Egyptian Geophysical Society
EGS Journal, vol. 3, No. 1, 65-88 (2005)

BURIAL HISTORY, THERMAL EVOLUTION AND HYDROCARBON POTENTIALITIES OF THE SOURCE ROCKS IN SHOAB ALI OIL FIELD, SOUTHERN PART OF THE GULF OF SUEZ, EGYPT

Wafaa E. Afify* and Gihan El-bakry **

** Geology Department, Faculty of Science, Benha University*
*** Gulf of Suez Oil Company (GUPCO)*

تاريخ الدفن والتطور الحرارى والمحتوى الهيدروكربونى لصخور المصدر فى حقل شعب على بالجزء الجنوبى من خليج السويس في مصر

الخلاصة: يعتمد تقييم صخور المصدر على محتوى الصخر من الهيدروكربونات ودرجة نضج المادة العضوية وأيضا على تأثير الحرارة على تلك الصخور. وتهدف هذه الدراسة إلى التعرف على تاريخ الدفن للمواد العضوية وأيضا التطور الحرارى لصخور الميوسين وما قبل الميوسين عن طريق رسم نماذج ثنائية الأبعاد لثماني آبار موجودة بمنطقة الدراسة. وقد أخذ فى الأعتبار عند تاريخ الدفن تغير معدلات الترسيب والتصلد للصخور المسامية وعوامل التعرية وانقطاع الترسيب وأيضا تغير الخواص الحرارية الفيزيائية بتغير نوع الصخر والعمق ودرجة الحرارة. وقد تم تقييم المحتوى الهيدروكربونى فى منطقة الدراسة عن طريق التسجيلات الكهربية المتاحة للآبار المدروسة كما تم رسم عدد من الخرائط التى توضح التوزيع الأفقى للتدرج الحرارى والمحتوى الهيدروكربونى لمنطقة الدراسة.

وقد خلص هذا البحث إلى أن صخور الطفلة والحجر الجيرى الطفلى الموجودة بعصر الميوسين تتباين من صخور مصدر فقيرة إلى غنية بينما صخور ما قبل الميوسين تتراوح ما بين صخور مصدر جيدة إلى جيدة جدا.

ABSTRACT: *The evaluation of the source rock is based on the source rock richness, maturation and thermal burial history. The present study aims to construct a two-dimensional model of burial history and thermal evolution for the Miocene and pre-Miocene rocks, penetrated by eight wells in Shoab Ali Oil Field, to illustrate the effect of time and temperature on the oil generation and maturation level of organic matter. Our reconstructions of the thermal history took into account processes such as: a) variable rates of sedimentation and consolidation of the porous rocks, b) erosion and interruption of sedimentation, c) change of thermophysical characteristics with lithology, depth and temperature of rocks and, d) dependence of water, matrix and mantle heat conductivity on temperature. The evaluation of the hydrocarbon-generation potential in the study area is achieved by using the wireline log analysis as a semi-quantitative method for determination of the organic matter concentration (by volume %). Moreover, a number of iso-parametric maps are drawn to show the horizontal distribution of the geothermal gradient and the total organic carbon content (TOC) of the investigated area. The results of this evaluation study show that the Miocene shale and argillaceous limestone are a variably poor to good source rock, while the Pre-Miocene rocks (Thebes, Esna, Sudr, and Matulla Formations) are good to very good source rocks.*

INTRODUCTION

Shoab Ali Field is one of the most prolific fields in the Gulf of Suez. It is located at the mouth of the Gulf of Suez, 43 kilometers to the southwest of El-Tor city on the Sinai side and about 70 kilometers to the northeast of Hurgada city on the eastern coast of the Red Sea (Fig. 1). The structural and stratigraphical style as well as the reservoir characteristics make this field one of the most complicated fields in the Gulf area. The Miocene and post-Miocene sections encountered in the field are similar to the stratigraphic sequence in the southern half of the Gulf of Suez. On the other hand, the thickness of the pre-Miocene section showed some variations in very short distances, reflecting a relatively rugged topography on the pre-Cretaceous section (S.Wasfi & H. Hattaba, 1980 and GUPCO Stratigraphic Report, 1982). The stratigraphic subdivisions penetrated in Shoab Ali Field, based primarily on paleontological zonation and well logging data, are represented in Fig. 2. Structurally, Shoab Ali Field is characterized by an extensive system of tilted blocks. It contains nine clysmic and cross faults. Two trends of faulting are clearly demonstrated (H. Helmy, 1985 and W.M. Meshref, 1976):

- Clysmic Faults (NW-SE) which are marked alphabetically (A, B, C, ------).
- Cross Faults (ENE-WSW) and those marked in Romanian Letters (I, II, III, ----).

