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Source rock evaluation and burial history modeling of the Middle Jurassic Khatatba Formation in the West Kanayes Concession of Matruh Basin, North Western Desert, Egypt.

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Abstract

The present study aimed to determine the hydrocarbon potential of the main source rock in the study area in Matruh Basin, Western Desert, Egypt. The geochemical analyses assist in the identification of the potential source intervals within the studied rock units. The Geochemical method used encompasses Petro-mode 1D software which is used for the construction and prediction of geological and geochemical models. A total of 26 cutting samples from the exploratory well were selected to be analyzed by Rock-Eval pyrolysis. There are two source rocks in Khatatba Formation (Zahra and Safa members). The geochemical results showed that Zahra and Safa source rocks in Matruh Basin vary from Excellent to poor organic carbon richness with kerogen types III and III/II. Also, these source rocks have kerogens that are thermally mature and mostly within the oil generation zone. In addition, the burial history models indicate that the Middle Jurassic Zahra and Upper Safa source rocks started the oil generation at the Early Cretaceous, with difference in the timing of oil window, whereas it recorded at 103 Ma at depth 6158 ft. and 108.23 Ma at 5865 ft. respectively. The Zahra source rock still in oil generation until today, there is no gas generation yet. While Upper Safa are still in oil generating until the first onset of gas generation during the Late Cretaceous at 77.53 Ma at depth 11686 ft., and then continue in gas generation with a minor appearance until today, with a transformation ratio of kerogen reached to 93% and 96% respectively.
Key words: Sourc Rock; Hydrocarbon potential; Rock-Eval pyrolysis; Burial history models; Matruh basin; Western Desert; Egypt.

1. Introduction

The study area is located in the northern part of the Western Desert of Egypt, occupying a current area of 3258 km². The area under study deals with Matruh Basin is a part of the West Kanayes concession. It lies between latitudes 30° 52' 00" - 30° 38' 00" N and longitudes 27° 54' 00" - 27° 34' 00" E Figure (1).

In the study at hand, the basin simulation software Petro-Mod 1D was used for modeling the petroleum history of the West Kanayes field located in Matruh Basin, North Western Desert, Egypt.

The basin modelling has been studied by many authors such as; Welte and Yükler (1980,1981), Allen and Allen (1990), Burrus et al. (1996), Poelchau et al. (1997), Welte et al. (1997), Uysal et al. (2000), Rodriguez and Littke (2001), Yahi et al. (2001), Mohamed et al. (2002), Osadetz et al. (2002), Sheng and Middleton (2002), Ershov et al. (2003), Demirel (2004), Galushkina et al. (2004), George et al. (2004) and Abd El Gawad et al. (2015).

Basin modeling is used to understand the geological and thermal evolution of a sedimentary basin (Welte and Yalcin, 1988; Burrus et al., 1991; Littke et al., 1994; Barker, 1999). The basin model integrates the geochemical, geophysical and geological basin properties from which oil and gas generation and migration as well as the temperature and pressure evolution in a basin can be calculated (Welte and Yükler, 1981; Wygrala, 1988).

Several oil fields in the northern part of the Western

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Desert are currently producing from thin and separated intervals within the Alam El Bueib thick section (Hagras et al., 1992). Most of the Western Desert's oil production comes from the northern basins, including Matruh and Shushan basins from the Jurassic-Cretaceous sands (Metwalli, 2004).

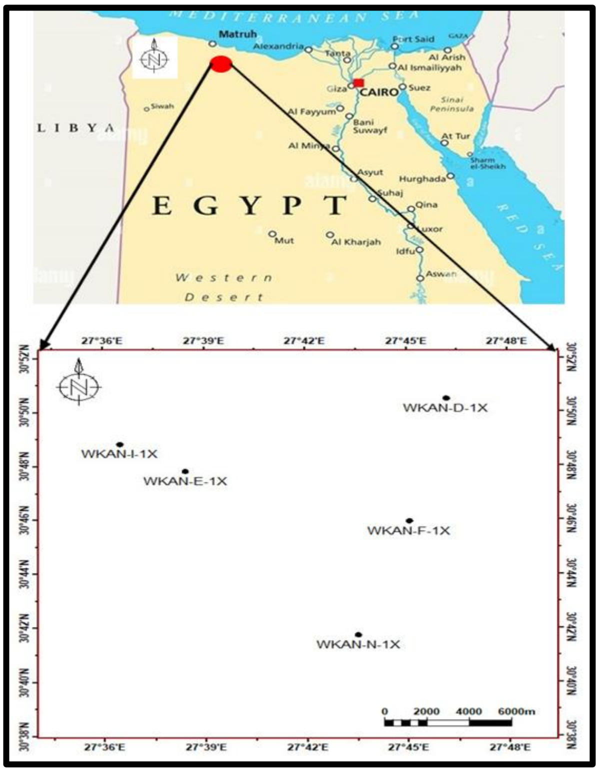

Fig. (1): Location map showing the studied wells in the West Kanayes concession, north Western Desert, Egypt.

The principal objectives of basin modeling are to reconstruct the thermal and burial histories of the basin and understanding the processes and mechanisms by which it formed. This is in addition, reconstructing the time evolution of a sedimentary basin in order to make quantitative predictions of geological phenomena leading to oil accumulations.

In recent years the evolutions of basin simulators have contributed to improve the treatment of geological discontinuities such as faults and salt domes. The basin modeling has expanded to include evaluation of secondary migration and trapping of hydrocarbons within basins. New techniques have emerged that tell us something about how and when various types of kerogens convert to hydrocarbons.

The results from evaluations of the source rocks, including basin modeling, and seismic data interpretation reduce the risk of exploration and may lead to the discovery of new prospective areas. The source rocks were defined as sedimentary rocks having the ability to accumulate oil and/or gas. The hydrogen content of kerogen is thought to be the most important parameter controlling the generation of oil and gas (Maowen et al., 2006; Kamali and Mirshady, 2004).

In the study at hand, EGPC, (1992), Khatatba Formation is Middle Jurassic except where it is represented by transitional facies into Bahrein and Wadi El Natrun Formations where it can be as old as Early Jurassic. Khatatba Formation is divided into two members (Zahra & Safa members) (Khalda, 2001).

Khatatba Formation contains some fair to excellent quality oil–prone source rock (type II kerogen) with gas-prone humic organic matter (type III) in most parts of the Western Desert. The source rocks are generally rich and mature (EGPC, 1992).

2. Geological Setting

The North Western Desert is considered as a part of the unstable shelf of Egypt (Said, 1962) and therefore its tectonic setting could be determined from surface and subsurface structures. The Matruh Basin is a part of the Egyptian Western Desert. This basin was affected by six major geotectonic cycles or phases, listed from younger to older as follows: The Red Sea phase (Oligocene–Miocene), Syrian Arc main phase (Paleogene), Sub Hercynian–Early Syrian Arc (Turonian–Santonian), Cimmerian/ Tethyian (Triassic–Early Cretaceous), Variscan–Hercynian (Late Paleozoic), and Caledonian cycle (Cambrian–Devonian) (Meshref, 1990). The Western Desert is divided from south to north into four tectonic frameworks, the Craton Nubian Arabian shield, Stable Shelf, Unstable Shelf, and Hinge Zone and Miogeosyncline (Schlumberger, 1984). Given this situation, the sedimentary basins of the northern Western Desert include two deep provinces separated by the east–west to east–northeast trends of the Ras Qattara and North Sinai uplift. The northern deep province includes the Late Jurassic–Early Cretaceous Alamein and Matruh/Shoshan basins, while the southern province includes the Late Cretaceous and younger Beni Suef, Gindi, and Abu Gharadig basins (Al-Ramisy, 2006; Makky et al., 2014). The recent geophysical and well data acquired by oil companies exploring the Western Desert have indicated that NE-SW and ENE-WSW trending Mid-Jurassic to Cretaceous basins are present in different parts of the North Western Desert. The tectonic regimes that affected Northern Egypt are responsible for the formation of basins and sub-basins. Shushan basin is one of these basins which is greatly affected by such tectonic regimes and is considered as Middle Jurassic to Cretaceous rift basin (Taha, 1992).

