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FACIES AND RESERVOIR PROPERTIES OF THE UPPER CRETACEOUS FORMATIONS IN GIFGAFA AREA, NORTHWESTERN SINAI, EGYPT

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ABSTRACT

The present study deals with the facies and petrophysical characters of the Upper Cretaceous rocks in Gifgafa area , northwestern Sinai. The sedimentological studies throw light on the facies and diagenetic history of the investigated rocks. The petrophysical properties evaluate the storage capacity of the rocks under investigation.

Petrophysically, the Upper Cretaceous rocks have bad storage capacity, except some horizons at the top of the Halal Formation (sandy clayey limestones) and at the middle and top parts of the Wata Formation(the clayey dolostones and dolostones) which have good storage capacity compared to the other horizons.

INTRODUCTION

The Upper Cretaceous rocks of Sinai have been extensively studied by many workers dealing with the stratigraphy, structures and sedimentology since Barron(1907) and Hume (1912, 1925), more recent studies are included in:Said (1990), Abu El-Enain (1998 & 2007), Eweda and El-Sorogy (1999), Issawi et al. (1999), Kora et al, (2001 a & b), (2002) and Genedi (2003 & 2005). There are fewer Studies dealing with the relation between petrophysical properties, facies and diagensis of the Upper Cretaceous rocks in northern Sinai.

Lithologically, the Cretaceous rocks in Sinai are composed of a lower clastic division and an upper non-clastic unit. At northwestern Sinai, a well exposed Upper Cretaceous section occurs at Gifgafa area between latit. °30 25`, 30 °30`N. and Long.°33 5`,°33 10`E.(Fig1).

Thus the aim of this study is to investigate the Upper Cretaceous rocks of Gifgafa area northwest Sinai to throw light on its storage capacity and its oil potentialities. To carry out the above investigations, a stratigraphic section representing the exposed Upper Cretaceous rocks was chosen, sampled, described and measured in details through field and laboratory studies. The measurements were carried out on 52 block samples from Gifgafa area.

Methodology :

The textural nomenclature of the studied rocks is based on the determination of their contents of carbonate, sand and mud (Table 1). Several thin sections representing the different lithologic varieties from the Upper Cretaceous at Gifgafa were prepared and microscopically examined for the petrographic characteristics. Impregnation with blue dye

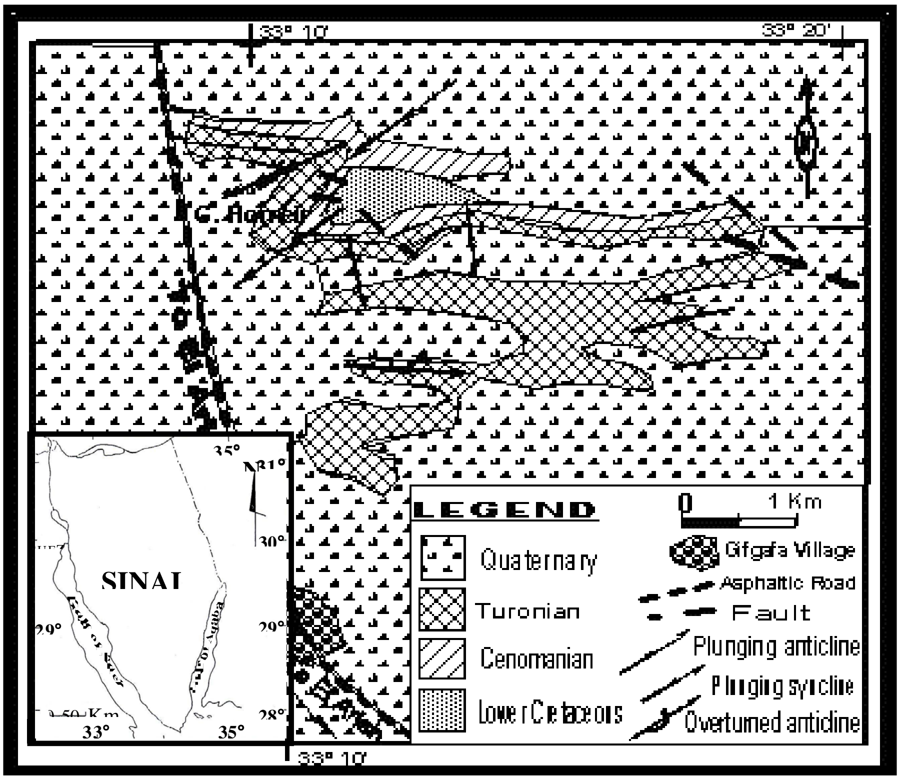


Fig. (1) : Geological map of the Gifgafa area.

was used for thin sections to evaluate the present porosity. Several methods of physical properties have been used for measuring the insoluble residue, porosity, density and permeability measurements. The bulk density is determined according to the saturation method (Kobronova, 1962, Dakhanova, 1977 and Ragab and Ayuad, 1985). In laboratory measurements of porosity, the saturation method of Koithara et al. (1968) is used based on the determination of the pore volume (Vp) and the bulk volume (Vb). On the other hand, Vp is determined by the immersion method (Dakhanova, 1977). The total porosity and permeability values (Kobranova, 1962; Core-lab, 1982 and Serra, 1984) are measured in the Petrophysical Lab. of the Egyptian Petroleum Research Institute (EPRI) using the Ruska gas permeameter. Irreducible water saturation (SWirr) is measured according to method proposed by Koithara et al. (1968). The storage capacity measurements using the two-electrode method are carried out and discussed according to many authors (e.g. Archie, 1952, Kobranova, 1962 and Serra, 1984).

