Upper Cretaceous Sandstone, Petrography Paleoenvironment And Diagenesis Impact On Chemical Composition.

Gebel Qabiliyat, South West Sinai, Egypt.

S.D.Abayazeed .[1*], A.M.Ibrahim [2], and D.A.Saadawy [2]

*1-Geological Sciences Department, National Research Centre – Egypt.

2-Al-Azhar University, Faculty of Science, Geology Department.

ABSTRACT

The present paper deals with Upper Cretaceous sandstones of Gebel Qabiliyat area, aiming to study the sandstone petrographic characteristics (textural maturity and mineralogical classification of sandstones), paleoenvironment, diagenesis and their impact on sandstone chemical composition. Textural maturity study; shows that Upper Cretaceous sandstones have a textural maturity ranges from immature to sub-mature, but clustered mainly as sub-mature sandstones and these sub- mature sandstones were formed under relatively shallow neritic environments. Mineralogical study shows that Cenomanian, Upper Cretaceous sandstones, are classified as Quartz arenite to sub-lithic arenite and mainly clustered as Quartz arenite. Turonian (Wata Fm.) sandstones are clustered as sub-lithic arenite. Coniacian – Santonian (Matulla Fm.) sandstones are classified clustered as quartz arenite. Paleoenvironment study shows that; Upper Cretaceous sandstones represent shallow neritic sediments formed in area of mild tectonic stability. Diagenesis study shows that; Upper Cretaceous sandstones were exposed to several physical and chemical stages during the different diagenetic Processes. Chemical composition study; abundance, behaviour and distribution of major and trace components reveals that; Upper Cretaceous sandstones seem to be deposited under relatively warm climate, slightly alkaline conditions and relatively shallow restricted medium.

Keywords: **Upper Cretaceous sanstone - Gebel Qabilate – Mineralogy - Paleoenvironment- Diagenesis – Quartz arenite - Chemical composition**.

INTRODUCTION

Little has been written on the geology and geochemistry of Gebel Qabiliyat area (Shahin, A. M. 1990; Faris, et al., 2000; Moustafa, A.R., 2004; Ibrahim, et al., a, b and c, 2015). The studied area (Fig,

International Journal of Scientific & Engineering Research Volume 9, Issue 5, May-2018
ISSN 2229-5518

1) lies between Latitudes 28º 19' 00□□ and 28º 31' 00□□N and longitudes 33º 22' 00□□ and 33º 34' 00□□ E. approximately. Upper Cretaceous outcrops in the examined localities range from Cenomanian to Maastrichtian in age (Fig. 2).

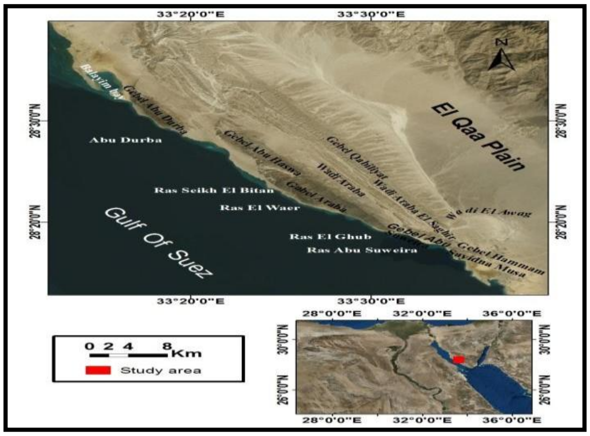

Fig. (1): Location map of the study area.

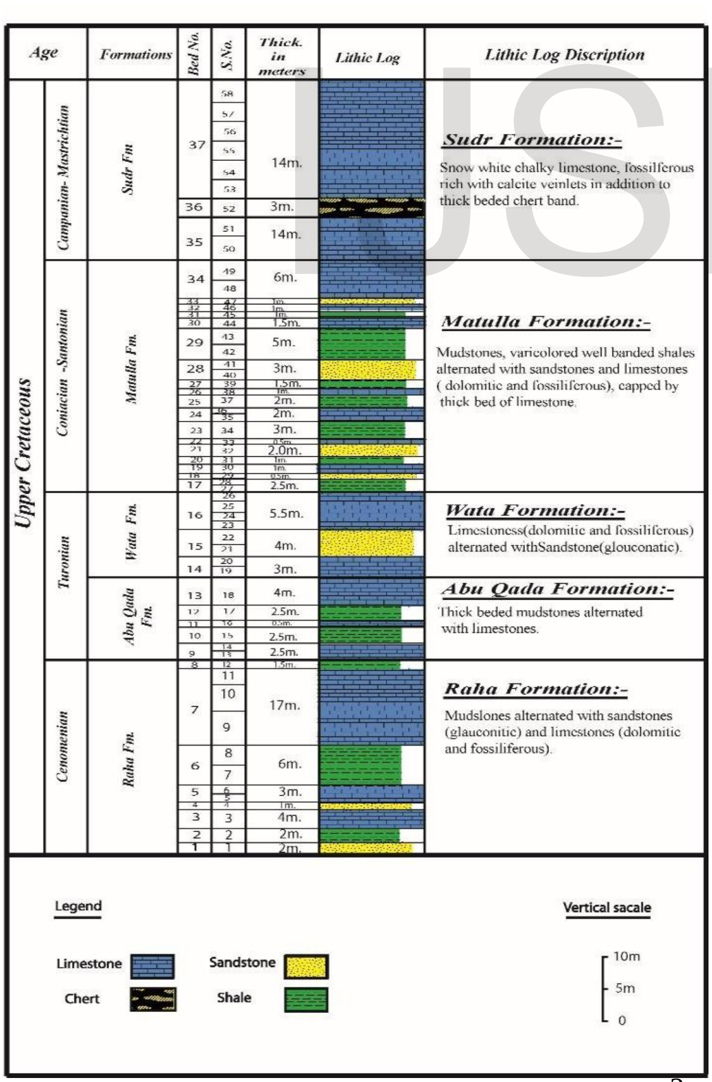

Fig. (2): Idealized composite columnar lithological section of Upper Cretaceous sedimentary formations(Gebel Qabiliyat area).

Petrographic Characteristics

1. Textural Maturity:-

According to Folk (1951, 1956, 1974) Textural maturity is one of the important keys to the physical mature of the environment of deposition. He suggested four stages of textural maturity (Table 1).These four stages are based on the idea that in transport, clay in first removed then grains are sorted and much later they are finally rounded. Folk (1974) stated that "immature sediments accumulate in loci such as flood -plains, alluvial-fans, or neritic or lagoon. Super mature sediments on the other hand indicate deposition in loci of intense abrasion and sorting such as beaches or desert dunes, where energy is constantly being expended on the grains.

Table (1): Textural maturity flow chart (after folk, 1974)

Textural maturity stage	Clay content %	Sorting	Roundness
Immature stage	**Over 5% clay**	**Poorly sorted**	**Very angular to sub-angular**
Sub mature stage	**Less than 5%**	**Moderately sorted**	**Very angular to sub-angular**
Mature stage	**Less than 5%**	**Well sorted**	**Sub-angular to sub-rounded**
Super mature stage	**Less than 5%**	**well sorted**	**Sub rounded to well rounded**

The study of the textural maturityof Upper Cretaceous sandstones in the investigated area using the items suggested by Folk (1974) resulted the classification shown in Table (2). It is clear that Upper Cretaceous sandstones have a textural maturity ranges from immature to sub- mature, but clustered mainly as sub- mature sandstones. These sub- mature sandstones represent a transitional stage between immature andsuper-mature sandstones, formed under relatively shallow neritic environments, where stresses exerted on the sediments were not strong enough to form super-mature sediments or, weak enough to form immature sediments. Also these sub-mature sandstones seem to be formed in area of mild tectonic instability (unstable shelves) giving all sub-mature sediments (Folk 1974).

Table (2): Textural maturity flow chart of Upper Cretaceous Sandstone.

Age		Formation	S.NO	Clay content %	Sorting	Roundness	Textural maturity stage
Upper Cretaceous	Con. – Sant.	Matulla	41	Less than 5%	M. Well sorted	V.A to S.A	Sub-mature
			32	More than 5%	p. sorted	V.A to S.A	Immature
			29	Less than 5%	M. sorted	V.A to S.A	Sub-mature
	Turonian	Wata	22	Less than 5%	M. sorted	V.A to S.A	Sub-mature
			21	Less than 5%	M. sorted	V.A to S.A	Sub-mature
	Cenomanian	Raha	4	Less than 5%	M. Well sorted	V.A to S.A	Sub-mature
			1	Less than 5%	M. sorted	V.A to S.A	Sub-mature

N.B: V.A to S.A: Very angular to Sub angular, V.A to S.R: Very angular to Sub rounded And S.A to S.R: Sub angular to Sub rounded.

