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Geochemical Assessment and Clay Mineralogical Studies of Eocene Rocks at Wadi Tayiba and Wadi Feiran Areas, Southwestern Sinai, Egypt

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Abstract

The study areas are represented by two examined sections, namely Wadi Tayiba and Wadi Feiran sections. The study areas, are represented by five formations namely; Thebes (Lower-Middle Eocene), Darat and Samalut (Middle Eocene), Khaboba (Middle – Late Eocene) and Tanka (Upper Eocene) Formations. Mineralogical compositions of the studied clay minerals reveal that the presence of montmorillonite, illite and kaolinite clay minerals. Clay chemical composition reveal that, the Eocene marine basin of deposition was relatively alkaline, close to the landmass that supplied the basin of deposition by quartz and clays. However the pH degree of alkalinity during the Darat Formation (Wadi Tayiba area) and Thebes and Samalut Formations (Wadi Feiran area) (less in SiO_2 content) was higher than that prevailed during the Thebes, Khaboba and Tanka Formation (Wadi Tayiba area) times.

Keywords: *Eocene, Wadi Tayiba, Wadi Feiran, Thebes, Darat, Samalut, Khaboba and Tanka formations, Clay, Montmorillonite, Kaolinite, Illite.*

1. Introduction

The present paper deals with petrography; paleo depositional environmental and petrophysical characters of Eocene carbonate rocks exposed at the Southwestern Sinai along the Western side of the Gulf of Suez. The study area lies between latitudes 28° 40' 00" and 29° 10' 00" N. and longitudes 33° 00' 00" and 33° 30' 00" E **(Fig. 1).** The study area is represented by two examined areas, namely Wadi Tayiba and Wadi Feiran. The Eocene succession is subdivided into the following formations (from older to younger): Thebes, (Samalut equivalent Darat), Khaboba and Tanka.

The Eocene succession has been studied by several authors such as ***Ansary, (1955); Said, (1960); Viotti & Demerdash, (1968); Youssef & Abdel Malik, (1969a); Bassioni et al. (1980); Issawi et al., (1981); El-Heiny & Morsi, (1986); Faris et al., (1986); Abuel Nasr & Thunell, (1987); Barakat et al., (1988); Abul-Nasr, (1990); El–Heiny et al. (1990); Said, (1990); Morsi, (1992); Abul-Nasr, (1993a); Abul-Nasr, (1993b); Magdy, (1997); Chillingar & Bissell, (1963) .***

2. Methodology

The present work aims to flash up at mineralogical and chemical studies to evaluate the geochemical of Eocene carbonate rocks at Wadi Tayiba and Wadi Feiran areas. The samples were prepared and measured in Egyptian Petroleum Research Institute (Central lab. sector) and Egyptian Minerals Resource Authority (Central lab. Sector) as follows:

I. Twenty six samples were selected and analyzed by the X-Ray diffraction (XRD) at Egyptian Petroleum Research Institute (Central lab. sector) by using PanAlytica (type X-Pert pro) with Ni-filter Cu- radiation, N=1.54418A at 40 KV 40 mA, and a normal scanning speed of 20 /min.

II. Nineteen samples were selected for geochemical study to determine the major and trace elements. The detailed chemical analysis was carried out at the Egyptian Minerals Resource Authority (Central lab. Sector). The analysis was made through automated powder diffractometer system of Philips PW 1710.

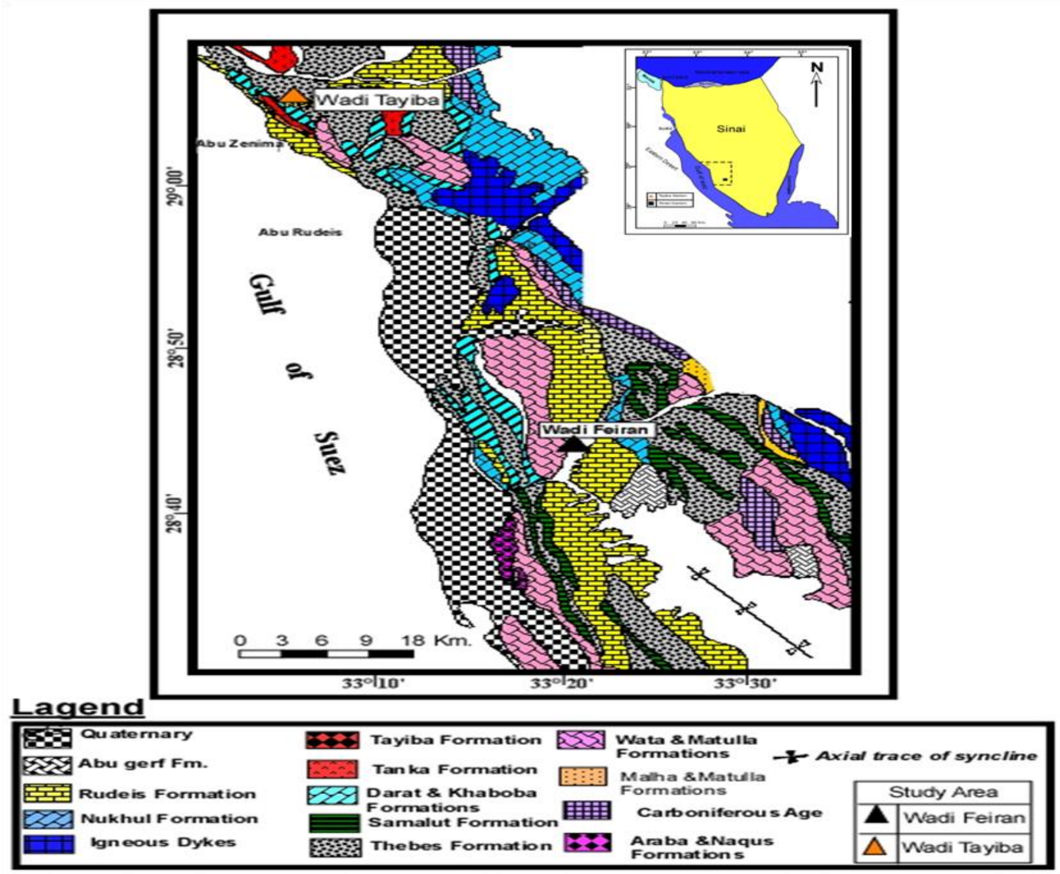

Fig. (1): Location and geological maps of the study area (After Conoco, 1992).

3. Lithostratigraphy

The Eocene successions exposed in the Southwestern part of Sinai are represented mainly by carbonate predominance. The Eocene successions recorded in the study areas range in thickness from 152 meters (at Wadi Tayiba) to 408 meters (at Wadi Feiran) **(Figs. 2&3).**

Eocene rocks, of the study areas, are represented by five formations namely; Thebes (Lower to Middle Eocene), Darat and Samalut (Middle Eocene), Khaboba (Middle to Late Eocene) and Tanka (Upper Eocene) formations.

The Thebes Formation is well represented in the study areas. It attains an average thickness of 48 meters in Tayiba area and average thickness of 268 meters in Feiran area, Thebes Formation is composed mainly of yellow to pale brown in color, thin bedded, moderately hard, and argillaceous limestones.

The Darat Formation is well distributed in the studied areas it is recorded in the Tayiba area with thickness of about 60 meters and overlies conformably the Thebes Formation. The Darat Formation composed mainly from limestones of yellowish brown in color, argillaceous, moderately hard, alternated with shale and fossiliferous.

The Samalut Formation is well represented in the study areas. It attains an average thickness of 140 meters in Feiran area. Samalut Formation is equivalent to the Darat Formation in the Tayiba section.

The Khaboba Formation is recorded in the Tayiba area with thickness of about 21 meters and overlies conformably the Darat Formation. The Khaboba Formation composed mainly from fossiliferous limestones.

The Tanka Formation in the Tayiba area is recorded by thickness of 22 meters. This formation is overlies conformably the Khaboba Formation. The Tanka Formation composed mainly from yellowish brown limestones, argillaceous, moderately hard, alternated and fossiliferous.

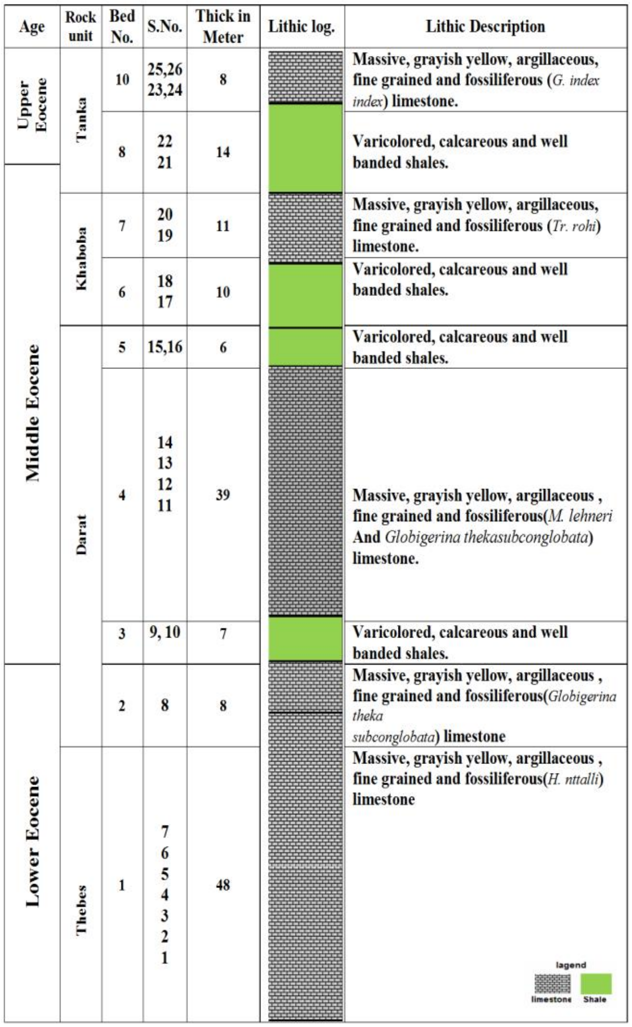

Fig. (2): Idealized columnar Lithic Log of the Eocene Formations recorded at Wadi Tayiba area.

