

Mineralogical and Geochemical Studies on Some Early Miocene Sediments of Southwestern Sinai, Egypt

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Abstract

The present work provides a comparison and a contrast of the lithostratigraphy, mineralogy, and geochemistry of the early Miocene rocks exposed in El-Markha and Wadi Gharandal sections (Nukhul and Rudeis formations) at Southwest Sinai. Miocene succession of Southwest Sinai is classified from base to top into: Nukhul and Rudeis formations. Rudeis Formation unconformably overlies Nukhul Formation and unconformably underlies Kareem Formation. The Early Miocene sequence revealed the presence of calcite as the dominant minerals in the nonclastic rocks. Quartz is the main mineral in the clastic rocks, while goethite is most important minerals in the iron-rich sand, whereas halite is foremost minerals in evaporate samples. Hematite, kaolinite, halite and gypsum are the secondary minerals constituting the studied rock units with varying amount. The foremost clay minerals present in Nukhul Formation are montmorillonite and kaolinite. In Rudeis Formation, the main clay minerals is montmorillonite. Geochemically, the studied sections are characterized by higher percentage of SiO₂ and Fe₂O₃ in iron-rich sand. SiO₂, Fe₂O₃ and Al₂O₃ gathering to form the ferruginous and glauconitic sandstone. The high content of SiO₂, Na₂O, Cl, CaO and SO₃ as main elements of compound together and forming gypsum and evaporitic sandstone. On the other hand, the high content of CaO and MgO gathering to give limestone, dolomitic limestone and dolomite. So, through the light on the geochemical conditions the two different formations are deposited.

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1. Introduction

The Miocene rocks in the Gulf of Suez areas have been studied by several authors (Said and El Heiny, 1967; El-Bakry et al., 2010; Hewaidy et al., 2012; Al-Husseiny, 2012; Abd El-Hafez et al., 2015). The Miocene sediments in the study areas are located between latitudes 29° 14' and 29° 18' N and longitudes 32° 55' and 33° 00' in Wadi Gharandal section. El Markha section is located between latitudes 29° 00' and 29° 03' N and longitudes 33° 10' and 33° 16' (Fig. 1).

The Miocene sediments developed on both rifts and in the central sub-basins display two markedly contrast sedimentary facies, a marginal and a deeper marine. The deeper marine facies is subdivided into two major groups namely Gharandal and Ras Malaab. On the other hand, the marginal (costal) marine facies is divided into four formations from base to top, namely Abu Gerfan, Gharamul, Gemsa and Sarbut El- Gamal respectively (El-Azabi, 1997). The Early Miocene is started with the deposition of algal limestone that changed later into fan-conglomeritic facies under the effect of the tectonic events (Abul-Nasr and Salma, 1999). The Nukhul Formation is Last Oligocene – Early Miocene age implying the Suez rift system started in the Oligocene. This study is based on the results of a biostratigraphic study of the Nukhul Formation at Wadi Babaa (Hewaidy et al., 2012). The Lower Miocene rocks can be classified into clastic (sandstones and argillaceous) and non-clastic (carbonate rocks with thin

evaporitic intercalations). The microscopic examination revealed different sandstone microfacies types such as: quartz arenite, calcareous quartz arenite, ferruginous quartz arenite, evaporitic quartz arenite, glauconitic quartz arenite and ferruginous evaporitic quartz arenite. The carbonate microfacies types in the studied formations include sandy micrite, biosparite, foraminiferal biomicroite, dolo-biomicroite, dolosparite, dolostone, pelsparite, oo-biosparite and evaporitic dolomicroite (Abd El-Hafez et al., 2015). The present work aims to shed more light at the lithostratigraphical, mineralogical and geochemical properties to evaluate the influence of geochemical conditions on the mineralogical composition.

2. Materials and Methods

To achieve this target, samples were collected to represent the different mineralogical and geochemical conditions. These samples were studied as follows:

2.1 X-ray diffraction (XRD)

Sixty-seven samples were selected and analyzed by XRD to identify the mineralogical composition. The analysis was carried out at the Egyptian Geological Survey and Mining Authority (central laboratories sector), using automated powder diffractometer system of Philips type Pan Alytica X-pert-pro with Ni-filter, Cu-radiation ($\lambda=1.542 \text{ \AA}$) at 40kV, 30mA and a normal scanning speed 0.02°/S. The reflection peaks between $2\theta = 2^\circ$ and 60° were obtained for the un-oriented analysis and between (2° - 35°) 2θ for the

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been overprinted twice by two major tectonic movements: the mid-Rudies and post-Kareem event (Abul-Nasr et al., 1999). The Nukhal Formation in the studied section is represented by limestone, sandstone and shales. Limestones are grayish white to yellow in color, massive, siliceous, hard, compact, dolomitic and fossiliferous lithofacies. Sandstones are yellow to reddish brown, compact, ferruginous, argillaceous with some salt intercalation. Shales are yellow brown to grayish in color, compact with veinlets of evaporities (Abd El-Hafez, 1986). The Rudeis Formation is formed of shale, sandstone and limestones. Shale are varicolored (greenish brown, grey, yellowish grey, yellowish brown and light grey) silty, semi-compact, ferruginous, calcareous, laminated high fossiliferous

lithofacies, (El-Bakry et al. 2010).

