INVESTIGATION OF UNCONVENTIONAL RESERVOIRS OF THE UPPER CRETACEOUS SOURCE ROCKS IN THE HAMEIMAT TROUGH SOUTH EAST SIRTE BASIN, LIBYA

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ABSTRACT

Study area situated in the center of the Hameimat trough which is located in the southeast of the Sirte basin. The Hameimat trough contains two of the largest oil fields in Libya, Gialo and Abu-Attifel fields. The Upper Cretaceous Rachmat, Tagrifet, and Sirte Formations are considered as the main source rock in Sirte Basin.

Organic geochemical study of the Upper Cretaceous Rachmat, Tagrifet and Sirte Formations show these Formations have total organic carbon content values of 0.53% to 3.35% fair to excellent as source rock. The Kerogen types are type II and III mixed continental and marine organic matter. The thermal maturity of these formations indicates a mature stage in oil window.

Oil saturation index (OSI: S1*100/TOC) shows that Sirte and Rachamt formations have low oil saturation, while the Tagrifet formation has good potential, where OSI exceeds 140 mg HC/g TOC in the most samples of the formation. The Tagrifet formation considers a good unconventional reservoir for shale oil, where the Sirte and Rachmat formations consider possible for shale oil with high risk.

Keywords: Unconventional reservoirs, Organic geochemistry, Sirte basin, shale oil and gas

1. INTRODUCTION

The desire for development and looking for other alternatives of the conventional resources, where shale oil and gas are considered one of the newly discovered solutions to compensate for the lack of energy resources and increase their prices. The growth of unconventional gas and oil resources has an increasing impact on regional and global gas markets prices.

The study evaluates quantity and quality of source rock, and determines the thermal maturity level of organic matter in the rocks. Also, this research provides to hydrocarbon potential.

There are several geological and geochemical studies of unconventional reservoirs that have been established in some of the world's regions, especially in the United States which gave a significant contribution to the development of this field. These studies provide information about how to estimate the hydrocarbon potential of the rock units and the relation between the generation and remain in place. [1] studied the Barnett Shale of north-central Texas, the study showed that excellent organic matter and brittle mineralogical composition are very important, His study revealed also that the low permeability of the Barnett Shale retain abundant petroleum which cracked to gas then kept as shale gas. Another study by [2] examined shale resource systems for shale oil, and concluded that organic matter in source rock is significant for its generation of hydrocarbon and retentive capacity.

[3] studied organic geochemical and shale gas potential of lower Silurian in the Ghadames basin, and refer that they are considered good characteristics for shale resource hydrocarbons production.

Previous studies of the Upper Cretaceous source rocks in the Sirte basin focused on source rock characterization rather than self-sourced reservoir characterization. [4] studied Habitat of oil in Abu Attiffel area Sirte Basin, where the Turonian and Cenomanian marine shale generation a significant amount of oil in Abu Attiffel field. [5] assessed the oil provenance and petroleum system of the east Sirte basinand revealed that both Upper

Cretaceous and pre-Upper Cretaceous formations provide hydrocarbon in the Agedabia, Hameimat, Maragh, and Sarir troughs.

This study is to investigate the unconventional hydrocarbon potential (shale oil and gas) of Upper Cretaceous source rock of the Sirte basin. The Sirte basin contains most hydrocarbons found in the Libya, and Upper Cretaceous source is considered as the main source rock in the basin [6] [7], which is a favorite as a Hydrocarbon target to replace the conventional reservoir.

1.1 Sirte Basin Overview

The Sirte Basin is the youngest sedimentary basins in the Libya and covers an area of 600.000km^2 in central Libya. The basin is characterized by basin-fill Mesozoic and Cainozoic sediments with a thickness reaches 7500m in Ajedabia trough [6]. The Sirte Basin province ranks 13th among the world's petroleum provinces, having recognized reserves of 36.7 billion barrels of oil, and 37.7 trillion cubic feet of gas [8]. It contains about 82% of all the oil and 32% of all the gas found in Libya, the oils are generally sweet with sulphur between 0.15% and 0.66%, and oil gravity range 44 to 32 degrees API [7].

Through the Paleozoic, the whole Sirte Basin area was a part of a slowly subsiding craton with an NW-SE trending horst-graben system. During the Hercynian event, the area was uplifted and made the Sirt-Tibesti Arch, which led to the erosion of the Paleozoic sediments [9]. A Hercynian unconformity separates Mesozoic and Cenozoic sediments from the underlying granitic, metamorphic and Cambrian– Ordovician basement [10].

1.2 Geological setting

The structural and stratigraphic evolution of the Sirte Basin was developed during four main tectonic phases, which extends from Late Carboniferous-Early Jurassic to the present: Intercontinental rifting expands from Late Carboniferous to Early Jurassic, Left lateral wrenching extending from Middle Jurassic to Early Cretaceous, Right lateral wrenching, from Late Cretaceous to Middle Eocene, Right lateral wrenching, and N-S compression extending from Late Eocene to the present. Rifting began in the Triassic-Early Cretaceous and reached to peak in the Late Cretaceous. The structure created the three main arms forming the Sirte complex rift Figure 1 [9]. The tectonic subsidence history of the Sirte Basin is characterized by periods of extending, alternating with periods of thermal subsidence [10].

During Triassic to early Cretaceous time started east Sirte basin to subsidence, where the Sarir-Hameimat Arm occurs prior to the main northwest-southeast horsts and grabens of the Sirte arm, trending east-west and dominated by shear faults with subordinate normal faults. Sirte Arm has been created from early Cretaceous Aptian time to late Cretaceous with the domination of normal faults and trending NW-SE except Maragh Trough, which has been developed during the early Triassic on the western margin of the Cyrenaica Platform. The Tibesti-Abu Tumayam arm extending NE-SW outspread into the north Tibesti, with a simple tectonic as compared to the other arms [9].

Sedimentation and stratigraphy of the Sirte Basin were controlled by the structural and the tectonic change. Sequence of the sediment represents deposits from Cambrian to Tertiary. Sediment thickness and depth in the basin are greatly variable from the troughs and platforms. The basement rocks are represented by the granitic and metamorphic rock of the late Precambrian to Early Cambrian age [11]. The basin was dominant by non-marine clastics deposition of Combro-Ordovician to Permo-Carboniferous, in the Late Permo-Carboniferous Hercynian which leads to uplifting the Area and forming the Sirte Arch. Subsequent late Jurassic-Early Cretaceous rifting led to the fragmentation of the arch, then Non-marine lacustrine deposition fine to coarse clastics took place in the Maragh, Hameimat, and Sarir troughs. The subsidence continued to mid-Paleogene and marine sediments were deposited. In the Late Paleogene, depocentre migrated northward into the present day Gulf of Sirte, and thin continental sediments deposited at top stratigraphic succession in the Neogene Figure 2 [5].

