

Basin Modeling Using the Source Rock Evaluation and Oil Characterization of the Cretaceous Succession in West of Nile Area, Western Desert, Egypt

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ABSTRACT

The study area is located in the western side of Beni Suef Basin, between latitudes 29° 04'-28° 59' N and longitudes 30° 53'-30° 57' 55" E in the northeastern Western Desert which considered the most important petroleum province in Egypt. The present work deals with the geochemical evaluation for both source and reservoir rocks of the Cretaceous sequence in terms of source rock evaluation and oil-source correlation. The source rock evaluation was carried out through the geochemical analysis, which was based mainly on laboratory chemical and microscopic analyses of sample sets chosen from WON C-3X well, and resulted in a determination of the amounts and types of organic matter and their maturity. Two source rock systems were identified, the first is from the Turonian represented by Abu Roash "F" and the second is from the Lower Albian represented by Lower Kharita Shale. The geochemical results inferred that Abu Roash "F" is considered as a strongly oil-prone source rock (I-II kerogen type), has well-preserved amorphous organic matter, and contributed to oil accumulation in Abu Rosh "G" reservoir in the study area. On the other hand, Lower Kharita Shale is considered as a strongly gas-prone source rock (III kerogen type), has amorphous organic matter and humic debris matter, and contributed to oil accumulation in Lower Kharita sand reservoir.

Keywords: West of Nile; Oil characterization; Geochemical evaluation

INTRODUCTION

The present work aims to determine and evaluate the Cretaceous Succession in West of Nile area (WON), through the interpretation and integration between the available data set of the source and reservoir rocks. The area under study considered as a part of Qarun Petroleum Company' development leases which located between latitudes 29° 04'-28° 59' N and longitudes 30° 53'-30° 57' 55" E, Beni Suef Basin, northeastern Western Desert, Egypt (Figure 1).

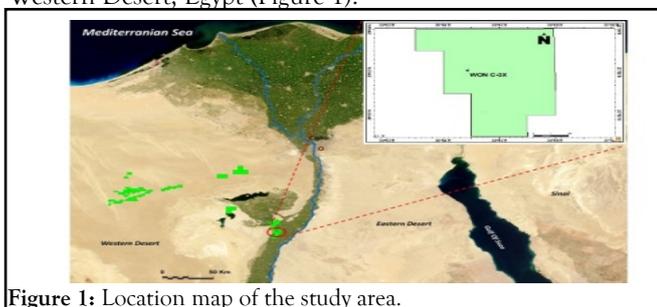


Figure 1: Location map of the study area.

The area is under exploration so far and considered as one of the main prospective portions for petroleum exploration in the area located to the west of the Nile River in Beni Suef Basin (Figure 2).

Among more than 30 exploratory and development wells scattered across the examined area, one of them selected for the source rock evaluation in this work represented by WON C-3X well which was drilled in April 2012 as an appraisal well by Qarun Petroleum Company to a total depth of 11,775 feet in Basement wash.

The well was considered as the second well in West of Nile (WON) area which encountered several pay intervals (Abu Roash "G"=11' and Lower Kharita sand=26') and has tested +500 BOPD from Abu Roash "G5" sand.

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Received: March 29, 2021; **Accepted:** April 12, 2021; **Published:** April 19, 2021

Citation: EL-Gawad EAA, Fathy M, El-Sherbiny M (2021) Basin Modeling Using the Source Rock Evaluation And Oil Characterization of the Cretaceous Succession in West of Nile Area, Western Desert, Egypt. J Geol Geophys. 10:988.

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Showed a dominant foraminiferal and local dolomitic wackstones. Planktic forams are the major allochems with subordinate quantities of Echinoderms, Molluscs, and other undifferentiated bioclast debris, the matrix is dominantly micrite, locally replaced by Ferron dolomite and pyrite, with an abundance of hydrocarbon stained, Micritised detrital clays and the reservoir quality is very poor [3].

MATERIALS AND METHODS

They include the source rock evaluation through the geochemical analyses by using screening analysis of one-hundred and sixty-three (163) cuttings samples to determine the Total Organic Carbon (TOC), one-hundred and twelve (112) cuttings samples were analyzed by Rock-Eval pyrolysis, twenty-eight (28) cuttings samples were submitted for visual kerogen microscopy analysis, which included kerogen typing, vitrinite reflectance (Ro) assessment, and Thermal Alteration Index (TAI). Besides, four cuttings samples from the Abu Roash "F" source interval were selected for extract characterization and correlation with the analyzed oils from WON C-3X.

