The Nature, Origin and Distribution of Kaolinite in the Lower Paleozoic Naqus Formation along Western Side of Gulf of Suez, Egypt

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Abstract: This paper sheds more light on genesis and evolution of the kaolin minerals in white sandstones of the Lower Paleozoic Naqus Formation at Wadi El-Dakhel and Wadi Qena along the western side of the Gulf of Suez. Naqus Formation is composed of fluvial, white to yellowish white, tabular planar cross-bedded and occasionally overturned bedded sandstones with relative abundance of kaolinitic matrix. Several thin beds (5-10cm thick), ferruginous, rippled sandstones have been observed at several intervals that can reflect a cyclic sequence of deposition. In each one of these cycles the average kaolinite content is decreased upward where considerable nodules extending laterally ≈10 m and ≈50 cm thick are recorded. These sandstones comprise three types: quartz arenite, quartz greywacke and ferruginous quartz arenite. Altered mica to kaolinite in the form of vermicular stacks are scattered throughout and embedded with a dark gray to nearly isotropic matrix. The main mineral constituents are quartz and kaolinite with accessories of montmorillonite, microcline and anatase. Kaolinite XRD pattern reflects a high degree of ordering. The concentration of Al_2O_3 decreases upward and vice versa for SiO_2 in each cycle confirming sequence of depositional cycles. The kaolinitic nodules in both studied sections are characterized by relatively high content of TiO_2 and Cr and low contents of P_2O_5, SO_3 and Sr pointing supergene origin. Scanning Electron Microscope (SEM) examinations show that the kaolinite filling the intergranular spaces in the form of: dispersed large kaolinite particles; vermicular stack or books shape; fan-shaped joined stacks; shaggy appearance is a characteristic feature of some kaolinite books; and fluctuated face-to-edges kaolin particles. The sinuous kaolinite structures (vermiform), with shaggy and smooth appearance, and fan-shaped units are related to alteration of mica, while face-to-edges fluctuation book-fabric is characteristic feature of authigenic kaolinite. Both were formed under fresh ground-water tropical conditions.
[Mohamed W. Abd El-Moghny. **The Nature, Origin and Distribution of Kaolinite in the Lower Paleozoic Naqus Formation along Western Side of Gulf of Suez, Egypt.** *Nat Sci* 2017;15(2):49-61]. ISSN 1545-0740 (print); ISSN 2375-7167 (online). http://www.sciencepub.net/nature. 9. doi:10.7537/marsnsj150217.09.

Keywords: Paleozoic, Naqus, kaolinite, vermicular, supergene, Wadi Qena, Egypt.

1. Introduction

The kaolin-group minerals include four members: kaolinite, dickite, nacrite, and the hydrated analogous, halloysite (Ruiz Cruz 2007). Kaolin minerals are extensively developed in a wide range of lithologies (e.g. laterites, bauxites, and altered igneous rocks) that have been formed in various depositional environments as tropical soils, food plain deposits (Dill et al. 1997). These minerals are typical of three main environments; weathering profiles; hydrothermal alterations; and reworked sediments. Kaolinite is easily formed and is widespread in soils developed under hot-warm, inter-tropical climates. It is concentrated mostly in the equatorial current belt and derived from soil erosion in southern India, Madagascar and Africa (Meunier 2005).

The studied area is located at northern Eastern Desert along western side of Gulf of Suez. The selected sections are occurred at Wadi El-Dakhel at the north and central Wadi Qena at the south (Fig. 1). The lithostratigraphy, sedimentology and chronology of the Naqus sandstones located at north Eastern Desert were extensively studied by several authors (e.g. Hassan, 1967; Said 1990; Issawi and Jux, 1982; Bandel et al., 1987; Klitzsch et al., 1990; Abdallah et al., 1992; Issawi et al., 1999; and Wanas, 2011). The Naqus Formation was introduced by Hassan (1967) in Wadi Araba, Durba area, Sinai, to describe the massive white kaolinitic sandstones of 462 m thick that rests on varicolored coarse sandstones of Wadi Araba Fm and underlies black shales of Durba Fm Naqus Fm has a wide distribution in Sinai, Gulf of Suez and south Western Desert, at Abu Ras plateau-north of Gilf Kebir and Wadi Malik, (Abdallah 1992). It is composed of unfossiliferous, white sandstones, medium to coarse-grained, massive and cross bedded with kaolinitic matrix. Naqus Formation occurs along the western side of the Gulf of Suez as scattered outcrops as a series of hills and masses ranging from 25-100 m thick.

Body fossils are difficult to detect in Naqus Fm and therefore biostratgraphic age determination is quite impossible. Depending on lithostratigraphic position of this formation many authors proposed its age of deposition. Naqus Formation is assigned to Pre-Carboniferous (Devonian) (Hassan, 1967), Carboniferous (Soliman and Abu El-Fetouh, 1969, 1970), Upper Ordovician-Lower Silurian (Issawi and Jux, 1982), Ordovician? (Abdallah et al., 1992) Cambro-Ordovician (El-Shahat and Kora, 1986) and Cambrian (Said and El Kelani 1988). Naqus Formation is coeval to upper part of Pre-Carboniferous, lower sandstones of Omara and Schultz (1965) and the massive sandstones, Adedia Formation of Soliman and Abu El-Fetouh (1969& 1970) and also to Pre-Cenomanian Dakhel Fm (Bandel, et al., 1987, personal communication). In the subsurface of Gulf of Suez region, Naqus Fm is correlated to the informal Nubia C by Klitzsch (1990) and Al Shahran and Salah (1997).

Surface exposures of the Lower Paleozoic strata are identified in the Eastern Desert at northern Wadi Qena and at Wadi El-Dakhel area (Abdallah et al 1992). They comprise of shore-face clastic sediments of the Araba Formation with its trilobites and bilobites tracks and the overlying white kaolinitic sandstones of Naqus Fm. The distribution and different thicknesses of Naqus Fm is mainly controlled by the paleorelief of Precambrian basement complex as discussed by Issawi and Jux (1982). They also concluded that although the fossils are not present in this formation but the genetic interpretation of its deposition indicates an Upper Ordovician to Lower Silurian age.

Abou El-Anwar and El-Wekeil (2013) studied in detail the geochemistry, mineralogy and petrography of the Naqus sandstones to shed more light on their provenance, tectonic setting and depositional environments. They assigned these sandstones of a detrital origin, being inherited from felsic- granitic and reworked quartzose sediments and transported by rivers to the basin of deposition. El-Wekeil and Gaafar (2014) shaded light on the economic potential of the white sandstones of the Naqus Formation in Wadi Qena, northern Eastern Desert. They concluded that kaolinitic lenses are randomly distributed throughout the whole sequence especially at its upper part. Kaolin represents a valuable co- product since its percent in the oreapproximately11%. It can be used in ceramic, white cement, paper industry and as filler in rubber, paints and plastics, in toothpaste, cosmetics, also as adsorbents in water and wastewater treatment and for metakaolin production which used in improvement of the quality of cement and concrete.

No attention was paid to the genesis and evolution of the kaolinitic minerals in white sandstones of the Naqus Formation along the western side of the Gulf of Suez. Therefore, the aim of this work is to investigate the petrographical, mineralogical and chemical properties of these deposits in order to assess the genesis of kaolinitic deposits.

2. Materials and methods

Two stratigraphic sections have been measured, in detailed described and sampled along western side of Gulf of Suez (Fig. 1) to study the origin of kaolinite in the Naqus Fm; the first section (I) has been measured at Wadi El-Dakhel (28° 35′ 32″ N-32° 26′ 59″ E) and the second section (II) is measured at east central Wadi Qena (27° 56′ 0″ N - 32° 26′ 51″ E). Twenty-one samples from the two measured sections were collected to represent the Naqus Formation: 8 from Wadi El-Dakhel and 13 from Wadi Qena sections. They were split into sub-samples for various methods of investigation. Thin sections of sandstone samples were studied using polarizing microscope to differentiate the various sandstone types and the amount of matrix in these samples. Micro-textures of the studied kaolinitic samples are observed by scanning electron microscopy (SEM). Chemical analyses of 10 bulk samples were obtained with Wavelength Dispersive X-Ray Fluorescence Spectrometry in the laboratory of the National Research Center, Cairo.