1. Mineralogical Classification of Sandstones:-

The triangular representation of Folk (1974) (Fig. 3) was applied for Upper Cretaceous sandstone Classification. Table 3 and Figures 3- 10 show the triangular representation of Upper Cretaceous sandstones. The study reveals that; Cenomanian sandstones are classified as Quartz arenite to sub-lithic arenite and mainly clustered as Quartz arenite. Turonian (Wata Fm.) sandstones are clustered as sub-lithic arenite. Coniacian – Santonian (Matulla Fm.) sandstones are classified clustered as quartz arenite.

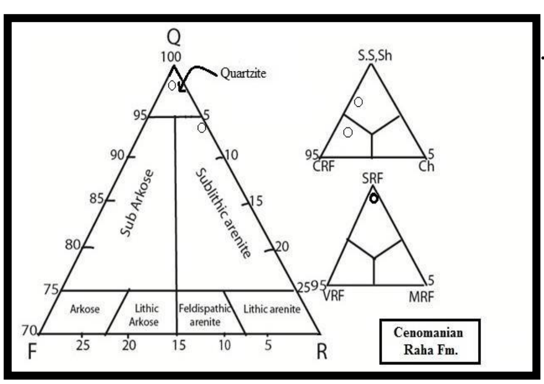

Fig (3): Classification of the terrigenous sandstones according to Folk (1974).

Table (3): Sandstones clan name for the thin sectioned studied sandstones.

Age		Formations	S.NO	Constituent%			Rock frag. Distribution			Sed. rock frag. Distribution			Sandstone type
				Q	F	RF	SRF	MRF	VRF	CRF	SS Sh	Ch^+	
Upper Cretaceous	Con.-Sant.	Matulla	41	99	n.d	1	100	n.d	n.d	97	3	n.d	Qz arenite
			32	99	n.d	1	100	n.d	n.d	97	3	n.d	Qz arenite
			29	95	n.d	5	100	n.d	n.d	96	4	n.d	Qz arenite
	Turonian	Wata	22	91	n.d	9	100	n.d	n.d	98	2	n.d	Sublithic arenite
			21	91	n.d	9	100	n.d	n.d	97	3	n.d	Sublithic arenite
	Cenomanian	Raha	4	94	n.d	6	100	n.d	n.d	97	3	n.d	Sublithic arenite
			1	98	n.d	2	100	n.d	n.d	98	2	n.d	Qz arenite

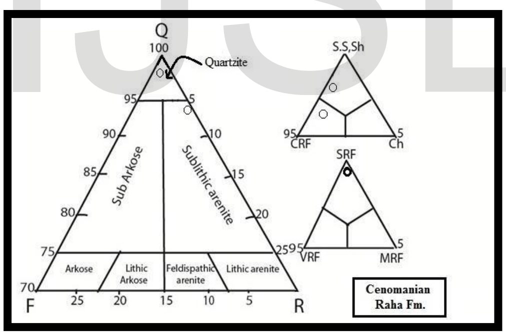

Fig (4): Classification of the studied Upper Cretaceous Cenomanian age (Raha Fm.) sandstones (after Folk 1974).

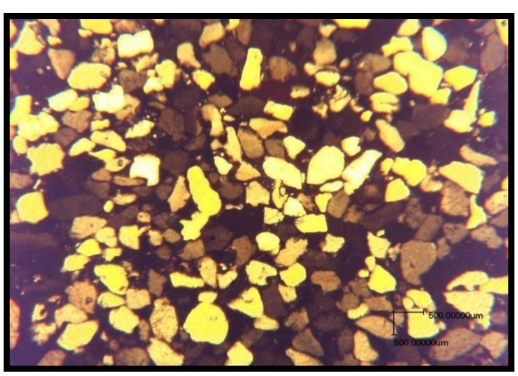

Fig.(5):Photomicrograph showing Quartz arenite sandstone mainly formed from Quartz grains, fine grained, moderately sorted, subangular to subrounded and submature. Cenomanian Raha Fm., S.No.1,X-Nicols, X500µm.

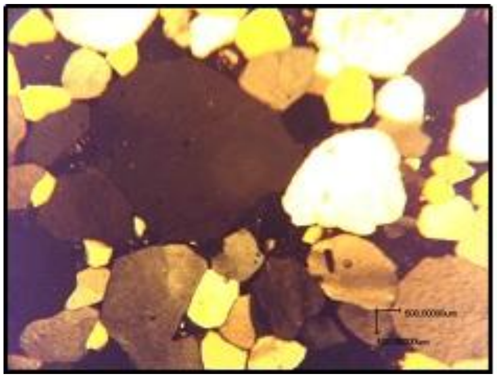

Fig.(6):Photomicrograph showing sublithic arenite sandstone mainly formed from Quartz grains with considerable amount of lithic fragments , very fine grained, moderately well sorted, very angular to subangular and submature. Cenomanian Raha Fm., S.No.4, X- Nicols, X 500µm.

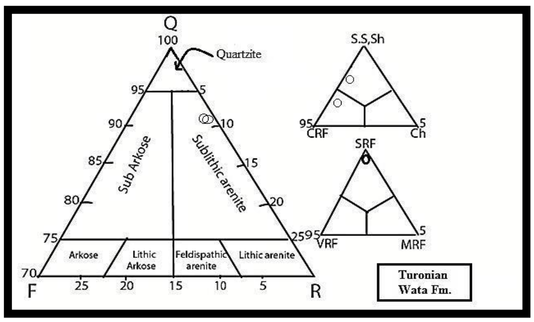

Fig (7): Classification of the studied Upper Cretaceous Turonian age (Wata Fm.) sandstones (after Folk 1974).

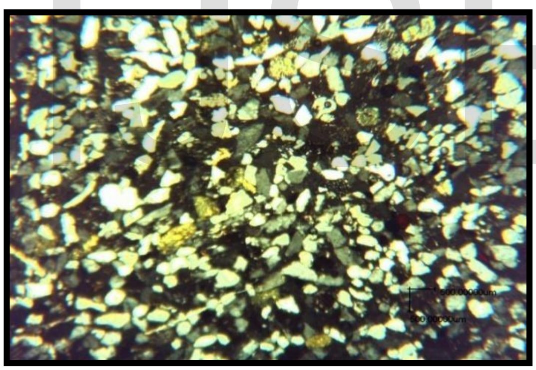

Fig.(8):Photomicrograph showing sublithic arenite sandstone mainly formed from Quartz grains with considerable amount of lithic fragments, very fine grained, moderately sorted, very angular to subangular and submature. Turonian Wata Fm. S.No.21, X-Nicols, X 500µm.

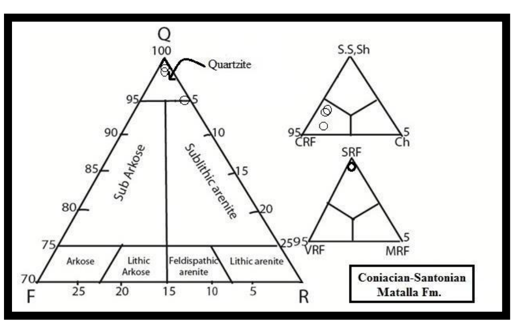

Fig (9):Classification of the studied Upper Cretaceous Coniacian- Santonian (Matulla Fm.) sandstones (after Folk 1974).

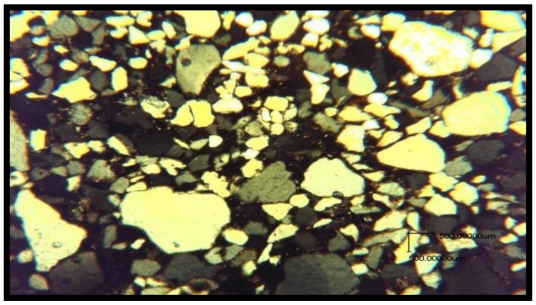

Fig. (10): Photomicrograph showing Quartz arenite sandstone mainly formed from Quartz grains, fine grained, moderately ill sorted, very angular to subangular and submature. Coniacian- Santonian Matulla Fm., S.No.41, X-Nicols, X 500µm.

