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STUDIES ON PETROLOGICAL AND PETROPHYSICAL PROPERTIES OF SOME CAMBRIAN AND LOWER CRETACEOUS CORE SAMPLES FROM BAHARIYA OASIS, WESTERN DESERT, EGYPT

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ABSTRACT

A Laboratory investigation has been done to study the petrographical and petrophysical properties of 28 core samples of top Cambrian and top Lower Cretaceous ages obtained fromBahariya Oasis well. NO. 1 at different depths. The studied samples are composed mainly of arenaceous shale and argillaceous sandstone mostly pigmented with iron oxides. The microscopic examination showed that these samples are influenced by allochemical diagenesis which is evidenced from the presence of iron pigment, silica, iron and carbonate cementation and by epidiagenesis due to the presence of broken grains, fissures and leaching evidence. The arenaceous shale samples of top Lower Cretaceous are higher in clay content than those of top Cambrian. Also, they have higher grain density due to the presence of much more iron content. The argillaceous sandstone samples of top Lower Cretaceous are lower in electrical resistivities and higher in effective porosity and permeability than those of top Cambrian. The argillaceous sandstone of top Cambrian (lower part) and top Lower Cretaceous could be considered as good reservoir rocks. The effective porosity is of a secondary origin. The laboratory studies show that the depositional environments of top Lower Cretaceous and top Cambrian are different.

INTRODUCTION

The Bahariya Oasis is an oval-shaped depression with a large number of hills, surrounded by an escarpment of about 100 m. high. This area is located 180 km west of the Nile Valley. Since a long time, the Bahariya Oasis has been the object of invetigations by researchers. These studies started as early as 1903 by Ball and Beadnell on the geology of the Oasis. It is well known that the Bahariya Oasis and the major parts of its conical hills in the depression are of Lower Cenomanian age (El-Akkad and Issawi, 1963). Most of the geologial studies depend on surface samples and aimed to study the stratigraphy, structures, sedimentology of iron ore, etc. (Said, 1962; El-Akkad and Issawi, 1963; Soliman et al., 1970; soliman and El Badry, 1980 and Others). However, a few data are known about the reservoir characteristics of sub-surface sediments in the area. For this purpose, 28 core samples of top Cambrian and top Lower Cretaceous were collected from the Bahariya Oasis well No. 1 to study their petrographical and petrophysical properties. The study well was drilled by Sahara Petroleum Comapny (SAPETCO) in 1957. It is locted at latitude 28° 25' 20.9" N and longitude 28° 58, 00.66" E (Fig.1).

LABORATORY TECHNIQUES

The petrographical and petrophysical properties of the core samples have been investigated using the following methods and techniques :

(a) Thin section under the microscope to study the mineralogical and petrological composition and porosity and consequently to recognize the environmental conditions under which the sediments were deposited.

(b) HCl and decantation methods to determine the percentages of carbonates (CO_3), sands and clays. The nomenclature of the tested core samples in the present paper is based on works done by Tickell (1965), Folk (1968) and Pettijohn (1975).

(c) Pychnometer method (Dakhanov, 1982) to measure the grain density (Pg in gm/cc.).

(d) water/Kerosen-immersion technique (Melnyk, 1986) to estimate effective porosity (o_e %) and bulk density (Pb in gm/cc.).

(e) Rotary technique (Cor lab., 1982) to estimate water saturation (Sw %) at 4800 rpm.