For the gases, there are fifty-two (52) IsoTubes (5300-11770 ft.) and forty-six (46) IsoJars (5300-11775 ft.) samples were submitted for compositional gas analysis, followed by isotopic compositional analysis ($\delta^{13}\text{C}$ and $\delta^{13}\text{D}$ Methane) for thirty-six

(36) samples, and only five (5) headspace gas samples were submitted for hydrogen isotopic ($\delta^{13}\text{D}$ Methane) analysis of methane.

Regarding the oil samples, geochemical analyses were carried out on two crude oil samples obtained from WON C-3X well, which recovered from the Abu Roash "G" Member at the depths of (6628-6638 ft., 6657-6664 ft., 6680-6692 ft) and the Lower Kharita Member at depth of (11206-11318 ft.). The analytical methods included API gravity determination, whole-oil gas chromatography with detailed C4-7 gas chromatography, liquid chromatography by MPLC, carbon isotopes, gas chromatography/mass spectrometry (GC/MS) on the saturate and aromatic fractions.

Rock-eval pyrolysis data

Espitalie published the first paper on Rock-Eval pyrolyzer application, which involved passing a stream of helium through a pulverized rock at 300°C, and then the temperature is programmed to increase [4]. Rock-Eval pyrolysis data give information about the quantity, type, and thermal maturity of the organic matter. The results including four basic parameters (S1, S2, S3, and Tmax). Peak (S1) represents any free hydrocarbons in the rock, which either were present at the time of deposition or generated from the kerogen since deposition. (S2) peak represents the genetic potential hydrocarbon would be generated by cracking the kerogen until only the residual non-generation carbon remains. (S3) peak represents the amount of oxygen present in the kerogen. T-max is the temperature at the highest yield of the (S2) peak. Waples [5] suggested an

interpretation for the Rock-Eval. Pyrolysis data as shown in Table 1.

Quality	TOC wt. %	SI mg Rock	HC/g S2 mg Rock	HC/g
Poor	0.0-0.50	0.0-0.50	0.0-2.5	
Fair	0.5-1.0	0.5-1.0	2.5-5.0	
Good	1.0- 2.0	1.0-2.0	5.0-10.0	
Very Good	> 2.0	> 2 .0	> 10	

Table 1: Evaluation of Rock Eval. Pyrolysis data.

Maturity and kerogen analysis

The type of organic matter is considered the second important organo-geochemical parameter in evaluating the generating potential of source rock because it completes the identification of the organic status. The type of organic matter is determined by a visual study of the isolated kerogen and also by Rock-Eval Pyrolysis. Visual Kerogen Analysis (VKA) was done by Zeiss Universal microscope system equipped with halogen, xenon, and tungsten light sources. Vitrinite Reflectance measurements (Ro) are performed on a polished plug in reflected light, while the Thermal Alteration Index (TAI) is performed on a strewn slide in transmitted light.

Oil sample analysis

The identifying and characterizing of the physical and chemical properties of the crude oils are very important because it provides accurate and valuable information that helps to relate them to specific source rocks, measure their grade of maturation, and determine the possible migration pathways.

Whole oil gas chromatography: A sample of whole oil is injected directly into a gas chromatograph to obtain the gas chromatography (GC).

Biomarkers: The relative amount of normal Alkanes, Isoprenoids, and Aromatics are characteristics of the source and should be essentially the same for oils derived from a particular source rock and its extract. Biological markers (Biomarkers) are complex molecular fossils from once-living organisms that are ubiquitous in sediments, rocks, and crude oils [6]. Biomarkers have a variety of applications in petroleum exploration such as oil-source rock correlations, Source thermal maturity, and Source age determination.

RESULTS AND DISCUSSION

Gas samples analyses

The interpretation of the gas data support the following observations: Total mud gas hydrocarbon concentrations range from 14 ppm to 14305 ppm and the highest concentration of 14305 ppm occurs within the Lower Kharita Member at 11317 ft. (Figure 6). Methane (C1) is present throughout the analyzed

section in generally very low to moderate concentrations (mostly <1000 ppm). The heavier components (C2+) are also present and generally show the same distribution as methane but in lower concentrations (mostly <100 ppm).

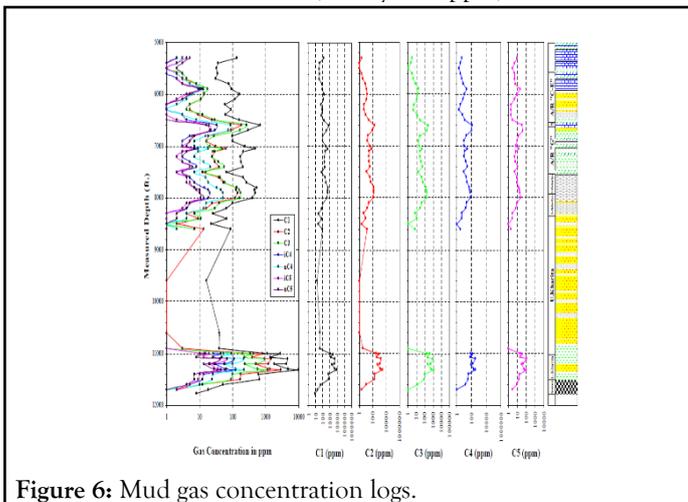


Figure 6: Mud gas concentration logs.

