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Characterization of Source Rock Potential and Basin modelling, Case Study: GPT Oil Field, Abu Sennan Area, North Western Desert, Egypt

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Abstract: Characterization of source rocks is one of the most important goals in oil exploration. The lack of core samples in most of the drilled wells is a problem in characterising source and reservoir rocks. Many attempts are introduced to evaluate source rocks by using open-hole logging data. In the present study wire line logs (GR, RD, ROHB, PHIN and DT) are used to characterise the Upper Cretaceous source rocks in GPT oil field. Moreover, one dimension basin modelling analysis is applied to show the burial history and thermal maturation of the study area. Source rock analysis show that most of the studied units have considerable amount of hydrocarbons, but they are not potentially enough to produce indigenous oil, except for Abu Roash "F" Member which has enough potential hydrocarbons to produce indigenous oil and gas; this reflects the indigenous nature of the encountered hydrocarbons of this member. Burial history modelling of the study area show that Khoman Formation is immature, Abu Roash “D, E, F and G” members are early mature and Abu Roash “F” Member is immature in one of the study wells.

Keywords: Source rocks, wireline logs, total organic carbon, Basin modelling.

I. INTRODUCTION

Most of commercial and non-commercial hydrocarbon accumulation as well as oil and gas shows have been found in the northern part of the Western Desert, north of latitude 29^0, particularly in the Abu Gharadig basin, [1]. The aim of this study is to evaluate the source rock potentials and burial history modeling for the GPT oil field that is located in Abu Sennan concession , southeastern part of Abu Gharadig basin, Fig. (1). The development of the GPT field, through 20 drilled wells revealed several oil pay zones from the Abu Roash sands and carbonates, as well as the gas bearing sands of the Bahariya and Abu Roash Formation. The GPT oil and gas field is the only gas producer from Khoman Formation throughout the Western Desert of Egypt.

The Upper Cretaceous section in the study area exceeds 2300m and includes the Bahariya Formation at the base, the Abu Roash Formation in the Middle and the Khoman Formation at the top, Fig.(2),[3]. Lithologically Khoman Formation (Campanian-Maastrichtian age) consists of two main units: the lower unit is mostly limestone interbedded with shale while the upper unit is of fine-grained white chalky massive limestone and massive dolomite.

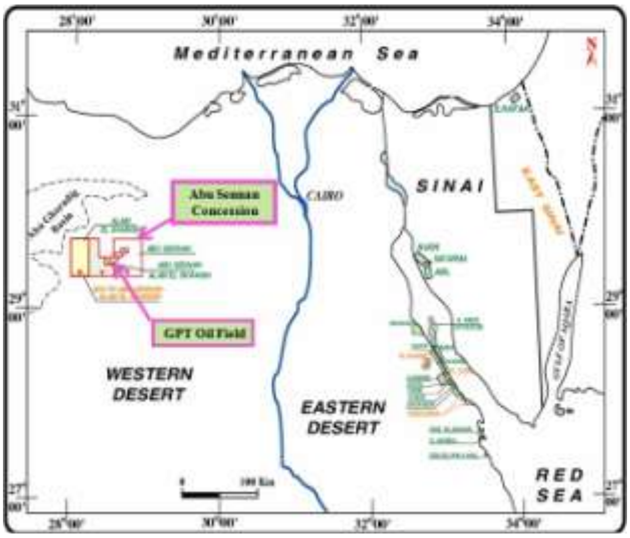

Fig. (1): Location map of the study area.

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Abu Roash Formation, is subdivided into seven lithostratigraphic members, termed from top to bottom as A, B, C, D, E, F, and G, which extend in age from the Santonian to the Upper Cenomanian.
Lithologically this formation consists of carbonates and alternating shales and sandstones. Bahariya Formation (lower Cenomanian) consists of argillaceous sandstone with some carbonates.

