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Diagenetic Processes, Geochemistry and Petrophysical Properties of the Upper Cretaceous Matulla and Thelmet Formations at Wadi El-ghaib, Southeastern Sinai, Egypt

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Abstract: The study of the microfacies associations in the Upper Cretaceous Matulla and Thelmet formations exposed at Wadi El-Ghaib revealed the presence of six microfacies types namely: quartz arenite, sublithic arenite, sparite, dolostone, ferruginous dolomitzed sparite and sandy micrite. The petrographic analysis of the sandstones and carbonate rocks showed that, the former rocks were diagenetically offered by compaction and pressure solution, dissolution and leaching, replacement and dolomitization, whereas cabonates were subjected to neomorphism, dolomitization and replacement. The geochemical analysis indicated that the studied sandstone and shale rocks of the Matulla and Thelmet formations are characterized by relatively: high percentages of SiO_2, Al_2O_3, Fe_2O_3, TiO, Ba, V and Rb, whereas the non-clastic carbonate rocks are characterized by high proportion of CaO, MgO, Fe_2O_3, Sr and Zn. The petrophysical characteristics of the rocks showed that the sandstones in the lower part of the Matulla Formation have a high porosity and permeability and thus, have a good storage capacity.

Keywords: Diagentic processes, geochemistry, petrophysics, cretaceous, Sinai and Egypt

INTRODUCTION

The study area is located between latitudes 28° 30' 00" and 28° 35' 00" N. and longitudes 34° 25' 00" and 34° 35' 00" E. (Fig 1). According to *Kora and Genedi, (1995),* the pre-rifting rocks constituting all the sedimentary cover were deposited on a stable shelf platform. The stratified succession includes a lower sandy part of Early Paleozoic age, which was partly eroded during the Late Paleozoic. This is overlain by Cretaceous-Eocene deposits which are floored by a basal sandy unit consisting of marine carbonate-dominated rocks.

Structurally, the majority of faults in the studied area are oriented in two directions, N 15° E. (Gulf of Aqaba trend) and N 60° W, along the Tih scarp (Sehim, 1990 ; Odah et al. 1997), The Upper Cretaceous strata are nearly horizontal but towards the Gulf of Aqaba they tend to be inclined (mostly 30°-40° NE).

According to Ghorab (1961), the Cretaceous sequence in Sinai and the Gulf of Suez region are classified into five formations; namely: the Sudr Chalk (Campanian – Maastrichhtian), the Matulla (Coniacian – Santonian), the Wata (Turonian), the Abu Qada and the Raha (Cenomanian).

Based on a study on the trend surface analysis of the thickness data Abu Khadra *et al.,* (1987), described the Thelmet and the Sudr chalk formations at the Galala Plateau which are equivalent to the Markha and the Abu Zenima members in Sinai Peninsula.

This study concerns with the surface succession of the Matulla and Thelmet formations (Coniacian–Santonian and Campanian) at Wadi El-Gaib, Southeastern Sinai area. It is a detailed study of the diagenetic processes, geochemical and petrophysical properties of the clastic and non clastic rocks of the Matulla andThelmet succession and its storage capacity.

Methodology:

A total of twenty-two samples were collected to represent the different rock types of the studied of Matulla and Thelmet succession. Twenty thin sections were prepared to determine their mineral composition, microfacies associations and diagenetic processes. The petrophysical properties of the rock including the bulk and grain density, packing index porosity, permeability and water saturation were measured. The porosity is determined according to the methods of Preabrojenky (Kobranova, 1962; Dakhonova, 1977 and

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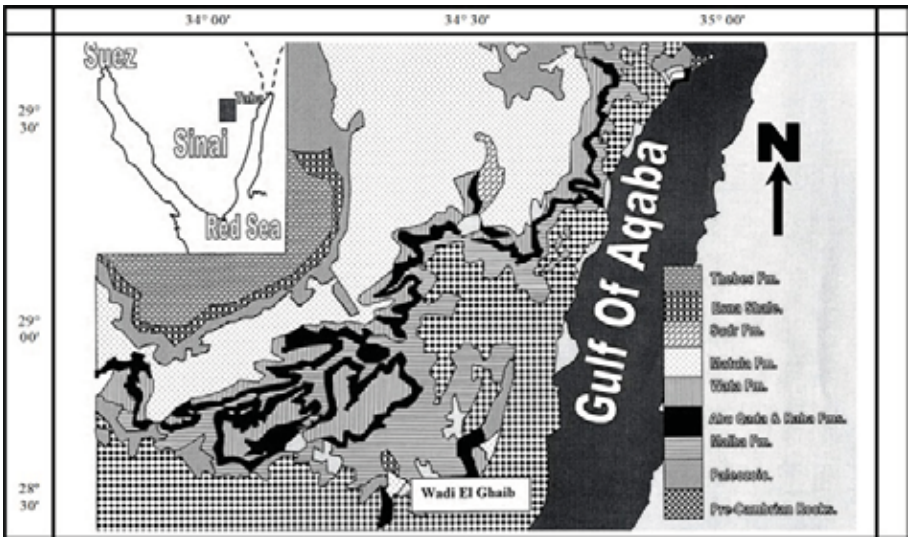