Lithostratigraphy :

Lithologically, the studied Gifgafa section is described through two formations from base to top: Halal and Wata formations (Fig.2).

The Halal Formation rests unconformably over the Lower Cretaceous non-fossiliferous sandstones of the Risan Aneiza Formation (Fig. 2) and attains a thickness of about

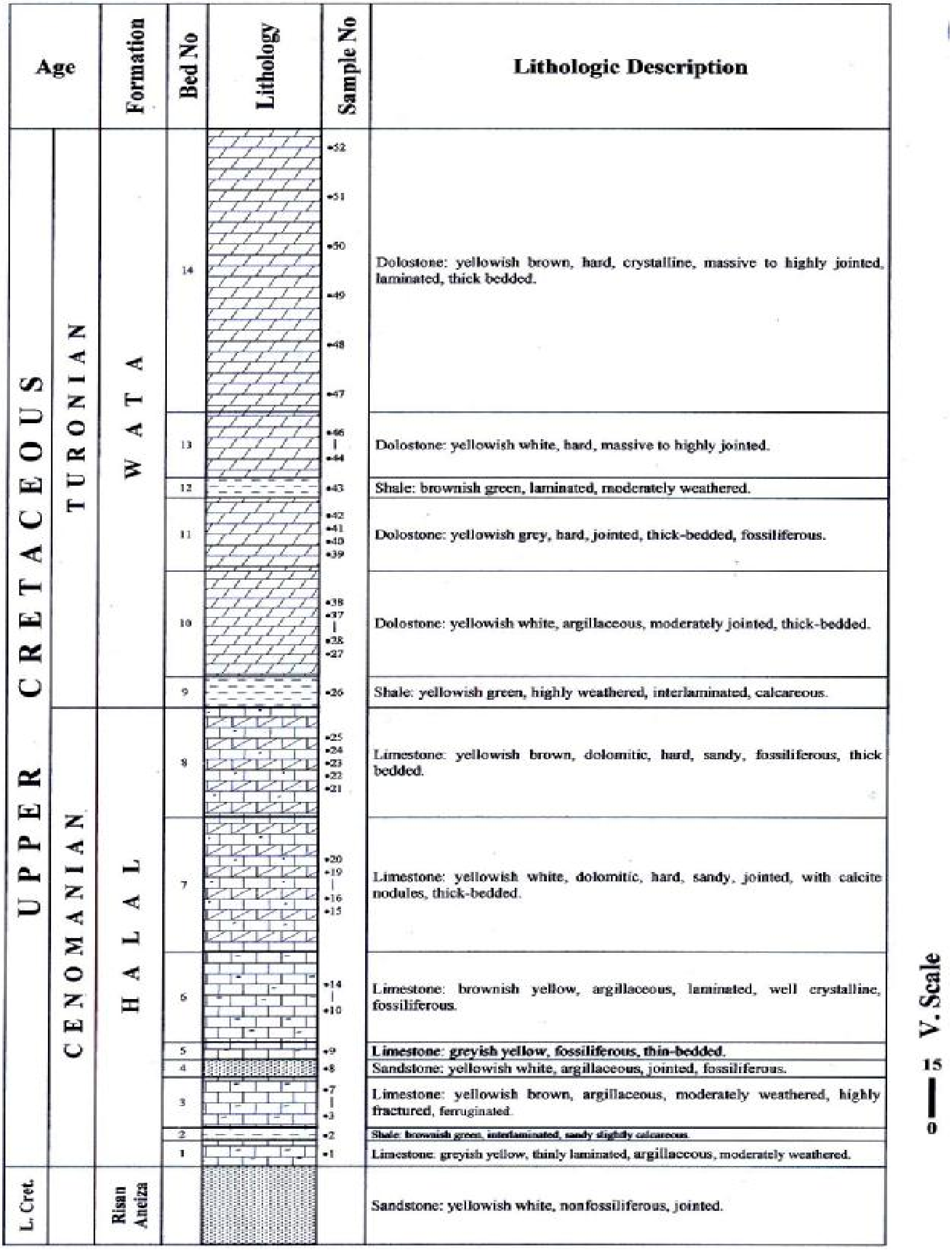


Fig. (2): Lithostratigraphic composite section of the studied formations of the Gifgafa area.

138m., mainly of grayish yellow to brownish yellow, clayey, thinly laminated moderate to highly weathered sandy limestones ferruginated and highly fractured at the base and intercalated with brownish green glauconitic, cross-bedded sandstones, shales, marls and dolostones with oyster banks, echinoderms and rudists are concentrated. Chert bands and nodules are interbedded. It underlies unconformably the Wata Formation.

The Wata Formation is well represented at the studied Gifgafa area especially at the most western part of the area. It overlies unconformably the Cenomanian Halal Formation and attains a thickness of 174 m. The Wata Formation is dominated by dolostones and dolomitic limestones intercalated with thin bedded calcareous shales. (Fig. 2).

