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Smectite Characterization of The River Nile Floodplain Soils, Sohag Governorate, Egypt

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Abstract

Fourteen representative samples from the River Nile floodplain soils, Sohag Governorate, Egypt were collected. These soils' physical properties, detailed bulk mineralogy and clay mineral species of clay fraction were determined using X-ray diffraction (XRD), Fourier Transform Infrared spectroscopy (FTIR), and advanced softwares. These soils are almost identical in terms of bulk and clay mineralogy throughout the governorate's districts. Their bulk mineralogy consists primarily of phyllosilicates (25-56%) and feldspars (21-43%) with less amounts of quartz (10–22%) and calcite (6–12%). The clay fraction mineralogy comprises smectite, kaolinite, illite (poorly and well crystalline), ordered smectite /illite mixed-layer mineral (R1), randomly ordered smectite /illite mixed layer minerals (R0) and kaolinite /smectite mixed layer minerals (K/S). Smectite (Ca-monmorillonite species) and smectite/illite mixed-layer minerals are the principal components of the clay fraction. According to these results, clay mineral species, amounts, and characterizations are accurately identified for application in soil management. This is important since soil fertility and clay mineralogy are closely related.

Keywords: Clay minerals, soil, River Nile, Sohag Governorate, smectite, Ca-monmorillonite species.

INTRODUCTION

As one of the world's longest rivers and the site of one of the earliest human civilizations, the Nile River and its sediments, soil, and water have been the subject of countless studies in a variety of scientific fields and disciplines (e.g., Hull, 1896; Lyons, 1906; Gregory, 1920; Awad, 1928; Huzayyin.1941; Butzer and Hansen, 1968; Wendorf and Schild, 1976; Said, 1990; Faragallah et al,2006; Abu Seif and El-Shater, 2010; Abu Seif, 2015; El-Shater et al., 2020, Thabit et al.,2023).

Despite the fact that there has been many research on clay minerals in the Nile deposits, the majority, if not all, of these studies have only focused on the definition of clay mineral groups and how they are distributed both horizontally and vertically in the examined locations (e.g., El Gabaly and Khadr in 1962; Fayed in 1970; Hanna and Beckmann, 1975; Melegy and El-Agami, 2004; Purzner, 2008; Abou El-Anwar, 2019 and 2021). Beyond this trend, further research on clay mineral species in the soils of the Nile River floodplain in the Sohag Governorate of Egypt was the goal of this study. The characteristics of smectite minerals, which represent the main component of clay minerals in these soils, have been studied in detail in this article. These specific clay mineral features, which are ultimately connected to soil fertility, undoubtedly influence the chemical and physical behavior of soils.

1. Study area:

The study region is located in the Sohag Governorate's flood plain soils, between longitudes 31° 15' and 32° 15'E and latitudes 26° 00' and 27° 00'N (Fig.1a). These soils are classified as Entisols by the US Soil Taxonomy (Soil Survey Staff, 1996). They are often sand, silt, and clay combinations, as well as various types of loams.