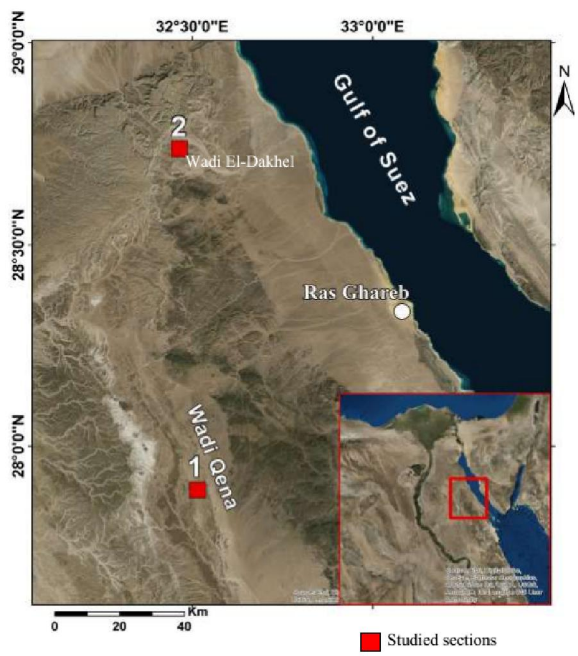

Figure 1: Landsat image of the northern Eastern Desert showing the locations of the studied sections.

3. Lithostratigraphy

The Naqus Formation in Wadi El-Dakhel section lies unconformably on Cambrian Araba Fm and overlain unconformably by Lower Cretaceous Malha Fm. In Wadi Qena section the lower surface of Naqus Fm is unexposed (Fig. 3a). The contact between the Naqus Fm and its underlying Araba Fm can be described in Gebel Somr El Qaa, northeast Wadi Qena

(Tawfik et al 2011). At Wadi El-Dakhel section, the exposed irregular contact between the Naqus and its underlying Araba formations is marked by upward change from varicolored (red, green, yellowish grey) silty sandstones with ichnofossils into white kaolinitic sandstones.

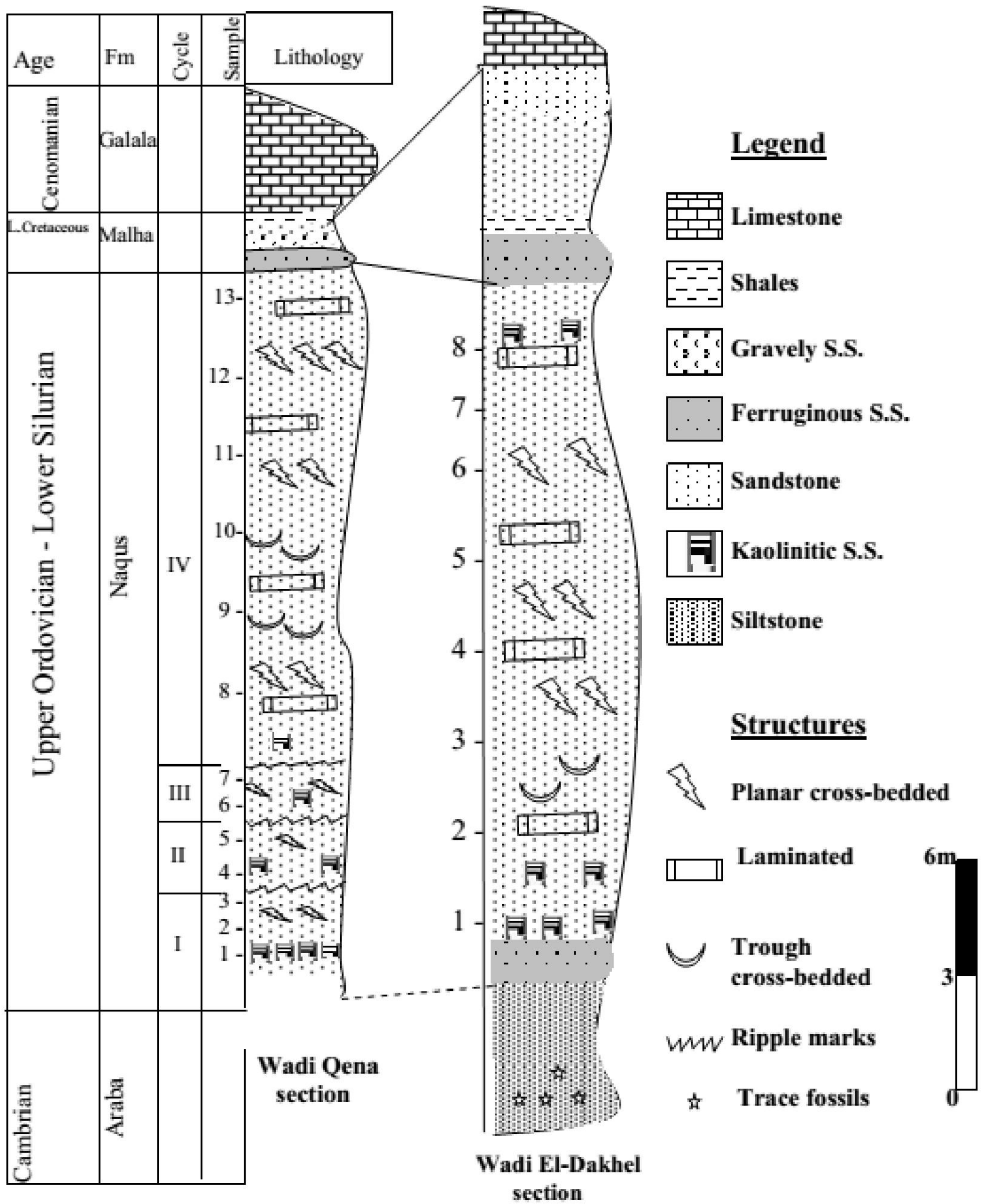

Figure 2: Lithostratigraphic sections of the studied sections.

The highly ferruginated upper part of the Araba Fm separates its overlying Naqus Fm and reflects sub-aerial exposition and paleosol conditions. The boundary between Naqus Fm and its overlying Malha Fm is marked by the presence of gravelly (up to 5 cm diameter), reddish brown to dark grey paleosol sandstones (Fig. 3b,c). The sandstones of the Naqus Formation in Wadi Qena section are characterized by presence of thin (5-10 cm thick), ferruginous, rippled sandstones at several intervals reflecting a cyclic sequence of deposition (Fig. 3d). The Naqus Fm is composed of tabular planar (Fig. 3e) and (less common) overturned bedded sandstones with relative abundance of kaolinitic matrix giving these sandstones their white color. Generally the average kaolinite content is decreased upward in the four depositional cycles of variable thicknesses. Occasionally kaolinite nodules extend laterally ≈10 m forming lenses with ≈50 cm thick (Fig.3f).