Age	Sample No.	Core No.	Depths (Feet)	Matrix analysis by weight: CO_3 (%)	Sand (%)	Clay (%)	Petrophysical data: P_g gm/cc.	P_b gm/cc.	O_e (%)
Top Lower Cret.	1	1	2332-2335	0.00	11.56	88.44	2.91	2.85	2.82
	2	1	2335-2338	0.39	12.94	86.67	2.86	2.82	1.68
	3	1	2353-2358	9.40	86.10	4.50	2.62	2.08	19.83
	4	1	2358-2362	11.32	87.18	3.50	2.65	2.19	17.98
Top Cambrian	5	3	4529-4532	0.67	42.39	56.84	2.52	2.43	5.25
	6	3	4532-4535	1.22	44.46	54.32	2.55	2.47	6.35
	7	3	4535-4538	2.41	50.49	47.10	2.66	2.15	17.07
	8	3	4538-4541	6.51	39.04	54.35	2.51	2.43	5.29
	9	3	4541-4544	7.04	36.15	56.81	2.65	2.44	5.30
	10	3	4544-4547	8.45	58.36	33.19	2.61	2.39	7.13
	11	4	5165-5168	6.72	22.13	71.15	2.65	2.62	1.64
	12	4	5171-5174	5.91	61.29	32.80	2.75	2.65	1.87
	13	4	5177-5180	16.74	69.86	13.40	2.62	2.56	2.59
	14	4	5180-5183	7.31	32.24	60.45	2.65	2.58	0.82
	15	4	5186-5189	2.51	16.65	80.84	2.67	2.65	1.50
	16	4	5189-5192	1.41	15.86	82.83	2.68	2.60	0.92
	17	5	5310-5313	3.61	51.94	44.45	2.59	2.31	19.86
	18	5	5313-5316	3.85	38.83	57.32	2.71	2.65	4.00
	19	5	5316-5319	5.10	74.40	20.50	2.63	2.60	2.45
	20	5	5319-5322	5.71	59.88	34.41	2.70	2.66	1.94
	21	5	5322-5325	6.39	79.31	14.30	2.73	2.67	4.80
	22	5	5325-5328	5.68	72.84	21.88	2.69	2.61	4.11
	23	6	5561-5564	4.89	79.32	15.79	2.62	2.13	18.76
	24	6	5564-5567	3.51	69.00	27.49	2.54	2.06	19.29
	25	6	5567-5570	2.76	57.93	39.31	2.46	2.17	14.85
	26	6	5570-5573	1.98	60.45	37.57	2.53	2.25	10.11
	27	6	5573-5576	1.32	98.68	00.00	2.55	2.14	15.85
	28	6	5576-5579	2.12	87.34	10.54	2.57	2.23	10.18

Table (1): Lithology matrix and petrophysical analysis results Of the studied core samples.

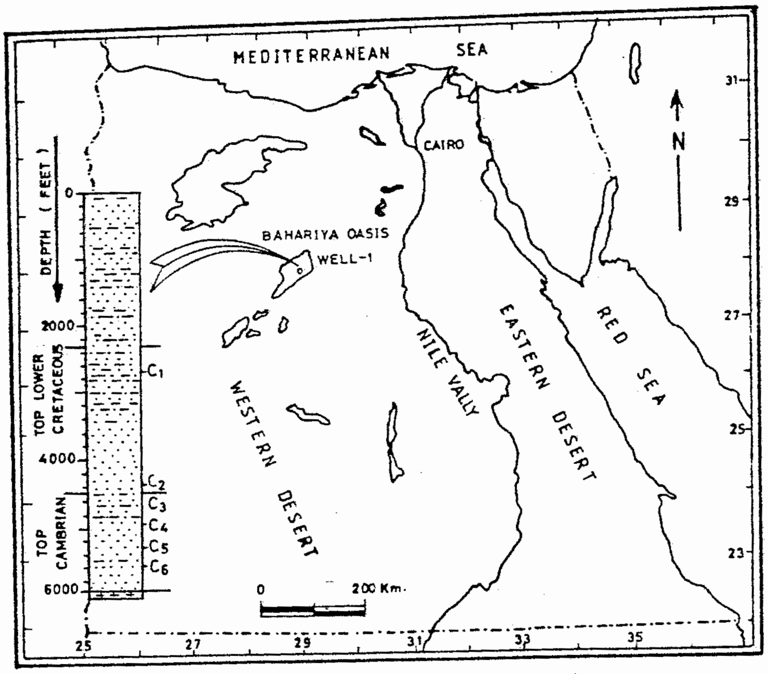

FIG.1 LOCATION MAP AND LITHOLOGY OF BAHARIYA WELL NO. 1.
(Argillaceous sandstone Arenaceous shale)

(f) A.C. bridge technique (Parkhomenko, 1967) to measure the apparent electrical resistivity (Ro in ohm.m and formation resistivity factor (F) at different concentrations of Nacl solution (6000, 60.000 and 12.0000 ppm).

DISCUSSION

The studied core samples were divided according to their ages into two groups : one belongs to top Cambrian and is represented by cores Nos. 3,4,5 and 6 at depths (4529'-4547'), (5165'-5192), (5310'-5328), and (5561'-5579') respectively and the other belongs to top Lower Cretaceous and is represented by core No. 1 at depth (2332'-2362'_.