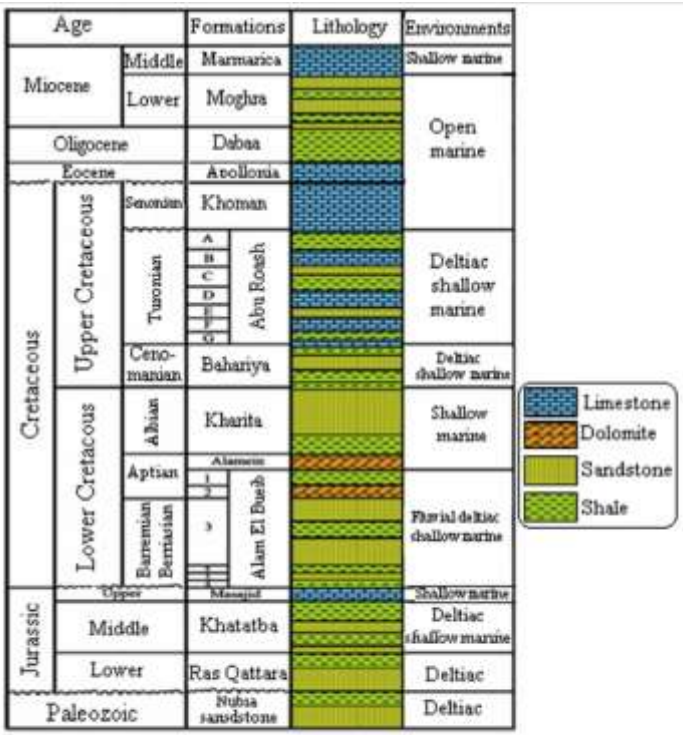

Fig. (2): Generalized stratigraphic column of North Western Desert [3].

II. MATERIALS AND METHOD

The main objective of the present study is to define the source rock, yield and state of maturity, to evaluate the hydrocarbon charge of the Upper Cretaceous formations (Khoman Formation and Abu Roash D, E, F, and G members) in seven wells in the study area,(GPT-1, GPT-2, GPT-5, GPT-9, GPT-10, GPT-14 and GPT-17). The first step in this evaluation begins with showing qualitatively the effect of source rock which is rich by organic materials on some specific types of logs such as; gamma-ray, resistivity, neutron, density and sonic. The second step is the quantitative evaluation by calculating the shale volumes and identifying the source rocks then determining the total organic content (vol. %), total organic carbon (wt %) and discriminating the source rocks from the non source rocks by using the sonic-resistivity or the density-resistivity combinations [2], these parameters will be helpful in defining the type of encountered hydrocarbons [4]. The third step is constructing a 1-D basin model to predict maturity and hydrocarbon generation for the study area. Complete suite of well logs is available for the study area, (GR, RD, DT, ROHB and PHIN).
Source rocks identification on wireline logs: The wireline log-based TOC content evaluation can provide continuous and in-situ results of the target formation. Organic shale formations respond to gamma ray, porosity and resistivity logs differently than the surrounding rocks [4–7].
Gamma-ray, resistivity, density and sonic logs are very helpful for identifying the source rocks. Gamma-ray log reading from organic-rich rock is relatively higher than that from the ordinary shales and limestone. [8, 9]. Regarding resistivity logs; both of shallow and deep resistivity is affected by the presence of organic matter in the shale by increasing of their values, consequently, the resistivity of the source rocks increases by a factor of 10 % or more [10]. The presence of organic matter in shale reduces the total bulk density [11]. The maturity of source rocks affect the sonic log readings in two ways: in case of immature source rock there is an increase of sonic travel time, while there is a decrease of travel time in mature source rock [12]. Figure (3) shows the response of wireline readings to organic matter, the deep resistivity log reading (LLD), increases at depth 1824m-1845m and the density-neutron log reading are low indicating the presence of organic rich rock(reservoir rock). At interval 1865m-1870m, the GR log readings are high and the density-neutron log reading are low indicating organic-rich shale.
Shale volume, total organic content and total organic carbon determination: The accurate determination of shale volume (Vsh) is very important step for further calculation of the formation porosities and the fluid saturation.

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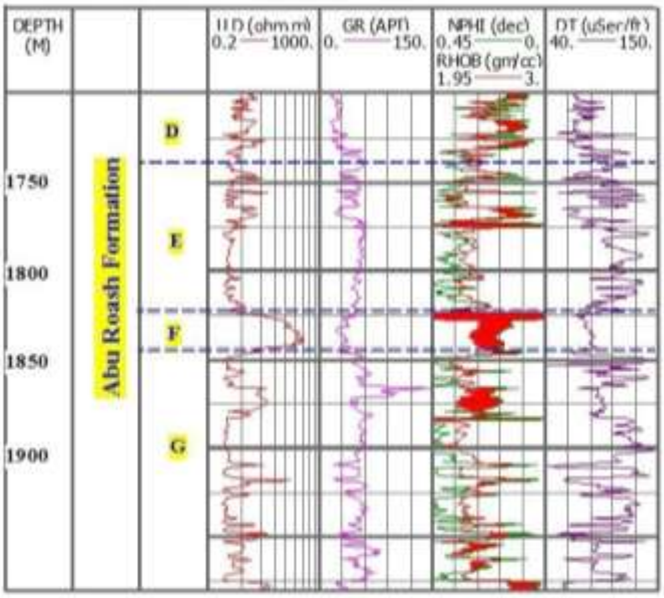

Fig. (3): Log data of GPT-2 well showing the effect of organic matter on log readings.

