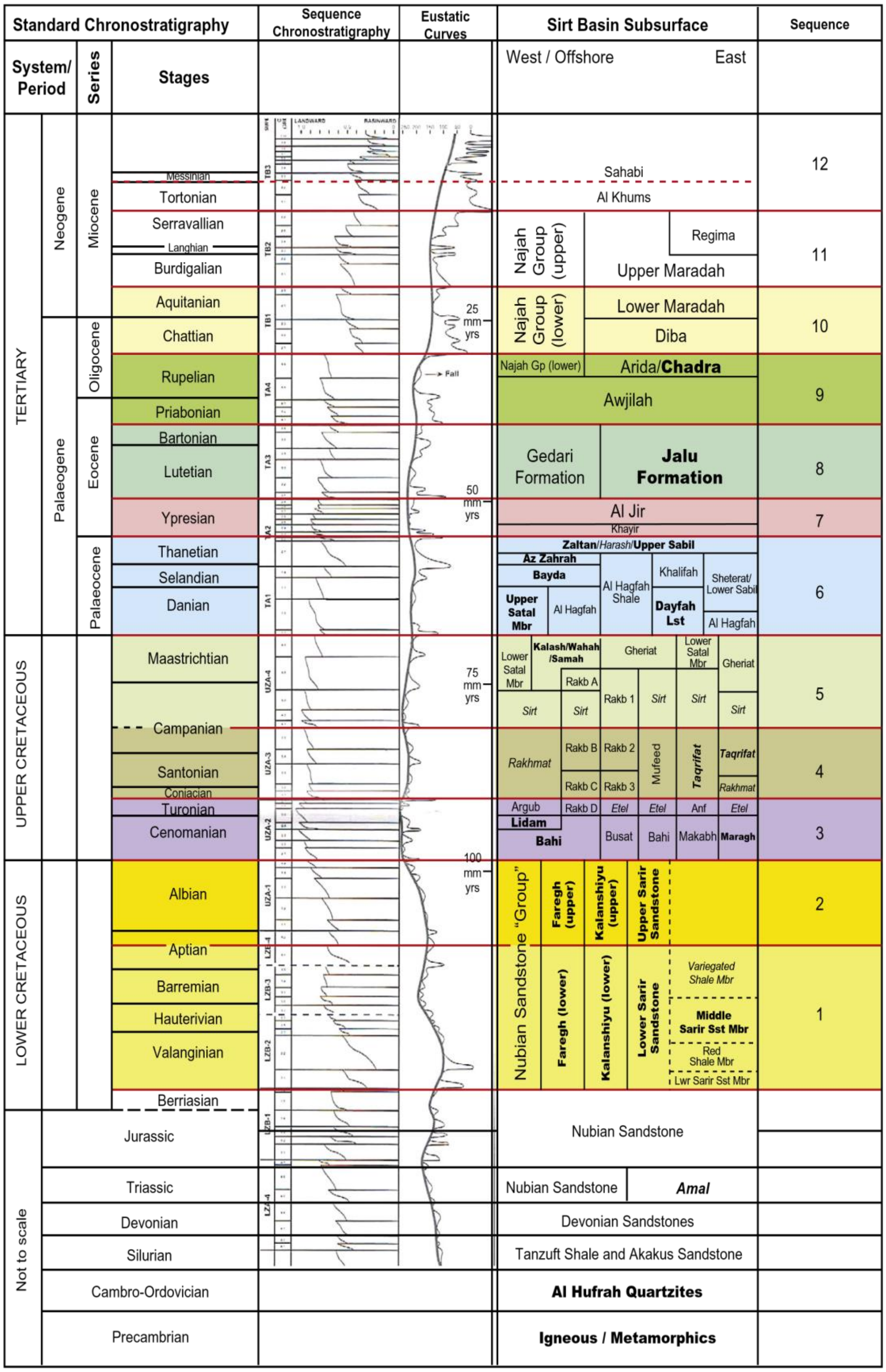
It is evident that the marine invasion of the Sirt Basin was a slow process spread over as much as 10 Ma, as illustrated by the Facies of the Cenomanian and Turonian sediments. This suggests that the Sirt Basin troughs were rather shallow during this period. This process continued into Coniacian times when the Rachmat Formation was deposited. The formation is based on a type section in the O2-59 well on Al Bayda Platform where 460 ft of dark grey shales with interbeds of dolomite and limestone is present. The shales are fissile, and usually slightly calcareous, and contain glauconite and pyrite. The dolomites and limestones are dense, finely crystalline and occasionally anhydritic. The formation is transgressive over the Etel Formation and older Cretaceous formations, or rests directly on quartzites, and a maximum flooding surface occurs within the formation.