Fig. 1: Location and geologic maps of the study area (after Eyal, *et al.,* 1980)

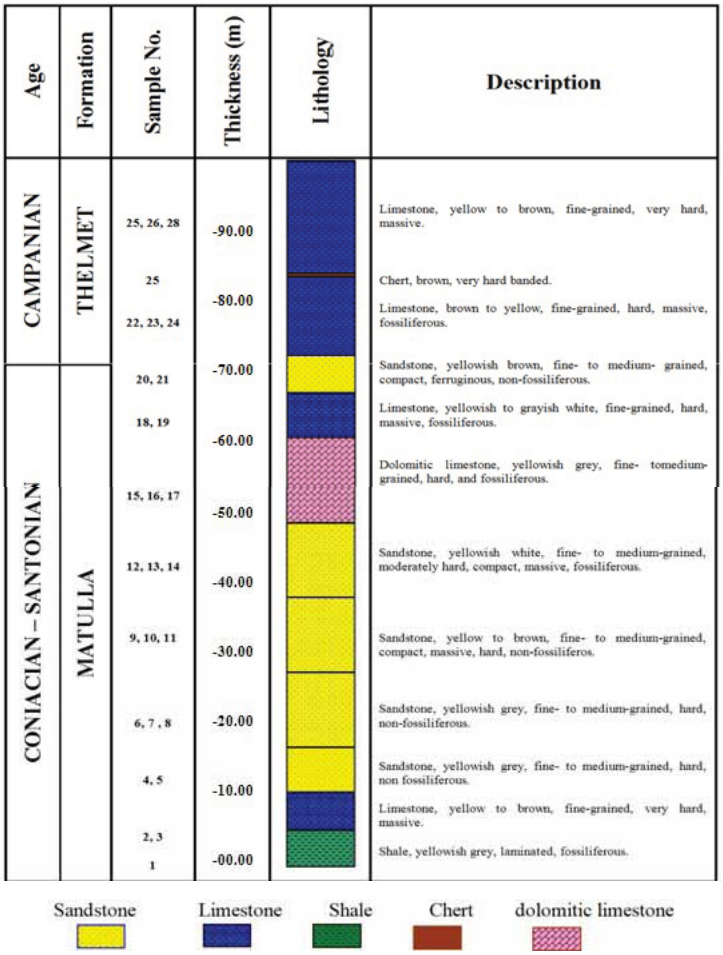

Fig. 2: Lithostratigraphic column of the Matulla and Thelmet formation at Wadi El-Ghaib.

Ragab *et al.,* 1985), the permeability according to Leverson (1967) and the packing index (P_I) is defined by El Sayed (1993).Eleven samples were chemically analyzed for their major and trace elements. The analysis was conducted X-ray fluorescence on Origaku 3070 instrument. Eight samples of different lithofacies were examined by Scanning Electron Microscope Model Philips X30 provided with EDX unit.

Lithostratigraphy:

The exposed Upper Cretaceous succession in the study area consists of six formations, namely (from base to top) Raha, Abu Qada, Wata, Matulla, Thelmet and Sudr (El-Deeb and El-Baz 2002).

The Matulla Formation attains a thickness of about 68 m. It overlies the Wata Formation and underlies the Thelmet Formation. It is composed mainly of shale, limestone, sandstone, dolomitic, limestone and sandstone. The lowest bed (~5m) consists of shale; which is yellowish grey, laminated, fossilferous and about 5 m. in thickness. It is followed by limestone (~5m) which is varies in color from grayish white to brown, fine grained, very hard, massive and fossiliferous. The overlying succession consists of four sandstone beds (~36m) which rang in color from yellowish grey to yellowish brown, fine- to medium- grained, moderately hard, compact, massive and sometimes fossiliferous. This is followed by a dolomitic limestone (~11m) which is yellowish grey, fine- to medium grained, hard and fossiliferous. Overlain by limestome (~6m) yellowish to grayish white, fine grained, hard, massive and fossiliferos. The uppers bed is sandstone (~5m) yellowish brown, fine- to medium- grained, compact, ferruginous and non fossiliferous.