The total headspace gas hydrocarbon concentrations are generally much higher than the mud gases and range between 214 ppm and 645,171 ppm and the maximum headspace gas concentration of 645,171 ppm is recorded within the Abu Roash “G” Member at 7400 ft. Neglecting this sample (analyzed in duplicate), which may have been affected by bacterial activity, the maximum headspace gas concentration is 36125 ppm, which is recorded within the Lower Kharita Member at 11200 ft. Methane (C1) is present throughout the analyzed section, in many instances incomparable or lower concentrations than the C2+ gases (Figure 7).

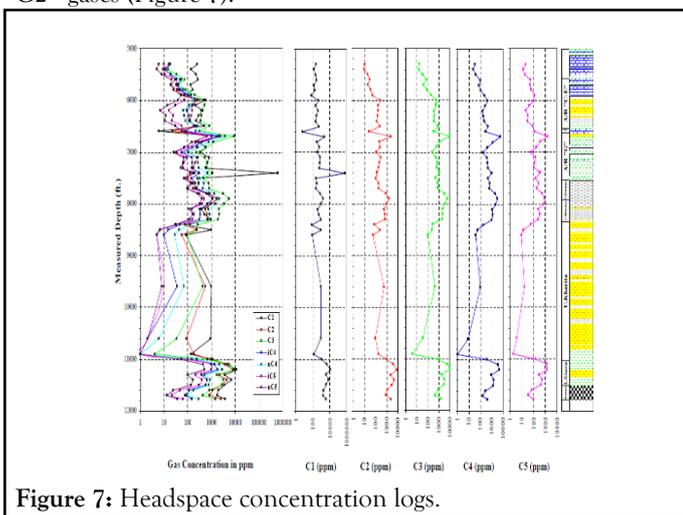


Figure 7: Headspace concentration logs.

The stable carbon isotopic values of methane ($\delta^{13}C_1$ values) for mud gases range from -41.1% to -46.9% (Figure 8), while for headspace gases range from -36.0% to -48.0% (Figure 9)

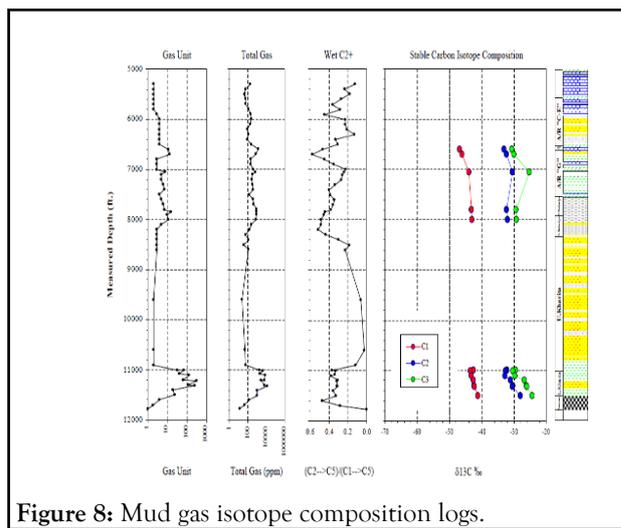


Figure 8: Mud gas isotope composition logs.

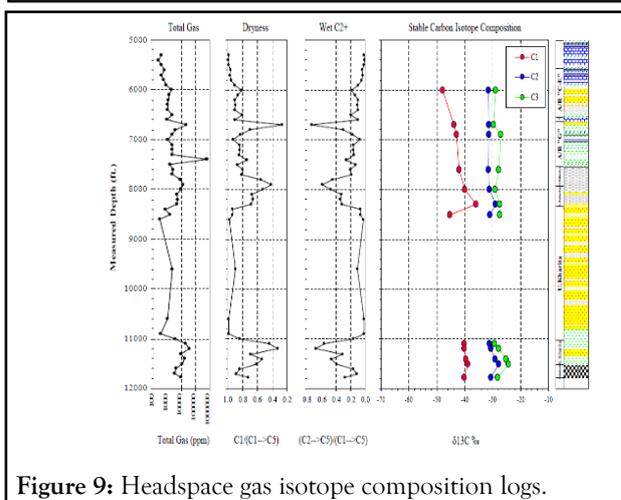


Figure 9: Headspace gas isotope composition logs.