1- Petrological studies :

Both groups of samples were examined under the microscope to study their petrographic characteristics.

Lithologically, the top Cambrian is composed of brick red micaceous clay, ferruginous and silty in parts, with abundant heavy minerals i.e. zircon, tourmaline, apatite and rutile. The sandy layers are indurated to semi-

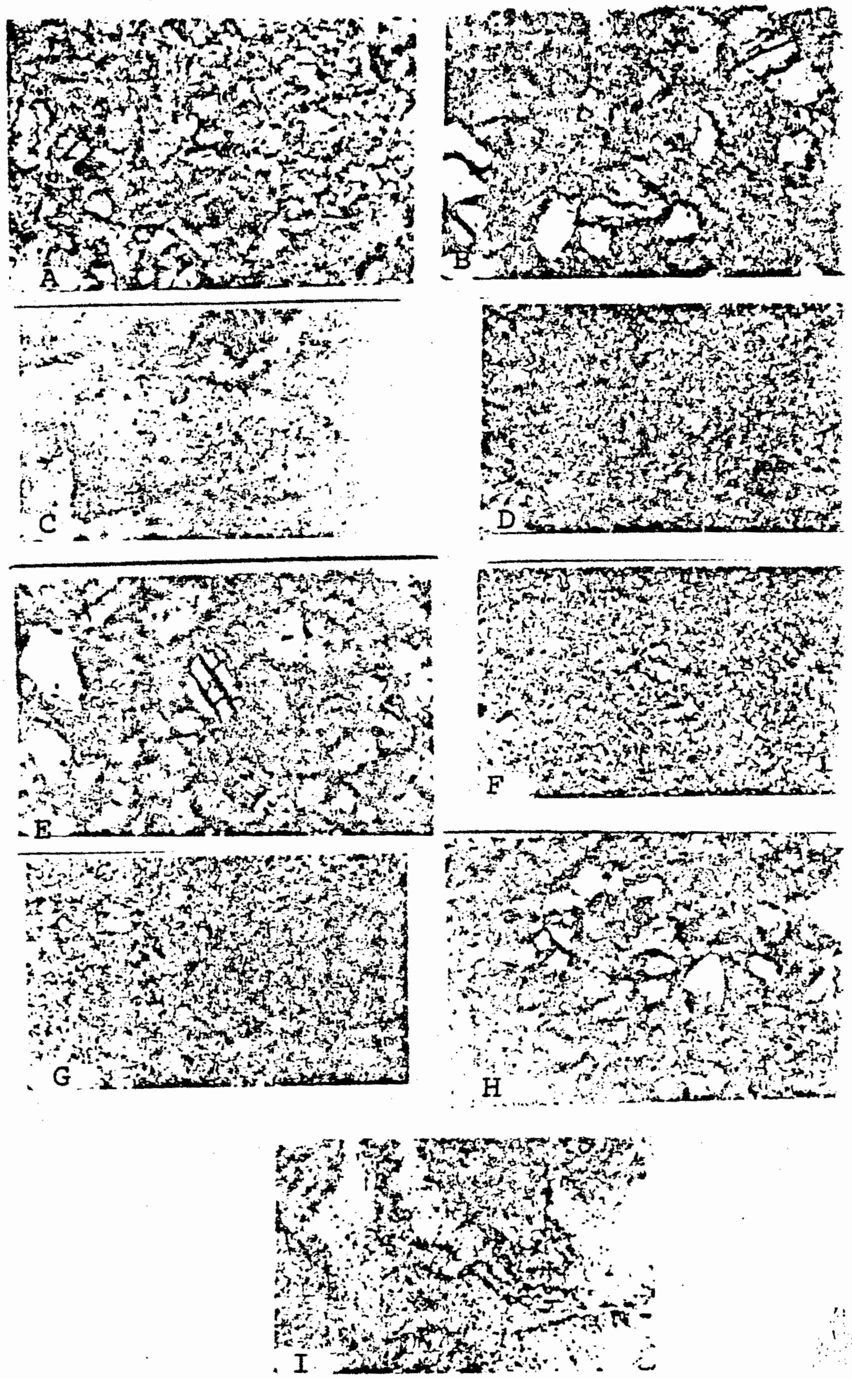

PLATE 1

Fig. A: Arenaceous shale (Top Lower Cretaceous).
Fine to very fine quartz in clay matrix. Abundant pyrite cubes and hematite grains. Pigmentation with limonite is remarkable.
Core No. 1. (2335') PPL:X50

