PETROPHYSICAL CHARACTERISTICS AND NET PAY PARAMETERS OF KAREEM FORMATION IN SHOAB ALI OIL FIELD, SOUTHERN GULF OF SUEZ, EGYPT.

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الخواص البتروفيزيائية وخواص الخزان لتكوين كريم بحقل شعب على–جنوب خليج السويس–مصر

الخلاصة. تهدف معظم الدراسات الكمية إلى تحديد بعض الخواص البتروفيزيائية مثل محتوى الطفلة و المسامية والتشبع بالماء وهذه الخواص تحدد نوع الهيدروكربون الموجود بالخزان (غاز أو زيت) فى بداية تكوينه ولكن ما يجب أن نعرفه هو: هل الآبار المحفورة سوف تنتج أم لا وكم عدد الآبار المنتجة فى منطقة الإستكشاف؟ وهل ستنتج زيتا" أم غازا"؟ وللإجابة عن هذه الأسئلة فإننا نحسب بعض االباراميترات البتروفيزيائية مثل النفاذية الفعالة وبعض خواص الخزان المتمثلة فى حجم الماء الكلى وحجم الحبيبات التى يمر من خلالها الزيت و المسامية الفعالة ومعامل التشبع بالماء و محتوى الطفلة والمحتوى الصخرى. وقد تم تقييم تكوين كريم فى ثمانية آبار بمنطقة الدراسة وحساب الباراميترات المختلفة للتعرف على نوع الهيدروكربون الموجود بتكوين كريم كما تم تصنيف الآبار بمنطقة الدراسة إلى آبار منتجة وأخرى غير منتجة.

ABSTRACT. *Most quantitative log analysis is aimed at determining shale content, porosity, and water saturation. These terms define the oil or gas in-place in the reservoir at initial conditions. What we really like to know is: are the wells good, that is, will they produce anything? How many wells are productive in the investigated area? And what will the wells produce oil, gas or water? To know this, we must determine values for permeability and net pay parameters for the studied wells.*

The wireline log analyses for eight wells in the study area have been used to evaluate the petrophysical parameters of the Middle Miocene Kareem Formation. These parameters include the effective porosity (¤$_e$), water saturation (Sw), movable hydrocarbon saturation (Shm), residual hydrocarbon saturation (Shr), bulk volume water (BVW), movable hydrocarbon pore volume (MHPV) and lithologic content in terms of volume of shale (Vsh) and matrix volume (Vs.s and Vcarb.). Moreover, the effective permeability was calculated.

To illustrate the horizontal distribution of the different petrophysical parameters, a number of isoparametric maps were drawn. The relationships between the net pay parameters were analyzed through the construction of four crossplots to evaluate the Kareem Formation characteristics. The application of the different log analysis methods and net pay parameters largely improved our knowledge and discriminated accurately between zones that are capable of commercial oil production and those that are not, and water productive or tight zones.

INTRODUCTION

Shoab Ali Oil Field is located offshore in the southern part of the Gulf of Suez, close to the Sinai shore, 43 kilometers to the southeast of El-Tor city and 67 kilometers to the southeast of GUPCO`s Ras Shukheir base (Fig. 1). The area of the field is partly covered by modern coral reefs in up to 5 meters of water, preservation of which has to be considered in the setting of the platforms *(Nagaty et al., 1982).* The structural and stratigraphical style as well as the reservoir characteristics makes 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 *(Wasfi & 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, *(Helmy, 1985 and Meshref, 1976).*

The present study is devoted to analyze the petrophysical and net pay parameters of Kareem Formation (Middle Miocene), in 8 wells in Shoab Ali Oil Field, these wells are (SA B-1, SA B-3, SA B6-A, SA A-2, SA C-5, SA B-4, SA C-4 and SA E-3 wells.),(Fig.1). The available well log data are: resistivity logs, porosity logs, gamma ray and caliper logs. These logs are corrected for environmental effects, filtered to remove the statistical variations and finally depth matched to create the composite logs as shown by *Knox, (1974) and Kerzner, (1984).*

The sandstones of the Kareem Formation are one of the most important reservoir lithologies in the Gulf of Suez basin and produce and/or test oil from many oil fields. Of ten potential reservoir units in the basin, 23% of the oil is produced from the Kareem Formation sandstones. Their net pay thickness range between 10 m and 200 m, Porosities range from 7 % to 33%, and permeability range from 20 md. to 730 md., *(Alsharhan, 2002).*

PETROPHYSICAL WELL LOG ANALYSIS.