Rakb Carbonate &Taqrifat Formation

In the eastern Sirt Basin a distinctive limestone horizon is present between the Rachmat and Sirt formations initially called the **Rakb Carbonate** but later defined as the **Taqrifat Formation** with a type section in the N1-59 well on the Amal Platform. In the type well the formation comprises 300 ft of porous calcarenite, with interbeds of calcareous shale. The limestones contain rudistids, Inoceramus and other pelecypods, gastropods, bryozoa, algae, ostracods and foraminifera, indicative of very shallow-water deposition. The age of the formation is late Santonian to early Campanian. The Taqrifat Formation is restricted to the eastern Sirt Basin, and has been mapped between the Awjilah and Harash fields where the maximum recorded thickness is 1,100 ft. The formation is a significant oil reservoir on the Awjilah and Nafurah fields and in the Latif area. The upper part of the Taqrifat Formation comprises dark-brown argillaceous micritic limestone containing planktonic foraminifera and passes laterally into Sirt Formation shales. It has source potential in the Intisar-Shatirah area, and geochemical evidence shows a match between the Taqrifat shale and the Intisar oil. The lithology and diagenesis of the formation are indicative of a temporary shallowing of the Upper Cretaceous seas in this area, with the upper part indicating a return to low-energy, open-marine conditions.

Sirt Formation

In the subsurface of the Sirt Basin the Rachmat Formation is overlain by a thick shale formation which is now named the **Sirt Formation.** The type section was defined in the O2-59 well on the edge of Al Bayda Platform. In this well it is composed of 570 ft of dark brown, waxy shales. The shales are subfissile to splintery and contain an abundant fauna of planktonic foraminifera which indicate a Campanian to early Maastrichtian age. The shales are carbonaceous and calcareous and contain thin stringers of shaly limestone. They form the principal oil source rock of the Sirt Basin and have generated huge volumes of both oil and gas. The shales contain zones with very high radioactive values, clearly visible on wireline logs, which coincide with zones of maximum organic richness. Geochemical fingerprinting shows the Sirt Formation to be the principal source rock at Messlah, Sarir, Awjilah-Nafurah and many other fields further west. The shales reach thicknesses of 2,500 ft in the Zallah Trough, 1,000 ft in the Maradah Trough and 2,000 ft in the Ajdabiya Trough. At As Sarir field about 250 ft of anoxic, marginal-marine shales containing abundant Campanian marine palynomorphs represent the Sirt Formation. Figure 4. Hallet, D., 2016.



Bold lettering indicates petroleum reservoir; italic script indicates source rock.

Source: Modified from Haq et al. (1988); Starkie et al. (2008)

Fig.4. Sirt Basin Simplified Time Stratigraphic Summary Chart.

Table II . Showing the Geochemical results of the study well (G1 – NC 98) by using the Rock-Eval 6 pyrolysis.

No.	Well	Stratigraphic Age	Depth (ft)	Tmax C⁰	PI mgHC/g rock	TOC %Wt	HI mgHC/ g TOC	OI mgo2/g TOC
1.	G1 – NC 98	L- Sirt SH	11470	439	0.03	3.06	372	21
2.		L- Sirt SH	11530	438	0.19	0.62	118	105
3.		L- Sirt SH	11560	437	0.22	0.52	154	100
4.		L- Sirt SH	11980	438	0.22	0.37	155	101
5.		L- Sirt SH	12070	439	0.24	0.54	194	150
6.		L- Sirt SH	12240	440	0.22	0.55	194	151
7.		L- Sirt SH	12540	439	0.24	0.54	192	144
8.		L- Sirt SH	12590	441	0.24	0.54	194	150

TOC= Total organic carbon, wt % / **T_{max}** = Temperature at maximum / **HI**: Hydrogen index / **OI**= Oxygen index , **PI**= Production index.