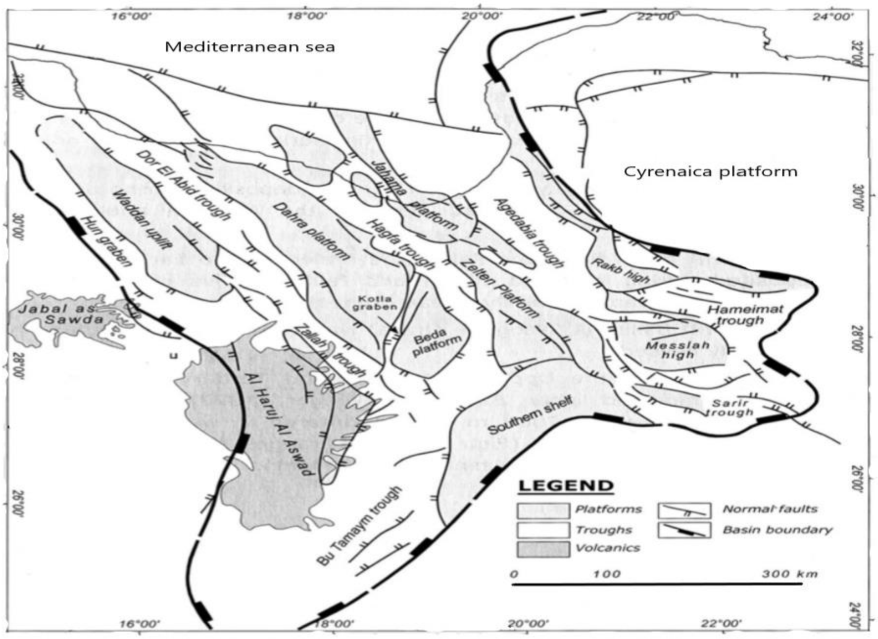

Fig. 1. structural map shows the tectonic framework of the Sirte basin (modified after Pawellek, 2007).

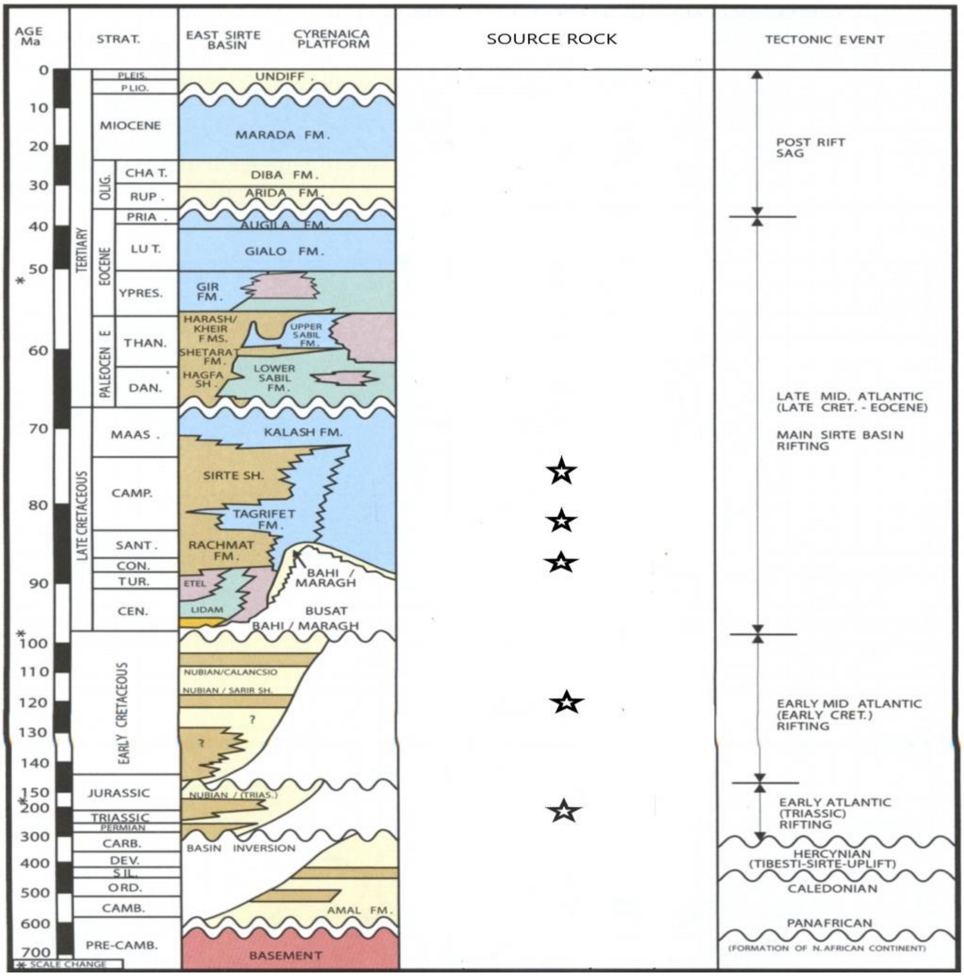

Fig. 2. Summary shows stratigraphic correlation of the East Sirte basin with tectonic and source rocks, (Modified after Burwood et al, 2003).

2. THE STUDY AREA

Hameimat Trough is located in the east part of Sirte basin and is surrounded by the Ajdabiya trough in the west, the Maragh trough and Amal Cyrenaica platforms in the north, Messlah high in the south, and ALjaghbub-Siwa high in the east. Hameimat Trough contains two of the largest oil fields in Libya, which are Gialo and Abu-Attifel fields.

The Area of this study is situated on Hameimat trough in the east part of Sirte basin, north of the giant Abu-Attifel oil field, at Latitude between 28^0 50' and 29^0 00' N and Longitude between 21^0 57' and 22^0 10' E Figure 3.

