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CONTRIBUTION TO THE MINERALOGY AND GEOCHEMISTRY OF THE UPPER CRETACEOUS MATULLA FORMATION AND SUDR CHALK, TABA AREA SOUTHEASTERN SINAI, EGYPT

Shams El-Din, M. Shaheen

Geology Department, Faculty of Science, Suez Canal University, Port-Said

ABSTRACT

The Upper Cretaceous exposures in southeastern Sinai are represented by Carbonate - dominated successions interbedded with a few sandstone, chert and marl horizons. The examined rock units in Taba area include Matulla Formation and Sudr Chalk were studied lithostratigraphically and mineralogically. On the other, the major and trace elements as well as $\delta^{18}O$ & $\delta^{13}C$ isotopes were focused on the studied rock units to interpret their depositional conditions.

Lithostratigraphically the Matulla Formation conformably overlies the upper carbonate beds of the Wata Formation and underlies the lower Markha Chalk Member (50m thick) of the Sudr Chalk. Mineralogically the non-clay minerals determined by X-ray analysis include calcite, dolomite, ankerite, gypsum, anhydrite, quartz and feldspars that mainly reflect the oscillating regressive transgressive conditions during sedimentation. The present clay minerals show concentration of illite, smectite and palygorskite in the upper Sudr Chalk. Chlorite, while kaolinite is encountered in the Matulla Formation. Most of these minerals are of detrital origin.

Chemically, the variation in the contents of major elements within the studied rock units is attributed to the nature of parent rocks in addition to the physicochemical conditions during weathering and transportation and deposition. Moreover, the horizons contain high contents of trace elements reflecting that these sediments have good accumulator's minerals, which represent the main host of trace elements.

The low values of $\delta^{18}O$ suggest that the primary signals has been diagenetically altered by more ^{18}O depleted meteoric ground water or by dissolution and recrystallization at higher temperature during burial diagenesis (Sakai & Kano, 2001). The encountered positive $\delta^{18}O$ values in the Matulla Formation may be attributed to dry climate intervals with some evaporation process. The more positive values of $\delta^{13}C$ encountered in the Sudr Chalk and the lower part of the Matulla Formation could be attributed to high productivity and the increase of Photo synthetic effects in a shallow marine environment. The $\delta^{13}C$ depletion recorded in the dolostone of the Matulla Formation achived a more diagenetic process.

INTRODUCTION

The Pre-rifting rocks along the western side of the Gulf of Aqaba constitute one of the famous sedimentary cover in southern Sinai. The Cretaceous rocks are widely distributed on the surface and subsurface at several parts of Sinai (Said, 1990). The Lower Cretaceous rocks are represented by continental clastic sediments in the central Sinai and the Gulf of Suez, while the Upper Cretaceous rocks are represented by carbonates with a few clastics (Abdallah and Adindani, 1963; Kora and Genedi, 1995; Abu El-Enain and Morsi, 1999).

According to Ghorab (1961), the Cretaceous rocks in Sinai and the Gulf of Suez region are classified into five formations, namely from base to top; the Raha and the Abu Qada Formations (Cenomanian), the Wata Formation (Turonian), the Matulla Formation (Coniacian-Santonian) and the Sudr Chalk (Campanian-Maastrichtian). According to Kora and Genedi (1995), the pre-rifting sedimentary cover was deposited on a stable shelf platform. This stratified succession includes a lower sandy Early Paleozoic rocks, which were partly eroded during the late Paleozoic. These Paleozoic rocks were later overlain by Cretaceous - Eocene marine carbonate - dominated rocks.

Structurally, the upper Cretaceous rocks are dissected by a common faults oriented in two major directions, N 15° E. (Gulf of Aqaba trend) and N 60° W, along the Tih Scarp (Sehim, 1990 and Qdah et al. 1997). The Upper Cretaceous strata are nearly horizontal, but tend to be inclined towards the Gulf of Aqaba (mostly 30° - 40° NE). Garfunkel and Bartov (1977) and Wilson et al. (2009) discussed the tectonics of the Suez rift and reported that the rocks of the Late Cretaceous extend all over southern Sinai without abrupt facies changes and that their present distribution was resulted by erosion phase following the Neogene and Quaternary tectonism. This is corroborated by the presence of rocks of Cretaceous age as large clasts in the Miocene conglomerates in southern Sinai.

The thickness variations are expression of long wave length oscillations of the Arabo-African platform. Based on the study of the trend surface analysis of the thickness data, Bartov and Steinitz (1977) concluded that a continuous tilting of the basement underlying the shelf existed from the Cenomanian to early Senonian. Also, Abu Khadrah et al., (1987), described the Thelmet and the Sudr Chalk formations at Galala Plateau which are equivalent to the Markha and the Abu Zenima members in Sinai Peninsula.

The field study indicated that the Upper Cretaceous rocks are well exposed at Wadi Tuweiba - Wadi Taba area (Fig.1) and are divided into five rock units. They are from base to top the Raha Formation, the Abu Qada Formation, the Wata Formation, the Matulla Formation and the Sudr Chalk. The Matulla Formation consists of Carbonates in the lower part and sandstone in the Upper part with few claystone beds. Sudr Chalk consists of snow white chalky limestone with intercalations of claystone, marl and chert bands.

The studied section represents the most Upper Cretaceous succession exposed in the Taba area stretching in a distance of about 3Km to the south of the Sonestta Hotel between Wadi Tuweiba and Wadi Taba (Fig.1). In the Taba area, the chert beds in the Campanian - Maastrichtian Sudr Chalk are associated with phosphatic horizons (El Assy, 1992) that are rich in open marine fauna in-

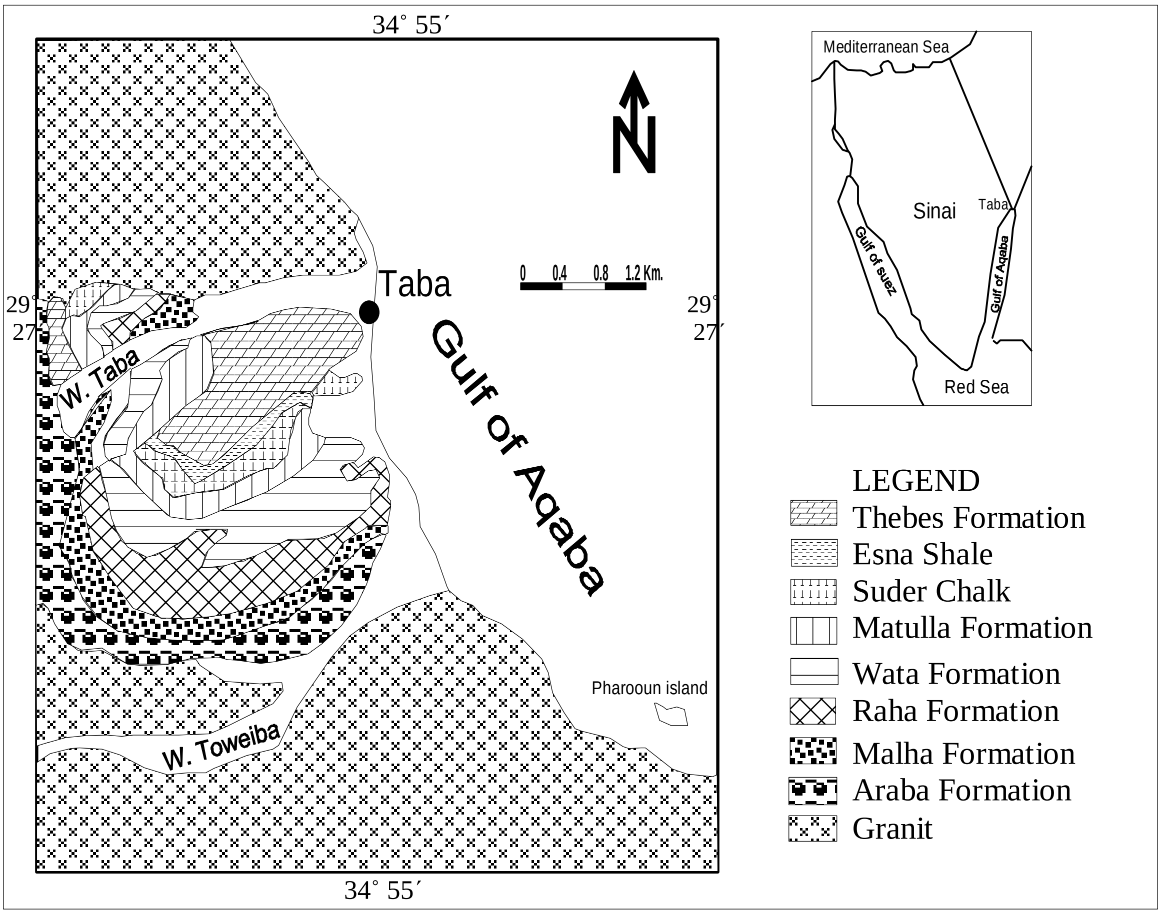

Fig. 1: Geological map of Taba area (after Bishay, 2004).

cluding heteromorph ammonites (Abdel Gawad, 1990). After the deposition of the Maastrichtian sediments, the area had been subjected to uplift and subsequent erosion leading to the removal of a great part of the Senonian deposits from the southern localities in eastern Sinai (Shahin & Kora, 1991). The erosional unconformity between the Cretaceous and the Tertiary in this area is related to syndepositional tectonics associated with the folding of the northeast- trending Syrian Arc deformational phase.

Many detailed lithostratigraphy biostratigraphy, sedimentary history and microfacies studies of the Upper Cretaceous rocks of Sinai are encountered, (e.g: Kora and Hamama, 1987; Malchus, 1990; Abdel Gawad and Zalat 1992; Kora et al., 1994; Kora and Genedi, 1995; Gameil, 1997; Genedi,1998; ElMansy and Barakat, 1998; Issawi et al., 1998; Samuel et al., 1998; Hegab et al., 2001; Mansour et al., 2001; Kora et al., 2001 a, b; Kora et al., 2002; Abd ElAziz 2002; Genedi, 2003 & 2005; El-Fawal, 2005 and Samuel et al., 2009). However, detailed chemical and mineralogical studies on these Upper Cretaceous rocks are a few (Khalil et al., 1992; Gadallah et al., 2003; Bishay, 2004; Genedi et al., 2006 and El-Hariri et al., 2007).