Petrography :

The petrographic components have been studied in several representative thin sections. The evaluation of the petrographic data was performed according to depositional texture (Dunham, 1962 with the modification of Embry and Klovan 1972), Folk (1959 and 1962) and Pettijohn et al. (1973) are used. The standard microfacies types of Wilson (1975) and Flugel (1982) and their related environments of deposition are discussed. Several microfacies types were recognized and their depositional environments were attempted.

I-Carbonate microfacies :

The encountered carbonates represent about 90% of the measured section of the Upper Cretaceous rocks of Gifgafa area. Several microfacies types were recognized and their depositional environments were attempted. The recognized carbonate microfacies are as follows:

1- Sandy bioclastic grainstone (sandy biosparite): (Pl. 1.A)

This microfacies is well represented by bed (6) of Halal Formation. In the field, it is composed of abundant bioclastic accumulation. Petrographically, it composed mainly of molluscan fragments, badly preserved algae, intraclasts, phosphate fragments, echinoderms and some pellets. Scattered quartz occur as fine to medium, subangular to subrounded grains. The skeletal cavities are filled with neomorphic calcite indicating cavity filling process. All the components are cemented by sparry calcite and microspar. The facies suggests deposition in moderately high energy, shallow water bioclastic shoals.

2- Foraminiferal shelly wackestone (biomicrite) : (Pl. 1B&C)

This microfacies represents about 25% of the measured sequence; encountered in the lower part (beds 5&7) of the Halal Formation and consists of skeletal grains embedded in a homogeneous micrite and microspar groundmass, containing ostracodes, pelecypods, benthonic forams (miliolids), echinoderm fragments (up to 4%) in addition to scattered silt sized quartz pellets and glauconite. The facies suggest normal marine salinity. The facies attributes indicate deposition in quite water below normal wave base in restricted shallow water, lagoons and bays behind the outer platform edge with water depth ranges from a few meters to tens of meters deep.

3- Bioclastic wackestone / packstone : (Pl. 1.D)

This microfacies appears in the lower part of the Halal Formation (bed 8). Petrographically, the rock consists mainly of skeletal grains represented by molluscan fragments, ostracod, fragments and echinoderms; embedded in micrite. The bioclasts constitute up to 50% of the rock volume. Completely recrystalized and partly dolomitized oyster and gastropod shell with forams and ostracods are encountered. Cementation by spary calcite is observed in the fracture, vugs and fossil cavities. Well-zoned dolomite crystals are encountered; partly replacing oyster as well as gastropod fragments. The microfacies suggest deposition on a shelf lagoon with shallow water and open circulation, just below or close to normal wave base.

4- Dolostone lithofacies :

Dolostones dominate the Upper Cretaceous sequence at Gifgafa area. Bioclastic components are not easily recognized due to pervasive dolomitization. However, some benthic forams and ostracod may be observed. Most of the dolostones were originated as mudstone-wackestone associated with lagonal platform of quite water and restricted circulation (sf.Wilson, 1975). The Upper Cretaceous dolostones comprise two types: unimodal planar dolostone and polymodal planar dolostone; described below.

a- Unimodal planar dolostone: (Pl. 1.E)

This microfacies is represented by a dirty yellow to grey, hard, massive beds (bed. 11 the Wata Formation). The dolostone consists of unimodal fine to medium crystals (~50 μm size). The dolomite rhombs are euhedral to subhedral, commonly planar and well zoned. Some of the unimodal and nonplanar dolomites occur as very fine crystals (~10-50μm) and mostly of cloudy centers. The unimodal size distribution of the dolomite crystals indicates a single nucleation event on unimodal substrate and uniform growth rate. The planar boundary shape gives an impression of faceted growth at which dolomite crystals have undergone at temperature less than the critical roughening temperature i.e (< 50 C°) and low supersaturation. They are sometimes surrounded by iron oxides and rarely by silt-sized quartz grains and glauconite grains up to 6%. This dolostone microfacies is equivalent to the finely crystalline unimodal, planner, subhedral mosaic dolomite preserving sedimentary structures of Amthor and Friedman (1992).

b- Polymodal planar dolostone : (Pl. 1, F & G)

This facies is encountered in the upper most part of the Wata Formation (bed No. 14) representing about 50% of its total rock types. The dolostone facies is yellow, compact, rarely laminated and alternates with thin shaly horizons. Petrographically, this facies is medium to slightly coarse crystalline (120-250μm) containing idiotopic equigranular dolospar, euhedral to less subhedral, polymodal, plannar which may indicate multiple nucleation event or variation of growth rates. The dolostone rhombs are zoned, with cloudy cores and clear rims.

II- Sandstone lithofacies:

This lithofacies is characterized by glauconitic, ferrugineous, fine to medium grained lithic arenite. Quartz grains are the most abundant constituent, averaging 60-70%. This lithofacies occurs in bed no. 4,of the Halal Formation.

Calcareous fossiliferous lithic arenite (Pl. 1H)

This microfacies is recognized in bed 4, of the Halal Formation. It is yellowish brown, ferruginous, laminated and planner-cross bedded with trace fossils. The facies is composed of 60% monocrystalline, fine to medium-sized, moderately sorted quartz grains, subrounded, highly corroded and coated by thin iron oxide film. Lithic fragments of chert,shale and carbonates constitute about 10% of the rock volume. The framework elements cemented by calcite, dolomite crystals and iron oxides; up to 15%. The recorded fossils are ostracods and molluscan shell fragments. Most of these fragments are partially or completely leached and filled with dolomite crystals which contain calcite inclusions suggesting that calcite was the earlier cement in sandstones. The presence of herringbone cross-bedding may represent deposition in a narrow littoral zone in intertidal environment of an advancing transgressive shore line deposited on restricted shallow marine shelves (Wilson,1975).

