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PETROPHYSICAL STUDIES FOR SOME LOWER CRETACEOUS FORMATIONS, WESTERN DESERT, EGYPT

By

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ABSTRACT

The Kharita, the Dahab and the Alamein Formations are representing the upper part of the Lower Cretaceous rock sequence in the northern part of the Egyptain Western Desert. Some core samples have been obtained from these rock units. They are subjected for both electrical resistivity and rock porosity measurements. Formation factor-porosity relations at four different brine concentrations have been performed. Petrophysical exponents (a, m & n) of the Archie's general formulae have been determined at the in situ formation water resistivity ($R_w = 0.72$ Ohm.m.). They are very helpful to perform an effective well-log interpretation for the studied intervals.

In addition, the correlated relationship between the variations in the interval velocities as a petrophysical character and the existing lithofacies changes in these above mentioned formations have been investigated.

INTRODUCTION

The study area (Fig. 1) comprises about 45000 sq.km being marked by Lat. 29°50′ and 31°40′N and Long 25°00′ and 28°00′ E, in which hydrocarbon exploration activities were carried out by different operators since 1940.

The drilled rock succession, in the study area, includes a sedimentary sequence ranging in age from Cambro-Ordovician to the Recent (Metwalli et al, 1979). The Lower Cretaceous rock sequence has been considered as a source of attraction for many petroleum geologists. This might be due to its probable high hydrocarbon potentiality. In the study area, the Lower Cretaceous rocks have been cored in few wells. Therefore, the all geological studies formerly done are mainly based on ditch samples (drill-cuttings).

Regional geology, structure, sedimentology and stratigraphy of the Lower Cretaceous rock units have been comperhensively studied by different authors (El-Gezzery et al, 1972; Abdin and Deibis, 1972; Barakat and Arafa, 1972; Metwalli and Abdel-Hady, 1973 & 1975; Philip et al, 1980; and Barakat and Darwish, 1984). The Lower Cretaceous sequence has been classified into different rock units by different authors (Tab. 1). In the present study, the classification assumed by Barakat and Darwish (1984) has been adopted.

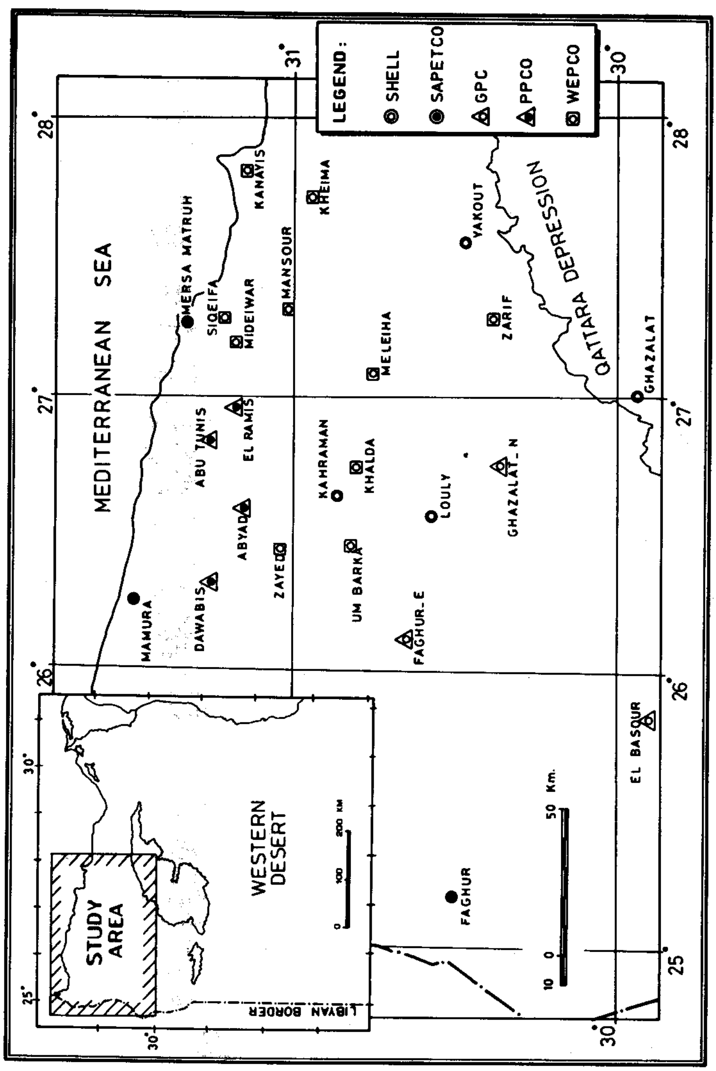

Fig.(1) Location Map

In addition, the well velocity survey data from 24 wells located in the concerned area and 23 core samples were obtained from the Egyptain General Petroleum Corporation and used in the present study. Out of the 23 core samples, only 9 calcareous sandstone samples were from the Kharita Formation, while 2 calcareous sandstone samples were from the Dahab Formation. Only 5 samples were belonging to the Alamein Formation. The rest are broken during measurements.

Table 1

Lower Cretaceous Classification of Different Authors in the Western Desert.