The main aim of the present work is to determine the nature of the depositional conditions of the studied Matulla Formation and Sudr Chalk in the Taba area that influencing the nature of the different minerals and the geochemical behaviour. The geochemical investigation include both major, trace elements as well as oxygen and carbon isotopes.

MATERIAL AND METHODS

Twenty five (25) samples were collected to represent the different rock types of the studied Matulla Formation and Sudr Chalk (Fig. 2). A lithistratigraphic section was constructed for the studied Matulla Formation and Sudr Chalk (Fig. 2). These samples were mineralogically and chemically analyzed. The major and trace elements were determined by XRF at the laboratories of the Nuclear Materials Authority in Cairo. The mineralogical composition of bulk samples was identified using X-ray diffractometer with Ni filtered, Cu K radiation at 40Kv and 25mA and a scanning speed of 1° perminute. The clay fraction (<2) were prepared by the sedimentation techniques described by Thorez (1976). Isotopic analyses of $\delta^{13}C$ and $\delta^{18}O$ were performed on whole rock samples which are carried at the Petrography Institute, Karlsruhe University, Germany. The $\delta^{13}C$ and $\delta^{18}O$ are given relative to the Peedee Belmanite Standard deviation better than $\pm$0.15% PDB. The data obtained from the mineralogical and geochemical analyses, integrated with stratigraphic evidence, are used for depicting the depositional environments.

RESULTS AND DISCUSSION

Lithostratigraphy:

The exposed Upper Cretaceous succession in the study area consists of five formations. They are namely from base to top; Raha, Abu Qada,Wata, Matulla and Sudr Chalk (El-Deeb and El-Baz, 2002). The latter is further subdivided into a lower Markha Chalk Member and an Upper Abu Zenima Chalk Member as suggested by Ghorab (1961). The following is the characteristics of the examined (Coniancian-Maastrichtian) rock units in Taba area.

1- Matulla Formation

The studied relatively soft slop forming deposits of the Matulla Formation are underlain by the hard fossiliferous cliff forming dolostones and limestones of the Wata Formation and are overlain by hard brown chert bands and white chalky limestones of the Sudr Chalk (Fig.2). The contact with Sudr Chalk is either sharp or with many swellings and load cast structures creating an irregular surface. In the studied section, no definite paleontological boundary between the Matulla Formation and the Wata Formation can be recognized but the boundary is based on the basis of lithological characteristics. The Matulla Formation is composed of green sandstone at the base followed by shales, marls, dolostones and fossiliferous cliff-forming limestones and is topped by phosphatic fossiliferous sandstones and dolostones (Fig. 2). A measured thickness of the Matulla Formation up to 22m thick in Wadi Taba area (Fig. 2) is of Coniacian-Santonian age according to the presence of *Heterotissotia neoceratites* PERON, *Plicatula ferryi* COQUANAD, and *Crassostrea heinzi* (PERON & THOMAS) at Wadi El Ghaib and Sheikh Attia (Kora and Genedi, 1995). The Matulla Formation was assigned tentatively to an Early Senonian age according to the occurrence of the *Discorbis turonicus* assemblage

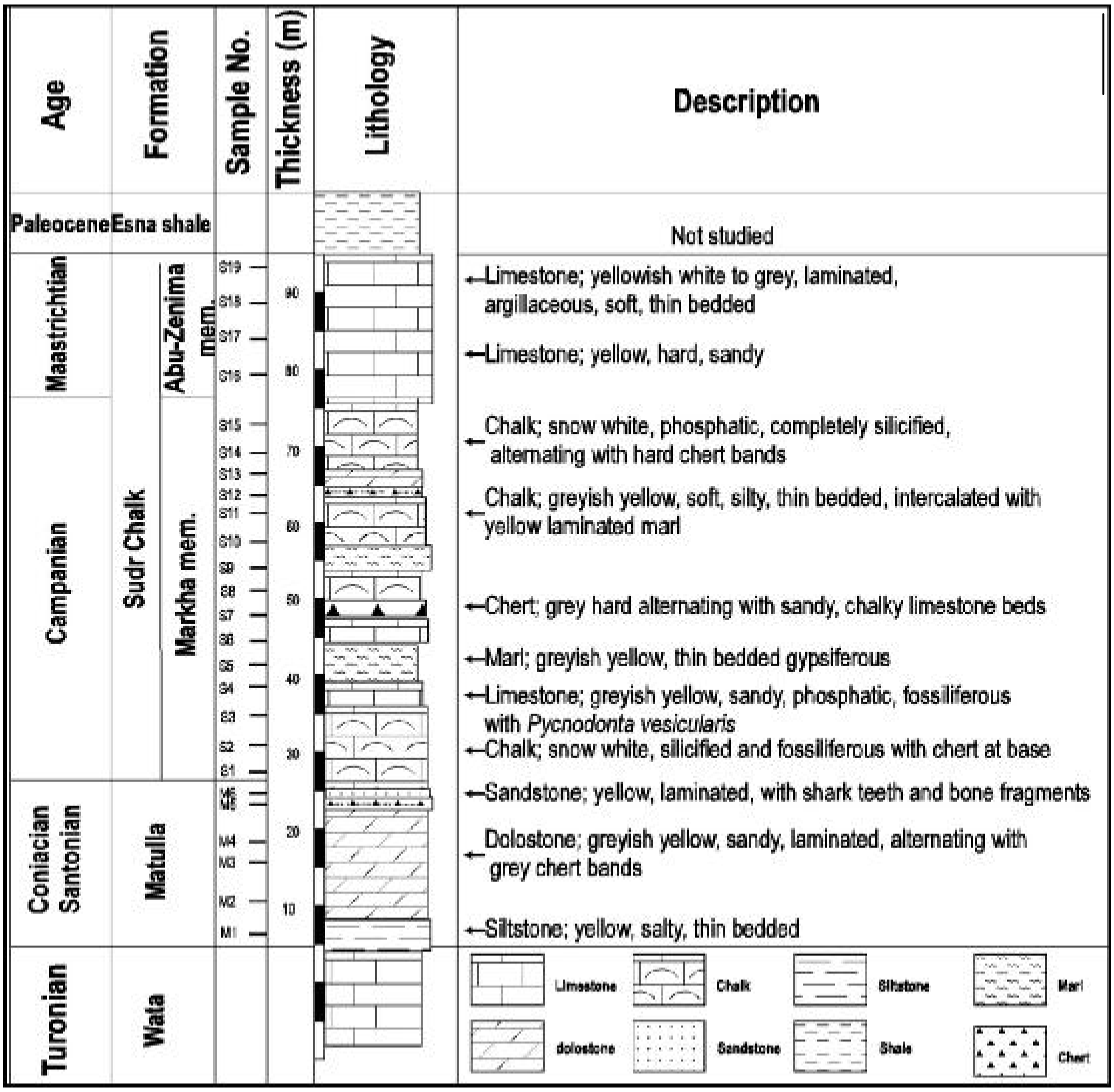

Fig.2. Lithostratigraphic description of the studied Coniacian-Maastrichtian rock units, Wadi Taba area, southeastern Sinai, Egypt.

(Ghorab, 1961; & Shahin and Kora, 1991). Similarly, an undifferentiated Coniacian - Santonian age was given to the Formation according to the presence of echinoids and bivalves including *Plicatula ferri, Pycnodonte costei, Nicaisolopha nicaisei, Oscillopha dishotoma* and *Flemingostrea boucheroni* (Ziko et al., 1993; Eweda and El-Sorogy, 1999; and El-Shazly, 1999). Accordingly, an Coniacian-Santonian age is accepted herein.

The great abundance of dolostones in the Matulla Formation is indicative to the stable sea margin environment (Lewy, 1975). The studied Matulla Formation is equivalent to the Themed Formation as described by Abdel-Gawad and Zalat (1992) and Ziko et al. (1993) from central west and central east Sinai, respectively.

The concentration of chert bands in the Coniacian-Santonian deposits is probably related to the nearness of the Arabo-Nubian Massif rich in silica sources (Flexer, 1968). Also, the close association of chert with dolomites suggests that the condition on a wide shelf fluctuated between normal marine and intertidal regimes (Steinitz, 1977).

2- Sudr Chalk :

The Sudr Chalk conformably overlies the Matulla Formation and is overlain by the Esna Shale of Paleocene age. It is assigned to be of Campanian - Maastrichtian age (Ghorab, 1961; Metwalli et al., 1987; and Eweda, 1992). The contact between the Sudr Chalk and the Matulla Formation in the field is established on the basis of lithological and paleontological grounds. Lithologically, there is a sharp facies change from the clastic facies of the Matulla Formation to the snow white carbonates of the lower member of the Sudr Chalk. This accompanied by the first appearance of large sized *Pycnodonte vesicularis* (LAMARK) at the base of the Chalk.

At Wadi Sudr area in west central Sinai where it denotes to carbonate sequence composed of snow-white chalky limestones at the base and argillaceous limestones at the top; with an estimated total thickness ranging between 110 and 140 m (Kora et al., 2003). The Sudr Chalk is characterized by its snow white colour. It can be subdivided into its two members as suggested by Ghorab (1961) in the study area. The lower Markha Chalk Member (about 50m thick) is composed of snow white partly silicified and partly phosphatic chalk intercalated by grey and brown chert bands, with some marl, dolostone and argillaceous limestone streaks. The Upper Abu Zenima Chalk Member (about 20m thick) consists of grey, argillaceous and thin bedded soft limestones. Its upper limit is marked by lithological variation from the overlying Esna shale. Cherif et al. (1989) mentioned that both members of the Sudr Chalk in the region of Abu Rudeis in west centeral Sinai are very similar and are composed of white chalks. According to Kora and Genedi (1995) & Eweda and El Sorogy (1999) the lower Markha Chalk Member is highly fossiliferous with *Pycnodonte vesicularis* (LAMARCK) which indicates a Companian age. The Abu Zenima Chalk Member is of Maastrichtian age according to the presence of the planktonic foraminifera (Kora and Genedi, 1995), such as *Globotruncana aegyptiaca* NAKKADY and *Gansserina gansseri* (BOLLI).