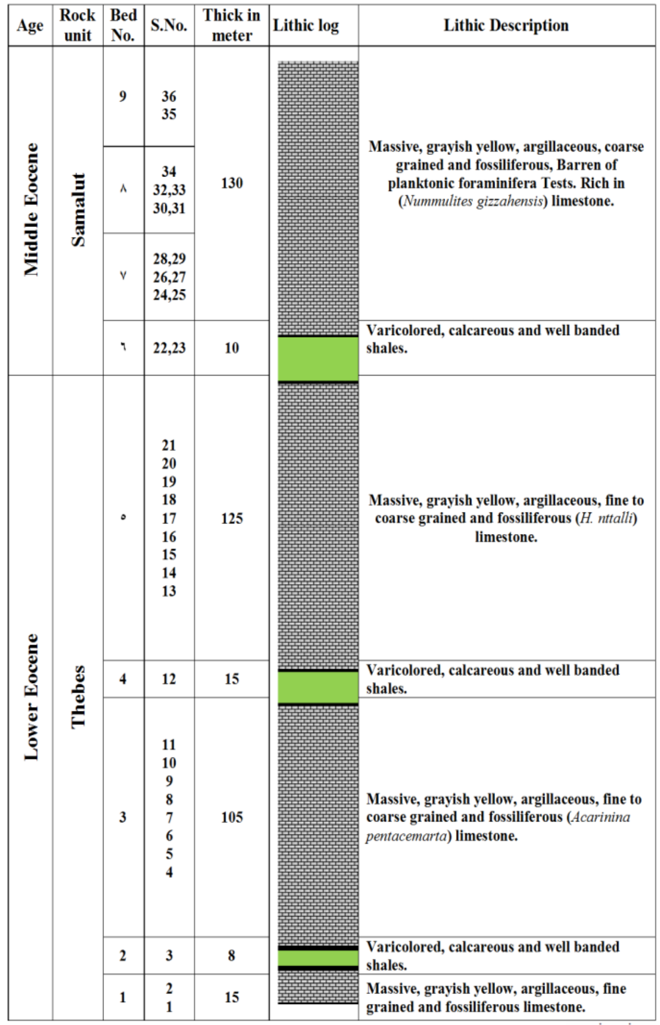

Fig. (3): Idealized columnar Lithic Log of the Eocene Formations recorded at Wadi Feiran area.

4. Clay Mineralogy

The mud rocks constitute about 0.50% of the studied Eocene sediments. The study of their mineral composition aims to understand the long history of these mud rocks.

Mineralogical composition

The selected Eocene mud rocks were mineralogically studied using X-ray diffraction analysis. The purpose of this study is to determine the mineralogical composition and its significance in the environmental interpretations.

The clay fraction with a particle size less than 2 microns is prepared according to the procedure describe by **Folk *(1968); Jackson (1959) and*** ***Carver (1971)*** taking into consideration all the precautions adopted in these methods. Oriented slides of clays are used as describe by ***Gibbs (1965) & (1968)*** each is a smear on glass slide. The X-ray diffraction analysis of the clay samples are shown in **(Tables 1&2 and Figs. 4&5)** favor the presence of montmorillonite (14A°, 12A°), illite and clay minerals.

The identification of these minerals is based on the spacing obtained from the single mineral. These spacing given in A°, are the following:

	N	G	H
Illite	10	10	10
Montmorillonite	14	17.7	10
Kaolinite	7	3.58	………

Table (1): X-Ray data for the Clay samples from Wadi Tayiba area.

AGE	FOR	S. No.	NORMAL 2θ	NORMAL dA°	NORMAL I/I°	GLYCOLATED 2θ	GLYCOLATED dA°	GLYCOLATED I/I°	Heated 2θ	Heated dA°	Heated I/I°	NINERAL DETECTED
LATE EOCENE	TANKA	23	12.09	7.31	83.14	12.31	7.18	86.02	---	---	---	Kaolinite
			24.59	3.61	100.00	24.87	3.57	100.00				Kaolinite
			28.2	3.16	6.00	28.43	3.14	3.00				Kaolinite
			5.79	15.24	42.46	5.08	17.39	65.40	8.95	9.87	100.00	Montmorillonite
			20.64	4.30	7.42	20.76	4.27	7.07	20.78	4.49	32.38	Montmorillonite
			26.38	3.37	19.63	26.64	3.34	31.30	26.35	3.35	49.45	Montmorillonite
		21	12.31	7.18	100.00	12.34	7.16	100.00	---	---	---	Kaolinite
			24.85	3.58	8.07	24.86	3.58	98.64				Kaolinite
			29.1	3.07	2.03	28.00	3.18	5.00				Kaolinite
			5.82	15.17	48.38	5.02	17.59	95.93	9.21	9.60	100.00	Montmorillonite
			20.82	4.26	8.07	20.81	4.26	12.33	26.63	3.34	34.36	Montmorillonite
			26.62	3.34	12.74	26.60	3.35	33.53	28.11	3.17	68.31	Montmorillonite
	KHABOBA	17	12.31	7.18	100.00	12.36	7.16	90.91	---	---	---	Kaolinite
			24.84	3.58	96.15	26.53	3.35	100.00				Kaolinite
			29.1	3.06	5.00	29.00	3.07	1.00				Kaolinite
MIDDLE EOCENE			5.83	15.15	40.14	5.27	16.74	58.76	9.25	9.55	100.00	Montmorillonite
			21.78	4.07	3.92	21.88	5.71	1.66	18.58	4.77	29.66	Montmorillonite
			26.59	3.35	5.28	15.50	4.06	2..94	28.19	3.16	34.29	Montmorillonite
	DARAT	16	21.87	4.06	15.93	5.24	16.85	30.42	5.00	14.7	8.24	Montmorillonite
			23.08	3.85	100.00	21.72	4.09	100.00	21.5	4.13	100.00	Montmorillonite
			32.14	2.78	20.50	33.31	2.28	20.21	33.01	2.71	22.46	Montmorillonite
		9	5.51	16.03	8.94	4.74	18.63	13.72	20.58	4.31	27.69	Montmorillonite
			20.80	4.26	100.00	20.71	4.28	14.43	26.42	3.37	100.00	Montmorillonite
			33.18	2.69	5.01	26.44	3.36	100.00	31.81	2.81	19.63	Montmorillonite

Table (2): X-Ray data for the Clay samples from Wadi Feiran area.

AGE	FOR	S. No.	NORMAL 2θ	NORMAL dA°	NORMAL I/I°	GLYCOLATED 2θ	GLYCOLATED dA°	GLYCOLATED I/I°	HEATED 2θ	HEATED dA°	HEATED I/I°	MINERAL DETECTED
MIDDLE EOCENE	SAMALUTE	F23	12.30	7.19	94.96	12.36	7.16	100.00	---	---	---	Kaolinite
			24.83	3.58	100.00	24.89	3.57	99.79				Kaolinite
			28.5	3.13	16.25	28.90	3.08	8.00				Kaolinite
			5.83	15.15	40.14	4.10	21.51	13.81	8.96	9.85	100.00	Montmorillonite
			21.35	4.01	5.50	5.21	16.93	77.67	21.70	4.09	40.00	Montmorillonite
			26.59	3.35	5.28	26.744	3.33	8.15	27.85	3.20	77.45	Montmorillonite
EARLY EOCENE	THEBES	F12	12.33	7.17	100.00	12.35	7.16	99.59	---	---	---	Kaolinite
			24.88	3.57	98.51	24.89	3.57	100.00				Kaolinite
			28.00	3.18	2.14	28.50	3.13	3.00				Kaolinite
			12.33	7.17	100.00	12.35	7.16	99.59	---	---	---	Kaolinite
			24.88	3.57	98.51	24.89	3.57	100.00				Kaolinite
			28.00	3.18	2.14	28.50	3.13	3.00				Kaolinite
		F3	6.32	14.02	58.24	5.13	17.21	100.00	8.86	9.97	52.36	Montmorillonite
			20.59	4.31	25.48	20.68	4.25	21.41	26.62	3.34	100.00	Montmorillonite
			26.34	3.38	69.70	26.61	3.34	59.76	28.14	3.17	49.47	Montmorillonite
			12.01	7..31	100.00	12.35	7.16	46.80	---	---	--	Kaolinite
			24.59	3.61	5.46	24.90	3.57	47.03				Kaolinite
			28.31	3.15	2.51	28.44	3.14	5.00				Kaolinite

