THE USE OF WELL LOGGING ANALYSIS TO EVALUATE THE SOURCE-ROCK POTENTIALITIES OF NUKHUL FORMATION IN OCTOBER OIL FIELD, NORTHERN GULF OF SUEZ, EGYPT.

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إستخدام التسجيلات الكهربية لتقييم امكانات الصخور المصدرية لمتكون النخل بحقل أكتوبر، شمال خليج السويس، مصر

الخلاصة. فى هذه الدراسة تم إستخدام التسجيلات الكهربائية والمعلومات الجيولوجية المتاحة لستة آبار فى شمال حقل أكتوبر بخليج السويس وذلك لتقييم امكانات الصخور المصدرية لمتكون النخل. وقد إستخدمت طريقة باسيه لتحديد النطاقات التى يمكن إعتبارها صخور مصدر داخل متكون النخل كما تم حساب حجم الطفلة ومحتوى الكربون العضوى وأيضا كمية المادة العضوية للمتكون المدروس . ولدراسة التطور الحرارى ودرجة نضج المواد الهيدروكربونية بمنطقة الدراسة تم رسم نماذج ثنائية الأبعاد وقورنت النتائج بتقارير التحليل الجيوكيميائى والتى تطابقت مع النتائج التى تم التوصل اليها بإستخدام التسجيلات الكهربائية.

ABSTRACT. *The open hole well log data (BHC, FDC, CNL, DLL and GR) of six wells (OCT-F1, OCT-F2, OCT-D4, OCT-D1, OCT-D3A and OCT-D5A) in October oil field, northern Gulf of Suez, Egypt are utilized to identify the source rock potentialities for the Lower Miocene Nukhul Formation. In this study the porosity/resistivity overlay technique is used to differentiate the source and non-source rock. Organo-source analysis of the studied rock unit takes place through the determination of shale volume (Vsh), the total organic carbon content (TOC), total organic matter (TORG) and the discrimination factor (D.F.). Moreover, six burial history diagrams were drawn for the succession penetrated by the wells drilled in the study area to illustrate the geothermal maturation concepts (geothermal gradient, time-temperature index TTI and vitrinite reflectance Ro). The results established by using well logging analysis were correlated with the results obtained from geochemical analysis. Organo-source analysis of Nukhul Formation illustrates that, this formation shows a considerable amount of organic carbon content and it is considered as non-source rock in some of the studied wells and it is thermally mature in some of the studied wells, as predicted from the values of Ro and TTI.*

INTRODUCTION

The main target of the present work is to evaluate the source rock potentials of the Nukhul Formation based on the results of well logging analysis carried out for the wells in the study area.

Determinations of the source potentiality concepts of Nukhul Formation in the present study takes place by determining the quantity of organic matter (wt. %TORG), the organic carbon content (wt. %TOC) and the maturity of the organic matter. Schmoker equation (1979) is applied to determine the quantity of organic matter and the total organic carbon content using density log readings. Maturity of organic matter (thermal maturity), on the other hand, is achieved by the burial history modeling for the geologic succession in the study area after correcting the bottom hole temperature and determining the geothermal gradient for the investigated wells. Moreover, the shale volume (Vsh), matrix volume (Vmat.) and fluid saturation (Sh & Sw) were calculated as well as the different petrophysical parameters needed to give a complete picture about the composition and the characteristics of Nukhul Formation

Discrimination between source and non-source rocks in the present study is achieved using two methods; sonic-R75 °F and density-R75 °F method, (Mayer and Nederlof, 1984), and porosity-resistivity overlay method, (Passey et al.; 1990).

Mayer and Nederlof, (1984), proposed a method used to discriminate between source and non-source rocks, through the use of a linear equation to calculate the discriminate function (D.F.). If D.F. is positive, the rock is a probable source rock, while if it is negative; the rock is probably non-source rock. The zero value of D remains undecided. This technique is applied on rocks that have shale volume (Vsh) more than 35%. Consequently, the shales were classified into source and non-source or undecided. The method of Passey et al.; (1990) employs the overlying of a properly scaled porosity curve (generally the sonic transit time curve) on a resistivity curve (preferably from a deep reading tool). In water-saturated, organic-lean rocks, the two curves parallel each other and can be overlain. Since both curves respond to variations in formation porosity; however, in either hydrocarbon reservoir rocks or organic-rich non-reservoir rocks, a separation between the curves occurs. Using the gamma ray curve, reservoir intervals can be identified and eliminated from the analysis.