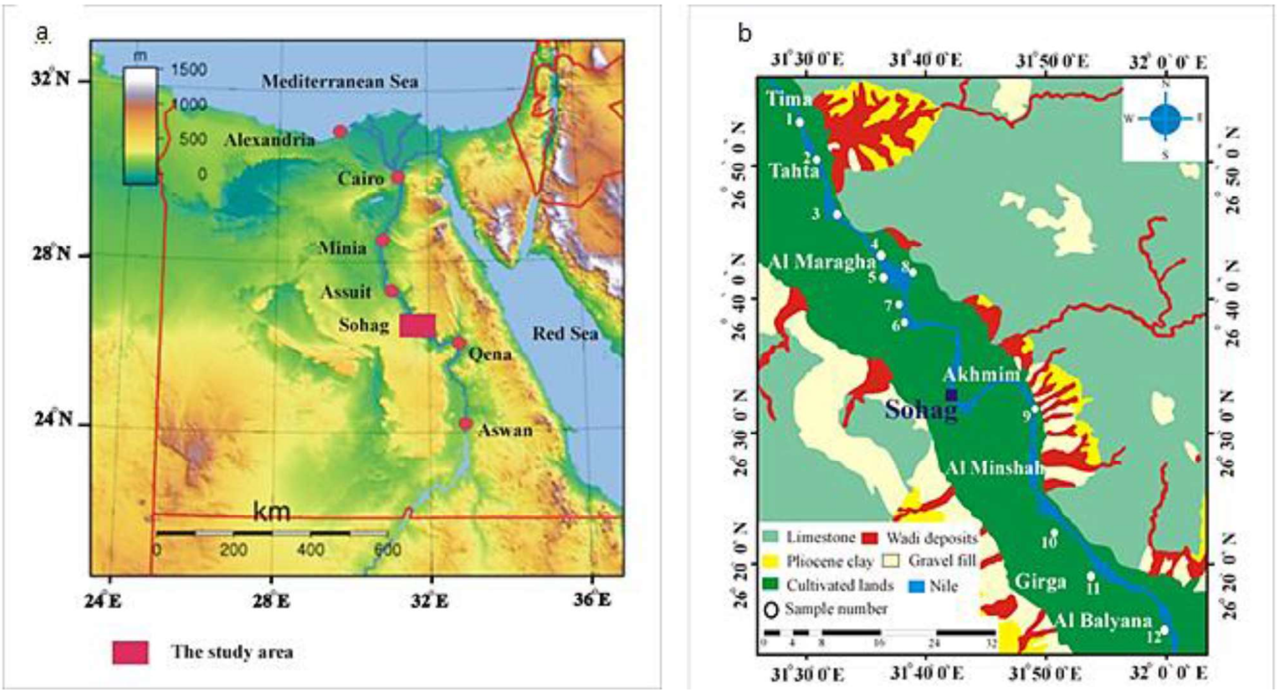

Fig 1: a) Location of Sohag Governorate, Upper Egypt (the studied area), b) A Sohag Governorate map showing the sample locations in its districts.

2. Geologic setting:

Since the beginning of the last century, the studied area surface geology has been the subject of a large number of investigations. The most significant works are of Wendorf & Said, 1967; Said, 1990; Issawi and McCauley, 1992; Omer and Issawi, 1998; El Haddad, 2014 and El-Shater et al., 2020).

Numerous litho- and bio-stratigraphical, mineralogical, palaeontological, sedimentalogical, and structural issues are covered in these investigations. They help greatly to interpret the present geology and litho-sedimentological characteristics of this area. Based on the recent stratigraphic works given by Said (1983), El-Haddad (2014) and El-Shater et al. (2020), the stratigraphic units recognized in Sohag area are the following (Fig.1b).

The Lower Eocene limestone sequence: -

In Sohag Governorate, lower Eocene limestone sequence (the oldest exposed rock unit) bounds the Nile Valley region. It was separated into two formations (Thebes and Drunka formations) based on differences in faunal composition and lithology: Thebes Formation, which conformably underlies Drunka Formation, was made of 30 m laminated limestone intercalated with flint bands and concretions. Drunka Formation (distinguished by its snow-white hue and extensive bedding) covers more than 90% of the examined area (Abu Seif, 2015).

The Late Oligocene-Miocene sequence:

This sequence includes the Katkut and Abu Retag formations. The coarse clastic sediments that cover the Eocene sequence are collectively referred to as the Katkut Formation. Its type section occurs at the southern flanks of Wadi El Yatim attaining more than 60 m thick (Issawi et al., 1999). The constituents of the Abu Retag Formation are gravels, coarse clastic deposits with a mottled brown color, and gravelly sands loaded with Basement pebbles with a thickness of 50 m that appear on the western Eocene limestone plateau's lower slopes (Mahran et al., 2013).

The Pliocene-Quaternary sequence:

This sequence embraces Madmoud, Armant, Issawia, Qena, Abbassia, Dandara and El Gir formations (Said, 1975 and 1981). Madmoud Formation (Pliocene) consists of intercalations of siltstones with chocolate brown claystone and fine sandstones near its upper part and symbolizes the stage of Paleonile, that start with the Mediterranean Sea incursion and culminated with the filling of canyon of the Nile. Armant Formation with 10–30 m thickness of mixed clastic–carbonate sequence. The Issawia Formation with up to 10 m thick of red breccias with good cementation that sporadically appear along the western and eastern borders of the basin. Fine sandstones and siltstones that are cross-laminated and up to 30 meters thick are the uppermost of the Qena Formation sequence, which began with coarse-grained cross-bedded sandstones cycles at the base. The Abbassia Formation (10 m thick) is made up of a yellowish white well-rounded sandy gravel series generated mostly from Lower Eocene limestone, and it overlies and cuts through the Qena and Armant formations. Nearer to cultivated land along the Nile eastern bank, the sand and silt intercalations comprise the Dandara Formation. El Gir Formation is composed of mixed conglomerate and sandstone with east ward changes in lithology to mixed siltsone, stromatolitic and biomicritic limestone and conglomerates. Study area Holocene sediments consist of three units: sand dunes, wadi deposit and flood plain deposits.