The Thelmet Formation and the Sudr Chalk described by Abu Khadrah et al. (1987); Kerdany and Cherif (1990); and Refaat (1993) in the western side of the Gulf of Suez are equivalent to the present Markha Chalk Member and Abu Zenima Chalk Member, respectively. Several micropaleontological studies carried out recently utilizing planktonic foraminifera, as well as calcareous nanofossil, biozonation schemes concluded that the Sudr Chalk in Sinai ranges from the Campanian in the lower part to the Maastrichtian in the upper part (e.g. Cherif et al., 1989; and Ayyad et al., 1996). According to Shahin and Kora (1999), the uppermost Maastrichtian biozone was eroded from east central Sinai. Moreover, Abdel-Gawad (1990) described heteromorph ammonites from the upper part of the Sudr Chalk in southern Sinai and assigned them to the upper most Campanian. However, some workers including Kerdany and Cherif (1990) and Issawi et al. (1999) reported that the Sudr Chalk belongs to the Maastrichtian in Sinai and terminates the Cretaceous history in the northeast Egypt.

El-Assy (1992) divided the Sudr Chalk in Sinai into three members and reported that the phosphate rocks of the middle member are of Campanian - Maastrichtian age. El-Sheikh (1995) assigned Late Campanian to Late Maastrichtian age for the Sudr Chalk in Wadi Taba. The lower boundary of the Sudr Chalk is defined either at the lowermost chalky limestone bed or at the high irregular sharp erosional sandy phosphatic chalky limestone bed. Its upper boundary is defined at the base of the lowermost clastic bed or terrigenous limestone bed of the Esna Formation. Generally, the transition between the Sudr Chalk facies and the Esna Formation facies is graditional.

Mineralogical composition:

The data of the relative percentages of the mineral compositions of the examined samples from Taba area are given in Table (1). Three carbonate minerals were identified in the studied samples; namely calcite, dolomite and ankerite. The carbonate minerals in the examined sandstones of the Matulla Formation do not exceed 3%, are authigenic as post depositional minerals.

Dolostones and limestones are the main carbonate rocks of the Matulla Formation and the Sudr Chalk. The mineralogical composition is mainly dominated by calcite with an average value of 5.0% and 50.5%; respectively. It is followed by ankerite with an average values 40.0% and 2.9%; respectively. Ankerite is more enriched(up to 86%) in the rocks of the Matulla Formation (Fig. 3).

Gypsum, anhydrite and halite are the main evaporite minerals encountered in the studied rock units (Fig. 3). The occurrence of these evaporites within the sediments are considered as post depositional phase that mainly reflects the oscillating regressive - transgressive conditions during sedimentation.

Francolite is the main phosphate mineral encountered in a few samples, with maximum concentration associated with the coarse - grained fossiliferous, completely silicified chalk representing the upper most bed of the Markha Chalk Member (Sudr Chalk) with an average value of 5.0%. Also, a considerable amount of the mineral is found within the

Table (1): Mineralogical composition in percent of the studied Coniacian-Maastrichtian rock units, Wadi Taba area, southeastern Sinai, Egypt

Sample No	Age	Rock unit	Gypsum	Anhydrite	Halite	Calcite	Dolomite	Ankerite	Phosphate	Quartz	Feldspars
S19	Campanian – Maastrichtian	Sudr Chalk	----	20.0	-----	78.0	-----	-----	-----	1.0	-----
S18			14.0	-----	-----	85.0	-----	-----	-----	-----	-----
S17			-----	-----	6.0	87.0	-----	-----	-----	6.0	-----
S16			-----	-----	-----	93.0	-----	1.0	-----	3.0	1.0
S15			10.0	-----	-----	12.0	-----	-----	15.0	59.0	-----
S14			-----	-----	3.5	22.0	-----	-----	-----	70.0	-----
S13			-----	-----	-----	11.0	-----	-----	-----	85.0	-----
S12			-----	-----	10.0	32.0	-----	-----	3.0	49.0	-----
S11			-----	-----	30.0	25.0	-----	-----	1.0	34.0	6.0
S10			-----	-----	-----	73.0	2.0	-----	2.0	20.0	-----
S9			-----	-----	-----	93.0	-----	-----	-----	6.0	-----
S8			-----	-----	-----	4.0	-----	-----	-----	93.0	-----
S7			-----	-----	-----	91.0	3.0	-----	1.0	5.0	-----
S6			-----	-----	8.0	65.0	-----	12.0	-----	13.0	-----
S5			-----	17.0	-----	42.0	-----	34.0	-----	7.0	-----
S4			20.0	-----	-----	56.0	-----	9.0	7.0	8.0	2.0
S3			28.0	-----	-----	-----	-----	-----	64.0	-----	-----
S2			15.0	-----	-----	-----	-----	-----	-----	75.0	4.0
S1			-----	-----	-----	92.0	-----	-----	-----	7.0	-----
Average			4.5	2.0	3.0	50.5	0.3	2.9	5.0	28.5	0.7
M6	Caniacian Santonian	Matulla Formation	10.0	22.0	-----	-----	-----	-----	-----	66.0	1.0
M5			-----	-----	-----	2.0	-----	----	9.0	86.0	1.0
M4			-----	-----	-----	3.0	-----	87.0	-----	8.0	2.0
M3			-----	-----	-----	13.0	-----	60.0	-----	26.0	1.0
M2			-----	-----	-----	8.0	-----	68.0	-----	21.0	1.0
M1			-----	-----	5.0	5.0	-----	27.0	-----	62.0	1.0
Average			1.7	3.7	0.8	5.2	-	40.3	1.5	44.8	1.2

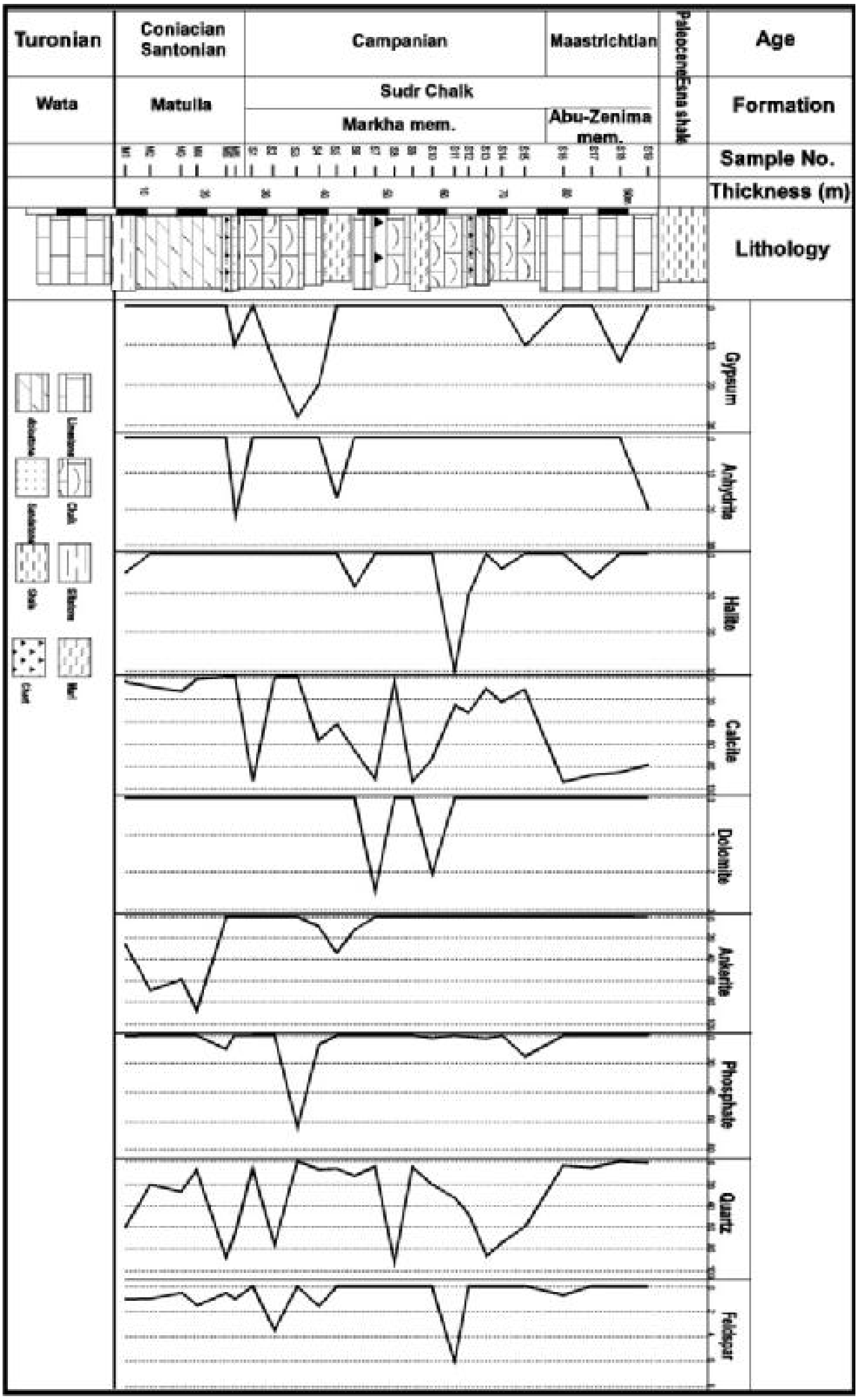

Fig.3. Vertical distribution of the bulk minerals in the studied Coniacian-Maastrichtian rock units, Wadi Taba area, southeastern Sinai, Egypt.

upper phosphatic sandstone bed of the Matulla Formation (9.0%).

Quartz is the most frequent constituent in the studied section (up to 92.5%) where its percentage is directly proportional to the sand content. Feldspars are recorded in minor amounts in the studied section. The highest feldspar content (6%) is recorded from the middle part of Sudr Chalk (Fig. 3).