Miocene shales and argillaceous limestone, and the pre-Miocene Thebes, Esna, Sudr and Matullua Formations represent source rocks in Shoab Ali Field.

Production is from all porous units, including Belayim (sands and fractured carbonates), Kareem, and Upper Rudeis sands, Lower Rudeis prograding sand bars, Nukhul alluvial fan sands, Thebes fractured limestone, Matulla and Nubia sandstone and fractured pre-Cambrian basement (Saoudi and khalil, 1984).

The main vertical and horizontal seal of the Shoab Ali structure, the seal that appears to control the common oil-water contact of the field, is the South Gharib Formation (salt and anhydrite) and Zeit Formation (anhydrite and shale). Also, there are intra-structure seal sections represented by Nukhul evaporites, Belayim evaporitic Members (Feiran and Baba) and the impermeable shale beds of the Miocene Clastics (Younis and Acombs, 1984).

PURPOSE AND SCOPE

This paper attempts to evaluate the source rocks in eight wells (A-2, B-1, B-4, B-3, C-4, B6-A, B-7 and C-5) in Shoab Ali Field at the southern part of the Gulf of Suez, (Fig.3), by using wireline log data.

To evaluate a source rock it is important to determine the quantity of organic matter (TOC, wt. %), the maturity of the organic matter and the type of organic matter. Determinations of the aforementioned concepts take place by using a geochemical analysis on core or ditch samples, which is expensive and not available in most cases. In Shoab Ali Field a geochemical analysis is performed for one well, SA-E3, while the evaluation of the source rock in the entire area is based on the geochemical evaluation study of the South Ghara concession, West of Shoab Ali Field. So, in this work we have tried to determine the total organic carbon content (TOC wt.) and the geothermal maturation concepts (geothermal gradient, time-temperature index TTI and vitrinite reflectance) for eight formations (the Miocene, Belayim, Kareem and Nukhul and the pre-Miocene Thebes, Esna, Sudr, Matulla and Nubia Formations) penetrated by the study wells, by using the available logging data and the time-stratigraphic data.

METHODOLOGY

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, 1981). According to Peters, 1986 the source rocks are classified as follows:

Source Rock Types (after Peters, 1986)

Quality	TOC (wt %) ranges
Poor	0 - 0.5
Fair	0.5 - 1.0
Good	1.0 - 2.0
Very good	> 2.0

Schmoker (1979) drew the attention to the determination of the organic matter within shale sequence using the combination of compensated formation density log (FDC) with the gamma-ray log (GR). The use of this method is preferred because the density log is more common and available than core samples. Moreover, the continuously recorded density log eliminates the statistical uncertainties of the limited sampling of the formation. Also, determination of TOC by log analysis proved to be less expensive than the classical analysis of core samples. 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:

$Q_o = (\rho_b - \rho) / (\rho_b - \rho_o)$ (Meyer and Nedelof, 1984) (1)

where:

Q_o is the organic content by volume (vol%).

ρ_b is the bulk density of a compacted shale sequence with no organic matter (ρ_b = 2.7 gm/cc).

ρ is the density of the shale sequence within the studied units.

ρ_o is the organic matter density, its value is approximately the same as

ρ_{water} = 1.0 gm/cc.

$$TOC = \frac{Q_o (100 * \rho_o)}{R * \rho}$$ (Schmoker and Hester, 1983) (2)

R is the ratio between the weight percent of organic matter and organic carbon and depends on certain parameters as depth and temperature. Schmoker used R= 1.3.