The Thelmet Formation is well developed in the studied area. It is about 26 m. thick, overlies the Matulla Formation and underlies the Sudr Formation. It is composed mainly of limestone and chert. Limestone (~25.5m) is yellow to brown, fine-grained, very hard, massive and fossiliferous. The chert (~0.5m) is brown in color and very hard banded, (Fig.2).

Microfacies Associations:

Sandstone Microfacies:

Based on the classification of sandstones adopted by *Folk (1974)*, the following microfacies types were recognized:

Quartz arenite: (Pl. 1, Figs. A, B&C ; Pl. 2, Figs. E&F):

This facies is composed of about 95% quartz grains cemented mainly by clay minerals, carbonate, evaporite and iron oxides. Quartz grains are medium to coarse sand-sized, moderately- to well-sorted, subrounded to rounded and occasionally well rounded. The rocks are sub-mature to mature. This facies is represented by samples No's 3, 4, 7, 10, 11, 12, 13 and 14.

Sublithic arenite: (Pl. 1, Figs. D, E&F ; Pl. 2 Figs. G&H):

The rock consists of quartz grains and lithic fragments. Quartz grains are medium to coarse sand-sized, subangular to subrounded, moderately sorted and rounded. The grains are predominantly monocrystalline and displayed both uniform wary extensions, they are cemented mainly by sparry calcite, iron oxide and clay materials. The rock is sub-mature. This facies is represented by samples No's 6, 8, 9, 20 and 21.

Carbonate Microfacies:

Applying the classifications of carbonates adopted by *Folk (1974) and Dunham (1962)*, the following microfacies were recorded:

Sparite (Pl. 2, Fig. A):

This microfacies consists of micrite patches grading into sparry calcite. The crystals are neomorphic and, in places form cement. Iron oxides are scattered in the groundmass. Texturally, this facies is considered to be a crystalline limestone (grainstone microfacies). It is represented by samples No. 2 and 3,

Dolostone (Pl. 2, Fig. B):

Dolomite crystals in this microfacies consist mainly of recrystallized microcrystals, while the non-bioclastic carbonate grains are absent. The clastic material consists mainly of sand. This microfacies is represented by samples No's. 15, 16 and 17.

Ferruginous dolomitized sparite: (Pl. 2, Fig. C):

This microfacies consists of dolomite crystals embedded in a sparitic matrix which is stained partially by iron oxides. Texturally, it is considered to be a crystalline rock (packstone/grainstone microfacies). This microfacies is represented by samples No's. 18 and 19.

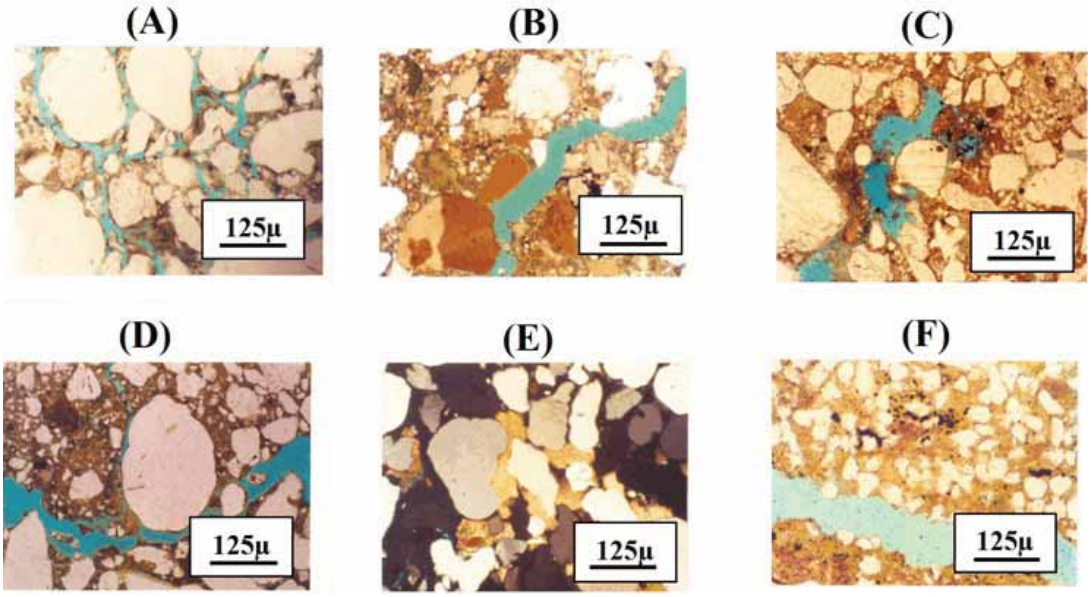

Fig. A: Photomicrograph of quartz arenite. Quartz grains are medium to coarse, sub-rounded to rounded and moderately- to well-sorted. The rock is sub-mature to mature and has a very good and connected porosity. (Sample No. 4, CN).

