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SOURCE ROCK EVALUATION OF SOME INTERVALS IN THE GULF OF SUEZ AREA, EGYPT

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ABSTRACT

In order to identify and evaluate the source rocks combination between resistivity, sonic, density and level of organic metamorphism (LOM) from three wells distributed in the central and southern part of the Gulf of Suez-Egypt is performed. Two analytical steps were carried out. The first one is represented by identification of source/non-source intervals using the method described by Meyer and Nederlof (1984) for calculation of discriminant score function (D). The second step is represented by calculation of TOC% using two methods, the first, which based on using the density information and the second was described through the ΔlogR and the overlay between the resistivity curve from one hand and sonic, density from the other. Data from three wells were collected and analyzed using the above-mentioned techniques. The results revealed that the central onshore part is richer in total organic carbon (TOC%) when compared with the other two localities, where it is classified as good source rock.

1- INTRODUCTION

The Gulf of Suez is among the important hydrocarbon provinces in Egypt. It has exposed to intensive exploration activities since the early twentieth Century. Many research papers concerning tectonic, structural and sedimentlogical studies of the Gulf of Suez were published (Abdel Gawad, 1970, Meshrif and Refai, 1976, Garfunkel and Bratov, 1977 Chent and Letouzey, 1983 and Meshrif, 1990). In general the structural system of the Gulf of Suez started during the Late Eocene and Oligocene times along series of strike-slip and normal faults as a result of the rotation movement between the African and Arabian plates. During rotation an extra extensional movements took place. The horizontal extension caused more thinning of the earth's crust. This rifting had its maximum width and depth during the Lower Miocene time (Chent and Letouzey, 1983). The resulted rift system displayed its maximum width (80 km) and depth during the Lower Miocene time, as shown by the over all extent of open marine facies known as the Rudeis Formation. The direction of the block rotation was not constant along the strike of the Gulf of Suez due to the regional reversal of the dip regime along the strike. Accordingly, the tilted blocks would be expected to rotate southwest of the northern and southern parts of the Gulf of Suez and northeast in the central part (Meshrif, 1990).

The infilling of the Lower Miocene trough was nearly completed at the end of Langhian time (nearly 15 MY). The deposition of the Middle-Upper Miocene evaporetic series suggests a shallow restricted environment. Since Pliocene times and probably before the rift trough narrows and the uplift on the shoulders accelerated (Kohn and Eyal, 1981). At present, the Lower Miocene coarse clastics near the border of the border faults of the rift system stay up to about 300m above sea level.

In the central province of the Gulf of the entire rift basin dips off to the northeast. Structural basement ridges in the southern part of this province segment the basin. Garfunkel and Bratov, 1977. Each basin segment separated by ridges within the southern central province has regional dip to the northeast.

The southern province has a very thick stratigraphic column of Miocene sediments with evaporates, which increases in thickness southward and expanding adjoining the Red Sea basin. This southern province is being considered as one of the productive parts in the Gulf of Suez area. The Miocene bay zone thins out southward in the direction of the Red Sea, so this province became with less importance in exploration activities for Miocene reservoirs.

Three depositional phases are assumed during the geologic history of the Gulf of Suez. The first comprises the deposition of formations ranging in age from a postulated Pre-Carboniferous to Eocene. These formations, which include the Nubian Sands, are important as reservoir roks and to lesser extent as source rocks.

The second phase is represented by the Lower Miocene and is characterized by its overall excellent qualities as source, reservoir and seal rocks. The third phase is of Upper-Middle Miocene to Upper Miocene and Pliocene age in essence (basically) closes the depositional history of the Gulf of Suez region.

Intensive investigations on the behavior of source rocks, its maturation, hydrocarbon migration and accumulation have been done since 1970. Different methods and techniques have been used to give actual evaluation of the source rocks in different provinces of the world Demaison and Moore (1980), Demaison *et al.* (1984), Durand (1980), El-Shazly *et al.* (1984), Meyer and Nederlof (1984), Moldowan *et al.* (1985), Passey *et al.* (1989), Tammam (1994).

Many studies have been done specially on the Gulf of Suez province for the purpose of source rock evaluation. Among these studies are Shahin and Shehab (1984), Atef (1988), Khalil (1988, Younis, (1991), Mostafa (1993), Barakat *et al.* (1996) and Halim *et al.* (1996). Younis (1991) concluded that the Black Shale of the Nubia-B is considered as the mature potential source rock of the Nubia reservoir. Mostafa (1993) concluded that the organic rich Upper Senonian Brown Limestone and Lower Eocene Thebes Formation carbonates are among the essential source rocks for generation of the hydrocarbon in the Gulf of Suez.

Abdel Baki (2000) explained the deposional and stratigraphical history of the Gulf of Suez in three stages, namely: a pre-Carboniferous-Eocene, Lower Miocene and Middle/Upper Miocene. The first stage is characterized by its hydrocarbon reservoir, the second by its source and reservoir behavior and the third close the depositional history of the Gulf of Suez, figure (1) shows the generalized stratigraphic section of the Gulf of Suez (Abdel Baki, 2000).

Following the shally and limy intervals, Carboniferous is characterized by relative thick black shale of the Nubia (B). This interval is highly indurated as deduced from the drilling information. Some intervals below and above the Nubia (B) are hydrocarbon pay zones. A thick Jurassic sequence ovelains unconformably the carboniferous and is formed of carbonate and marls. Cenomanian unconformably overlains the Jurassic and is mainly formed of carbonate facies with some intercalations of shale. On the top of Cretaceous, Eocene limestone was deposited under marine conditions. Up from Eocene carbonate and by the beginning of Oligocene/ Miocene period the tectonic development of the dynamic Gulf of Suez has dominated. Miocene facies are significant as source and reservoir rocks. They are either marine or non-marine facies.

.Kerogene is formed in the early burial stage from decomposition of plant and algal debris accumulated under reducing condition environment in the sediments. Up a temperature of 75°C (Waple, 1984). Kerogen begins to transform into different modes of hydrocarbon under adequate time span. Liquid oil is first formed during kerogen transformation (catagenesis stage), followed by wet and then dry gas (metagenesis stage). In some cases specially where gas reservoirs are shallow bacterial action play a considerable role in forming methane under temperature.