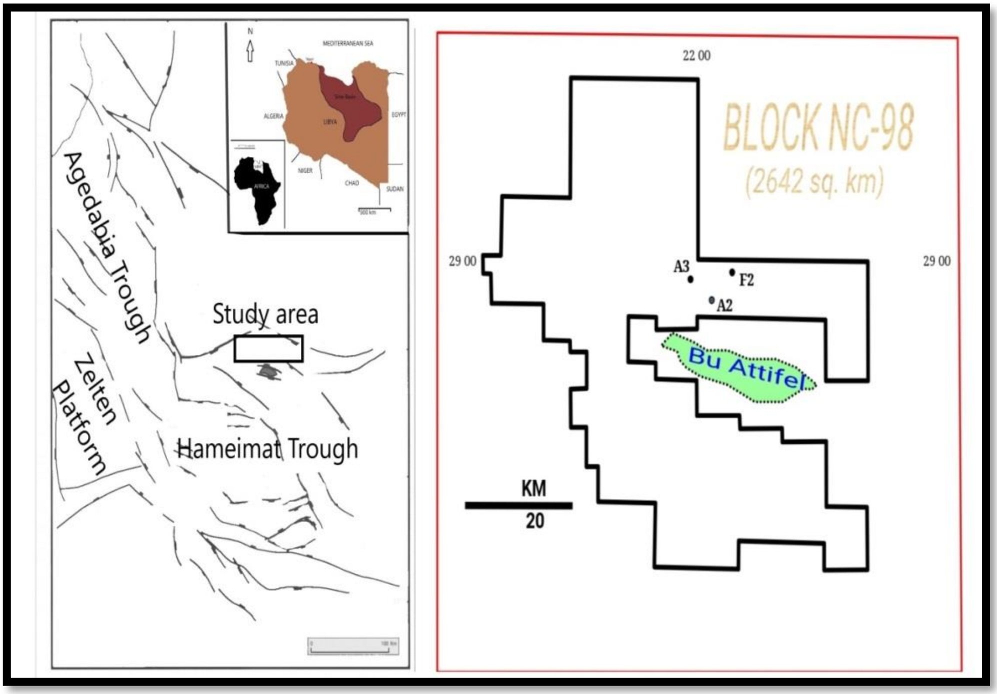

Fig. 3. Shows location map of study area, (modified after Waha Oil Company, 2005).

Three wells have been drilled in the center of Block NC98 (A2, A3, and F2). This research focuses on studying geological and geochemical analysis of Rachmat, Tagrifet, and Sirte formations.

3. RESEARCH METHOD

The present research uses subsurface data of three wells that have been drilled in the Hameimat trough. The study is mainly focusing on the characterization of organic facies and their properties. this research use the Rock-Eval pyrolysis data and maturity parameters.

The Rock-Eval pyrolysis method is a generally used by petroleum geochemists for source rock evaluation, such as the volume of free hydrocarbons extant in the sample, the remaining hydrocarbon content, the TOC content, and the thermal maturity level of the sample. In the Rock-Eval analysis, the rock is heated to 25 min in an inert atmosphere with a temperature exceeding 600°C [13] [14]. Also Organic maturity is an optical assessment underneath a microscope of the light reflected of the vitrinite maceral, or thermal alteration index used for old shales is to measure the color of organic macerals are present in the rock. Another technique: Tmax is a different indicator of the thermal maturity of the rock, which expresses the temperature of maximum development of the S2 peak [15].

4. RESULTS

The Rock Eval results for twenty two cutting samples from three formations Rachmat, Tagrifet, and Sirte selected from three wells were drilled in the central of Block NC98. These analyses were done in order to assess the quantity, quality, and maturity of organic matter and the interpret the petroleum potential of these formations. The results are shown in Table (I). Total organic carbon content of the formations varies from 0.53% to 3.35%. The hydrogen index (HI) is in the range of 97 to 391 mg/g TOC, and the Tmax values from 435 to 449 °C.

4.1 Organic Richness

TOC contents of the Upper Cretaceous Formations are varied with depth and location as shown in Figure 4. TOC value in the Rachmat formation range between 0.7 to 3.35% in the well A2 and 0.53 to 1.70% in well F2 , suggests fair to good source potential, also the values of TOC in this formation increase upward which indices to rise of sea level at that time and good preservation. The samples from the overlying Tagrifet Formation show TOC values between 1.29 to 2.57% in all wells, indicative of good potential source rock.

TOC values from Sirte shale samples range from 1.67 to 2.09% in well A2 while from 1.21 to 1.4% in well A3, which suggests fair to good source potential.

Organic matter in all formation range from 0.53 to 3.35%. The sample from the Rachmat formation in the well A2 depth (12990 ft) TOC is 0.7%, also samples from well F2 depth (12660, 13430, and 13550) have low TOC

values 0.89, 0.53 and 0.59% respectively, these values suggests poor for unconventional source. The samples with TOC values up to 1% as in Tagrifet and Sirte have good characteristics of the unconventional source, That which corresponds with [16] higher organic matter provides more pores and fractures and then good reservoir capacity.

TABLE (I) SHOW THE RESULTS OF THE ROCK EVAL ANALYSIS.

Well	Formation	Depth ft	Toc	S1	S2	S3	PI	Tmax	Hi	Oi
A2	Sirte	10530	2.09	0.21	2	0.56	0.1	436	135	38
	Sirte	10680	1.67	1.15	2.9	0.44	0.29	436	178	27
	Tagrifet	10950	1.92	1.16	2.62	0.58	0.3	438	186	41
	Tagrifet	11460	2.57	1.51	5.04	0.93	0.23	440	232	43
	Tagrifet	11940	1.29	0.32	2.13	0.42	0.13	447	222	44
	Rachmat	12660	3.35	0.51	6.52	2.81	0.08	449	168	84
	Rachmat	12840	1.15	0.32	2.24	1.21	0.13	442	195	105
	Rachmat	12990	0.7	0.47	0.94	0.94	0.33	435	134	134
A3	Sirte	10580	1.4	0.64	3.47	0.45	0.15	441	391	32
	Sirte	10730	1.21	0.78	2.53	0.54	0.23	440	306	45

	Tagrifet	10850	1.41	2.04	3.22	0.59	0.39	440	228	42
	Tagrifet	11210	1.29	2.09	4.52	0.42	0.31	444	209	33
	Tagrifet	11330	2.35	2.99	8.38	0.64	0.26	443	270	27
	Tagrifet	12230	1.45	3.51	1.4	0.63	0.71	436	97	43
	Rachmat	12530	2.49	0.22	4.62	0.64	0.05	447	186	26
F2	Tagrifet	11110	1.50	3.31	4.49	0.46	0.42	441	277	28
	Tagrifet	11150	1.91	2.82	3.31	0.45	0.46	439	206	28
	Rachmat	12477	1.08	0.32	2.33	0.49	0.12	446	197	42
	Rachmat	12660	0.89	0.35	2.04	0.57	0.15	445	208	58
	Rachmat	12780	1.70	0.33	2.58	0.43	0.11	446	162	27
	Rachmat	13430	0.53	0.21	0.76	0.47	0.22	441	143	89
	Rachmat	13550	0.59	0.2	0.1	0.44	0.17	446	169	75