The lithostratigraphy of the Matruh Basin is composed of rock units ranging from the Precambrian to recent geologic time Figure (2). (EGPC, 1992). Its Paleozoic sediments vary from early Cambrian to Late Permian and un-conformably overlie a Precambrian basement and are in turn unconformably overlain with Jurassic sediments (the Eghei, Khatatba, and Masajid formations) and/or younger deposits (Fawzy and Dahi, 1992). During the Early Cretaceous, thick Neocomian–Albian marine sediments to continental clastics were deposited; these sediments are subdivided into the Betty, Shaltut, and Alamein formations. These rock units are overlaid by the Dahab (mainly shale) and Kharita (clastics) formations. Conversely, the Late Cenomanian and Turonian sediments are composed of coarse clastics at the base from a shallow marine environment (Bahariya Formation) up to fine clastic and non-clastic sediments from deep marine sediments at the top of the chalk limestone Abu Roash (Turonian–Coniacian) and Khoman formations (Soliman and El Badry, 1980). The Abu Roash Formation is subdivided into A, B, C, D, E, F, and G members. The A, C, E, and G members consist primarily of clastics, while the B, D, and F members are composed primarily of carbonates (Schlumberger, 1995) Figure (2).

3. Materials and Methods

In this study, Rock-Eval machine progressively heats (Pyrolysis) the powder of (26) cutting samples of W KAN F-1X well in an inert atmosphere. The Pyrolysis processes release the following, Release of the free hydrocarbons to give (S1) peak in the Rock-Eval Pyrolysis represents the hydrocarbon that is vaporized and driven off from the sample at low temperature (to about 300°C) and are measured in mg HC/g rock. The pyrolysis derived (S2) value in mg HC/g rock represents the amount of the hydrocarbons generated through thermal cracking of the contained kerogen at (300–550°C). It indicates the capability of the rock to generate hydrocarbons. It represents the remaining generative capacity of the rock and it decreases with increasing maturity level giving a false estimate to the source potential of the mature samples. Therefore, the source generating potential in a mature rock should be corrected by adding the generated free (S1) to the remaining (S2) to give the original generating capacity (Waples, 1985), (S3) is Releasing of organically bound CO2 over the temperature range (300– 550°C). a total 26 samples of the studied rock units to evaluate Middle Jurassic Khatatba source rocks (Zahra and Safa members) illustrated in Table (1) from well (W KAN F-1X) in the West Kanayes Concession of the Matruh Basin. The Evaluation methods includes, the TOC (organic carbon content), %Ro value (vitrinite reflectance), Rock Eval pyrolysis parameters such as, Hydrogen Index (HI), Oxygen Index (OI) and Production Index (PI). Two burial history models were constructed using the Petro-Mod 1D software to determine the oil and gas window and the time of hydrocarbon generation.

4. Results and discussion

This study assessed the Zahra and Safa formations as the source rocks for produced hydrocarbons in the W KAN F-1X, well of the West Kanayes Concession at the Matruh Basin. The results of the TOC and Rock-Eval pyrolysis analyses of these formations are shown in Table (1), the hydrocarbon potentiality, types of kerogen, thermal maturation and generation and one-dimensional basin modeling are determined and discussed.

4.1. Hydrocarbon Potentiality

Tissot and Welte (1978, 1984), Hunt (1979, 1996) and Waples (1985) classified the maturation of organic matter in sediments and generation of different hydrocarbons according to vitrinite reflectance (%Ro) into: (Diagenesis %Ro < 0.5, Catagenesis (Oil and wet gas) %Ro 0.5 – 2, Metagenesis (Dry gas) %Ro 2 – 4) . In this study, TOC, S1 and S2 data were used to determine the hydrocarbon potentiality of the studied rock units in the W KAN F-1X, well Table (1).

Most of analyzed samples have a high quantity of TOC more than 0.5 (wt. %), the Zahra Formation contains organic carbon ranging from 0.56 wt.% at depth 12800 ft to 1.18 wt.% at depth 12990 ft and therefore it is considered a poor to fair organic carbon richness Figure (3). On the other hand, The Upper Safa member source rock has a wide range of organic carbon values from 0.73 wt.% at depth 13900 ft to 9.81 wt.% at depth 13780 ft with average value 2.47 wt.% Table (1), it has a fair to excellent organic carbon richness Figure (3).

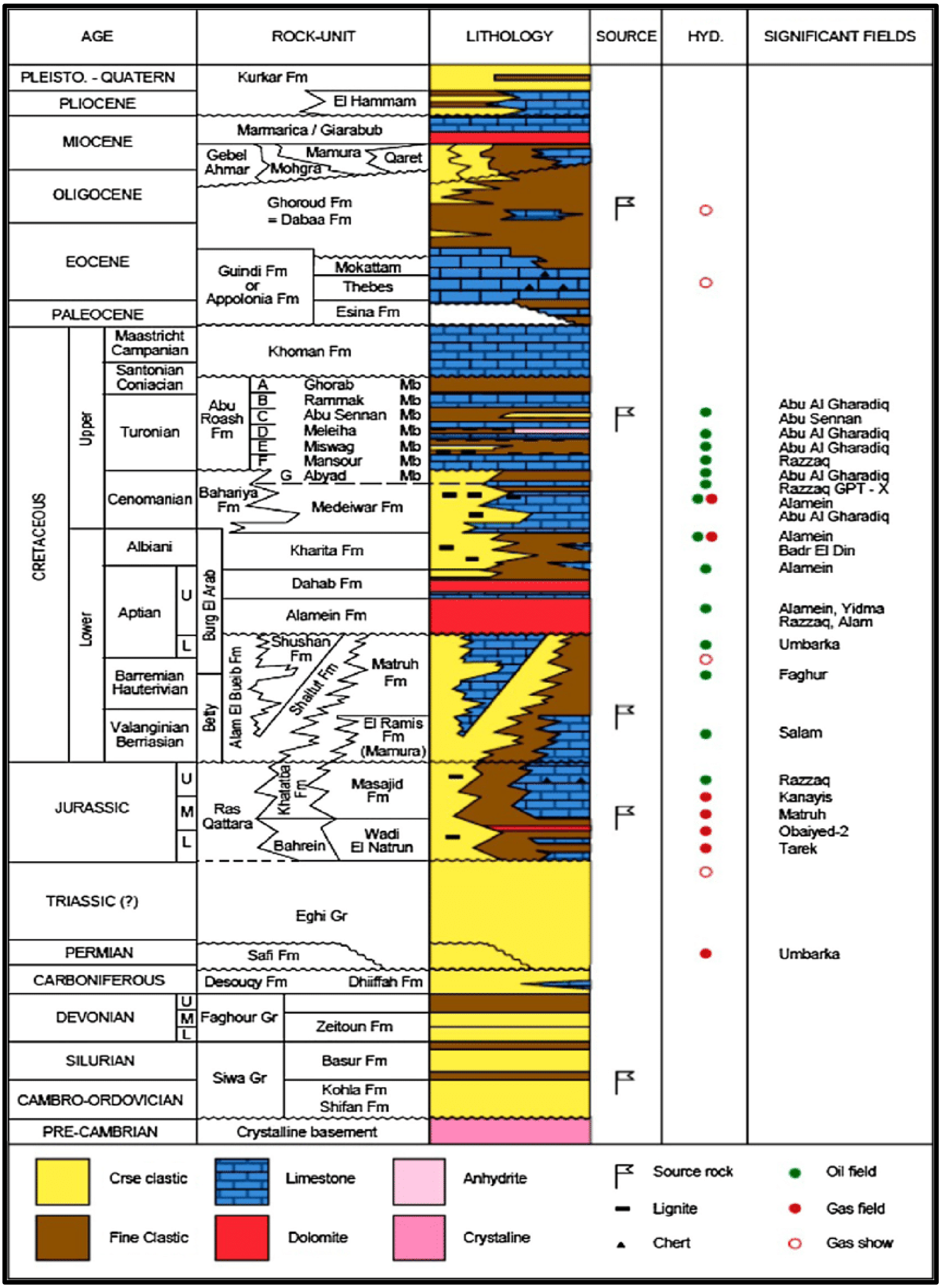

Fig. (2): Generalized stratigraphic column of the North Western Desert, after (Schlumberger, 1995).