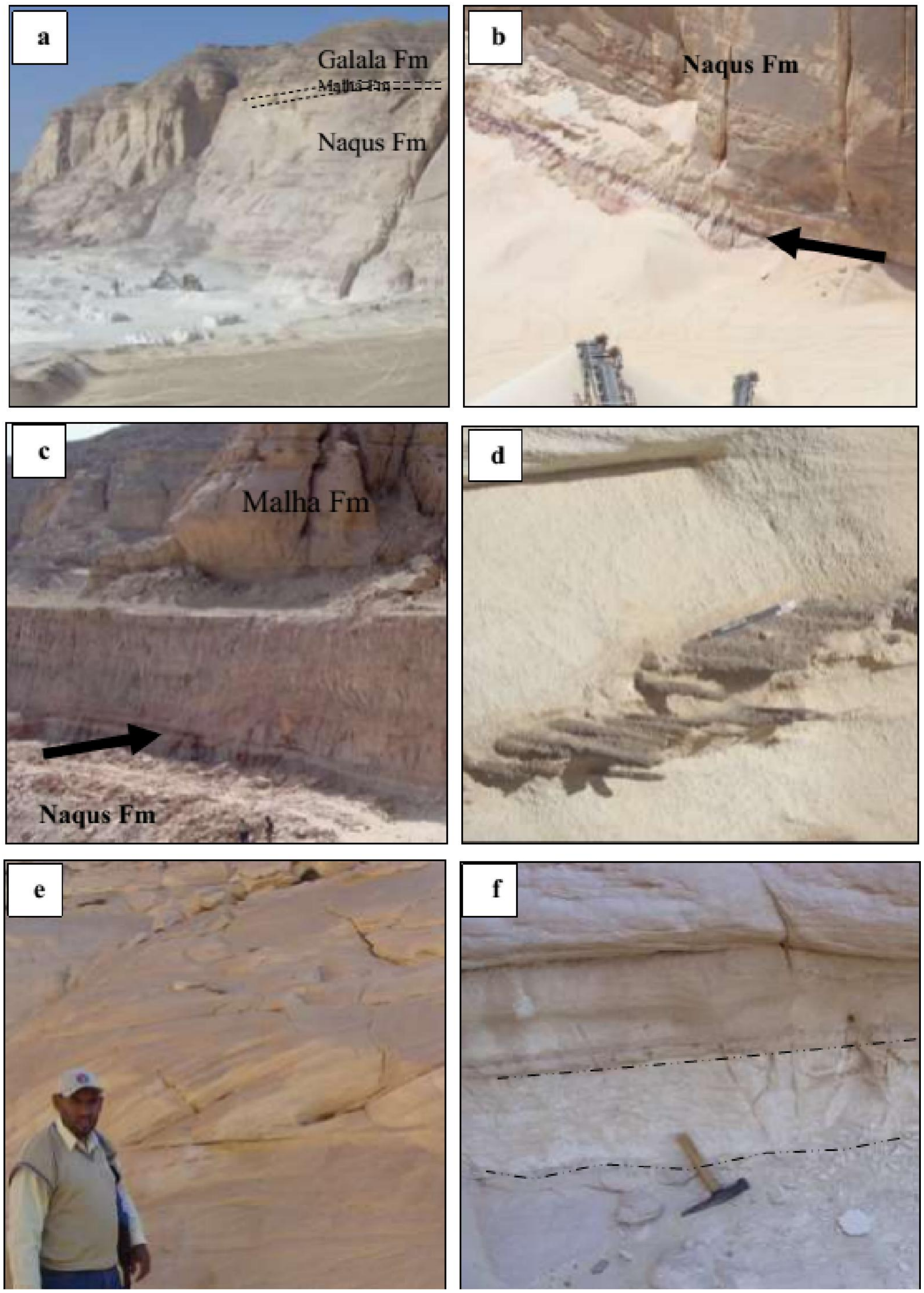

Figure 3. Photographs show the field characters of Naqus Fm: a) lithostratigraphic section at Wadi Qena and the contact between Naqus and Cretaceous Malha and Galala formations; b,c) the ferruginous paleosol beds (arrows) at lower and upper surfaces of Naqus Fm (respectively) at Wadi El-Dakhel section; d) thin rippled ferruginous sandstones; e) planar cross-bedded sandstones of Naqus Fm; f) white kaolinite nodule in Naqus sandstones at the lower part of Wadi Qena section.

4. Petrographical examination

During these studies, petrographical descriptions of the sandstones and evaluations based on mineralogical and micro-textural features were made in accordance to Folk (1980). A number of 16 samples were collected from the sandstones of the Naqus Formation and their petrographical description was made on thin sections. The petrographical examination revealed that these sandstones can be classified into three sandstone facies types: quartz arenite, quartz greywacke and ferruginous quartz arenite.

i) Quartz arenite

It is recorded in both Wadi Qena (samples No. 3Q, 5Q, 7Q, 9Q, 10Q) and Wadi El-Dakhel (samples No.14D, 15D, 16D) sections. This type is dominated in the upper part of each cycle and made up of yellowish white, massive to semi-friable sandstones. Quartz grains form more than 95% of the rock with some (<5%) feldspar grains and mica, particularly muscovite, and both are altered into kaolin minerals (Fig. 4a, b). Some of the authigenic kaolinite developed in few samples. Quartz grains are of monocrystalline (less common polycrystalline), moderately sorted, angular, and elongated to spherical, medium to coarse sand-size in open packing texture. Silica overgrowth is recorded surrounding a lot of quartz grains (Fig.4a) reflecting diagenetic dissolution of outer surface of some quartz grains.

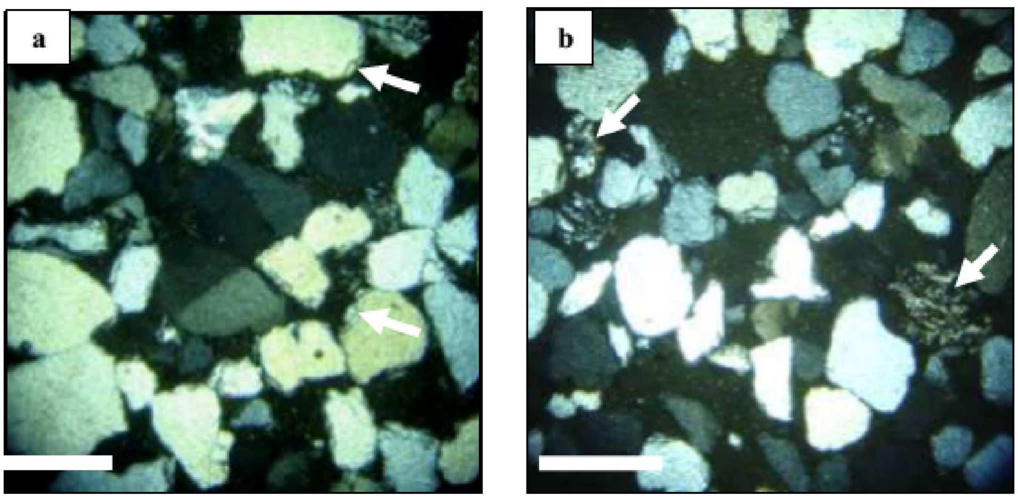

Figure 4: Photomicrographic views of quartz arenite sandstone of Naqus Fm. (a) Some quartz grains are encrusted by silica overgrowth (arrow). (b) Quartz arenite with a partial dissolution of white mica (arrows). Bare scale = 0.5mm.