Thermal Maturity of Organic Material:

The concentration and molecular distribution of hydrocarbons contained in a rock depend on both the type of the parent organic matter and its degree of thermal alteration (Stoneley, 1995). In this study, the thermal maturation analysis has been carried out through the calculation of Time-Temperature Index (TTI) as well as calculation of vitrinite reflectance (R_o).

i) Vitrinite Reflectance:

Thermal evolution of source rocks changes many physical and chemical properties of the organic matter, so the changes in these properties are used as indicators for maturity. The most common parameter used in industry, as a standard against which all other parameters are calibrated, is the vitrinite reflectance. 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, as shown in the following table.

Stages of maturation and types of hydrocarbon products (after Waples, 1985)

Ro %	Stages of Maturation	Types of Hydrocarbons
0.4		
0.5	Immature stage	Condensate from resinite
0.6	Early mature stage	
0.65		
0.7		
0.8	Peak generation	Oil generation
1.0		
1.35	Late generation	
2.0		Wet gas
> 2.0		Dry gas

In our study, R_o is determined by using Oehler (1983) charts and (Welte and Yukler, 1981) equation:

$$R_o \% = 1.301 \log TTI - 0.5282 \quad (3)$$

where TTI is the time-temperature index determined by Lopatin, (1971) method.

ii) Geothermal Effect:

It is unanimously accepted that the temperature and time are important agents influencing the process of oil generation and in the subsequent cracking of oil to methane. Based Lopatin (1971) method, which was modified by Waples, (1980-1985), the time-temperature index of maturity was calculated at the base of the studied sequence (Miocene and pre-Miocene Formations). The effect of increasing temperature is essentially exponential, as compared to that of increasing time. So that, the calculation of geothermal gradient (GG) is important in determining the maturation of organic matter. The geothermal gradient is calculated as follows:

$$GG = \frac{\text{bottom hole temperature} - \text{surface temperature}}{\text{total depth}} \times 100 \quad (4)$$

Before calculating the geothermal gradient, bottom hole temperature must be corrected.

In the present study, the bottom hole temperature was corrected by using Shell (1979) chart.

APPLICATIONS

Total Organic Carbon Content (TOC):

The total organic carbon content was calculated from the formation density log using equations (1) and (2) for the penetrated sequence in the studied wells, Tables (2-9). The TOC wt.% for the Belayim Formation ranges from 0.6% at C-4 well to 1.57% at A-2 well, while the TOC wt.% of the Kareem Formation is about 1.71% at C-5 well and 2.75% at B6-A well. Regarding the Nukhul Formation, the TOC wt.% ranges from 0.19% at A-2 well to 2.32% at B-1 well, and the TOC wt.% for the Thebes Formation equals 0.49 % at B-1 well and 2.12% at B6-A well. On the other hand, the TOC wt.% of the Esna Formation is about 1.39% at B-1 well and 2.12% at B-3 well. The Sudr Formation shows a range of TOC wt.% from 2.59% at B6-A well to 4.35% at B-7 well, while the Matulla Formation shows a range of TOC wt.% from 2.76% at B6-A well to 3.49% at B-4 well. Finally, the TOC wt.% of the Nubia Formation is about 2.52% at B-4 well to 2.96% at B-7 well. Figs. (4-11) are contour maps for the calculated TOC of the studied formations. The maps illustrate that the average TOC wt.% for the investigated formations increasing generally towards the northeastern part of the study area.

Geothermal Maturation:

The geothermal gradients within the study area are calculated for the studied wells, Table (1). The calculated values range from 1.7 ^{o}F/100 ft (3.1 ^{o}C/100m) at B-1 well to 2.2 ^{o}F/100 ft (3.95 ^{o}C/100m) at B6-A well. Fig. (12) is a contour map showing the geothermal gradients in the area of study. The data reveals an increase in the geothermal gradient towards the northeastern part of the map.

Eight burial history models are constructed for the study wells to calculate the TTI at the base of the penetrated stratigraphic sequence, (Figs. 13-20). The calculated values of TTI are presented in Tables (2-9).