Plate I

(A) : Sandy bioclastic grainstone (sandy biosparite) showing molluscan fragments with medium to fine quartz grains. C.N., bed 6, the Halal Formation, Gifgafa area, northwest Sinai.

(B) : Bioclastic wackestone/packstone (biomicrite) showing skeletal grains of pelecypods, foraminiferal and other shell fragments embedded in micritic matrix. C.N., bed 5, the Halal Formation, Gifgafa area, northwest Sinai.

(C) : Foraminiferal shelly wackestone (biomicrite). The rock composed of large foraminiferal tests embedded in micritic groundmass. C.N., bed 7, the Halal Formation, Gifgafa area, northwest Sinai .

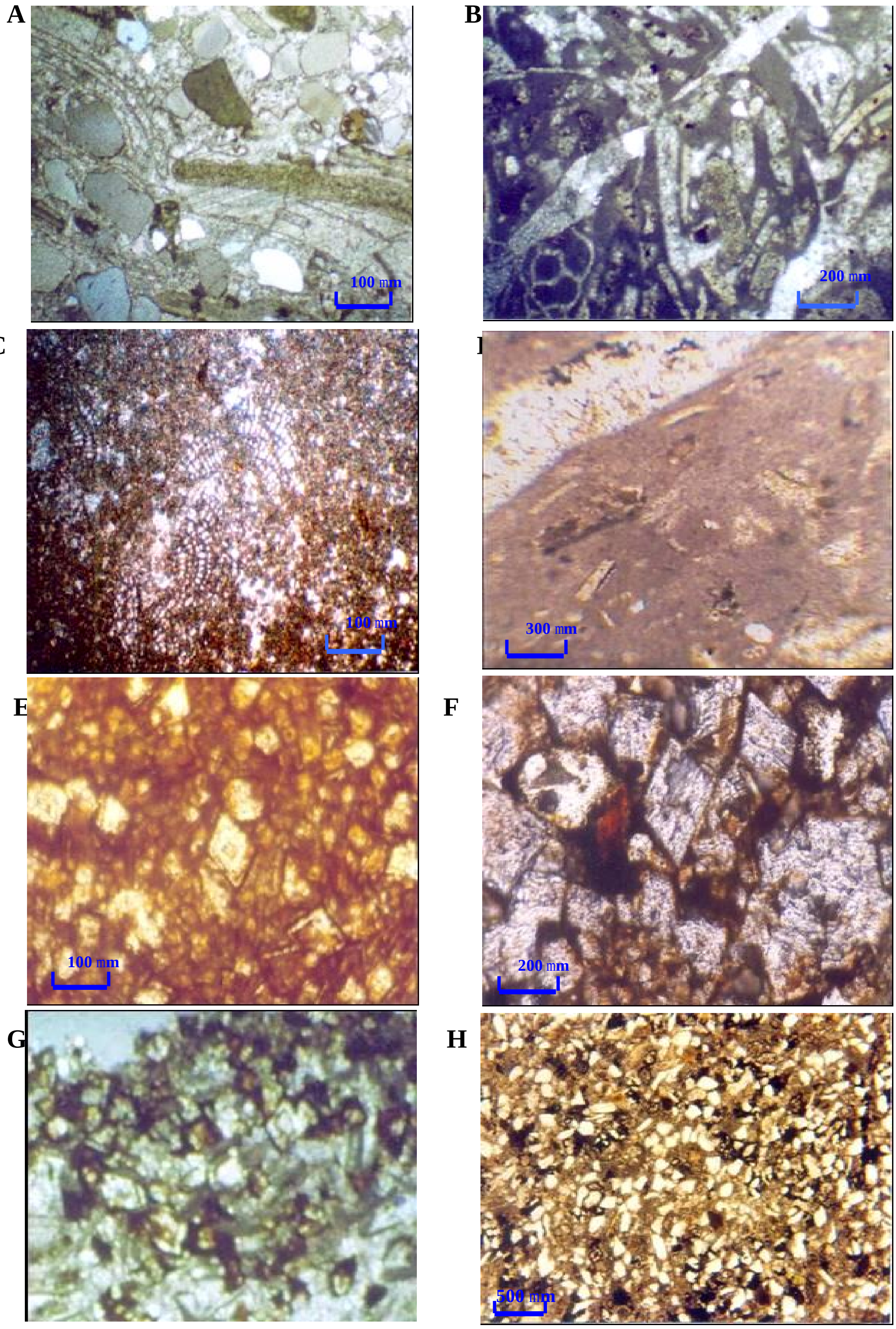
(D): Bioclastic wackestone / packstone showing skeletal grains embedded in micrite. C.N., bed 8, the Halal Formation, Gifgafa area, northwest Sinai.

(E) : Unimodal planar dolostone showing euhedral dolomite crystals. C.N. bed 11, the Wata Formation, Gifgafa area, northwest Sinai.

(F&G) : Polymodal planar dolostone showing euhedral zoned dolomite crystals. C.N., bed 14, the Wata Formation, Gifgafa area, northwest Sinai.