The well log data of eight (8) wells are evaluated to conclude the petrophysical and net pay parameters for the Kareem Formation in the investigated area. The formation evaluation approach system in the present study includes the following:

1- **Determination of shale volume:-**

Shale volume is determined by using the single-curve shale indicator method (self-potential, gamma ray, resistivity and neutron logs) and the double-curve shale indicator method for a better determination of shale volume, in terms of neutron-density, sonic-density, and neutron-sonic combinations , as shown by *Abdallah and Said (1993).*

2- **Determination of matrix content:**

The identification and estimation of matrix rock constituents (volume of sandstone and carbonates) was made using the simultaneous equations technique proposed by *Burke et al., (1969), Harris et al., (1969) and Abu el-Ata and Ismail, (1985).*

3- **Determination of porosity:**

Rock porosities are usually measured using density, neutron and sonic tools (porosity logs), in clean and shaly zones, through the equations proposed by *Wyllie et al., (1958) and Batman and Konen, (1977).* Moreover, the effective porosity is calculated using the equations of *Clavier et al., (1984).*

4- **Determination of fluid saturations:**

The determination of the fluid saturation means principally the discrimination of the various types of fluid components (water and hydrocarbons) which fill the pore spaces of the rock.

Before going through the calculation of the water saturation, the cementation exponent (m) was determined by using the equation of *Rasmus, (1983)* and the graphical method explained by *Pickett, (1966) and (1973).* The uninvaded zone water saturation (Sw) and the invaded zone water saturation (Sxo) are determined using *Clavier et al., (1984)* equations. After calculating the water saturation for the studied interval, the total hydrocarbon saturation with their residual saturation (Shr) and moveable saturation (Shm) are calculated.

5- **Determination of permeability:**

Rock formation permeability is one important flow parameter associated with subsurface production and injection. Its importance is reflected by the number of available techniques typically used to estimate it. The three major permeability measurement techniques used by the industry are, wireline-log analysis (including the RFT method), laboratory testing of core samples, and well testing *(Ahmed et al., 1991).*

Five methods are established for obtaining permeability from wireline tool measurements *(Allen et al., 1988):* (i) empirical correlation of permeability with porosity and intergranular surface area; (ii) measurement of producible formation fluid with nuclear magnetism log (NML); (iii) estimate of mineral concentrations by the geochemical logging tool (GLT); (iv) correlation of permeability with Stoneley wave velocity by acoustic logging tools; and (v) pressure/time measurement of formation fluids with the RFT tool. The parameters used to infer permeability from logs are measured at in-situ conditions, the complexity of rock structures and inadequate parameterization make the log-derived permeability transforms nonuniversal. Therefore, no single relationship can be safely applied for all reservoir conditions. The main advantage of wireline log based techniques is the ability to provide a continuous estimation of permeability with relatively low cost and short time of acquisition and evaluation. This translates into efficiency and cost effectiveness.

Many empirical equations are derived to estimate the relative permeability. The more general relationship was proposed by *Wyllie and Rose, (1950),* that incorporates irreducible water saturation and has the form:

$$K = C\phi^{x} / (S_{wi})^{y}$$

Based on the general expression of Wyllie and Rose several investigators *(Tixier 1949, Timur 1968, Morris and Biggs 1967 and Coates and Dumanoir 1974)* proposed several empirical equations from which permeability can be estimated from porosity and irreducible water saturation derived form well logs:

$K^{1/2} = 250(\phi^{3}/S_{wi})$ Tixier

$K^{1/2} = 100(\phi^{2.25}/S_{wi})$ Timur

$K^{1/2} = (300/w^{4})(\phi^{w}/S^{w}_{wi})$ Coates-Dumanoir

$K^{1/2} = 70\,[\phi^{2}_{e}(1 - S_{wi})/S_{wi}]$ Coates

where;

K is permeability (in md),

ϕ is porosity (fraction unit),

S_{wi} is irreducible water saturation (fraction unit), and C, x, y, e, and w are constants *(Schlumberger, 1989).*

6- Determination of net pay parameters:

Net pay parameters are an indication of the integrated effect of the pore volume, water saturation, bulk volume water (BVW) and the moveable hydrocarbon pore volume (MHPV). *Teti and Krug, 1987,* proposed two equations to determine the bulk volume water (BVW) and the moveable hydrocarbon pore volume (MHPV):

BVW=PHIC * Sw

MHPV=PHIC * MOS * h

where;

PHIC is the corrected porosity (fraction unit),

Sw is the water saturation (fraction unit),

MOS is the movable oil saturation (fraction unit),

h is the thickness of the pay zone (in feet).