Lopatin (1971) and Waples, (1990), identified the limits and types of hydrocarbon products, from the calculated time-temperature index, TTI, as follows:

TTI value	Type of Hydrocarbon Product
15	onset on oil generation
75	peak of oil generation
160	end of oil generation
500	40° oil preservation deadline
~ 1000	50° oil preservation deadline
~ 1500	wet gas preservation deadline
> 65,000	dry gas preservation deadline

The maximum calculated TTI value in the study area is 2.33 at the base of the Nubia Formation. This value is lower than the minimum limit for oil generation is determined by Waples. This indicates that the oil in

TABLE (1) : GEOTHERMAL GRADIENT OF THE STUDY AREA.

well	geothermal gradient F/100 Ft.	geothermal gradient C/100m.
A-2	1.8	3.24
B-1	1.7	3.1
B-4	1.8	3.367
B-3	1.8	3.36
C-4	1.9	3.42
B6-A	2.2	4.01
B-7	2.2	3.95
C-5	1.9	3.396

TABLE (2): ESTIMATED GEOCHEMICAL PARAMETERS FOR A-2 WELL.

FORMATION	TOC Wt.%	Ro equation	Ro chart(1)	Ro chart(2)	SUM TTI
BELAYIM	1.57	<0.2	<0.4	<0.4	0.557
KAREEM	2.39	<0.2	<0.4	<0.4	0.599
NUKHUL	0.198	<0.2	0.43	0.5	1.146

TABLE (3): ESTIMATED GEOCHEMICAL PARAMETERS FOR B-1 WELL.

FORMATION	TOC Wt.%	Ro equation	Ro chart(1)	Ro chart(2)	SUM TTI
BELAYIM	0.762	<0.2	<0.4	<0.4	0.519
KAREEM	2.52	<0.2	<0.4	<0.4	0.589
NUKHUL	2.32	<0.2	<0.4	<0.4	0.892
THEBES	0.49	<0.2	0.46	0.5	1.747
ESNA	1.39	<0.2	0.5	0.5	1.556

TABLE (4): ESTIMATED GEOCHEMICAL PARAMETERS FOR B-4 WELL.

FORMATION	TOC Wt.%	Ro equation	Ro chart(1)	Ro chart(2)	SUM TTI
BELAYIM	1.357	<0.2	<0.4	0.5	1.107
KAREEM	2.49	<0.2	<0.4	0.5	1.207
MATULLA	3.49	<0.2	0.56	0.505	1.7
NUBIA	2.52	<0.2	0.62	0.52	2.24

TABLE (5): ESTIMATED GEOCHEMICAL PARAMETERS FOR B-3 WELL.

FORMATION	TOC Wt.%	Ro equation	Ro chart(1)	Ro chart(2)	SUM TTI
BELAYIM	0.765	<0.2	<0.4	<0.4	0.65
KAREEM	2.31	<0.2	<0.4	0.5	0.897
NUKHUL	1.34	<0.2	<0.4	0.505	1.412
THEBES	0.901	<0.2	0.45	0.505	1.542
ESNA	2.12	<0.2	0.5	0.505	1.591

TABLE (6): ESTIMATED GEOCHEMICAL PARAMETERS FOR C-4 WELL.

FORMATION	TOC Wt.%	Ro equation	Ro chart(1)	Ro chart(2)	SUM TTI
BELAYIM	0.601	<0.2	<0.4	<0.4	0.656
KAREEM	2.13	<0.2	<0.4	0.5	0.938
NUKHUL	0.75	<0.2	0.45	0.52	1.808

TABLE (7): ESTIMATED GEOCHEMICAL PARAMETERS FOR B6-A WELL.

FORMATION	TOC Wt.%	Ro equation	Ro chart(1)	Ro chart(2)	SUM TTI
BELAYIM	0.62	<0.2	<0.4	0.5	0.224
KAREEM	2.75	<0.2	<0.4	0.5	1.017
THEBES	2.12	<0.2	0.46	0.5	1.254
ESNA	1.87	<0.2	0.52	0.505	1.339
SUDR	2.59	<0.2	0.54	0.505	1.413
MATULLA	2.76	<0.2	0.55	0.508	1.46
NUBIA	2.86	<0.2	0.62	0.52	2.33

TABLE (8): ESTIMATED GEOCHEMICAL PARAMETERS FOR B-7 WELL.