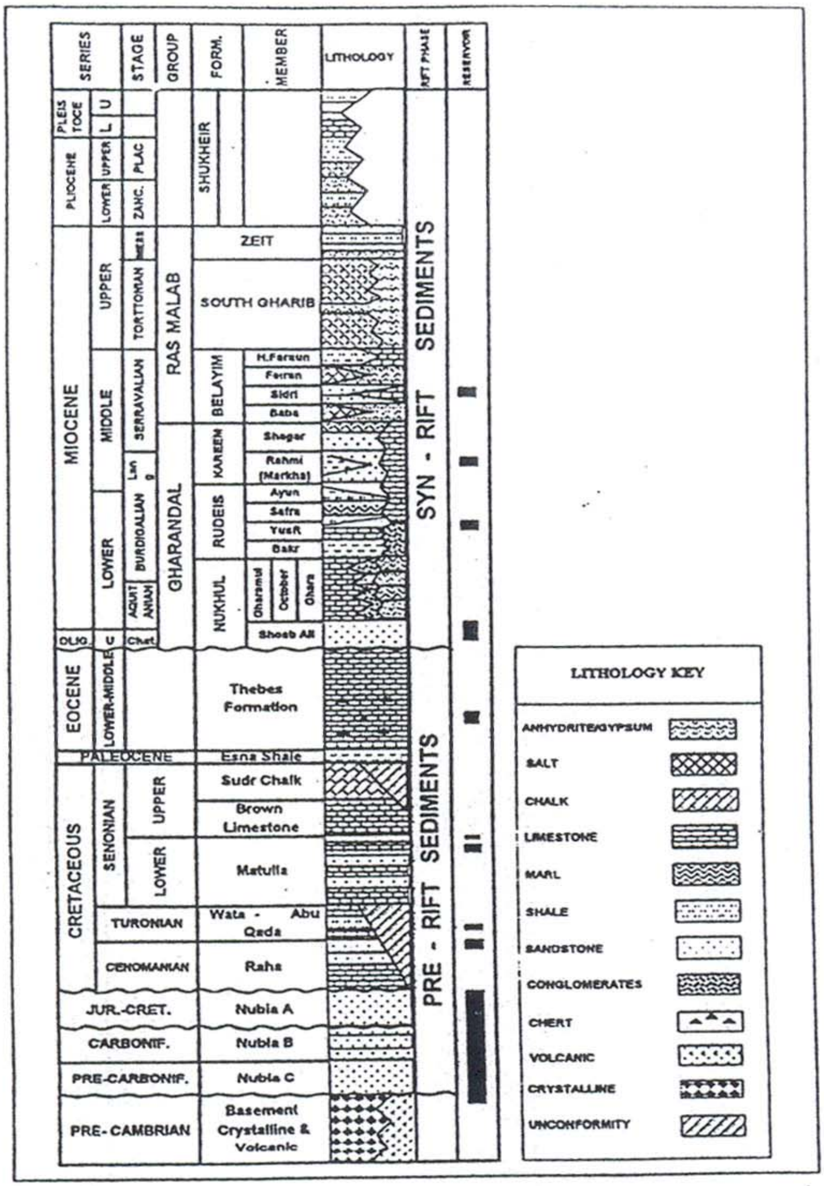


Fig. (1): Generalized stratigraphic column of the Gulf of Suez (Abdel Baki, 2000)

2- METHODOLOGY

Based on well log data various analytical methods have been in order to differentiate source from non-source rocks. Also, the present day capacity of the source rock can be calculated in form of total organic carbon (TOC%) content of the rock expressed in wt%. Schmoker (1979), Schmoker and Hester (1983 and 1989) used both gamma ray and density logs for calculation of the wt% TOC. Passey *et al.* (1990) have used the ΔlogR for calculating the TOC%. Organic matter may be either of aquatic and bacterial, which is laminated or plant origin, which is dispersed. When a barren rock (free of fluids and organic matter) is considered, its density is high. During compaction fluids are expelled and the density increases accompanied by decreasing in interval transit time. If a rock contains considerable amount of organic matter, it attains high resistivity values, relative high gamma ray due to the presence of uranium enrichment that absorbed by the organisms from seawater and low density. It is worth mentioning that organic matter formed in fresh water have low gamma ray level because of the scarcity or absence of uranium ions. Both bulk density and interval transit time indicate lower values for organic rocks when compared with the lean one.

Generally, two important methods have been used to evaluate the source rock possibility in the study intervals. The first one is the method described by Meyer and Nederlof (1984) to discriminate between the source and non-source intervals , while the second one is represented by calculation of the TOC% using the method described by Schmoker and Hester (1983) which relates the fractional volume of organic matter to the total organic carbon percent and that given by Passey *et al.* (1990)

Schmoker and Hester (1983) treated the case they dealt with as four component system including pyrite. Due to the absence of pyrite the present case it is considered as three component one forms of: the rock matrix (m), interstial pores (i) and organic matrix (o). So, the formation density log is a function of the densities and fractural volumes of these three components, where:

$\rho = \varphi_o \rho_o + \varphi_i \rho_i + (1-(\varphi_o + \varphi_i)) \rho_m$ …….(1)

Where:

ρ: is the density value obtained from log

$\rho_{o:}$ is the organic matter density and taken to be 1.01 gm/c.c.

ρ_I: is the density of the interstitial pores

ρ_m: is the matrix density

Considering a fixed porosity of the rock matrix, and ρ_m can be changed into another factor called “volume-weighted average of grain and pore-fluid density (ρ_{mi}), in this case equation (1) takes the form:

$\rho = \varphi_o \rho_o + (1-\varphi_o) \rho_{mi}$ ....……… (2)

$\varphi_o = (\rho-\rho_{mi})/(\rho_o-\rho_{mi})$ .... (3)

The wt% of organic carbon (TOC%) is related to the fractional volume of organic matter (φ_o) by the equation:

$TOC\% = (\varphi_o \rho_o / R\rho)*100 = ((\rho-\rho_{mi}/\rho_o-\rho_{mi}) \rho_o)/R\rho$. (4)

Where: R: is the ratio between organic matter and organic carbon, where organic carbon can be calculated from geochemical analysis.

Based on well log data Meyer and Nederlof (1984) have introduced a statistical cross-plot method for identification of source and non-source rocks. Four log data types, namely, resistivity, sonic, density and gamma ray have been used in this work. Resistivity is a common tool because it is used as one parameter sharing the other three tools. Resistivity depends on temperature; therefore some sort of corrections should be taken into consideration before considering formation resistivities. According to Schlumberger (1989) the measured resistivity (Rt) at a temperature (t) is related to the standard resistivity at 75^{o}F (24^{o}C) is given by Arps formula as follows:

$Rt=R75*82/(T+7)$…………………..….(5)

where

Rt: measured resistivity.

R_{75}: Standard resistivity.

T: Temperature in ^{o}F.