Fig. B: Photomicrograph of quartz arenite. Quartz grains are medium to coarse, subrounded to rounded and well-sorted. Calcite and dolomite are present as cements. The rock is mature and has a very good and connected porosity. (Sample No. 10, CN).

Fig. C: Photomicrograph of quartz arenite. Quartz grains are medium to coarse, subrounded, and moderately-sorted. The rock is sub-mature with argillaceous matrix. Porosity is very good and connected. (Sample No. 12, CN).

Fig. D: photomicrograph of sublithic arenite. Quartz grains are medium to coarse, rounded and well-sorted. The sandstone is having argillaceous matrix and ferruginous cement. Porosity is very good and connected (Sample No. 6, CN).

Fig. E: Photomicrograph of sublithic arenite. Quartz grains are medium to coarse, sub-angular to subrounded and moderately-sorted. The sandstone is sub-mature. Cements consist of calcite, dolomite and evaporite (Sample No. 9, CN).

Fig. F: Photomicrograph of sublithic arenit. Quartz grains are fine, sub-angular to subrounded, moderately-sorted, The rock is sub-mature having argillaceous matrix and iron oxides cement . Porosity is very good and connected (Sample No. 21, CN).

Sandy micrite (Pl. 2, Fig. D):

Micrite and quartz grains are the main components of this microfacies. Quartz grains are sub-rounded to rounded. Texturally this association is considered to be a wackstone microfacies . It is represented by samples No 22, 23, 24, 26, 27 and 28.

Diagenetic Processes:

Digenesis of Sandstones:

The main diagenetic processes of sandstones are in (Fig. 3):

Compaction and Pressure Solution:

- Most of the studied sandstones were subjected to high pressure due to the overlying sediments. They are tightly-packed as a result of grains adjustment made under such pressure which led also to the development of sutured contacts, (Pl. 1, Figs. B &E). It is clear the high compaction reduced the total interganular porosity of these sandstones.