APPLICATION AND RESULTS.

The calculated petrophysical and net pay parameters (table 1), are represented in the form of gradient and distribution maps for the Kareem Formation allover the study area. However, the basin and lithofacies conditions are delineated from the isopach,

Table (1):- The estimated petrophysical and net pay parameters.

WELL	THICK	VSH	PHIT	PHID	PHIN	PHIS	PHIN-D	PHIE
B-1	330	40	30	20	33	41	30	18
B-3	550	19	25	26	24	38	25	20
B-6A	132	46	26	26	2	38	13	14
A-2	940	42	11	3	20	33	11	6
C-5	243	41	23	14	31	27	23	13
B-4	683	11	27	27	28	36	27	24
C-4	824	62	30	23	37	36	30	11
E-3	344	63	32	24	40	39	32	12

WELL	Vmatri	Vs.s	Vcarb	SW	Sxo	Sh	Shm	Shr
B-1	30	29	1	69	70	31	1	30
B-3	55	53	2	89	97	11	8	3
B-6A	27	27	0	81	94	19	13	6
A-2	46	44	2	33	66	67	32	35
C-5	35	20	15	69	90	31	21	10
B-4	61	57	4	34	76	66	42	24
C-4	7	6	1	96	99	3	3	0
E-3	4	4	0	77	98	23	21	2

WELL	BVW	MHPV	Kused (md.)
B-1	12.6	11.2	106
B-3	17.8	8.5	200
B-6A	11.3	9	70
A-2	2.3	17.5	10
C-5	9.1	18	62
B-4	8.5	20.5	670
C-4	10.7	7.8	15
E-3	9.2	24	30

shale, sandstone and carbonate maps. The reservoir potentials are defined through the gradient and fluid saturation maps. The net pay parameters of the Kareem Formation can be determined from the bulk volume water map and the moveable hydrocarbon pore volume map. Moreover, four crossplots were developed for the ϕ_e versus Sw, BVW, MOS and MHPV to develop the net pay parameters of the Kareem Formation in the study area.

1- Basin and lithofacies conditions:

The depositional condition prevailed during the deposition of the Kareem Formation was illustrated by an isopach map of the investigated area (Fig.3). The map shows a marked subsidence towards the west and a northwest-southeast high, which matches with the horst block structure of the studied area. Also, this map exhibits a marked thinning towards the west and a general thickening towards the northeastern part of the map. The variation in thickness of the Kareem Formation was attributed to the deposition of the formation over the complicated structure which is characterized by a slight tilting of the area towards the southwest with a number of numerous fault-blocks that were tilted to the southwest, southeast and northwest, and which subsided differentially.

The lithofacies analysis of the Kareem Formation shows the distribution of the shale, sandstone and carbonates in the study area. The shale percentage map (Fig.4) shows an increase in shale percentage at the northwest-southeast direction of the map and a gradual decrease in shale content in the north-south parts of the map. The sandstone percentage map (Fig.5), exhibits a remarkable increase towards the northeast and the southern parts of the map. A high content of sandstone is located at SA B-4 well. The carbonate percentage map (Fig.6) shows a general increase in the carbonate content towards the northeast and northwest directions with a low content at the central part of the map at SA B-4 and SA C-4 wells. The carbonates are nearly missing in the east direction. The lithofacies analysis of the Kareem Formation revealed that the formation was formed in open marine conditions with variable continental influences.

2- Reservoir potentials:

The capability of the Kareem Formation as possible reservoir rock is assessed from the wireline log evaluation through the examination of the porosity and fluid saturations. The effective porosity gradient map of the Kareem Formation (Fig.7) shows porosity high at the central part of the map and porosity lows at the other parts of the map. The porosity attains its maximum value at SA B-4 well and its minimum value at SA A-2 well. The distribution of the effective porosity is generally controlled by the rock lithologies and the tectonic framework which was active during the deposition of the Kareem Formation.