Also, we can determine the thermogenic origin of the gases in the interval from the Abu Roash "F" to the Lower Kharita Members based on Bernard diagram (Figure 10).

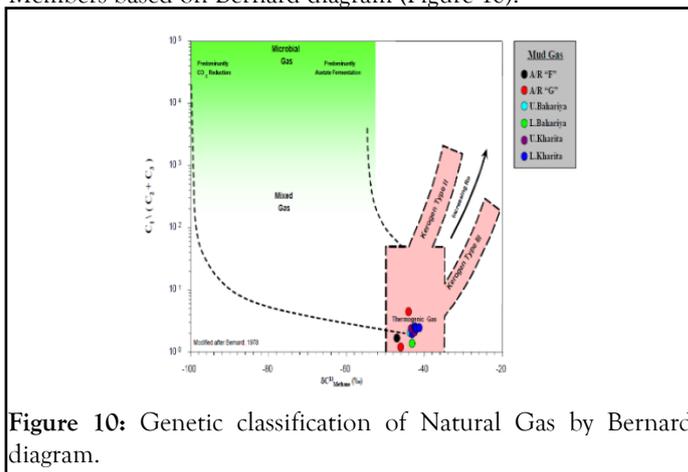


Figure 10: Genetic classification of Natural Gas by Bernard diagram.

Oil sample analyses

General characteristics of the oil: The whole-oil gas chromatogram shows an n-alkane distribution from n-C4 to n-C41 (Figures 11 and 12). The measured API gravity value was quite low for Abu Roash “G” (23.6°), while it was (47°) for Lower Kharita which can be termed “waxy” because of the broad distribution of waxes $\geq n-C_{25}$ in high concentrations resulted in

the high measured API gravity (47°) since waxes are less dense than other oil components.

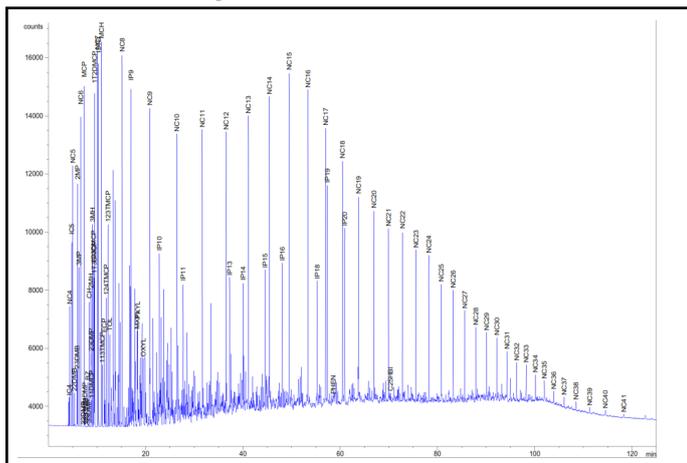


Figure 11: Whole-oil gas chromatogram of Abu Roash "G".

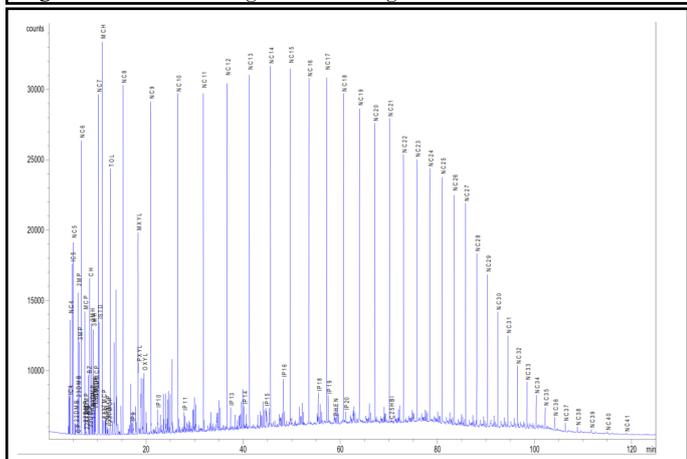


Figure 12: Whole-oil gas chromatogram of Lower Kharita.

Source characterization from oil geochemistry: For this concern, Isoprenoid/n-alkane ratios plot was used which depends on the relative abundances of Pristane/n-C17 and Phytane/n-C18 as indicators of biodegradation, maturity, and organic facies (Figure 13).