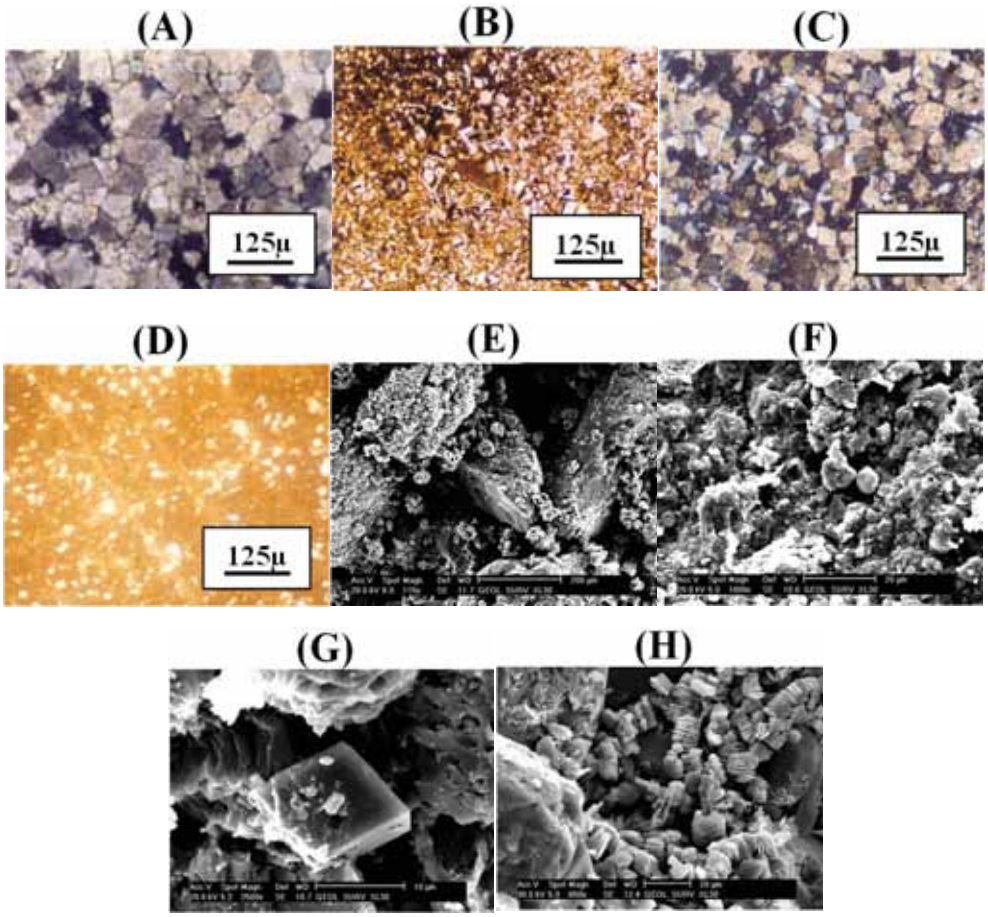

Fig. A: Photomicrograph of sandy sparite microfacies (Sample No. 2, CN).
Fig. B: Photomicrograph of dolostone microfacies (Sample No. 16, CN).
Fig.C: Photomicrograph of sandy ferruginous dolomitzed sparite microfacies (Sample No. 18, CN).
Fig. D: Photomicrograph of sandy micrite microfacies (Sample No. 27, CN).
Fig. E: Scanning Electron micrograph showing very good porosity between the quartz grains, which are coated with clay particles, (Sample No. 4).
Fig. F: Scanning Electron micrograph showing very good porosity between quartz grains (Sample No. 10).
Fig. G: Scanning Electron micrograph showing good porosity between quartz grains. Kaolinitic matrix and calcitic cement are seen (Sample No. 11).
Fig. H: Scanning Electron micrograph showing a considerable porosity between quartz grains although partially reduced by authigenic kaolinite booklets (Sample No. 14).

- **Dissolution and leaching:** Dissolution features in the studied sandstones are shown in (Pl. 1, Figs B, C & E). The leaching process is shown in (Pl. 1, Figs. A, D).
- **Replacement and dolomitization:** Dolomite is present as a cement in some sandstones due to replacement of calcite (Pl. 1, Figs. B, D).

Diagenesis of Limestones:

- **Neomorphism:** This process is represented in micrite and sparite (Pl. 2, Figs. A, B & D) of recrystallization to coarse mosaic of spars.
- **Dolomitization and ferrugination replacement:** (Pl. 2, Figs. B&C). The studied carbonate samples indicated that dolomitization process took place after the sediments were cemented. This process played a very important role in the development of secondary porosity. Frrugination replacement is shown in (Pl. 2, Figs. A, C). Iron oxides in-filled the pores and partially or completely replaced calcite.

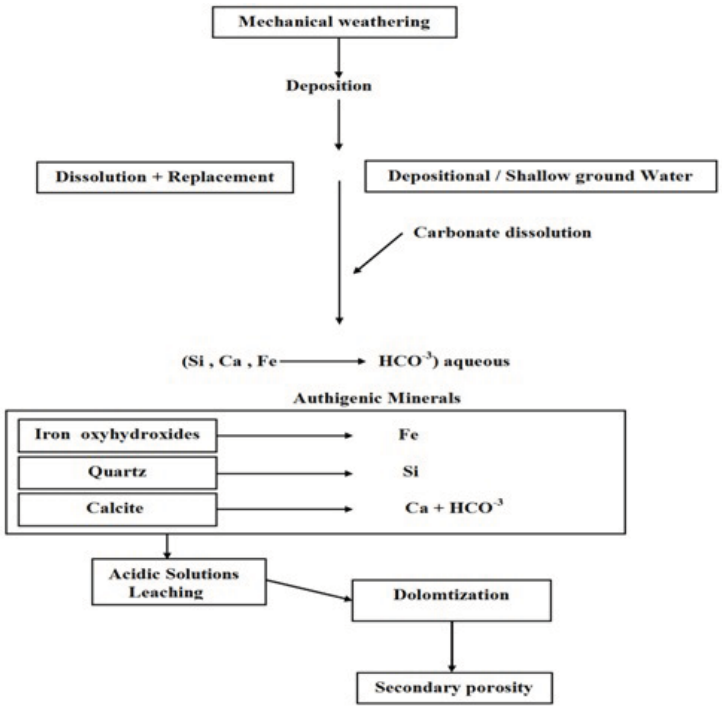

Fig.3: Schematic chart illustrating the diagenetic processes which affected of the Matulla sandstone.

Geochemistry:

The successions of the Matulla and Thelmet formations are characterized by the presence of various types of rocks, according to the average of Turekian and Wedepohl (1961) (Table 1).

Their sandstones are represented by the microfacies: quartz arenite and sublithic arenite. The contents of SiO_2 and Al_2O_3 range from 80 to 93.81% and from 0.51 to 4.87%, respectively. The contents of Fe_2O_3, MnO and CaO range from 0.96 to 4.64% , from 0 to 2.52 % and from 0 to 4 %, respectively. Also, the contents of Na_2O, K_2O, P_2O_5, MnO and TiO_2 range from 0.22 to 1 %, from 0.48 to 1.48%, from 0 to 0.12%, from 0 to 0.34% and from 0.18 to 0.46 %, respectively (Table 1).