Chrono-stratigraphic units	BECKMAN, J. P (1967)	NORTON, P. (1967)	AADLAND & HASSAN (1972)	ABDIEN & DEIBIS (1972)	EL-GEZEERY & O'CONOR (1975)	METWALLI et. al. (1980)	BARAKAT & DARWISH (1984)
CENOMANIAN	BAHARIYA Fm.	Kharita Sandstone Member (BURG EL-ARAB FORMATION)	BAHARIYA Fm.	CLASTICS	Meleiha Shaly Member (KHARITA Fm.)	BAHARIYA Fm.	BAHARIYA Fm.
LOWER CRETACEOUS – ALBIAN	MM 64 (MERSA MATRUH SHALES (Dark Shales))	Kharita Sandstone Member (BURG EL-ARAB FORMATION)	KHARITA Fm.	CLASTICS	Kheima Sand Member (KHARITA Fm.)	KHARITA Fm.	KHARITA Fm.
LOWER CRETACEOUS – APTIAN	APTIAN LIMESTONE (MERSA MATRUH SHALES (Dark Shales))	×× ; Alamein Carbonate Member ; ××× (BURG EL-ARAB FORMATION) ; MAMURA FORMATION ; MERSA MATRUH FORMATION	ALAMEIN Fm. ; UNNAMED UNIT	ALAMEIN Fm. (Upper Carbonate Unit) ; Intercarbonate Unit ; Lower Carbonate Unit	Dahab Shaley Member ; ALAMEIN Fm. ; Mireir Shaley Member (ALAM EL-BUEIB Fm.) ; MATRUH Fm.	Alamein Dolomite ; Clastic Unit (ALAMEIN Fm)	DAHAB Fm. ; ALAMEIN Fm. ; MIDEIWAR Fm ; ABYAD Fm.
LOWER CRETACEOUS – BARREMIAN	BY 91 (MERSA MATRUH SHALES (Dark Shales))	Alam El-Bueib Member (BURG EL-ARAB FORMATION) ; MAMURA FORMATION ; MERSA MATRUH FORMATION	ALAM EL-BUEIB Fm. ; MAMURA Fm. ; MERSA MATRUH Fm.	APTIAN CLASTICS	Umbarka Sand Member (ALAM EL-BUEIB Fm.) ; MATRUH Fm.	ALAM EL-BUEIB Fm.	MATRUH Fm ; ALAM EL-BUEIB Fm.
LOWER CRETACEOUS – NEOCOMIAN	BY 103 ; Carbonate Shale facies of MAMURA (MERSA MATRUH SHALES (Dark Shales))	BETTY FORMATION ; MAMURA FORMATION ; MERSA MATRUH FORMATION	BETTY Fm. ; BETTY Fm. ; MERSA MATRUH Fm.	APTIAN CLASTICS	Basal Betty Member (ALAM EL-BUEIB Fm.) ; MATRUH Fm.	BETTY Fm.	BETTY Fm.
JURASSIC	LIMESTONE & SHALES	MASAJID Fm.	MASAJID Fm.	JURASSIC	MASAJID Fm.	MASAJID Fm.	MASAJID Fm.

×× Undifferentiated Aptian Burg EL-Arab sandstones and shales (B. A. marker)
××× Unnamed Unit

The objective of the present study is to determine the different petrophysical parameters needed for reservoir description and fluid saturation detection. In addition, the litho-velocity relationships are investigated in order to enhance reservoir zonation.

METHODS AND TECHNIQUES

The available full-diameter well-core samples are drilled into small plugs of 2.5 cm diameter and 4.0 cm length. These plugs are cleaned from the résidual hydrocarbons by use of different types of organic solvents and soxhelt extractor apparatus (Keelan, 1972).

In order to study the conductive solids (clay minerals) in the reservoir rock pore spaces, four different brine solutions were prepared. They used for sample saturation to measure sample electrical resistivity in four measuring series.

They were selected in manner that two of them are less concentrated than the in situ formation water concentration (1/100 and 1/200 times). The concentration of the saturant used in the third measuring cycle was 140 gm/l (in situ concentration). The last one has a concentration of 1.3 times of the in situ formation water concentration.

Electrical resistivity measurements starts after the accurate estimation of the plug dimensions while the samples were 100% saturated with the most dilute solution. The electrical resistivity (R_o) was measured at normal conditions (Tab. 2) by use of a universal bridge type (Model T.F. 2700), feed-back function generator (FG-601), and a Hassler type core holder with two copper electrodes covered with chamois pads. In order to minimize the electrode polarization, a minimum constant A.C. current (3-5 mA) of 1000 Hz frequency (Hassan, 1969) was used during the all measurements. On the other hand, sample porosity was measured (Tab. 2) on the same plugs by use of the saturation method adopted by Koithara *et al.*, (1965).

The resistivity index (I) is determined by measuring the electrical resistivity of desaturated sample (R_t) at different values of water saturation (S_w). The samples were saturated with a brine concentration equivalent to the in situ formation water concentration (Table 3).

The delineation of the relationship between the variation of the interval velocity in the Alamein, the Dahab, and the Kharita Formations and their lithofacies changes have been done. The interval velocities for these formations have been computed from the available well velocity survey data of 24 wells scattered allover the concerned area (Fig. 2). Tab. 4 shows the computed interval velocities for these formations in some selected wells.

Table 2

The measured resistivity value, the corresponding formation factors and porosity fraction:

Sample No	Well Name	Rwl = 5.4 Ohm.m				Rw2 = 4.5 Ohm.m				Rw3 = 0.72 Ohm.m			
		Ro	F	Ro	F	Ro	F	Ro	F	Ro	F	Ro	F
		Alamein Carbonates (Ghazalat Well)											
17	Ghazalat	23.7	43.9	216.0	40.0	229.6	51.03	170.8	38.0	106.9	148.5	91.8	127.6
18	Ghazalat	140.4	26.0	118.8	22.0	129.6	28.8	113.4	25.2	32.7	45.4	41.3	57.4
19	Ghazalat	351.0	65.00	242.1	63.4	299.0	66.4	329.4	73.2	134.0	186.0	144.6	200.8
20	Ghazalat	133.6	34.7	154.4	28.6	124.2	32.03	124.7	32.2	59.9	83.15	63.3	87.9
21	Ghazalat	297.0	55.0	275.2	50.9	196.3	43.6	214.6	47.7	101.8	141.4	113.7	157.9
		Upper Alamein Clastics.											
22	Mersa-Matruh	13.5	2.5	14.02	2.6	13.2	2.94	13.5	3.00	6.12	8.5	5.80	8.10
23	Mersa-Matruh	15.3	2.8	14.3	2.64	11.2	2.9	13.9	3.10	6.82	9.5	5.99	8.32
24	Mersa-Matruh	28.5	5.3	28.5	5.3	27.4	6.1	30.2	6.70	28.80	40.0	29.00	14.04
25	Faghur	17.3	3.2	19.4	3.6	14.8	3.3	16.3	3.60	10.80	15.0	10.50	14.60
26	Faghur	15.3	2.8	15.3	2.8	12.5	2.7	12.75	2.70	6.90	9.6	7.13	9.90
29	Ghazalat	15.25	2.82	13.4	2.5	12.1	2.68	12.1	2.60	6.42	8.9	6.50	9.00
31	Mersa-Matruh	30.2	5.6	31.9	5.9	26.5	5.88	27.9	6.20	32.40	45.0	33.60	46.70