FORMATION	TOC Wt.%	Ro equation	Ro chart(1)	Ro chart(2)	SUM TTI
SUDR	4.35	<0.2	0.53	0.505	1.514
MATULLA	3.15	<0.2	0.54	0.505	1.585
NUBIA	2.96	<0.2	0.58	0.52	2.021

TABLE (9):ESTIMATED GEOCHEMICAL PARAMETERS FOR C-5 WELL.

FORMATION	TOC Wt.%	Ro equation	Ro chart(1)	Ro chart(2)	SUM TTI
BELAYIM	0.824	<0.2	<0.4	0.5	1.02
KAREEM	1.71	<0.2	0.4	0.505	1.653
NUKHUL	0.714	<0.2	0.48	0.52	1.995

TABLE (10): Ro FROM THE STUDY FOR SA-E3

FORMATION	R_O
SGH	<0.4
BEL	0.44
KAR	0.39
NUKHUL	0.37
THBES	0.34
ESNA	0.3
SUDR	0.27
MATULLA	0.26

TABLE (11): Ro FROM THE LABORATORY FOR SA – E3

DEPTH	R_O
4600	<0.4
4950	0.44
5400	0.39
5890	0.37

TABLE (12) COMPARISON BETWEEN TOC% FROM LABORATORY AND THE STUDY FOR SA-E3

DEPTH	TOC% FROM LABORATORY TORY	TOC % FROM THE STUDY
4550	1.08	2.063657407
4600	0.8	0.68751
4650	0.83	0.690822
4700	0.51	0.424445
4800	0.83	0.6071127
4850	0.75	0.5411205
4950	1.52	1.88154
5000	2.01	2.541359
5050	1.79	1.647773
5100	1.48	1.282353
5150	1.58	3.70008
5200	1.16	3.11765
5250	0.63	0.305882
5300	0.41	0.258824
5350	0.84	0.762292
5400	0.95	0.94118
5800	2.01	1.76471
5850	5.91	6.617039
5890	5.91	6.739193

the study area has migrated from a nearby oil field. Fig. (21) is a contour map showing the distribution of the TTI values calculated at the base of the Esna Formation.

Vitrinite reflectance, on the other hand, was determined by using equation (3) and two charts of Oehler (1983). The first chart (chart 1) is relating the geothermal gradient (^oF/100 ft), with the formation depth (ft) and age (million years). The second chart (chart 2) is based on the TTI values determined by using Lopatin method.

Theoretically, Lopatin`s method should give more accurate maturity than the maturities determined from chart (1). This is because chart (1) is based on equations which handle the effect of time somewhat simplistically. It is because of this simplicity that the chart is approximate, (Oehler, 1983).

The vitrinite reflectance values are represented in Tables (2-9). The R_o values determined for the studied formation reveals that the source rocks are immature. This indicates that the oil in the reservoir rocks is migrated from another basin to the study area. Saoudi (1989) confirmed this conclusion. He concluded that " hydrocarbons generated in the Ghara trough to the west of Shoab Ali Field, migrated updip and were finally trapped in the Shoab Ali Field". Figure (22) is a contour map of the R_o values for Esna Formation, revealing that this Formation is immature allover the study wells.

Log and Lab Correlation.

From the comparison between the geochmical data reported for SA-E3 well and our study results one can observe the following:

Two immature source zones were encountered. The first zone at 4550 to 5400 feet varying from moderate to good potential and contains type II/III kerogen from a mixed terrestrial and marine origin. The second zone (5800-5890 ft) has an excellent source potential of type II marine derived kerogen.

For illustration, data are given in tables 10, 11, 12, and Figs. 23, 24, showing geochemical evaluation log and pyro-analysis crossplot.

CONCLUSIONS

Total Organic Carbon (TOC):

- Belayim Formation is a fair to good source rock (TOC = 0.6%-1.5%).
- Kareem Formation is a good to excellent source rock (TOC = 1.71%-2.75%).
- Nukhul Formation is a very poor to excellent source rock (TOC = 0.2%-2.32%).
- Thebes Formation is a poor to excellent source rock (TOC = 0.5%-2.12%).
- Esna Formation is a good to excellent source rock (TOC = 1.39%-2.12%).
- Sudr and Matulla Formations are excellent source rocks (TOC = >2 %).