PALEOENVIRONMENTS:

The textural maturity of sandstones is dependent on the environment, but volumetric importance of specific environments is determined by tectonic activity. The mineral composition of sandstones is controlled by source area, lithology and this in turn is also affected by tectonism (Krynine, 1945). To determine and give a clear picture about the paleoenvironment of Upper Cretaceous sandstones, factors affecting the paleoenvironment were collected and tabulated (Table 4). It shows that; Cenomanian sandstones are texturally sub- mature and mineralogically sub-lithic to quartz arenite. Turonian (Wata Fm.) sandstones are texturally sub-mature and mineralogically sub-lithic arenite. Coniacian-Santonian (Matulla Fm.) sandstones are texturally immature to sub- mature and mineralogically clustered as quartz arenite.

Table (4): Factors relationship affecting the paleoenvironment of Upper Cretaceous sandstones (Folk, 1974).

Upper Cretaceous stages	***Grain size***	***Clay content***	***Sorting***	***Roundness***	***Textural maturity***	***Rock type***
Coniacian – Santonian	**Very fine sand**	**Less than 5%**	**Moderately sorted**	**V.A to S.A**	**Sub-mature**	**Qz arenite**
Turonian	**Very fine sand**	**Less than 5%**	**Moderately sorted**	**V.A to S.A**	**Sub-mature**	**Sublithic arenite**
Cenomanian	**fine sand**	**Less than 5%**	**Moderately sorted**	**V.A to S.A**	**Sub-mature**	**Sublithic arenite**

Since textural maturity is very largely a result of the environment of deposition and according to Folk's assumption (1974), it is clear that the sub-mature sandstones recorded were deposited under shallow neritic marine environment. Although the environment of deposition is apparently the immediate controlling factor in textural maturity, the tectonic framework exercises an indirect control by determining which environment shall be volumetrically dominant and which environment shall be rare in a given region or stratigraphic section. This means that Upper Cretaceous, except Coniacian- Santonian (Matulla Fm.), sandstones represent transitional stages of maturity and mineralogy between immature rocks (usually arkoses or lithic arenites) and sub- mature rocks usually orthoquartzites. Consequently, the studied Upper Cretaceous sandstones represent shallow neritic sediments which are moderately sorted and texturally sub-mature, were formed in area of mild tectonic stability.

DIAGENESIS:-

Mineralogical composition in combination with texture is an important criterion of diagenesis, the following paragraphs deal with the sandstone diagenesis:

1. Texture:

The major direct evidence of diagenesis in the studied sandstones is the crosscutting relationships which are conclusive evidence of replacement. The most frequent texture of this kind in the

studied sandstones is the etching of quartz grains by carbonates (Fig.11).

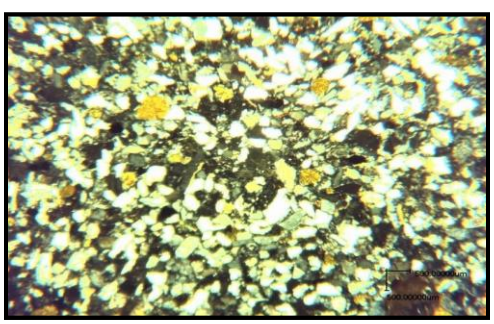

Fig. (11): Photomicrograph showing apparent protrusions of calcite, etching, into quartz grains. Suggesting that calcite has replaced large parts of detrital quartz.
G.Qabiliyat, Turonian Wata Fm., S.No.21, X-Nicols, X500µm.

Overgrowths are sometimes observed on the quartz grains of the studied sandstones. The surface of the original quartz grains are coated by a thin red brown rim of iron oxide and the shape of the grains have changed from rounded to subhedral (Fig12)

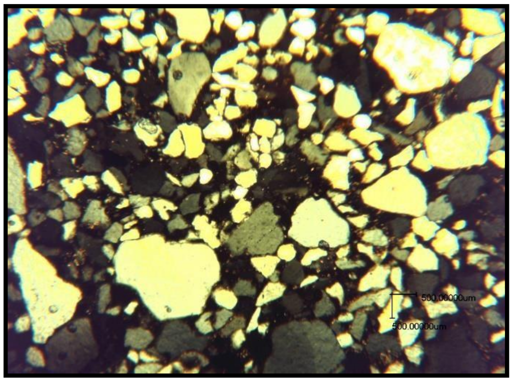

Fig.(12):Photomicrograph showing overgrowth on the detrital quartz grains the surface of the original quartz grains have changed from rounded to subhedral
. Notes that; quartz grains are mainly clustered as monocrystalline quartz. G. Qabiliyat Coniacian-Santonian Matulla Fm., S.No.41, X- Nicols, X500µm.

Mineralogical Composition:

The more soluble minerals are unlikely to be found as detrital in most sandstones that were deposited by water (Pettijohn et.al 1973). Though the presence of carbonates in the studied sandstones are diagenetic rather than detrital.

1. Physical Compaction and pressure solution:-

Processes of Diagenesis:

Sandstones which are not cemented early by diagenesis show signs of compaction. The most important process of compaction is pressure solution. In the studied Upper Cretaceous sandstones, the presence of both concavo-convex and/or sutured contact textures (Fig 13 and 14) indicates that compaction at grain contacts is maximal favoring that the sediments were compacted early in diagenesis, (Van de Kamp and Leake, 1994, Sohn, et. al. 1997).

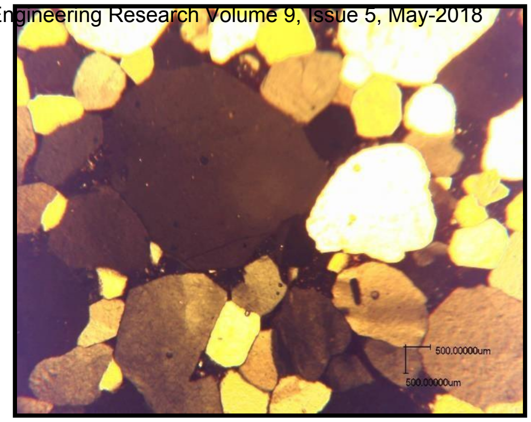

Fig. (13): Photomicrograph showing the presence of both concavo-convex and/or sutured contact textures indicates that compaction at grain contacts is maximal.
G. Qabiliyat Cenomanian Raha Fm., S.No.1, X-Nicols, X500µm.

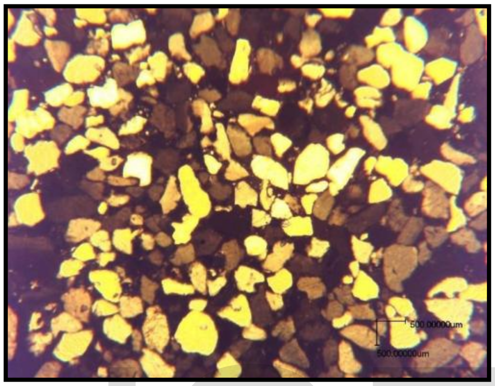

Fig. (14): Photomicrograph showing the most important process of compaction, pressure solution.G. QabiliyatCenomanian Raha Fm., S.No.4, X-Nicols, X500µm.

2. Chemical Processes of Diagenesis:-

2.1. Exogenesis:-

2.1. a. Dissolution and replacement:-

The early diagenesis of the studied sandstones includes the dissolution and replacement of certain framework minerals. Quartz grains show incipient to partial dissolution. In calcite replacing quartz, carbonate precipitation can be brought about by an increase in the pH and/or temperature (Siever, 1972). Increase of pH (> 9) and temperature enhances silica solubility. In the studied sandstone, quartz grains are corroded and etched at thin margins to produce irregularly shaped grains (Fig.11). It seems that the chemical characteristics of pore waters were high in temperature and alkalinity pH (> 9) leading to dissolution of quartz grain margins and precipitation of calcite.

The presence of *quartz overgrowths* (Fig.12) indicates that calcite is a later precipitate postdating quartz overgrowths, whereas the early precipitation of calcite inhibits later quartz overgrowth formation.

The studied Upper Cretaceous sandstones show relative scarcity of accessory heavy minerals. This phenomenon can be attributed according to Pettijohn (1941) to the assumption that heavy minerals show tendency to be absent in older rocks due to their partial dissolution by the intrastratal solution.