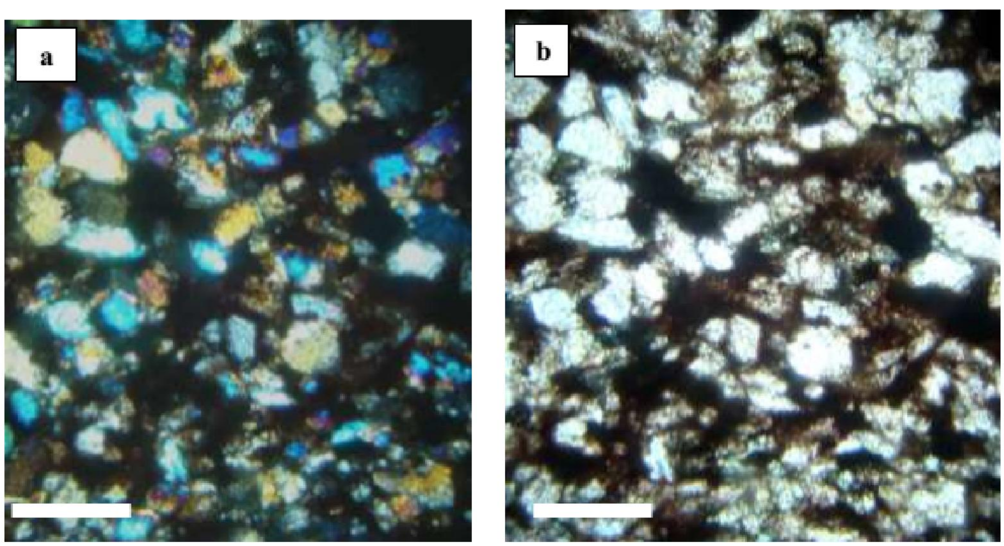

Figure 5: Photomicrographs show the ferruginous quartz arenite; a) under polarizing microscope; and b) under ordinary light. Bare scale = 0.5mm.

ii) Ferruginous quartz arenite

This type in both stratigraphic sections is recorded at several intervals of the succession as thin laminated and rippled sandstones as well as the lower and upper contacts of the Naqus Formation. This lithofacies is composed of red, yellowish brown, semi-compact and massive sandstones. The quartz grains forming up to 75% of the rock are well sorted, angular, spherical to elongated and sized in fine sand-grained and are cemented by red iron oxide cement (Fig. 5).

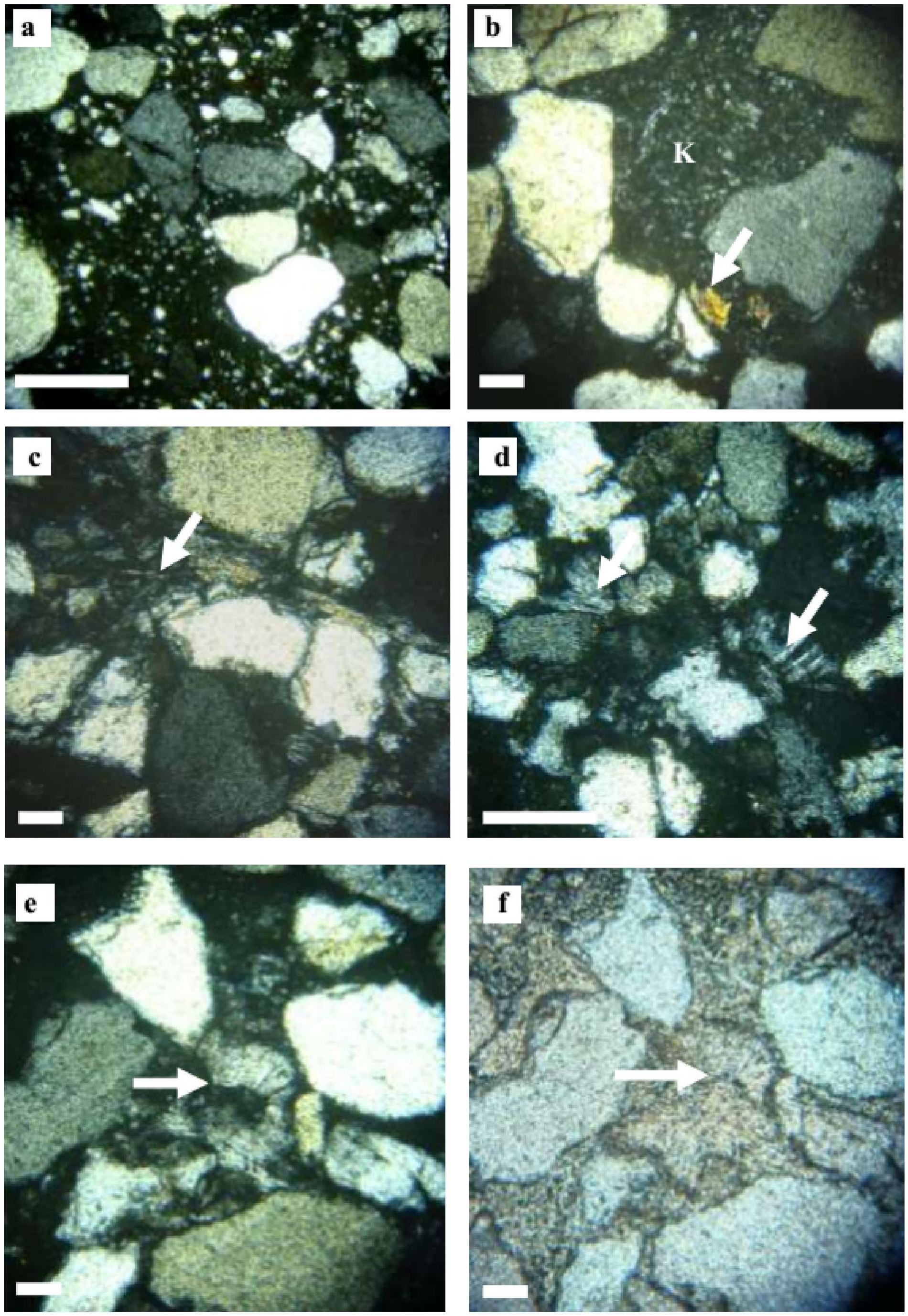

Figure 6: Photomicrographs show the quartz greywacke sandstone type; a) the scattered matrix in quartz wacke; b) authigenic kaolin (K) and muscovite grains (arrow); c) muscovite grain (arrow) that partially altered into clay matrix; d) vermicular stacks of sericite (?) as a result of partially dissolved mica grains (arrows); e) authigenic clay matrix (arrow); f) as (e) under ordinary light. Bare scale = 0.5mm.

iii) Quartz greywacke

This type well developed in the upper part of the Naqus Formation at Wadi El-Dakhel and at several intervals of Wadi Qena section and is represented by samples No. 1W, 8W, and 1Q, 4Q, 6Q, 8Q respectively (Fig. 6). This lithofacies is represented by pale grey to white, friable, laminated sandstone. Quartz grains form up to 80% of the rock and they are ill- to moderately-sorted, spherical to elongated shape and medium to coarse sand-grained with open packing texture. Less common fine crystalline calcite cement is observed. Matrix is represented by fine to very silty detrital grains. Authigenic kaolinite well observed in this sandstone type of about 8->20% of the whole rock comprising a quartz sub-greywacke that is developed to greywacke sandstone types (Fig 6).

Feldspar grains are entirely or partially sericitized and/or kaolinized. In addition, long vermicular stacks or books of sericite are scattered throughout and embedded in a dark gray to nearly isotropic (under crossed nicols) matrix presumed to 'degraded' sericitic mica.

5. X-Ray Diffractometry (XRD) Analyses

The XRD analyses shown in figure (7) recorded quartz, kaolinite, and lesser amounts of both montmorillonite and microcline in the Wadi El-Dakhel sandstone sample (8W). Quartz and kaolinite are only detected in Wadi Qena sandstone samples. The XRD pattern of Wadi Qena kaolinite nodule sample revealed presence of anatase as accessory mineral beside quartz and kaolinite (Fig. 7). The kaolinite patterns of both areas sandstones show sharp, narrow peaks and reflect high degree of ordering.