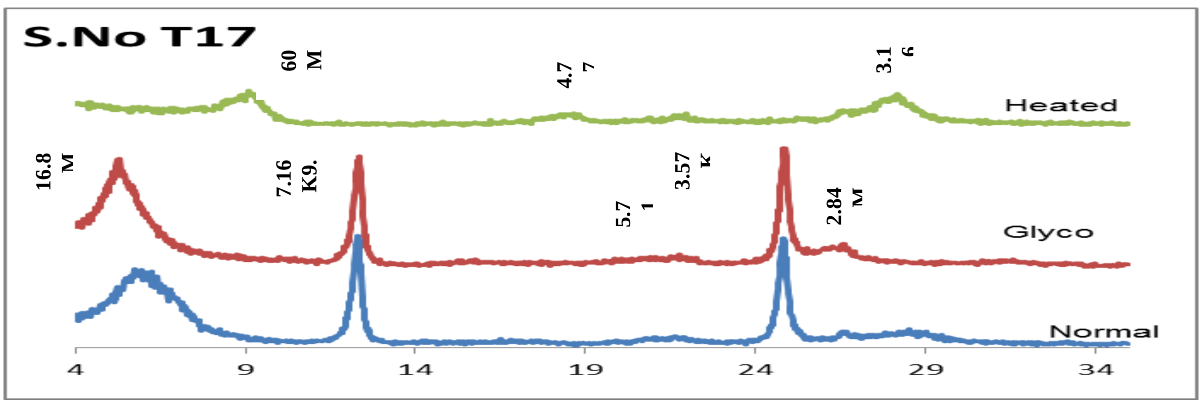

Fig. (4): X- ray diffraction pattern of clay sample No (T17) of Wadi Tayiba area.

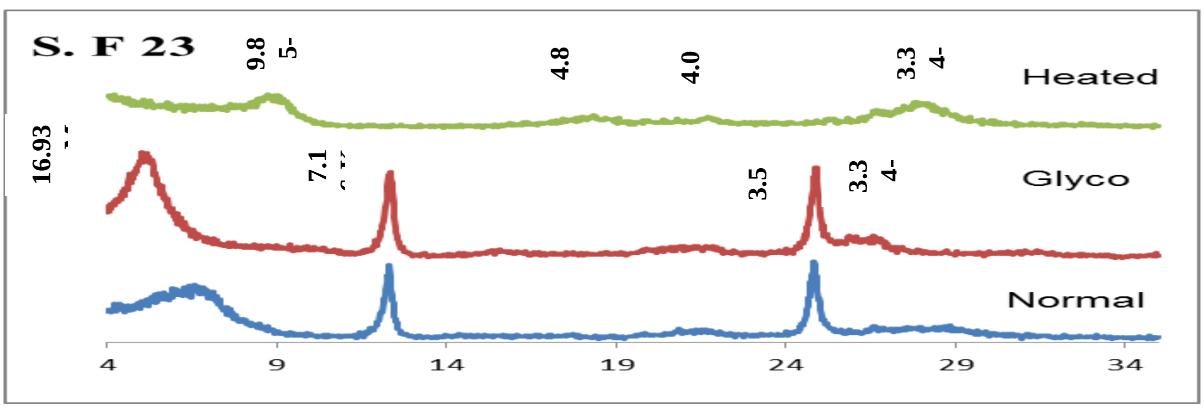

Fig. (5): X- ray diffraction pattern of clay sample No (F23) of Wadi Feiran area.

According to ***Krauskopf (1979)*** Clay minerals preserve a record of the environment from which they comes and the nature of the clay minerals originally formed probably depends on the environment of the weathering. ***Millot (1970*** in this study on transformation of clay minerals reached the following conclusions:

The detection of montmorillonite, illite clay minerals favor their formation under alkaline waters and alkaline diagenesis where they show stability ***Millot (1970).*** The presence of montmorillonite being favored by alkaline solution containing Ca $^{+2}$, Mg $^{+2}$ and Fe $^{+2}$ and illite by abundant K^{+}, ***Krauskopf (1979).***

Again the presence of both kaolinite and illite in the study areas reveal that they were formed by the action of surface and underground water. The presence of kaolinite indicates that the geomorphological condition was favorable for the permanent removal of K^{+}, Na^{+}, Ca^{2+}, and Mg^{2+} by leaching.

As previously noted and from the clay mineral associations reported in the studied Eocene mud rocks, it's clear that the environment of deposition for the clay minerals identified was alkaline environment and that the origin of the clay minerals present is chloritic more probably than illite origin where montmorillonite, and illite can be derived from weathering of chlorite rapid than weathering from illite ***Droste, et al. (1962).***

5. Geochemical Investigation of Clay Minerals

The Abundance and distribution of the major chemical components and some trace elements are detected in the Eocene mud rocks under investigation. The Abundance and distribution of chemical elements in the sedimentary rocks in general, are governed by a set of parameters such as the medium of deposition, temperature , salinity, depth , distance from shore line, turbidity, Eh, and pH…etc. Consequently the study of the distribution of the chemical components in the investigated areas could help in interpreting the environment of deposition.

Abundance and Distribution of Major Components

The major elements detected in the studied mud rocks are Si, Al, Fe, Na, K, Ca and Mg. Among the major elements of silicate rock only calcium is not included in this list.

Silicon Oxide

Silica is the dominant constituent of all clays and shales; it's present as a part of the clay minerals complex as decomposed of detrital silicates, and as free silica. The silica content in the Wadi Tayiba area, Middle Eocene (Darat and Khaboba formations) **(Tables No. 3&4 and Fig. 6)** ranges between 40.7% and 43.4% and between 42.2% and 44.1% with average of 42.05% and 43.15% respecttively. The silica content in Wadi Tayiba area, Upper Eocene (Tanka Formation) ranges between 48.5% and 49.8% with an average of 49.15%. The silica content in the Wadi Feiran area, Early Eocene (Thebes Formation) **(Tables 5&6 and Fig. 7)** ranges between 38.00% and 46.00% with average of 42.00%. Middle Eocene (Samalut Formation) has an average of 42.5%. The distribution of the silica content recorded in Wadi Tayiba and Wadi Feiran areas shows an increasing in the silica content from Early to Middle (Wadi Feiran) and from Middle to Upper Eocene (Wadi Tayiba) formations.

Table (3): Chemical composition (major oxides in wt%) of the Eocene clayes (Wadi Tayiba area).

AGE	Formation	S. No.	SiO_2 %	Al_2O_3 %	Fe_2O %	CaO %	MgO %	Na_2O %	K_2O %	L.O.I %	Total
Upper Eocene	Tanka	23	48.5	16.5	1.88	15.3	0.27	2.6	1.99	12	99.61
		21	49.8	14.6	1.99	15.4	0.23	2.3	2.04	13	99.81
Middle Eocene	Khaboba	18	44.1	12.8	3.8	19.2	0.08	2.7	1.82	15	99.92
		17	42.2	13.8	5.5	17.8	0.06	2.6	1.87	16	99.65
	Darat	16	43.4	14.1	4.2	18.6	0.05	2.4	1.93	15	99.86
		9	40.7	13.4	4.5	25.2	0.89	0.4	0.33	15	99.65

Table (4): Avarege chemical composition (major oxides in wt%) of the Eocene clayes (Wadi Tayiba area).

Age	Middle Eocene				Upper Eocene	
Formation	Darat		Khaboba		Tanka	
Sample. No	9 & 16		17 & 18		21 & 23	
Chemical oxides	Range	Average	Range	Average	Range	Average
SiO2%	40.7 - 43.4	42.05	42.2 - 44.1	43.15	48.5 - 49.8	49.15
Al2O3%	13.4-14.1	13.75	12.8 - 13.8	13.3	14.6 - 16.5	15.55
Fe2O3%	4.2 - 4.5	4.35	3.8 - 5.5	4.65	1.88 - 1.99	1.93
CaO%	18.6 - 25.2	21.9	17.8 - 19.2	18.5	15.3 - 15.4	15.35
MgO%	0.05 - 0.89	0.47	0.06 - 0.08	0.07	0.23 - 0.27	0.5
Na2O%	0.4 - 2.4	1.40	2.6 - 2.7	2.65	2.3 - 2.6	2.45
K2O%	0.33 - 1.93	1.13	1.82 - 1.87	1.84	1.99 - 2.04	2.02
L.O.I%	15.00	15.00	15.00 – 16.00	15.5	12 – 13	12.5