Fig. B: Argillaceous sandstone (Top Lower Cretaceous).
Coarse to very coarse quartz grains with rare clay minerals (most probably authigenic kaolinite) filling inter-pore spaces. Broken grains are common with surface alteration and replacement by secondary inclusions. Iron-oxides and albite feldspare are recorded.
Core No. 1. (2353')base X nicols:X100.

Fig. C: Siliceous sandstone (Top Cambrian).
Organic matter mixed with clay minerals partially filled a microfissure.
Core No. 5 (5310'-5313') PPL:X50

Fig. D: Glauconitic sandstone (Top Cambrian).
Medium to fine quartz grains with noticeable amount of glauconite pellets and grains. Few disseminated iron-oxides. The components are admixed in lime-mud cement.
Core No. 3 (4532') PPL:X50

Fig. E: Argillaceous sandstone (Top Cambrian).
Coarse to medium quartz grains, angular to subangular with some broken and deformed grains. The grains are closer copacet in a lime-mud matrix.
Core No. 4 (5182'-5184') PPL:X100.

Fig. F: Siliceous sandstone (Top Cambrian).
Localized empty and elongated microfissures surrounded by organic matter. Notice few detarital quartz grains.
Core No. 5 (5310'-5313) X nicols:X50

Fig. G: Glauconitic Ferruginous sandstone (Top Cambrian).
Medium to fine quartz grains. subangular to subrounded with scattered glauconites and showing effect of iron invasion (left).
Core No. 6 (5561'-5564') X nicols:X100

Fig. H: Glauconitic ferr ginous sandstone (Top Cambrian).
Medium to fine quartz grains: with deformed and broken glauconite pellets. Relics of lime mud admixed with clay matrix are common.
Core No. 6 (5561'-5564') X nucols:X50.

Fig. I: Siliceous sandstone (Top Cambrian).
Cryptocrystalline silica. Fractured with isolated unconnected empty pores. Notice rims of organic matter around the fissures.
Core No. 5 (5310'-5313) PPL:X50

Sample No.	Core No.	Depths (Feet)	R_1	F_1	R_2	F_2	R_3	F_3	S_w (%)	K (md)
			at NaCl conc. 6000 ppm		at NaCl conc. 60000 ppm		at NaCl conc. 120000 ppm			
1	1	2332-2335	19.20	20.21	10.67	71.13	2.27	32.43	8.30	4.58
3	1	2353-2358	25.58	26.93	7.15	47.67	1.89	27.00	10.66	9.45
4	1	2358-2362	28.18	29.67	8.20	63.11	4.90	70.01	7.89	11.23
9	3	4541-4544	12.70	13.37	2.04	20.27	1.58	22.57	5.50	0.030
13	4	5177-5180	70.79	74.52	33.58	223.87	24.84	354.81	2.52	0.05
18	5	5313-5316	16.51	17.38	6.70	44.67	3.55	50.71	4.07	1.39
19	5	5316-5319	59.12	62.23	26.67	177.82	19.73	281.84	3.25	7.12
21	5	5322-5325	56.43	59.19	23.77	158.49	13.97	199.53	6.12	24.76
23	6	5561-5564	31.62	33.28	15.80	105.33	2.50	35.71	7.68	6.45
25	6	5567-5570	32.03	33.72	19.32	128.80	10.11	144.43	7.09	1.99
27	6	5573-5576	28.16	29.66	6.85	45.62	2.24	32.00	4.73	--

Table (2): Apparent electrical resistivity, formation resistivity factor water saturation and permeability of some rock samples.