To achieve objectives of the present work, two early Miocene stratigraphic sections are represented; one in El-Markha and the second at Wadi Gharandal as follows:

3.1 El-Markha Section

The sedimentary succession of El-Markha section is represented by the Nukhul and Rudeis formations, which is about 170m thick together; Nukhul Formation is about 100m thick. It is unconformably capped by the Rudeis Formation which is 70m thick, and unconformably overlies Tayiba Formation of the Upper Oligocene. The Rudeis Formation is unconformably overlain by Kareem Formation of the Middle Miocene age (Fig. 2).

Period	Epoch	Age	Rock units				Thickness m.	Sample No.	Lithology	Description
			Group	Formation	Member					
Tertiary	Neogene	M. Miocene	Langhian	Ras Maalat	Kareem	Rhami				Shale: Brown grey to brown compact, gypsum veinlets fissile, ferruginous and siliceous.
				Gharandal	Rudies	Mreir	24	34-38		Limestone: Yellowish white hard, compact, fossiliferous, evaporitic patch, brownish yellow sandstone in lower part.
		Burdigalian	Asl			11	31-33		Shale: multi-colored (brown grey, brown, greenish grey), silty, semi compact, ferruginous, intercalation of yellow compacted limestone.	
			Mheiherratt			35			Sandstone: Yellowish to reddish brown, hard, compact, gypsiferous, evaporitic, intercalation of yellowish to brownish saltbed, brownish gray, silty, semi-compact and calcareous, ferruginous shale.	
		Early Miocene	Agutiantian	Nukhul			100	1-30		Limestone: Yellowish white, hard, compact, fossiliferous, reddish yellow ferruginous dolomite in the upper part.
										Sandstone: Yellowish to reddish brown, very dense, compact ferruginous rust-colored (bearing iron), argillaceous, intercalation of yellowish brown of salt bed.
										Limestone: Yellowish to white, massive, hard, compact fossiliferous, intercalation of reddish brown, to brownish yellow dolomite with brownish yellow, evaporitic sandstone with conglomerate bed at the base not exposure.
	Paleogene	Upper Oligocene	Chattian						Limestone: Yellowish to grayish white, massive, hard, compact, grayish brown to brownish yellow, evaporitic shale intercalation.	

Figure 2. Lithostratigraphic columnar section of Early Miocene sequence in El-Markha section, Southwest Sinai, Egypt.

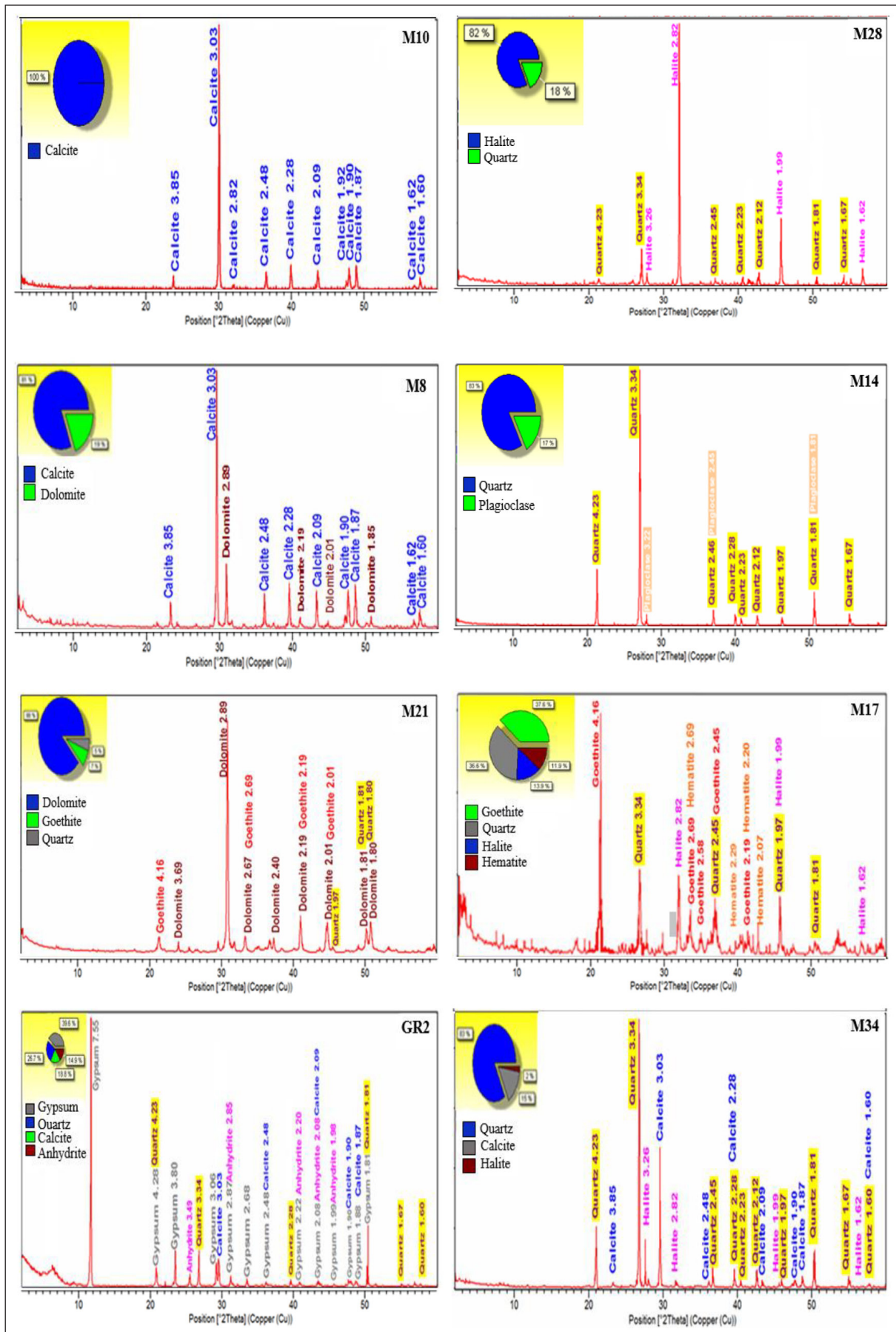


Figure 4. X-Ray Diffraction chart of the studied bulk samples of the studied sections.