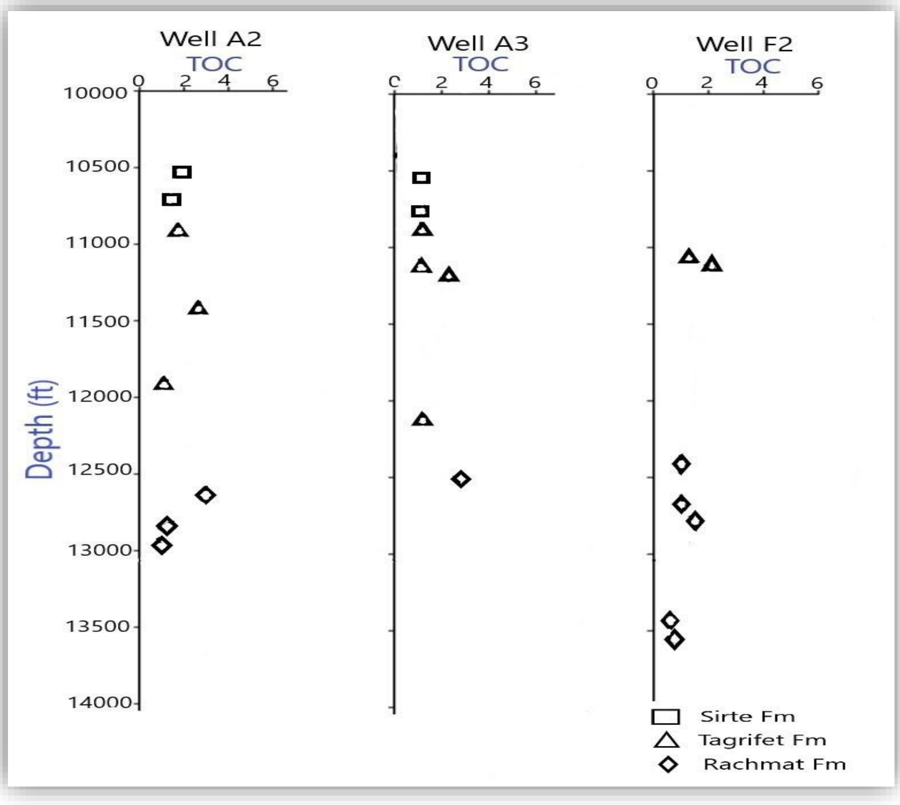

Fig. 4. shows change of TOC vs Depth in the three wells.

4.2 Quality of Organic Matter and Kerogen Type

The Hydrogen Index (HI) and Oxygen Index (OI) give information about the quality and type of organic matter [13]. The results of the Rock Eval analysis show hydrogen index is in the range of 97 to 391 mg/g TOC. These values indicate variation in organic facies and types, which suggest type II and type III kerogen. The Hydrogen index values greater than 150 mg/g TOC is considered a high potential to generate oil and gas as in Tagrifet formation. Low Hydrogen index values less than 150 mg/g TOC indicates gas prone [17]. Besides the Hydrogen index values decrease with increased maturity.

Modified Van Krevelen diagram of the Hydrogen Index (HI) and Oxygen Index (OI) Figure 5, shows that the majority of Rachmat formation samples from all wells are the type II/III kerogen (terrestrial and marine organic matter) with relatively high OI, while the Tagrifet and Sirte formations samples indicates to type II to type II/III kerogen (marine and terrestrial organic matter). In the Tagrifet formation, HI range between 186 and 277 mg/g TOC represents both oil and gas prone. The samples of Sirte formation from well A3 HI reach to 391 which suggests type II kerogen.

The HI vs Tmax plot Figure 6 indicates the presence of two types of organic matter type II and type III kerogen. Also, the scheme of HI vs. TOC Figure 7 is corresponding with other plots and shows type II and type III kerogen of all formations and both oil and gas prone.

4.3 Thermal Maturity

The maturity of organic matter can be evaluated from vitrinite reflectance (Ro) or Tmax and PI. In general, the source rock reached to oil window when Tmax is passed 435^o (R_O =0.6%) and PI about 0.1. Tmax value greater than 470° and PI about 0.4 the source rock reached to gas zone [17]. Table (II) displays vitrinite reflectance values between 0.5 to 1.12% that suggests the organic matter is mature to middle mature. Moreover spore color index (SCI) values agree with vitrinite reflectance values which indicates these formations in the mature phase. Figure 8 shows the Tmax from three wells ranging between 436 to 449° , indicating the formations in the oil window according to vitrinite reflectance and spore color index.

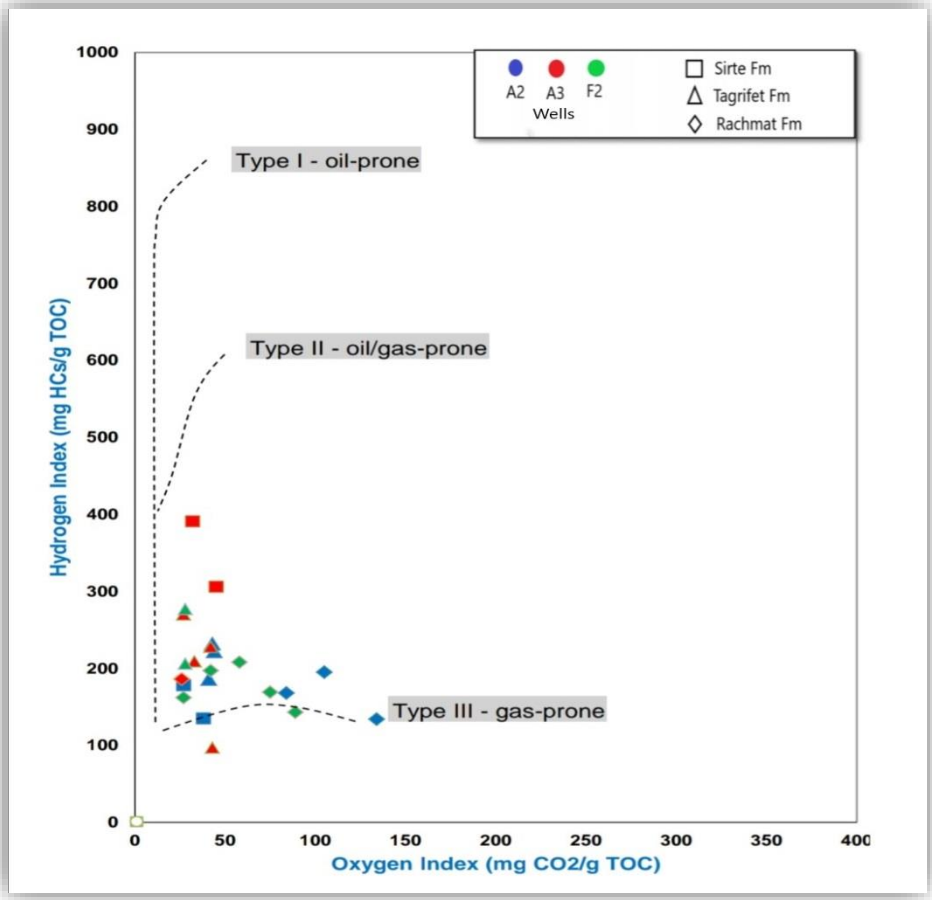

Fig. 5. Plot of hydrogen index vs. oxygen index display the organic matter types of Rachmat, Tagrifet and Sirte formations.