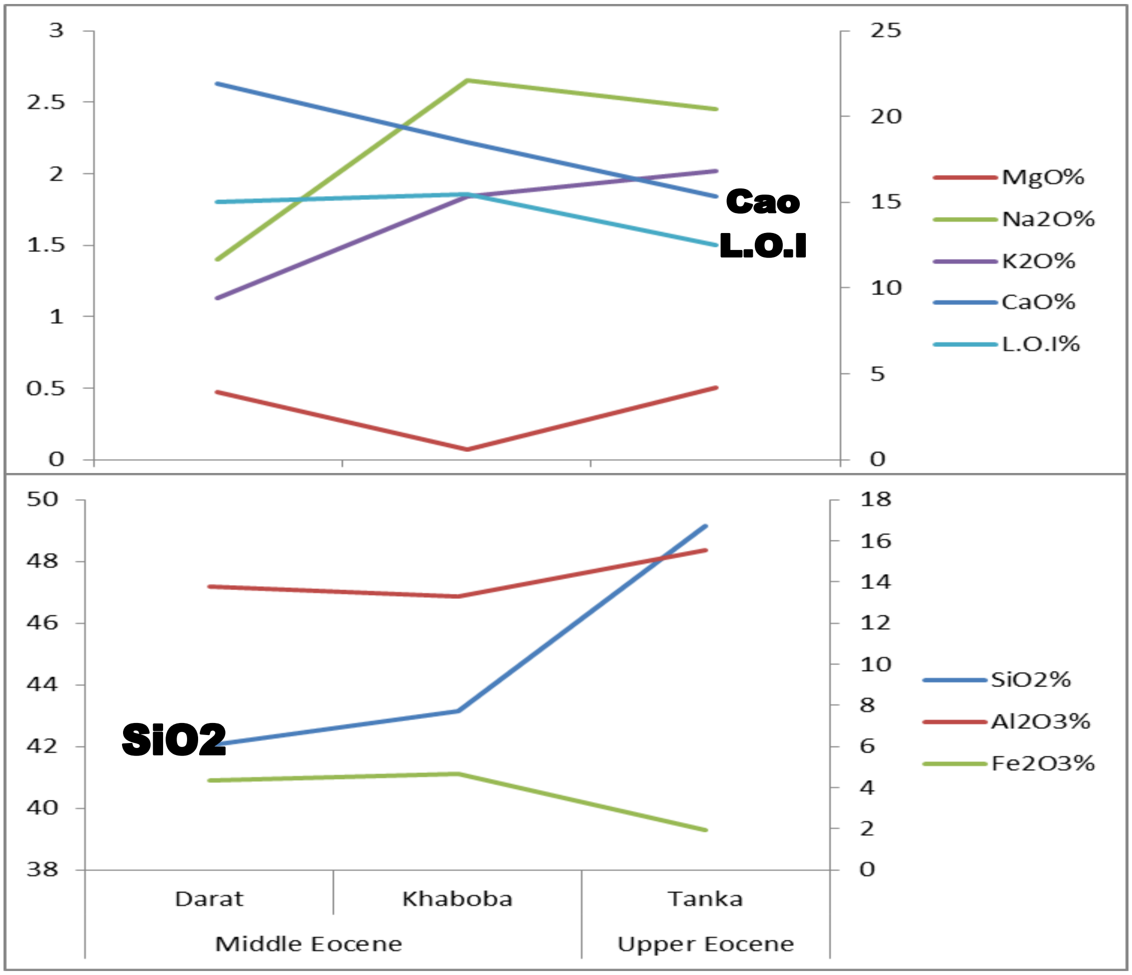

Fig. (6): distribution curve of average major oxides of Wadi Tayiba samples.

Table (5):Chemical composition (major oxides in wt %) of the Eocene clayes (Wadi Tayiba area).

Age	Formation	TOTAL	L.O.I %	Na_2O %	MgO %	CaO%	Fe_2O_3 %	Al_2O_3 %	SiO_2%	S. no.
Upper Eocene	Samalut	99.98	19.5	1.5	1.5	13.8	2.7	15.5	42.5	23
Early Eocene	Thebes	99.97	14	1.4	1.2	17	2.4	15.3	46	12
		99.99	21	0.04	1.11	21.12	2.3	14.5	38	3

Table (6): Avarege chemical composition (major oxides in wt%) of the Eocene clayes (Wadi Feiran area).

Age	Early Eocene		Middle Eocene
Formation	Thebes		Samalut
Sample. No	3 & 12		23
Chemical oxides	Range	Average	---
SiO_2%	38.00 – 46.00	42.00	42.5
Al_2O_3%	14.5 - 15.3	14.90	15.5
Fe_2O_3%	2.3 - 2.4	2.35	2.7
CaO%	17.00 - 21.12	19.06	13.8
MgO%	1.11 - 1.2	1.15	1.5
Na_2O%	0.4 - 1.5	0.95	1.5
K_2O%	1.5 - 1.8	1.65	1.8
L.O.I%	19.5 – 21.00	20.25	19.5

Aluminum Oxide

Alumina is similar to silica in its occurrence, where silica and alumina tend to organize together into clay minerals, if they do not alumina stays in situ with iron, whereas silica is removed with lime and magnesia *Millot (1970).* The alumina content in the Wadi Tayiba area, Middle Eocene (Darat and Khaboba formations) **(Tables No. 3&4 and Fig. 6)** ranges between 13.4% and 14.1% and between 12.8% and 13.8% with average of 13.75% and 13.3 % respectively. The alumina content in Wadi Tayiba area, Upper Eocene (Tanka Formation) ranges between 14.6% and 16.5% with an average of 15.55 %. The alumina content in the Wadi Feiran area, Early Eocene (Thebes Formation) **(Tables No. 5&6 and Fig. 7)** ranges between 14.5% and 15.3% with average of 14.90%. Middle Eocene (Samalut Formation) has an average of 15.5%.

The distribution of the alumina content recorded in Wadi Tayiba and Wadi Feiran areas shows an increasing in the alumina content from Early to Middle (Wadi Feiran) and from Middle to Upper Eocene (Wadi Tayiba) formations. According to *Pettijohn (1975),* the silica / alumina ratio is generally a good index of the grain size, the higher the silica content, and the lower the alumina the coarser the grain size. The silica / alumina ratio for the studied mud rocks **(Table No. 7 and Fig. 8)** indicates that the grain size of Wadi Tayiba area mud rocks is coarser than that of Wadi Feiran area. Suggesting that Wadi Tayiba area mud rocks are of the sandy type (sandy shale, sandy or silty clay). Again the predominance of silica content relative to the alumina content indicates that Wadi Tayiba area mud rocks were formed in warmer climatic zones *Corbel (1959), Henin, (1947) and Edelman (1947).*

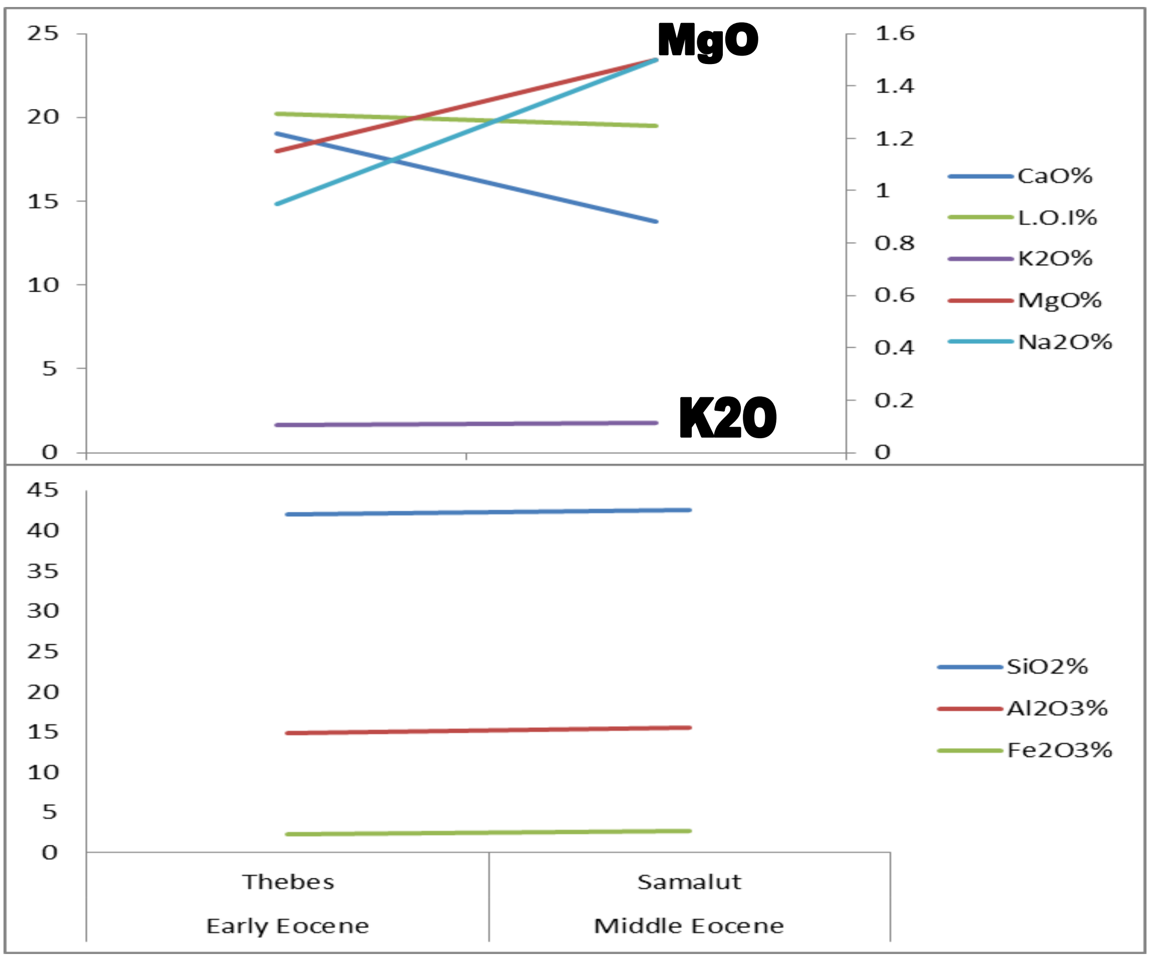

Fig. (7): Distribution curve of average trace mineral of Wadi Feiran samples.