Table (1): TOC and pyrolysis data for the studied rock units in W KAN F-1X well.

Formation	Depth (ft)	Petroleum Potential				Kerogen Type (quality)		Thermal Maturation		GP	R0
		TOC Wt.%	S1 mg/g	S2 mg/g	S3 mg/g	HI	OI	Tmax	PI	S1+S2	%
ZAHRA	12800	0.56	0.1	0.5	0.94	89	168	448	0.17	0.6	0.91
	12940	0.84	0.08	0.66	0.46	79	55	450	0.11	0.74	--
	12990	1.18	0.15	1.35	1.18	114	100	449	0.10	1.50	0.80
UPPER SAFA	13050	2.44	0.27	3.69	1.20	151	49	451	0.07	3.96	1.23
	13150	3.72	0.47	4.53	0.53	122	14	450	0.09	5.00	1.26
	13200	2.41	0.29	2.06	0.48	85	20	447	0.12	2.35	1.27
	13310	1.81	0.32	1.89	0.53	104	29	459	0.14	2.21	--
	13400	0.95	0.10	0.93	1.22	98	129	441	0.10	1.03	--
	13440	1.63	0.15	1.06	0.83	65	51	457	0.12	1.21	1.47
	13530	0.94	0.17	0.82	0.94	88	100	456	0.17	0.99	1.47
	13540	1.25	0.13	1.09	0.51	87	41	440	0.11	1.22	1.51
	13550	1.02	0.12	0.86	2.28	84	224	448	0.12	0.98	--
	13600	1.44	0.18	1.32	0.80	92	56	452	0.12	1.50	--
	13630	1.86	0.14	1.12	0.49	60	26	456	0.11	1.26	1.48
	13700	1.65	0.19	1.25	1.38	76	84	461	0.13	1.44	1.51
	13750	1.39	0.13	1.04	0.55	75	40	465	0.11	1.17	--
	13760	2.40	0.27	2.02	0.81	84	34	462	0.12	2.29	1.32
	13780	9.81	1.20	11.56	0.84	118	9	465	0.09	12.76	1.58
	13840	3.97	0.41	3.47	0.64	87	16	465	0.11	3.88	1.20
	13860	2.90	0.43	2.45	0.96	84	33	468	0.15	2.88	1.03
	13870	5.41	0.78	5.41	0.73	100	13	468	0.13	6.19	1.02
	13900	0.73	0.09	0.52	1.48	71	202	442	0.15	0.61	--
	14000	1.77	0.06	0.32	0.96	18	54	432	0.16	0.38	1.15
LOWER SAFA	14100	0.58	0.05	0.29	0.96	50	164	453	0.15	0.34	--
	14140	1.02	0.06	0.41	0.51	40	50	440	0.13	0.47	0.93
	14160	0.83	0.08	0.95	0.90	115	109	435	0.08	1.03	1.05

TOC: Total Organic Carbon (wt%).
S1: Volatiles produce at low degree of temperature (mg HC/gm rock).
S2: Max. hydrocarbons release from kerogen cracking (mg HC/gm rock).
S3: Carbon dioxide yield (mg CO2/gm rock).
T_{max}: Max. temperature at which max. hydrocarbons yield (deg C).
HI: Hydrogen index (S2 × 100/TOC) (mg HC/gm TOC).
OI: Oxygen index (S3 × 100/TOC) (mg CO2/gm TOC).
GP: Genetic potential (S1+S2) (mg/g).
Ro: Vitrinite reflectance (%).

Finally, the Lower Safa member contains organic carbon content ranged from 0.58 wt.% at depth 14100 ft to 1.02 wt.% at depth 14140 ft, so it is a fair to good organic carbon richness, as shown in Figure (3). The S1 values range from 0.05 to 1.2 mg/g rock with average value of 0.12 mg/g rock Table (1). Using the classification of (Peters, K.E., Cassa, M.R., 1994) therefore it is considered a poor potential source rock for all of the studied formations Figure (4). Also, the values of S2 which range from 0.29 to 11.56 mg/g rock with average value 1.41 mg/g rock reflects a poor to fair hydrocarbon generation source rock in most formations source rocks, except in Upper Safa member which is considered as a poor to very good hydrocarbon generation source rock Figure (5).

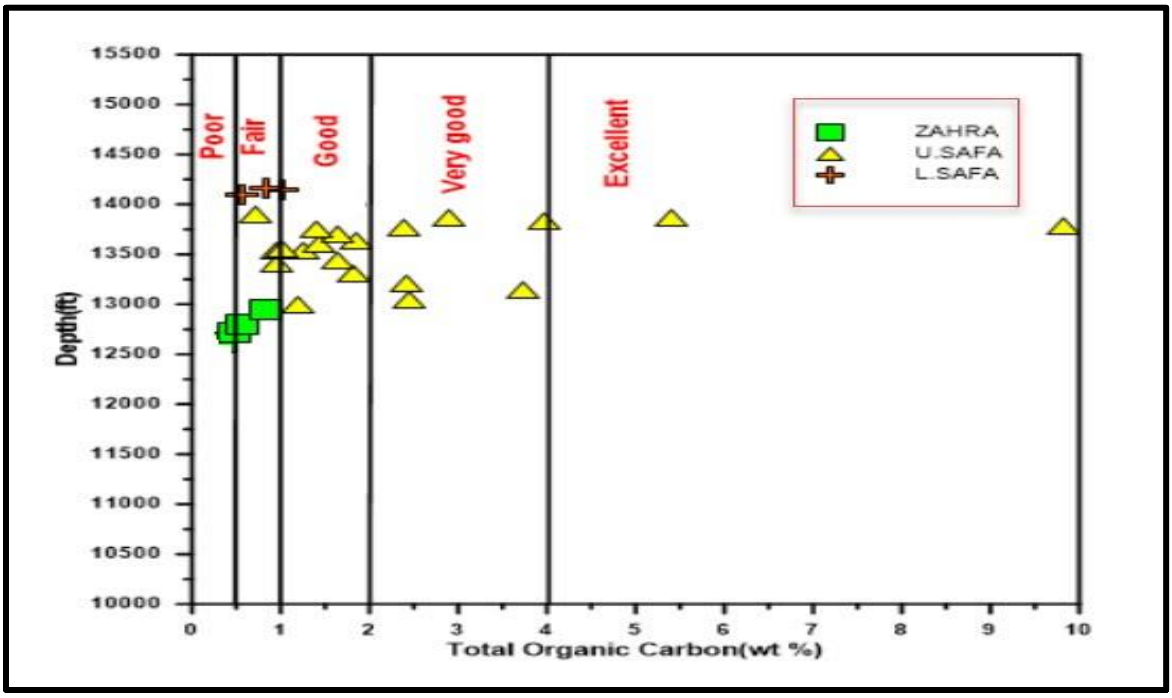

Fig. (3): Total organic carbon (TOC) versus depth of the studied samples, for (Middle Jurassic, W KAN F-1X, West Kanayes oil field, Western Desert, Egypt).