The water saturation map of the Kareem Formation (Fig. 8) illustrate that the water saturation in the study area increases towards the north, northeast and northwest directions of the investigated area, where it reaches its maximum value at SA E-3 well (97%) and its minimum value at SA A-2 well (33%). The hydrocarbon saturation map of the Kareem Formation (Fig.9) expresses a change in the direction of increasing trends as compared to the water saturation map, where the hydrocarbon saturation increases to the south and southwestern parts of the map. The residual and movable hydrocarbon saturation maps (Figs. 10 and 11) show nearly identical configuration to that of the total hydrocarbon saturation map. From the distribution of the residual and movable hydrocarbon saturation, it is clear that the migrations of the movable hydrocarbons are to the structurally high areas and the restrictions of the residual hydrocarbons are at the lower places of hydrocarbon generation.

3-Net pay parameters:

The determinations of the net pay parameters as well as the permeability are very important due to the discrepancies between log methods and test results. Net pay parameters were empirically developed sensitizing net pay cutoffs for the porosity (phic), water saturation (Sw), bulk volume water (BVW), movable hydrocarbon saturation (shm) and movable hydrocarbon pore volume (MHPV). Minimum cutoffs for the phic, shm and MHPV were accepted as 5%, 9% and 10% respectively. On the other hand, maximum cutoffs for the Sw and BVW were accepted as 70% and 10% respectively.

Four cross plots are constructed to determine net pay parameters by using minimum and maximum cutoffs of these parameters (Fig. 12). A cross plot between the porosity and the water saturation (Fig. 12a) shows number of producing wells as the plotted points are above the maximum water saturation cutoff (70%). Wells SA A-2, SA B-4, SA B-1 and SA C-5 are considered as a good reservoir for hydrocarbon commercial production because the plotted points are below the water saturation cutoff. A cross plot between the porosity (phic) and the bulk volume water (BVW) in Kareem Formation (Fig.12c) discriminates between the hydrocarbon producing wells into oil and mixed oil and water wells through the maximum cutoff of bulk volume water (10%), where; wells SA A-2, SA B-4, SA E-3 and SA C-5 are considered as oil producing wells, while wells SA B6-A, SA B-3, SA B-1 and SA C-4 can be classified as mixed oil and water producing wells. The cross plot between the porosity and movable hydrocarbon saturation (Fig. 12b) reveals an increase in the number of commercial wells which are plotted over the cutoff line of movable oil saturation, while the crossplot between the porosity and movable hydrocarbon pore volume (MHPV) (Fig. 12d) define the accurately commercial hydrocarbon production wells which are plotted over the minimum cutoff line (SA A-2, SA B-4, SA B-1, SA E-3 and SA C-5 wells).

Moreover, the lateral variations of these net pay parameters are represented by a number of iso-parametric maps to complete the picture of hydrocarbon potentialities and to delineate the favorable areas for accumulation of these hydrocarbons. The bulk volume water distribution map (Fig. 13) reflects a general increase of bulk volume water towards the east and northeast parts of the map. The maximum bulk volume water is recorded at SA B-3 well where it reaches 13% while the minimum value is recorded at SA A-2 where it reaches 7.5%.

The movable hydrocarbon pore volume map (Fig. 14) reveals a saturation high occupying the central and southern parts of the study area, maximum movable hydrocarbon pore volume is recorded at SA E-3, SA B-4 and SA B-1 wells. These wells can be considered as commercial oil wells, because the values of contour lines reflect a maximum movable hydrocarbon pore volume (> 10%).

Figure (15) represents the effective permeability map for the studied area. The effective permeability of Kareem Formation in the study area increases at the central and southwestern parts of the map. The maximum values of permeability is recorded at SA B-4 (300 md), while the minimum value is recorded at SA A-2 (<10 md).

CONCLUSIONS AND RECOMMENDATIONS.

Based on the results of the current study, Kareem Formation in the investigated wells can be considered as a good reservoir rock. Moreover, most of the wells in the investigated area are productive wells, they can be classified into oil producing wells (SA A-2, SA B-4, SA E-3 and SA C-5) and mixed oil and water producing wells (SA B6-A, SA B-3, SA B-1 and SA C-4). The conclusions obtained from this work are matched with the reports of GUPCO, where; the average effective porosity in this study is 15% and the average effective porosity from GUPCO report (ER-89-40) is about 16%. Moreover, the cumulative production of Kareem Formation in Shoab Ali oil field is 16% MMSTB, (GUPCO report, ER-89-40). Also, Kareem Formation is considered as one of the producing reservoirs in the study area, (GUPCO report, ER-84-1 GH), and five of the studied wells (SA A-2, SA B-1, SA B-3, SA B-4, and SA C-4) are producing from Kareem Formation (Fig. 2). It is recommended to carry out core analysis in Shoab Ali oil field and comparing the derived results with the results calculated from the log analysis to have complete and reliable picture about the different reservoirs in the studied area.