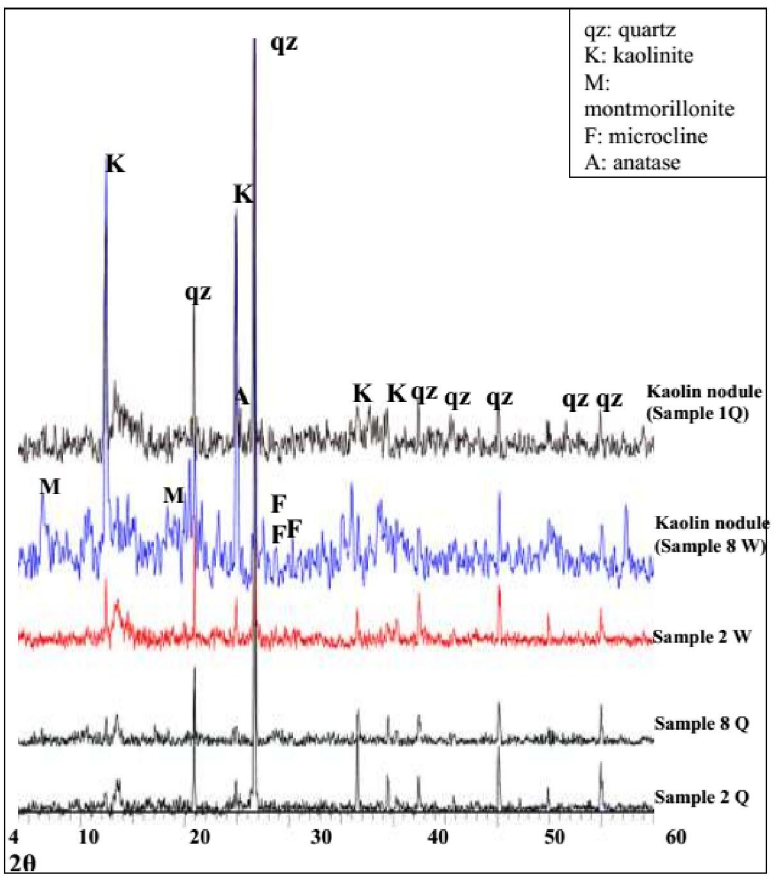

Figure 7: XRD patterns of some studied sandstones and kaolinitic nodules samples in both Wadi Qena (Q) and Wadi El-Dakhel (W) sections.

6. Scanning Electron Microscope (SEM) analysis

Scanning Electron Microscope (SEM) investigation of the Naqus sandstone samples of both studied sections pointed to kaolinite enrichment in these samples. Kaolinite is recorded as vermicular (Fig. 8 a-d), euhedral and pseudo-hexagonal plates (booklet) (Fig. 8 e-f), and neomorphosing detrital muscovite (Fig. 9 a-e). The hexagonal kaolinite plates occur either as discrete individual platelet or associated with the stacks. Vermicular kaolinite stacks with a varying size (up to 30µm) are common in these deposits (Fig. 8b). Some joined stacks form the fan-shaped units (Fig. 9 b). The "shaggy" appearance (Fig.9c) of kaolinite books are observed in some kaolinitic samples where these stacks or books are of irregular edges and surfaces but occasionally much smoother (Fig. 9 d,e).

The majority of kaolinite particles lacks the parallel orientation and has face-to-edges fluctuation although some has a parallel particle orientation. Large kaolinite particles are dispersed in pore spaces of the studied sandstones (Fig. 8d) due to large volume of intergranular pore spaces, as well as geochemical conditions of deposition. SEM examination revealed presence of silica overgrowth on some quartz grains of the Naqus sandstones (Fig. 9f).

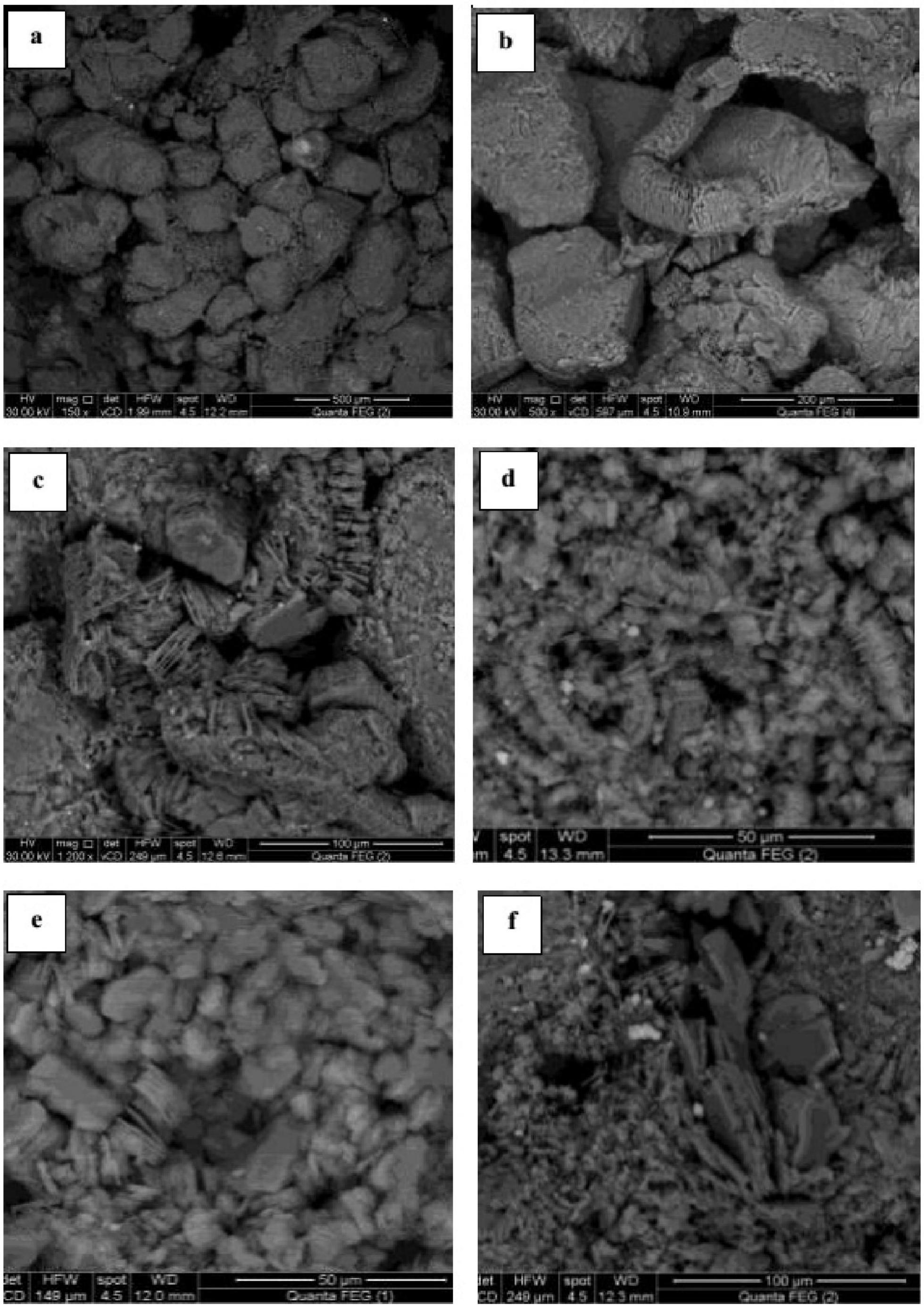

Figure 8: SEM images show the kaolinite texture in the Naqus sandstone: a) intergranular kaolinite in quartz grains; b,c,d) vermicular kaolinite stacks; e,f) hexagonal kaolinite plates.