The clay minerals composition of the Matulla Formation and Sudr Chalk are shown in Fig (4). The identified clay minerals of these formations consist mainly of smectite, chlorite and mixed layer minerals with illite, Kaolinite

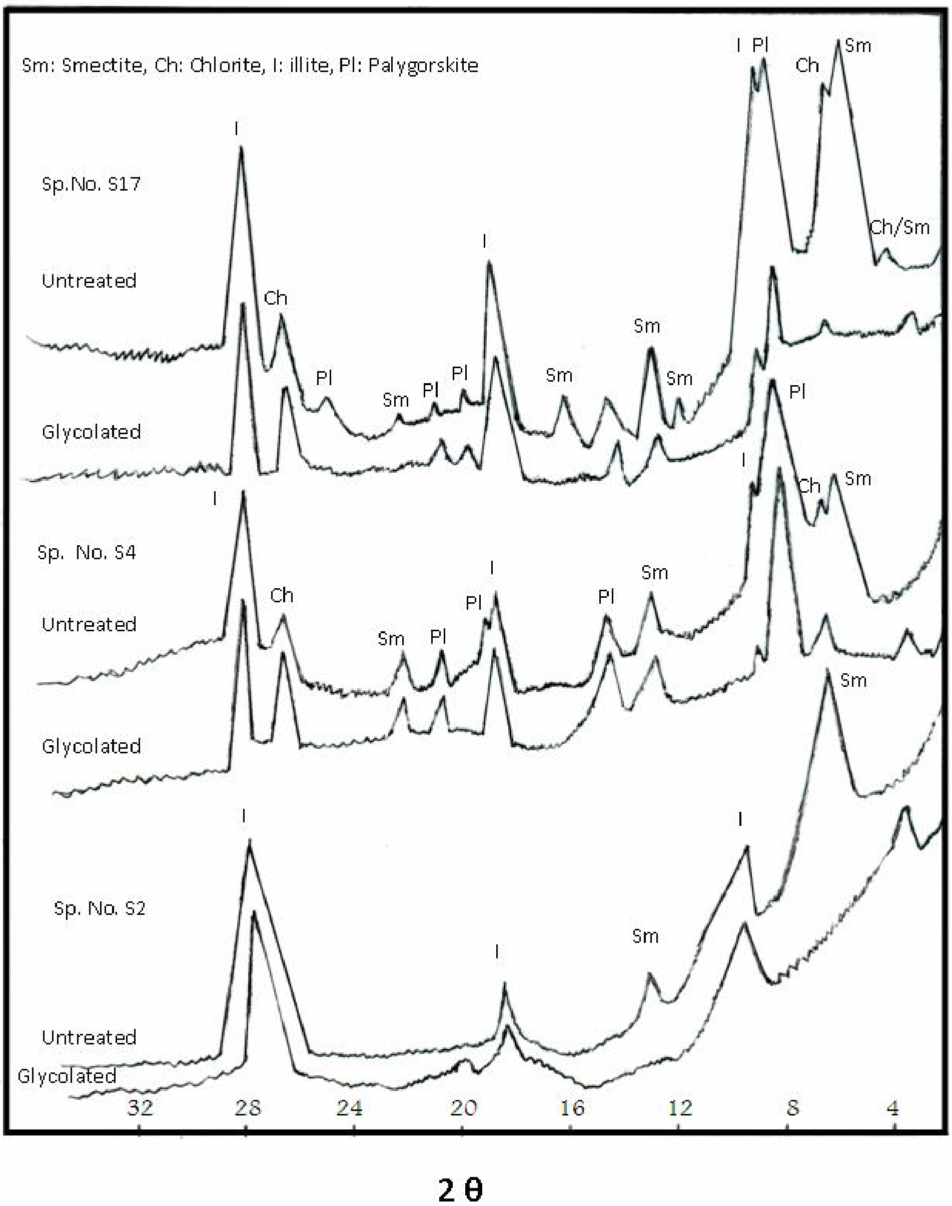

Fig.4 : Representative X- ray diffractograms of clay minerals from the studied samples

and palygorskite. The occurrence of clay minerals is generally controlled by the source materials, environments of deposition and deep burial digenesis (Millot, 1970). The relative frequency distribution of kaolinite in the samples of the Matulla Formation is 2.7%. It is rarely encountered in the sediments of the Sudr Chalk. Thus it may be concluded that the sediments of the Matulla Formation was possibly deposited in a shallow subtidal to intertidal conditions, while those of the Sudr Chalk was formed in slightly deep marine conditions.

Smectite is detected in most of the studied samples with a very local concentration in phosphatic sandstone. The higher content of smectite is recorded in the phosphatic marl, shale and sandstone beds compared to the carbonate horizones. The sedimentation of smectite may have caused a significant drop of the Mg content in the marine water which favoured the deposition of phosphates (Eslinger and Sellars, 1981). This may indicate that most smectites in the studied samples are authigenic in origin and especially present in an environment with low hydrodynamics.

Illite is concentrated in the sediments of the Sudr Chalk in camparison with that of the Matulla Formation. It is authigenic in origin as it crystallized from smectite in k^+-rich transitional marine area of intertidal facies. Whitney (1990), stated that K^+ is increased with subsequent evaporation leading to the conversion of smectite to illite in intertidal facies. Chlorite is concentrated in argillaceous carbonate rocks of the Sudr Chalk. It originates diagenetically from smectite (Ghetti and Brigatti, 1991).

The mixed layer chlorite / smectite are recorded in the clay fraction of most samples in the studied Formations and enriched in the carbonate beds. They are authigenic in origin formed by the reaction of the associated illite and smectite with Mg_2^{+-} rich fluids and from the reaction of smectite with concentrated kaolinite of k-feldspars .

Palygorskite is recorded in the studied formations (Fig. 5) and it is less common in the lower limestone beds than the upper beds of the Sudr Chalk. The palygorskite is authigenic in origin, formed according to the Mg, Si and Al activities in the liquor. It occurs in near shore platform facies associated with some shell fragments and precipitates as

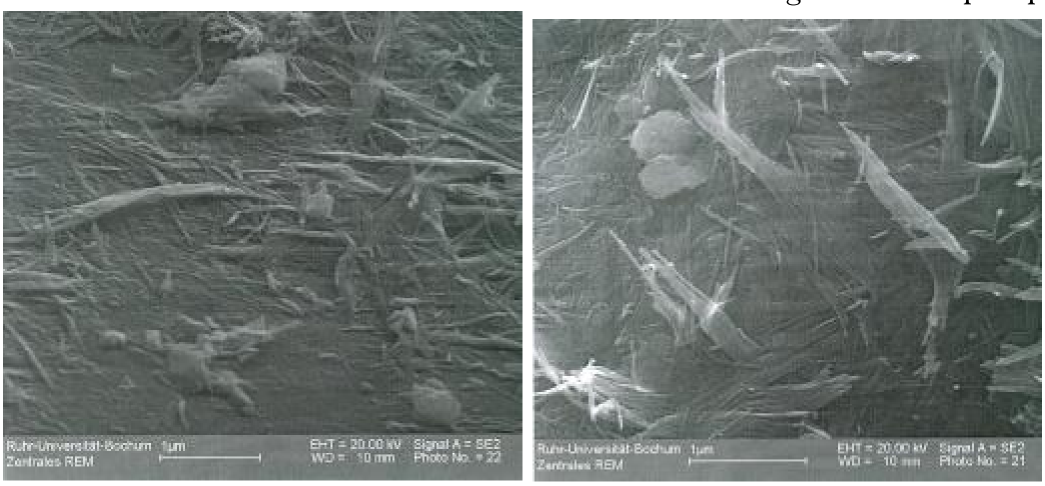

Fig.5. SEM micrograph of palygorskite in limestone bed (S.N.S17), Sudr Chalk, Wadi Taba area, southeastern Sinai, Egypt.

crystals in shallow basin during anoxic periods (Deconinck and Accarie, 1990). It is associated with and altered to dolomite (Zili et al. 1990). An oscillanting wet and dry periods of water table with transformation mechanism from pre- existing clay minerals in Mg-rich solutions is refered to as an origin of this mineral.

Geochemistry

The results of the chemical analysis of both major and trace element constituents in the studied carbonate lithofacies, marls, chert and sandstones are given in Table (2) and the mutual distribution of some elements in the studied carbonates at Taba area is illustrated in Figs (6 & 7).

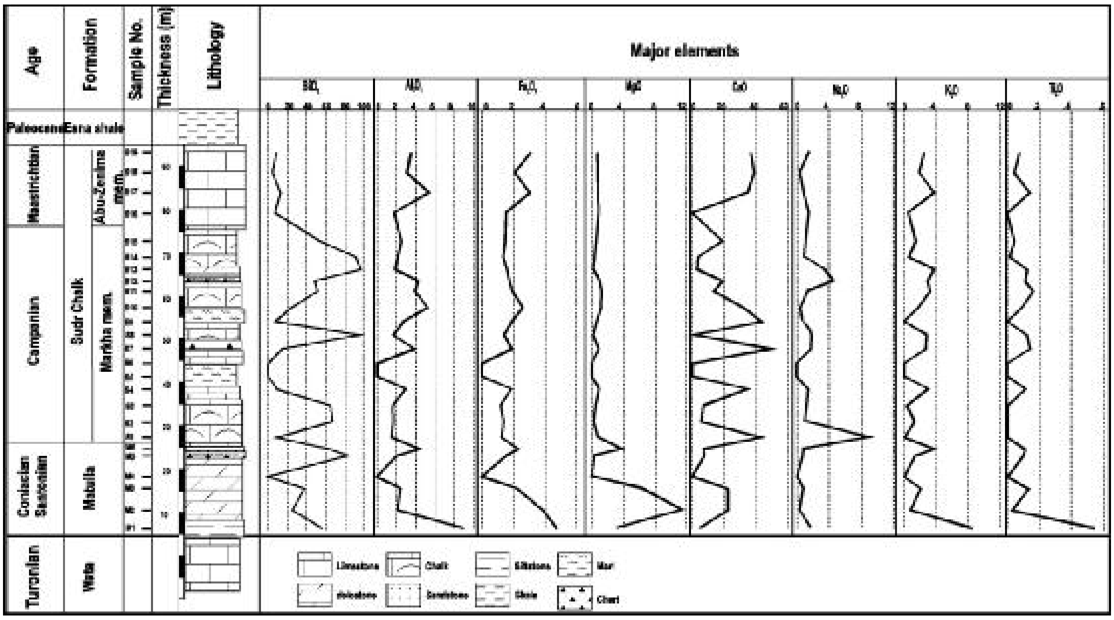

Fig.6. Vertical distribution of major oxides encountered in the studied Coniacian-Maastrichtian rock units, Wadi Taba area, southeastern Sinai, Egypt.