Table 2 (Contd.)

Alamein Carbonates (Ghazalat Well)

Sample No	Well Name	Rw4 = 0.06 Ohm.m				Porosity
		Ro	F	Ro	F	Fraction
17	Ghazalat	10.9	181	9.36	156.1	0.031
18	Ghazalat	3.33	55.6	4.23	70.6	0.058
19	Ghazalat	15.6	260.0	16.5	275.0	0.054
20	Ghazalat	6.04	100.7	6.5	107.8	0.042
21	Ghazalat	10.3	172.3	11.55	192.5	0.035
		Upper Alamein Clastics.				
22	Mersa-Matruh	0.67	11.22	0.612	10.2	0.250
23	Mersa-Matruh	0.72	12.10	0.690	11.5	0.219
24	Mersa-Matruh	3.20	53.30	3.100	52.4	0.102
25	Faghur	1.20	20.00	1.200	20.0	0.186
26	Faghur	0.76	12.75	0.775	12.9	0.200
29	Ghazalat	0.67	11.22	0.650	10.9	0.283
31	Mersa-Matruh	3.60	59.80	3.600	60.7	0.100

Table 3

Calculation of Resistivity Index versus water saturation for the studied samples

Sample No	O.O rpm Ro(Ohm.m)	1000 rpm		2000 rpm		3000 rpm	
		I1	SW	I2	SW	I3	SW
Upper Alamein Clastics (Horizontal Direction)							
22	0.8160	1.2500	0.5284	0.5350	0.1439	2.2868	0.0682
23	0.8160	1.0625	0.6160	1.8750	0.2740	2.5000	0.0479
24	1.3908	1.2295	0.8270	1.3197	0.6380	1.6393	0.5172
25	0.8480	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆
26	0.8262	1.0247	0.5632	1.5309	0.4655	1.8518	0.3735
29	1.0980	1.1111	0.6983	1.2222	0.2500	1.7778	0.1983
31	1.4364	1.0978	0.8420	1.2030	0.7543	1.3158	0.6666
Upper Alamein Clastics (Vertical Direction)							
22	0.7140	1.1143	0.5284	1.9571	0.1439	2.5428	0.0682
23	0.9180	1.2778	0.6160	1.6444	0.2740	1.7277	0.0479
24	1.4421	1.2253	0.8270	1.5810	0.6380	1.5810	0.5172
25	0.9050	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆☆
26	0.8466	1.0181	0.5632	1.8072	0.4655	1.3617	0.3735
29	0.9150	1.2000	0.6983	1.1667	0.2500	1.9870	☆☆☆
31	1.8360	1.0294	0.8420	1.0588	0.7543	1.1000	0.6666

Table 3 (Contd.)

Alamein Carbonates (Horizontal Direction)

17	6.3240	3.1452	0.3333	4.1942	0.0100	6.2903	0.0050
18	5.1040	1.0933	0.7500	1.1853	0.6250	1.2962	0.3125
19	9.5400	1.8218	0.3080	2.2787	0.1540	2.4444	0.0050
20	6.5720	2.4516	0.3846	3.4510	0.1538	3.7097	0.0050
21	6.4900	2.0339	0.1800	5.2800	0.0625	6.9491	0.0050
Alamein Carbonates (Vertical Direction)							
17	6.0690	2.3064	0.3300	2.6554	0.0100	2.7395	0.0000
18	5.1700	1.0174	0.7500	1.2659	0.6250	1.8549	0.3125
19	9.4870	1.2290	0.3080	1.3408	0.1540	1.8994	0.0000
20	6.6250	1.6080	0.3846	1.9120	0.1538	2.7200	0.0000
21	5.7500	1.8435	0.1800	3.0609	0.0625	3.6348	0.0000

☆☆☆These samples were broken during experimental tests.

FORMATION FACTOR-POROSITY RELATION

The relationship between the formation resistivity factor and the porosity of a porous medium has been investigated both theoritically (Fricke, 1924; Clavier, et al and Bussian, 1983) and empirically (Archie, 1942; Perez-Rosales, 1982; Hassan and El-Sayed, 1983; and El-Sayed, 1987) through more than 50 years. Laboratory studies indicate that pore space framework, in which the electric conduction take place, is not rather simple. The pore-wall, which consists of grain surfaces, in reservoir rocks is extremely irregular due to many diagenetic controls (authigenetic mineral growth and/or desolution). This irregularity, in most cases, creates regions of stagnation called traps. Therefore, the pore space can be divided into flowing and stagnent region (Perez-Rosales, 1982) for fluids as well as for electric currents. From this view point, the formation factor-porosity relation depends upon the pore space history.

The formation factor - porosity relations of both the Kharita and the Dahab Formations as clastic units (upper Alamein clastics) were constructed to reveal the probable effect of the brine concentration on both the cementation exponent(m) and the multiplier(a) of the Archie's general equation;

$F = a.\varnothing^{-m}$ _____________ (1)

Where; F = formation resistivity factor,

$\varnothing$ = rock porosity, fraction.