REFERENCES

Abdallah, M.E.M. and Said, A.A. (1993):The utilization of the double curve clay indicator in the determination of the clay content in shaly reservoirs. Ain Shams sci. Bull., vol.31, pp.497-513.

Abu el-Ata, A.S.A. and Ismail, A.A. (1985): Computerized solution for the simultaneous equations to identify the rock matrices of the Abu Madi and Sidi Salem Formations in the Central part of the Nile Delta, Egypt. E.G.S. Proc. of 4th Ann. Meet., pp.376-397

Ahmed, U., Cary, S.F. and Coates, G.R, (1991): Permeability estimation: the various sources and their interrelationships, JPT, May, pp. 578-587.

Allen, D. et al., (1988): Proping for permeability: An introduction to measurements. The technical review, Schlumberger, Houston, pp. 6-20.

Alsharhan, A.S. (2003): Petroleum geology and potential hydrocarbon plays in the Gulf of Suez rift basin, Egypt. AAPG Bul.vol. 87, no. 1, pp. 143-180.

Batman, R.M. and Konen, C.E. (1977): Wellsite log analysis and the programmable pocket calculator.SPWLA Trans., 18th ann.log Symp., Houston, Texas, pp. 107-123.

Burke, J.A., Campbell R.L. and Schmidt A.H.(1969): The lithoporosity cross plot – a method of determining rock characteristics for computation of log data. SPWLA, 10th Ann. Log for computation of log data Symp., pp. 25-43.

Clavier, C., Coates, G. and Dumanoir, J. (1984): The theoretical and experimental bases for the "Dual Water" model for interpretation of shaly sands. Society of Petroleum Engineers Journal, vol. 24, pp. 153-169.

Coates, G.R. and Dumanoir, J.L. (1974): Anew approach to improved log derived permeability. The Log Analyst, 15, no.1

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

GUPCO Stratigraphic report, (1984): Shoab Ali oil field evaluation: ER 84-1 (GH).

GUPCO Stratigraphic report, (1989): Shoab Ali field study: ER 89-40 (GH).

Harris, M.H. and McCammon, R.B. (1969): A computer oriented generalized porosity-lithology interpretation of neutron, density and sonic logs. AIME, Denver, Colorado, U.S.A.

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

Kerzner, M.G. (1984): A solution to the problem of automatic depth matching. SPWLA, 25th Ann. Log Symp. Trans., paper W.

Knox, CH.C. (1974): Quality control of well logs. SPWLA, 15th Ann. Log Symp. Trans. Paper A.

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

Morris, R.L. and Biggs, W.P. (1967): Using log-derived values of water saturation and porosity. Trans. SPWLA , Ann. Log. Symp.

Nagaty, M., Rashed, R. and yonis, M. (1982): Shoab Ali field study. ER 82-6 (S-A).

Pickett, G.R. (1966): Acoustic character logs and their application in formation evaluation. Jour. Pet. Tech. Trans., AIME, pp. 659-667.

Pickett, G.R. (1973): Pattern recognition as a means of formation evaluation. Paper A, in 14th Ann. Log. Symp. Trans., pp. 1-21.

Rasmus, J.C.(1983): A variable cementation exponent "M" for fractured carbonates. The Log Analyst, vol. 24, no. 6, pp. 92-108.

Schlumberger, (1989): Log interpretation principles/applications.

Teti, M.j. and Krug, J.A.(1987): Log analysis methods and empirical derivation of net pay parameters for carbonate reservoirs in the eastern Montana Part of the Williston Basin. The Log Analyst., pp. 259-281.

Timur,A. (1968): An investigation of permeability, porosity, and residual water saturation relationships for sandstone reservoirs. The Log Analyst, 9, no. 4.

Tixier, M.P. (1949): Evaluation of permeability from electric-log resistivity gradients. Oil and Gas J. (June 16).

Wasfi, S. and Hattaba, H. (1980): Preliminary biostratigraphic results of Shoab Ali field. ER 80-4 (SA).

Wyllie, M.R.J. and Rose, W.D. (1950): Some theoretical considerations related to the quantitative evaluation of the physical characteristics of reservoir rock from electrical log data. J. Pet. Tech.

Wyllie, M.R., Gregory, A.R. and Gardner, C.H. (1958): An experimental investigation of factors affecting elastic wave velocities in porous media. Geophys., vol. 23, no. 3, pp. 202-217.