2.1. b. Authigenesis:

Calcite is the most important cement in the studied sandstones. Textural relationships indicate that calcite, is a nearly cement replaced by dolomite in the later mesogenic stage. Authigenic quartz is detected in the studied sandstones, it occurs as overgrowths on quartz grains.Quartz overgrowths in the studied sandstones were mostly developed without pressure solution effect reflecting probably precipitation of authigenic quartz in open pores from migrating ground water rather than from pressure solution processes (Mankiwicz and Steidtmann (1979).

2.2. Mesogenesis:

Calcite is the most important cement in the studied sandstones. Textural relationships indicate that calcite, is an early cement replaced by dolomite in the later mesogenic stage.

2.3. Telogenesis:

The final phase of diagenesis seen in the studied sandstones mainly affects the mineral suit formed during mesogenesis. The subsequent influx of meteoric water was clearly reflected in the shift of the stability field of mesogenic minerals into oxidizing, near surface conditions where dolomite might be replaced by calcite usually by the action of oxidizing meteoric (slight acidic) waters. Any ferrous iron in the precursor dolomite was oxidized to produce iron oxides rather than be incorporated in the replacement calcite.

A paragenetic sequence for the early diagenesis is presented in Figure (15). The dissolution of detrital minerals resulted in release of the following ions into intrastratal solution (Fig.16), iron and silica were derived from the clayey beds present at the studied sections and calcium carbonate from the adjacent carbonate beds.

International Journal of Scientific & Engineering Research Volume 9, Issue 5, May-2018
ISSN 2229-5518

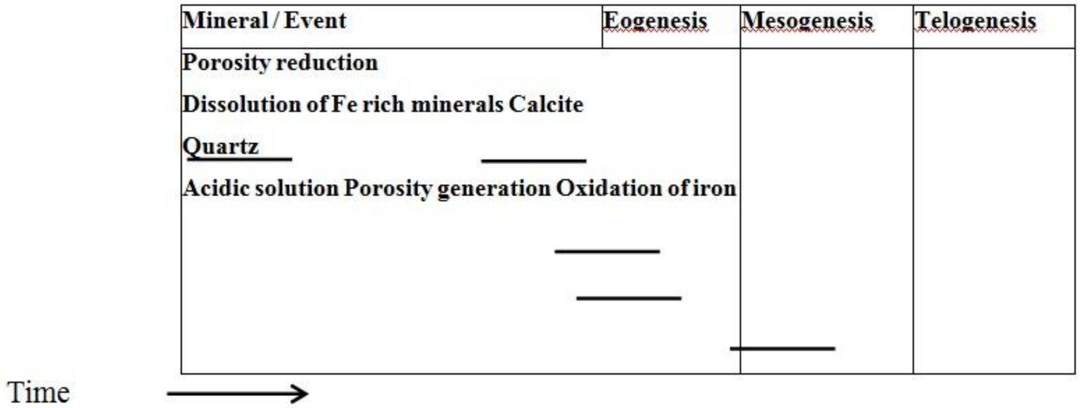

Fig. (15): Paragenetic relationship between diagenetic events and authigenic minerals in the studied sandstone (modified after Ibrahim 2000).

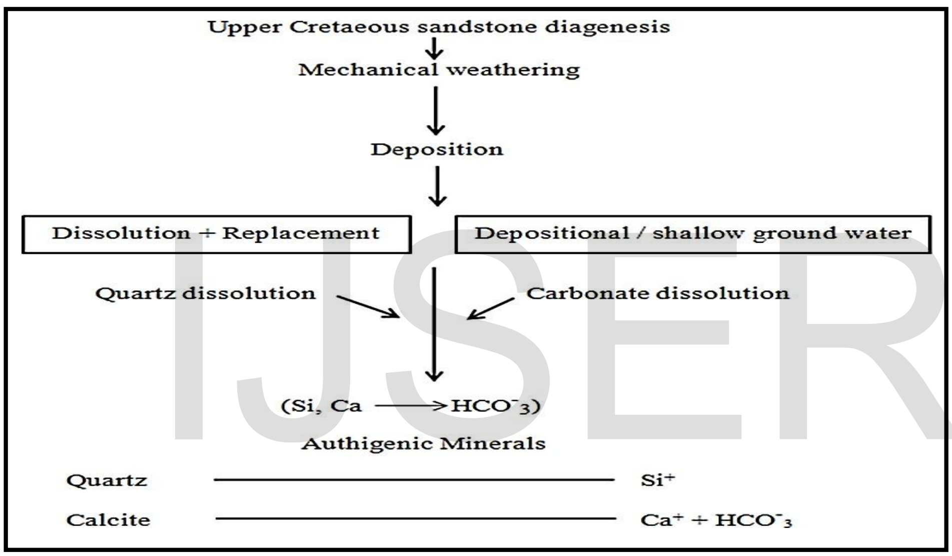

Fig. (16): Digenetic scheme for early diagenesis of studied sandstone, involving the release of ions through dissolution of unstable detrital mineral. The ions released are subsequently precipitated as authigenic phase under the control of pore fluids composition, Eh, pH, and ionic activity (modified after Ibrahim 2000).

SANDSTONE CHEMICAL COMPOSITION

Complete chemical analysis was carried out for 7 represented sandstone samples in addition to the quantitative determination of the trace elements, Ti, Mn, Cr, Cu, Pb, Ni, Rb, Sr, Zn, and Zr.

1. Abundance, behavior and distribution of major components:

a. Silicon and aluminum oxides:-

The average distribution of silica and alumina shows a reversible trend in distribution, whereas with increase in silica content, the aluminum decreases (Table 5-6 and Fig. 17). Goldschmidt (1934) stated that "alumina remains dissolved both in acid solutions with less than pH 4 and in basic solution higher than pH 9 which means the pH of the environment during deposition of alumina fall between pH 4 and pH 9. Dekimpe et al. (1961) noted that with increasing pH there is a decrease in the silica content. Accordingly Upper Cretaceous sandstones seem to be deposited under relatively warm (Corbel, 1959) and slightly alkaline conditions.

B.Iron oxide:

The distribution of iron oxide within Upper Cretaceous sandstone reveals that, there is an increase in iron content with decrease in age from Cenomanian towards Coniacian - Santonian. The variation in the relative abundance of iron oxide can be attributed to the relative position from the shore line, where approaching the shore the amount of iron oxide increases. It indicates that Upper Cretaceous sandstones were formed under relatively high Eh causing oxidation of ferrous iron to ferric iron under slightly alkaline pH (Starkey and Helvosron, 1927).

C.Calcium and magnesium oxides:

Generally calcium and magnesium elements originate as chemical precipitates in sandstones primarily as carbonates and much may be diagenetic (Pettijohn, 1972). The distribution of both calcium and magnesium oxides is shown in Table (5-6) and Fig. (17), while table (7) and Fig. (18) show the averages and ratios of calcium and magnesium oxide in relation to petrographic sandstone types of Upper Cretaceous sandstones. From the table it was clear that the CaO/ MgO ratio dos not show any particular trend for distribution and this variation can be attributed to the relative position of Upper Cretaceous rock units form shore line.

Table (5): Chemical composition (Major components in Wt. %) of UpperCretaceous sandstones.