Large sets of data comprising the carbonate intervals (limestone) are considered for this statistical analysis. Limestone can be either source or non-source rock. The differences between them can be observed from the recorded tool. Geochemical data were considered as comparative tool to the calculated parameters from the wire line logs. Based on the method described by Kendall, (1961), Meyer and Nederlof (1984) explained a statistical method depends on which is called "Discriminant score function, D". The chief property of this function is that the distance between the means of class one and class two projections is minimized whereas at the same time the spread of points within the classes is minimized (Davis, 1973). The method is based on assigning a dummy (random) value (y) to each observation, where:

$Y= N2/N1+N2$ for class one ……………(6)

and

$Y= -N1/N1-N2$ for class two……………(7)

Where: N1and N2 is the source and non-source rock, respectively. By regressing y against any log parameter, the resulting pseudoregression equation gives the Discriminant function (D). The following equation were derived by Meyer and Nedelof (1984) for the limestone intervals:

IN CASE OF SONIC/RESISTIVITY

$D= -7.335+3.41*LOG_{10}\Delta T+0.453*LOG_{10} R_{75}$...……………………... (8)

IN CASE OF DENSITY/RESISTIVITY

$D= 2.512-7.92* LOG_{10}\rho+0.339* LOG_{10} R_{75}$….(9)

The equations used for calculation of the dicriminant score (D) in case of shale formations are given as:

$D=6.906+3.186*LOG_{10}\Delta T+0.487 * LOG_{10}R_{75}$…...(10)

$D=2.278-7.324*LOG_{10}\rho+0..387*LOG_{10} R_{75}$...………............…… .(11)

Passey *et al.* (1990) proposed a relative new idea in source rock evaluation, which called ΔlogR technique. Overlay relations between formation resistivities from one hand and sonic, density, neutron readings from the other can be used for calculation of the ΔlogR. The idea of the method is based on curve separation between baselined fine-grained non-source rock and the actual source rock interval. The following relations are used for ΔlogR calculation for sonic and density overlays.

In case of resistivity/sonic

$\Delta logR_t = log_{10} (R/R_{baseline)}+.02*(\Delta t-\Delta t_{baseline})$ for resistivity sonic overlay-plot ………..(12)

In case of resistivity/density

$\Delta logR_{den} = log_{10} (R/R_{baseline)}-2.5*(\rho_{b}-\rho_{b\ baseline})$ for resistivity density overlay-plot……..(13)

Where:

ΔlogR: is the curve separation measured in log. (Resistivity cycles).

R: is the measured resistivity values obtained from resistivity tool

Δt and ρ_b : are the measured sonic and density values from well log

$R_{baseline:}$ is the resistivity corresponding to the measured $\Delta t_{baseline}$ and $\rho_{baseline}$

It can be seen from these relations that the used parameters with the temperature are all of porosity response. So they being considered as important in source rock evaluation (Meyer and Nederlof, 1984).

Calculation of TOC% from the calculated or measured ΔlogR needs another parameter called Level of Organic Metamorphism (LOM) where:

$TOC\% = \Delta logR*10^{(2.297-0.1688LOM)}$……..(15)

When the TOC% value exceeds one then the rock can be considered as source rock (Tissot and Welt, 1984).

Level of Organic Metamorphism (LOM) can be obtained from a variety of sample analysis (e.g. virginite reflectance, thermal alteration index and $T_{max.}$ The T_{max} method described by Hood *et al.* (1975) was used in this study. This method is based on the data obtained from the Bottom Hole Temperature, which was used for calculation of the heating rate and then the effective heating time t_{eff} using the relation:

$T_{eff.} = 15/(dT/dt)$… …………………….(16)

Effective heating time is defined as the time during which a rock has been within 15°C of its maximum temperature to calculate the level of organic metamorphism (LOM) using the diagram given by Hood *et al.* (1975).

3- RESULTS AND DISCUSSIONS

Three wells located at the central and southern part of the Gulf of Suez are considered in this investigation. Well log analysis based on resistivity, sonic and density logs is carried out. The first step, which is represented by calculation of the discrimanent score function (D) is used to distinguish between the source and non-source rock intervals. Kareem Formation of the Lower Miocene age is represented in well (A) and is mainly composed of shale and limestone. Each rock type is considered separately in calculating the D function and the TOC% values. The whole studied successions are divided lithologically into seven intervals (four shale and three limestone). All intervals show positive D values. The method described by Schmoker and Hester (1983) was applied. TOC% values of the seven intervals were calculated using density values of 2.6 and 2.8 gm/c.c. (as matrix values) for shale and carbonate intervals, respectively. Figures (3 to 9) show the depth-TOC% relation and table (1) shows the derived TOC% results of well (A). As seen from this table and figures TOC% values of the shally intervals range between 1.3 and 1.42 and for limestone it ranges between 1 and 3.7.

Regarding well (B) located onshore at the central part of the Gulf of Suez, the study interval is mainly composed of limestone of Upper Senonian age. TOC% in this well range between 2.8 and 3.3 as illustrated in Figure (10) and Table (1) .Regarding well (C) located at the southern part of the Gulf of Suez, the intervals belong to Nukhul Formation of Lower Miocene age and is mainly composed of shale except the interval 2772-2782m, where it is mainly of anhydrite. TOC% values range between 1.29 to 1.32 as shown in Fig. (11 and 12). ΔlogR method of Passey *et al.* (1990) was applied to calculate the TOC% values for the same intervals in the same wells. Regarding well (A), TOC% values range between 0.2 and 2 for the shale intervals and between 0.3 and 5 for the limy intervals as shown by figures (13 and 14) and Table (1). TOC% values of the study intervals at well B range between 2 and 6 (Figs. 15 and 16; and Table 1). In well (C) TOC% values range between 0.5 and 1.5 as seen by Fig. (17) and Table (1). Comparison between the results obtained from both methods of calculation and that obtained from geochemical data show some sort of coincidence in TOC% values.

Table 1. Calculated TOC% of the three studied wells

Well	**Rock type**	**Interval (m)**	**Age**	**TOC% (Schmoker and Hester (1983)**	**TOC% (Passey *et al.* 1990)**
A	Shale	2650-2730	*Lower Miocene* (Kareem Formation)	1.3-1.42	0.2-2
	Limestone	2730-2770		2.42-2.6	1-5
	Shale	2770-2801		1.33-1.37	0.5-1
	Limestone	2801-2819		1-2.5	1-5
	Shale	2819-2850		1.32-1.38	0.4-1.5
	Limestone	2850-2858		2.4-3.7	0.3-1.5
	Shale	2858-2860		1.35-1.37	0.3-1.5
B	Limestone	1390-1490	Upper Senonian (Sudr Formation)	2.8-3.3	2-6
C	Shale	2920-2970	Lower Miocene(Nukhul Formation)	1.29-1.33	0.5-1.5
	Shale	2980-3000		1.25-1.32	0.5-1.5