(H) : Calcareous lithic fossiliferous arenite showing fine to medium angular to subrounded, moderately sorted quartz grains. C.N., bed 4, the Halal Formation, Gifgafa area, northwest Sinai.

Plate I



Diagenesis

A brief discussion of the diagenetic processes described from the studied formations can be summarized as follow: compaction, cementation, grain solution and replacement, dissolution and dolomitization.

a- Compaction:

This is recorded in the calcareous fossiliferous lithic arenite where concavo-convex contacts are traced within the quartz grains indicating that these sandstones have been affected by compaction and pressure solution as diagenetic processes (Pl.1.H).

b- Cementation:

Calcite, dolomite and iron oxides are the main cementing materials. Calcite cement is common in the studied sandstone and occurs in forms of microspar and spar. The possible source of this carbonate cement may be of the neomorphism by early marine precipitation of micrite matrix and biogenic carbonates from scattered fossils. This is evidenced from the dissolution of some fauna leaving molds which in late stage filled with sparry calcite. Dolomite cement is encountered in which calcite crystals are partly dolomitized. Iron oxides are also present as cement showing patches or spots filling the pore spaces (Pl.1, A, B,G & H).

c- Grain solution and replacement :

In which most of the quartz grains were embayed as a result of corrosion, then a replacement of the original detrital grains by calcite have been taken place as indicated from some of the studied sandstones (Pl.1,H).

d- Dissolution:

Some shells and skeletal fragments are dissolved leaving cavities, vugs and pores which have been later filled with spary calcite and enveloped by micrite (Pl.1,A,B&D).

e- Dolomitization:

It is the major process recorded in the studied carbonate rocks.The dolomitization mechanism of the studied rocks can be explained by the mixing zone model of Han Shaw et al., (1971) and Badiozamani (1973) due to the replacement of calcite by dolomite proceeded preferentially in an undersaturated water with respect to dolomite. This indicates a secondary origin formed by the replacement through a mining zone mechanism(Pl.1,E&F).

Petrophysical properties :

The petrophysical analyses were done to estimate the following:

1. Solid phase properties (bulk and grain density).

2. Storage capacity properties (porosity, permeability, irreducible water saturation).

Using the laboratory measurements, numerous bi-variant relationships have been constructed to show the important trends by which lithologic component could be implemented. The sampled Upper Cretaceous section of Gifgafa area is discussed from base to top in order to determine reservoir properties through the Halal and Wata formations. The analysed samples selcted from the Halal Formation are mainly subdivided into: (1) sandy clayey limestones and (2) sandy dolomitic limestones, while the Wata Formation are subdivided into: (1) clayey dolostone and (2) dolostone.

Halal Formation :

(1) Sandy clayey limestones :

The average composition of the sandy clayey limestone samples was 66% carbonates, 14.1% sand and 19. 9% mud (Tab. 1). The grain and bulk densities average 2.15 g/ cm^3 and 2.51 g/cm^3 respectively. The average total porosity much higher compared with the effective porosity 23.60% and 5.01% respectively. Consequently, the permeability values are low and average 2.09 mD. The irreducible water saturation average 11.21%. The effective porosity and total porosity are directly proportional to each other in a very good relationship (r = 0.82, Fig.3a). The effective porosity is inversely proportional to the mud content (r = -0.80, Fig. 3b) and the bulk density (r = -0.84, Fig. 4a). On the other hand, the total porosity shows a very good inverse relationship to the bulk density (r = -0.81,Fig.4b).

The low effective porosity values of these samples led to low permeability values in an excellent relationship (r = 0.90, Fig.6). The permeability data are greatly affected by the mud content (r = -0.79).

(2) Sandy dolomitic limestones :

The composition of the sandy dolomitic limestone samples was 64.7% carbonates, 22.6% sand and 12.66% mud. The average grain and bulk densities are 2.13 g/cm^3 and 2.44 g/cm^3, respectively (Tab.1). The total is much higher than the effective porosity (19.7% vs. 7.6%). Consequently permeability values are low and average 4.25 mD. The irreducible water saturation average 18.41%. The effective porosity and total porosity are related to each other in a good relationship (r = 0.77, Fig. 3a). The effective porosity is inversely proportional to the mud content (r = -0.69, Fig. 3b) and the bulk density (r = -0.84, Fig.4). On the other hand, the total porosity has a very good inverse relationship to the bulk density (r = -0.79, Fig.4a). The grain and bulk density are related to each other by an excellent relationship (r = 0.91, Fig.5). These relationships show a good effect towards the pore spaces percentage on the bulk density values.

The low effective porosity values of the analyzed samples led to low permeability values with a very good relationship (r = 0.88, Fig.6). Accordingly, the permeability data are greatly affected by the clay content (r = -0.83, Fig.7b).