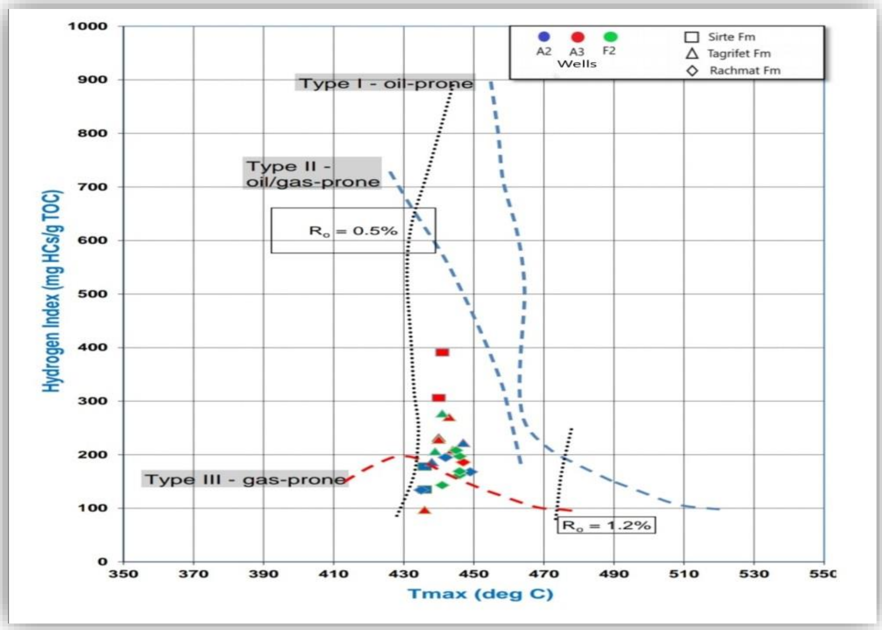

Fig. 6. HI vs. Tmax diagram indicate the formations are in the oil window and type II and type III kerogen.

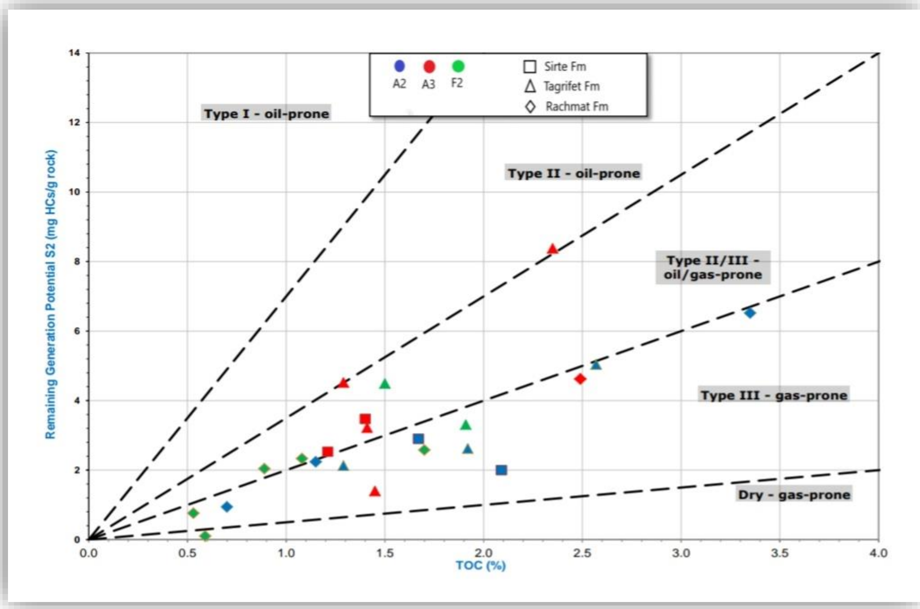

Fig. 7. Cross plot of S2 and TOC shows the type of organic matter of the three formations.

TABLE (II) INCLUDE MATURITY DATA (VITRINITE REFLECTANCE RO AND SPORE COLOR INDEX SCI).

Well	Formation	Depth ft	Ro%	SCI
A2	Sirte	10530	0.59	3
	Sirte	10680	0.78	-
	Tagrifet	10950	0.83	4.5
	Tagrifet	11460	0.72	3
	Tagrifet	11940	0.5	-
	Rachmat	12660	0.9	5
	Rachmat	12840	0.8	5
	Rachmat	12990	1.08	7
A3	Sirte	10580	0.95	4
	Sirte	10730	0.79	3.5
	Tagrifet	10850	-	4
	Tagrifet	11210	1.02	4
	Tagrifet	11330	0.66	4.5
	Tagrifet	12230	1.12	6
	Rachmat	12530	-	5
F2	Tagrifet	11110	0.5	-
	Tagrifet	11150	-	-
	Rachmat	12477	-	-
	Rachmat	12660	-	-
	Rachmat	12780	0.7	-
	Rachmat	13430	0.8	-
	Rachmat	13550	0.85	-

PI and Tmax data for most of the Rachmat in three wells range over 0.1 and 435° indicates characteristic of oil zone and Tmax reaches to 449° in well A2 according to peak oil generation. The Tagritet formation records Tmax values between 436 and 447° indicating that these rocks are within oil window. The samples of Sirte formation have Tmax values 436° in well A2 and do not pass 441° in well A3, suggesting that they are located in the early oil zone.

Plot of Tmax vs PI Figure 9 illustrates most of the studied samples are located in the mature zone, but some samples of Tagrifet formation have high PI values which placed them in the zone of hydrocarbon staining or contamination, and this is mostly migrated oil because of presence this formation as a reservoir in another field [6] [7]. In General, all samples are in a mature oil zone. The Upper Cretaceous formations entered the oil window at a depth of about 10000 ft, and the gas window start at a depth of 15000 ft.