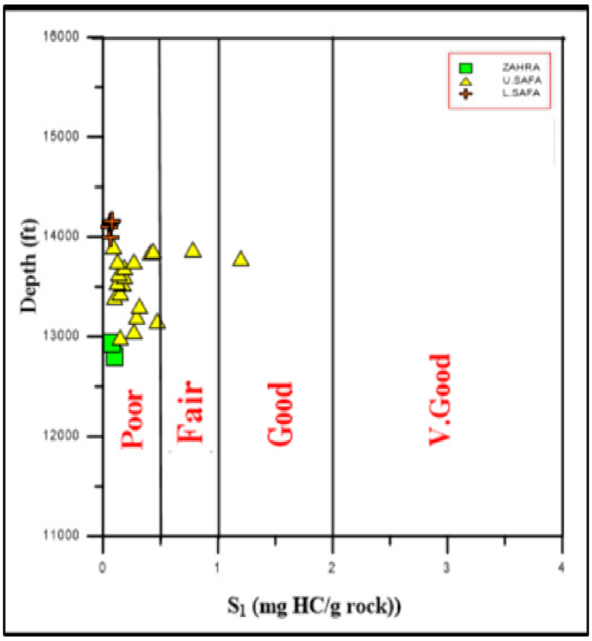

Fig. (4): Hydrocarbon potentiality of the middle Jurassic source rocks, W KAN F-1X, West Kanayes oil field, Western Desert, Egypt.

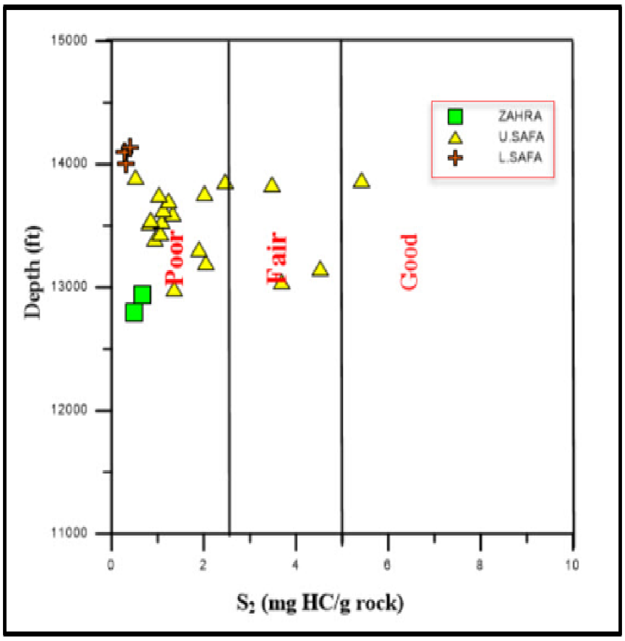

Fig. (5): Hydrocarbon generation of the middle Jurassic source rocks, W KAN F-1X, West Kanayes oil field, Western Desert, Egypt.

4.2. Quality of the organic matter

The organic matter can be qualitatively evaluated by determining the types of kerogen (organic matter) using the Rock-Eval pyrolysis data according to Espitalie et al. (1977). According to Waples (1985) used the hydrogen index values (HI) for immature kerogens to differentiate the types of organic matter. Hydrogen index below about 150 (mg HC/g TOC) indicates a potential source for generating gas (mainly type III kerogen). On the other hand, hydrogen indices between 150 and 300 (mg HC/g TOC) contain more type III kerogen than type II and therefore have marginal to fair potential for liquids. Kerogens with hydrogen index above about 300 (mg HC/g TOC) contain substantial amounts of type II macerals, and thus are considered to have good source potential for generating liquid hydrocarbon and minor gas. Kerogens with hydrogen indices above about 600 (mg HC/g TOC) usually consist of nearly pure type I or type II kerogen. They have excellent potential to generate liquid hydrocarbons. The relationships between HI and OI (Espitalie et al. 1977) for the W KAN F-1X well were also used to detect the kerogen types for the studied Middle Jurassic source rocks. The modified Van Krevelen diagram discusses the relation between the hydrogen index (HI) versus oxygen index (OI) in W KAN F-1X well. The diagram showed that most of the studied samples of Zahra Formation, and Lower Safa member were related to Type-III kerogen that capable to generate mainly gas with minor oil. While the Upper Safa member reflect that the expected kerogen type is also mainly type (III), as shown in Figure (6).

4.3. Maturation levels

The maturation levels of the studied Middle Jurassic source rocks in the W KAN F-1X well Table (1) were detected based on several maturity parameters (%Ro, Tmax and PI). Espitalie et al. (1985) and Peters (1986) reported that if (Tmax < 435 °C and %Ro < 0.5) the organic matters are in immature stage. If (Tmax 435 °C to 465 °C and %Ro 0.5 to 2.0) the organic matters are in mature stage. If (Tmax > 470 °C and %Ro > 1.35) the organic matters are in over mature stage.

The vitrinite reflectance (%Ro) and Max. temperature at which max. hydrocarbons yield (Tmax) values for Zahra and Lower Safa source rocks range from (0.80 to 1.05%) and (435 to 453 °C) respectively, Table (1) reveal that these source rocks are reaches the mature stage Figure (7), whereas Upper Safa source rock has (%Ro and Tmax) values from (1.02 to 1.58) and (432 to 468 °C) respectively, Table (1) reveal that this source rock is reaches the mature and over mature stages Figure (7). The Figure (8) shows that the Zahra and Lower Safa source rocks have ability to generate oil, while Upper Safa has ability to generat oil and gas. The cross plot of HI versus T-max (Espitalié et al., 1985). Determine the thermal maturity and kerogen type, showed that most of the studied source rocks are a mature source rock from type IV to type III gas prone except U. Safa source rocks considered as source rocks of type III to II and are capable to generate a mixture of oil and gas and oil prone as in Figure (9). The cross plot of Tmax versus PI as shown in Figure (10) shows that the studied samples are mature with low rate of conversion, and capable to generate mainly oil with some gas.

Table (2): Input data used for burial and thermal histories models in the studied well.

Layer	Top [ft]	Base [ft]	Thick [ft]	Deposition age from [ma]	Deposition age to [ma]	Lithology
Marmarica	0	286	286	16	11.6	**Limestone**
Moghra	286	1995	1709	23	16	**Sand & Limestone**
Dabaa	1995	3066	1071	37.2	23	**Shale**
Apollonia	3066	3396	330	55.8	37.2	**Limestone**
Khoman	3396	3932	536	83.5	65.5	**Limestone**
Abu Roash	3932	6241	2309	92.5	83.5	**Shale & Limestone**
Bahariya	6241	7088	847	99.6	92.5	**Sand & Shale**
Kharita	7088	8567	1479	112	99.6	**Sand & Siltstone**
Dahab	8567	8720	153	114	112	**Shale & Limestone**
Alamein	8720	8962	242	119	114	**Dolomite**
AEB - 1	8962	9196	234	120.8	119	**Shale & Sand**
AEB -2	9196	9339	143	121.7	120.8	**Sand & Limestone**
AEB -3	9339	10403	1064	124	121.7	**Sand & Shale**
AEB -4	10403	10431	28	138	136.2	**Shale & Siltstone**
AEB -5	10431	10916	485	144	138	**Sand & Siltstone**
AEB -6	10916	11852	936	152	144	**Shale & Sand**
Masajid	11852	12693	841	163	152	**Limestone**
Zahra	12693	13009	316	163.7	163	**Shale & Limestone**
U. Safa	13009	14013	1004	164	163.7	**Shale & Siltstone**
L. Safa	14013	14180	167	166.5	164	**Sand & Shale**