Table (7): Silica/Alumina average/ratio of the Eocene mud rocks.

Age	Early Eocene	Middle Eocene			Upper Eocene
Study area	W. Feiran	W. Feiran	W. Tayiba		W. Tayiba
Formation	Thebes	Samalut	Darat	Khaboba	Tanka
SiO_2	42.00	42.5	42.05	43.15	49.15
Al_2O_3	14.90	15.5	13.75	13.3	15.55
SiO_2/Al_2O_3 ratio	2.82	2.74	3.06	3.24	3.16

***Millot (1949)*, presented the following lines A) in an environment from which cations are evacuated, either by weak lessivage in an acid environment or by vigorous lessivage in a natural environment , the solubility and stability of SiO_2 and Al_2O_3 are such that the new formation of clays of kaolinitic type in which the SiO_2/Al_2O_3 ratio equals two. B) in an environment in which solution is not renewed captions are abundant, producing a basic pH: The solubility and stability of SiO_2 and Al_2O_3 are such that the new formations of clays are of micaceous type in which the SiO_2/Al_2O_3 ratio is greater than 3. As noticed from **(Table 7)** the SiO_2/Al_2O_3 ratio of the of Wadi Tayiba mud rocks is greater than 3, that means cations are abundant, producing a basic pH and the new formation of clays are of micaceous type (Illite, Montmorillonite, Vermiculite and Chlorite) and not of kaolinitic type in which the SiO_2/Al_2O_3 equals two. It seems that Wadi Feiran mud rocks change from the clay to sandy through silty type in Wadi Tayiba area which was formed in warmer climatic zones under basic alkaline medium.

Sodium and Potassium Oxides

The sodium content in the Wadi Tayiba area, Middle Eocene (Darat and Khaboba formations) **(Tables No. 3&4 and Fig. 6)** ranges between 0.4% and 2.4% and between 2.6% and 2.7% with average of 1.40% and 2.65% respectively. The sodium content in Wadi Tayiba area, Upper Eocene (Tanka Formation) ranges between 2.3% and 2.6% with an average of 2.45%. The sodium content in the Wadi Feiran area, Early Eocene (Thebes Formation) **(Tables No. 5&6 and Fig. 7)** ranges between 0.4% and 1.5% with average of 0.95%. Middle Eocene (Samalut Formation) has an average of 1.5%.

The potassium content in the Wadi Tayiba area, Middle Eocene (Darat and Khaboba formations), **(Tables No. 3&4 and Fig. 6)** ranges between 0.33% and 1.93% and between 1.82% and 1.87% with average of 1.84% and 43.15% respectively. The potassium content in Wadi Tayiba area, Upper Eocene (Tanka Formation) ranges between 1.99% and 2.04% with an average of 2.02 %. The potassium content in the Wadi Feiran area, Early Eocene (Thebes Formation) **(Tables No. 5&6 and Fig. 7)** ranges between 1.5% and 1.8% with average of 1.65%. Middle Eocene (Samalut Formation) has an average of 1.8%. The distribution of both sodium and potassium contents recorded in Wadi Tayiba and Wadi Feiran areas **(Table No. 8 and Fig. 9)** show an increasing in content from Early to Middle (Wadi Feiran) and from Middle to Upper Eocene (Wadi Tayiba) formations.

Millot (1970)*, stated that crystalline igneous and metamorphic rock contain on the average as much potassium as sodium , and the K/Na ratio equals 2.8 for clays (or 2.94 in case of K_2O/Na_2O). According to ***Garrels & Christ (1965) and Weaver (1967), K /Na ratios are equally important (Low ratios favor the formation of Montmorillonite and chloritic materials and high ratios favor the formation of illite) and high values are more likely to occur in continental than marine environments.

Martens (1939), mentioned that the increase in K_2O is always toward the coarser fractions due to the presence of feldspars, consequently the decrease in K_2O suggests the scarcity of feldspars in Wadi Tayiba area relative to Wadi Feiran area. The computed ratio, **(Table No. 8 and Fig. 9)** favors the following:-

I. Since the K_2O/Na_2O ratios are almost less than 1.0 (Wadi Tayiba area) consequently the studied mud rocks are characterized by the predominance of silts over the clays. Moreover the X-ray study indicated the predominance of montmorillonite while illite (hydromica rich by K) is occasionally present.

II. The very low ratios are due to that montmorillonite and chlorites are the main clay minerals.

III. The predominance of Na_2O over K_2O (Wadi Feiran area) mostly points to that the weathering products were not transported to long distance from the source area which did not permit dissolution of Na due to hydrolysis as well as the sodium alumino-silicate minerals are dominant constituent of the crystalline rocks of the source area. Moreover, the crystalline rock of the source area was tightly chemically weathered leading to the migration of most of potassium in comparison with sodium *Vinogradove and Ronov (1956).*

Iron Oxide

The iron oxide content in the Wadi Tayiba area, Middle Eocene (Darat and Khaboba formations) **(Tables No. 3&4 and Fig. 6)** ranges between 4.2% and 4.5% and between 3.8% and 5.5% with average of 4.35% and 4.65% respectively. The iron oxide content in Wadi Tayiba area, Upper Eocene (Tanka Formation) ranges between 1.88% and 1.99% with an average of 1.93 %. The iron oxide content in the Wadi Feiran area, Early Eocene (Thebes Formation) **(Table No. 5&6 and Fig. 7)** ranges between 2.3% and 2.4% with average of 2.35%. Middle Eocene (Samalut Formation) has an average of 2.7%. The distribution of the iron oxide content recorded in Wadi Tayiba and Wadi Feiran areas shows an increasing in the iron oxide content from Early to Middle (Wadi Feiran) and from Middle to Upper Eocene (Wadi Tayiba) formations.

Calcium and Magnesium Oxides

The calcium content in the Wadi Tayiba area, Middle Eocene (Darat and Khaboba formations) **(Tables No. 3&4 and Fig. 6)** ranges between 18.6% and 25.2% and between 17.8% and 19.2% with average of 21.9% and 18.5% respectively. The calcium content in Wadi Tayiba area, Upper Eocene (Tanka Formation) ranges between 15.3% and 15.4% with an average of 15.35%. The calcium content in the Wadi Feiran area, Early Eocene (Thebes Formation) **(Tables No. 5&6 and Fig. 7)** ranges between 17.00% and 21.12% with average of 19.06%. Middle Eocene (Samalut Formation) has an average of 13.8%. The distribution of The calcium content recorded in Wadi Tayiba and Wadi Feiran areas shows an increasing in the calcium content from Early to Middle (Wadi Feiran) and from Middle to Upper Eocene (Wadi Tayiba) formations. The magnesium content in the Wadi Tayiba area, Middle Eocene (Darat and Khaboba formations) **(Tables No. 3&4 and Fig. 6)** ranges between 0.05% and 0.89% and between 0.06% and 0.08% with average of 0.47% and 0.07% respectively. The magnesium content in Wadi Tayiba area, Upper Eocene (Tanka Formation) ranges between 0.23% and 0.27% with an average of 0.5%. The magnesium content in the Wadi Feiran area, Early Eocene (Thebes Formation) **(Tables No. 5&6 and Fig. 7)** ranges between 1.11% and 1.2% with average of 1.15%. Middle Eocene (Samalut Formation) has an average of 1.5%. The distribution of The magnesium content recorded in Wadi Tayiba and Wadi Feiran areas shows an increasing in The magnesium content from Early to Middle (Wadi Feiran) and from Middle to Upper Eocene (Wadi Tayiba) formations.

Calcium and magnesium are considered to be two ions with similar characteristics. ***Pettijohn (1975)*** stated that “lime in the shales occur chiefly as the carbonate, and can also present in the form of Gypsum in some shales". ***Millot (1970)*** stated that “during the reorganization of clays by transformation from degraded minerals as well as by the new formation of magnesium clay minerals, magnesium is consumed in large quantities in the hydrosphere. Montmorillonite and illite are magnesium clay minerals whereas calcium does not come into play.

Table (8): K_2O/Na_2O average ratios of the Eocene mud rocks.

Age	Early Eocene	Middle Eocene			Upper Eocene
Study area	W. Feiran	W. Feiran	W. Tayiba		W. Tayiba
Formation	Thebes	Samalut	Darat	Khaboba	Tanka
K_2O	1.65	1.8	1.13	1.84	2.02
Na_2O	0.95	1.5	1.40	2.65	2.45

Abundance and Distribution of Trace Elements

The distribution of the trace elements in the crust of weathering is chiefly related to the degree of intensity of weathering rather than the composition of the mother rock. The elements Ti, Ni, Cu and Zn may be accumulated in the weathering crust rich by the clayey fractions. The organic matter plays an important role in enriching Cu, Ni, and P. ***Strakhov et al. (1959)*** considered that the chemical elements during their migration act variably depending on the physicochemical conditions of weathering; in case of migration in the form of colloidal and true solutions, most of the elements are adsorbed onto the clayey fractions. Consequently, the dispersed elements must be studied in the clays and never in the sand fractions in order to understand the long history of the units hosting these minerals ***Keith and Degens (1959).***

Fig. (8): Distribution curve of average trace mineral of Wadi Feiran samples.