Kerogen Type

Based on the geochemical analyses of the key Well G1 – NC 98, Table (1).the Hydrogen Index(HI)Values range between 118 - 372 (mgHC/gTOC), within the interval from 11470 ft to 12590 ft, indicate that the significant hydrocarbon potentiality occur within the Upper Part of the Lower Sirt basin Succession (L- Sirt SH) with a high HI value 372 (mgHC/gTOC), and low OI value 21(mg co_2 /g Toc) characterized by good values of Hydrogen Index indicate Kerogen Type II Oil prone with respect maturity. In Contrast the Lower Part of the Sirt basin Succession (L- Sirt SH) have (HI) value range between 118 to 194(mgHC/gTOC), with high (OI) values range between 100 -151(mg co_2 /g Toc) were plotted the Lower Part of the Sirt basin Succession (L- Sirt SH) in modified van krevlen diagram (Fig No. 5) in oxidizing area Type III Kerogen. However the Lower Part of the Lower Silurian Succession characterized by medium values of Hydrogen Index indicate Kerogen Type III Gas prone (Fig No.6) (Peters, 1986).

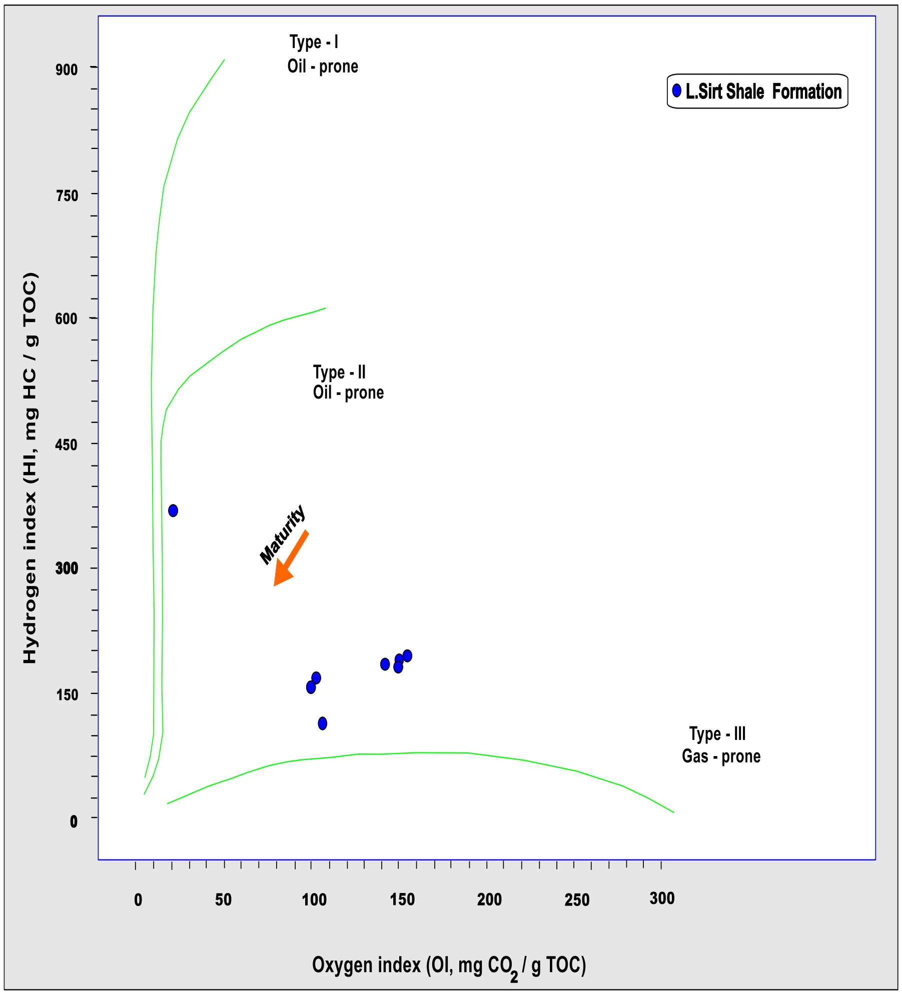


Fig .5. Showing: Hydrogen Index vs. Oxygen Index.