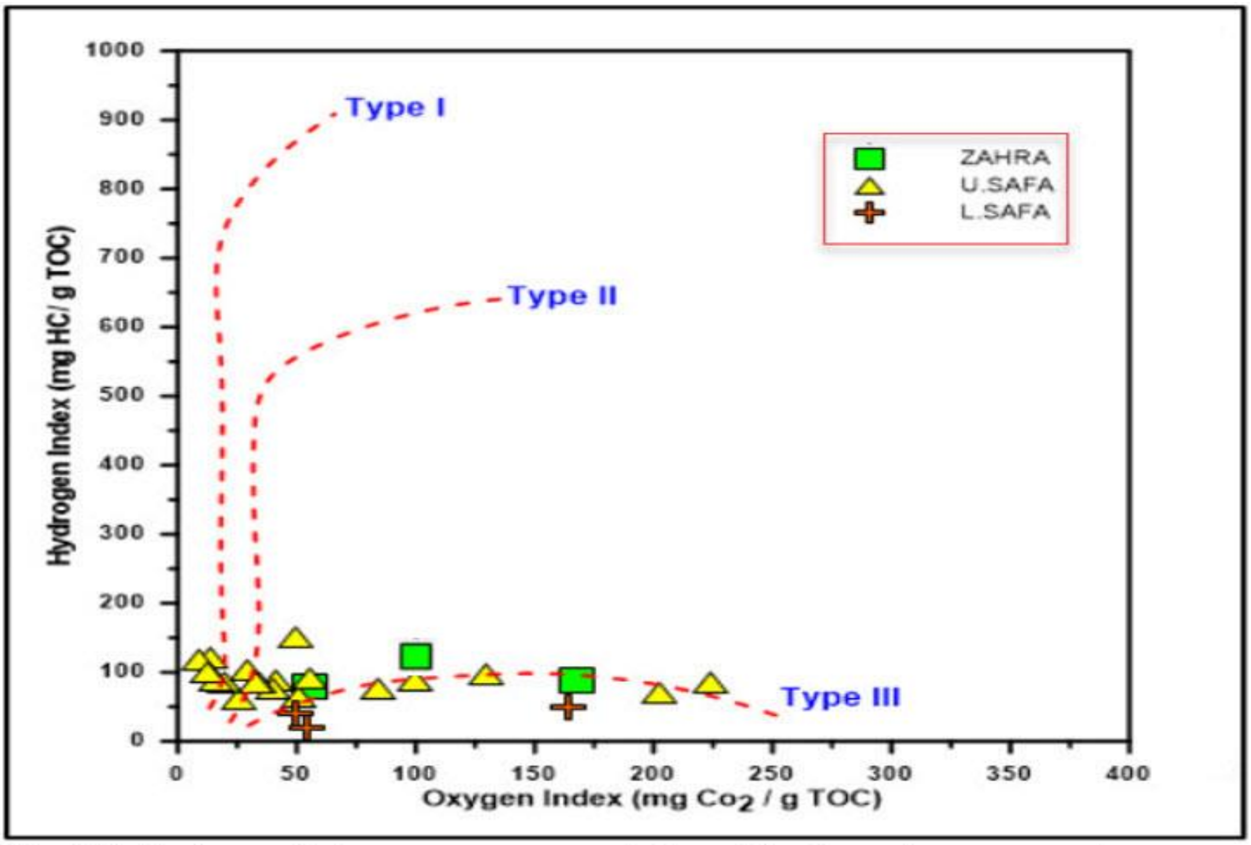

Fig. (6): Hydrogen index versus oxygen index of the Jurassic source rocks.

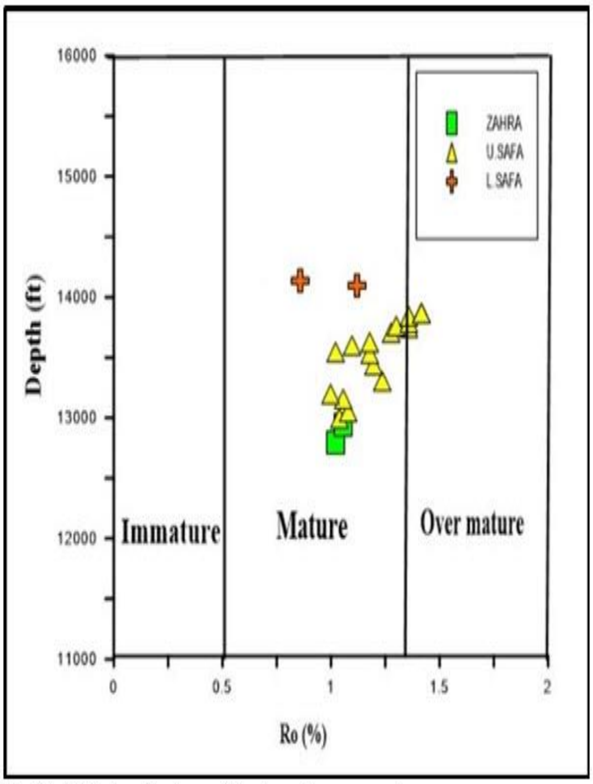

Fig. (7): Vitrinite reflectance of the Jurassic source rocks.

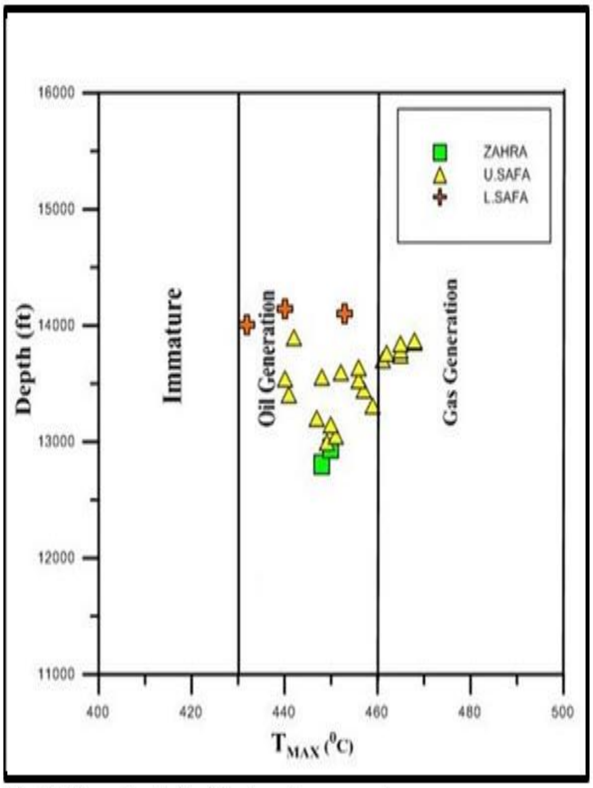

Fig. (8): Thermal maturity of the Jurassic source rocks.

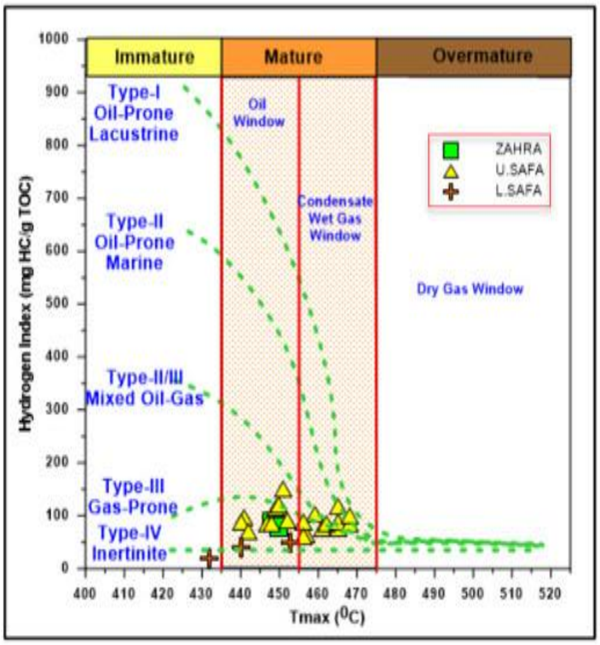

Fig. (9): Plot of (HI) versus (Tmax) for the studied samples recovered from WKAN F-1X well, West Kanayes oil field, Western Desert, **(Espitalié et al., 1985).**