GEOLOGIC SETTING

The study area (October Field) is located in the northern portion of the Gulf of Suez ,between latitudes 28^0 59' 25"N and 28^0 47' 46" N and longitudes 33^0 59' 59" E and 32^0 57' 33"E. Six wells were studied including, October platform (D) which represented by wells October-D1 ,October-D3A, October-D4, October-D5A, and October platform (F) which represented by October-F1 and October-F2 wells, Fig. (1).

The stratigraphic units in October Field are ranging in age from Pre-Cambrian to Recent, as shown in (Fig. 2). It has four production horizons and it is structurally trapped in a complex of rotated fault blocks. The main four reservoirs in October field are Nubia Sandstone (from Carboniferous to Lower Cretaceous), Nezzazat Group (Cretaceous), Nukhul Formation (Lower Miocene) and Asl Formation (Middle Miocene). Structurally, October Field is a series of rotated fault blocks typical of the Gulf of Suez rift. It consists of at least six separate reservoirs in four stratigraphic horizons, with different hydrocarbon types and various reservoir drive systems. In this field, oil prone source rocks are deposited in lagoonal and open marine environments, while gas prone source rocks generally host terrestrial organisms and high land plants, (Schlumberger, 1995). The Nukhul Formation deposits are most commonly conglomerates, sandstone and limestone (Alsharhan, 2003). In the study area the formation, in most of the investigated wells is consisting mainly of limestone interbeded with thin beds of marl, limestone, shale, and sandstone at the top of the formation, and conglomerate, consisting of chert, sand, and quartz at the base of the formation, (El-Nahrawey, 2006). The Nukhul sediments directly overlie Middle Eocene to Jurassic sediments, where the Nukhul Formation was deposited on the low areas and substantially high areas, Lelek et al., (1992).

INTERPRETATION & DISCUSSION

The available data obtained for interpretation are well logging data including composite, sonic, density, neutron, gamma ray, caliper and deep and shallow resistivity logs.

Quantity of Organic Material.

The amount of organic material

present in the sedimentary rocks is almost always measured as total organic carbon (TOC) content, which is the first and most important screening technique used to indicate which rocks are of no interest to us (TOC < 0.5%), which ones might be of slight interest (TOC between 0.5% and 1%), and which are definitely worthy of further consideration (TOC > 1%), (Waples, 1985 & 1980). In the present work, the total organic carbon is calculated by using Schmoker and Hester (1983) equation and Meyer and Nederlof (1984) equation, after applying the borehole corrections to the density log readings.

From table (1); the maximum value of total organic carbon (TOC) for Nukhul Formation is (4.9%) while the minimum value is (2.8%). According to the estimated values of TOC, Nukhul Formation can be considered as excellent source rock where TOC% > 2.

Discrimination between source and non-source rocks.

The methods for separation of the source from non-source rocks on well logging analysis was carried out in the present study using density-R75 ^{o}F, sonic-R75 ^{o}F method, and Passey et al., method.

1- Sonic-resistivity and density-resistivity Method.

This method depends on simple classification rule for separating the source from non-source rocks by using two equations on the basis of log combinations of sonic-resistivity and density-resistivity, where, the organic-rich layers are usually characterized by a relative decrease of sonic transit time and the bulk density. On the other hand, it shows an increase in the resistivity, so that the resistivity can be used as source indicator for a given source rock. It is very important to correct the resistivity at one standard temperature (75 ^{o}F). This correction can be done using Arps (1953) formula:

$$R_t = R_{75} \text{ X } 82 / (T+7)$$

$$R_{75}=R_t \text{ X } (T+7) /82$$

Where; R_t is the true resistivity, R_{75} is the resistivity at 75 ^{o}F and T is the formation temperature (in ^{o}F). To calculate the discrimination function, Meyer and Nederlof (1984) separated source from non-source rocks depending on suitable equation which define the line of separation. This line is called the discrimination function (D.F) which is determined by using the following equations:

$$D(\Delta T)=-6.906+3.186\log_{10}\Delta T + 0.487\log_{10} R_{75}$$

$$D(\rho b) =-6.906+3.186\log_{10} \rho b + 0.487\log_{10} R_{75}$$

Where; $D(\Delta T)$ is the discrimination function from sonic log, ΔT is the sonic log reading, R_{75} is the resistivity corrected to standard temperature of 75 ^{o}F, $D(\rho b)$ is the discrimination function from density log and Pb is the density log reading.