In front of the shale zones, the porosity tool will record too high porosity values, while the resistivity log will record too low resistivity values. In the present study, shale volume is calculated using a number of single log indicators. Such indicators include volume of shale determination using only one log parameter by applying simple mathematical relationships. The values obtained from gamma ray log are considered the most accurate and are exclusively used in the final interpretations of the shale volume [13, 14].

The total organic content (TORG) of the shale has been calculated for the seven logged wells, using Schmoker equation [15]. The total organic content is calculated for Khoman Formation and Abu Roash “D, E, F and G members” from density log, using Hester et al, equation [16]. Moreover, Passey, et al, [17] technique (ΔLogR technique) is used. This technique depends on overlaying porosity logs (e.g., sonic, density, and neutron) and resistivity logs to calculate the TOC content curves.

Discrimination of source rocks from non-source rocks: Mayer and Nederlof [18], introduced a method used to discriminate between source and non-source rocks, depending on sonic, density and resistivity logs. Accordingly, two equations for the discrimination function (D) are used on the basis of log combinations (sonic-resistivity) and (density–resistivity) to differentiate between source and non source rock. This technique is applied on the shale rocks (Vsh of the studied zones > 30%). Based on such application, the shale beds can be differentiated into three types: source rocks, non-source rocks or undecided, according to the polarities of both the (D) values of the two mentioned combinations, as shown in table (1). The type of the encountered hydrocarbons can be defined from the relationship between the discrimination function (source or non-source) and the hydrocarbon preservation (present or absent), accordingly, four cases are established, [19]:

1- Indigenous hydrocarbons; if the rocks are source and the hydrocarbons are present.
2- Hydrocarbons migrated to other places; if the rocks are source and the hydrocarbons are absent.
3- Exogenous hydrocarbons; if the rocks are non-source and the hydrocarbons are present.
4- No hydrocarbons of any type; if the rocks are non-source and the hydrocarbons are absent.

1-D maturity models: maturity modelling is a method for estimating the level of maturation of the source rocks and predicting depth required for hydrocarbons to generate the source rocks and determining the time of petroleum generation. Source rock maturation and the consequent petroleum generation are controlled mainly by both the geologic time (the age of such rocks) and the temperature gained during their subsidence. The principal objectives of basin analysis are to reconstruct the thermal and burial histories of the basin and understanding the processes and mechanisms by which it is formed; as well as reconstructing the time evolution of sedimentary basin in order to make quantitative predictions of geological phenomena leading to oil accumulations, [20]. The development of Tissot's kinetic model, [21] and Lopatin's TTI model, [22] and the latter's popularization and calibration against vitrinite reflectance (R_0) and thermal alteration index (TAI) by Waples, [23], represented important initial steps in uniting chemical and geochemical technology with geology. According to waples, [24] stages of maturation and types of hydrocarbon products from the calculated vitrinite reflectance (R_0) and time-temperature index, TTI, are as following:

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R_0 % ≤ 0.5 Immature stage (Condensate from resinite)
R_0 % = 0.6 early mature stages
R_0 % = 0.8 Peak generations (Oil generation)
R_0 % ≥ 1.35 late generations (Wet gas & Dry gas)
TTI ≥ 15 onset of oil generation
TTI ≥ 75 peak of oil generation
TTI ≥ 160 end of oil generation

TABLE 1 THE TYPE OF SHALE BASED ON DISCRIMINATE FACTOR.

Discriminate factors	Type of shale
D1 (ΔT) and D2 (ρb) > 0.0	Source Rock
D1 (ΔT) and D2(ρb) < 0.0	Non-Source Rock
D1 (ΔT) < 0.0 and D2 (ρb) >0.0	Undecided as Source Rock
D1 (ΔT) > 0.0 and D2 (ρb) <0.0	Undecided as Source Rock