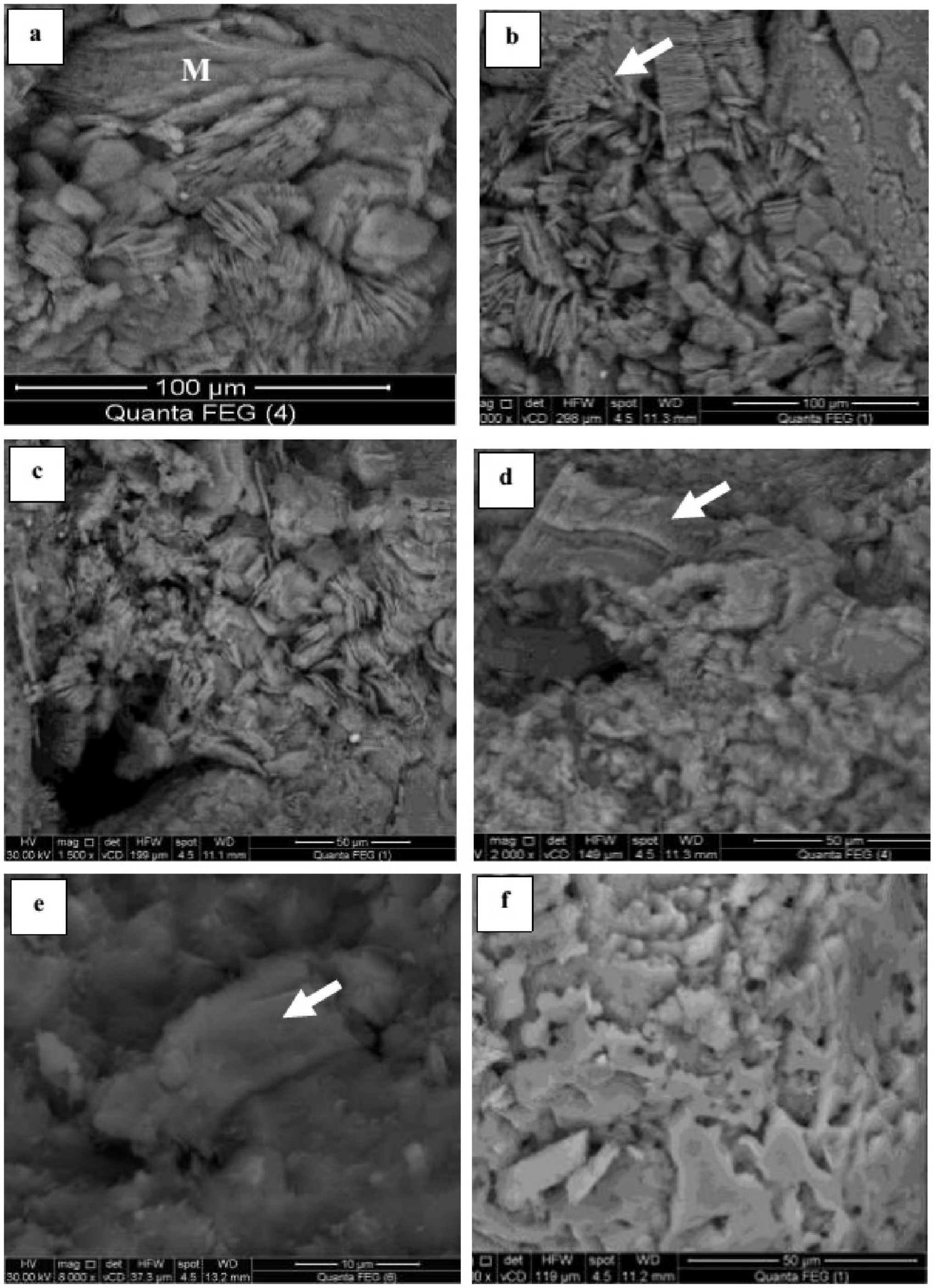

Figure 9: SEM images show a) neomorphosing detrital muscovite (M); b) some stacks joined together to compose a fan-shaped unit (arrow); c) the "shaggy" appearance of kaolinite books; d) altered feldspar grain to kaolinite. Its edges and surfaces of these stacks or books are irregular (arrow) and e) edges and surfaces of kaolinite stacks or books sometimes much smoother (arrow); f) quartz overgrowth on quartz grains.

7. X-ray Fluorescence (XRF) Analysis

The geochemical analysis of sandstone and kaolinite nodule samples of both studied sections as a whole rock and silt-clay fraction are given in table (1). Both SiO_2 and Al_2O_3 content are the chief chemical constituents (up to 98.34 %) of both sand and silt-clay fractions ranging from (91.34-52.33% and 33.7-5.17% respectively). The trace contents of the other major oxides (CaO, MgO, Na_2O and K_2O) in either sand or silt-clay fractions can be scientifically considered of negligible value. The concentration of SiO_2 is decreased in silt-clay fraction while the Al_2O_3 is increased in this fraction. It can be noted that the concentration of both SiO_2 and Al_2O_3 oxides fluctuate vertically in the analyzed samples of the studied sections that may related to the different depositional cycles. Al_2O_3 content increases downward in these cycles and form the kaolinitic nodules.

Al_2O_3 has a positive correlation with TiO_2 and L.O.I. as well as some trace elements as Zn, Pb, Sr, Ga, Y, and Zr. TiO_2 is mainly related to anatase mineral which developed during the kaolinite formation. Anatase was detected by XRD analysis in kaolinite nodule sample. Except the ferruginous sandstone samples, the studied sandstones are characterized by lower Fe content (0.10-0.15%).

Table 1: The chemical analysis of some studied sandstone samples of Naqus Formation.

Oxides (Wt%)	**Sample Size**	**Wadi Qena**							**Wadi El-Dakhel**		
		Kaolin nodule	**2Q**	**4Q**	**5Q**	**6Q**	**8Q**	**9Q**	**2W**	**4W**	**8W**
SiO_2	**sand**		91.34	89.56	91.2	84.7	89.26	93.17	92.11	89.85	
	<63µm	60.81	85.33	80.36	82	78.9	74.19	86.6	72.02	80.2	52.33
TiO_2	**sand**		0.18	0.16	0.17	0.37	0.11	0.09	0.94	0.16	
	<63µm	1.13	0.24	0.37	0.29	0.64	0.33	0.03	0.18	0.4	1.56
Al_2O_3	**sand**		6.37	7.42	5.5	11.2	8.44	5.17	5.9	7.35	
	<63µm	27.67	7.71	14.28	12.4	14.9	18.36	6.8	21.18	13.6	33.7
$Fe_2O_3^{tot.}$	**sand**		0.11	0.11	0.11	0.14	0.08	0.07	0.17	0.06	
	<63µm	0.1	0.13	0.21	0.15	0.26	0.22	0.01	0.004	0.2	< 0.01
MnO	**sand**		0.001	0.003	0.002	0.002	< 0.01	0.005	< 0.01	0.004	
	<63µm	0.33	< 0.01	0.004	0.004	<0.01	< 0.01	0.003	0.06	0.003	0.32
MgO	**sand**		0.05	0.05	0.05	0.18	0.04	0.02	0.03	0.02	
	<63µm	0.1	0.07	0.09	0.08	0.27	0.11	0.09	0.03	0.09	0.04
CaO	**sand**		0.19	0.14	0.015	0.16	0.23	0.015	0.08	0.35	
	<63µm	0.26	0.24	0.2	0.23	0.23	0.31	0.17	0.03	0.2	0.04
Na_2O	**sand**		0.03	0.02	0.03	0.04	0.03	0.03	0.19	0.02	
	<63µm	0.56	0.02	0.03	0.03	0.05	0.03	0.02	0.06	0.03	0.11
K_2O	**sand**		0.02	0.01	0.02	0.02	0.01	0.01	0.02	0.01	
	<63µm	0.06	0.02	0.02	0.01	0.03	0.02	0.01	0.01	0.02	0.04
P_2O_5	**sand**		0.06	0.05	0.05	0.07	0.01	0.03	0.17	0.05	
	<63µm	0.15	0.07	0.08	0.08	0.09	0.23	0.03	0.06	0.07	0.13
SO_3	**sand**		< 0.01	0.04	0.04	0.09	0.2	< 0.01	0.08	0.08	
	<63µm	0.43	0.12	0.07	0.09	0.14	0.11	< 0.01	0.08	0.06	0.21
Cl	**sand**		0.02	0.02	0.1	0.05	0.02	0.02	0.2	0.02	
	<63µm	0.29	0.02	0.02	0.02	0.04	0.03	< 0.01	0.06	0.01	0.06
LOI	**sand**		1.59	2.36	2.4	2.88	1.5	1.19	1.5	1.99	
	<63µm	8.01	5.95	4.13	4.1	4.27	5.95	5.2	4.68	4.2	11.25
Traces (ppm)											
Cr	**Sand**		49	44	47	31	30	36	46	23	
	<63µm	145	38	47	36	55	50	52	nd	nd	181
Cu	**Sand**		23	24	22	27	26	21	41	19	
	<63µm	21	30	28	31	38	45	34	nd	nd	23
Zn	**Sand**		5	7	5	9	9	8	11	13	
	<63µm	16	11	10	12	10	25	20	19	nd	16
Pb	**Sand**		46	6	47	7	15	17	86	36	
	<63µm	387	48	14	47	21	19	21	nd	nd	433
Ni	**Sand**		24	73	22	30	35	52	30	41	
	<63µm	29	21	36	17	44	39	38	35	nd	26
Sr	**Sand**		110	84	121	125	91	53	318	54	
	<63µm	311	116	156	109	168	209	167	26	nd	499
Ga	**Sand**		7	7	7	11	8	11	14	4	
	<63µm	31	6	16	5	15	15	14	112	nd	43
Y	**Sand**		5	6	5	10	6	7	20	8	
	<63µm	331	11	15	9	33	13	15	nd	nd	54
Zr	**Sand**		167	193	156	268	99	87	699	125	
	<63µm	641	331	749	324	1337	431	223	nd	nd	460