MATERIALS AND METHODS

Fourteen representative samples from the River Nile floodplain soils were collected from Sohag Governorate covering the soils of all its districts. Figure (1b) show the location of the sampling sites. Wet sieving and pipette analysis were used in tandem to determine the particle sizes. Plotting the relative percentages of the silt, sand, and clay fractions on a triangle diagram was done. (Shepard, 1954). A calcimeter (Bascomb, 1961) was used to measure calcium carbonate, and the Kalembasa and Jenkinson method (1973) was used to measure organic carbon.

The bulk samples were ground by agate mortar before mounting for XRD run. Orientation had been avoided where the peak intensities are used for semi-quantitative evaluation of mineral composition. The clay fractions (less than 2 µm) separated by pipette method were saturated with potassium, magnesium, calcium and lithium ions from 0.1 N chloride solutions, washed salt-free and dried. Additionally, each sample was scanned using three clay-sized fractions slides per sample: one without treatment, the other heated for two hours to about 550 ^{o}C and the third one spent an overnight exposure to ethylene glycol atmosphere vapor at 80 ^{o}C.

The mineral composition of both bulk rock samples and clay fractions was examined using monochromatic Cu $k_{\acute{\alpha}}$ (k = 1.54 Å) radiation at 40 kV and 35 mA using a Philips X-ray diffraction equipment model PW/1710, located in the Department of Physics at Assiut University in Egypt. On the basis of Moore and Reynolds (1997), calculation techniques and semi-quantitative estimates of the proportions of the mineral clays were made. The XRD data were numerically processed through the use of Lanson (1997)'s curve decomposition techniques. Fitting a computed curve to the summation of Gaussian or Lorentzian curves with the measured X-ray pattern is the decomposition program's main task. The user first selects the number of curves (each curve represents a population of clay minerals) that the program must handle, as well as the approximate location, intensity, and width at half height (WHH) of each curve. Using background subtraction and curve decomposition routines, the clay mineral phases can be quantitatively identified (Lanson, 1997). By using the techniques described by Moore and Reynolds (1997), diffractogram simulations can be used to estimate the relative proportions of each component based on peak areas identified through decomposition methods, as well as the amounts of illite and smectite present in each phase.

The IR spectrum analysis in this study was done on approximately 2gm of dried samples which mixed with 1gm of high purity Potassium Bromide using an agate mortar. This was carried out using prisms having a wavelength ranging from 2.5 mm to 19 mm (4000–400 cm^{-1}).

RESULTS AND INTERPRETATION

1. Physical properties of the studied soils:

The physical properties of the studied soils including the granulometric results, pH, calcium carbonate and organic carbon contents are presented in Table (1). Based on the ternary diagram of Shepard (1954), the studied soil samples occupy the fields of clayey silt and sandy silt (Fig.2a).

Table (1): Physical properties of the Nile soils in Sohag Governorate.

District	Village	**Sand%**	**Silt%**	**Clay%**	**pH**(soil; water1:2.5	**CaCO3 %**	**Organic matter%**
Tema		**17**	**55**	**28**	**7.7**	**7**	**1.1**
Sakoulta	Awamia	**41**	**40**	**19**	**7.9**	**5**	**2.1**
Tahta	Nageeeldeek	**25**	**49**	**26**	**8.2**	**10**	**0.7**
	Sawammaa	**16**	**44**	**27**	**8.1**	**8**	**0.9**
Maragha		**13**	**48**	**27**	**8.3**	**9**	**0.9**
	Exsas	**33**	**45**	**21**	**7.8**	**7**	**0.8**
	Shandweel	**18**	**55**	**23**	**7.7**	**7**	**1**
	Elshaikhyousif	**11**	**58**	**22**	**8.3**	**8**	**1.4**
Sohag	Talawsat	**12**	**63**	**25**	**7.9**	**4**	**1.8**
Akhmim	Kolla	**17**	**61**	**22**	**7.3**	**6**	**1.3**
Elmanshah		**30**	**48**	**22**	**7.6**	**3**	**1.2**
Gerga	South Gerga	**23**	**53**	**24**	**7.6**	**2**	**1.1**
Elbalina		**22**	**48**	**28**	**8.3**	**7**	**1.2**
Dar Elsalam	Awladelshaikh	**14**	**56**	**30**	**7.4**	**8**	**1.7**