Age	Cenomanian		Turonian		Coniacian - Santonian		
Fms.	**Raha Fm.**		**Wata Fm.**		**Matulla Fm.**		
Oxides (Wt. %)	**S.No.1**	**S.No.4**	**S.No.21**	**S.No.22**	**S.No.29**	**S.No.32**	**S.No.41**
SiO_2	82.56	44.40	69.00	70.00	66.70	78.56	92.92
Al_2O_3	11.14	10.13	10.19	11.18	12.23	9.04	1.13
Fe_2O_3	0.01	0.10	0.13	0.03	3.11	0.21	0.10
MgO	0.52	4.53	0.43	0.53	2.01	0.42	0.35
CaO	1.18	12.52	0.46	0.36	2.15	3.18	1.23
Na_2O	0.12	0.76	1.97	1.96	2.09	0.17	0.08
K_2O	0.15	2.30	4.77	4.85	1.50	0.15	0.36
P_2O_5	0.15	0.13	0.29	0.35	0.17	0.10	0.65
SO_3^{-2}	0.15	0.25	1.00	1.50	0.25	0.15	0.18
Cl^-	0.08	2.60	0.69	0.76	0.10	0.18	0.05
L.O.I.	3.28	20.52	3.00	2.50	8.17	7.08	0.99
Total	99.96	99.89	99.83	99.68	99.60	99.86	99.93

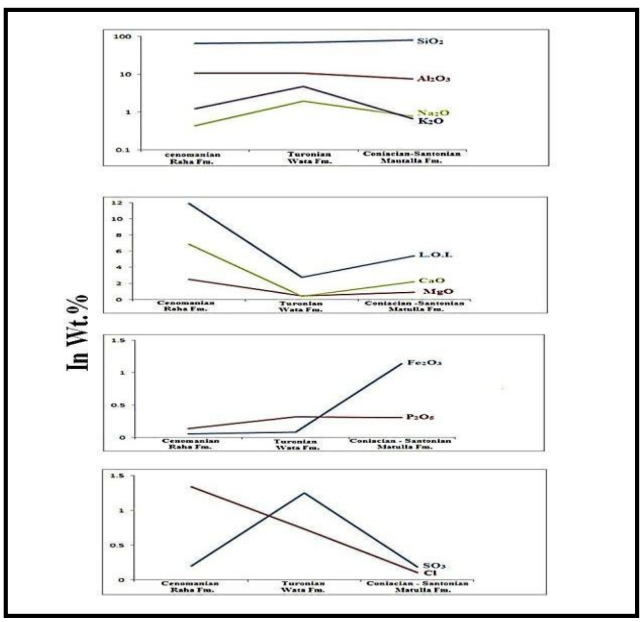

Fig. (17): Averages distribution curves of the studied Sandstone major chemical oxides.

Table (6): Average chemical composition (Major components in Wt. %) of Upper Cretaceous sandstones.

Age	Cenomanian			Turonian			Coniacian - Santonian		
Fms.	Raha Fm.			Wata Fm.			Matulla Fm.		
Oxides (Wt. %)	Min.	Max.	Aver.	Min.	Max	Aver.	Min.	Max.	Aver.
SiO_2	44.40	82.56	65.48	70.00	69.00	69.50	66.70	92.92	79.39
Al_2O_3	10.13	11.14	10.64	10.19	11.18	10.69	1.13	12.23	7.47
Fe_2O_3	0.01	0.10	0.06	0.03	0.13	0.08	0.10	3.11	1.14
MgO	0.52	4.62	2.53	0.43	0.53	0.48	0.35	2.01	0.93
CaO	1.18	12.52	6.85	0.36	0.46	0.41	1.23	3.18	2.19
Na_2O	0.12	0.76	0.44	1.96	1.97	1.97	0.08	2.09	0.78
K_2O	0.15	2.30	1.23	4.77	4.85	4.81	0.15	1.50	0.67
P_2O_5	0.13	0.15	0.14	0.29	0.35	0.32	0.10	0.65	0.31
SO_3^{-2}	0.15	0.25	0.20	1.00	1.50	1.25	0.15	0.25	0.19
Cl^-	0.08	2.60	1.34	0.69	0.76	0.73	0.05	0.18	0.11
L.O.I.	3.28	20.52	11.90	2.50	3.00	2.75	0.99	8.17	5.41

Table (7): CaO / MgO ratio of the studied Upper Cretaceous sandstone.

Age	Cenomanian	Turonian	Coniacian –Santonian
Formations	Raha Fm.	Wata Fm.	Matulla Fm.
CaO	6.85	0.41	2.19
MgO	2.53	0.48	0.93
Ratio	2.71	1.17	2.36

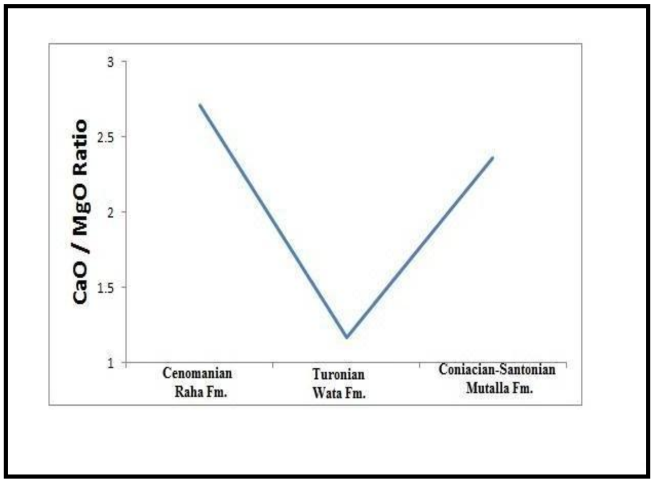

Fig. ***(18):*** **CaO / MgO ratio of the studied Upper Cretaceous sandstone**.

d. Sodium and potassium oxides:-

The distribution of sodium and potassium oxides (Tables 5-6, Fig. 17) shows that Upper Cretaceous sandstones have slightly predominance of K_2O over N_2O except Coniacian – Santonian (Matulla Formation) and this can be attributed according to (Pettijohn, 1972) to the predominance of illite over montmorillonite andmicas over feldspars, contrary to Coniacian – Santonian (Matulla Fm.) which shows the predominance of Na_2O over K_2O and this is mostly due to the predominance of montmorillonite over illite.

e. Phosphorous oxide:

Kukal (1971) stated thatphosphate is an important Component of shelf sediments, its presence is indicative of slow sedimentation. The presence of abnormal phosphorous pentoxide content relative to the average (0.04 %) given by Turekian and wedepohl(1961), suggests that slightly reduced alkaline (pH 7- 7 .8) environment prevailed in which the rate of sedimen- tation was slow (Kukel, 1971). Alsothe relatively low P_2O_5 content detected in Cenomanian sandstones can be attributed to the fact that the prevailing reduced conditions during Cenomanian were replaced by slightly oxidizing conditions upwards in the section preventing the deposition of the phosphate ion.

f. Total sulphate:

Generally the average content of SO_3 range from 0.19 % to 1.25 % (Table7-8 and Fig.15) which is higher than the average given by Pettijohn (1963) (range from 0.07 % to 0.10 %). The relatively high content indicates evaporation medium, enhancing that these Upper Cretaceous sandstones were deposited relatively undershallow marine conditions.

g. Soluble chlorides:

The soluble chlorides content of Upper Cretaceous Sandstones are relatively higher than the average given by turkian and wedipohl (1961) (10 ppm) indicating the prevalence of warm climate as well as relatively shallow restricted medium. However, the absence of salt beds enhances that evaporation was not complete. It is to be noted that the beds containing high soluble chlorides have also high sulphate content.

2. Chemical Composition as a function of Sandstone type:

Based on the relationship between log SiO_2 / $A1_2O_3$ and log Na_2O / K_2O ratios Pettijohn et al., (1973) proposed a classification for the sandstones. Upper Cretaceous sandstone studies reveal that; Cenomanian (Raha Fm.) sandstones range from lithic arenite to arkose and the samples are mainly clustered as of lithic arenite type. Turonian (Wata Fm.) sandstone samples are mainly clustered as of arkose type. Coniacian- Santonian (Matulla Fm.) sandstones ranges from litharenite to quartz arenite and the samples are mainly clustered as of lithic arenite type (Figs 19 and 20). Moore and Dennen (1970) proposed a plot of Si-Al-Fe atomic ratio to classify clastic sediments. Figures (21 and 22) illustrate the ternary plot of Si-Al-Fe ratios of Upper Cretaceous Sandstones. These figures suggest that Cenomanian (Raha Fm.) sandstones ranges from sandstone to sub- greywacke and the samples are mainly clustered as of sub-greywacke type.

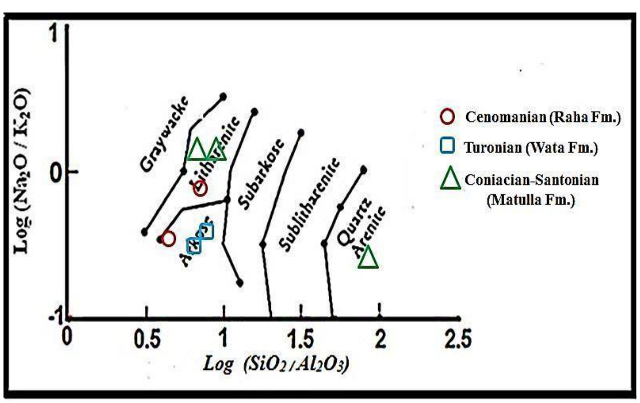

Fig. (19): Log SiO_2 / Al_2O_3 Vs. Log Na_2O / K_2O ratios of the studied Upper Cretaceous sandstones (after Pettijohn 1972).