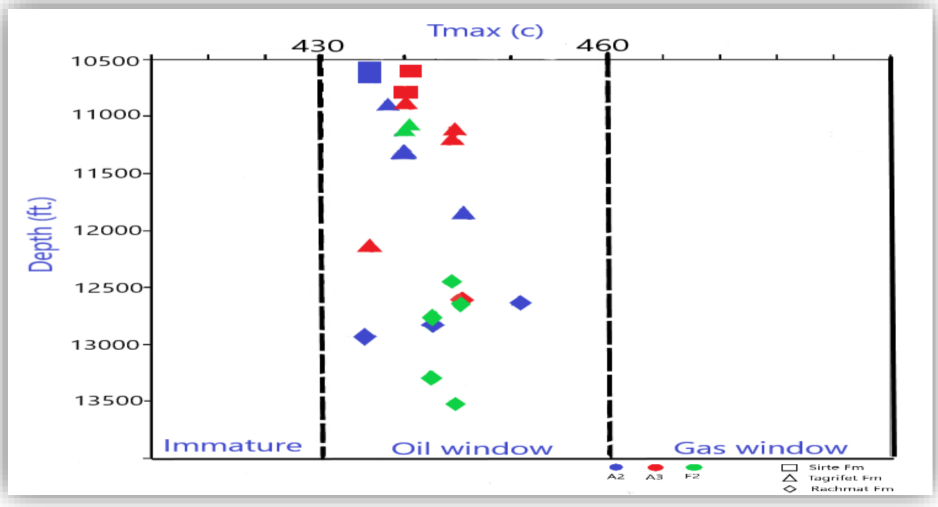

Fig. 8. shows the change of Tmax vs Depth in the three wells.

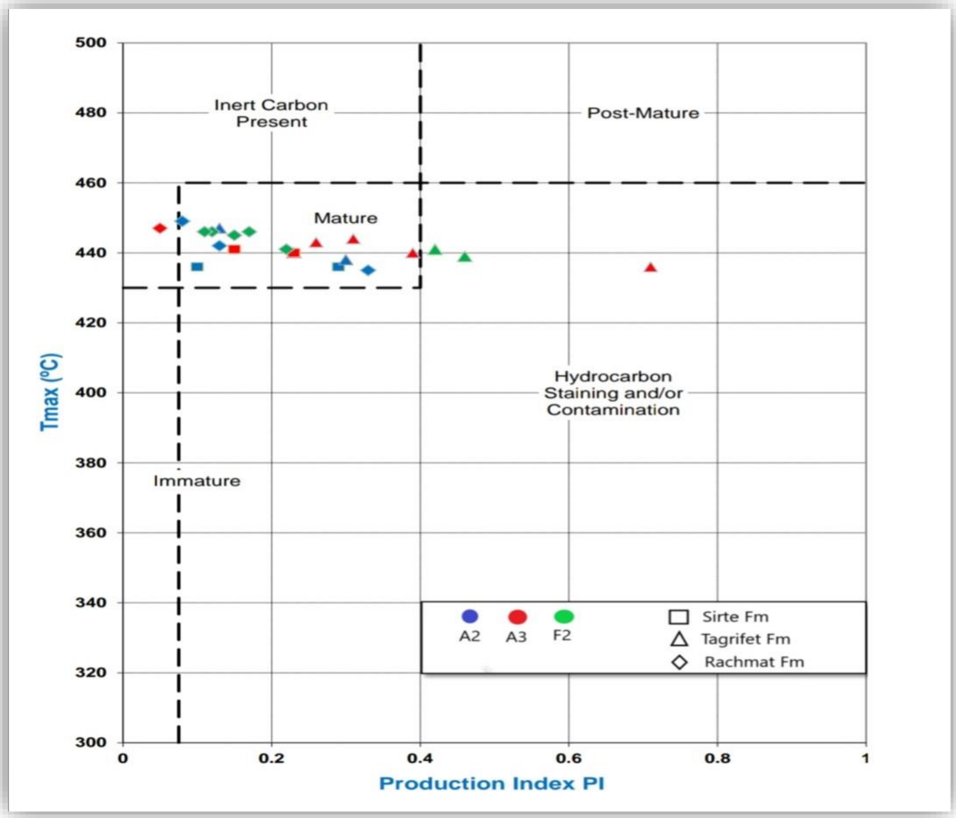

Fig. 9. Tmax vs. Production Index (PI) plot for assessing thermal maturity of formations from three wells.

4.4 Hydrocarbon Potential

The quantity, quality, and maturity of organic matter are considered as criteria to evaluate source potential [13]. The study area contains a very thick section of upper Cretaceous source rock about 2600ft, with TOC range from 0.53 to 3.35% which suggests a fair to very good source. The Hydrogen Index (HI) and Tmax of Samples indicates to type II to type II/III kerogen, and both oil and gas generation. The S2/S3 of Tagrifet formation is greater than 4.5 and reaches to 13 in well A3 indicating an oil-prone source, the S2/S3 of Sirte shale range 3.5 to 5.6 suggests both oil and gas potential, but S2/S3 of Rachmat formation suggests more gas generation with value in total less than 3.

A plot of S1+S2 versus TOC values Figure 10 indicates the formations are poor to the fair potential of Rachmat, but Sirte and Tagrifet fair to good potential. S1 value of Rachmat range between 0.2 to 0.5 appearance poor potential of this formation. S1+S2 value of Sirte formation suggests fair generation potential, while S1+S2 value of Tagrifet formation indicates good generation potential with S1 more than 3 in wells A3 and F2.

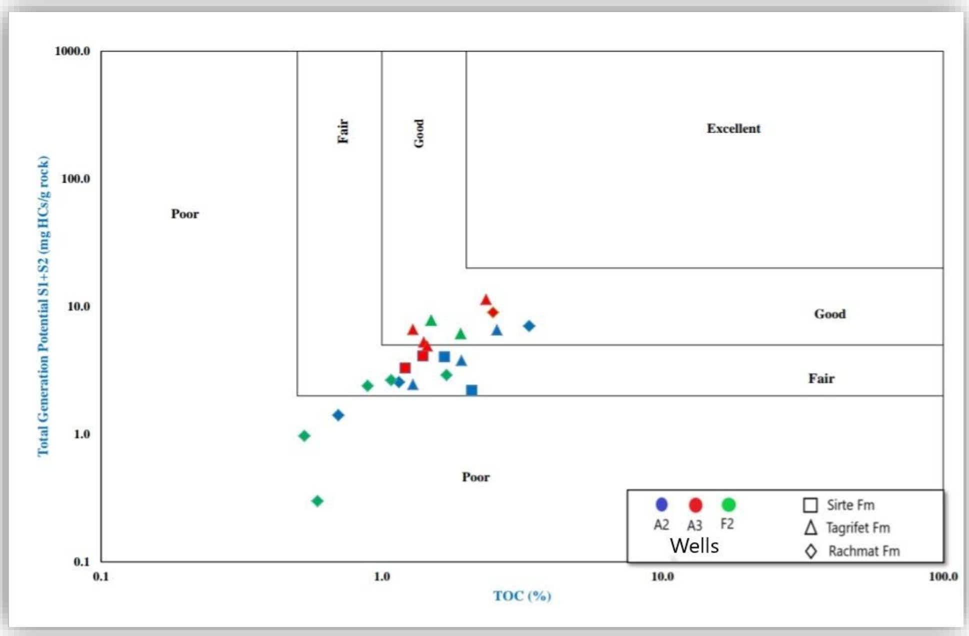

Fig. 10. TOC versus total hydrocarbon generating potential of formations show generating potential.