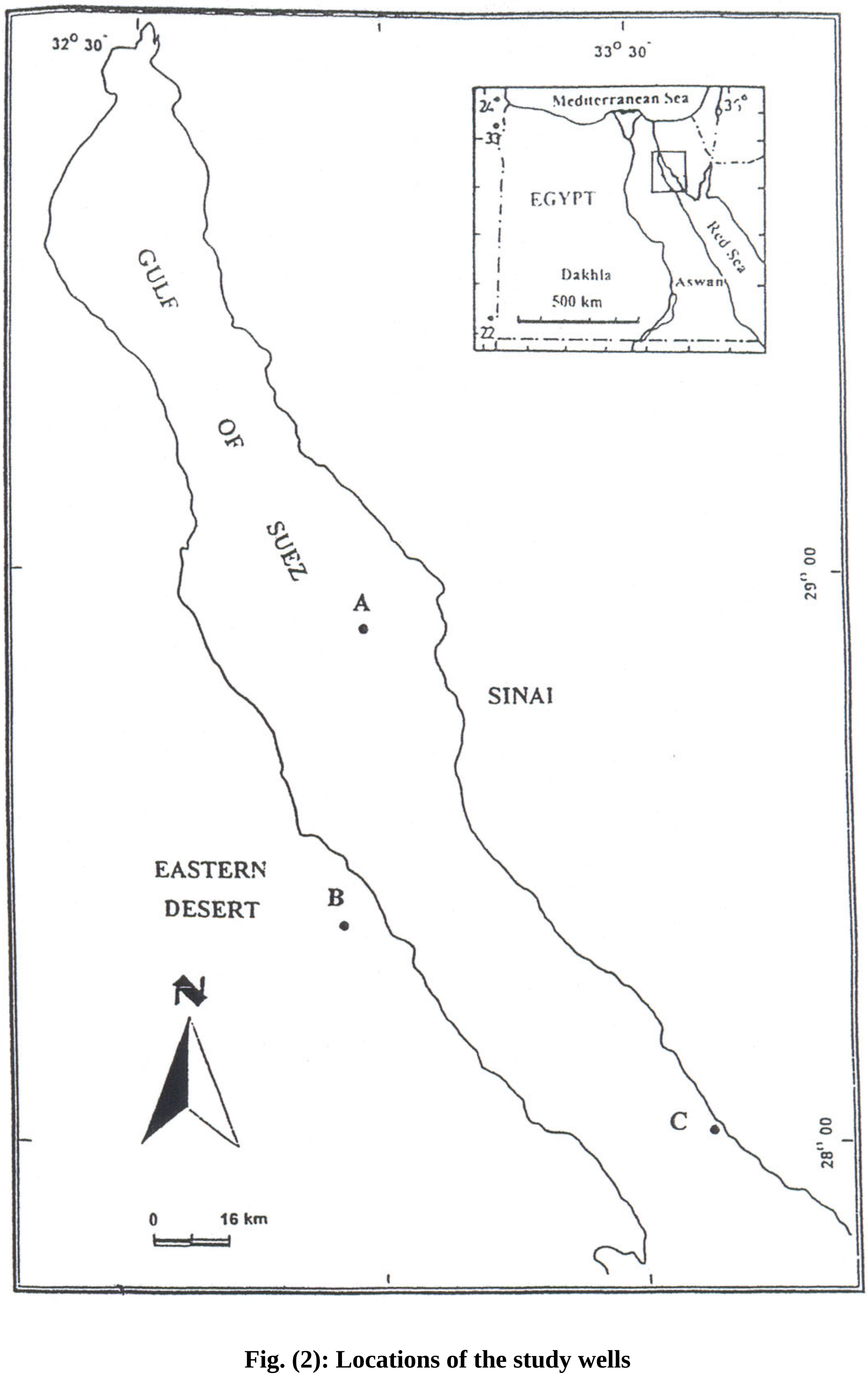


Fig. (2): Locations of the study wells

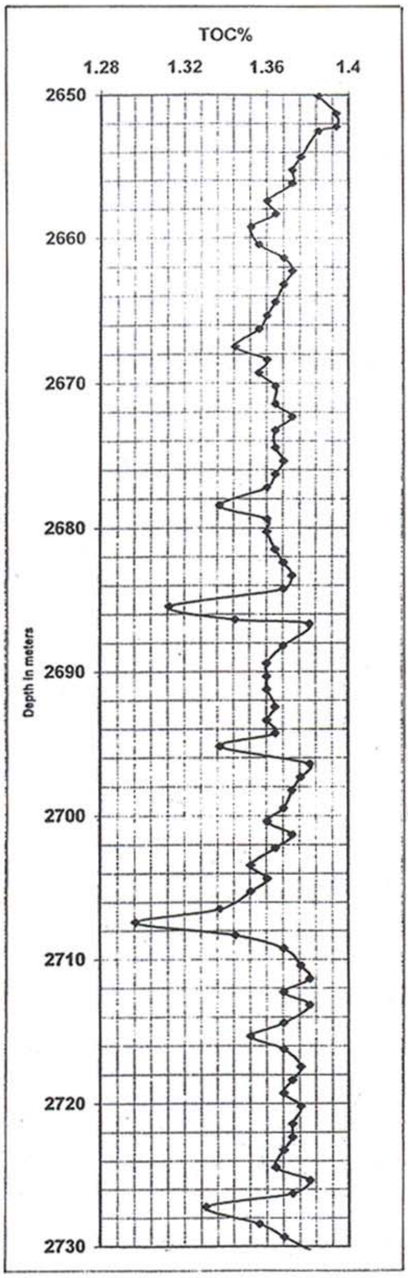


Figure (3) Toc%-Depth relation of Kareem Formation (depth range between 2650-2730m shale type Well A)

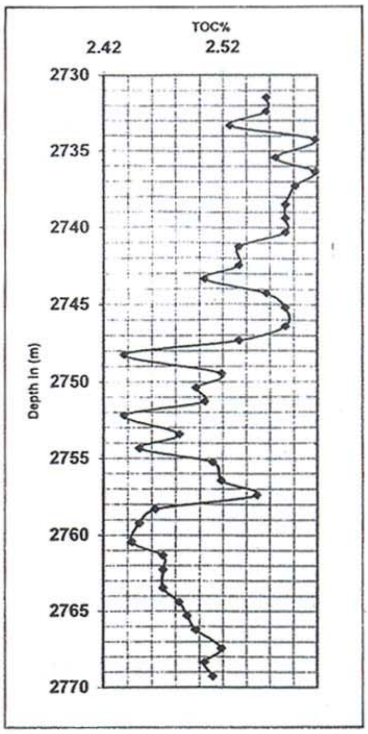
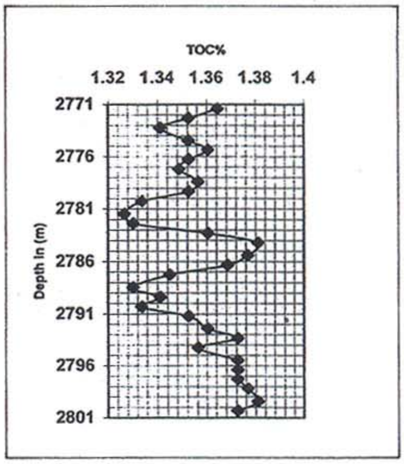