The estimated TOC for the studied source rocks indicate that at optimum maturity both gas and oil could be generated from these rocks.

The geothermal gradient in the study area increases from about 1.7 ^oF/100 ft to 2.2 ^oF/100 ft This could be due to the conduction dominated system where the thermal field is controlled by terrestrial heat flow from the Basement and by the thickness, lithology and porosity of the lithologic section.

The time-temperature index (TTI) determined from the burial history diagrams of the stratigraphic succession penetrated by the study wells is lower than the minimum limit of oil generation (TTI < 15), indicating that the oil in the study area is migrated from a nearby region (the Ghara Trough).

Vitrinite reflectance measurements indicate that all the studied source rocks are immature; (R_o <0.6). This conclusion is confirmed with Gupco's results on the geochemical analysis of SA-E3 well.

RECOMMENDATIONS

- Carry out a log-derived TOC method against laboratory data for GOS wells.
- Investigate further the northeastern part of the study area.
- Apply log methodology to other areas of the GOS, where source quality is unknown.
- Explore the deeper parts of Shoab Ali Field as the studied wells are located at the higher parts of the area.

REFERENCES

Exploration Logging International INC., (1984): Geochemical report on well SA-E3: GUPCO internal report.

GUPCO Stratigraphic report, (1982): Stratigraphy of Shoab Ali area: ER 81-54 (SA).

Helmy, H. (1985): Pre-Miocene (Basement) structural interpretation in South Ghara concession: GUPCO ER 84-24 (GH) GUPCO internal report.

Lopatin, N.V., (1971): Temperature and geologic time as factors in coalification (in Russian):Akad. Nauk SSSR Izv. Scr. Geol., no. 3, pp. 95-106.

Meshref, W.M., et al., (1976): Structural interpretation of the Gulf of Suez and its oil potentialities: EGPC 5th Exploration Seminar Cairo, 21pp.

Meyer, B. L. and Nederlof, M. H., (1984): Identification of source rocks on wireline logs by Density-Resistivity and Sonic Transit Time-Resistivity crossplots: AAPG Bulletin, V. 68, no. 2, pp. 121-129.

Oehler, J., (1982): Using geothermal gradient to estimate the source rock quality: AAPG Memoir 42.

Peters, K. E., (1986): Guidelines for evaluating petroleum source using programmed pyrolysis", AAPG Bull. Vol. 70, P. 318-329.

Saoudi, A. and Khalil B., (1984): Distribution and hydrocarbon potential of Nukhul sediments in the Gulf of Suez: EGPC 7th Exploration Seminar, Cairo.

Schmoker, J. W. (1979): Determination of organic content of Appalachian Devonian shales from formation density logs: AAPG Bulletin, V. 63, pp. 1504-1509.

Schmoker, J. W. and Hester, T, C., (1983): Organic carbon in Bakken formation, United States portion of Williston Basin: AAPG Bulletin, V. 67, pp. 2165-2174.

Stoneley, R. (1995): An introduction to petroleum exploration for non-geologists: Oxford University Press, Oxford. 119 pp.

Waples, D. (1980): Time and temperature in petroleum formation: Application of Lopatins method to petroleum exploration: AAPG Bulletin, V. 64, no. 6, pp. 916-926.

Waples, D. (1985): Organic geochemistry in petroleum exploration: Reidel Publ. Co, Dordrecht & IHRDC, Boston. 232 pp.

Wasfi S. and Hattaba H., (1980): Preliminary biostratigraphic results of Shoab Ali field, a re-interpretation of the Israeli stratigraphic data: ER 80-14 (SA).

Welte and, D. H. and Leythaeuser, D. (1981): Application of organic geochemistry and quantitative analysis to petroleum origin and accumulation: AAPG Bulletin, no. 49, pp. 2248-2268.

Younis M. and Acombs T., (1984): Shoab Ali oil field evaluation: GUPCO ER 84-1 (GH) GUPCO internal report.