Wata Formation

(1) Clayey dolostones

These samples consist of average 67.5% carbonates, 5.75% sand and 26.8% mud (Tab.1). The grain density average 2.15 g/ cm^3. The relatively low grain density (2.15 g/ cm3) is accompanied with low bulk density (2.55 g/cm^3, Tab.1). The obtained total porosity is much higher than the effective porosity, 24.24% vs. 6.64%. Consequently, the permeability values are also low, average 4.18 mD. The irreducible water saturation average 14.41%. The effective porosity and total porosity are directly proportional to each other in a good relationship (r = 0.86, Fig.3a). The effective porosity is inversely proportional to the mud content (r = -0.69, Fig.3b) and bulk density (r = -0.82). On the other hand, the total porosity is related to the bulk density by an inverse relationship (r = -0.72, Fig.4a). The grain density and bulk density are related to each other by a very good relation (r = 0.86, Fig. 5). These relationships show a good effect of the pore spaces percentage on the bulk density values. The effective porosity and permeability are related to each other by a very good inverse relationship (r = 0.83, Fig.6). The permeability data are greatly affected by the mud content (r = -0.80).

(2) Dolostones :

The carbonate content of the dolostone is about 89.7%. Their sand content average 4.43% and mud content average 5.9% (Table 1). The bulk density average 2.22 g/cm^3. The relatively low variation in bulk density is accompanied with a low variation in the grain density values average 2.55 g/cm^3 (Table 1). Therefore, the obtained total porosity average 21.2% and the effective porosity values are low and average 9.34%, consequently. The permeability values are low and average 9.56 mD. The irreducible water saturation average 21.33%. The effective porosity and total porosity are directly proportional to each other in a good relationship (r = 0.71, Fig.3a) whereas the mud content has no effect on the effective porosity values (r = 0.19). On the other hand, the effective porosity has a very good inverse relationship to the bulk density (r = -0.86, Fig.4a). The total porosity is related to both the bulk and grain density by an excellent relationship (r = 0.93, r= 0.95,Fig. 4b). These relationships show a good effect of the pore spaces percentage on the bulk density values.

The low effective porosity values of these samples led to low permeability values (r = 0.91, Fig.6).

Table (1): The average composition and petrophysical properties of 58 rock samples for the Upper Cretaceous rocks, Gifgafa area, northwest Sinai .

FM	Rock type	S. No.	CARB %	SAND %	MUD %	s b g/cm^3	s g g/cm^3	fe %	ft %	K mD	Swirr %
Wata	Dolostone	Min	83.4	0.5	3.6	2.13	2.43	3.61	18.54	0.16	15.35
		Max	95.1	8.6	8	2.27	2.67	15.68	26.34	28.91	30.36
		Average	89.7	4.4	5.9	2.22	2.55	9.34	21.15	9.58	21.33
		St. D	4.9	3.5	1.5	0.1	0.08	4.44	2.86	10.45	6.67
	Clayey dolostone	Min	52.9	0.00	3.1	1.7	2.35	3.63	11.85	0.10	5.45
		Max	94.9	9.8	38.3	2.4	2.81	10.77	38.66	11.44	23.61
		Average	67.5	5.8	26.8	2.2	2.55	6.64	24.24	4.18	14.41
		St. D	13.6	3.4	10.8	0.2	0.11	2.12	7.12	3.37	5.61
Halal	Sandy dolomitic limestone	Min	58.9	18.1	9.5	2	2.11	2.75	5.40	0.22	7.25
		Max	72.4	26.3	16.6	2.3	2.74	12.50	33.33	9.38	31.17
		Average	64.7	22.6	12.7	2.1	2.44	7.60	19.68	4.25	18.41
		St. D	4.24	3.00	2.47	0.08	0.24	3.30	9.99	3.50	7.35
	Sandy clayey limestone	Min	56.36	11.28	13.53	2.03	2.40	2.71	18.70	0.16	6.28
		Max	75.19	18.98	29.98	2.26	2.67	9.13	30.40	8.09	16.81
		Average	65.98	14.13	19.89	2.15	2.51	5.01	23.60	2.09	11.21
		St. D	6.90	2.76	5.14	0.06	0.08	2.11	3.81	2.48	3.58

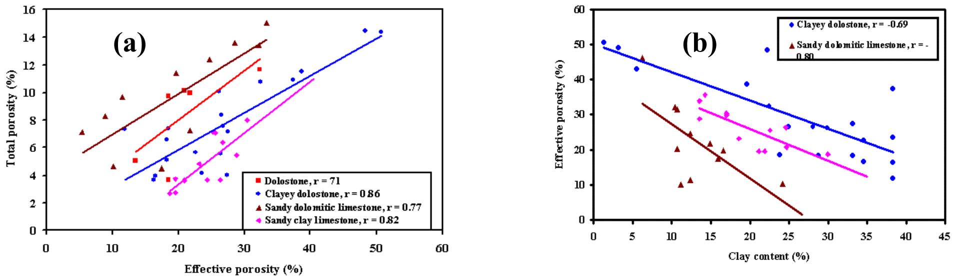


Figure (3): The relation between effective porosity and, (a) the total porosity (%), and (b) the mud content (%) of the Upper Cretaceous rocks, Gifgafa area, northwest Sinai .