nd = not detected

8. Interpretation and Discussion

As it is known, the studied sandstones may form important source of clay minerals depending on their mineral constituents, porosity, permeability and depositional facies. Texturally, the studied sandstones are made up well- to moderately-sorted, rounded to subangular grains that tend to high porosity volume, and permeability, and permitted the passage of solutions containing dissolved silica and alumina derived from the source area. The field observations of the Naqus sandstones at Wadi Qena section recorded presence of cyclic sequences of deposition based on existing of thin (5-10 cm thick), ferruginous, rippled sandstones at four intervals. These cyclic sequences are supported petrographically by the transition upward from greywacke to quartz arenite. Such sedimentary structures as planar bedding, sometimes overturned, and less common convolute bedding are developed in sandstones of Naqus Formation. These sedimentary structures indicate fluvial depositional environments of Naqus Formation contrarily to the fluvio-glacial origin that suggested as by Issawi and Jux (1982). In this respect, Bandel et al. (1987) mentioned no evidence is recorded to support the glacial origin of the Naqus sandstones.

The topmost part of Naqus Formation is separated from its overlying Lower Cretaceous Malha Formation by reddish brown, yellow, ferruginous gravelly sandstones reflecting period of subareal exposition, non-accumulation, and the effect of chemical weathering. This subareal exposition of the studied area is mainly related to tectonic activity following Klitzsch (1986) who mentioned that gentle block faulting occurred and causing the development of the NNW-SSE structural relief along the northern Eastern Desert.

The sandstones of Naqus Fm comprise of quartz arenite, quartz greywacke and ferruginous quartz arenite. These sandstones are composed chiefly of quartz, kaolinite with depleted mica and feldspars. The quartz grains (≈ 95-75 % of the rock) are well- to moderately- sorted, spherical to sub-spherical and elongated shape and sized of medium to coarse sand-grained with open packing texture. These textural characteristics increased the porosity content of the studied sandstones. The altered muscovite to kaolinite is observed in both the petrographical and Scanning Electron Microscope (SEM) investigations (Figs 6, 9a,b). Authigenic kaolinite composes about 8-20% of the whole rock to form quartz sub-greywacke that is developed to greywacke sandstones. The sinuous kaolinite structure (vermiform), with shaggy and smooth appearances, and fan-shape units reflect an altered mica and authigenic nature of kaolinite through fresh ground-water and tropical conditions. In fact, vermiform kaolinite occurs in modern soils in the tropics (Fitzpatrick, 1980). The chemical weathering of fresh mica (muscovite) flakes initiates at its edges to form irregular edged kaolinite book that may be formed during an early diagenesis. Hinckley (1965) mentioned that the presence of the long sinuous forms is moreover evidence for authigenic development. The existence of two types of books, namely those with a shaggy appearance believed to be formed from mica and others with smoother edges are considered by most observers to be authigenic. Muscovite neomorphosis and kaolinite authigenesis are the first diagenetic modifications in most of the non-marine sediments, and are the products of freshwater diagenesis. The predominance of platy stacks of kaolinite texture reflects a long time and slow recrystallization process. Experimental data indicate that a rapid precipitation leads to spherical morphologies, whereas slower recrystallization processes originate platy particles and stacks (Bentabol et al., 2006).

The XRD analyses of the sandstones and kaolinite nodules revealed sharp, narrow peaks pattern of high ordered authigenic kaolinite. The XRD pattern of Wadi Qena kaolinite nodule sample revealed presence of anatase as accessory mineral. Anatase as diagenetic product can be considered to have been formed during and after deposition of studied sandstones. Also it is mostly an authigenic mineral (Folk 1980) concentrated in sedimentary kaolinitic deposits (Railsback 2003).

The formation of kaolinite is dependant largely on chemistry of flowed water as well as the porosity and permeability of these deposits rather than the feldspar content. Geochemically, both SiO_2 and Al_2O_3 fluctuate vertically in the studied sections which support different depositional cycles. Al_2O_3 content increases downward in these cycles forming the kaolinitic nodules. The high Al_2O_3 content (33.7%) in sandstones sample of the upper part of Naqus Fm at Wadi El-Dakhel section is due to presence of kaolinite, montmorillonite and microcline minerals. These minerals are as detected by XRD analysis (Fig. 7). Meanwhile, negligible values of CaO, MgO, Na_2O and K_2O (major oxidesof the crust) in either sand or silt-clay fractions improve that the presence of Al_2O_3 as kaolinite mineral. The studied kaolinitic nodules in both studied sections are characterized by relatively high contents of TiO_2, Zr and Cr and vice versa for P_2O_5, SO_3 and Sr (Table 1) suggesting supergene origin. In this respect, McGraw-Hill (2003) considered supergene (or hypergene) to mineral deposits or enrichments formed by descending solutions. The recorded > 100 ppm Cr (Dill et al.1997) and low contents of SO3, P_2O_5 and Sr (Rye et al. 1992) refer to supergene origin of the kaolinite nodules considering the elements of Dill et al. (1997).

Zr is widely accepted as very immobile under weathering conditions (Ece et al., 2013) and the relative decreasing of Zr in the kaolinitic nodules (31-43 ppm) may be related to source rocks rather than weathering action. The studied sandstones are characterized by the low Fe contents compared to the values given Argast and Donnelly (1987) and Weaver (1989). The depletion of Fe oxides in sandstones may be due to the leaching of Fe and its redeposition in the ferruginous sandstones.

Pore-water chemistry probably varied throughout the water table following deposition of the sands. In areas of continued freshwater influx oxygenated conditions prevailed and kaolinite formed (Kantorowicz 1984). In most cases kaolinite origin is clearly related to leaching of preexisting minerals, which is favored at acidic conditions and in the presence of organic mater. During the pH rise subsequent to dissolution, kaolinite precipitates, since its solubility decreases rapidly as neutral pH values are reached. Formation of kaolinite through this process is enhanced in continental sandstones during an early diagenesis (Ruiz Cruz and Andreo, 1996a). Although some of studied kaolin particles have a parallel particle orientation, the majority has face-to-edges fluctuation which indicates their formation in fresh porewater conditions. The clay suspension in a fresh water environment forms an edge-to-face type flocculation of clay particles (Hinckley 1965).

Conclusion

The detailed field, petrographical, mineralogical and geochemical studies of the Naqus sandstones at Wadi El-Dakhel and Wadi Qena sections recorded the following conclusions: 1) cyclic sequences sedimentation; 2) textures of Naqus sandstones favored the formation of kaolinite; 3) high degree of ordered authigenic kaolinite is reflected by their sharp, narrow peaks pattern; 4) the sinuous kaolinite structure (vermiform), with shaggy and smooth appearances, fan-shape, and face-to-edges fluctuation are related to altered mica in the tropics conditions: 5) high Al_2O_3 content and negligible values of CaO, MgO, Na_2O and K_2O improve that the presence of Al_2O_3 as kaolinite mineral; and 6) relatively high contents of TiO_2, Zr and Cr and vice versa for P_2O_5, SO_3 and Sr suggest supergene origin of the studied kaolinite.