In the study area, the discrimination function shows negative separation allover the formation except some zones show positive values, illustrating that the shale rocks are probably non-source rocks in the investigated wells.

2- Porosity-Resistivity overlays.

Passey et al., (1990), used the "Δlog R" separation for determining organic-rich rocks. This technique uses common widely available well logs (porosity logs) to identify organic-rich source rocks, where it employs the overlying of a properly scaled porosity curve (sonic transit time curve more accurate) on a resistivity curve. The application of this method at OCT-F1 well, Fig. (3) reflects that the upper part of the formation can be considered as source rock, where the porosity curve reveals good separation from resistivity curve which move to the right due to generated hydrocarbons. The other zones of the formation are water saturated intervals as the resistivity curve moves to the left from porosity curve with thinly bedded shales. At OCT-F2 well, Fig. (4) source rocks are represented by a number of limited zones at the upper part of the formation, where the porosity curve moves to the left and is accompanied by increase in resistivity to the right, responding to generated hydrocarbon. The other zones of the formation are water saturated intervals because the resistivity curve moves to the left from porosity curve with thinly bedded shales. The porosity/resistivity overlay of OCT-D4 well, Fig. (5) reflects the presence of water saturation within the upper zones of the formation because the resistivity curve moves to the left from porosity curve with thinly bedded shales except some zones at the upper most and middle part which reveals source rock as the porosity curve moves to the left and is accompanied by strong increase in resistivity to the right, responding to generated hydrocarbon. The lower part shows hydrocarbon reservoir rock where, the resistivity curve moves to the right. Nukhul Formation in this well is characterized by approximately low GR values and high value of resistivity due to non-conductive oil and gas. The porosity/resistivity overlay of OCT- D1 well, Fig. (6) shows that the upper part of the Nukhul Formation is non source rock, where there is no separation between the two curves except some intervals that show negative separation (resistivity curve move to the left) which are organic-lean intervals with the presence of shale and shaly beds. The lower part of the formation reveals hydrocarbon reservoir where the resistivity curve moves to the right from the porosity curve due to increasing in the resistivity of non-conductive generated oil and gas. The source rock exhibits a good separation between the two curves at interval depth from 9702ft to 9718 ft. The resistivity curve moves to the left from the porosity curve at depth 9724 ft to the end of the formation which are organic-lean with shale beds. Figure (7) shows the porosity/resistivity overlay of OCT-D3A well, in which the upper part of the formation can be considered as water saturated. The lower part at depth 10556 ft illustrates the presence of hydrocarbon reservoir zone; it is characterized by approximately low GR values and high value of resistivity due to non-conductive oil and gas. Regarding OCT-D5A well, the sonic/resistivity overlay (Fig.8) reveals that, the source rock at the upper most and middle zones of the formation, where good separation between resistivity and porosity curves. Hydrocarbon reservoir rock is exhibited at depth from 12046 ft to 12132 ft and from 12310 ft to the end of the formation where, the resistivity curve move to the right and porosity curve is constant with low value of GR. The other parts of the formation illustrate that water saturation within the upper zones of the formation due to the resistivity curve move to the left from porosity curve with thinly bedded shale; this separation may be due to higher salinity formation fluids in these zones.

Thermal Burial history modeling.