Table 4

Formation velocity analysis.

WELL	Abyad	Mideiwar	Siqeifa	Kanayis	Khalda	Um	Barka Louly	Yakout	Ghazalat-N	El-Basour
FORMATION	V int	V int	V int	V int	V int	V int	V int	V int	V int	V int
Kharita	1555	3720	3567	3796	4009	3963	4299	3277	2810	2735
Dahab	1669	3857	3643	4314	4070	4268	4131	Missed	2875	Missed
Alamein	2027	3963	4070	4869	4726	4558	4619	Missed	2895	Missed
Mideiwar	1875	3750	3598	3659	4223	4329	4467	Missed	2990	Missed
Abyad	2666	4756	3506	4131	5031	4695	5534	Missed	2915	2760
Matruh	1928	3659	3659	—	4345	3963	4619	3689	3015	2746
Alam El-Bueib	1921	3537	3667	—	—	4512	4588	3963	3065	Missed
Betty	1883	>3537	3918	—	—	3329	—	4009	Missed	Missed

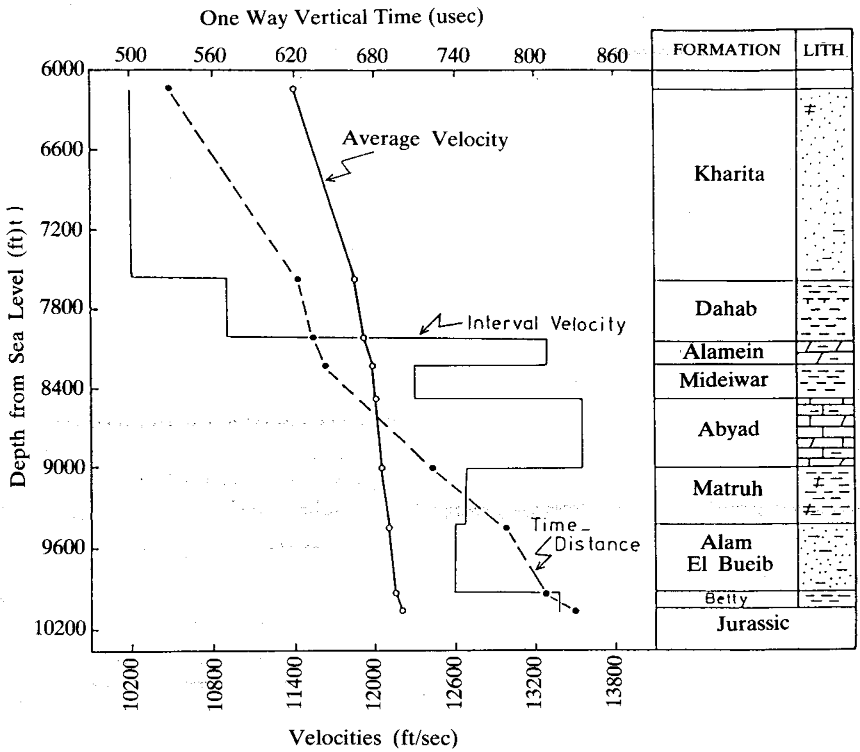

Fig. 2: Abyad Well Formation Velocities

The plot (Figs 3&4) exhibits the formation factor versus rock porosity for the samples of the upper Alamein clastics (Figs. 3A&B) and samples from the Alamein Formation (Figs. 4A&B) at four different brine concentrations. The electrical resistivity of the fully saturated (100%) rock (R_o) was measured in both horizontal and vertical directions.

The analysis of these relations indicates that the calculated cementation exponent(m) increases vigorously by the increasing of the brine concentration. Nevertheless, the multiplier(a) almost remains constant with value about 1.0. This phenomenon can be explained by the existence of clay minerals of high cation exchange capacity (CEC) acting as conductive solids among the reservoir rock formation fines. Clay minerals were mainly kaolinite and illite (El-Dairy, 1986).