Table 3: Relative clay mineral contents in Abu Had shales

Sample No.	Smectite %	Kaolinite %	Mixed-Layer %
1	99.70	0.30	---
2	71.50	28 50	---
3	92.50	7 50	---
4	91.45	8.55	---
5	69.00	30.92	---
6	100.00	---	---
7	90.00	9.80	---
8	74.20	25.80	---
9	61.44	38.56	---
10	55.00	45.00	---
11	76.33	23.67	---
12	58.45	41.55	---
13	---	11.33	88.67
14	---	17.00	83.00

and Issawi, 1963) and referred to epigenetic stage of diagenesis (Fairbridge, 1967). Cementation by iron oxides, silica and carbonate (lime-mud) resulted in reduction of the original porosity of the rock (allochemical diagenesis), while formation of secondary porosity by broken grains and fissures is referrred to semi-isochemical diagenesis (Schmidt and McDonald, 1979 and Bjorlykkee, 1983).

The studied core samples of top Lower Cretaceous may also be subdivided into two rock types. The upper part is arenaceous shale (2332'-2338') and the lower part is mainly argillaceous sandstone (2353'-2362'). Lithologically, it is composed of hematitic, limonitic, brick red agrillaceous sandstone and conglomeratic in parts. Petrographically, the upper part is composed of fine to very fine quartz grains in clay matrix rich in organic matter. Pyrite cubes and hematitic grains are pigmented with limonitic patches (Fig. A). The lower part is composed of coarse to very coarse broken quartz grains with authigenic kaolinite filling interpore spaces. Iron oxides and albite feldspars are also present (fig. B). Generally, the abundance of pyrite cubes and grains is accompanied by decrease in

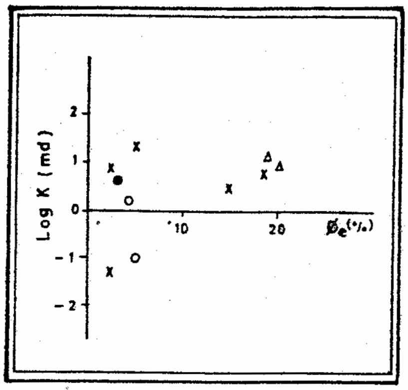

FIG.3 PERMEABILITY-EFFECTIVE POROSITY RELATIONSHIP.

o Top Lower Cret. arenaceous shale
▲ Top Lower argillaceous sandstone
● Top Cambrian arenaceous shale
x Top Cambrian argillaceous sandstone

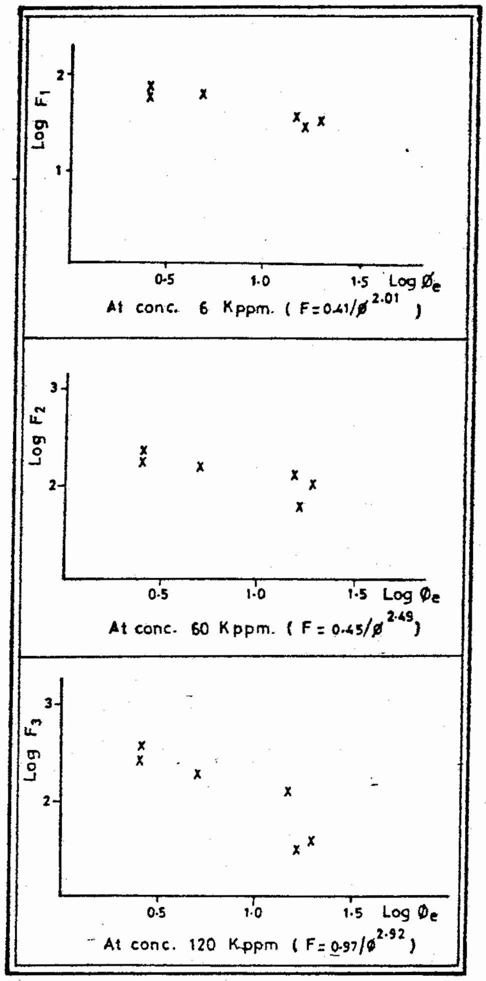

FIG.4 FORMATION RESISTIVITY FACTOR-POROSITY RELATIONSHIP OF TOP CAMBRIAN ARGILLACEOUS SANDSTONE.