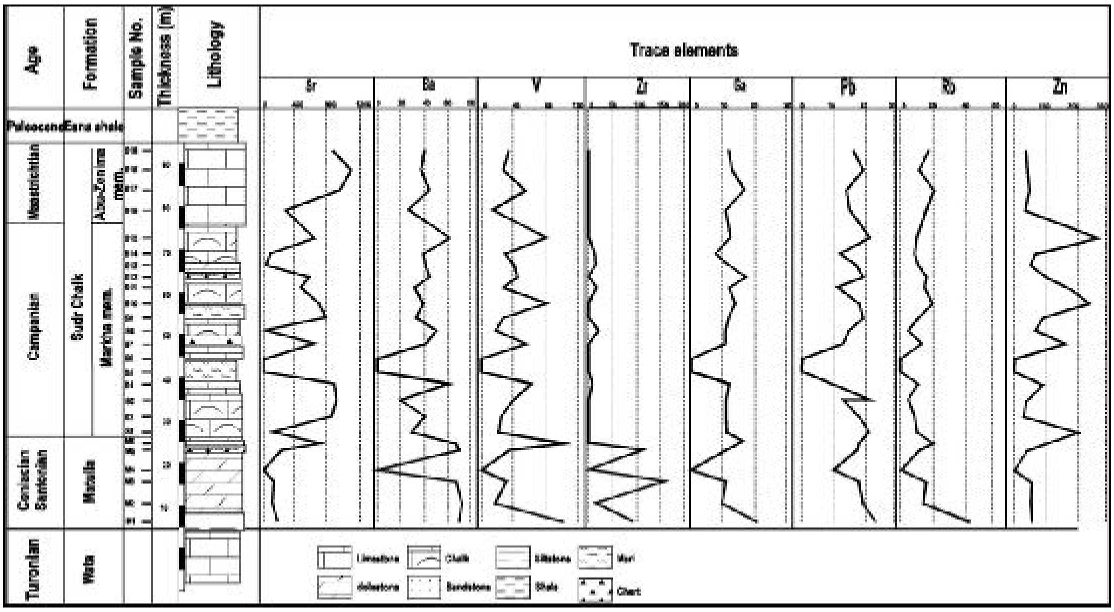

Fig.7. Vertical distribution of the trace elements encountered in the studied Coniacian-Maastrichtian rock units, Wadi Taba area, southeastern Sinai, Egypt

Table (2): Chemical composition of the studied Coniacian-Maastrichtian rock units, Wadi Taba area, southeastern Sinai, Egypt

Rock units	Sp.n	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	Sr	Ba	V	Zn	Ga	Pb	Rb	Zr	$\delta^{18}O$	$\delta^{13}C$
Sudr Chalk	S19	8.00	3.98	3.07	0.78	37.16	1.50	0.24	0.07	874	40	37	36	12	16	18	-	-	-
	S18	5.02	2.87	2.10	0.87	38.81	0.44	0.19	0.04	1100	37	29	39	13	19	12	-	-4.82	.62
	S17	12.60	5.35	2.99	0.90	34.45	0.81	0.37	.0.14	971	44	57	47	17	14	21	-	-1.18	1.88
	S16	7.37	1.52	1.57	0.81	0.46	1.31	0.05	-	299	27	15	32	11	15	16	-	-2.61	.91
	S15	53.43	2.39	1.44	0.58	18.59	1.14	0.13	0.03	651	61	82	261	12	21	10	-	-4.05	.12
	S14	89.39	2.21	1.32	0.43	3.61	0.88	0.06	0.01	109	39	31	72	8	12	9	13	-4.10	.16
	S13	96.29	1.91	1.45	0.20	2.99	3.09	0.36	0.12	53	41	43	51	12	17	11	14	.62	2.18
	S12	47.97	4.31	1.71	0.93	19.02	4.54	0.30	0.11	571	45	47	99	17	19	16		-3.62	.16
	S11	50.37	3.90	1.94	1.30	13.91	1.30	0.32	0.16	481	32	29	170	12	11	15	16	-	-
	S10	24.33	5.20	2.60	1.16	32.02	0.36	0.17	0.08	712	39	81	231	14	18	20	-	-1.12	1.18
	S9	7.49	2.96	1.91	0.67	43.11	0.67	0.02	0.00	790	33	30	88	12	19	11	-	-2.16	.32
	S8	97.21	1.77	1.39	0.26	1.30	1.73	0.28	0.12	41	50	19	62	11	15	5	21	-.13	1.62
	S7	14.46	3.85	1.90	0.91	50.20	1.73	0.27	0.14	661	41	59	160	11	13	13	-	-4.01	-.66
	S4	9.33	2.99	1.86	1.00	34.33	1.46	0.29	0.11	901	60	63	89	12	21	11	7	.00	-
	S3	64.92	1.69	1.29	0.46	6.91	0.82	0.03	-	933	19	42	37	11	13	5	-	-3.18	-1.01
	S2	66.52	1.66	1.31	0.28	5.99	9.11	0.13	-	861	40	26	29	11	18	9	-	-	-
	S1	9.19	1.48	1.21	0.71	42.83	0.81	-	-	144	29	22	197	11	21	11	-	.00	-
Average		39.5	2.9	1.83	0.72	22.62	1.86	0.18	0.06	597	40	42	100	12	16	12	4	-2.33	0.58
Matulla Formation	M6	64.02	4.28	2.24	3.54	7.18	0.50	0.36	0.11	721	66	103	97	16	18	20	-	.82	-1.62
	M5	83.87	2.03	1.53	0.29	6.12	0.53	0.12	0.08	249	69	37	37	11	17	11	113	-	-
	M3	37.92	2.30	2.15	6.17	22.09	0.79	0.20	0.13	149	67	33	52	11	18	16	157	-.64	1.26
	M2	25.34	2.06	3.80	11.31	22.13	0.28	0.08	0.03	139	71	19	51	10	19	14	15	-1.82	2.08
	M1	56.09	8.97	4.68	3.23	5.04	1.62	0.86	0.55	192	69	103	54	21	23	43	93	1.62	1.43
average		53.45	3.93	2.88	4.9	12.5	0.74	0.32	0.18	290	68	59	58	14	19	21	75	-0.02	0.88

1- Major oxides:

SiO_2, Fe_2O_3, Al_2O_3 and TiO_2

Most of the chemical results of sandstones indicate that SiO_2 is related antipathetically with the clay mineral content. In the present study the results of the major oxides indicate that the high values of SiO_2 (53.45%) in the Matulla Formation probably refers to the presence of more detrital sands and argillaceous material in the Sudr Chalk. Silica is so far, the most dominant in all rocks studied. The average content of silica in the Matulla Formation (53.45%) and the Sudr Chalk (39.05%) are lower than the average crustal composition (61.5%) of Wedepohl (1995). The average content of Al_2O_3% is relatively high (3.93% and 2.9%); respectively in the Matulla Formation and the Sudr Chalk, while the averages of Fe_2O_3% are 2.88% and 1.83%; respectively. The distribution of Al_2O_3 content is consistent with Fe_2O_3, indicating their origin from argillaceous material. The relative high amount of the detected iron suggests weathering and oxidation of sulphides precursor which were probably embedded in argillaceous material. From the vertical distribution (Fig. 6), there is concomitant similar behaviour for both Al and Fe indicating that the bulk of iron is detrital and is brought to the basin of deposition in association with terrigenous material. The deposition of Fe_2O_3 in marine environment requires a lower Eh and pH values (Magaritz and Berner, 1979).

TiO_2 and Al_2O_3 are generally ranked among the more immobile elements during weathering and diagenesis (Nesbitt and Wilson, 1992). According to Young and Nesbitt (1998), Al and Ti hydroxides are in soluble under pH ranges of 4-10 and 2-14; respectively. So that under most environmental conditions Al^{3+} and Ti^{4+} in solution would precipitate as hydroxides or oxides or would be incorporated in clay minerals. Ti is closely related to Al, (Fig. 8) as indicated by high positive correlation (0.82; Table 3). This suggests that Ti associated in clay fraction. Emelyanov and Shimkuss (1986) suggest that the distribution of Ti shows as maximum corresponding to the fine silty muds (0.001- 0.01 mm fraction). The increase of Ti/Al in some samples of the studied rock units can be interpreted to the presence of detrital Ti-bearing minerals such as ilmenite or rutile. Mohamed et al. (1986) and El-Sherbini and Genedi (1989) observed that when the clay and other silicate minerals increase, TiO_2 becomes exceedingly high and is observed on the clay minerals.

Na_2O and K_2O

Sodium content in the studied sediments exceeds potassium (Table.2). The average Na_2O contents in the sediments of the Matulla Formation (0.74%) are lower than that of the Sudr Chalk (1.86%). It is suggested that the original sediments were so Na_2O- rich, being derived almost exclusively from soda-rich source rocks, while contemporaneously the finer materials, products of decomposition, being Na_2O poor due to normal leaching during weathering. El-Kammar et al. (1988) attributed the high Na_2O content for the limestone of the lower part of the Thebes Formation to the presence of halite superficial encrustation which is probably derived by capillary action from underlying the Esna Shale and precipitated at the weathering zone. The high K_2O and Al_2O_3 contents, and thus high positive (r=0.84;