Preservation and Depositional Environment

The Upper Part of the Lower Sirt shale Succession characterized by hydrogen index HI values over than 372 mgHC/g TOC (Fig .6) and Low oxygen index OI values 21 with high TOC (3.06 Wt%) very rich (Fig.7) The depletion of oxygen with rich of hydrogen indicate that the reducing environment was predominated referring to Anoxic environment. This environment is considered as the best condition of organic matter preservation with hydrogen content. Represent to Oil Window Stage.

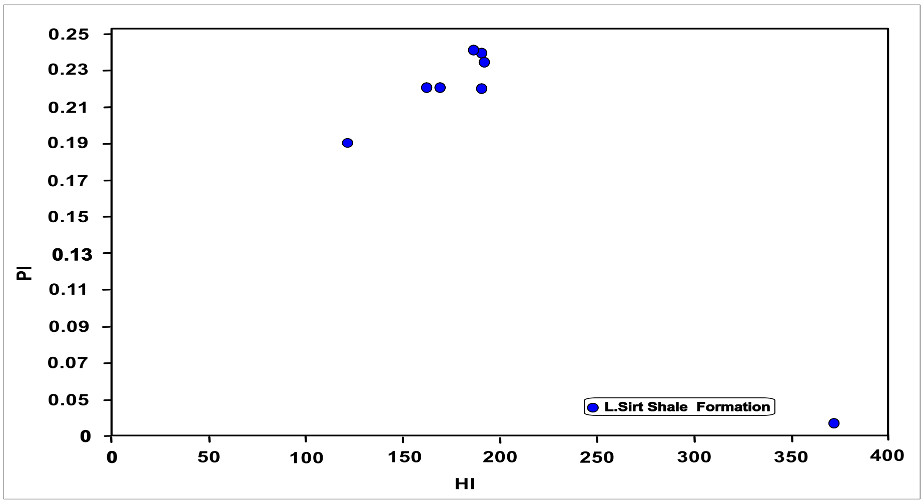


Fig. 6. Hydrogen Index vs. Productivity Index.

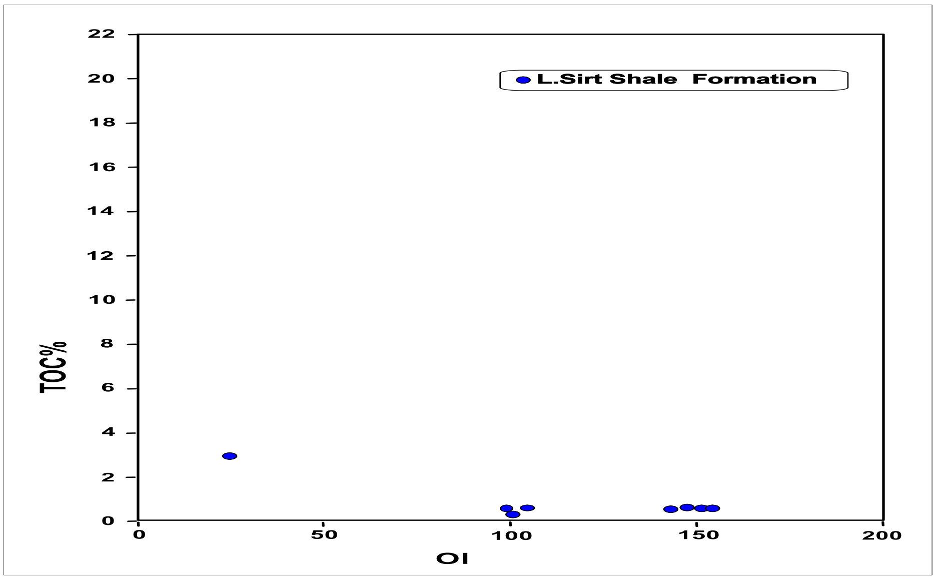


Fig. 7. Total Organic Carbon vs. Oxygen Index

Conclusion

The main source kitchens for the petroleum accumulations of the Eastern Embayment are composed of organic-rich shales present in the Rakhmat and Sirt Shale formations of the Upper Cretaceous (Coniacian to Campanian) which have been buried sufficiently for oil generation on a very large scale both in the Hameimat and Ajdabiya troughs.

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