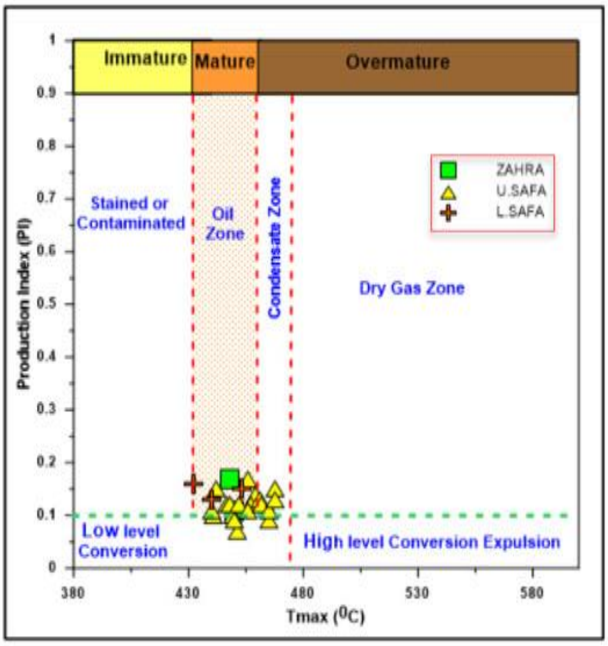

Fig. (10): Tmax versus PI of the studied source rock from W KAN F-1X well, West Kanayes oil field,Western Desert,(modified after **(Langford and Blanc-Valleron,1990)**

4.4. Basin modeling

Basin modeling is used to understand the geological and thermal evolution of a sedimentary basin (Welte and Yalcin, 1988; Burrus et al., 1991; Littke et al., 1994; Barker, 1999). The basin model integrates the geochemical, geophysical and geological basin properties from which oil and gas generation

and migration as well as the temperature and pressure evolution in a basin can be calculated (Welte and Yükler, 1981; Wygrala, 1988). In the study at hand, the basin simulation software PetroMod 1D was used for modelling the petroleum history of the West Kanayes field located in Matruh Basin, North Western Desert, Egypt. Well control for the basin model is provided by one well (W KAN F-1X) in the study area. All modeling input data, including events such as erosion, deposition, hiatus, or non-deposition, the present depth, the lithology of the formations, and the present thicknesses, are given in Table (2). The model was calibrated against both the measured %Ro and the present-day temperatures of the above well by adjusting the geothermal gradient (GG) until matching was observed.

4.4.1 Burial and Thermal Histories

The burial history modeling is an important method to interpret the geo-history of a basin and to predict the timing and extent of petroleum generation in sedimentary basins. It is crucial in determining the generation, migration and preservation of hydrocarbons in the basin. This modeling is dependent upon a sound regional model for the tectonic and depositional history of the basin (Waples, 1994). During the burial history of the area the source rock is not qualified as an effective hydrocarbon generator before, it maintains sufficient thermal maturation. Although it involves a complex series of reactions it can be though simply as a cooking process. Both time and temperature play the major roles in the maturation where, low temperature with long time gives the same results as high temperature with short time (Tissot and Welte, 1984). In this study, the present-day Geothermal Gradients (GG) of each studied well was calculated using the corrected BHTs such that

GG= (corrected BHT-Surface temperature) × 100/Total depth (Oehler, 1983) (1)

The calculated geothermal gradients from temperature logs are listed in Table (3). Figure (11) shows the geothermal gradients map calculated for the study area, which indicates that the geothermal gradient almost the same with little increases toward the center and southwest directions of the study area. The geothermal gradient ranges from 1.44 ºF/100 ft -1 in W KAN E-1X well to 1.42 ºF/100 ft -1 in W KAN I-1X that a provide a favorable condition for the source rock maturation and petroleum generation especially with long time. The re-constructed burial histories of the studied well (W KAN F-1X) in west Kanayes oil field (Matruh Basin) by time-depth history plots after applying the temperature effects show a close relationship to the basin tectonic evolution and the distribution of temperature through the basin Figure (12).

Table (3): Geothermal gradients calculated from temperature data of the wells.

Well Name	Geothermal Gradient (°F/100ft $^{-1}$)
W KAN D-1X	1.43
W KAN E-1X	1.44
W KAN F-1X	1.43
W KAN I-1X	1.42
W KAN N-1X	1.43

4.4.2 Timing of hydrocarbon generation

Burial history modeling of the different hydrocarbon-bearing rock units in the studied area, help us to determine the time and amount of hydrocarbon generation in W KAN F-1X well. The construction of burial history model, is showed that we have two source rocks in Khatatba formation (Zahra and U. Safa). The Zahra and U. Safa source rocks started the oil generation at the Early Cretaceous, with difference in the timing of oil window, whereas it recorded at 103 Ma at depth 6158 ft. and 108.23 Ma at 5865 ft. respectively. The Zahra source rock still in oil generation until today, there is no gas generation yet. While U. Safa are still in oil generating until the first onset of gas generation during the Late Cretaceous at 77.53 Ma at depth 11686 ft., and then continue in gas generation with a minor appearance until today. As shown in Table (4) and as illustrated in the burial history & hydrocarbon zones of the study well in Figure (13).