2. Bulk mineralogy of the studied soils:

The bulk mineralogy XRD patterns of the studied soils show that their mineral contents are almost the same for all samples of Sohag Governorate. Hence, these soils are mainly of phyllosilicates (25-56%,) and feldspars (21-43%,) with remarkable amounts of quartz (10-22%) and calcite (6-12 %) (Table 2 and Fig 3). The feldspars recorded in these soils include both of the alkali group (orthoclase) and plagioclase groups (disordered calcian albite, bytownite and labradorite).

The IR spectra of bulk samples of the studied soils were measured in transmittance between 400 and 4000 cm^{-1} (Fig.4). From their IR spectra, feldspars appear at the bands1146, 1090, 1034, 1011, 790, 588, 533 and 464 cm^{-1}. Additionally, the bands at 792 cm^{-1} in these spectra were attributed to non-crystalline silica. Broad XRD peaks at 4.07 Å (Fig. 2b) support the presence of opal-CT, which is shown by this band and the 628 cm^{-1} band. Additionally, quartz was responsible for the faint band at 695 cm^{-1} as well as the bands at 798 and 778 cm^{-1}. Lastly, The IR spectra reveal that calcite appeared at the bands 1432 to 1455 and 876 cm^{-1}.

Table (2): The bulk mineralogy of the River Nile soils in the Sohag Governorate.

District	**Village**	**Phylosilicates%**	**Quartz%**	**Feldspars %**			**Calcite%**
				Plagioclase%	**K-Feldspars %**	**Total feldspars %**	
Tema		**49**	**12**	**20**	**12**	**32**	**7**
Sakoulta	**Awamia**	**25**	**22**	**38**	**5**	**43**	**10**
Tahta	**Nageeeldeek (Tahta1)**	**39**	**18**	**23**	**8**	**31**	**12**
	Sawammaa (Tahta2)	**34**	**13**	**27**	**11**	**28**	**7**
Maragha	**Maragha1**	**41**	**19**	**23**	**7**	**32**	**9**
	Exsas (Maragha2)	**45**	**12**	**23**	**12**	**35**	**8**
	Shandweel (Maragha3)	**48**	**16**	**17**	**9**	**29**	**8**
	Elshaikhyousif (Maragha4)	**44**	**15**	**19**	**16**	**33**	**10**
Sohag	**Talawsat**	**49**	**10**	**13**	**21**	**34**	**7**
Akhmim	**Kolla**	**51**	**16**	**18**	**9**	**27**	**6**
Elmanshah		**44**	**14**	**16**	**15**	**31**	**11**
Gerga	**SouthGerga**	**53**	**17**	**14**	**7**	**21**	**9**
Elbalina		**50**	**12**	**20**	**12**	**32**	**6**
Dar Elsalam	**Awladelshaikh**	**56**	**10**	**19**	**9**	**28**	**11**
Average		**45**	**15**	**21**	**11**	**31**	**9**

3. Clay fraction mineralogy of the studied soils:

3.1. Qualitative analysis of the clay minerals of the Studied Soils:

The X-ray diffractograms of the clay fraction of the studied soils show also uniformity in their recorded peaks and consequently refer to similar clay minerals (Fig.2b). In all XRD patterns, the background level at small (2Θ) angles, as well as the peak at 5.32 Å (EG treatment), indicates the presence of illite–smectite mixed layers. Broad first-order reflections, frequently asymmetrical forms, and a few weak and broad diffraction band or shoulder associations are visible in the clay minerals of the majority of soils investigated. Frequently, the same set of (00l) peaks shows somewhat similar breadths (width of the diffraction peak at half its height above background) and irrational spacings.

Techniques (air drying, solvating with EG, and heating at 550°C) for treating unsaturated samples were applied to one sample from the soils of the Sohag Governorate under study and the following changes were observed in the sample's XRD pattern: (1) A well-defined peak at 14–15 Å is produced in air- high dried samples, which is followed by weaker peaks at 7–7.2 Å; (2) Two peaks, split from the superimposed 14 to 15 Å peak in EG solvated preparations one at the original 14 Å and the other at 17 Å.