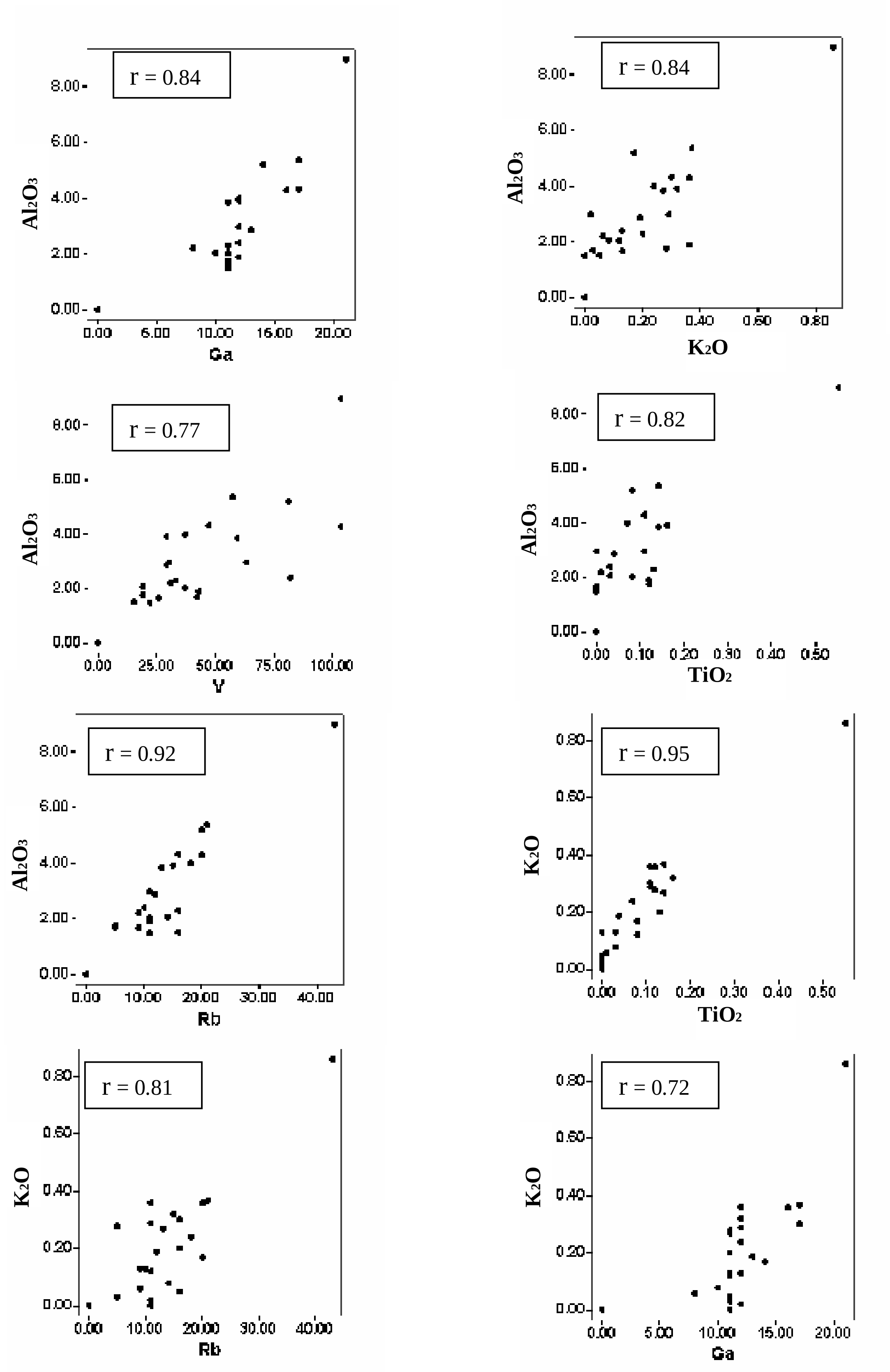

Fig. 8. Variation diagrams showing the relations between some major and trace elements in the studied Coniacian-Maastrichtian rock units, Wadi Taba area, southeastern Sinai, Egypt.

Table (3) Correlation coefficient matrix of major oxides and trace elements for the studied rocks in Taba area

	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	Sr	Ba	V	Zn	Ga	Pb	Rb	Zr
SiO_2	1.0	0.04	-0.20	-0.06	-0.57	0.33	0.27	0.21	-0.26	0.39	0.22	-0.01	0.24	0.20	0.02	0.28
Al_2O_3		1.0	0.13	0.15	0.28	0.02	0.84	0.82	0.33	0.49	0.78	0.26	0.84	0.50	0.92	0.2
Fe_2O_3			1.0	-0.05	0.24	0.01	0.06	-0.02	0.23	0.02	-0.03	-0.14	0.04	0.02	0.13	0.30
MgO				1.0	0.07	-0.19	0.12	0.18	-0.19	0.55	0.08	-0.06	0.16	0.29	0.32	0.35
CaO					1.0	-0.15	-0.03	-0.06	0.54	0.12	0.17	0.43	0.28	0.38	0.16	-0.17
Na_2O						1.0	0.15	0.02	0.19	0.07	-0.01	-0.09	0.21	0.24	0.02	-0.11
K_2O							1.0	0.95	0.07	0.51	0.67	0.03	0.72	0.39	0.81	0.31
TiO_2								1.0	-0.1	0.47	0.6	0.03	0.62	0.32	0.82	0.47
Sr									1.00	0.07	0.38	0.17	0.44	0.34	0.15	-0.36
Ba										1.0	0.59	0.2	0.65	0.76	0.56	0.52
V											1.0	0.47	0.74	0.56	0.69	0.1
Zn												1.0	0.29	0.38	0.15	-0.21
Ga													1.0	0.80	0.82	0.17
Pb														1.0	0.57	0.21
Rb															1.0	0.36
Zr																1.0

Fig.8) may suggest more illitic compositional clays.

The K_2O average contents in the studied rocks of the Matulla Formation (Table.2) are higher than those of the Sudr Chalk, and the K_2O average contents are much lower compared with the value 2.45% reported by Wedepohl (1978). The obtained positive correlation (Table.3 and Fig.8) between K_2O and Al_2O_3 and TiO_2 (r=0.84 and 0.95; respectively) explains the fact that k is mainly present in the clay fraction in carbonate rocks.

CaO and MgO

In the Matulla Formation the CaO content ranges from 5.04% to 7.18%, with an average of 12.5%. In contrary CaO content in the Sudr Chalk (0.46% to 38.81%) shows higher average (22.68%), reflecting the presence of limestone. In the studied carbonates of the Sudr Chalk MgO does not show great variations in the studied rocks (Table. 2).

The MgO released by the breakdown of high - Mg - calcite makes a significant contribution of Mg to dolomitization ground waters. The studied MgO and CaO averages are much lower than those reported by Turekian and Wedepohl (1961) and Wedepohl (1978). It worth to mention that the high average MgO content in limestones is partly related to the high contents of palygorskite clay mineral present. This reflects that the presence of such clay mineral depends on the more diagenetic environment.

2- Trace elements :

The distribution of trace elements in the studied rocks is largely determined by the mineral composition of the detrital fraction of the parent rocks and the physicochemical conditions prevailing during transportation and deposition. The variation of the trace elements with respect to lithology and the concentrations of Sr, Ba, V, Zn , Ga, Pb, Rb and Zr (ppm) in the samples are illustrated in Table (2). The vertical distribution (Fig.6) indicates that the enrichment of Sr element up to 1100 ppm is located at phosphatic limestone bed in the Sudr Chalk. Sr enters the basin of deposition largely combined mainly with calcite. This fact is further supported by the positive correlation (Table.3) between Sr and CaO in the studied carbonate rocks (r=0.54). Comparing the Sr contents with their average value in carbonates given by Turkian and Wedepohl (1961), the studied carbonates of the Sudr Chalk is relatively similar. The studied Upper Cretaceous carbonates are lower in Sr content relative to the recent carbonates (2800 ppm of Land Hopps, 1973). This is due to the stabilization of the carbonate minerals during diagenetic process.

The average contents of Ba in the studied carbonates are (68 ppm and 40 ppm) in the Matulla Formation and the Sudr Chalk; respectively (Table. 2). The average of Ba contents are much lower compared with that of Bellanca et al.(1999) in carbonate (147 ppm). It is know that Ba enrichment in sedimentary deposits can be considered as indicators of high flux of biogenic material to the sediments and therefore of high surface - water productivity (Van Os et al, 1994). Also it is strongly adsorped with clay minerals, reflecting positive correlation with Al_2O_3 MgO and K_2O (r=0.49, 0.55 and 0.51; respectively, Table 3). The enrichment of barium in the Sudr Chalk and Esna Shale formations may be related to high biological productivity in the surface water of the open marine environment (Kora and Genedi, 1995).

Vanadium concentration ranges from 22 ppm to 82 ppm with an average 42 ppm in the Sudr Chalk (Table.2). The vanadium content of the examined limestone is much higher than the corresponding V Value for the average limestone reported by Wedepohl (1978). This may related to the clay content, which reflecting positive correlation with Al_2O_3 (r=0.78) and K_2O (r=0.67) as in table (3).

The contents of Zn and Pb in the studied sediments are relatively high in comparison with carbonate values given by Wedepohl (1978). Pb content varies from 13 ppm to 23 ppm with an average values (19 ppm and 16 ppm) in the Matulla Formation and the Sudr Chalk; respectively, while Zn content is also present in relatively high concentration in comparison (58ppm and 100ppm respectively) with the data given by Wedepohl (1978). The increase in Pb reveals that the studied carbonates were probably deposited under alkaline reducing conditions (Krauskopf 1979). Most of Pb and Zn could be attributed to the presence of clay minerals on which they can be adsorbed. The high content of these elements correlates with Al_2O_3 in most of the studied sediments, which reflecting positive correlation with Al_2O_3 (r=0.5 and r= 0.26; respectively (Table.3). This suggests that the clay minerals represent the main host of Pb and Zn which are inherited from the land. Gallium and Rubidium do not vary greatly in the studied rock units, where the average Ga contents are 14 ppm and 12 ppm in the Matulla Formation and the Sudr Chalk respectively; (Table. 2) The average Rb contents in the examined carbonates are 21 ppm and 12 ppm. The obtained Ga contents are higher than that reported by Wedepohl (1978), while the average Rb value in the studied carbonates are very lower than the average value 79 ppm reported by Wedepohl (1978). The high positive correlation between Ga and Rb with Al_2O_3 in the examined sediments (Table.3 and Fig.8; r=0.84 and 0.92), reflects that the clay minerals represent the main host of Rb and Ga. Similarly the correlations between Ga and Rb with K_2O in the examined sediments (Table. 3 and Fig. 8) are highly significant (r=0.72 and 0.81; respectively). This suggests that the main bulk of Ga and Rb is associated with k- bearing minerals.

The average value for the Zr for the studied carbonates in the Sudr Chalk is much lower than the content (80 ppm) proposed by Wedepohl (1978), while in the Matulla Formation, the average value reachs about (75 ppm). The high Zr content (0.75 ppm) in the investigated sandstones of the Matulla Formation reflects the high Zr source of these sediments.