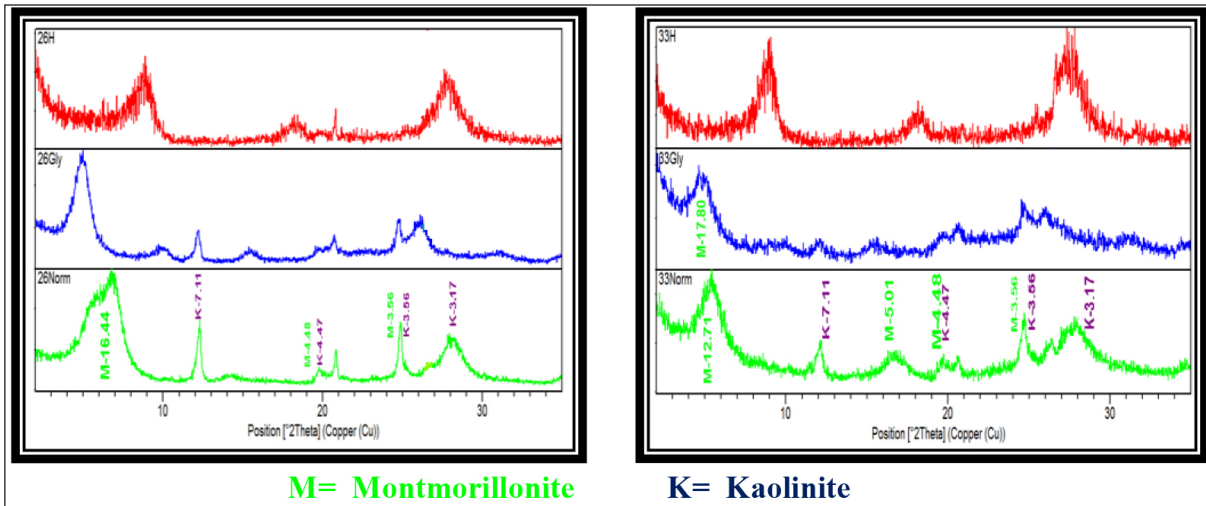


Figure 5. X-Ray Diffraction pattern of the studied clay rich samples in El-Markha section (Samples No. 26 and 33).

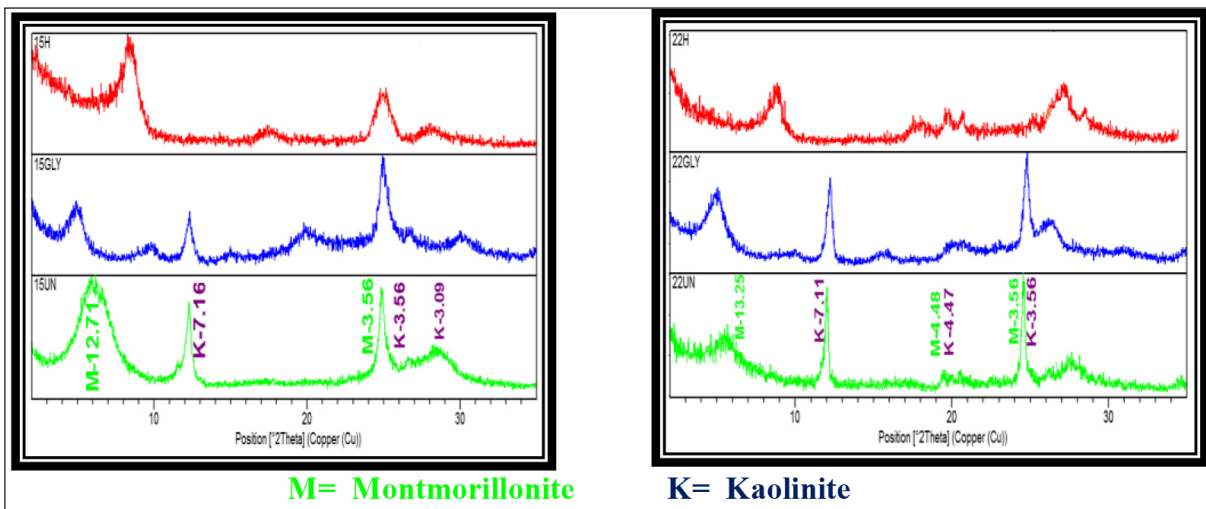


Figure 6. X-Ray Diffraction pattern of the studied clay rich samples in Wadi Gharandal section (Samples No. 15 and 22).

Montmorillonite is the most common mineral in shale of all rock units. Nukhul Formation samples contain montmorillonite about (52.63-72.03 %) with an average 60.91 %, while the samples of the Rudeis Formation are composed of (31.27-85.26 %) with an average 60.95 % of this mineral, (Figs. 5, 6, and 11).