Figure (4): TOC%-Depth relation of Karem Formation (depth range from 2730-2770 carbonate type Well A)



Figure(5): TOC%-Depth relation of Kareem Formation (depth interval from 2765 to 2805m shale type Well A)

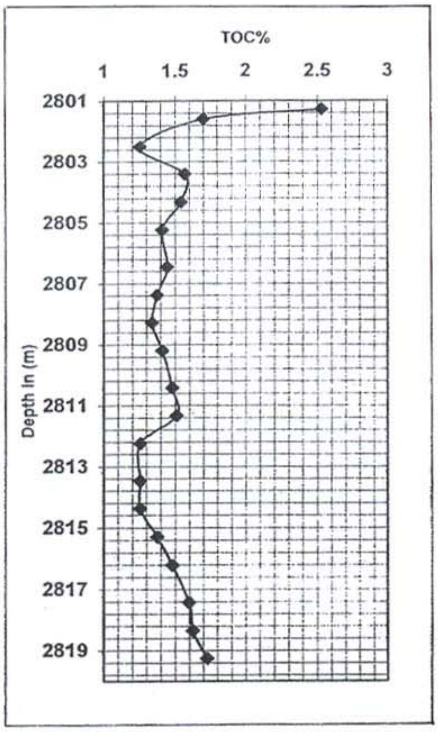


Figure (6): TOC%-Depth relation of Kareem Formation(depth range from 2801 -2820m carbonate type Well A)

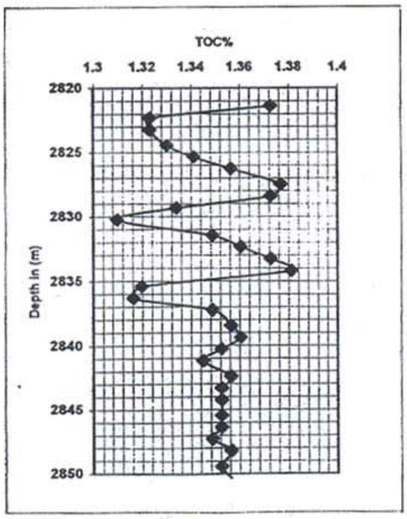


Figure (7): TOC%-Depth relation of Kareem Formation (depth range from 2822-2850 shale type)

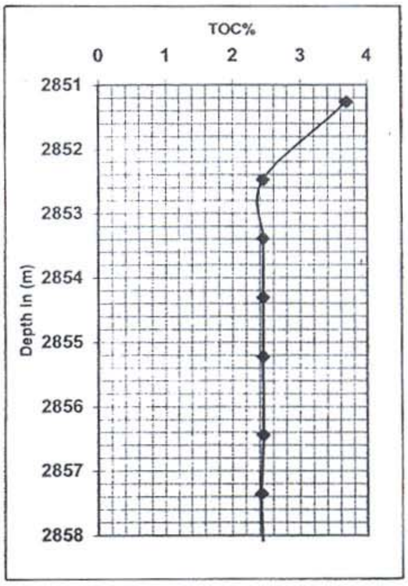


Figure (8): TOC%-Depth relation of Kareem Formation (depth range from 2851-2858 carbonate type Well A)

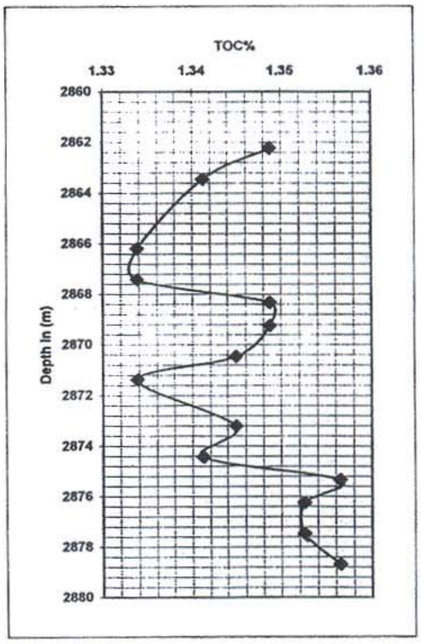


Figure (9): TOC%-Depth relation of Kareem Formation (depth range from 2860-2878 shale type Well A)

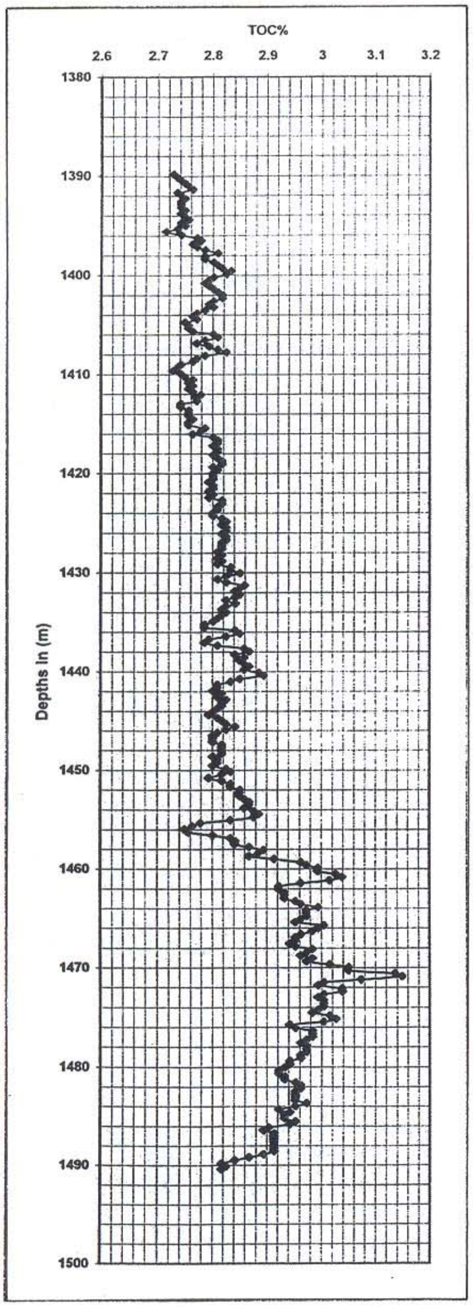


Figure (10): TOC%-Depth relation of Upper Senonian depths from 1390-1490m carbonate type Well B)

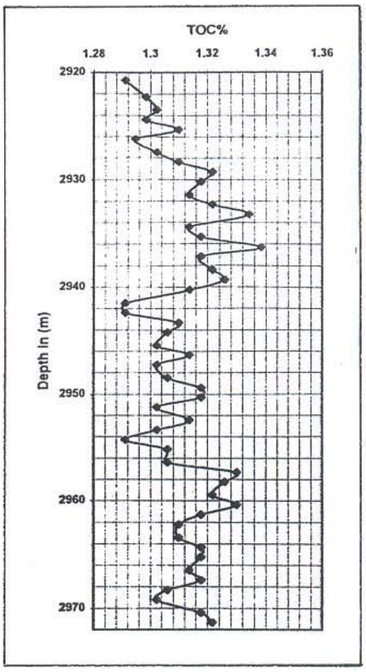


Figure (11): TOC%-Depth relation of Nukhul Formation (depths from 2920-2970 shally type Well B)