4.5 Unconventional reservoir potential

A geochemical log of the formations show good Characteristics, and good quality of organic matter with an average TOC of more than 1.5%. In addition, S1 and S2 indicate a good generation potential. The thermal maturity shows that an oil window was reached Tmax is between 435 to 449C. R_o is equivalent to Tmax [14] and shows values between 0.67 to 0.92 % which indicates to shale oil potential with some gas when compared with type II and type III kerogen Figure 7.

When R_o is less than 0.9% the generated oil is largely saved in the source rock, while Ro is more than 0.9%, the expelled oil from the source rock it may be reserved on the surface of the source rock and in the linked micro-fractures and part of the oil can migrate into the interbedded sandstone Figure 11 [16].

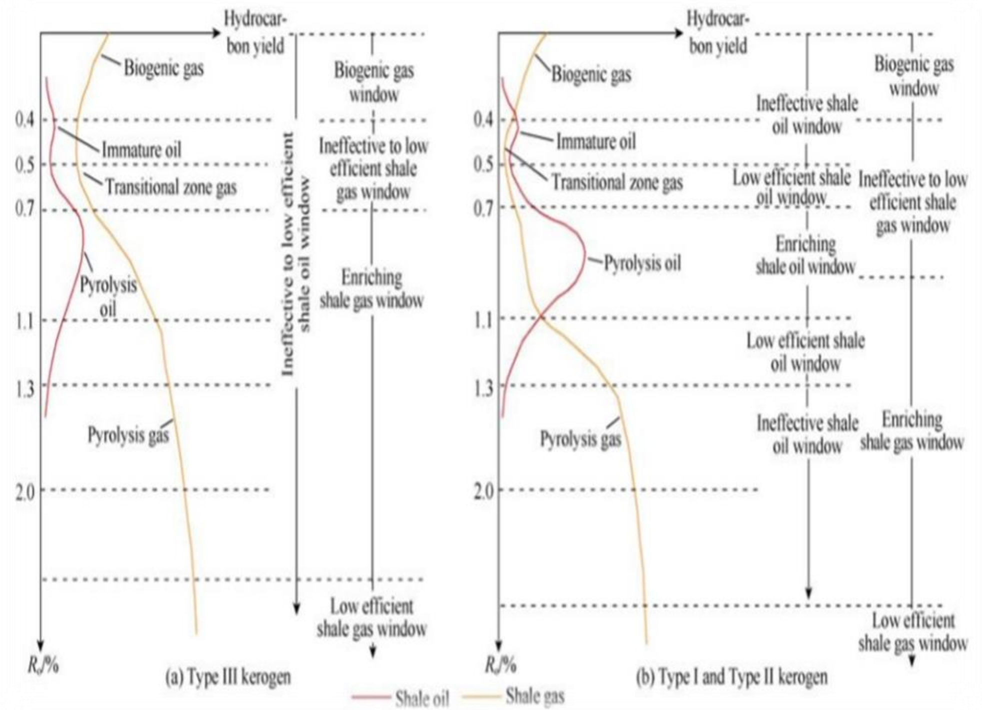

Fig. 11. thermal maturity R_0 indicated to shale oil and gas. (Shuangfang, et al., 2012).

Oil Saturation Index (OSI; S1*100/TOC) is an important geochemical indication to evaluate the oil confined in the reservoir designated by the oil crossover effect. When the oil saturation index extends a value of about

100mg HC/g, is TOC used to recognize potential reservoir intervals while an oil cross over value of less than 100mg HC/g is considered a high risk based on geochemical results. The value of less than 100mg HC/g it does not rule out the potential of having producible oil, because these sections may have been dried or volatile fluids have evaporated [2].

In this study oil saturation index (OSI) of the three formations indicate that the Rachmat formation has the lower oil saturation in three wells Figure 12, 13 and 14 with value less than 40 mg HC/g TOC of all samples except one value in well A2 about 67 mg HC/g TOC indicating high risk. The Sirte formation have low to moderate oil saturation values but in general with high rick Figure 12 and 13. The Tagrifet formation in well A2 has moderate values and reach 97 mg HC/g TOC Figure 12, while the Tagrifet formation in wells A3 and F2 Figure 13, and Figure 14 OSI exceed 140 mg HC/g TOC in most samples and reaches up to 242 mg HC/g TOC in well A3 with TOC values between 1.45 to 2.35% which estimate as excellent potential.

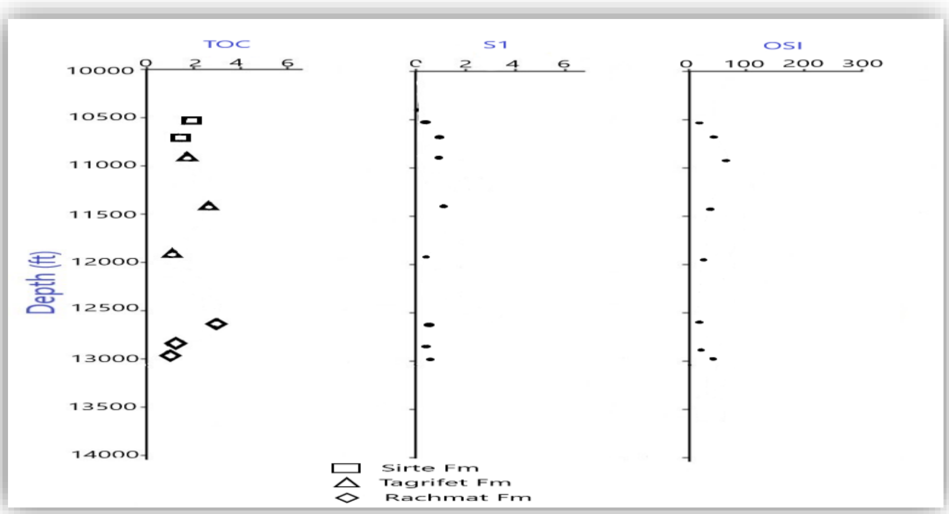

Fig. 12. illustrates oil saturation index of Rachmat, Tagrifet, and Sirte formations in well A2.