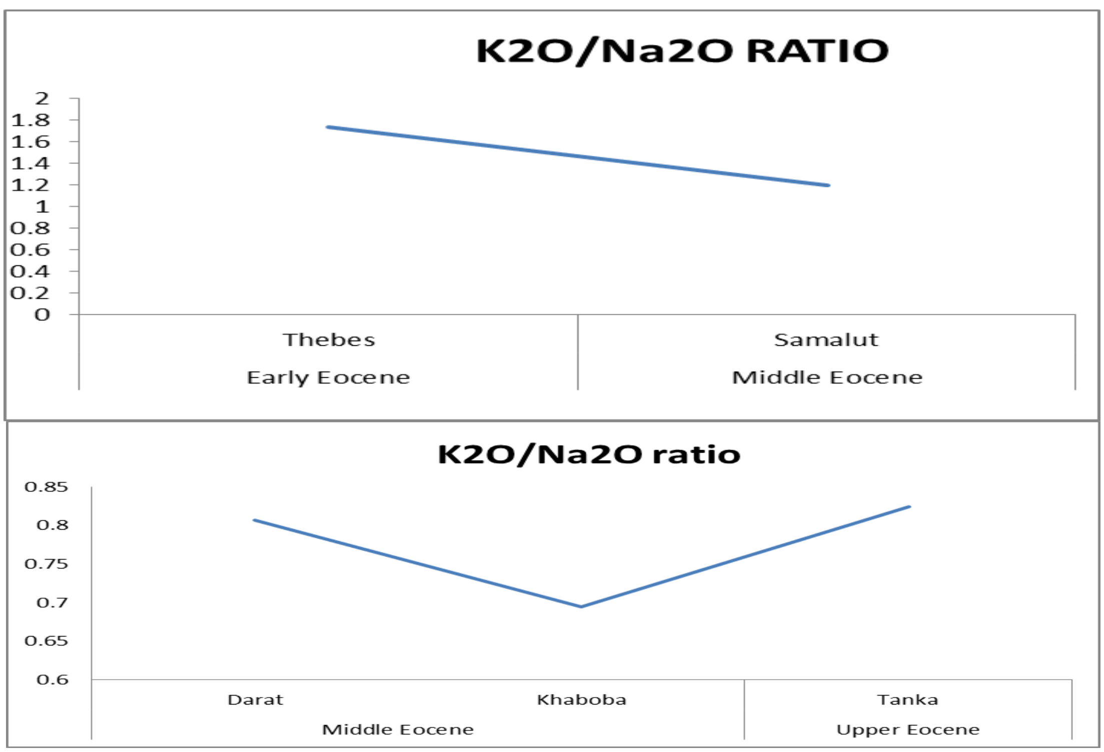

Fig. (9): Silica/alumina average/ratio of the Eocene mud rocks.

Titanium

Titanium is the most abundant trace element recorded in the Eocene mud rocks. At Wadi Tayiba area, Middle Eocene (Darat and Khaboba formations). The titanium content ranges between 300 and 400 ppm and between 800 and 900 ppm with averages of 350 ppm and 850 ppm respectively. The titanium content in Wadi Tayiba area, Upper Eocene (Tanka Formation) ranges between 150 and 1800 ppm with an average of 1650 ppm **(Tables No. 9&10 and Fig. 10).** At Wadi Feiran area, Early Eocene (Thebes Formation) the titanium content ranges between 5500 and 6500 ppm with average of 6000 ppm Middle Eocene (Samalut Formation) has an average of 5500 ppm **(Tables No. 11&12 and Fig. 11).** The distribution of titanium content recorded in Wadi Tayiba and Wadi Feiran areas shows an increasing in the Titanium content from Early to Middle (Wadi Feiran) and from Middle to Upper Eocene (Wadi Tayiba) formations. The higher titanium content of the Middle Eocene, Samalut Formation, (Wadi Feiran area) than those given by ***Turekian and Wedepohl (1961)*** (4,600 ppm) can be attributed to the occurrence of titanium in probably authigenic anatase and rutile and is also structurally bound in iron minerals ***Goldberg and Arrhenius (1958).***

Table (9): Chemical composition (Trace elements in ppm) of the Eocene clayes (Wadi Tayiba area).

Age	Formation	S. No.	P ppm	Mn ppm	Ti ppm	Sr ppm	Rb ppm	Pb ppm	Zn ppm	Cu ppm	Ni ppm	Cr ppm	V ppm	Ba ppm
Upper Eocene	Tanka	23	1200	2700	1800	247	74	27	25	29	14	73	80	203
		21	900	2200	1500	250	76	28	27	28	15	75	81	200
Middle Eocene	Khaboba	18	600	3200	1200	325	48	8	137	16	88	80	128	782
		17	800	2600	800	329	47	6	130	15	87	81	130	785
	Darat	16	900	2400	900	331	49	7	134	17	91	85	133	793
		9	400	1400	400	83	40	11	110	53	26	86	186	341

Isayeva (1971), suggested that under reducing environments titanium dissolved and can be adsorbed by clays. It seems that the prevailed conditions favor deposition of titanium as hydrolysates at low alkaline pH values under relatively oxidizing environment. Regarding the status of ***Arrhenius (1954),*** the different concentrations of titanium within the studied Eocene mud rocks reflect different rates of sedimentation which cause the higher Ti content for Middle Eocene Samalut Formation (Wadi Feiran area) relative to the studied Eocene Mud rock formations (Wadi Tayiba and Wadi Feiran areas).

Table (10): Avarege chemical composition (Trace elements in ppm) of the Eocene clayes (Wadi Tayiba area).

Age	Middle Eocene				Upper Eocene		Average concentration after Krauskopf (1979)
Formation	Darat		Khaboba		Tanka		
Sample. No	9&16		17 & 18		21& 23		
Trace Elements	Range	Average	Range	Average	Range	Average	
Ti	300 – 400	350	800 - 900	850	150 - 1800	1650	4600
Mn	900 -1400	115	2400 -2600	2500	2200-2700	2450	850
P	400 -1100	750	800 - 900	850	900 - 1200	1050	750
Sr	83 – 331	207	352 - 392	372	247 - 250	249	400
Rb	40 – 49	46	47 – 48	48	74 – 76	75	140
Pb	7 – 11	9	6 – 8	7	27 – 28	28	20
Zn	110- 134	122	130 – 137	134	25 – 27	27	90
Cu	17 -53	35	15 – 16	16	28 – 29	29	50
Ni	26 – 91	59	87 – 88	87	14 -15	15	80
Cr	85- 86	86	80 -81	81	73 -75	74	100
Ti	300 – 400	350	800 - 900	850	150 - 1800	1650	4600
Mn	900 -1400	115	2400 -2600	2500	2200-2700	2450	850

Phosphorous

At Wadi Tayiba area, Middle Eocene (Darat and Khaboba formations) the phosphorous content ranges between 400 and 1100 ppm and between 800 and 900 ppm with average of 750 and 850 ppm respectively. The phosphorous content in Wadi Tayiba area, Upper Eocene. (Tanka Formation) ranges between 900 and 1200 ppm with an average of 1050 ppm **(Tables No. 9&10 and Fig. 10).** At Wadi Feiran area, Early Eocene (Thebes Formation) the phosphorous content ranges between 500 and 3300 ppm with average of 1900 ppm. Middle Eocene (Samalut Formation) has an average of 3000 ppm **(Tables No. 11&12 and Fig. 11).** The distribution of the phosphorous content recorded in Wadi Tayiba and Wadi Feiran areas shows an increasing in the phosphorus content from Early to Middle (Wadi Feiran) and from Middle to Upper Eocene (Wadi Tayiba) formations. According to ***Turekian and Wedepohl (1961)*** the higher phosphorus content than that given by the Turkian and Wedepohl (750 ppm) for the studied Eocene mud rocks indicate that oxidizing conditions prevailed during the digenesis of the deposited sediments were favorable for phosphorus fixation.

Manganese

At Wadi Tayiba area, Middle Eocene (Darat and Khaboba formations) the manganese content ranges between 900 and 1400 ppm and between 2400 and 2600 ppm with average of 1150 and 2500 ppm respectively. The manganese content in Wadi Tayiba area, Upper Eocene (Tanka Formation) ranges between 2200 and 2700 ppm with an average of 2450 ppm **(Tables No. 9&10).** At Wadi Feiran area, Early Eocene (Thebes Formation) the manganese content ranges between 200 and 300 ppm with average of 250 ppm. Middle Eocene (Samalut Formation) has an average of 3000 ppm **(Tables No. 10&11).**

The distribution of manganese in the studied Eocene mud rocks does not show any particular trend. The higher manganese content than that given by ***Turekian and Wedepohl (1961),*** (850 ppm) can be attributed to that manganese is less mobile under oxidizing condition and it will be mobilized in reducing environment ***Manheim (1961), Wedepohl, (1964) and Hartmann(1964)***, It seems that the Eocene mud rocks were formed under oxidizing environments causing enrichment of manganese **(Figs. No. 10&11).**