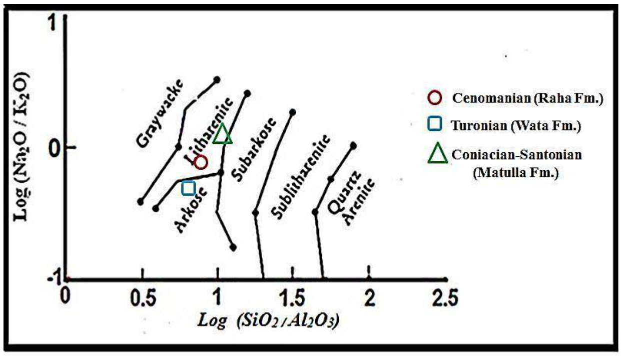

Fig. (20): Average Log SiO_2 / Al_2O_3Vs. Log Na_2O / K_2O ratios of the studied Upper Cretaceous sandstones (after Pettijohn 1972).

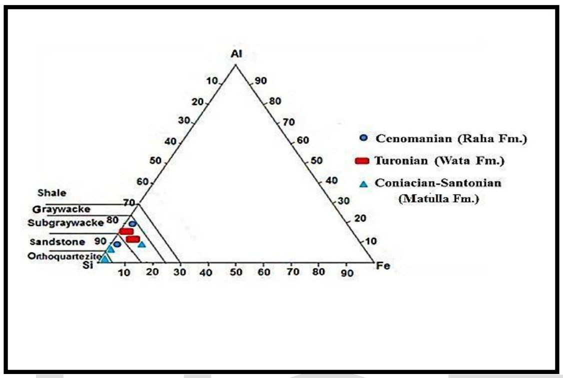

Fig. (21): Ternary plot of Si -Al -Fe of the studied upper cretaceous sandstones (after Moor and Dennen 1970).

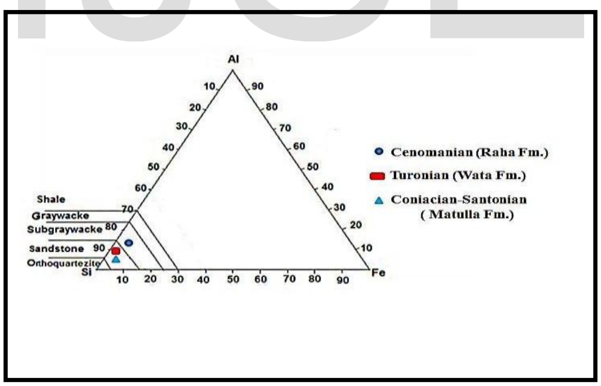

Fig. (22): Average Ternary plot of Si -Al-Fe of the studied upper cretaceous sandstones (after Moor and Dennen 1970).

Turonian (Wata Fm.) sandstones are mainly clustered as of sub- greywacke type. Coniacian - Santonian (Matulla Fm.) sandstones have a wide range from ortho-quartzite to sub- greywacke and the samples are mainly clustered as of sandstone type. Blatt et al., (1980) proposed another classificationfor the sandstones based on their chemical composition in relation to tectonic setting. He added that a plot of Fe_2O_3+

MgO, Na_2O and K_2O on a ternary diagram makes a fairly effective separation, with someoverlap, among Eugeosynclinal sandstones (mostly greywacke). Taphrogeosynclinal sandstones (mostly arkoses) and Exogeosynclinal sandstones (mostly lithic sandstones). According to the relationship suggested by Blatt et al., (1980), it seems that Cenomanian (Raha Fm.) sandstone samples are mainly clustered in the Exogeosyncline zone. Turonian (Wata Fm.) sandstone samples are mainly clustered in the Taphrogeosyncline zone. Coniacian- Santonian (Matulla Fm.) sandstones range from Eu-geosyncline to Taphrogeosyncline and the samples are mainly clustered in the Exogeosyncline zone (Figs. 23 and 24).

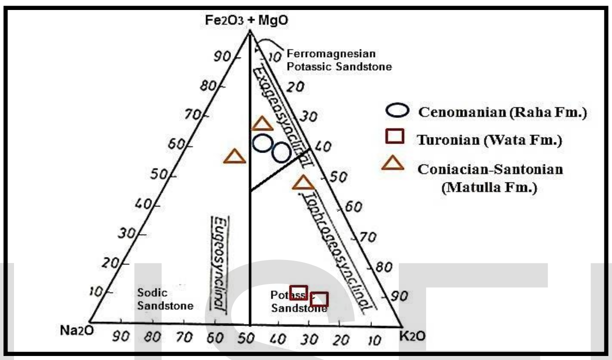

Fig. (23): Chemical composition of the studied Upper Cretaceous Sandstones in relation to tectonic setting (after Blatt 1980).

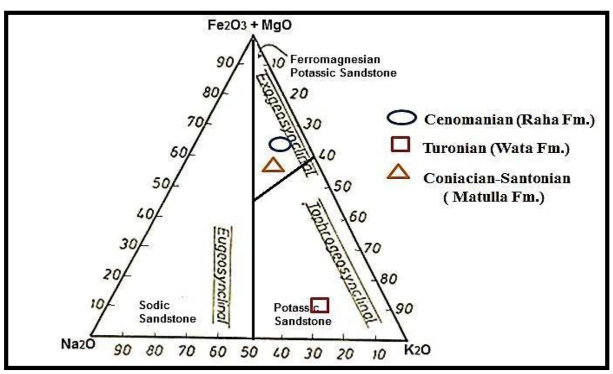

Fig. (24): Average chemical composition of the studied Upper Cretaceous Sandstones in relation to tectonic setting (after Blatt 1980).

Table (8) gives a summary of the results obtained from the study of the chemical composition as a function of sandstone type. From table (8) it is clear that methods of interpreting sandstone types tested here are helpful to certain extent in disclosing Upper Cretaceous sandstone types.

Table (8): Chemical composition as a function of sandstone types, using different classifications.

Age		Formations	S. NO.	S.S type according to Moore &Dennen (1970)	S.S type according to Pettijohn (1972)	S.S type according to Blatt (1980)
Upper Cretaceous	Coniacian – Santonian	Matulla Fm.	41	Ortho-quartezite	Quartz Arenite	Taphro- geosyncline
			32	Sandstone	Litharenite	Exo- geosyncline
			29	Sub-greywacke	Litharenite	Eu- geosyncline
	Turonian	Wata Fm.	22	Sub-greywacke	Arkose	Taphro- geosyncline
			21	Sub-greywacke	Arkose	Taphro- geosyncline
	Cenomanian	Raha Fm.	4	Sub-greywacke	Arkose	Exo- geosyncline
			1	Sandstone	Litharenite	Exo- geosyncline

3. Abundance and distribution of trace elements:

a. Titanium:

Titanium is the most abundant trace element recorded in Upper Cretaceous sandstones (table 9-10 and fig 25). Titanium follows aluminum in its way of distribution as both have intermediate ionic potential which on hydrolysis, solutions of the two elements precipitate hydroxides at still low alkaline pH values. The concentration in titanium content can be attributed to the depth of water. The study of Upper Cretaceous Cenomanian (Raha Fm.) sandstones seems to be deposited under shallow marine conditions than Turonian (Wata Fm.) sandstones. Coniacian – Santonian (Matulla Fm.) sandstones of the lowest titanium content relative to Cenomanian and Turonian seem to be deposited under deeper conditions than those of Cenomanian and Turonian sandstones causing decreasing in the titanium content. The relative depth of the basin of deposition causes relative increase in the pH value (environment of deposition becomes more alkaline) which in turn cause increasing in the solubility of aluminum (Krouskopf 1956, and Wey, 1961), leading to the lower Ti content recorded in Coniacian- Santonian (Matulla Fm.) Sandstones. According to Turekian and Wedepohl (1961), the average concentration of titanium in sandstones is 1,500 ppm. The higher Ti content of the studied sandstones relative to that given by Turekian and Wedepohl (op. cit) can be attributed to the prevalence of conditions which favor the deposition of Ti as hydrolysates at low alkaline pH value. Again according to Arrhenius (1954) the different concentrations of Ti within Upper Cretaceous sandstones reflect different rates of sedimentation which cause the higher Ti content for Cenomanian (Raha Fm.) and Turonian (Wata Fm.) relative to Coniacian – Santonian (Matulla Fm.) sandstones. It seems that Cenomanian sandstones were formed under shallower conditions than Turonian and Coniacian- Santonian sandstones, and titanium was deposited as hydrolysates under weakly alkaline conditions.