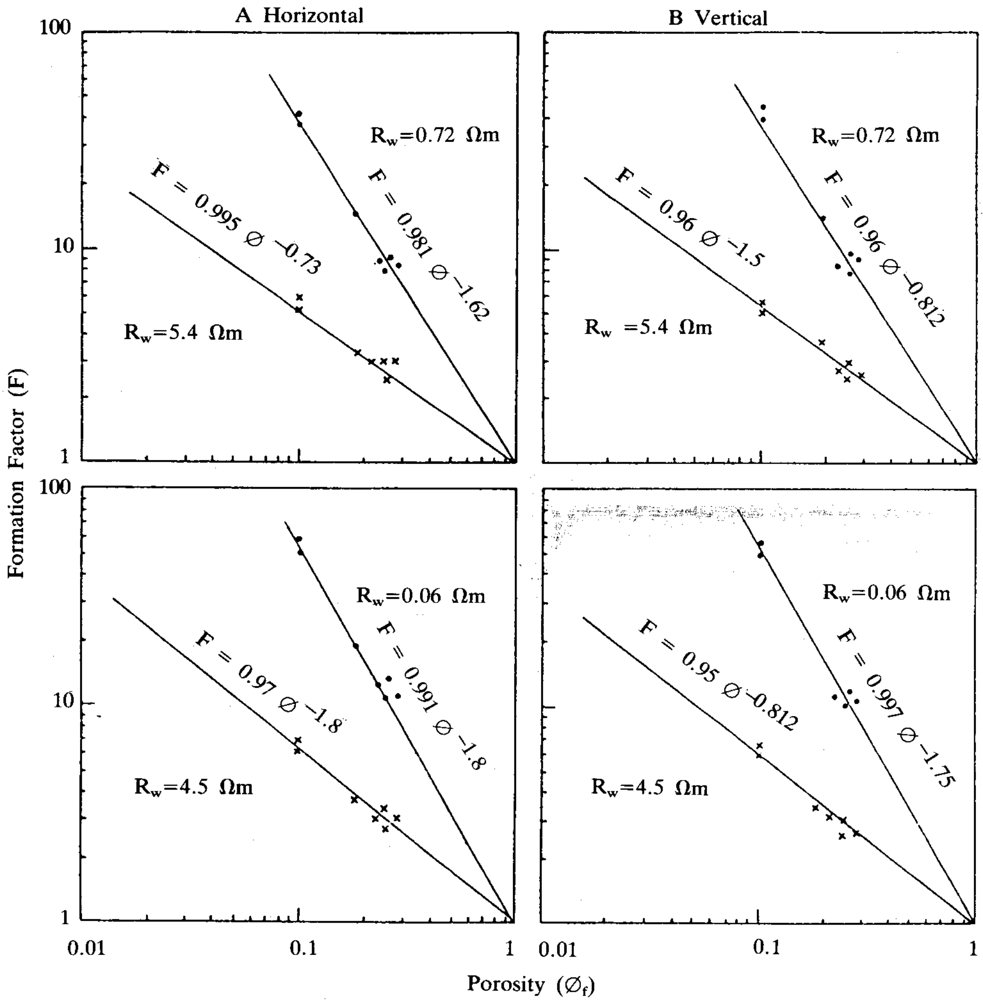

Fig. 3: Formation Factor-Porosity Relation for the Upper Alamein Clastics

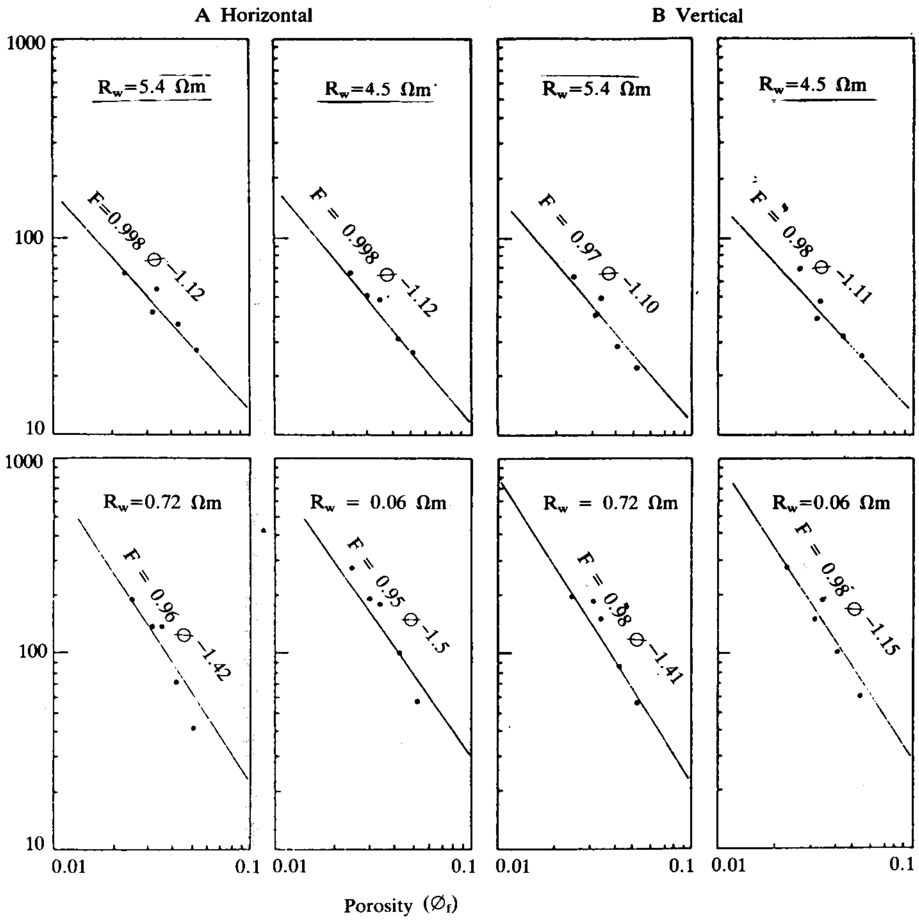

Fig. 4: Formation Factor-Porosity Relation for the Alamein Carbonates (Ghazalat Well).

(a/m) RATIO

An attempt was made to calculate the value of (a/m) ratio for both the horizontal and the vertical directions of electric resistivity measurements (Tab. 5). The data reveals constant values for samples of both upper Alamein clastics and Alamein Formation when rock samples were saturated with dilute solutions (0.7 & 1.4 gm/l). The values of (a/m) ratio are slightly decreased as the brine concentration increased especially in case of limestone samples of the Alamein Formation.

On the other hand, the values of (a/m) ratio have been decreased vigorously by the increasement of the brine concentration (140 & 182 gm/l) in case of sandstone samples of the upper Alamein clastics (Kharita and Dahab Formations). The authors believe that the (a/m) ratio could be used as a lithofacies and a hydrofacies indicator. Its application could be extended to performing reservoir zonation.