III. RESULT, APPLICATION AND DISCUSSION

The calculated values of shale volume (Vsh) and total organic carbon content (TOC %) are represented in table (2) and (3) respectively. From table (2) the highest recorded shale content in the study area is about (36% to 56%) in Abu Roash “E” and “G” members. The values of TOC for the study formations prove that these formations have source potential (TOC >1%), [25].The maximum value of TOC% for Khoman Formation is 7.6 % at GPT-10 well which is located at the east of the study area. Regarding Abu Roash “D, E, F and G” members, the TOC% increases at the central and northern parts of the study area with its maximum value 8.2% at GPT-17 well.
The application of Passey, et al. technique on the study wells show that Khoman Formation and Abu Roash “D, E, F and G” are non-source rocks. Figure (4) shows resistivity/porosity overlays of GPT-1well, the upper part of Khoman Formation is non-source rock where there is no separation between the resistivity and porosity curves except for some intervals that show negative separation (resistivity curve move to left) which are organic–lean intervals with the presence of limestone beds. The middle part of the formation reveals hydrocarbon reservoir where the resistivity curve moves to the right from the porosity curve due to increasing the resistivity of the non-conductive generated oil and gas which are characterized by approximately low GR values, at the lower part of Khoman Formation resistivity curve move to the left from the porosity curve indicating organic–lean limestone beds, Fig. (4A).

TABLE 2. SHALE VOLUME FOR THE STUDY ROCH UNITS

Well	Khoman Formation	Abu Roash Formation			
		"D"	"E"	"F"	"G"
GPT-1	0.16	0.16	0.42	0.23	0.36
GPT-2	0.24	0.22	0.52	0.22	0.17
GPT-5	0.24	0.16	0.54	0.22	0.29
GPT-9	0.12	0.19	0.43	0.26	0.39
GPT-10	0.27	0.19	0.56	0.25	0.28
GPT-14	0.14	0.18	0.45	0.2	0.37
GPT-17	0.14	0.21	0.4	0.26	0.36

TABLE 3.TOTAL ORGANIC CARBON CONTENT (TOC %) OF THE STUDIED FORMATIONS

Well	Khoman Formation	Abu Roash Formation			
		"D"	"E"	"F"	"G"
GPT-1	6.7	4.5	8.1	6.6	7.4
GPT-2	5.2	4.6	7.6	6.5	7.9
GPT-5	-	4	7.2	5.2	6.4
GPT-9	6.7	3.2	7.3	5	5.2
GPT-10	7.4	3.7	6.4	5.2	4.7
GPT-14	5.5	3.4	5.5	5.8	4.8
GPT-17	5.5	3.3	10	8.2	7.2

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Regarding Abu Roash "D, E, F and G" members, Fig. (4B) most of the intervals are non-source rocks where there is no separation between the resistivity/porosity curves except some intervals show negative separation (resistivity curve move to left) which are organic–lean intervals. At intervals from 1586 m to 1592 m and from 1740 m to 1756 m the resistivity curve moves to the right from the porosity curve indicating hydrocarbon reservoir (Abu Roash "D "and "F" members).
To discriminate the source rocks and non-source rocks the discriminate function is calculated and the results are represented in table (4). Organo-source analysis is applied for the study formations to show the vertical changes in shale volume (Vsh %), total organic matter (TORG), total organic carbon content (TOC %), discrimination function (D.F) and hydrocarbon saturation (Sh) zone wise at the locations of the drilled wells. The organo-source analysis of Abu Roash "E" and "G" members in all the study wells reveal the presence of considerable amount of shale and total organic carbon content as well as organic matter content within these members but the discriminate function is negative in most of the study intervals, indicating that the members are non-source rocks and the hydrocarbons are exogenous in origin except for some zones which give positive values indicating source rock and hydrocarbons are indigenous, Fig. (5A and 5B).