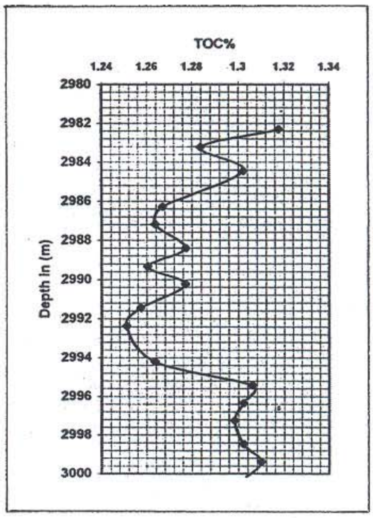


Figure (12): TOC%-Depth relation of Nukhuln Formation (depths from 2980-3000m shale type Well C)

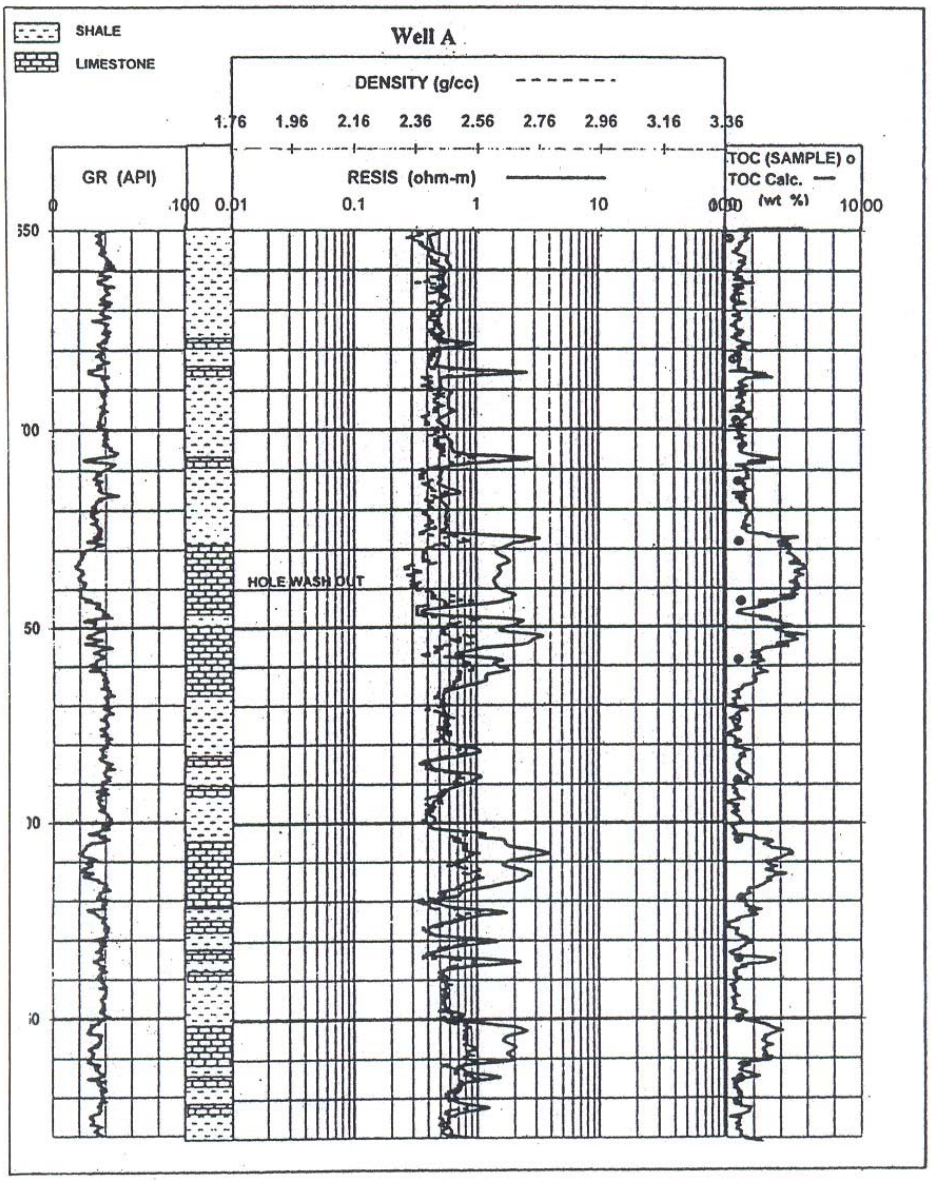


Figure (13): Density-resistivity overlay and calculated TOC% of Well A

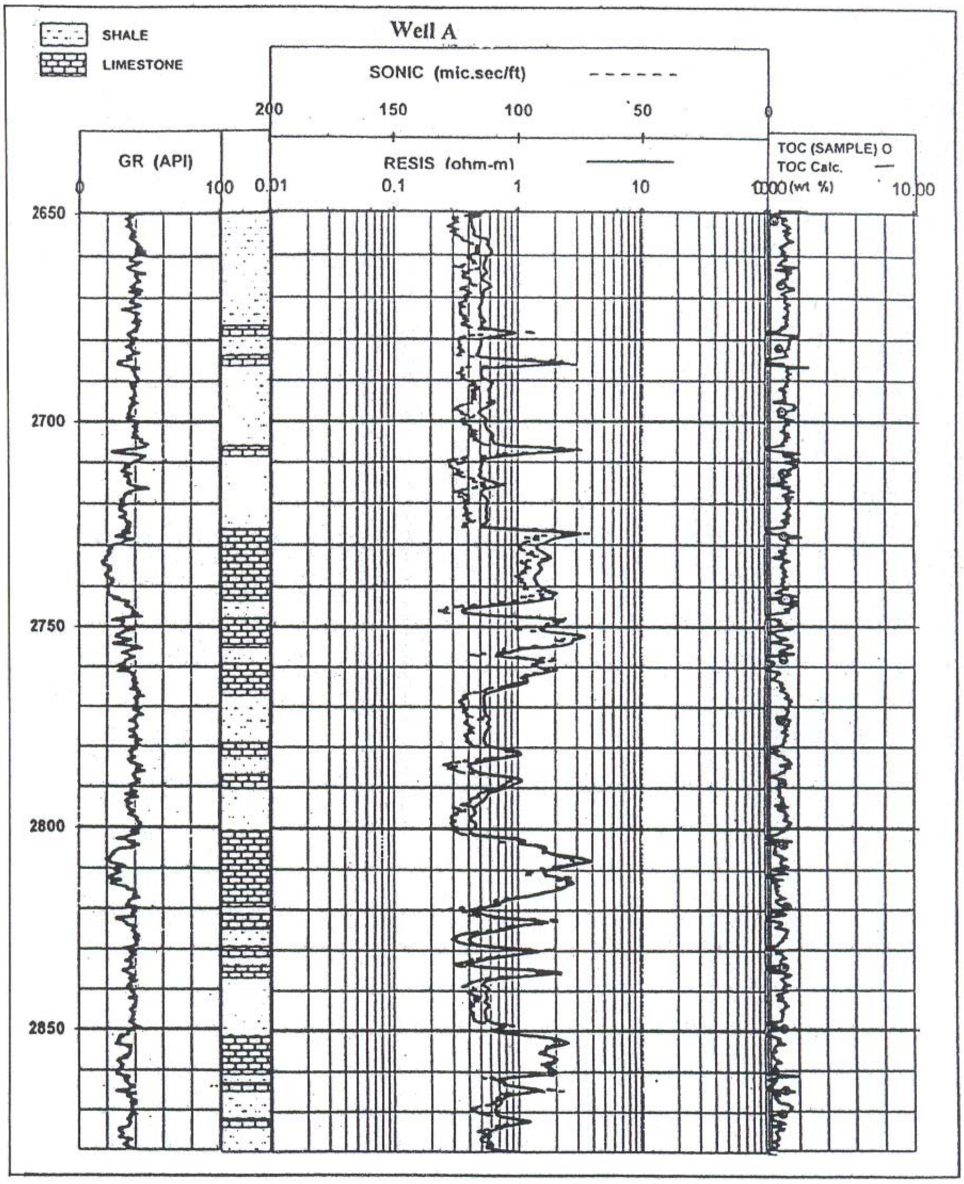


Figure (14): Sonic-resistivity overlay and calculated TOC% of Well A

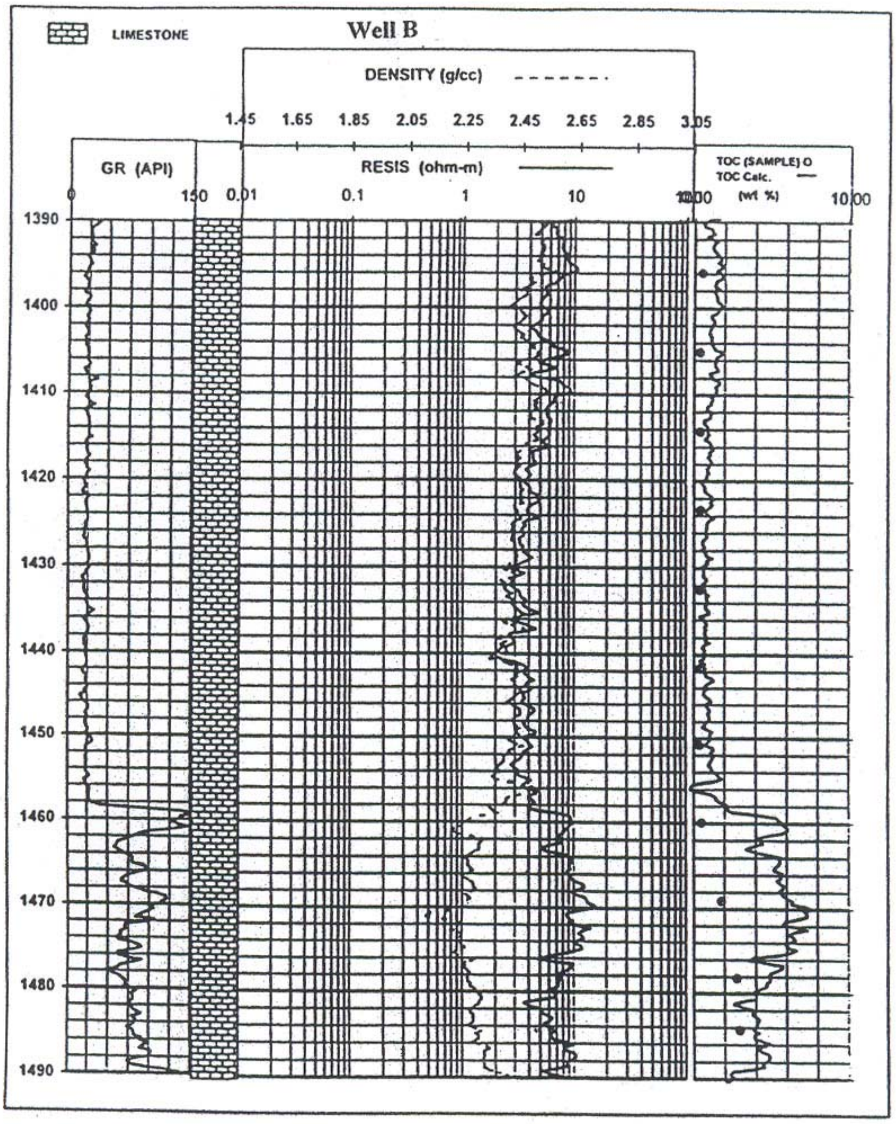


Figure (15): Density-resistivity overlay and calculated TOC% of Well B

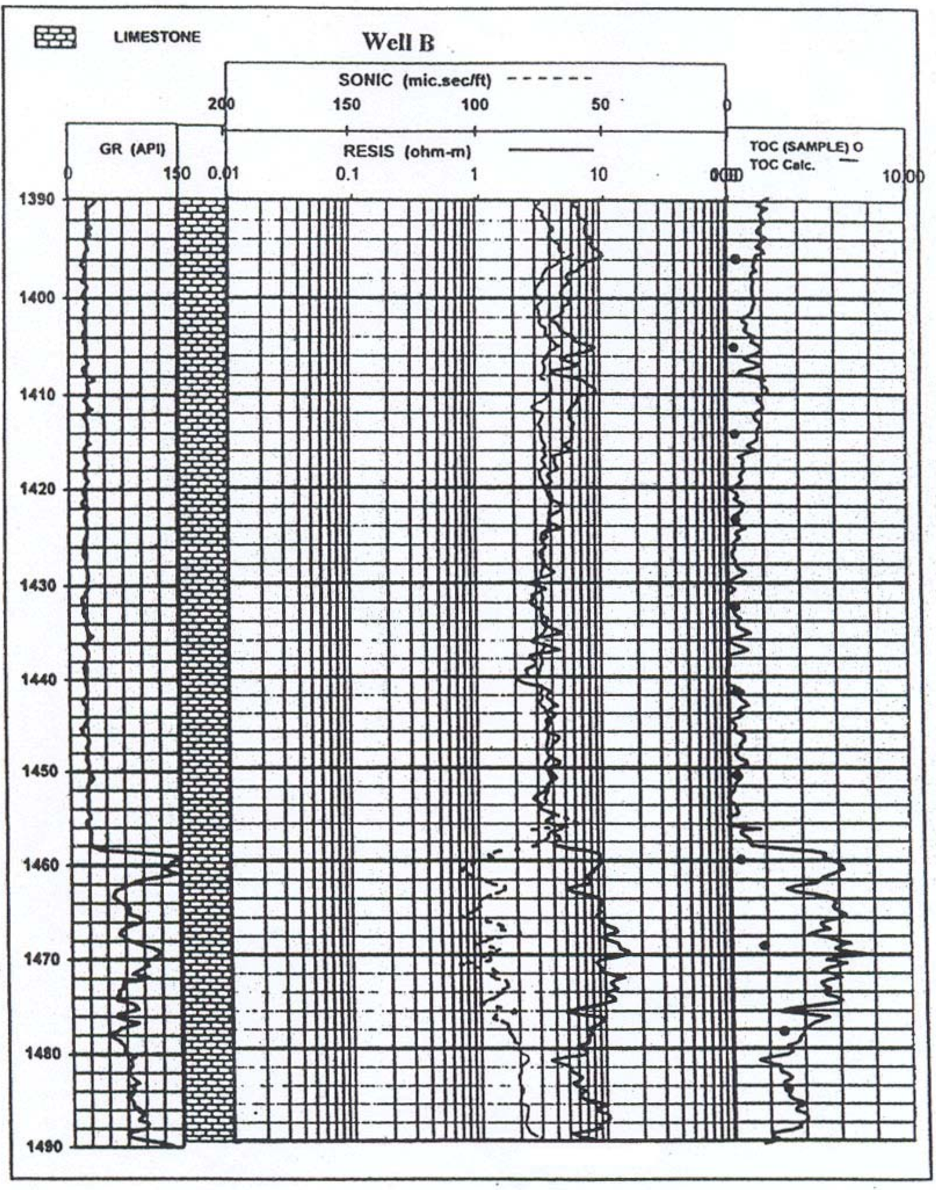