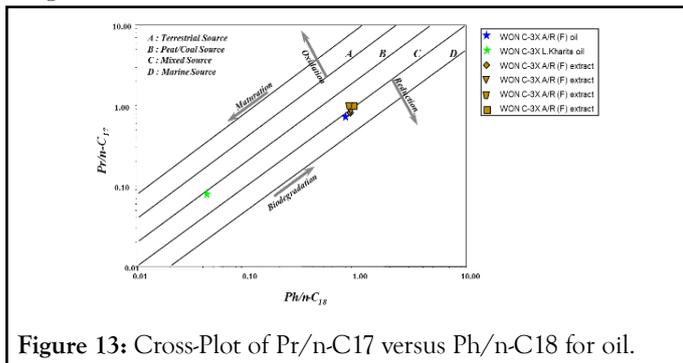


Figure 13: Cross-Plot of Pr/n-C17 versus Ph/n-C18 for oil.

For Abu Roash "G" oil the Pr/Ph ratio (1.25), and the pristane/n-C17 and phytane/n-C18 ratios of 0.79 and 0.72, respectively, suggest that this oil was generated from predominantly marine organic matter with perhaps some terrestrial input at a low to moderate thermal maturity.

On the other hand, the Lower Kharita oil the Pr/Ph ratio is 2.39, and the pristane/n-C17 and phytane/n-C18 ratios are very

low at 0.08 and 0.04, respectively. These data suggest that this oil was generated from predominantly terrestrial organic matter (peat/coaly source (?)) with perhaps some marine and/or lacustrine input.

Oil thermal maturity: In order to estimate the expulsion temperature and assess the maturity of the hydrocarbon several plots have been used. Based on the modified cross-plot of or light hydrocarbon parameters (Figure 14) we can determine that [7].

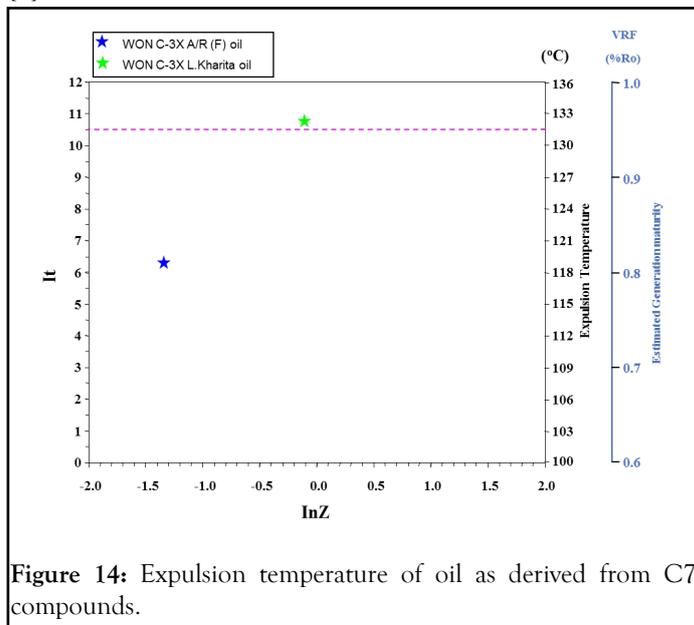


Figure 14: Expulsion temperature of oil as derived from C7 compounds.

The analyzed oil of Abu Roash "G" has It value of 6.30, for which the C7-derived expulsion temperature is ~119°C, which corresponds to a maturity level of about 0.8% Ro equivalent and in perfect agreement with the assessed maturity of the associated gas.

The Lower Kharita oil has It value of 10.8, for which the C7-derived expulsion temperature is about ~132°C, which corresponds to a maturity level of about 0.97% Ro equivalent and is about the same as the gas maturity from the gas in the same reservoir and likely means that the oil and gas are co-genetic.

The oil bulk composition ternary diagram (Figure 15) suggested that the Abu Roash "G" oil sample is dominated by saturates (51.9%), with an elevated amount of aromatics (17.5%), and a fairly high NSO+Asph content (30.6%). Such a composition indicates that the oil was derived from a source rock at early to mid-oil window maturity.

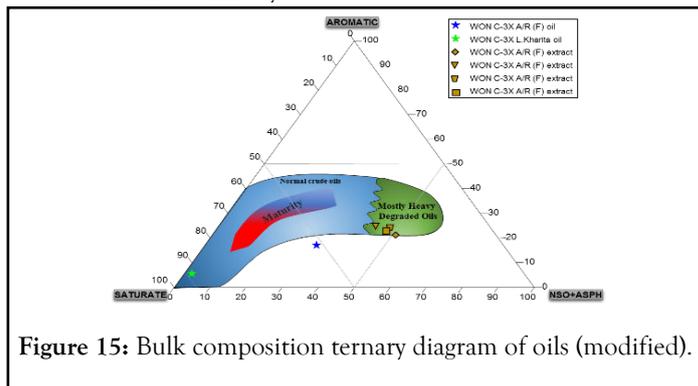


Figure 15: Bulk composition ternary diagram of oils (modified).