Acknowledgment

The author is grateful to Prof. Mahmoud M. Hassan and to Prof. Mohsen M. Ali, for carefully reading this paper.

References

1. Abdallah A.M., Darwish M., El-Aref M. and Helba A.A., 1992. Lithostratigraphy of the Pre-Cenomanianclastics of north WadiQena, Eastern Desert, Egypt, In: Sadek, A. (Ed.), Proceeding of the First International Conference on Geology of the Arab World, Cairo University. pp. 255-282.
2. Abdallah A.M., 1992. Palaeozoic rocks in Egypt. Technika Poszukiwan Geologicznych. Geosynoptyka Geotermina 3. pp. 1-12.
3. Abou El-Anwar, E.A., and El- Wekeil S.S. 2013. Contribution to the provenance and paleoclimate of the LowerPaleozoic sandstones of Naqus Formation, WadiQena, Northern Eastern Desert; Integration of support petrography, mineralogy and geochemistry, J. App. Sci. Res., 9 (10): pp. 6529-6546.
4. AL-Sharhan A. S. and Salah M. G. 1997. Lithostratigraphy, sedimentology and hydrocarbonmhabitat of the Pre-Cenomanian Nubian Sandstone in the Gulf of Suez oil province, Egypt. GeoArabia, 2, 4. pp. 385-400.
5. Argast S. and Donnelly T.W., 1987. The chemical discrimination of clastic sedimentary components: J. Sediment. Petrol., 57. pp. 813–823.
6. Bandel k., Kuss J. and Malchus N., 1987. The sediments of WadiQena, Eastern Desert, Egypt. Journal of African Earth Sciences,.6(4). pp. 427-455.
7. Bentabol M., Ruiz Cruz M.D., Huertas F.J., Linares J. 2006. Hydrothermal synthesis of Mg- and Mg-Ni-rich kaolinite. Clays Clay Miner, 54. pp. 667-677.
8. Dill H.G., Bosse H.R., Henning K.H., Fricke A. 1997. Mineralogical and chemical variations in hypogene and supergene kaolin deposits in a mobile fold belt the Central Andes of northwestern Peru. Mineralium Deposita 32: pp 149-163.
9. Ece I. Ö., Ekinci B., Schroeder P.A., Douglas C.e, Esenli F., 2013. Origin of the Düvertepe kaolin–alunite deposits in Simav Graben, Turkey: Timing and styles of hydrothermal mineralization. Journal of Volcanology and Geothermal Research, 255. pp. 57–78.
10. EL-Shahat A., Kora M. 1986. Petrology of the Early Palaeozoic rocks of Um Bogma area, Sinai. Mansoura Science Bulletin. 13. pp. 151-184.
11. EL-Wekeil S.S. and Gaafar F.Sh, 2014. Characterization and economic potential of the white sandstones of the Naqus Formation in Wadi Qena, northern Eastern Desert, Egypt Middle East Journal of Applied Sciences 4(2). pp. 392-408.

12. Fitzpatrick E.A. 1980. Soils. Their Formation, Classification and Distribution. 2nd edition. Longman, London. 453 p.
13. Folk R. L. 1980. Petrology of Sedimentary Rocks: Hemphill Pub. Co., Austin, Texas. 184 p.
14. Hassan A.A. 1967. A New Carboniferous Occurrence in Abu Durba, Sinai, Egypt. Proceedings of the 6th Arab Petroleum Con., Baghdad, 2. 8 p.
15. Hinckley N.D. 1965. Mineralogical and chemical variations in the kaolin deposits of the coastal plain of Georgia and South Carolina. American mineralogist. Vol. 50. pp.1865- 1883.
16. Issawi B., El-Hinnawi M. Francis M., and Mazher A. 1999. The Phanerozoic geology of Egypt, A geodynamic approach. Geol. Surv. Egypt, Spec. Publ., 76: 462 p.
17. Issawi B., Jux U. 1982. Contributions to the stratigraphy of the Palaeozoic rocks in Egypt. Geological Survey Paper 64. pp. 1-28.
18. Kantorowicz j. 1984. The nature, origin and distribution of authigenic clay minerals from middle Jurassic ravenscar and brent group sandstones. Clay Minerals. 19. pp 359-375.
19. Klitzsch E. 1986. Plate tectonics and cratonal geology in Northeast Africa (Egypt, Sudan). Geol. Rdsch. 75. pp. 755-768.
20. Klitzsch E. 1990. Palaeozoic. In: Said, R. (Ed.), The Geology of Egypt. Balkama, Rotterdam. pp. 393-406.
21. Klitzsch E., Groschke M., and Herrmann-degen W. 1990. Palaeozoic and pre-Campanian Cretaceous strata at Wadi Qena. In: Said, R. (Ed.), "The Geology of Egypt". Rotterdam and Boston, Balkema. pp. 321-327.
22. McGraw-Hill 2003. Dictionary of Geology and Mineralogy. 2nd Edition. McGraw-Hill Companies, Inc. All rights reserved. New York, Chicago, San Francisco, London. 420 p.
23. Meunier A. 2005. Clay. Springer Berlin Heidelberg New York. 472 p.
24. Omara S. and Schultz G. 1965. A Lower Carboniferous microfauna from south-western Sinai, Egypt. Palaeontographica, Vol. 117, No. 1-3. Stuttgart. pp.47-58.
25. Railsback L.B., 2003. An earth scientist's periodic table of the elements and their ions. Geology 31. pp 737–740.
26. Ruiz Cruz, M.D. 2007. Genesis and evolution of the kaolin-group minerals during the diagenesis and the beginning of metamorphism. In: Fernando Nieto and Juan Jimenez-Millan, eds. "Diagenesis and Low-Temperature Metamorphism. Theory, methods and Regional Aspects" Seminarios SEM, 3:41-52.
27. Ruiz Cruz, M.D. and Andreo, B. 1996(a). Genesis and transformation of Dickite in Permo-Triassic Sediments (Betic Cordilleras, Spain). Clay Miner., 31. pp. 133-152.
28. Rye R.O., Bethke P.M., Wasserman W.D., 1992. The stable isotope geochemistry of acid sulfate alteration. Economic Geology 87. pp. 225–262.
29. Rytwo G. 2008. Clay minerals as an ancient nanotechnology: historical uses of clay organic interactions, and future possible perspectives. Macla, 9. pp. 15-17.
30. Said M., EI-Kelani A., 1988. Contribution to the geology of southeast Sinai. In: 26th Ann. Meet. Geol. Soc. Egypt, Cairo. pp. 30-31.
31. Said R., 1990. The Geology of Egypt, Balkema, 734 p.
32. Soliman M.S., EI-Fetouh M.A., 1969. Petrology of the Carboniferous Sandstones in West Central Sinai. Egypt. J. Geol., 13. pp. 61-143.
33. Soliman S.S., and Abu El Fetouh M. 1970. Carboniferous of Egypt: Isopach and lithofacies maps. AAPG. Vol. 54. No. 10. pp.1918-1930.
34. Tawfik A. H., Ghandour M. I., Wataru M., and Abdel-Hameed T. A. 2011. Petrography and geochemistry of the Lower Paleozoic Araba Formation, northern Eastern Desert, Egypt: implications for provenance, tectonic setting and weathering signature. Journal of geosciences, Osaka city University. Vol. 54, part. 1. pp. 1-16.
35. Wanas H.A. 2011. The Lower Paleozoic rock units in Egypt: An overview, China Univ. of Geosciences (Beijing), Geosciences Frontiers, 2(4). Pp. 491-507.
36. Weaver C.E. 1989. Clays, Muds, and Shales. Developments in sedimentology (44). Elsevier. 819 P.

1/21/2017