The thermal burial history diagram is a method for estimation of the level of maturation of the source rocks and prediction of the depth required for hydrocarbons to generate by these source rocks and determine the timing of petroleum generation. The process of source rock maturation and the consequent petroleum generation is controlled mainly by both the geologic time (the age of such rocks) and the temperature gained during their subsidence. In 1971, Lopatin described a simple method by which the effect of both time and temperature could be considered in calculating the thermal maturity of organic material in sediments. He developed a time-temperature index of maturity (TTI) to quantify his methods. The Loptatin method was later developed and calibrated against vitrinite reflectance (Ro) and thermal alteration index (TAI) by Waples (1980). These methods use data for calculation including surface temperature, the present day formation tops and their corresponding ages, the geothermal gradients and the magnitude of erosion events and their duration. The maximum bottom hole temperature are used to calculate the present day geothermal gradient or from geothermal gradient maps if available. Also, the periods of unconformities (as uplift or non-deposition and erosion) can be graphed. For most kerogens, the onset of oil-generation is taken to be near 0.6% R_o, peak generation and migration is about 0.9% R_o and the end of liquid-hydrocarbon generation is thought to be about 1.35% $R_{o,}$ (Waples, 1985)

The burial history diagram of OCT-F1 well, (Fig. 9) reveals that the drilled section in this well is thermally immature except the Carboniferous formations, (TTI is about16). The early stage of oil generation (0.6%Ro) would be expected at depth 11118 ft in Esna Formation and the top of oil window or peak of oil generation would be expected at depth 13552 ft in Nubia Sandstones.

Figure (10) illustrates the thermal burial history model of OCT-F2 well. The Nukhul Formation in this well is thermally mature, (TTI is about 16). The early stage of oil generation (0.6%Ro) would be expected at depth 9050 ft in Rudies Formation. The top of oil window or peak of oil generation would be expected at depth10638 ft in Nukhul Formation.

Regarding OCT-D4 well, the vitrinite reflectance measurements (Ro) from the relationship between time-temperature index (TTI) and the maturity indicator (%Ro) that predicted from the burial history diagram (Fig.11), the early stage of oil generation (0.6%Ro) would be expected at depth 9840 ft in Nukhul Formation. The top of oil window or peak of oil generation would be expected at depth 10228 ft in Eocene Formation. The Nukhul Formation and Eocene formations are thermally mature as the estimated TTI for both wells is 15 and 19.95 respectively.

The drilled section in OCT-D1 well is thermally immature as demonstrated by the thermal burial history and the relationship between time-temperature index (TTI) and the maturity indicator (%Ro), Fig. (12). The early stage of oil generation (0.6%Ro) would be expected at depth 10951 ft and suggested the top of oil window at depth 12476 ft.

In OCT-D3A well, the thermal burial history and the relationship between time-temperature index (TTI) and maturity indicator (%Ro) reveal that the investigated formations are immature. The early stage of oil generation (0.6%Ro) would be expected at depth10235 ft. From Fig. (13) it was found that, Eocene and Miocene Formations are immature.

The sedimentary succession in OCT-D5A well are thermally immature except for the Nukhul Formation and Eocene formations as demonstrated by the thermal burial history (Fig. 14) and the relationship between time-temperature index (TTI) and the maturity index (%Ro), table (7), which reveal, that the early stage of oil generation (0.6%Ro) would be expected at depth 11885 ft in Nukhul Formation. The top of oil window or peak of oil generation would be expected at depth 12323 ft in Eocene formations.

The determined values of Ro and TTI are represented at tables (2-7). The geochemical results of the present work were compared with the results of the geochemical analysis report of GUPCO, for two wells in the study area, (OCT-D1 and OCT-F1 wells). The results of the geochemical analysis, table(8), show that the Eocene, Paleocene and U.Senonian formations in OCT-D1 are excellent source rocks as indicated from the TOC values, regarding the Ro values, the onset of oil generation is at the U.Senonian (0.65 Ro). The geochemical analysis of OCT-F1 well illustrates that the U.Senonian formations are excellent source rocks, while the Cenomanian formations are fair source rocks and the Nubia(B) is a poor source rock.

CONCLUSIONS.

The source potentialities of Nukhul Formation were studied using well logging techniques. The available data were corrected and weighted zone-wise to determine the different parameters needed to evaluate the source potentialities of Nukhul Formation. The estimated total organic carbon content reveals that Nukhul Formation is an excellent source rock, where TOC% > 2. On the other hand, the graphical methods used in this paper (porosity/resistivity overlays) show that some of the shale zones of Nukhul Formation in the study area can be considered as source rocks. Burial history modeling of the stratigraphic units in the studied area illustrate that Nukhul Formation is thermally mature in some of the studied wells, (OCT-F2, OCT-D4, OCT-D3A and OCT-D5A) as predicted from the values of Ro and TTI.

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