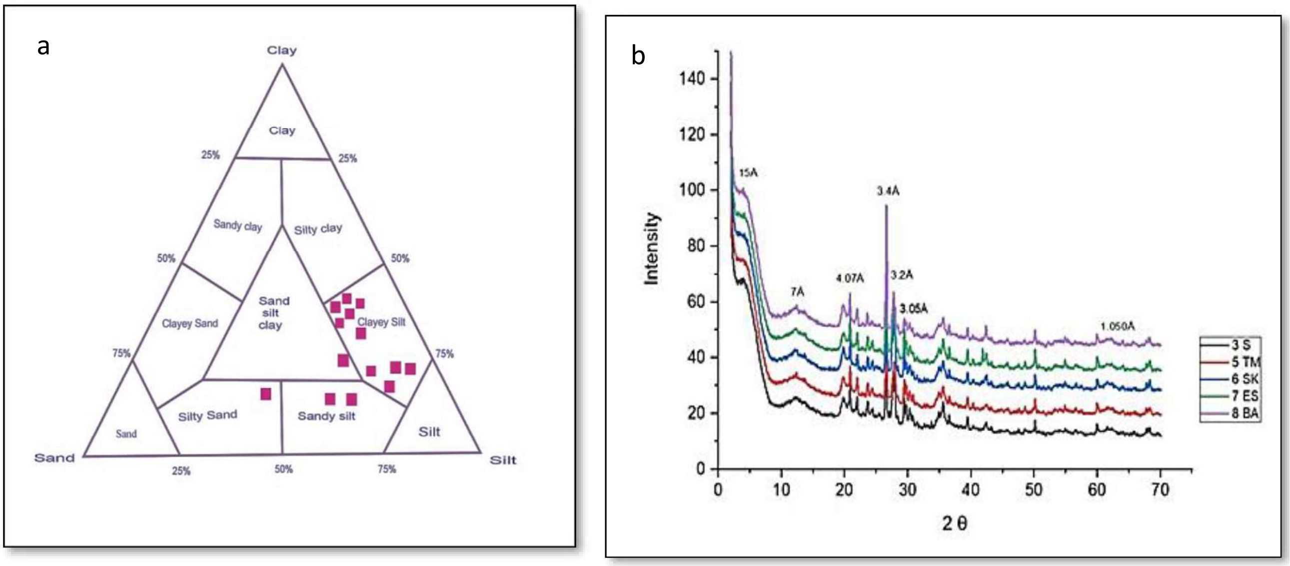

Fig. 2: a) Sediment nomenclature based on sand-silt-clay ratios (after Shepared, 1954). b) Representative X-ray diffractograms showing the similarity of bulk mineralogy of the River Nile soil in the studied area (5TM=Tema; 6SK=Sakolta; 7ES=El maragha; 8BA=El baliana; 3S=Sohag).

The reflections at 7-7.2 Å are kept; (3) Heating at 550°C collapses all of the mentioned peaks and significantly boosts the strength of a peak near 10 Å, while the reflections at 7-7.2 Å are preserved. (Figs. 5b). The saturations of Mg^-, K^-, and Li^- of the samples improved the ability to distinguish between other minerals with similar d-spacing (vermiculite and chlorite) and smectite: Smectite expands to 17–18 Å upon glycolation of Mg-saturated samples, whereas vermiculite and chlorite remain at 14 Å; and Smectite collapses to 10 Å upon K-saturation under air-dried circumstances or heating at 550°C, giving rise to a diffraction pattern similar to that of illite, while chlorite stays at 14 Å.

Based on the qualitative identification methods of Moore and Reynolds (1997), Brindley and Brown (1980), Brindley (1981), and Velde (1995) Hillier (2003) and the curve decomposition (Lanson,1997), smectite (Ca-montmorillonite), kaolinite, illite (poorly and well crystalline), ordered smectite/illite mixed-layer mineral (R1), randomly ordered smectite /illite mixed layer mineral (R0) and kaolinite/smectite mixed layer mineral (K/S) (Fig.6) are among the clay mineral species that are defined by the behaviour of minerals reflections under natural conditions (air-dried), Mg-, K- and Li-saturation, ethylene glycolation and heating to 300 and 550°C.