Table (9): Chemical composition (Trace components in ppm) of the Upper Cretaceous sandstone.

Age	**Cenomanian**		**Turonian**		**Coniacian – Santonian**		
Fms.	**Raha Fm.**		**Wata Fm.**		**Matulla Fm.**		
Trace elements in (P.P.M)	**S.No.1**	**S.No.4**	**S.No.21**	**S.No.22**	**S.No.29**	**S.No.32**	**S.No.41**
Ti	1260	7010	12770	12170	3600	2400	1260
Mn	80	770	235	230	760	769	770
Cr	n.d	100	50	94	116	61	n.d
Cu	59	68	50	58	48	55	90
Pb	33	120	67	58	n.d	70	n.d
Ni	38	67	72	51	31	65	70
Rb	n.d	64	53	33	n.d	45	n.d
Sr	120	220	170	270	40	60	25
Zn	n.d	110	69	29	48	90	n.d
Zr	140	640	225	1500	n.d	360	370

\

Table (10): Average chemical composition (Trace components in ppm) of Upper Cretaceous sandstone.

Age	Cenomanian			Turonian			Coniacian - Santonian			A.C
Fm.	Raha Fm.			Wata Fm.			Matulla Fm.			
Trace elements in (P.P.M)	Min.	Max.	Aver.	Min.	Max.	Aver.	Min.	Max.	Aver.	
Ti	1260	7010	`4135	12170	12770	12470	1260	3600	2420	1500
Mn	80	770	425	230	235	233	760	770	767	10 -100
Cr	n.d	100	100	50	94	72	61	116	89	35
Cu	59	68	64	50	58	54	48	90	65	1 – 10
Pb	33	120	77	58	67	63	n.d	70	70	7
Ni	38	67	53	51	72	62	31	70	56	2
Rb	n.d	64	64	33	53	43	n.d	45	45	60
Sr	120	220	170	170	270	220	25	60	42	20
Zn	n.d	110	110	29	69	49	48	90	69	16
Zr	140	640	390	225	1500	863	370	360	365	34

N.B: A.C: Trace elements average concentration after Turkian and Wedipohl (1961).

Manganese:

According to Turekian and Wedepohl (1961) the average concentration of Mn in sandstones is 10-100 ppm. The higher Mn content of the studied sandstones than that given by Turekian and Wedepohl (op. cit) can be attributed to the conditions prevailed during the deposition of the studied sandstones, whereas Mn is less mobile under oxidizing conditions. Under reducing environment Mn is mobilized and precipitated as divalent ion in carbonates formed there (Manheim, 1961; Wedepohl, 1964 and Hartmann, 1964). Again Krauskopf (1979) stated that; the metal is dissolved from its compounds in igneous rocks as Mn $^{+2}$ and remains in this form as long as the solution is slightly acidic and not too oxidizing. If the solution becomes more oxidizing the manganese precipitates as one of the oxide minerals. It seems that the sandstone rich in manganese were deposited under slightly oxidizing conditions from weakly alkaline solution as sulphides or hydroxides. The abrupt-decrease in manganese content detected form Coniacian-Santonian (Matulla Fm.) towards Cenomanian (Raha Fm.) sandstones can be attributed to their formation under deeper condition

(Matulla Fm.) leading to a relative increase in the pH and more mobilization and leaching for manganese detected in their sandstones (Raha Fm.).

Chromium:

The detected average Cr content in Upper Cretaceous sandstones shows a higher content relative to that given by Turekian and Wedepohl (1961) (35 ppm) and this abnormality may be attributed to the presence of clays in the form of montmorillonite (Frolich, 1960 and Kukal, 1971) which in turn favours an alkaline environment of deposition.

Copper:

The distribution of copper in Upper Cretaceous sandstones does not show any particular trend. According to Turekian and Wedepohl (1961) the average concentration for copper in sandstones is 1— 10 ppm showing that the studied sandstones are characterized by a higher copper content. Kukal (1971) suggested that copper is informed to be appreciably concentrated in manganese solutions. Copper distribution is related to that of manganese in the studied sandstones suggesting that it is adsorbed onto hydrate manganese oxides. Kukal (op.cit) then proved that copper occurs in sediments with a higher amount of organic matter enhancing deposition under reduced conditions particularly in the Coniacian-Santonian sandstones. Nicholis (1967) stated that "high content of- copper (>90 ppm) especially in sedimentary rocks suggests the possibility of original formation under water deeper than 250 meter" hence the studied sandstones might have been deposited under waters shallower than 250 meter.

Lead:

The distribution of Pb in Upper Cretaceous sandstones follows Mn and Cr in their way of distribution. According to Turekian and Wedepohl (1961) the average concen- tration of Pb in sandstones is 7 ppm Kukal(1971) stated that; the increased content of nickel may also occur in sediments with a larger amount of organic matter.For the studied sandstones it seems that nickel was deposited under reducing conditions. showing that it is much lesser than Pb content of Upper Cretaceous sandstones. The abnormal lead values of the studied sandstones could be attributed to the environment of deposition which was slightly acidic to slightly alkaline while reduced conditions caused the deposition of the heavy elements as sulphides.

Nickel:

According to Turekian and Wedepohl (1961) the average concentration of nickel in Sandstones is 2 ppm favouring that the studied sandstone are much enriched by nickel. The lower Ni content than that given by Nicholis (1967) (Ni > 190 ppm) for deep sea sediments indicates that: the environment of deposition of Upper Cretaceous sandstones was not deep (shallower than 250 meter).

Rubidium:

According to Turekian and Wedepohl (1961) the average concentration of Rubidium content in Sandstones is 60 ppm favouring that the studied sandstone fall within the average concentration of Turekian and Wedepohl (op.cite)

Strontium:

The distribution of strontium trace element within Upper Cretaceous sandstones shows no particular trend (Table 39). This random distribution can be attributed according to Krauskopf (1979) to the fact that Sr^{+} with a radius between those of Ca^{++} and K^{+} can substitute for both so that its trend is a compromise between the trends for the two major elements .Chilingar (1963) stated that" Strontium increases towards shore-ward where warm waters". Kukal (1971); Kitano and Kawasaki (1958) and Bathurst, (1968) suggested that the strontium content is mainly affected by the aragonite amount and the strontium content appears to be reliable in- dicator of the salinity and temperature of the environments where strontium increases with both salinity and temperature. Pilkey and Codell (1963) recorded that differences in salinity cause greater changes in shell composition than differences in temperature. The higher average strontium content detected in the studied sandstones than this given by Turekian and Wedepohl (1961) 20 ppm reflects that Upper Cretaceous sandstones were formed under slightly high salinity and temperature favouring a good conditions for the formation of aragonite and under these, conditions Sr ($r = 1.21A^{0}$) can easily substitute both Ca^{2+} ($r = 1.08A^{0}$) and K^{+}($r = 1.46A^{0}$) in their minerals and causing the, enrichment of Upper Cretaceous sandstones by Strontium. According to Kukal (1971) it seems that the environment of deposition for sandstones was alkaline environment permitting such substitutions for both Ca^{2+} and K^{+} by Sr^{2+}.

Zinc:

The distribution of Zn in Upper Cretaceous sandstones does not show any particular trend. According to Turekian and Wedepohl (1961) the average concentration of Zn content in sandstones is 16 ppm showing that the studied sandstones are characterized by high zinc content particularly those of the Cenomanian. According to Krauskopf (1979) Zn^{+} (ionic radii = 0.83 A^{0}) follows Mg^{2+} (ionic radii = 0.80A^{0}) in its way of distribution. It seems that the Upper Cretaceous sandstones were formed under alkaline environment causing enrichment of sandstones by zinc.

Zirconium:

The distribution of Zr in Upper Cretaceous sandstones does not show any particular trend. According to Turekian and Wedepohl (1961) the average concentration of Zr content in sandstones is 34 ppm showing that the studied sandstones are characterized by abnormal Zirconium content particularly those of the Turonian (Wata Fm.). The study of Upper Cretaceous Cenomanian (Raha Fm.) sandstones seems to be deposited under shallow marine conditions than Turonian (Wata Fm.) sandstones. Coniacian – Santonian (Matulla Fm.) sandstones of the lowest Zirconium content relative to Cenomanian and Turonian seem to be deposited under deeper conditions than those of Cenomanian and Turonian sandstones causing decreasing in the Zirconium content.