Kaolinite is the most minor mineral in shale of all rock units excluding two samples (19 and 44) of the Rudeis Formation at Wadi Gharandal section where it is the main component. Nukhul Formation contains 27.97-47.37% with an average of 39.09% while Rudeis Formation contains of 14.74-68.73% kaolinite with an average of 39.05% (Figures 5, 6 and 10).

4.1.2 Semi-quantitative determination of clay minerals

The semi-quantitative analysis of the studied samples is shown in Tables (1 and 2) and Figures (7 and 8). This method is mentioned by Pierce and Siegel (1969) and Siegel et al., (1981) to detect the clay minerals by using the peak height of the strongest reflections of the individual clay minerals.

Table 1. Relative frequency distribution of the detected clay minerals (wt. %) in the studied samples (El-Markha section).

Age	For.	Mem.	S.No	Montmorillonite	Kaolinite
Early Miocene	Rudeis	Asl	33	85.71	14.29
			31	75.68	24.32
	Hawara		26	82.76	17.24
			22	57.14	42.86

Table 2. Relative frequency distribution of the detected clay minerals (wt. %) in the studied samples (Wadi Gharandal section).

Age	For.	Mem.	S.No.	Montmorillonite	Kaolinite
Early Miocene	Rudeis	Asl	44	31.27	68.73
			38	85.26	14.74
		Hawara	36	82.76	17.24
			32	76.1	23.9
			29	52.94	47.06
			22	60.53	39.47
			19	44.37	55.63
			18	54.4	45.6
	Nukhul	17	72.03	27.97	
		16	70.92	29.08	
		15	56.9	43.1	
		10	57.98	42.02	
		8	52.63	47.37	
		6	55	45	

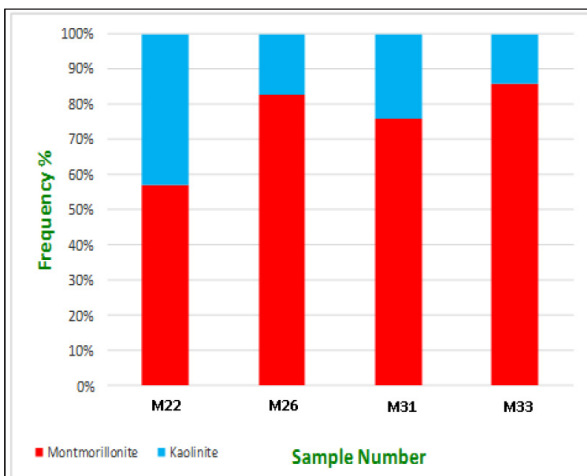


Figure 7. Frequency distribution of the detected clay minerals in the studied samples (El-Markha section).

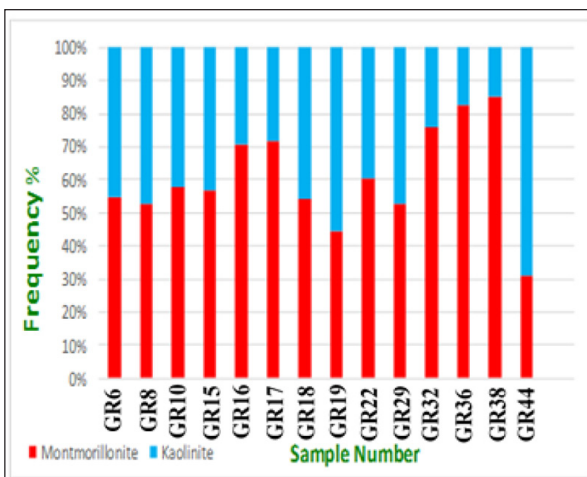


Figure 8. Frequency distribution of the detected clay minerals in the studied samples (Wadi Gharandal section).

4.1.3 Mineralogical Composition by Scanning Electron Microscopy

A petrographical study when combined with scanning electron microscope (SEM) investigations (Figs. 9, 10, 11, and 12) provides a good mean in identifying the mineralogical characteristics and the diagenetic process affecting the rock forming minerals. (El-Hariri, 2008 and Mousa et al., 2009).

The following SEM study is used to illustrate and identify the authigenic minerals, pore geometry and diagenetic events produced by different environments for examining sandstone, limestone, and clay minerals (Nukhul and Rudeis formations):

- 1- Dolomite crystal is shown in Figure 9, sample No. 4, Nukhul Formation at Markha section.
- 2- Kolinit is shown in Figure 10, sample No. 27, Rudeis Formation at Wadi Gharandal section.
- 3- Montmorillonite is shown in Figure 11, sample No. 27, Rudeis Formation at Wadi Gharandal section.
- 4- Iron oxides (Hematite and goethite in Figure 12, Sample No. 16, Nukhul Formation (El-Markha section).

5. Geochemical Composition

The main objective of the geochemical studies is to investigate the compositional variations of the studied samples and the vertical and lateral changes of the major and trace constituents and its mutual relationship. The following discussion is focused on the major and trace element response to the physicochemical conditions and deals with the abundance and distribution of these elements.