indurated. Petrographically, the top Cambrain sediments show a wide range of mineralogical composition and variations as shown in plate I i.e. argillaceous sandstone (Fig. E); siliceous sandstone (Figs. C F & I); glacuonitic sandstone (Fig. D) and glauconitic ferruginous sandstone (Figs. G & H). The variation in mineralogical composition is mostly accompanied by variation in the enironmental conditions such as source rock supply, chemical composition, pH, Eh and water depth (Pettijoh, 1975). Pyrite and organic matter reflect an acidic environment (cores 1 & 5-Figs. A, B & C); while glauconites and carbonates confirm alkaline enivornment (cores 3,5 & 6-figs. D, E, G & H). The recorded glauconite grains in the studied samples reflect a slow deposition, agitated saline environemnt and slow rate of deposition (Fairbridge, 1967 and Weaver and Pollard, 1973). Commonaly, the mineralogial assemblages are cemented by iron-oxides in the later stager of diagenesis, lmost probably due to subaerial exposure of those sediments i.e. redoxmorphic stage of diagensis (Dappies, 1979) The recorded microfissures and some broken grains (Figs. E,F,G & I) togerther with silica (Figs. F & I) can be most probably attributed to the effect of tectonism on the sediments of the Bahariya Oasis (El-Akkad

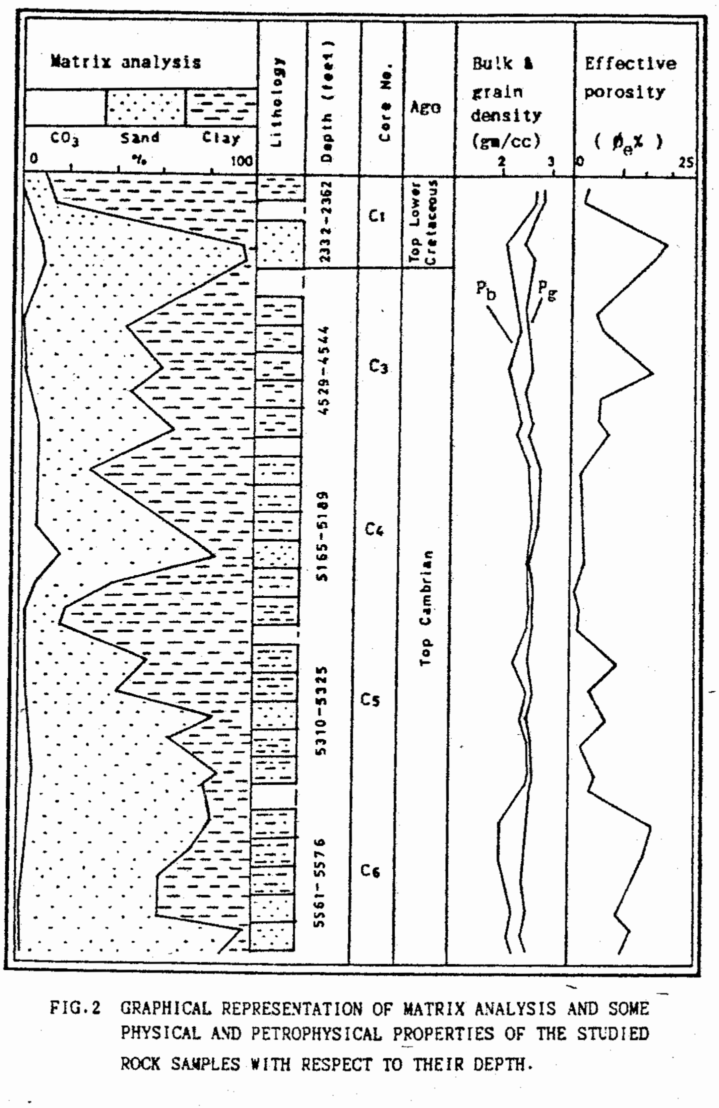

FIG. 2 GRAPHICAL REPRESENTATION OF MATRIX ANALYSIS AND SOME PHYSICAL AND PETROPHYSICAL PROPERTIES OF THE STUDIED ROCK SAMPLES WITH RESPECT TO THEIR DEPTH.

iron oxides which suggests a sort of diagenetic formation in the studied samples (Pettijohn, 1975).

2- Petrophysical studies :

As mentioned before, the studied samples are composed mainly of alternating beds of arenaceous shale and argillaceous sandstone (Figs. 1 & 2). The following is a discussions about their petrophysical characteristics :

The arenaceous shale samples of top Cambrian are characterized by high grain density (Pg) which ranges from 2.51-2.71 gm/cc. due to the presence of some heavy minerals and iron grains in their lithology matrix. They have low effective porosity (O_e) ranging from 0.82-6.35% because of existance of high amount of clay (54.32-82.83%). Water sautration (S_w) varies from 4.07-5.50%. Also, apparent electrical resistivity (R_o) is between 12.70-16.51 ohm.m.