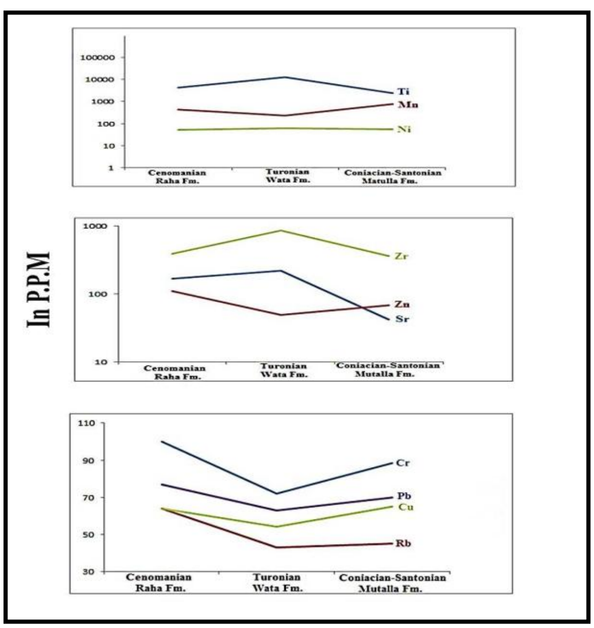

Fig. (25): Averages Distribution curves for the studied Sandstone trace chemical components

REFERENCES

Arrhenius G. (1954): Origin and accumulation of alumo-silicates in the ocean. Tellus, Stockholm, v. 3, pp. 215- 220.

Blatt, H. And Middleton, G. and Hurray, R.C. (1980): Origin of sedimentary rocks Prentice-Hall, New Jersey. pp. 634.

Chilingar G.V. (1963): Ca/Mg and Sr/Ca ratio of calcareous sediments as a function of depth and distance from shore. Jour. Sed. Petrol., Meuasha, v.33, pp. 256 .

Corbel J. (1959): Vitesse de 1'erosion. Zeitschr.f. Geomorphologie, N.F., Bd. 3, pp. 1-28, Gottingen.

Dekimpe, C.R. Gastuche, M.C. and Brindley, G.W. (1961): Ionic coordination in alumina-silicic gels in relation to clay mineral formation. Am. Mineral., v.460, pp.1370-1381.

Faris, M.; El Deeb, W.Z. and Mandur,M. (2000). Biostratigraphy of some Upper Cretaceous / Lower Eocene succession in southwest Sinai, Egypt. Ann. Geol. Surv. Egypt. v. 23 , pp. 135 - 161 .

Folk, R.L. (1951): Stages of textural maturity in sedimentary rocks. Jour. Sed. Petrol v.21, pp.127-130.

Folk, R.L. (1956): The role of texture and composition in sandstone classification. Jour. Sed. Petrol, v. 26, pp. 166-171.

Folk, R.L. (1974): The natural history of crystalline calcium carbonates effect of magnesium content and salinity. Jour. Sed. Petrol, v.44, pp. 40-53.

Frolic F. (1960): Beitrag zurGeochemi des chroms. Geochim. Cosmochim, Acta, 20pp.215-340.

Goldschmidt, V.M. (1934): Drei vortrage über Geochemie. Geol. Foren. Fo'rhandl, v.56, pp. 385-427.

Hartmann, M. (1964): Zur Geochemie von Mangan und Eisen in der Ostsee. Meyniana 14, 3.

Ibrahim A.M. (2000): Elgunna Cambrian - Lower Cretaceous sandstones, Southern Sinai, Egypt: Composition and paleoclimatic inferences**.** ISSN1110-2527, Sedimentology of Egypt, vol. 8, pp. 119-132.

Ibrahim A.M., Abayazeed, S. D. and Saadawy D. A., 2015a: Upper cretaceous carbonate rocks, Gebel Qabiliyat, South West Sinai, Egypt: Petrography and Geochemistry. IJISET- International Journal of Innovative Science, Engineering& Technology, India, Vol. 2 Issue 5, p. 1026-1043

Ibrahim A.M., Abayazeed, S. D. and KAMEL, S. A., 2015b: Diagenesis impacts on petrophysical parameters, IJISET-International Journal of Innovative Science, Engineering& Technology, India, Vol. 2 Issue 9, ISSN2348- 7968, p.300-316.

Ibrahim A.M., Abayazeed, S. D. and KAMEL, S. A., 2015c: Depositional Environments and Geochemistry Of Upper Cretaceous Carbonate Rocks, Gabal Nezzat- West Central Sinai- Egypt, IJISET-International Journal of Innovative Science, Engineering& Technology, India, Vol. 2 Issue 8, ISSN2348- 7968, p.285-299.

Kitano, Y. and Kawasaki, N. (1958): behavior of strontium ion in the process of calcium carbonate separation from bicarbonate solution .Jour .Earth Sci., Nagoya Univ. v.6. pp.63-74.

Krauskopf, K.B. (1956): Dissolution and precipitation of silica at low temperature. Geochim. Cosmochim, Acta, 10, pp. 1-27.

Krauskopf, K.B. (1979): Introduction to Geochemistry. Me-Graw-Hill, New York, pp. 617.

Krynine, P.D. (1945): Sediments and the search for oil. Producers Monthly9, pp.12-22.

Kukal, Z. (1971): Geology recent sediments Academic press London New York, pp. 90.

Manheim, F. (1961): A geochemical profile in the Baltic Sea Geochim. Cosmochim. Acta 25, 52.

Mankiewicz, D. and J. R. Steidtmann. (1979): Depositional environments and diagenesis of the Tensleep Sandstone, eastern Big Horn Basin, Wyoming. Soc. of Econ. Paleo. and Miner. SpecialPub. 26. pp. 319-336.

Moore, B.R., and Dennen, W.H. (1970): A geochemical trend in silica- aluminium-iron ratios and the classification of clastic sediments. Jour. Sed. Petro.v. , 40, pp. 1147.

Moustafa, A.R. (2004): Explanatory Notes for the Geologic Maps of the Eastern Side of the Suez Rift (Western Sinai Peninsula), Egypt. Department of Geology, Faculty of Science, Ain Shams University, Cairo 11566, Egypt. pp. 34 .

Nicholis C.D. (1967): Trace elements in sediments: an assessment of their possible utility as depth indicators. Marine Geology Amsterdam v. 5, pp. 539-555.

Pettijohn F.J. (1941): Persistence of heavy minerals and geologic age. J. Geol. 49, pp. 610-625.

Pettijohn, F. J., Fetter, P.E., and Siever, R. (1973): Sand and sandstones, New York: Springer Verlag, Berlin pp. 618.

Pilkey, O.H., and Goodell.H.G. (1963): Trace elements in recent and fossil mollusk shells. Bull. Am. Ass. Petrol.Geol. Abst., Tulsa v. 47, pp.366.

Sahu, B. K. (1964): Depositional mechanisms from the size analysis of elastic sediments: Jour. Sed. Petrol. v. 34, pp. 73-83.

Shahin, A. M. (1990). Biostratigraphy of the Late Cretaceous - Early Tertiary succession of Gabel Ekma, southwestern Sinai, Egypt. 7th Sympos. Phanero. Develop. Egypt, Cairo, Al Azhar Univ. Abst. No. 3, 5.

Siever, R. (1972): Sand and sandstones, New York: Springer Verlag, Berlin pp. 618.

Starkey, R.L and Helvorson, H.O., (1927): Studies on the transportation of iron in nature-II: concerning the importance of micro-organisms in the solution and. ppt of .iron. Soil. Sci.. , v. 24, pp., 81-101.

Turekian, K.K. and Wedepohl, K.h. (1961): Distribution of elements in Sama major units of earth's crust, Geol. Soc. Amer. Bull.v. 72, pp. 175-192.

Van de Kamp, P.C., Leake, B.E. (1994): Petrology, geochemistry, provenance and alteration of Pennsylvanian – Permian arkose, Colorado and Utah. Geological Society of America Bulletin 106, pp.1571 – 1582.

Wedepohl, K.H. (1964): Unters uchungen am kupferschiefer in Nordwestdevtschland; ein Beitrag zur Deutung der Genese bitumiooser sedimente. Geochim. Cosmochim. Acta, 28.305.