RESISTIVITY INDEX

Resistivity index (I) is defined as the ratio of the electrical resistivity of a partially saturated sample(R_t) to its electrical resistivity as 100% saturated (R_o) with brine solution;

$$I = R_t/R_o = c.\ S_w^{-n} \qquad (2)$$

Table 5

The Multiplier (a) and the Cementation Factor (m) of the General Relation ($F = a.\varnothing^{-m}$)

Alamein Carbonates

Brine Con. gm/l	Rw(Ωm)	☆ a_H	☆ m_H	☆☆ a_v	☆☆ m_v	a_h/m_H	a_v/m_v
0.7	5.4	0.998	1.12	0.970	1.10	0.9	0.9
1.4	4.5	0.998	1.12	0.98	1.11	0.9	0.9
140.0	0.72	0.960	1.42	0.98	1.41	0.7	0.7
182.0	0.06	0.950	1.50	0.98	1.51 ?	0.6 ?	0.8 ?
Upper Alamein Clastics							
0.7	5.4	0.995	0.73	0.96	0.75	1.3	1.3
1.4	4.5	0.970	0.77	0.95	0.812	1.3	1.3
140.0	0.72	0.981	1.62	0.96	1.50	0.6	0.6
182.0	0.06	0.991	1.80	0.997	1.75	0.56	0.56

☆ a_H and m_H are the multiplier and cementation factor in horizontal direction respectively.

☆☆ a_v and m_v are the multiplier and cementation factor in vertical direction respectively.

Where; c = multiplier
S_w=water saturation, fraction.
n = saturation exponent.

Resistivity index is used as a guide to possible production of a certain fluid under reservoir conditions. The resistivity index(I)-water saturation(S_w) relations, representing both the upper Alamein clastics and samples of the Alamein Formation, are shown in Fig. 5. An examination of the data (Tab. 4) plotted (Figs. 5A&B) reveals that;

1. The multiplier (c) equals 0.93 for horizontal direction and equals 0.91 for the vertical one.

2. The saturation exponent (n) is relatively very low (n=0.37 and 0.41) for horizontal and vertical directions respectively. These low values may indicate that the upper Alamein clastics are entirely water-wet (Wyllie, 1963).

The analysis of the plot (Figs. 5C&D) shows that the calculated multiplier(c) through out the two measuring directions is nearly of the same value (c = 1.7&1.6). The calculated saturation exponents in the two directions are very low. It implies that rocks of the Alamein Formation are mainly water-wet.

The regression line equations (Figs. 5A&C) calculated in horizontal direction for both the upper Alamein clastics and the Alamein Formation could be used for fluid saturation estimation.

LITHO-VELOCITY ANALYSIS

Figures 6,7 and 8, demonstrate the constructed velocity gradient maps of the interested formations (Alamein, Dahab and Kharita). The correlation between these maps with the lithofacies distribution maps of these formations (El-Dairy, 1986) illustrate that these velocity gradient maps can give a clue to these lithofacies variations.

The velocity gradient map of the Alamein Formation is represented in Fig. 6. It illustrates a variable increasing rate of velocity from high values as in the northern portions (Mamura and Marsa-Matruh areas) to low values as in southeast and southwest portions of the area. This is due to the slightly facies change, in general, from the highly velocity dolomite to less velocity dolomitic limestone (El-Dairy, 1986). These dolomite and dolomitic limestone are streaked with minor and thin beds of shales (central portion) or sandstone (southern and southwestern portions) which decrease the velocity considerably in these portions.

The velocity gradient map of the Dahab Formation (Fig. 7) shows, in general, features similar to that existed in Alamein Formation, while the lithofacies maps of the two formations (El-Dairy, 1986) are slightly different. This may be due to the composition of the Dahab Formation which is formed of hard calcareous dolomitic shales with frequent carbonate streaks. Towards the southeastern and southwestern portions of the concerned area, which is thought to be an uplifted areas (El-Dairy, et al, 1987), the Dahab Formation is believed to be sandstone interbedded with claystone. This explains the considerable decrease of velocity in these areas.