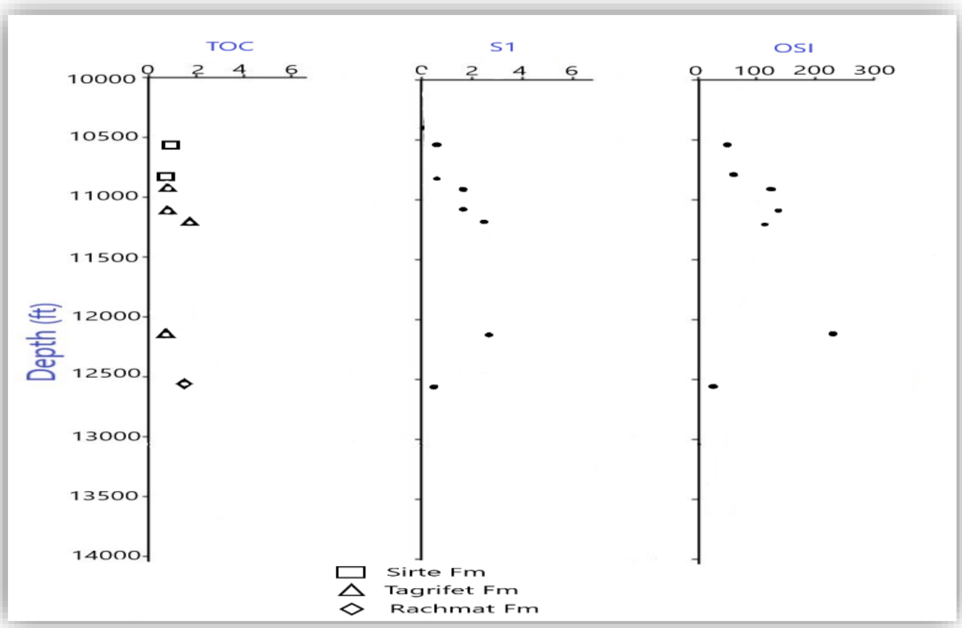

Fig. 13. illustrates oil saturation index of Rachmat, Tagrifet, and Sirte formations in well A3.

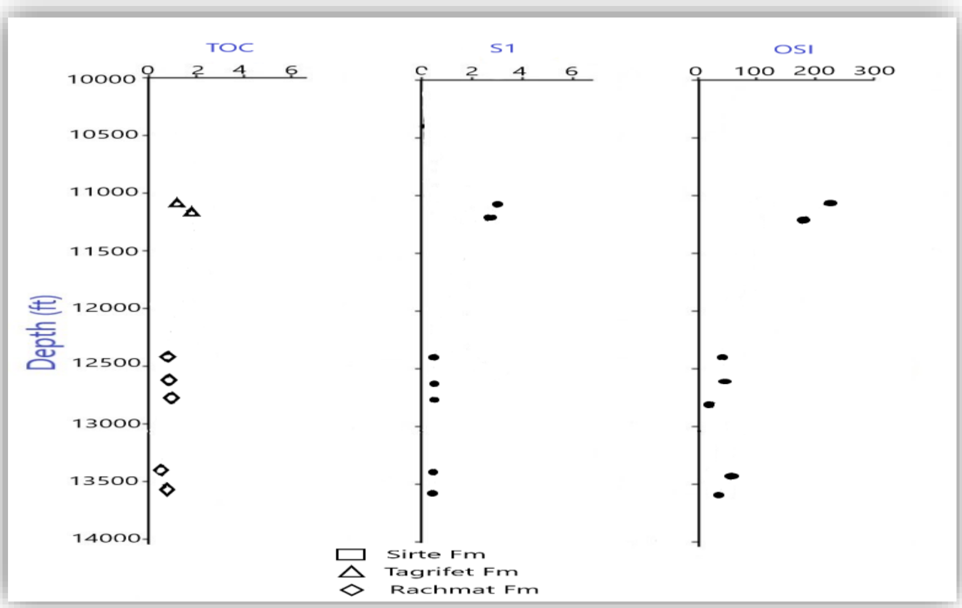

Fig. 14. illustrates oil saturation index of Rachmat, Tagrifet, and Sirte formations in well F2.

5. CONCLUSIONS

- The total organic carbon content of the formations varies from 0.53% to 3.35% with an average of more than 1.5%.
- There is an indicator of the presence two types of organic matter type II and type III kerogen in addition to mixed terrestrial and marine organic matter.
- Kerogen types refer to both oil and gas generation.
- The maturity level of formations indicates characteristics of oil zone and Tmax reaches to 449^{o} c, according to peak oil generation.
- The Rachmat and Sirte have low oil saturation with high rick in three wells, while the Tagrifet formation indicates to high oil saturation.
- The upper Cretaceous formations are able to produce shale oil in the southeast Sirte basin.

6. RECOMMENDATIONS

- studying the organic facies of Formation at a small scale.
- Drilling new exploration wells to evaluate source rocks of Sirte basin as an unconventional reservoir, especially Tagrifet formation.
- Measure porosity and permeability of source rocks in the Sirte basin.
- Make XRD analysis of The Upper Cretaceous source rocks and assessing mineral composition.

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التحقيق في الخزانات الغير تقليدية لصخور المصدر الكريتاسي العلوي في منخفض الحميمات جنوب شرق حوض سرت، ليبيا

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الملخص

منطقة الدراسة تقع في وسط منخفض الحميمات في شمال شرق حوض سرت. منخفض الحميمات يحتوي على اثنين من اكبر الحقول النفطية في ليبيا وهي حقلي جالو وأبو الطفل. تكوينات الكريتاسي العلوي الراشمات وتاقرفت وسرت تعتبر صخور مصدر اساسية في حوض سرت.

دراسة الجيوكيمياء العضوية لتكوينات الكريتاسي العلوي الراشمات وتاقرفت وسرت تبين ان هذه التكوينات تحتوي على مادة عضوية كلية تتراوح من 0.53 الى 3.35% مقبول الى ممتاز كاصخر مصدر، ونوعية الكيروجين تكون من النوع الثاني والثالث خليط من المادة العضوية القارية والبحرية. النضج الحراري لهدة التكوينات يدل على انها في مرحلة النضوج في نافدة النفط.

مؤشر تشبع النفط يوضح ان تكوني سرت والراشمات تكون قليلة التشبع بالنفط، بينما تكوين تاقرفت يكون ذات امكانية جيدة، حيث مؤشر تشبع النفط يتجاوز 140 mg Hc/g Toc في معظم عينات التكوين. ويعتبر تكوين تاقرفت خزان غير تقليدي جيد للنفط الصخري. بينما تكوني سرت والراشمات تكون ذات احتمالية للنفط الصخري مع مخاطرة عالية.

الكلمات الدالة: الخزانات الغير تقليدية، الجيوكيمياء العضوية، حوض سرت، النفط والغاز الصخري.