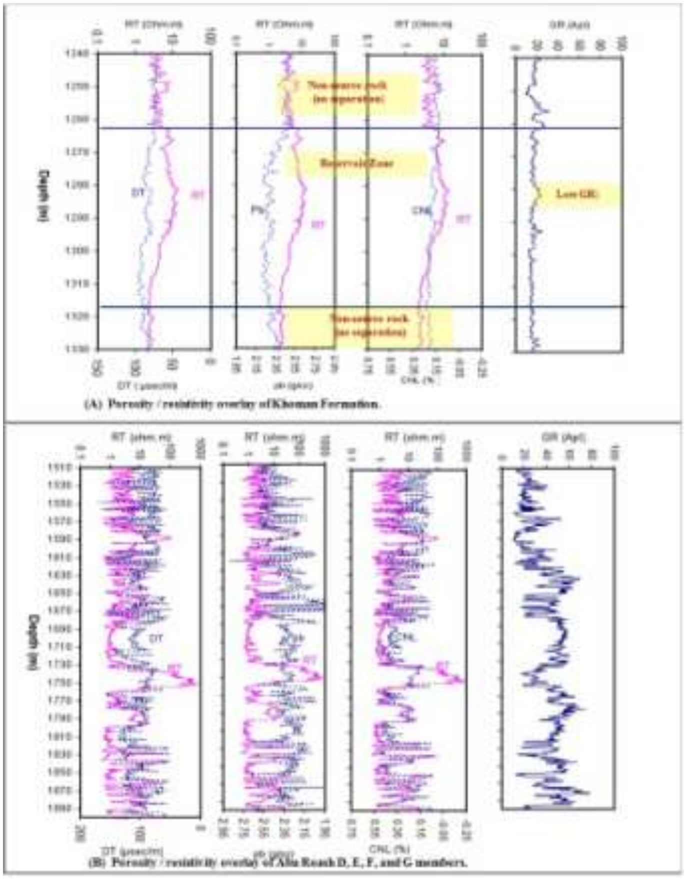

Fig. (4) Resistivity/porosity overlay of GPT-1 well.

TABLE 4. AVERAGE VALUES OF DISCRIMINATION FUNCTION(D.F).

Well	Abu Roash Formation			
	"E"		"G"	
	ΔT	pb	ΔT	pb
GPT-1	-0.20	-0.11	-0.16	-0.08
GPT-2	-1.33	-0.11	-0.21	-0.10
GPT-5	-0.20	-0.14	-0.23	-0.08
GPT-9	-5.48	-0.19	-0.28	-11.8
GPT-10	-0.25	-0.26	-0.41	-0.21
GPT-14	-0.27	-0.27	-0.25	-0.28
GPT-17	-0.25	-0.12	-0.23	-0.10

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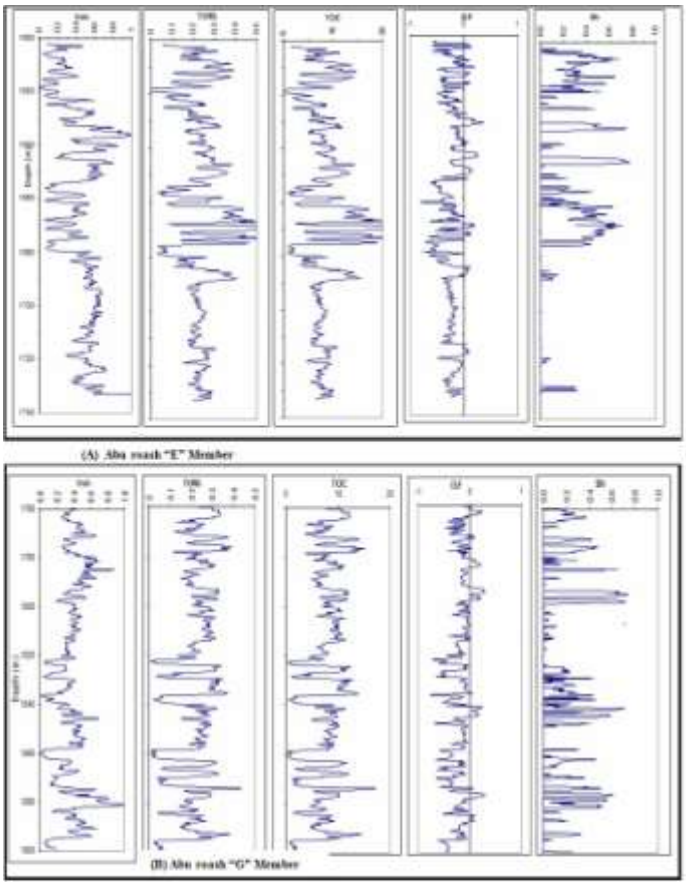

Fig. (5) Organo-Source Analysis of GPT-1 Well.