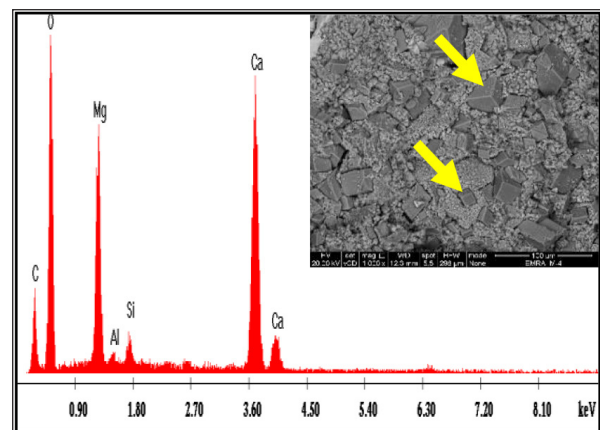


Figure 9. EDX and SEM photomicrograph showing dolomite crystals (arrows). Sample No. 4, Nukhul Formation (El-Markha section).

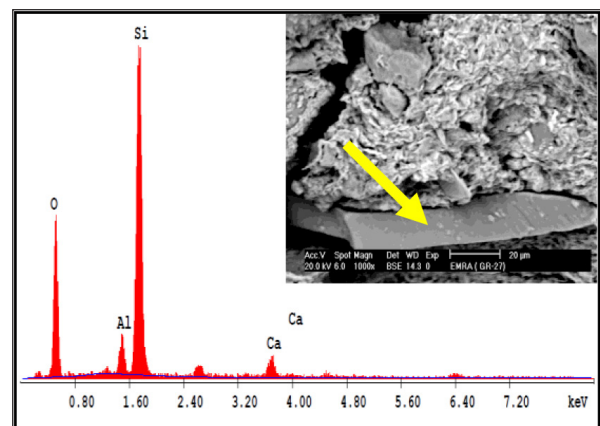


Figure 10. EDX and SEM photomicrograph showing kaolinite (arrow). Sample No. 27, Rudeis Formation (Wadi Gharandal section).

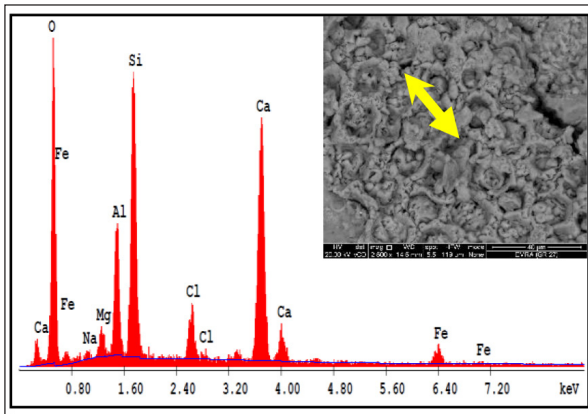


Figure 11. EDX and SEM photomicrograph showing montmorillonite mineral (arrow). Sample No. 27, Rudeis Formation (Wadi Gharandal section).

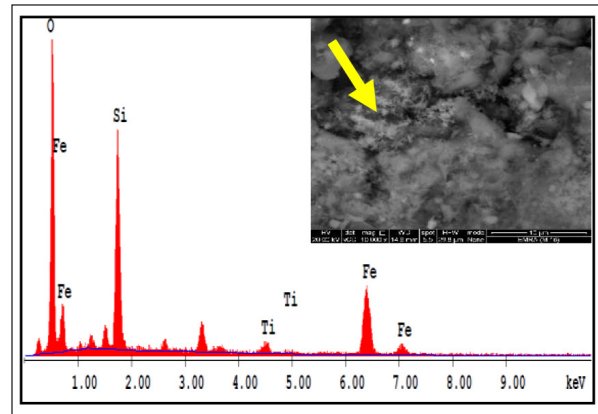


Figure 12. EDX and SEM photomicrograph showing iron oxides (goethite & hematite) (arrow). Sample No. 16, Nukhul Formation (El-Markha section).

Forty-two samples representing El-Markha and Wadi Gharandal sections were chemically analyzed for their major and trace elements.

The obtained data of both major and trace element constituents in the studied Early Miocene rocks with the average composition of each rock unit is given in Tables 3

and 4. The average composition of each studied rock unit is compared with those reported by other workers as shown in Table 5. The vertical distributions of the elements in the studied Lower Miocene successions are shown in Figures 13 and 14. The cluster analysis from the studied two sections are shown in Figure 15.

Table 3. Major oxides in wt. % and Trace elements in ppm of the Early Miocene rocks (El-Markha section).