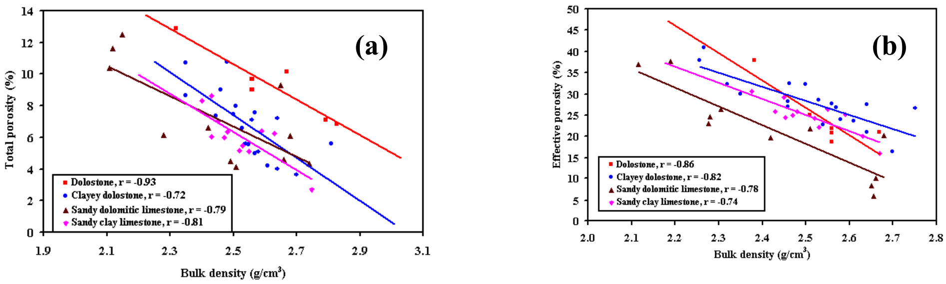


Figure (4): The relation between the bulk density (g/cm^3) and, (a) the total porosity (%), and (b) the effective porosity of the Upper Cretaceous rocks Gifgafa area, northwest Sinai .

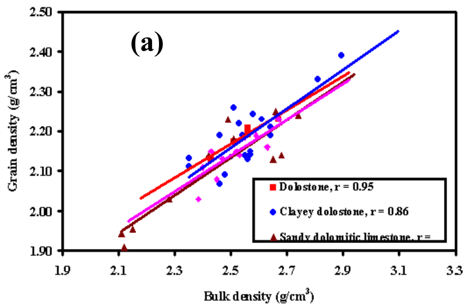


Figure (5): The relation between the bulk density (g/cm^3) and grain density (g/cm^3) of the Upper Cretaceous rocks Gifgafa area, northwest Sinai .

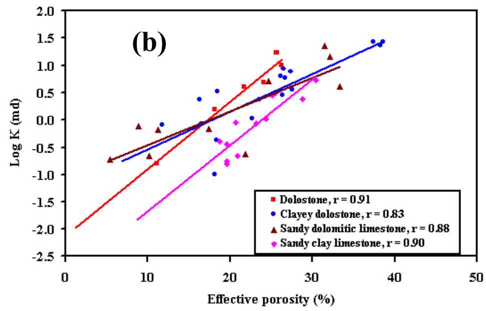


Figure (6): The relation between the effective porosity (%) and log of the permeability values (Log K) of the Upper Cretaceous rocks Gifgafa area, northwest Sinai.

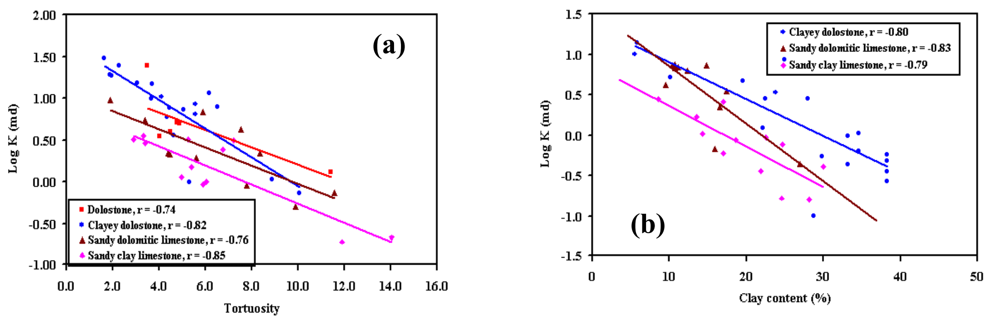


Figure (7): The relation between log of the permeability and (a) tortuosity and (b) mud content (%) of the Upper Cretaceous rocks Gifgafa area, northwest Sinai.

Reservoir Zonation and Economic Reliability:

Permeability ranging from 10-100 millidarcies are good, below that are low and above that are considered exceptionally high (Selley, 1994). The average permeability values of the Upper Cretaceous rocks of the Gifgafa section are average 2.09 and 4.25 mD of the sandy clayey limestone and sandy dolomitic limestone of the Halal Formation respectively, and the average permeability values of the clayey dolostone and dolostone of the Wata Formation are 4.18 and 9.58 mD respectively.

In general, the Upper Cretaceaos of the Gifgafa section has bad storage capacity properties except some horizons encountered in some parts of the formation such as the sandy clayey limestone rocks at the top of the Halal Formation, the clayey dolostone rocks in the middle parts of the Wata Formation are moderately values and in the dolostone rocks at the top of the Wata Formation to somewhat good values (Fig. 8) .