Thermal maturity analysis of organic matter has been carried out in the present study through the calculation of vitrinite reflectance (Ro) using Welte and Yukler equation [27], then calculating the time temperature index of maturity at the base of the studied intervals and finally constructing the 1-D burial history models for the study wells, the calculated values of (Ro) and (TTI) are presented in table (5) and table (6). Onset of oil generation is observed at GPT-5 well, where the values of TTI for Abu Roash "F" Member and "G" Member are 20.52 and 23.74 respectively. Considering the rest of the study wells the TTI values are lower than the minimum limit for oil generation that is determined by Waples, this indicate that the oil in these wells has migrated from a nearby oil field. The maturity indicator (R_0%) for Khoman Formation indicate that the formation is immature at all the study wells except at GPT-1 well and GPT-2 well. The Abu Roash "D, E, G and F" members are mature in all the study wells, while Abu Roash "F" member is immature at GPT-1 well. According to the burial history models for the study area, early maturation stage is observed at Khoman Formation in GPT-1 and GPT-2 wells and at Abu Roash "D" Member in the remaining wells. Peak of oil generation is recorded at Abu Roash "E, F and G" in all the study wells. Figure (6) is one of the burial history models in the study area for GPT-1 well, the early stage of oil generation (0.6 R_0%) would be expected at depth 1068 m at the top of Khoman Formation, the peak of oil window is expected at 1347 m at the top of Abu Roash "D" Member.

TABLE 5. AVERAGE VALUES OF TIME TEMPERATURE INDEX (TTI)

Well	Khoman Formation	Abu Roash Formation			
		"D"	"E"	"F"	"G"
GPT-1	0.55	0.86	0.99	2.06	2.12
GPT-2	1.17	2.09	2.14	2.18	2.27
GPT-5	0.74	12.14	12.15	20.52	23.74
GPT-9	1.01	4.2	4.71	4.73	4.75
GPT-10	1.85	8.02	7.8	8.17	8.46
GPT-14	1.21	2.51	2.7	4.81	5.09
GPT-17	0.28	0.73	0.74	0.81	0.82

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TABLE 6. THE AVERAGE VALUES OF VITRINITE (R_0)

Well	Khoman Formation	Abu Roash Formation			
		"D"	"E"	"F"	"G"
GPT-1	0.68	0.72	0.77	0.45	0.73
GPT-2	0.68	0.71	0.72	0. 63	0.73
GPT-5	0.45	0.62	1.1	1.2	1.2
GPT-9	0.42	0.9	0.91	0.91	0.92
GPT-10	0.48	0.72	0.8	0.81	0.81
GPT-14	0.43	0.74	0.8	0.81	0.81
GPT-17	0.48	0.72	0.73	0.75	0.77

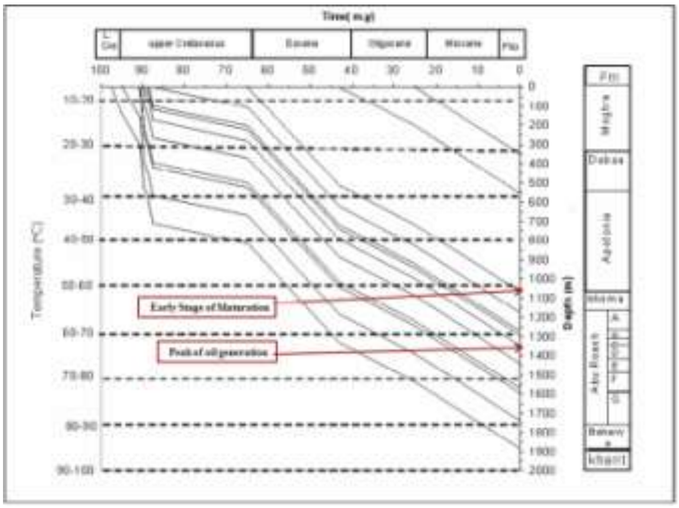

Fig. (6): Burial History and Thermal Maturation Model for the Penetrated Sequence at GPT-1 Well.

IV. CONCLUSIONS

Source rock identification and quantification in absence of core analysis can be achieved by using wireline logs (GR, RD, ROHB, PHIN and DT. The application of qualitative and quantitative analyses for Khoman Formation and Abu Roash “D”, “E”, “F” and “G” members using the available log data in the present study show that most of study rock units contain very high organic content but they are not of enough potentiality to produce indigenous oil, therefore they are not source rocks as improved by the resistivity/porosity technique and organo-source analysis, so the hydrocarbons in the study area are exogenous in origin. The actual source rocks may be located somewhere outside the study area, and the generated oil has been migrated to and accumulated in the study area. Burial history, thermal maturity, and timing of petroleum generation have been modelled for four rock units at seven wells throughout the GPT oil field. The results indicate that Khoman Formation is immature, The Abu Roash “D, E, G and F” members are early mature in all the study wells and Abu Roash F Member is immature in one of the study wells. It is recommended to carry out core analysis in the study area and comparing the derived results with that calculated from the logging analysis to have complete and reliable picture about the different source rocks and reservoirs in the study area.

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