Age	Rock units		S. No.	Major element oxides %													Ba	Sr	Cr
	Form.	Mem.		SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	K ₂ O	Na ₂ O	P ₂ O ₅	SO ₃	Cl	L.O.I			
Early Miocene	Burdigalian	Rudeis	M38	17.02	0.18	2.79	1.64	0.02	5.22	32.8	0.23	3.01	0.13	0.4	2.12	34.16	430.9	257.9	64.8
			M35	16.22	0.38	4.35	5.04	0.13	7.8	27.42	0.45	4.5	0.21	0.3	3.13	30.07	452.6	184.9	148.1
			M34	55.01	0.65	2.9	2.26	0.06	1.47	17.41	0.78	2.81	0.15	0.4	1.9	14.03	464.3	270.1	66.6
			M33	44.2	0.81	17.25	4.05	0.01	6.01	1.04	0.84	7.72	0.05	0.7	6.92	10.15	502.4	235.2	110.9
			M32	2.49	0.04	0.26	1.27	0.12	0.69	53.2	0.02	0.32	0.14	0.2	0.08	4.09	348.3	152.5	28.5
		M31	47.32	0.89	18.65	2.93	0.01	2.66	1.26	0.41	9.15	0.09	0	8.21	8.07	530.4	209.5	117	
		M30	39.91	0.58	4.1	8.66	0.01	3.23	0.79	0.5	15.2	0.12	0.3	13.9	12.68	504.7	175.5	285	
		M29	34.84	0.15	2.63	8.13	0.34	3.14	2.4	0.4	10.52	0.24	0.3	12	24.55	372	118.8	11.2	
		M28	16.24	0.17	4.72	2.69	0.03	2.31	0.97	0.42	19.03	0.09	0.4	17.7	35.28	425.1	118.7	106.1	
		M26	45.75	0.86	16.2	3.67	0.01	5.65	0.32	0.54	5.57	0.05	0.3	7.04	13.98	558.3	132.9	108.7	
	M24	22.46	0.36	7.48	2.65	0.02	0.81	0.22	0.25	18.33	0.05	1.2	17.5	28.54	444.4	106.6	77.1		
	M23	73.28	0.71	12.75	2.94	0.03	1.47	0.65	1.46	1.9	0.1	0.1	1.1	3.42	619.8	117.6	103.4		
	M22	49.85	1.18	19.35	3.99	0.01	4.15	3.85	0.83	1.48	0.01	0.1	2.33	12.8	583.9	277.1	116.9		
	A ver.	35.74	0.535	8.73	3.84	0.062	3.435	10.95	0.548	7.656	0.11	0.3	7.21	20.66	479.8	181.3	103.4		
	M21	4.7	0.04	0.42	7.12	0.37	22.15	23.8	0.07	0.4	0.07	0.5	0.8	39.3	317.9	113	57		
	M20	6.7	0.06	0.83	14.6	0.36	3.86	35.79	0.27	2.25	0.35	0.3	3.53	31.02	245.7	95.5	87.6		
	M19	42.7	0.31	6.32	8.64	0.09	2.46	1.07	0.39	11.1	0.14	0.8	10.2	15.49	376.7	105.3	74.2		
	M17	16.16	0.11	0.99	47.65	0.74	1.71	2.25	0.05	3.87	1.17	0.7	5.82	21.48	196.2	57	125.9		
	M16	48.83	0.69	0.46	10.39	0.3	1.59	0.82	0.68	11.41	0.07	0.1	12.9	11.5	432.9	96.2	103.6		
	M13	21.1	0.26	0.26	3.35	0.08	0.86	5.69	0.59	21.15	0.12	1.3	24	20.96	418.2	88.9	57.3		
M10	0.26	0.01	0.08	0.46	0.05	0.23	54.57	0.06	0.23	0.14	0.6	0.26	42.75	329.9	166.2	31.11			
M8	0.54	0.01	0.04	1.33	0.05	3.85	52.4	0.01	0.02	0.12	0.8	0.01	40.54	337.6	175.2	32.1			
M4	4.21	0.12	0.34	0.5	0.07	22.01	26.75	0.55	2.8	0.08	0.4	2.1	40.01	376.6	178.3	43.2			
M3	44.43	0.71	4.13	2.46	0.02	1.86	2.7	1.38	12.8	0.21	1.7	15.1	12.23	547.8	439.7	71			
M2	2.23	0.01	0.08	0.44	0.02	0.52	53.93	0.04	0.01	0.1	0.6	0.01	41.78	340.2	236.4	28.4			
M1	12.4	0.05	1.2	3.01	0.12	4.27	39.2	0.01	2.03	0.34	0.5	2.4	34.3	330.8	152.9	39.1			
A ver.	17.022	0.198	1.26	8.33	0.19	5.44	24.9	0.34	5.67	0.24	0.69	6.43	29.3	354.21	158.7	62.54			

The mineralogical and chemical composition of clastic sedimentary rocks is controlled by various factors, including:

- (1) The composition of their source rocks.
- (2) Environmental parameters influencing the weathering of source rocks (e.g., atmospheric chemistry, temperature, rainfall and topography).

Table 4. Major oxides in wt. % and Trace elements in ppm of the Early Miocene rocks (Wadi Gharandal).