The trace elements of these rocks consist of Sr, Rb, Pb, Zn, Cu, Ni, Cr, V and Ba, that range from 40 to 210 ppm, from 29 to 46 ppm, from 2 to 7 ppm, from 3 to 10 ppm, from 3 to 175 ppm, from 2 to 205, from 7 to 39 ppm, from 11 to 494 ppm, from 16 to 280 ppm and from 183 to 341 ppm, respectively. The percentages, of Al_2O_3, SiO_2, Fe_2O_3, V and Ba are relatively high in the shale beds, (Table 1).

The carbonate rocks are characterized by four microfacies types: is spasrite, dolostone, ferruginous dolosprite and sandy micrite. The contents of CaO, MgO, SiO_2 and Fe_2O_3 are range from 25.63 to 46.92 %, from 1.15 to 23 %, from 0 to 15.94% and from 0.62 to 3.31%, respectively (Table 1).

Table 1: Chemical composition of the Matulla and Thelmet rock.

Formation	Sample No.	MAJOR ELEMENT (%)											TOTAL	TRACE ELEMENTS (PPM)								
		SiO_2 %	Al_2O_3 %	FeO_3 %	Cao %	MgO %	Na_2O %	K_2O %	P_2O_5 %	MnO %	TiO_2 %	L.O.I %		Sr	Rb	Pb	Zn	Cu	Ni	Cr	V	Ba
Thelmet	26	15.94	0	3.31	44.92	1.17	0	0.19	0.09	0.205	0.01	33.46	99.295	176	24	0	9	0	0	10	10	179
	23	13.94	0	3.01	44.92	1.15	0.20	0.15	0.12	0.195	0.02	36.12	99.825	172	22	0	8	0	0	8	9	182
Matulla	21	80	4.87	4.64	0	2.52	0.22	1.48	0.12	0	0.40	5.08	99.33	89	39	7	175	2	39	11	280	186
	18	0	0	0.62	46.12	8.70	0	0.64	0.022	0.018	051	43.32	99.95	47	24	3	63	0	0	10	17	180
	15	13.3	0	0.89	25.63	23	0	0	0.02	0.171	0	36.40	99.855	197	27	0	23	0	0	18	29	179
	12	93.02	0.76	2.25	0.41	0.22	0.38	0.41	0.051	0.014	0.42	1.92	99.8	40	29	2	9	195	32	338	19	241
	10	92.83	0.78	2.02	0.43	0.20	0.51	0.48	0.054	0.016	0.46	2.02	99.45	35	31	3	7	205	35	342	21	245
	9	82.1	4.27	0.96	4	1.1	1	0.88	0	0.14	0.18	4.82	99.45	210	46	10	15	46	7	70	70	341
	7	93.81	0.51	3.58	0.57	0	0.29	0.54	0.054	0.017	0.29	0.23	99.891	77	29	4	3	178	36	494	16	272
	3	1.77	0	1.01	55.95	0.66	0	0	0.20	0.088	0.09	39.0	99.768	420	23	0	19	0	0	6	0	340
	1	63.23	16.84	5.5	0.85	3.91	0.81	0.35	0.028	0.003	0.70	7.08	99.301	83	40	11	120	53	26	86	186	244

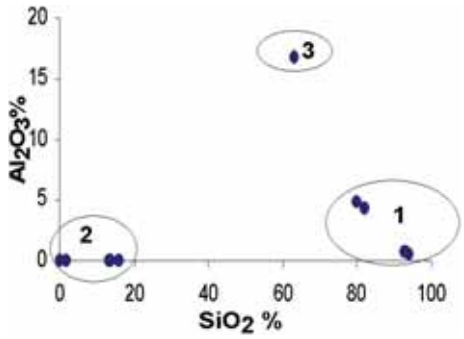

Fig. 4: Silica versus Alumina

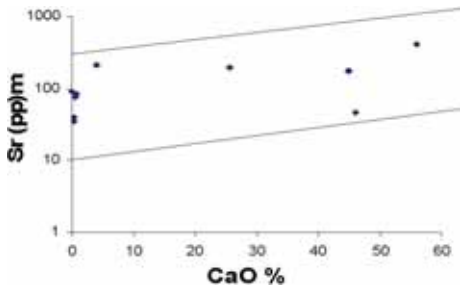

Fig. 5: Calcium oxide versus strotium

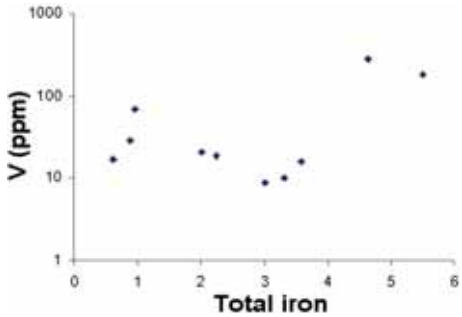

Fig. 6: Total iron versus vanadium.