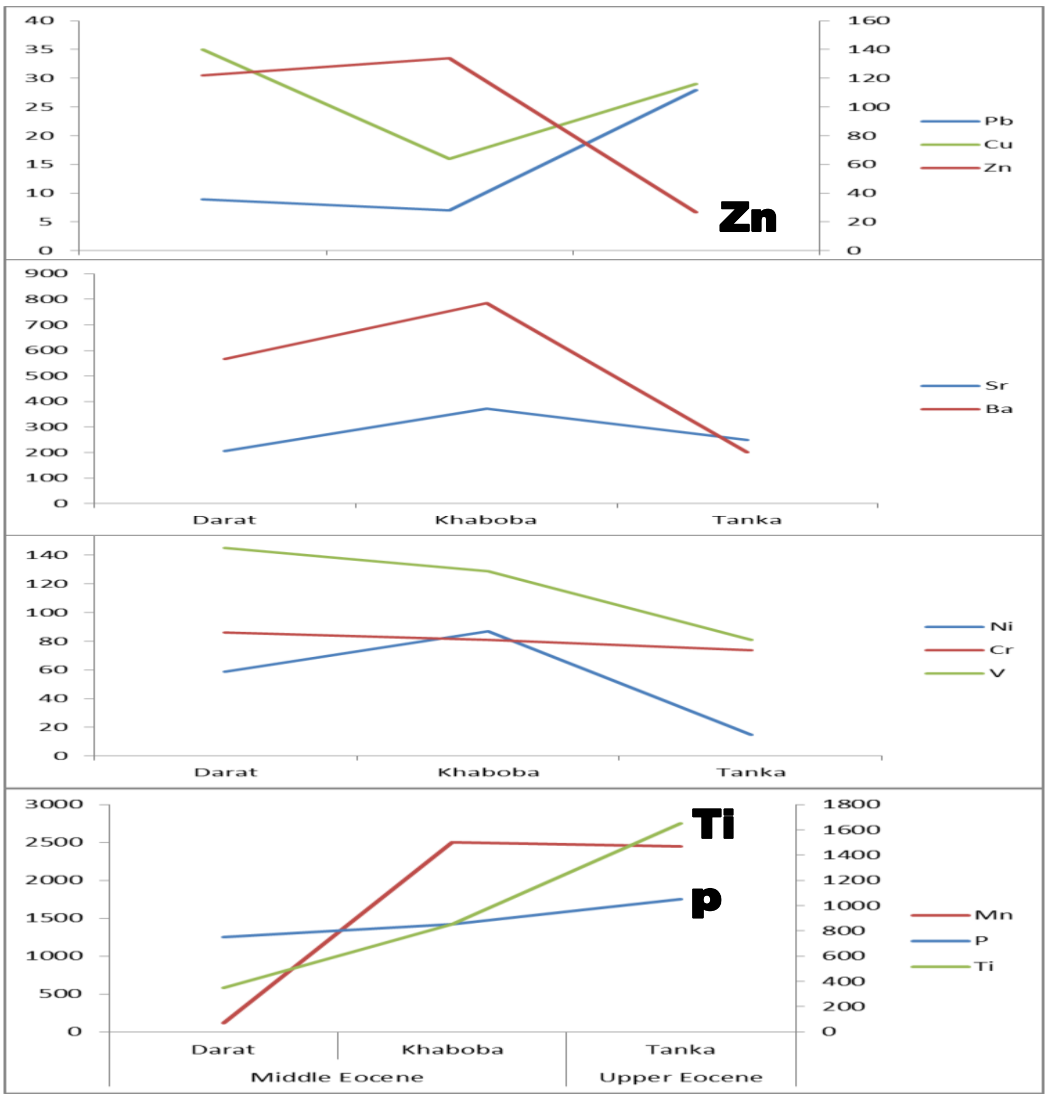

Fig. (10): distribution curve of average trace mineral of Wadi Tayiba samples.

Table (11): Chemical composition (Trace elements in ppm) of the Eocene clayes (Wadi Feiran area).

Age	Formation	S. No.	P ppm	Mn ppm	Ti ppm	Sr ppm	Rb ppm	Pb ppm	Zn ppm	Cu ppm	Ni ppm	Cr ppm	V ppm	Ba ppm
Middle Eocene	Samalut	23	3300	300	5500	75	22	0	75	3	15	25	27	530
Early Eocene	Thebes	12	1400	100	5300	50	24	0	80	4	13	31	25	550
		3	500	200	6500	340	26	0	60	0	0	9	18	793

Strontium

At Wadi Tayiba area, Middle Eocene (Darat and Khaboba formations) the strontium content ranges between 83 and 331 ppm and between 352 and 392 ppm with average of 207 and 372 ppm respectively. The strontium content in Wadi Tayiba area, Upper Eocene (Tanka Formation) ranges between 247 and 250 ppm with an average of 249 ppm **(Tables No. 9&10 and Fig. 10).** At Wadi Feiran area, Early Eocene (Thebes Formation) the strontium content ranges between 50 and 340 ppm with average of 195 ppm. Middle Eocene (Samalut Formation) has an average of 75 ppm **(Tables No. 11&12 and Fig. 11).**

The detected strontium in the studied mud rocks reveals the absence of any particular trend of distribution. The lower Sr content detected than the average given by ***Turekian and Wedepohl (1961)*** (400 ppm) can be attributed to the decrease in the supply of calcium and potassium where according to ***Krauskopf (1979),*** Sr^{+2} (1.2 A°) can substituted both Ca^{+2} (1.08 A°) so that its trend is a compromise between the trends of the two major elements. Strontium appears to be poor salinity indicators in mud rocks and it is especially corporate in the carbonate phase and suffers all the digenetic changes of the carbonates.

Barium

At Wadi Tayiba area, Middle Eocene (Darat and Kabob formations) the barium content ranges between 341 and 793 ppm and between 782 and 785 ppm with average of 567 and 784 ppm respectively **(Tables No. 9&10 and Fig. 10).** The Barium content in Wadi Tayiba area, Upper Eocene (Tanka Formation) ranges between 200 and 203 ppm with an average of 202 ppm. At Wadi Feiran area, Early Eocene (Thebes Formation), **(Tables No. 11&12 and Fig. 11).** The barium content ranges between 550 and 793 ppm with average of 617 ppm. Middle Eocene (Samalut Formation) has an average of 530 ppm. The distribution of barium trace element in the studied Eocene mud rocks shows that there is a decrease in the average barium content. The lower barium average content detected for the studied Eocene mud rocks is less than that given by ***Turekian and Wedepohl (1961),*** (600 ppm) indicating deposition under conditions of alkaline weathering causing leaching of barium.

Table (12): Avarege chemical composition (Trace elements in ppm) of the Eocene clayes (Wadi Feiran area).

Age	Early Eocene		Middle Eocene	Average concentration after Krauskopf (1979)
Formation	Thebes		Samalut	
Sample. No	3 , 12		23	
Trace Elements	Range	Range		4600
Ti	5500 – 6500	5500	4600	850
Mn	200 – 300	300	850	750
P	500 – 3300	3300	750	400
Sr	50 – 340	75	400	20
Pb	ND	ND	20	90
Zn	60 – 80	75	90	50
Cu	0 – 4	3	50	80
Ni	0 – 13	15	80	100
Cr	9 – 31	25	100	130
V	18 – 25	27	130	600
Ba	550 -793	530	600	4600

Lead

At Wadi Tayiba area, Middle Eocene, (Darat and Khaboba formations) The lead content ranges between 7 and 11 ppm and between 6 and 8 ppm with average of 9 and 7 ppm respectively **(Tables No. 9&10 and Fig 10).** The lead content in Wadi Tayiba area, Upper Eocene (Tanka Formation) ranges between 27 and 28 ppm with an average of 28 ppm. At Wadi Feiran area, Early Eocene (Thebes Formation) and Middle Eocene (Samalut Formation) lead is not detected **(Tables No. 11&12 and Fig. 11).** The detected averages lead content shows lower values than that driven by ***Turekian and Wedepohl (1961)***, (20 ppm), except for Wadi Tayiba, Upper Eocene, and Tanka Formation mud rocks which show higher values. The distribution of lead in the studied Eocene mud rocks does not show any particular trend. The low detected values of lead than that given by ***Turekian and Wedepohl (1961)*** can be attributed to the environment of deposition which was slightly alkaline, oxidizing environment where the Eh was relatively high ***Krauskopf (1979)***. The higher average lead content of Wadi Tayiba, Upper Eocene, and Tanka Formation mud rocks can be attributed to a decrease in Eh values.

Zinc

At Wadi Tayiba area, Middle Eocene (Darat and Khaboba formations) the zinc content ranges between 110 and 134 ppm and between 130 and 137 ppm with average of 122 and 134 ppm respectively. The zinc content in Wadi Tayiba area, Upper Eocene (Tanka Formation), ranges between 25 and 27 ppm with an average of 27 ppm **(Tables 9&10 and Fig. 10).** At Wadi Feiran area, Early Eocene (Thebes Formation), **(Tables No. 11&12 and Fig. 11).** The zinc content ranges between 60 and 80 ppm with average of 70 ppm. Middle Eocene (Samalut Formation) has an average of 75 ppm. The distribution of zinc in the studied Eocene mud rocks does not show any particular trend. The distribution of the zinc content recorded in Wadi Feiran areas shows an increasing in the zinc content from Early to Middle Eocene. At Wadi Tayiba area, Middle Eocene shows an increasing in the zinc content from Darat to Khaboba formations. Upper Eocene, Tanka Formation of Wadi Tayiba area shows a decreasing in the zinc content. The detected averages of zinc content show lower values, at Wadi Feiran area (Early and Middle Eocene) and at Wadi Tayiba (Upper Eocene) area, than that given by ***Turekian and Wedepohl (1961),*** (90 ppm). According to ***Krauskopf (1979),*** Zn (ionic radii =0.83 A°) follows Mg (ionic radii = 0.80 A°) in its way of distribution.