Age	Rock units		S. No.	Major element oxides %													Trace				
	Form.	Mem.		SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	K ₂ O	Na ₂ O	P ₂ O ₅	SO ₃	Cl	L.O.I	Ba	Sr	Cr	Pb	Rb
Early Miocene	Burdigalian	Rudeis	GR63	1.01	0.02	0.21	0.24	0.01	1.03	53.1	0.01	0.52	0.06	0.2	0.53	42.7	337.8	394.5	36.3	15.5	48.4
			GR59	24.6	0.82	9.44	4.51	0.03	1.28	5.68	0.42	23.42	0.07	1.5	16	11.88	492.3	390.4	116.8	22.7	83.5
			GR53	2.05	0.04	0.56	0.36	0.01	1.27	50.5	0.06	0.51	0.17	0.2	1.29	42.56	345.1	407.9	37.4	15.6	50.2
			GR49	15.7	0.12	2.5	1.01	0.02	1.15	34.9	0.14	5.69	0.42	0.5	5.54	32.01	424.5	446	63.1	19	61.4
			GR45	9.83	0.17	2.7	1.72	0.05	1.85	38.2	0.2	1.61	1.07	3	5.87	33.7	383.4	486	57.3	17.2	55.1
		GR38	43.9	0.79	14.31	6.69	0.02	3.25	5.7	0.51	4.59	0.09	0.2	6.1	13.52	424.5	371.2	63.1	19	61.4	
		GR34	13.1	0.13	3.54	5.7	0.23	2.51	34.8	0.1	2.15	0.61	0.5	5.15	31.04	367.3	1660	45.1	21.1	69.7	
		GR29	39.1	0.82	14.02	5.7	0.05	2.58	8.58	0.56	7.41	0.1	0.2	8.1	12.38	435.8	361.3	95	20.2	75.2	
		GR25	41.4	0.89	16.76	5.78	0.02	3.94	9.7	0.61	3.4	0.11	0.1	5.72	11.24	392.2	374.7	88.4	20.6	81.3	
		A ver.	21.2	0.42	7.11	3.52	0.05	2.1	26.8	0.29	5.477	0.3	0.7	6.03	25.67	400.3	543.6	66.9	18.99	65.13	
	GR17	40.4	0.97	17.18	5.58	0.03	3.95	2.5	0.59	5.56	0.06	0.1	7.56	15.15	494.6	263.1	126.1	23.2	92.1		
	GR15	41.5	1.08	16.07	5.49	0.02	2.1	1.5	0.67	13.08	0.05	0.1	8.17	9.7	499.7	167.3	128.6	23.1	91.9		
	GR11	9.18	0.17	2.75	11.6	0.39	2.23	29.5	0.16	2.11	1.3	0.5	4.83	34.87	328	706.9	64.8	15.3	48.1		
	GR10	45.9	0.71	17.39	3.86	0.01	1.21	0.96	0.46	8.4	0.04	0	6.43	13.8	490.7	176.2	130	23.1	95.6		
	GR9	9.89	0.19	3.05	5.6	0.16	2.3	34.5	0.15	2.01	0.94	1	4.6	35.15	360.1	663.5	56.6	17.7	52.8		
	GR6	43	0.65	16.12	4.6	0.04	1.21	1.13	0.38	7.9	0.05	0	12.1	12.53	480.1	174.6	133.6	23.2	94.2		
	GR2	20	0.16	2.5	1.9	0.04	2.26	35.4	0.14	1.9	0.14	20	2.33	13.35	596	594.4	61.4	18.5	58.2		
	GR1	14.2	0.25	3.11	2.26	0.33	1.15	32.1	0.28	4.01	0.09	0.1	5.63	36.18	458.9	366.1	87.7	20.8	74.9		
	A ver.	28	0.52	9.77	5.11	0.128	2.05	17.2	0.35	5.62	0.333	2.71	6.46	21.34	463.51	389.01	98.6	20.61	75.98		

- (3) Duration of weathering.
- (4) Transportation mechanisms of clastic material from source region to depocentre.
- (5) Depositional environment (e.g., marine versus fresh water).
- (6) Post-depositional processes (e.g., diagenesis, metamorphism) Hayashi et al., (1997).

6. Cluster Analysis

The cluster analysis of data obtained from X-ray fluorescence analysis is shown in Figure 15. These data represented the different various microfacies which indicate the presence of clastic sediments (Abd El-Hafez et al., 2015) such as quartz arenite, ferruginous quartz arenite, calcareous quartz arenite, iron-rich sand and shale and non-clastic rock units such as limestone, dolostone and gypsum. This type of analysis was performed by using cluster (SPSS) program.

Only two super-clusters, namely A and B were extracted representing all the different microfacies. The first super cluster (A) is Calcium oxides which are divided into two clusters (A₁ and A₂). The first one (A₁) consists of CaO, Zr, Sr and Br which are the main components of dolo-biomicroite, foraminiferal biomicroite, and biosparite microfacies (pure limestone). It is divided into four factors. The first factor includes CaO, MgO, Fe₂O₃, Zr, and Br which are all common components of (Dolostone) microfacies. The second factor consists of CaO, SO₃, S₁O₂, Ba, Sr and Zr which are all common components of the (Gypsum) factor. Factor number three include CaO and Fe₂O₃, Sr, Br and Zr which are the main components of Pelsparite and evaporitic dolomicroite microfacies (limestone). The last factor include CaO, SiO₂, Al₂O₃, Sr and Zr and Br which are all common components of Sandy micrite, foraminiferal biomicroite, and dolosparite microfacies (Sandy limestone).

The second super-cluster (B) is silicon dioxides which are divided into two clusters B₁ and B₂. The first cluster (B₁) is divided into two sub-clusters.

The first one (A₁) consists of CaO, Zr, Sr and Br which is the main components of dolo-biomicroite, foraminiferal biomicroite, and biosparite microfacies (pure limestone). The last one (A₁) is divided into four factors. The first factor involves CaO, MgO, Fe₂O₃, Zr and Br which are all common components of (Dolostone) microfacies. The second factor consists of CaO, SO₃, S₁O₂, Ba, Sr and Zr which are all common components of the (Gypsum) factor. Factor number three includes CaO and Fe₂O₃, Sr, Br and Zr which are the main components of Pelsparite and evaporitic dolomicroite microfacies (limestone). The last factor consists of CaO, SiO₂, Al₂O₃, Sr and Zr, and Br which are all common components of Sandy micrite, foraminiferal biomicroite, and dolosparite microfacies (Sandy limestone).