The trace elements consist of high contents of Sr and Ba ranging from 47 to 420 ppm and from 179 to 340 ppm respectively, (Table 1). The percentages, of the other trace elements are low.

The relation between Al_2O_3 and SiO_2, (Fig. 4) in the studied samples reveals clustering into three types of rock units. The first group represents sandstones which are present in the Matulla Formation. The second group represents the carbonate sediments which are present in the Matulla and Thelmet formations. The third group of rock units represents clays at the base of Matulla Formation.

The relationship of CaO versus Sr (Fig. 5) reflects a positive correlation. They show also that carbonate has high content of Sr in the Mutalla and Thelmet Formations.

The relationship between vanadium and total iron reflects very good correlation for the clay beds and the sandstones of the Matulla Formation (Fig. 6).

Petrophysical Properties:

Petrophysical data deal with the rock-forming mineral matrix and the fluid contents, whereas the storage capacity properties depend on the grain- to -grain relationships.

Petrophysical properties (grain density, bulk density, packing index, porosity, permeability and water saturation) were measured to define the best place, as well as the storage capacity, (Table 2).

Table 2: Pertrophysical parameters of the Matulla and Thelmet rocks.

Formation	Sample No.	Bed No.	Grain density (g/cm^3)	Bulk density (g/cm^3)	Packing index	Porosity %	Permeabilty (mD)	Water Saturation %
THELMET	28	12	2.6	2.32	1.12	12	0.008	25
	27		2.71	2.36	1.14	12	0.007	26
	26		2.7	2.39	1.29	11	0.006	28
	24	10	2.69	2.44	1.10	10	0.007	30
	23		2.71	2.4	1.09	9	0.005	32
	22		2.73	2.54	1.07	7	0.003	37
MATULLA	21	9	2.66	1.83	1.45	28	0.422	12
	20		2.72	1.87	1.45	31	0.444	10
	19	8	2.71	2.06	1.32	19	0.372	16
	18		2.70	2.10	1.28	22	0.388	16
	17	7	2.72	2.07	1.31	21	0.382	15
	16		2.70	2.08	1.29	22	0.375	14
	15		2.69	2.04	1.32	24	0.381	12
	14	6	2.65	1.70	1.56	29	3020	10
	13		2.64	1.72	1.53	29	3045	9
	12		2.65	1.72	1.52	30	3060	8
	11	5	2.63	1.81	1.45	30	3080	7
	10		2.63	1.5	1.42	30	3120	8
	9		2.64	1.83	1.44	31	3169	7
	8	4	2.63	1.65	1.59	31	3535	6
	7		2.65	1.69	1.57	32	3721	5
	6		2.64	1.71	1.54	33	3965	5
	5	3	2.64	1.73	1.53	33	4042	5
	4		2.65	1.73	1.51	34	0.006	4
	3	2	2.69	2.41	1.12	10	0.008	24
	2		2.71	2.44	1.11	8	0.001	28
	1	1	2.58	1.65	1.56	6		38

Matulla and Thelmet formations are interesting rock units for study. They include different types of rocks as sandstone, limestone and shale.

The sandstone of the Matulla Formation is divided into two parts, the first includes one layer (layer No. 9) which is characterized by a very good porosity, medium water saturation and low permeability. The porosity of this layer rang between 28 and 31%, the water saturation from 10 to 12%, and the permeability is 0.422 to 0.444 m D.

The second type consists of four layers (layers Nos. 3, 4, 5 and 6) which are characterized by very good porosity and permeability, and low water saturation except for one sample. The porosity ranges between 29 and 34%, permeability is 3020 to 4042 mD, and water saturation is 4 to 24 %.

The limestone of the Thelmet Formation consists of two parts (beds Nos. 10 and 12, represented by samples Nos. 22-24 and 26-28) separated by a chert bed. This formation is characterized by high water saturation (25 - 37 %) medium to low porosity (7 - 12 %) and low permeability (0.003 to 0.008 m D).