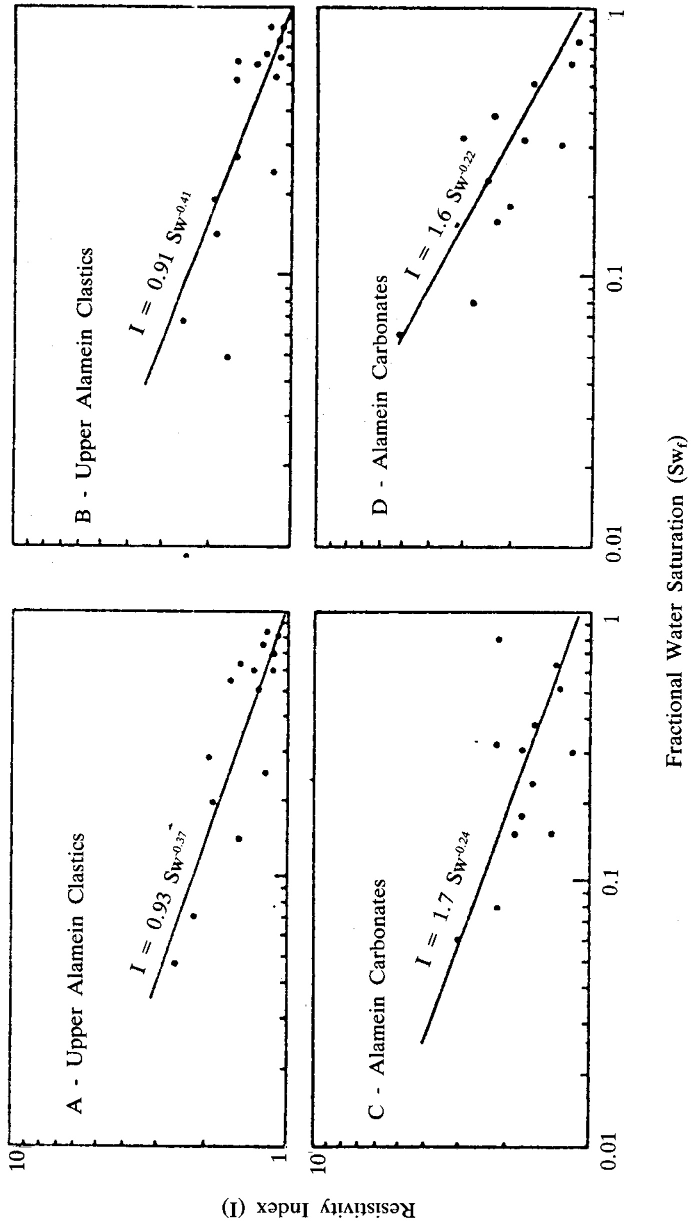

Fig. 5: Resistivity Index versus Water Saturation, $R_w = 0.72\ \Omega m$

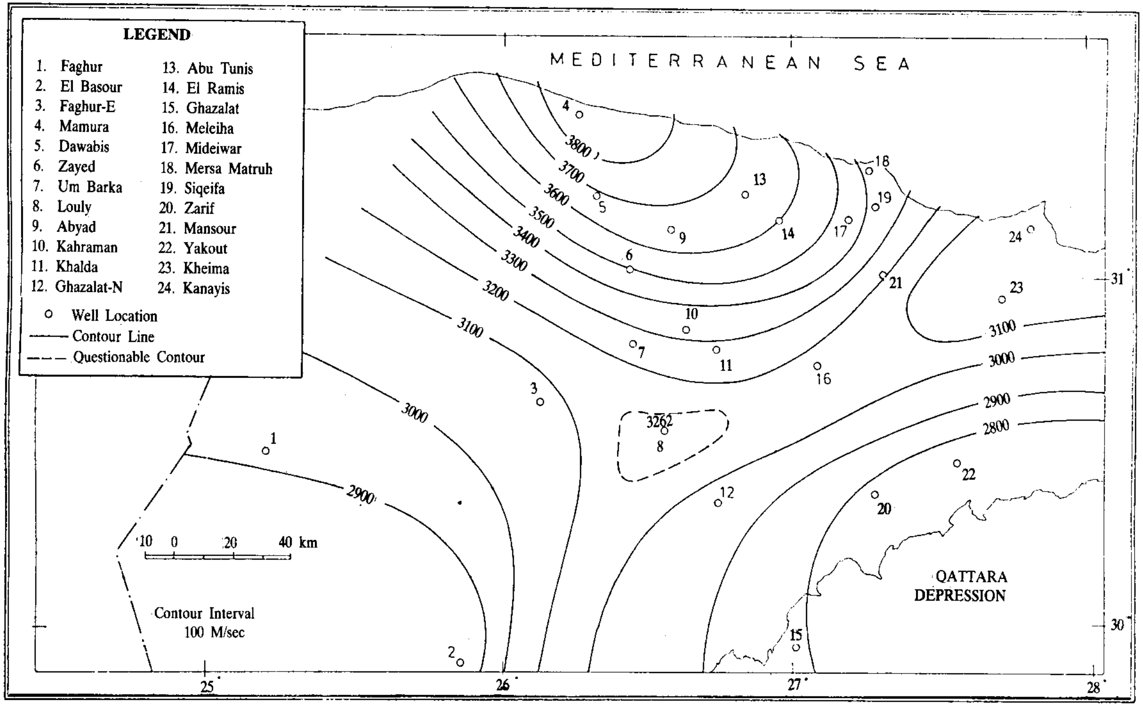

Fig. 6: Velocity Gradient Map of Alamein Formation

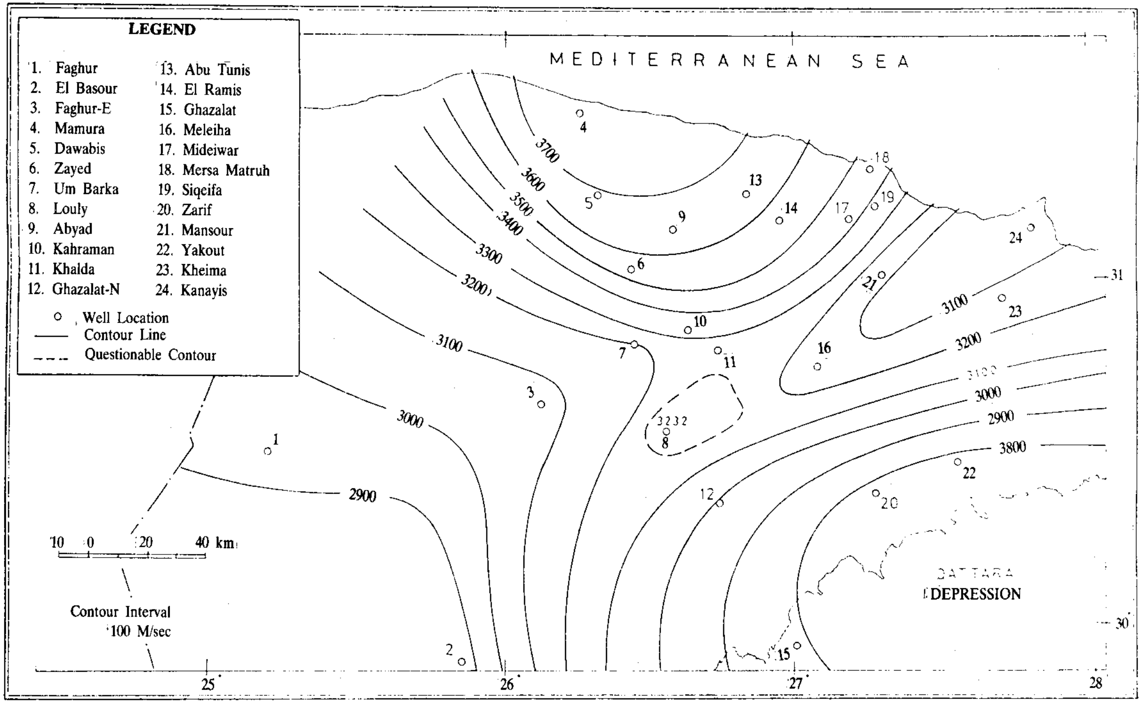

Fig. 7: Velocity Gradient Map of Dahab Formation

Velocity gradient map of the Kharita Formation (Fig. 8) shows a systematical increase in velocity towards the northern direction of the study area. This may be due to the homogenity in lithofacies distribution of this formation which is composed of predominant sandstone with a few carbonate and shale streaks at the northern portions of the area. These streaks suffer from a rapid decrease as it is gone to the south direction. This can explain the general decrease in velocity gradient from the north to the south directions.