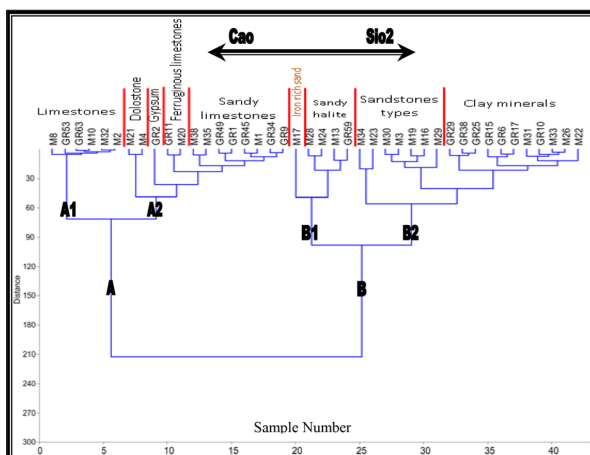


Figure 15. Cluster analysis of the Early Miocene rock units in studied areas, Southwest Sinai, Egypt.

The first one represented by SiO₂, Fe₂O₃, V, and Cr which include the main components of iron-rich sand. The second one includes SiO₂, Na₂O, Cl, Zr, Sr, and Ba which are the main common components of sandy halite bed. The second cluster (B₂) is divided into three factors. The first one includes the main components of calcareous quartz arenite and glauconitic quartz arenite such as SiO₂, Al₂O₃, CaO, Zr, and Br. The second factor is represented by SiO₂, Fe₂O₃, Na₂O, Cl, Zr, Br, Cr and, Sr of all common components of ferruginous evaporitic quartz arenite, Ferruginous quartz arenite and evaporitic quartz arenite microfacies. The last one is represented by SiO₂, Al₂O₃, Fe₂O₃, MgO, Zr, Br, Sr, V, Rb and Cr of all common components of clay minerals factors. The Montmorillonite is a main mineral while kaolinite is a minor mineral.

7. Conclusions

The present study is concerned primarily with exposed Early Miocene rocks in Southwestern Sinai along the Eastern side of the Gulf of Suez, at Wadi Gharandal and El-Markha sections. Both areas represented by the Nukhul and Rudeis formations. The Miocene succession variety in thickness ranges from 170 meters at El-Markha section to 325 meters at Wadi Gharandal section and is characterized by the presence of different rock types such as: sandstone, ferruginous sandstone, evaporitic sandstone, calcareous sandstone, iron-rich sand, evaporites, highly fossiliferous limestone, evaporitic limestone, dolostone, sandy limestone, dolomitic limestone and shale.

Mineralogically, the X-ray diffraction analysis of the Early Miocene sequence revealed the presence of calcite as the dominant minerals in the nonclastic rocks. Quartz was the dominant mineral in the clastic rocks, while goethite was the dominant mineral in the iron-rich sand, halite was the dominant mineral in the evaporite samples. Hematite, kaolinite, halite and gypsum are secondary minerals constituting the studied rock units with varying amounts.

The clay minerals in the studied samples of different formations were analyzed by the application of a semi-quantitative analysis which shows that the main clay minerals present in the Nukhul Formation are montmorillonite and kaolinite. In the Rudeis Formation, the main clay mineral is montmorillonite excluding two samples in which kaolinite is the main mineral.

From the data obtained by chemical analysis and the use of SPSS program it became clear that only two super-clusters namely (A and B) were extracted representing all the different microfacies. The first-super cluster (A) is Calcium oxides which are divided into two clusters (A₁ and A₂). The first one (A₁) consists of CaO, Zr, Sr, and Br which are the main components of dolo-biomicroite, foraminiferal biomicroite, and biosparite microfacies (pure limestone). The last one (A₁) is divided into four factors. The first factor involves CaO, MgO, Fe₂O₃, Zr, and Br which are all common components of (Dolostone) microfacies. The second factor consists of CaO, SO₃, S₁O₂, Ba, Sr and Zr which are all common components of the (Gypsum) factor. Factor number three includes CaO and Fe₂O₃, Sr, Br, and Zr which are the main components of Pelsparite and evaporitic dolomicroite microfacies (limestone).

The last factor includes CaO, SiO₂, Al₂O₃, Sr and Zr,

and Br which are all common components of Sandy micrite, foraminiferal biomicrite and dolosparite microfacies (Sandy limestone).

The second super cluster (B) is Silicon dioxides which are divided into two clusters (B₁ and B₂). The first cluster (B₁) divided into two sub-cluster. The first one which are represented by SiO₂, Fe₂O₃, V, and Cr which include the main components of (Iron-rich sand). The last one includes SiO₂, Na₂O, Cl, Zr, Sr, and Ba which are the main common components of (Sandy halite) bed. The second cluster (B₂) is divided into three factors. The first one includes the main components of (Calcareous quartz arenite and glauconitic quartz arenite) such as SiO₂, Al₂O₃, CaO, Zr and Br.

The second factor is represented by SiO₂, Fe₂O₃, Na₂O, Cl, Zr, Br, Cr, and Sr of all common components of (Ferruginous evaporitic quartz arenite, Ferruginous quartz arenite and evaporitic quartz arenite) microfacies.

The last one is represented by SiO₂, Al₂O₃, Fe₂O₃, MgO, Zr, Br, Sr, V, Rb and Cr of all common components of (Clay minerals) factors. Montmorillonite is a main mineral, while kaolinite is a minor mineral.

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