3- Isotopic composition

The paleoenvironmental conditions of the Upper Cretaceous sediments are evaluated by using the obtained stable isotopic composition. Many authors have investigated the application of stable carbon and oxygen isotopes to the determination of paleosalinity as Anderson and Arthur (1983) Further, isotopic data provide information on the mixing of marine and fresh waters. This is possible because values of both $\delta^{18}O$ and $\delta^{13}C$ are lower in lake and river water than in the ocean.

Generally, the samples with $\delta^{13}C$ and $\delta^{18}O$ values heavier than - 2 % and -5%; respectively are of marine origin (Keith and Weber, 1964). The bulk $\delta^{18}O$ values show a wide range of low negative values (Table.2 and Fig .9), which shows substantial variability of the studied section from + 1.62 ‰ to 4.82%. The positive values are generally recorded in the siltstone where an negative values are recorded in the dolostone samples of the Matulla Formation. The Sudr Chalk samples have more negative $\delta^{18}O$ values. The average $\delta^{18}O$ in the studied rock units is strikingly shifted towards lighter values averaging - 0.02 and -2.33 for the Matulla Formation and the Sudr Chalk; respectively (Table.2). This suggests that diagenetic controlling phenomena may have played a dominant role in changing the original oxygen isotopic composition of the analysed marine deposits. Keith and Weber (1964) gave the following discriminant equation to differentiate between marine and fresh water carbonates.

$$Z= 2.048 (\delta^{13}C+50) + 0.498 (\delta^{18}O+50)$$

If Z (the fractionation factor) is above 120, the carbonate rocks are classified as marine and if it is below 120, it is classified as fresh water carbonates. All calculated Z values of the studied samples are above 120 which means that the samples in concern were mainly deposited in marine water environment.

It is observed from the scatter diagram (Fig.10), that there is no proper correlation between $\delta^{18}O$ and $\delta^{13}C$ in most of the analysed samples. This could be attributed to the fact that during recrystallization, the $\delta^{18}O$ changes towards the lighter values, while the $\delta^{13}C$ retains its original value more easily (Lëtolle, 1979). In contrast to these light $\delta^{18}O$ data, three heavier values are recorded in the studied rock units. This figure show that nearly all samples are found in the field located between the field (1) of Israeli Upper Cretaceous limestone (Bogoch et al, 1994) and that of the Recent hypersaline dolomites (field 3) of Taxas (Behrens and Land, 1972). Also these plotted samples coincide with the base of the field (2) of the Mediterranian Upper Cretaceous pelagic limestone (Scholle and Arthur, 1980) and Israeli Dolostone (Bogoch etal., 1994). The $\delta^{18}O$ values of the dolostone samples of Matulla Formation are shifted on the plot towards the recent hypersaline zone (field 3). This may be attributed to the evaporation in shallow marine conditions and /or post depositional evaporate content.

Many workers have shown that $\delta^{18}O$ is concentrated in Mg - calcite relative to pure calcite. Therefore, the heavier values may be attributed in part to dolomitization and mainly to a higher salinity, because during the evaporation, $\delta^{18}O$ is preferential concentrated in the vapour phase (Hoefs, 1980). The low values of $\delta^{18}O$ suggest that the primary signals have been diagenetically altered by more $\delta^{18}O$ depleted meteoric ground water or by dissolution and recrystallization at higher temperature during burial diagenesis (Sakai & Kano, 2001). The encountered positive $\delta^{18}O$ values in the Matulla Formation may be attributed to dry climate intervals with some evaporation process.

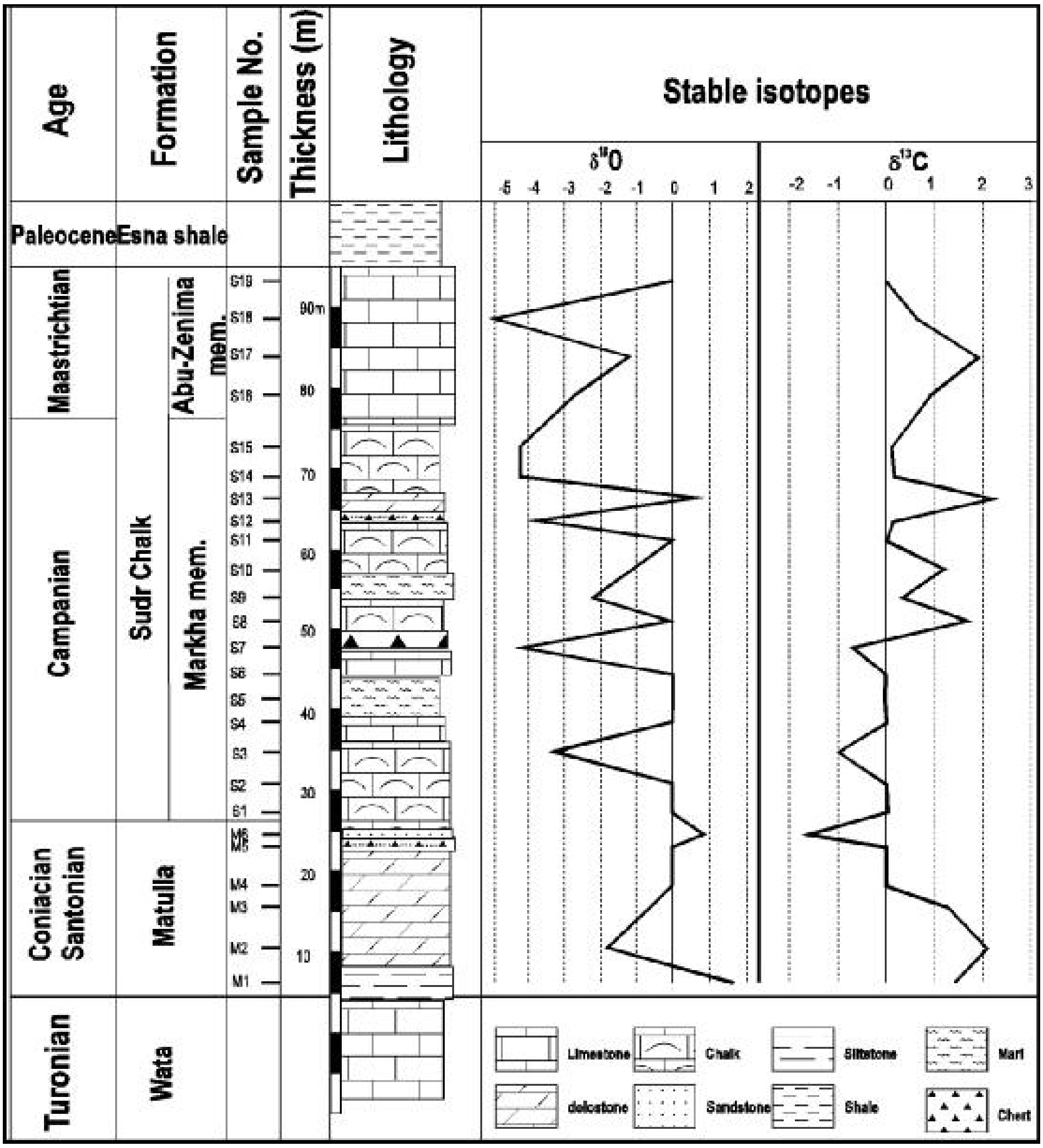

Fig.9. Vertical distribution of the stable isotopes ($\delta^{18}O$ and $\delta^{13}C$) encountered in the studied Coniacian-Maastrichtian rock units, Wadi Taba area, southeastern Sinai, Egypt

The nearly constant $\delta^{18}O$ values in the Sudr Chalk sediments are fluctuate around the normal marine limits. The high negative values of $\delta^{18}O$ followed by another positive excursion crossing the Cenomanian / Turanian boundary of order 6.32% ranges from 4.2% to +2.12% reflect dry periods with marine incursions at times of rising sea level (Genedi, 2005). El-Hinnawi et al. (1990) indicated that with increase in diagenesis $\delta^{18}O$ becomes more negative. The more negative $\delta^{18}O$ values are the higher temperature during deposition. It is found that the depletion in $\delta^{18}O$ with a mean of -0.02 and -2.33% PDB for the studied rock units may have resulted from dolomitization diagenetic process with the cooperation of fresh water as meteoric water diagenesis (Genedi 2005). Moreover the open marine conditions of deposition together with the presence of lower oxygen isotopic values (-3.5 to - 4.1 $\delta^{18}O$% PDB) are good indicator that the dolomites were formed by early replacement of marine carbonates in a meteoric marine diagenetic setting (Holail et al., 1997).

The measured $\delta^{13}C$ values grade from the heavier values (2.18%) in the Campanian-Maastrichtian to the lighter ones (-1.62%) in the Coniacian-Santanion (Fig.10). Clearly, these values exhibit only small variability in $\delta^{13}C$ around the normal marine salinity values. However, heavier $\delta^{13}C$ values are recorded in some samples analysed from the Matulla Formation and the Sudr Chalk (Fig.10). Here, the more positive values of $\delta^{13}C$ encountered could be attributed to high productivity and the increase of photosynthetic effects in a shallow marine environment, which preferentially removed the $\delta^{13}C$ from the water as postulated by Duplessy (1972). Such higher $\delta^{13}C$ values in the Abu Qada Formation were detected in Gabal Nezzazat (Shahin, 1991) as a result of the presence of organic carbon. The $\delta^{13}C$ depletion of the Pleistocene limestones has been emphasized by Allen and Mathews (1982) with increasing diagenesis. The post depositional exchange between the original carbonates and the higher $\delta^{18}O$ and $\delta^{13}C$ derived from the fresh ground water is a main factor in lowering the $\delta^{18}O$ values in most of the succession. Diagenetic alteration can take place during burial, and the increased temperatures associated with this burial also cause a lowering of $\delta^{18}O$.

CONCLUSION

1- The studied Upper Cretaceous rock units at Wadi Taba including Coniacian - Santonian Mataulla Formation followed by Compainan - Maatrichtian Sudr Chalk. The Matulla Formation overlies the hard cliff forming carbonates of the Wata Formation and conformably underlies the snow white Sudr Chalk. The later includes sequences of lower Markha Chalk Member and Upper Abu Zenima Member. It is overlain by the Esna Shale of Paleocene age.