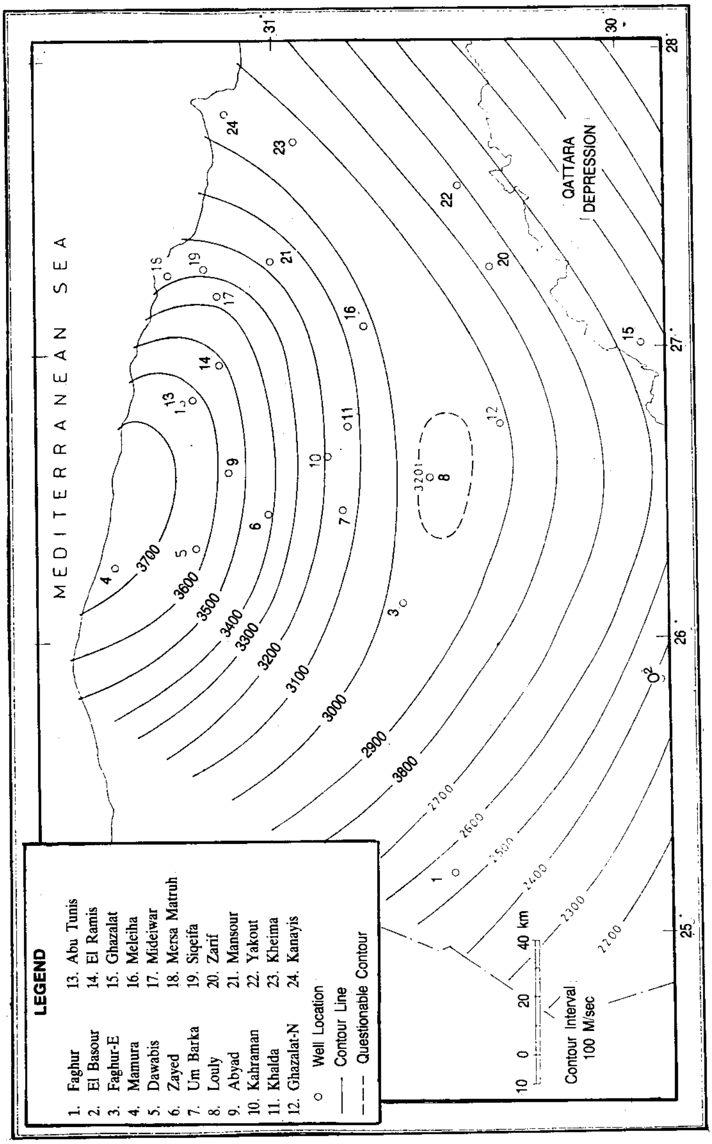

Fig. 8: Velocity Gradient Map of Kharita Formation

CONCLUSIONS

1. The formation resistivity factor-porosity relations show the effect of conductive solids (kaolinite and illite), at different brine concentrations, on the multiplier(a) and cementation exponent(m) for the concerned rock samples.

2. The (a/m) ratio could be considered as a lithofacies discriminating parameter, at certain formation water salinity, for the studied formations. It can easily performed for any sedimentary basin.

3. The calculated saturation exponents(n) indicate that smaples, under investigation, are mainly water-wet (low saturation exponent). The saturation exponent measured in horizontal directions can be used for fluid saturation calculation in the concerned rock sequence.

4. In general, it can be concluded that the high velocity can be attributed to massive rocks (carbonate or argillaceous sandstone rocks), while low velocity can be returned to loose rocks (mainly sandstones).

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دراسات بتروفيزيائية لبعض مكونات الطباشير السفلى الصحـــــراء الغربيـــة ـ مصــــــر

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تمثل متكونات الخريطة دهـــب والعلمين الجزء العلوي لتتابع صخور عصر الطباشيري السفلى في الجزء الشمالي من الصحراء الغربية المصرية . ولقد أمكن الحصول على بعض العينات الاسطوانية لهذه المتكونات السالفة الذكر بهدف دراستها حتى يتسنى تقييم هذه المتكونات ، وقد اشتملت الدراسة على الآتي :

١ ـ قياس المقاومة الكهربائية النوعية لبعض العينات الاسطوانية عند تشبعها بمحلول كلوريد الصوديوم المكافىء لدرجة تركيز الاملاح في مياه المتكون ، وكذلك عند درجات تشبع مختلفة بغرض حساب دليل المقاومة .

٢ ـ قياس المسامية باستخدام طريقة التشبع .

وبتحليل نتائج هذه القياسات تم استنباط علاقات ومعاملات بتروفيزيائية هامة تدخل في عملية حساب المخزون الإحتياطي من الموائع (ماء ـ غاز ـ زيت) في صخور المتكونات قيد الدراسة .

كما احتوت الدراسة أيضاً على مضاهات سرعات الموجات الزلزالية ـ كإحدى الخواص البتروفيزيائية ـ لهذه المتكونات الثلاث مع سحنها الصخرية على طول المنطقة وعرضها . وقد أمكن التوصل إلى أن السرعات الزلزالية العالية يمكن ارجاعها إلى قوة تماسك الصخور كما في صخور الكربونات والحجر الرملي الطيني بينما تعزى السرعات المنخفضة إلى درجة تفكك الصخور كما في الحجر الرملي .