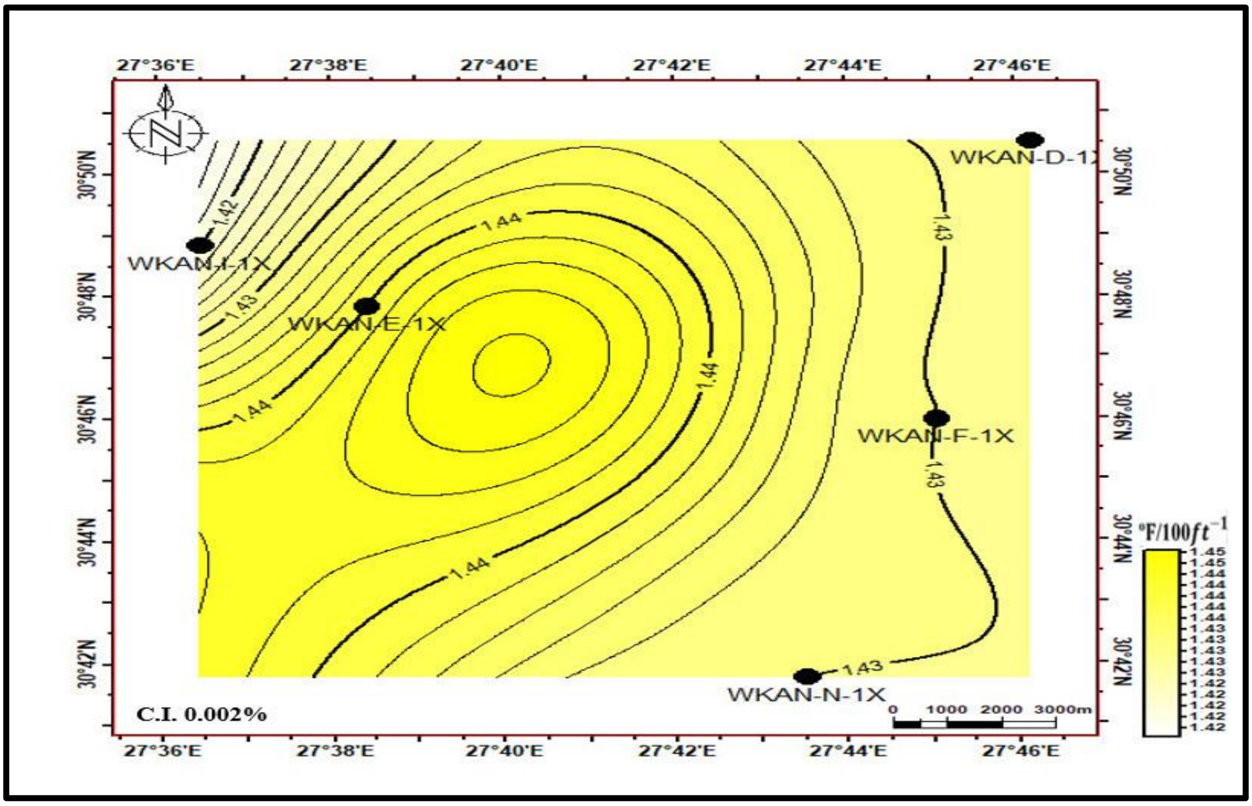

Fig. (11): Geothermal gradients map (ºF/100ft $^{-1}$) of the study area

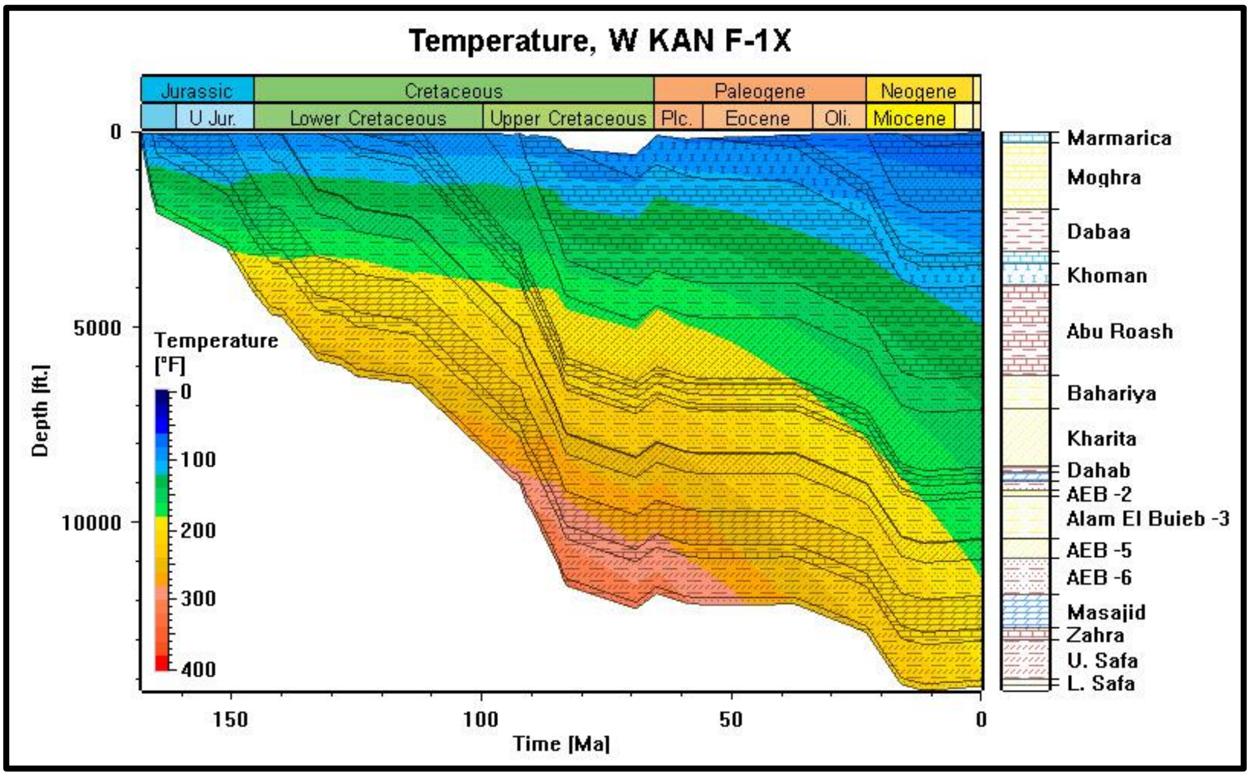

Fig. (12): Burial and thermal history in the study well W KAN F-1X, West Kanayes oil field, Western Desert, Egypt

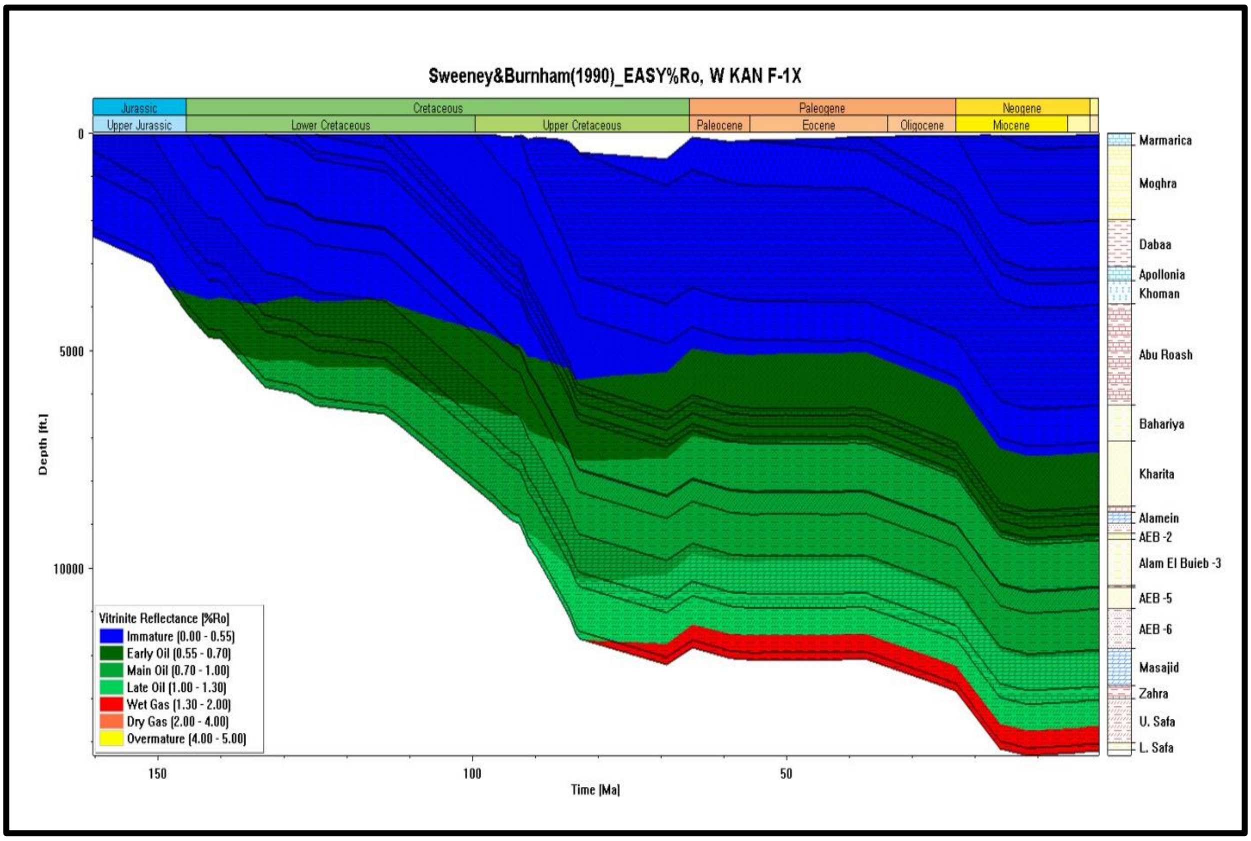

Fig. (13): The burial history and hydrocarbon zones in W KAN F-1X well, West Kanayes oil field, Western Desert, Egypt.

Table (4): Depth and time of the hydrocarbon generation of the study area.

Source Rock	Oil Window			Gas Window		
	Time (ma)	Depth (ft)	Age	Time (ma)	Depth (ft)	Age
ZAHRA	103	6158	Early Cretaceous until today	No Gas Generation		
UPPER SAFA	108.23	5865	Early Cretaceous	77.53	11686	Late Cretaceous until today

4.4.3 Transformation ratio and hydrocarbon generation rate

Transformation ratios give information on the fraction of convertible kerogen that converted at a given time and temperature. The nature of the organic matter and the temperature history in time, and of lesser importance pressure, determine the temperature corresponding to the thresholds and the volumes of hydrocarbons generated, during the evolution stages of kerogen in hydrocarbon formation Tissot and Welte, (1984). The hydrocarbon generation of the Zahra source rock started hydrocarbon generation during the Early Cretaceous and still in generation until finished generation during the Eocene time, where the transformation ratio of the source rock ranged from TR 4 % and continue in transformation until reached the peak of transformation ratio equals TR 93%, as shown in Figure (14). While the U. Safa source rock started the hydrocarbon generation during the Early Cretaceous with a small peak, but the main phase of oil generation was started during the Late Cretaceous time at 86 Ma, then continued oil generation until finished generation during the Paleocene time, where the transformation ratio reached the maximum ratio TR 96 % and there is no gas generation as shown in Figure (15).