Copper

At Wadi Tayiba area, Middle Eocene (Darat and Khaboba formations) the copper content ranges between (17 and 53 ppm) and between (15 and 16 ppm) with averages of 35 and 16 ppm respectively. The copper content in Wadi Tayiba area, Upper Eocene (Tanka Formation) ranges between 28 and 29 ppm with an average of 29 ppm **(Tables No. 9&10).** At Wadi Feiran area, Early Eocene (Thebes Formation) the copper content ranges between 0.00 and 4 ppm with average of 2 ppm. Middle Eocene (Samalut Formation) has an average of 3 ppm **(Tables No. 11&12).** Copper distribution curve in the studied Eocene areas, mud rocks does not show any particular trend **(Figs. No. 10&11).** At the same time the averages detected are lower than that given by ***Turekian and Wedepohl (1961),*** (50 ppm). ***Kukal (1971),*** stated that "copper is inferred to be appreciably concentrated in manganese concretions, it also occurs in sediments with an increased amount of organic matter. Copper distributions are not related to that of manganese in the studied mud rocks enhancing the deposition of copper with organic matter.

Nickel

At Wadi Tayiba area, Middle Eocene (Darat and Khaboba formations) the nickel content ranges between 26 and 91ppm and between 87 and 88 ppm with average of 59 and 87 ppm % respectively. The nickel content At Wadi Tayiba area, Upper Eocene (Tanka Formation) ranges between 14 and 15 ppm with an average of 15 ppm **(Tables No. 9&10).**

At Wadi Feiran area, Early Eocene (Thebes Formation) the copper content ranges between 0.00 and 13 ppm with average of 7 ppm. Middle Eocene (Samalut Formation) has an average of 15 ppm **(Tables No. 11&12).** The distribution of nickel content in the studied, Eocene areas, mud rocks does not show any particular trend for distribution at the same time the averages detected are lower than that given by ***Turekian and Wedepohl (1961),*** (80 ppm) **(Figs. 10&11).**

According to ***Landegren and Manheim (1963)*** the contribution of Ni is due to adsorption reactions in the sea and biological processes. For the studied, Eocene areas, mud rocks correlation between Nickel and Magnesium enhances their relation to Magnesium distribution, proving their occurrence with the magnesium clay minerals.

Chromium

At Wadi Tayiba area, Middle Eocene (Darat and Khaboba formations) the chromium content ranges between 85 and 86 ppm and between 80 and 81 ppm with averages of 86 and 81 ppm respectively. The chromium content at Wadi Tayiba area, Upper Eocene (Tanka Formation) ranges between 73 and 75 ppm with an average of 74 ppm **(Tables No. 9&10).**

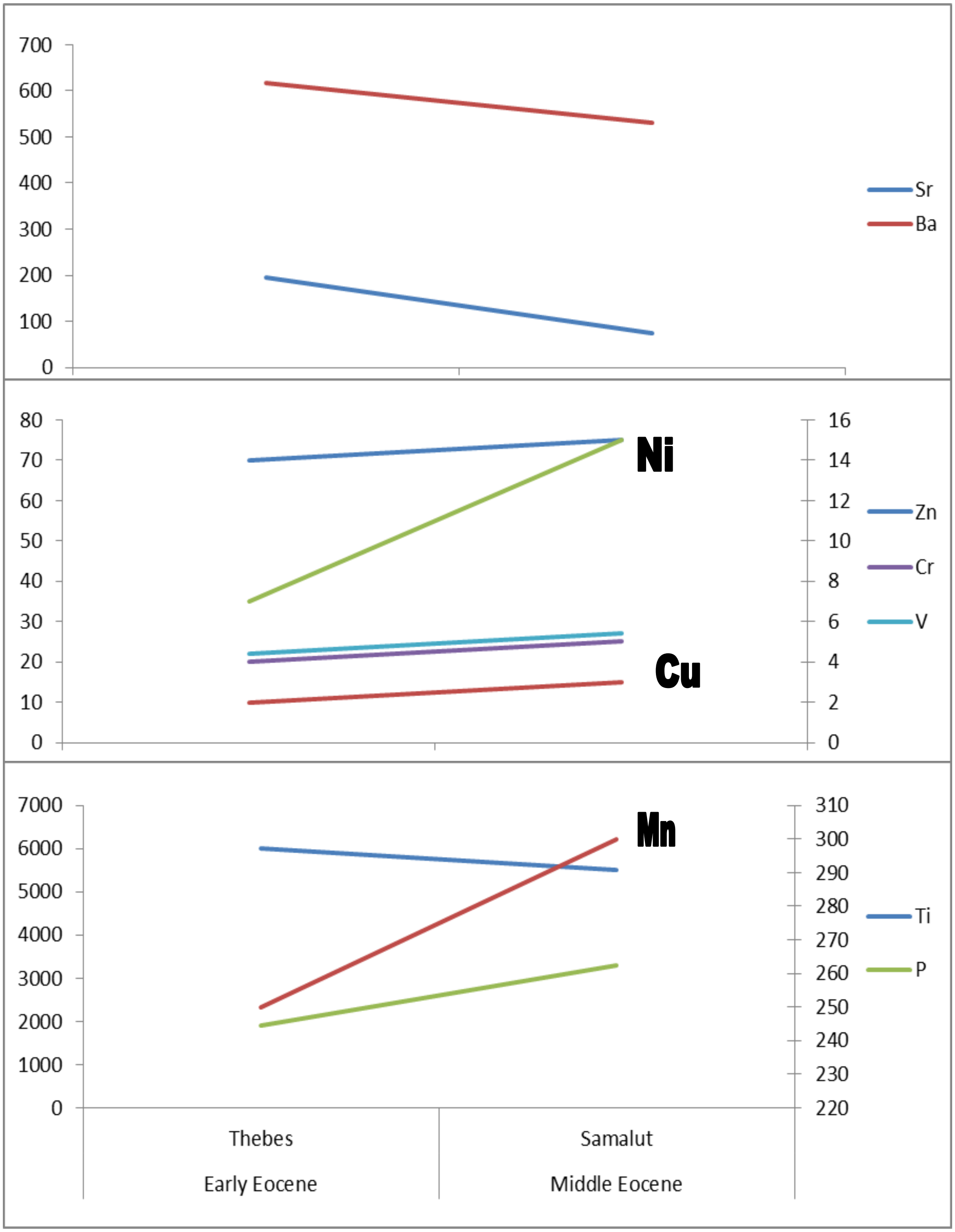

Fig. (11): Distribution curve of average trace mineral of Wadi Feiran samples.

At Wadi Feiran area, Early Eocene (Thebes Formation), the chromium content **(Tables No. 11&12)** ranges between 9 and 31 ppm with average of 20 ppm. Middle Eocene (Samalut Formation) has an average of 25 ppm. According to ***Turekian and Wedepohl (1961),*** the averages detected are lower than that given by ***Turekian and Wedepohl (1961),*** (100 ppm). The lower detected values indicate increasing in oxidation potential during diagenesis causing chromium migration.

Vanadium

At Wadi Tayiba area, Middle Eocene (Darat and Khaboba formations), the vanadium content ranges between 133 and 156 ppm and between 128 and 130 ppm with average of 145 and 129 ppm respectively. The vanadium content in Wadi Tayiba area, Upper Eocene (Tanka Formation) ranges between 80 and 81 ppm with an average of 81 ppm. **(Tables No. 9&10).**

At Wadi Feiran area, Early Eocene (Thebes Formation), the vanadium content ranges between 18 and 25ppm with average of 22 ppm Middle Eocene (Samalut Formation) has an average of 27 ppm **(Tables No. 11&12).** According to ***Turekian and Wedepohl (1961)***, the averages detected are lower than (130 ppm). The lower detected values indicate increasing in oxidation potential during digenesis causing vanadium migration. Or that it was deficient in the source crystalline igneous rock also the scarcity of magnetite and illuminate minerals may be the reason of such deficiency.

6. Summary and Conclusions

The present paper deals with the lithostratigraphy, mineralogy and geochemical studies on Eocene rocks exposed at the Southwestern Sinai along the Western side of the Gulf of Suez. The study area lies between latitudes 28º 40' 00" and 29º 10' 00" N. and longitudes 33º 00' 00" and 33º 30' 00" E.

Lithostratigraphically: Eocene successions exposed in the Southwestern part of Sinai are represented mainly by carbonate predominance. The Eocene successions recorded in the study areas range in thickness from 152 meters (at Wadi Tayiba) to 408 meters (at Wadi Feiran). Lower, Middle and Upper Eocene rocks, of the study areas, are represented by five formations namely; Thebes (Lower-Middle Eocene), Darat and Samalut (Middle Eocene), Khaboba (Middle-Late Eocene) and Tanka (Upper Eocene) formations.

Clay mineral composition studies favor the presence of montmorillonite, illite and kaolinite clay minerals. It is clear that the environment of deposition for the clay minerals identified was alkaline environment and that the origin of the clay minerals present is chloritic more probably than illite origin where montmorillonite, and illite can be derived from weathering of chlorite rapid than weathering from illite.

Clay geochemical studies reveal that, the distribution of the silica and the alumina contents recorded in Wadi Tayiba and Wadi Feiran areas shows an increasing in the silica content from Early to Middle (Wadi Feiran) and from Middle to Upper Eocene (Wadi Tayiba) formations.

The Eocene marine basin of deposition was relatively alkaline, close to the landmass that supplied the basin of deposition by quartz and clays.

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