The Lower Kharita oil sample is dominated by saturates (92.34%), with a low amount of aromatics (5.38%), and a very low NSO+Asph content (2.28%). Such a composition suggests that the oil was derived from a source rock at late oil-window maturity but is also influenced by the waxiness of the oil. These data are in agreement with the maturities derived from the It value (Figure 14) and the associated gas.

Extract characterization

The screening analysis (Rock-Eval pyrolysis) indicated that the carbonate-rich rocks from the Abu Roash "F" member are highly oil-prone source rocks with high total organic carbon contents (1.99-2.78 wt%) and very good hydrocarbon generating potential for mainly oil (pyrolysis S2 yield of 8.60-17.35 mgHC/g Rock and HI values of 432-626 mgHC/gTOC). The samples show pyrolysis S1 values of 0.39-1.25 mgHC/g Rock, resulting in low Production Indices ($\ll 0.10$), suggesting that the encountered free hydrocarbons from the Abu Roash "F" member is due to in-situ generated free hydrocarbons without influence from migrated hydrocarbons or contamination. This means that the extracts represent the source rock, so if they match an oil, there is a very high likelihood of correlation between the source rock and the oil(s). The measured Tmax values are 428-430°C for the Abu Roash "F" rocks, suggesting early oil-window-mature source rocks ($\sim 0.60\%$ Ro_{eq}) at their current depth and locality.

Based on Figures 13 and 15 we can determine that the samples were generated from source rocks deposited in an anoxic environment with dominantly marine organic matter at moderately low thermal maturity, the level of thermal maturity for both the host rocks and the associated bitumens is $\sim 0.60\%$ Ro_{eq} and have saturate/aromatic ratios between 1.17 and 1.50 and contain 44.0 to 52.4% non-hydrocarbons (NSO+Asphaltenes).

Oil-source rock correlation

Oil-source rock-correlation between the oil recovered from the Abu Roash "G" Member in WON C-3X well and the extracts from the same well is very similar since the rocks from the A/R "F" member is excellent, oil-prone sources at early oil-window thermal maturity.

Basin modeling

A quantitative analysis of the subsidence rates through time called burial history, relies primarily on the de-compaction of stratigraphic units to their present thickness at the time of interest [8].

Before constructing the burial history, the essential input data were prepared, which included the formation tops from ground levels, the absolute time of deposition (in millions of years), the hiatus age, the lithologic composition, the thickness and age of the eroded intervals, and the heat flow data calculated from the observed geothermal gradients, whereas the average porosities and densities of these reservoir units were determined from the petrophysical logs.

The reconstructed burial history of the WON C-3X well by the time-depth history plot, after applying the temperature effect, showed a close relationship to the basin tectonic evolution, and the distribution of temperature through the basin can be noticed (Figure 16).

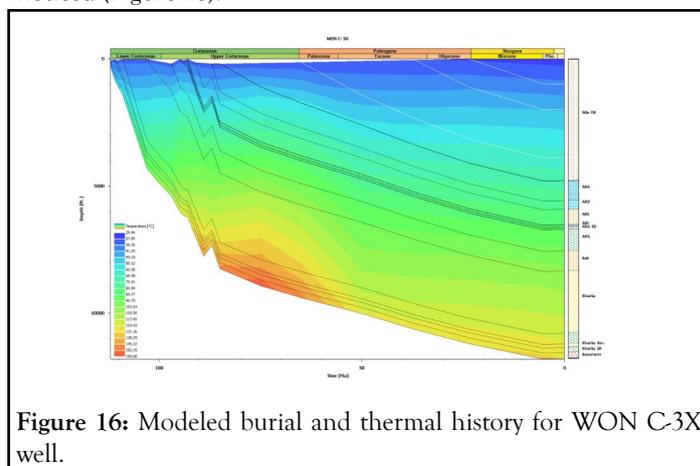


Figure 16: Modeled burial and thermal history for WON C-3X well.

Also, after constructing the thermal and burial history model, and locating the oil window of Abu Roash "F" source rock, by using [9-12] easy %Ro, we found that, the well entered the early oil window (0.55%-0.7% Ro) since the Miocene and still prevalent till now (Figure 17).