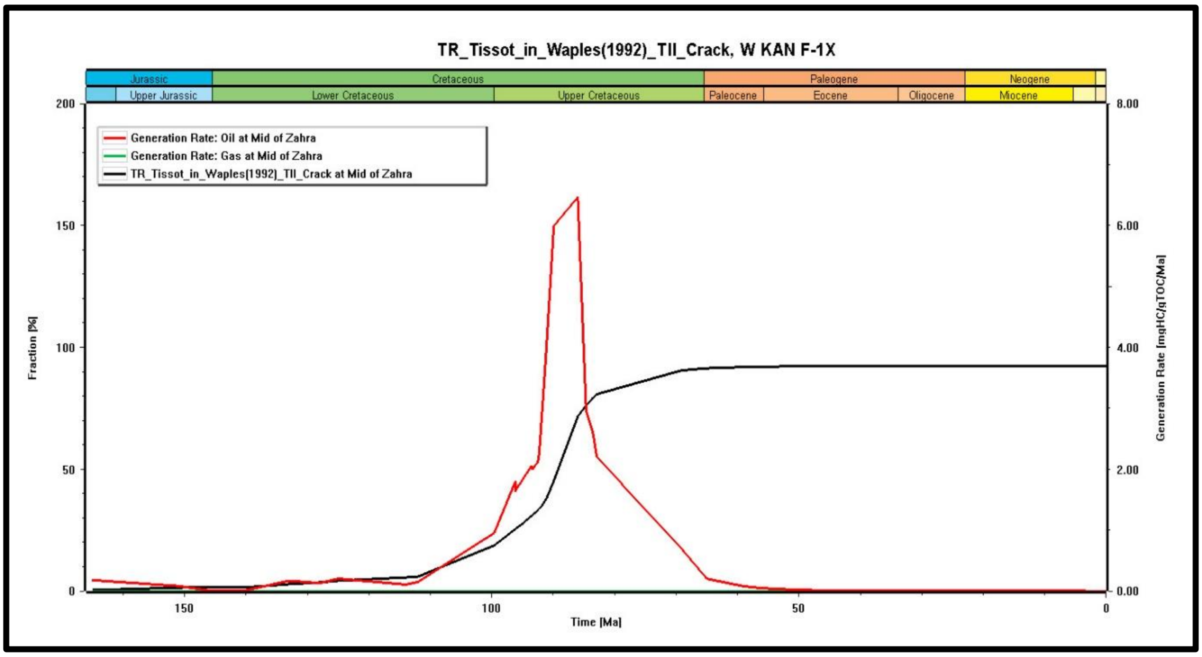

Fig. (14): Plot of the transformation ratio and rate of hydrocarbon generation from ZAHRA source rocks in W KAN F-1X well

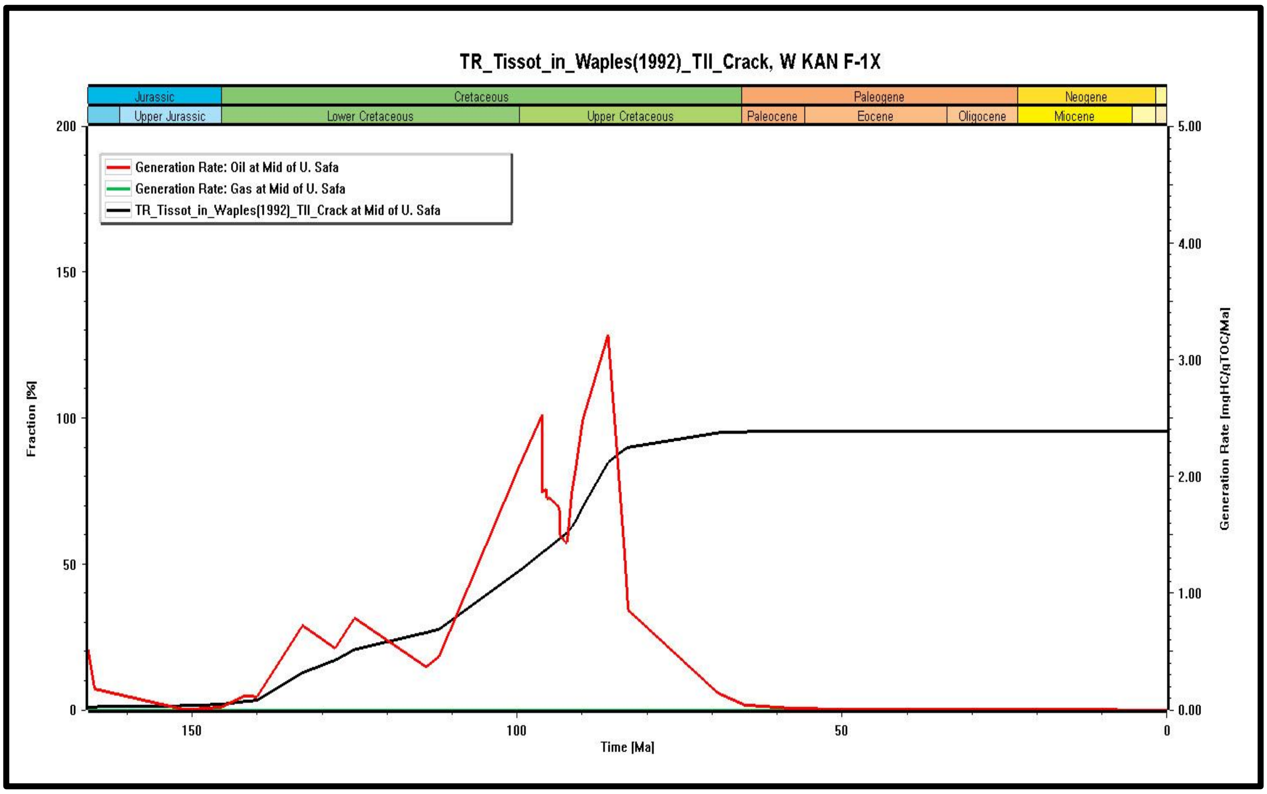

Fig. (15): Plot of the transformation ratio and rate of hydrocarbon generation from U. SAFA source rocks in W KAN F-1X well.

5. Conclusions

The main conclusions of this study can be summarized as follows:

- Based on the TOC and Rock-Eval pyrolysis results, Zahra Formation has a poor to fair organic carbon richness and the Upper Safa member source rock has a fair to excellent organic carbon richness and the Lower Safa member has a fair to good organic carbon richness. The S1 values range from 0.05 to 1.2 mg/g rock with average value of 0.12 mg/g rock, therefore it is considered a poor potential source rock for all of the studied formations. Also, the values of S2 which range from 0.29 to 11.56 mg/g rock with average value 1.41 mg/g rock reflects a poor to fair hydrocarbon generation source rock in most formations source rocks, except in Upper Safa member which is consider a poor to very good hydrocarbon generation source rock.
- The HI and OI values indicate that the kerogen is mainly Type III (Zahra Fm. and Lower Safa member) with a terrestrial origin, mixed Type III/II (Upper Safa member) with marine and terrestrial origins.
- The maturity parameters (%Ro and Tmax) and the burial history models indicate that, Zahra and Lower Safa source rocks are located in mature stage while the Upper Safa source rock is located in mature and over mature stages, these source rocks have entered the main oil and gas generation stages.
- The hydrocarbon generation of the Zahra source rock was started oil generation during the Early Cretaceous time at 103 Ma at depth 6158 ft., and still in oil generation until today, where the transformation ratio reached to TR 93%, and the Upper Safa source rock started the oil generation during the Early Cretaceous time at 108.23 Ma at 5865 ft, then continued oil generation until the first onset of gas generation during the Late Cretaceous at 77.53 Ma at depth 11686 ft, where the transformation ratio reached the maximum ratio TR 96%.

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