The limestone of Matulla Formation consists of two parts. The first one (bed No. 2, samples Nos. 2and 3), is characterized by a high water saturation (24 - 28%), medium porosity (8 - 10 %), and low permeability (0.006 and 0.008 mD). The second part (beds No's. 7 and 8, samples Nos.

(15–19) is characterized by a high porosity (19 - 24 %), medium permeability (0.372 - 0.388 mD). and water saturation (12 - 18%). The obtained petrophysical data reveled that the highest porosity values are displayed by beds Nos. 3 – 6, which have also good permeability. It can be concluded that these beds have the best storage capacity through this succession.

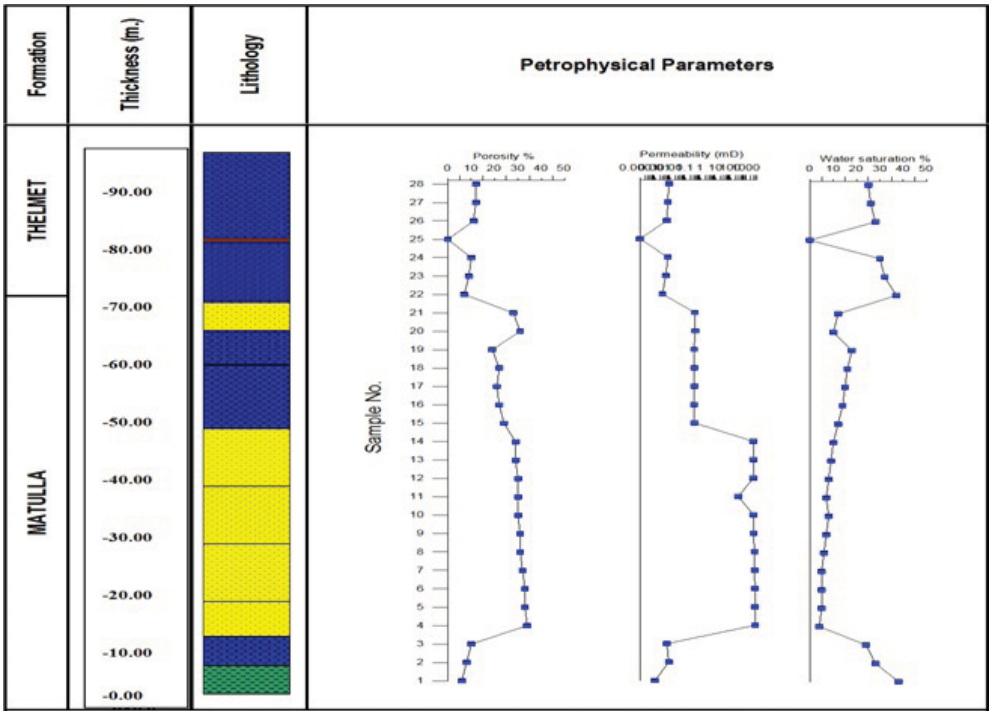

Fig. 7: Vertical variation in petrophysical parameters of the Matulla and Thelmet successions.

Summary and Conclusions:

Studing the diagenetic processes and geochemical and petrophysical aspects of the Matulla and Thelmet rocks (Coniacian – Santonian and Campanian) in Wadi El-Ghaib area, (southeastern Sinai) reveal that the sandstone, shale and carbonate rocks are characterized by the following:

The sandstone beds are divided into two parts; the lower is characterized by quartz arenite and sublithic arenite microfacies, medium to coarse-grained, sub-rounded to rounded, and sub-mature to mature. Dissolution, leaching, replacement and dolometization are the predominant diagenetic processes. High percentage of SiO_2, Al_2O_3, Fe_2O_3, TiO, Ba, V and Rb are encountered. The rock has very good porosity and permeability is occurred and low water saturation. It can be concluded that, theseThe rock have high percentage of SiO_2, Al_2O_3, Fe_2O_3, TiO, Ba, V and Rb. Also, very good porosity, medium water saturation and low the permeability.

- The limestone of Matulla Formation consists of two parts. The lower part is characterized by sparite microfacies. Neomorphism and and ferrugination represent the diagenetic processes. It has high percentages of CaO, Sr and Zn, as well as high water saturation, medium porosity and low permeability. The upper part on the other hand, is characterized by the presence of dolostone and ferruginous dolomitzed sparite microfacies. Dolometization and ferrugination replacement are the diagenetic processes. Dolometization processes led to higher porosity, intermediate permeability and water saturation.
- The limestone of the Thelmet Formation consists of two beds represented by sandy micrite microfacies. Neomorphism represents the diagenetic processes in this rock unit. High percentages of CaO, SiO_2, Sr and Zn as well as high water saturation, low to medium porosity and low permeability characterize this unit.

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