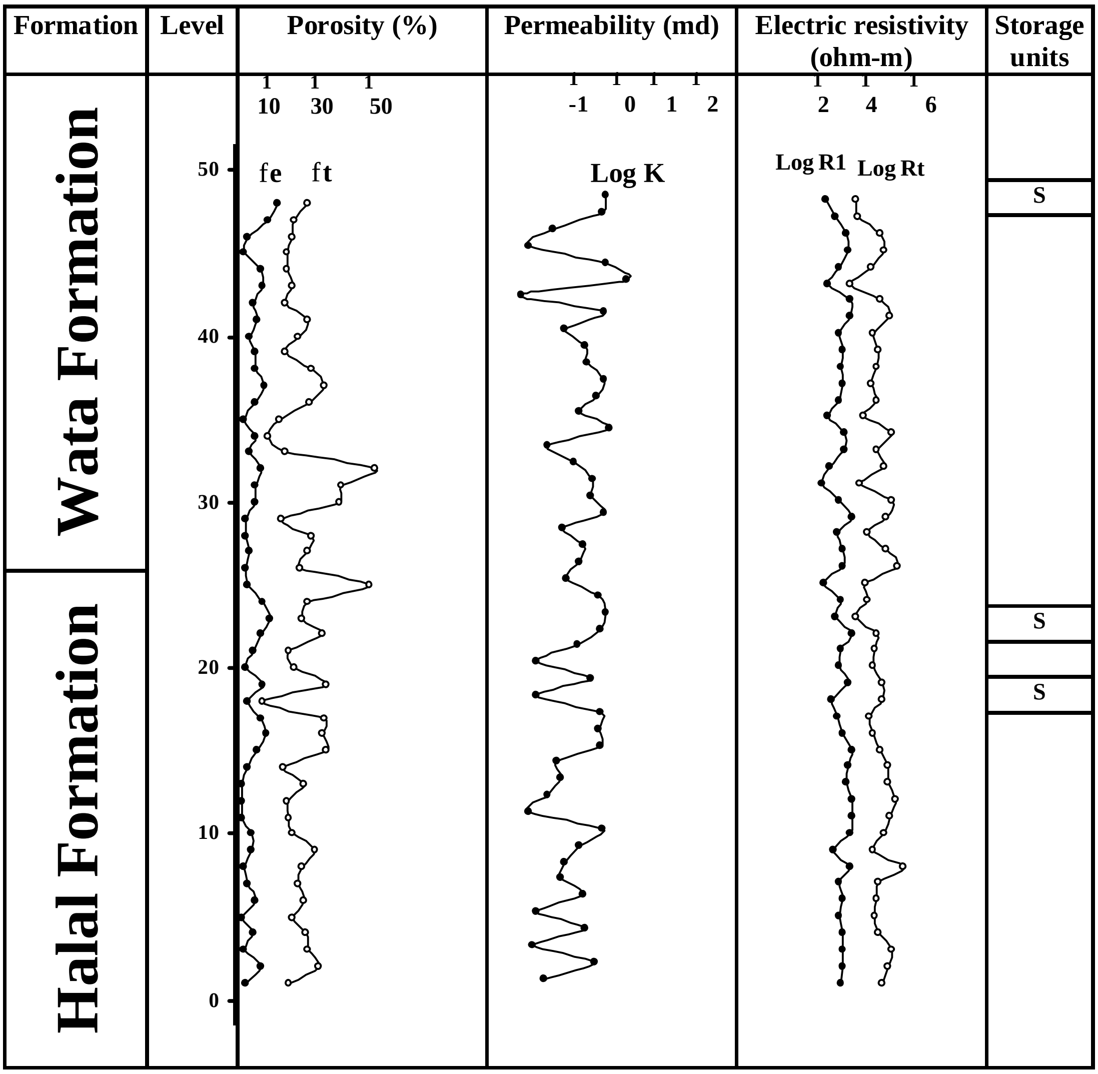


Fig. (8): Chart showing the vertical variation of the studied petrophysical parameters of the Upper Cretaceous rocks in Gifgafa section.

SUMMARY AND CONCLUSION

The Upper Createaceous rocks exposed in Gifgafa area, northwest Sinai are differentiated into a lower rock unit (the Halal Formation);overlain unconformably by the Wata Formation. The Halal Formation (138m. thick) consists of dolostone alternating with fossiliferous limestones, the lower part of the formation includes cross-bedded glauconitic sandstones, shales with limestones and dolostone interbeds. The Wata Formation (174m. thick) consists of limestones, dolostones, with few marl and shale interbeds. The sediments are characterized by diverse fauna including echinoderms, miliolids, rudists and oysters, which indicate middle and outer shelf environment prevailed in Cenomanian-Turonian exposures of northwest Sinai. With respect to the reservoir properities, the average permeability values of the sandy clayey limestone and sandy dolomitic limestone of the Halal Formation are 2.09 and 4.25 mD respectively. The average permeability values of the clayey dolostone and dolostone of the Wata Formation are 4.18 and 9.58 mD respectively. The Upper Cretaceaos rocks of the Gifgafa section has bad storage capacity except some horizons encountered in some parts of the formations such as the sandy clayey limestone rocks at the top of the Halal Formation. The clayey dolostone rocks in the middle parts of the Wata Formation have moderate porosity values. The dolostone rocks at the top of the Wata Formation have relatively good values.

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الملخص العربى

السحن وخواص الخزان لمتكونات الطباشيرى العلوى فى منطقة جفجافــة، شــمال غــرب ســينا ء، مصــر

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قسم الچيولوچيا - كلية العلوم - جامعة الزقازيق

الدراسة الحالية توضح السحن والخواص البتروفيزيائية لصخور الطباشيرى العلوى فى منطقة جفجافة، شمال غرب سينا ء، الدراسات الترسبية ألقت الضوء على السحن وتاريخ العمليات المابعدية للصخور المدروسة، الخواص البتروفيزيائية قيَّمت القدرة التخزينية للصخور تحت الدراسة وأوضحت أن صخور الطباشيرى العلوى لها قدرة تخزينية سيئة، ماعدا بعض الطبقات فى قمة متكون الراحة (الحجر الجيرى الطينى الرملى)، وفى وسط وقمة متكون الواطا (الحجر الدولوميتى الطينى والحجر الدولوميتى) التى لها قدرة تخزينية جيدة نسبياً بالمقارنة بالطبقات الأخرى.

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FACIES AND RESERVOIR PROPERTIES OF THE UPPER CRETACEOUS FORMATIONS IN GIFGAFA AREA, NORTHWESTERN SINAI, EGYPT

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