The argillaceous sandstone samples of top Cambrian show wide variations in their physical and petrophysical properties. O_e ranges from 1.87% (due to allochemical materials filling the pores) to 18.76% (due to effect of microfissures). P_b is between 2.06 and 2.68 gm/cc. S_w ranges from 2.52-7.86%. K varies between 0.057 md (impermeable) to 24.76 md(permeable). The relation between K and ϕ_e is shown in fig. 3, K is affected by the presence of microfissures. Also, the laboratory work showed wide ranges in their electric measurements, R_o varies between 16.51-70.79 ohm.m. This variation depends on effect of ϕ_e and S_w as shown in fig. 4.

The arenaceous shale samples of top Lower Cretaceous which lies in the upper part of the study section are characterized by high grain density (2.86-2.91 gm/cc.) due to the presence of much more iron content in the lithology matrix. The measured R_o is about 19.20 ohm.m.

The argillaceous sandstone samples of top Lower Cretaceous have medium values of ϕ_e (17.98-19.835) and low values of P_b (2.08-2.19 gm/cc.). S_w is about 7.89%. This samples are considered as permeable rocks, K is between 9.45-11.23 md as shown in fig. 3. R_o ranges from 25.58-28.18 ohm.m. This variation is controlled by ϕ_e (Fig. 4).

More details about the physical and petrophysical measurements, in addition to lithology matrix analysis of the different rock samples are listed in Tables 1 and 2.

Also, all these results are represented graphically in Fig. 2.

Formation resistivity factor (F) - effective porosity (ϕ_e) relationships are constructed for the argillaceous sandstone samples of top Cambrain samples when sturated by NaCl solution of concentrations 6000, 60000 and 120000 ppm in three successive cycles (Fig. 5), to establish the empirical formula $F = a/\phi^m$ (Archie, 1942), where a is a constant and m is the cementation factor, by using the least square method and correlation coefficient program. The chosen empirical equation is $F = 0.41/\phi^{2.01}$ at conc. 6000 ppm., where the correlation coefficeint (r) = -966 (Fig. 5).

SUMMARY AND CONCLUSIONS

Twenty eight core samples collected from Bahariya well NO. 1 at different depths have been studied petrographically and petrophysically. These rock samples are composed mainly of arenaceous shale and argillaceous sandstone. According to their ages, they are classified into two groups : One of top Cambrian and the other of top Lower Cretaceous.

The arenaceous shale samples of top Cambrian consist of brick red micaceous clay, ferruginous, silty in part, with abundant heavy minerals, while those of top Lower Cretaceous are composed of fine to very fine quartz grains in clay matrix rich in organic matter and some patches of iron oxides.

The argillaceous sandstone samples of top Cambrian consist glauconitc ferruginous sandstone, while those of top Lower Cretaceous are composed of coarse to very coarse broken quartz grains with authigenic kaolinite filling inter-pore spaces and some pyrite cubes.

Petrophysically, the arenaceous shale samples of top Cambrian are different from those of top Lower Cretaceous. The second group has higher grain density due to the presence of much more iron content in the lithology matrix. Its rock samples contain higher percentage of clay.

The top Cambrain argillaceous sandstone samples are differentiated into two parts; the lower part is characterized by high effective porosity and permeability and low water saturation and the upper part is characterized by low effective porosity and permeability and high water saturation.

The argillaceous sandstone core samples of both top Cambrian (its lower part) and top Lower Cretaceous may be considered as good reservoir rocks because of thir high effective porosity and permeability. The secondary porosity was generated by epidiagenesis. From the effective porosity and the electrical resistivity measurements it was found that the best formula for determining the formation resistivity factor of top Cambrian argillaceous sandstone is $F = 0.41/\phi^{2.01}$.

The laboratory studies show that the two groups of rock samples are different in their depositional environments inspite of the similarity in their lithological compositions. The first group of top Cambrian rocks were deposited in alkaline environment as indicated by glauconite and carbonate cements and the second group was deposited in acidic environment as indicated by the presence of pyrite and organic matter.

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