Figure (16): Sonic-resistivity overlay and calculated TOC% of Well B

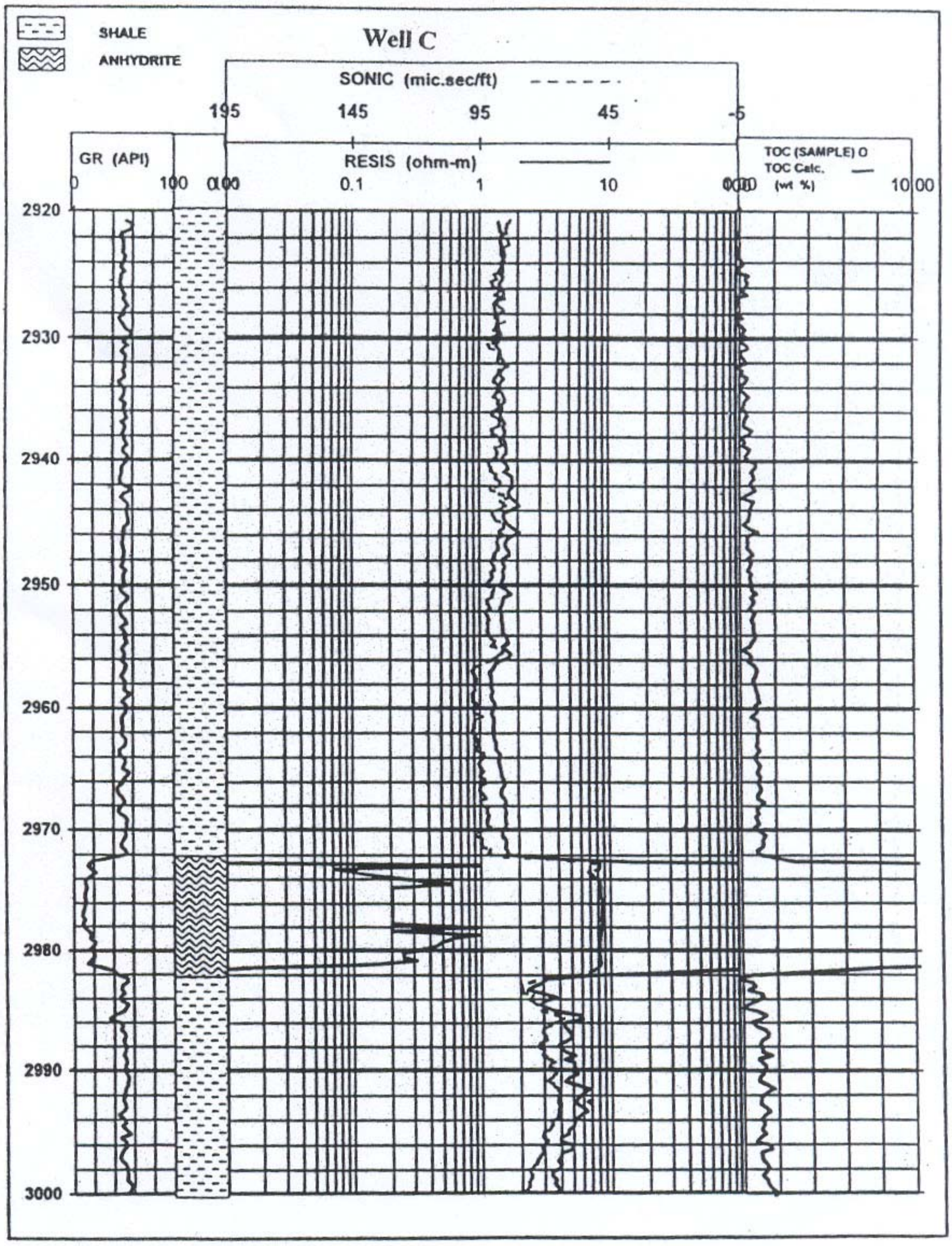


Figure (17): Sonic-resistivity overlay and calculated TOC% of well C well.

4- CONCLUSIONS

The obtained results from log analysis in three wells (A, B and C) distributed through different provinces in the Gulf of Suez revealed the following remarks:

1- Kareem Formation of well A located at the central part of the Gulf of Suez and forms of successive shale and limestone intervals is being considered as fair to good source rock.

2- Upper Senonian which forms completely of limestone at well B located Onshore at the central part of the Gulf of Suez is considered as good source rock.

3- Nukhul Formation in well C located at the southern part of the Gulf of Suez is characterized by its shale content and considered as fair to good source rock.

4- Both techniques of well log analysis can be used in cases similar to the current study.

5- Comparison between the results obtained from log analysis and that from geochemical investigation positive correlation.

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