2- The Coniacian - Santonian rocks of the Matulla Formation indicating the depositional environments of shallow subtidal to intertidal conditions. This is well indicated by the presence of shark teeth, oysters and ammonites. During most of the Campanian - Maastrichtian age marly and chalky limestones of the Sudr Chalk represent a gradual rising of the sea level, where the sedimentation was dominated by open - marine conditions. These

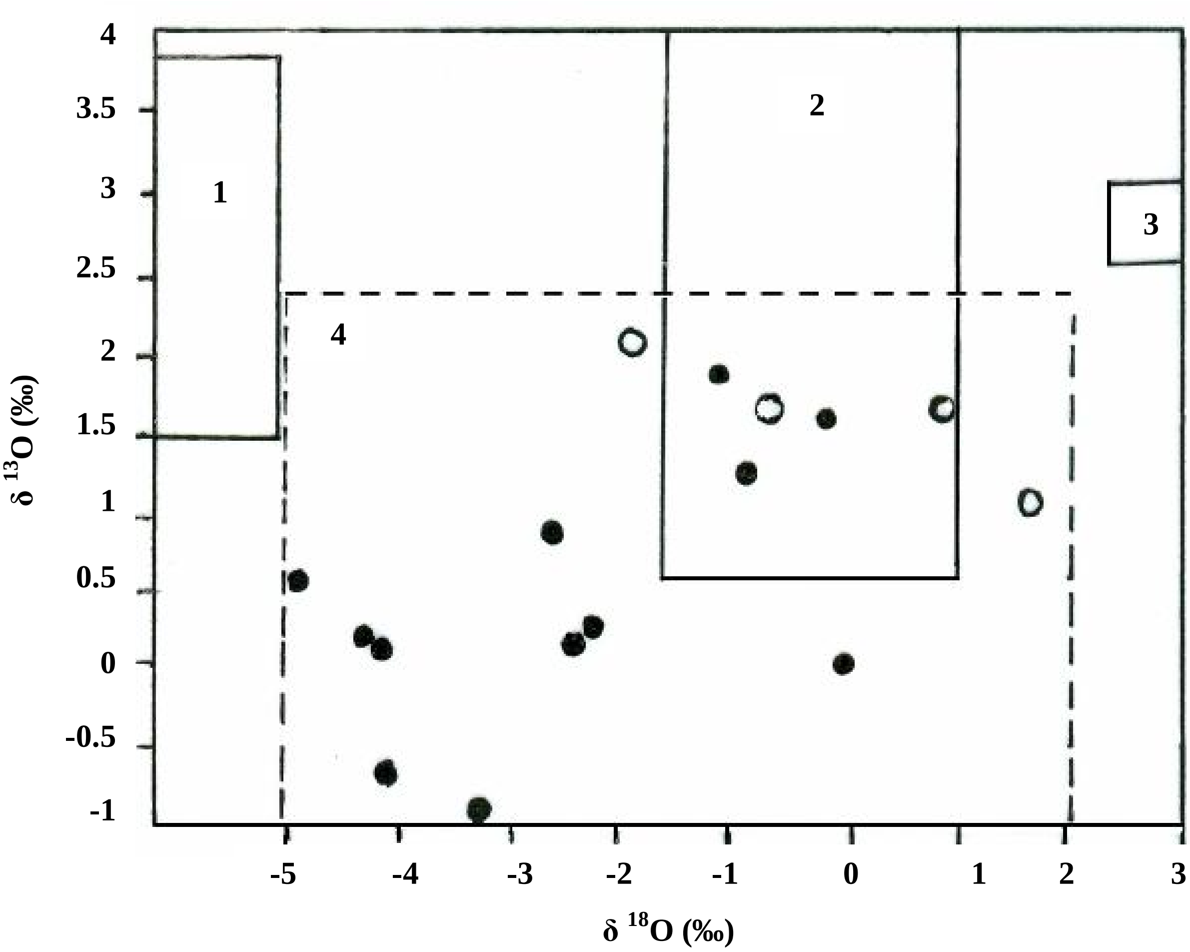

Fig.10: Cross plot of carbon versus Oxygen stable isotope composition of the studied Coniacian-Maastrichtian rock units of Taba area, southeastern Sinai, Egypt.

-solid circles = rock units of Sudr Formation
- white circles = rock units of Matulla Formation
1- Filed of Turonian limestone from Israel (Bogoch *et al.*, 1994)
2-Field of Cenomanin Mediterranean Pelagic limestones (Scholle and Arthur, 1980) and dolostone from Israel(Bogoch et al., 1994)
3- Filed of Recent hypersaline (Behrens and Land, 1972)
4- Field of the studied samples

open marine conditions of the Sudr Chalk are represented by oyster banks.

3- The mineralogical composition of the studied rock units is mainly calcite followed by ankerite and dolomite, while gypsum, anhydrite and halite are the main post-depositional evaporite minerals.

4- The clay minerals show concentration of illite, chlorite, smectite and palygorskite in the Sudr Chalk. Kaolinite is rarely encountered in the Sudr Chalk than the Matulla Formation. The clay minerals identified suggest deposition in conditions that oscillated from near shore deposits to slightly deep marine conditions.

5- The Matulla Formation is characterized by its higher contents of SiO_2, Al_2O_3, Fe_2O_3, MgO, K_2O, Zr, V and Ba and by its lower contents of CaO, Na_2O , Zn and Sr compared to the overlying Sudr Chalk. The high positive correlation between some of trace elements and Al_2O_3, K_2O and MgO, may be related to the clay minerals which are inherited from the land, and reflects variation in their depositional origin.

6- The heavier vales of $\delta^{18}O$ may be attributed to the evaporation in shallow marine conditions, which leads to a higher salinity. The nearly constant values of $\delta^{18}O$ reported in the Sudr Chalk are fluctuating around the normal marine values. The encountered heavier values of $\delta^{13}C$ (2.18%) in the Sudr Chalk and the lighter ones (-1.62%) in the Matulla Formation exhibit only small variability in $\delta^{13}C$ around the normal marine salinity values.

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الملخص العربى

إضافة إلى معدنية وچيوكيميائية متكون المطلة وطباشير السدر فى منطقة طابا جنوب شرق سيناء – مصر

شمس الدين محمد شاهين

قسم الچيولوچيا، كلية العلوم ببورسعيد – جامعة قناة السويس

تظهر صخور الكريتاسى العلوى فى منطقة وادى طابا مقسمة إلى خمس وحدات صخرية تم دراسة رواسب متكون المطلة وطباشير السدر منها فقط ذلك من الناحية الاستراتيجرافية والمعدنية والچيوكيميائية وذلك بهدف إلقاء الضوء على ظروف ترسيبها.

فمن الناحية الليثوستراتيجرافية وجد أن متكون المطلة وعمره كونياسى إلى سانتونى يختلف تكوينه فيما بين الحجر الرملى والحجر الدولوميتى والطين الصفحى وسمكه حوالى ٢٢م، أما طباشير السدر فيمثل الصخور العلوية للكريتاسى المتأخر ويبلغ سمكه حوالى ٧٠م ممثلة فى عضوى طباشير المارخة فى الجزء السفلى منه وطباشير أبوزنيمه فى الجزء العلوى.

ويتكون عضو طباشير المارخة من طبقات الطباشير البيضاء المتبادلة مع طبقات المارل وحجر الصوان ويحتوى على محاريات الكمبانى الكبيرة، أما عضو طباشير أبوزنيمه وعمره مسترختى فهو عبارة عن حجر جيرى يحتوى على نسبة من الطين، وقد لوحظ أن هذين المتكونين (المطلة وطباشير السدر) يسفلهما متكون الواطا الذى يتكون أساساً من الحجر الجيرى المحتوى على الأمونيتات، أما طبقات الطين الصفحى والمارل لطفل اسنا الذى يتبع الباليوسن قد وجدت مترسبة فوق طباشير السدر.

وتشير الدراسة المعدنية إلى أن معادن الكربونات الأساسية الموجودة فى هذه الوحدات الصخرية ممثلة بالكالسيت والأنكيرايت والدولوميت، أما الكوارتز وقليل من الفلسبارات فيمثلان المكونات الرئيسية لمجموعة المعادن الخفيفة هذا بالإضافة إلى بعض معادن الفوسفات وبالنسبة لمعادن الطين فقد كانت هناك زيادات ملحوظة فى كل من الأسمكتيت والإليت فقد تركزت فى طبقات الحجر الرملى والحجر الجيرى، ولوحظ أن زيادة معدن الكلوريت فى طبقات الحجر الجيرى والمارل ناتج من العمليات اللاحقة للترسيب التى أثرت على معدن الاسمكتيت بينما يرجع تركيز معدن البلاجورسكيت وهو من المعادن الليفية الذى يترسب أساساً فى البحيرات والبحار الضحلة إلى عمليات إعادة الترسيب من تلك البيئات كما سجل فى طباشير السدر.

ومن الناحية الكيميائية فيعزى الاختلاف فى محتوى الوحدات الصخرية المدروسة من العناصر الرئيسية إلى إختلاف طبيعة صخور المصدر والظروف الفيزيوكيميائية التى سادت خلال تاريخها الترسيبى وكذلك طبيعة العمليات اللاحقة للترسيب وقد وصلت العناصر الشحيحة إلى حوض الترسيب عن طريق الطين ولذلك فإن محتواها فى الصخور يعكس طبيعة هذه المعادن.

وترجع نظائر الأكسجين الثقيلة إلى عمليات التبخر فى ظروف مائية ضحلة ممايؤدى إلى زيادة الملوحة ولم يمكن الاستدلال على درجات الحرارة القديمة من نظائر الأكسجين وذلك لتأثر الصخور المدروسة بالكثير من العمليات اللاحقة للترسيب.

JOESE 5

CONTRIBUTION TO THE MINERALOGY AND GEOCHEMISTRY OF THE UPPER CRETACEOUS MATULLA FORMATION AND SUDR CHALK, TABA AREA SOUTHEASTERN SINAI, EGYPT

Shams El-Din, M. Shaheen

Geology Department, Faculty of Science, Suez Canal University, Port-Said

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