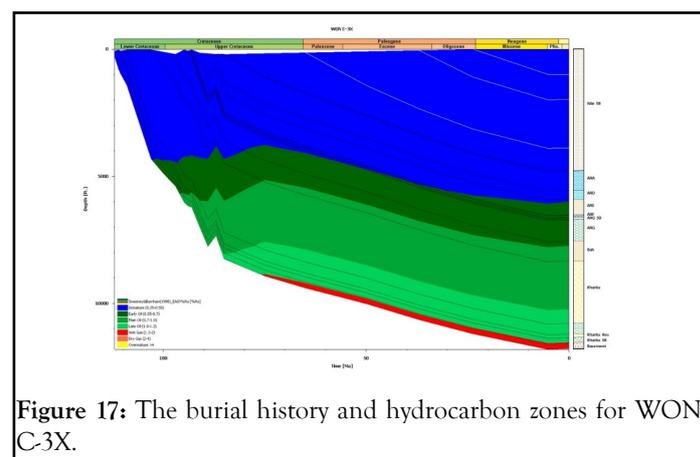


Figure 17: The burial history and hydrocarbon zones for WON C-3X.

Source rock maturity: Based on the calculated vitrinite reflectance values from the basin modeling, the maturity values were categorized by the same manner represented in the basin modeling as, early mature oil (0.5%-0.7 % Ro), mid mature oil (0.7%-1.0% Ro), late mature oil (1.0%-1.3% Ro) and super mature stage (1.3%-2.6% Ro), whereas the mid mature stage represents the main phase of the hydrocarbon generation and expulsion. The 3-D maturity distribution of Abu Roash "F" source reflected the presence of a potential source (immature) at the central part, while the effective source (early mature) at the rest of the area (Figure 18).

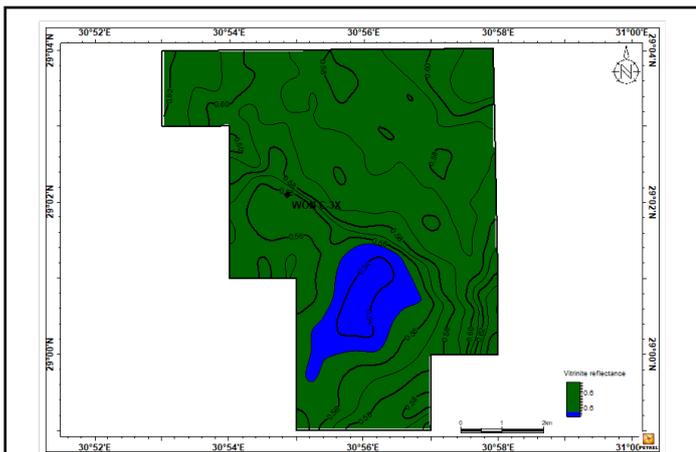


Figure 18: Maturity map for Abu Roash “F” Member in the study area.

Hydrocarbon generation: The proportion of generated hydrocarbon that expelled from the source rock during the main stage of oil formation is strongly dependent upon the type and initial amount of kerogen percent. The Abu Roash “F” Member generation map reflects that, the generated hydrocarbon from the early mature source rock reached about 1180 Kg/m² (Figure 19).

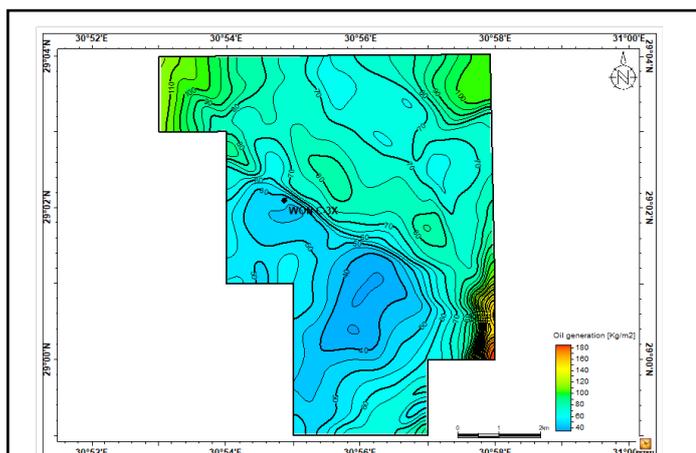


Figure 19: Generation map for Abu Roash “F” Member in the study area.

Migration and accumulation efficiency : Only if sufficient hydrocarbons were generated in the source rock, primary migration (i.e. expulsion of hydrocarbon from the source rock) will occur whether diffusion or pressure-driven mechanisms operate. As might be expected, there is a lag between the onset of petroleum generation and expulsion because a minimum degree of petroleum saturation within the source rock is required.

The possible pathways for hydrocarbon movement (migration pathways) from the expulsion (kitchen) area to the possible areas for hydrocarbon accumulation (trap) are illustrated in Figure 20.

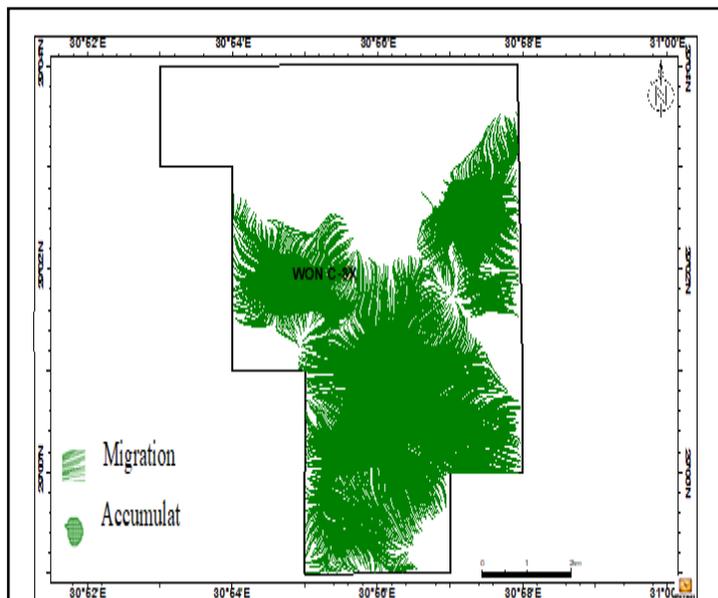


Figure 20: Migration pathways and accumulation areas for Abu Roash “F” Member in the study area.

CONCLUSION

This study is carried out to determine and evaluate the source rock of the Cretaceous Succession in the West of Nile area (WON), through the interpretation and integration between the obtained data either from the source rock (ditch cutting, gases) or reservoir rocks (oil samples). The data were discussed in terms of Total Organic Carbon (TOC), Rock-Eval pyrolysis, visual kerogen microscopy analysis. The stratigraphic succession was defined from the drilled wells in the area, which exhibited rock units ranged in age from the Albian (Kharita Formation), which non-conformably overlain the Pre-Cambrian Basement complex, to the Santonian (Abu Roash “A” Member) while the Khoman and Tertiary rock units (Apollonia, Dabaa and Moghra) were eroded and replaced by the Miocene complex system of old ancestral Nile channel fill. Petrographically, there was a dominant foraminiferal content, with an abundance of hydrocarbon stained and micritised detrital clays, and the reservoir quality is very poor.

The geochemical results revealed that the Abu Roash “F” Member is a source rock, with fair to High TOC and Fair to very good hydrocarbon generating potential, and is considered as a strongly oil-prone source rock (III kerogen type). Also, the kerogen microscopy showed dominated by well-preserved amorphous organic matter (that may be derived from liptinite), associated with rare to moderate amounts of humic fragments (opaque and biostructured phytoclasts), rare to moderate amounts of cuticles, spores, and foraminiferal were observed in a few samples from this interval. The top of the oil window (defined by 0.6% Ro) based on the tentative maturity profile assumed to be encountered close to the top of the Abu Roash “G” Member, while the well-known Abu Roash “F” oil-prone source rocks are currently marginally mature for oil generation. Moreover, the analyzed deeper section below 10800 ft. in the

Kharita Formation is currently in the late-mature stage for oil generation (1.0-1.3%Ro).

The crude oil geochemical analyses were carried out on two samples obtained from WON C-3X well. Abu Roash "G" oil has a low API gravity value (23.6°), unaltered "original" oil, generated from predominantly marine organic matter with perhaps some terrestrial input at a low to moderate thermal maturity, expulsion temperature is about ~119°C, which corresponds to a maturity level of about 0.8% Ro equivalent. On the other hand, the Lower Kharita API was high (47°), subjected to evaporation fractionation or incurred a light-end loss on sample collection and/or handling, generated from predominantly terrestrial organic matter (peat/coaly source (?)) with perhaps some marine and/or lacustrine input, expulsion temperature is ~132°C, which corresponds to a maturity level of about 0.97% Ro equivalent. The oil-source rock-correlation showed a similarity between the oil recovered from the Abu Roash "G" Member in WON C-3X well and the extracts.

The integration between the available data of the penetrated sedimentary units led to the construction of 1-D basin model, to evaluate the burial and thermal history of the sedimentary sequence. The thermal modeling showed that, the oil window in the study area was started during the Miocene age. The maturity distribution throughout the study area reflected the presence of immature Abu Roash "F" sediments occupied the central part of the map, whereas an early mature sediments are located at the reset area. Also, the generated hydrocarbon from the early mature source rock reached about 180 Kg/m², and the migration pathways and accumulation areas were assumed.

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