According to the same authors, clay minerals are mainly composed of intricate juxtapositions of two or more distinct species; this is especially true of mixed-layered clay minerals. This is supported by illogical spacings, and width of most reflections. These interstratified formations frequently coexist with the finest proportion of sediments, according to Righi and Meunier (1995). The most prevalent mixed-layered structure found in the soils under investigation was illite-smectite (I/S), a sedimentary rock and soil characteristic that forms under stable conditions and has varying ratios of smectitic and illitic layers (Moore and Reynolds, 1997 and Righietal. 1997).

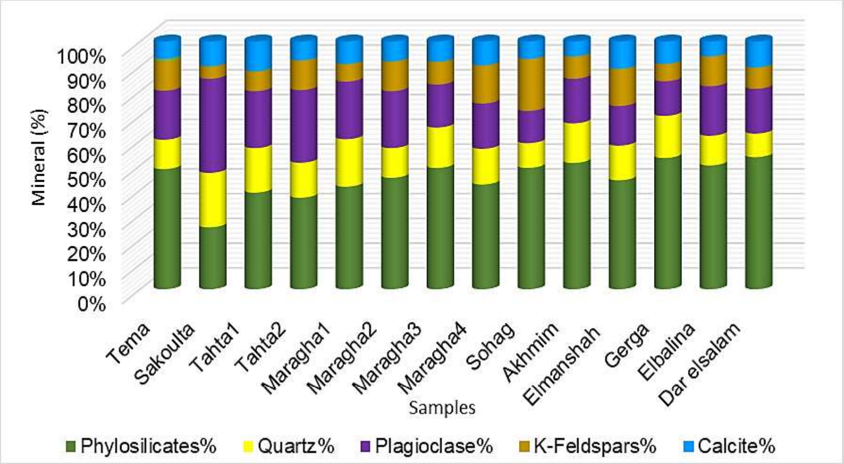

Fig. 3: Mineral contents of the bulk samples showing their similarity along the River Nile soil in the studied area. The asymmetry,

3.2. Quantitative analysis of the clay minerals of the studied Soils:

The semi-quantitative estimation of clay mineral contents and the numerical analysis method of X-ray diffraction recordings (curve decomposition), reveals that the smectite and smectite /illite mixed layer minerals make up the majority of clay mineral content of these soils (average,75%) whereas the illite,kaolinite and kaolinite/smectite mixed layer mineral compose the remaining (average, 25 %) (Table

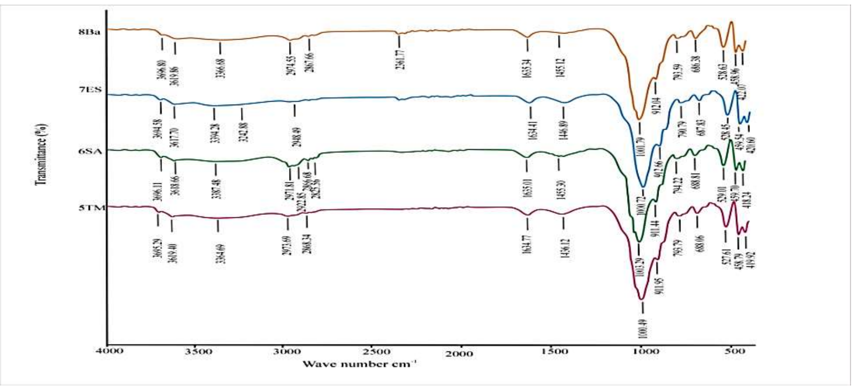

Fig. 4: Representative IR spectra of the bulk mineralogy of the Nile soils in Sohag Governorate (3S, 5TM, 6SK, 7ES and 8BA representing samples from Sohag, Tema, Sakolta, Elmaragha and Elbalina districts, respectively).

4. Origin of smectite

Generally speaking, various rock types weathering and under particular climatic circumstances results in the formation of clay minerals. The location of the soils along the River Nile and their vast depth (approximately 150 m) from the consolidated rocks suggest that they are most likely sedimentary in origin (Abdel Moneim, 1992). Additionally, not all of the detected minerals can be accounted for by the basement complex, Thebes Limestones, or Nubian Sandstone. The basic igneous and metamorphic materials that were carried downstream from the Ethiopian plateau of Abyssinia during previous pluvial periods are thought to have weathered into the investigated soils (Blockhuis et al., 1954 and Said, 1981).

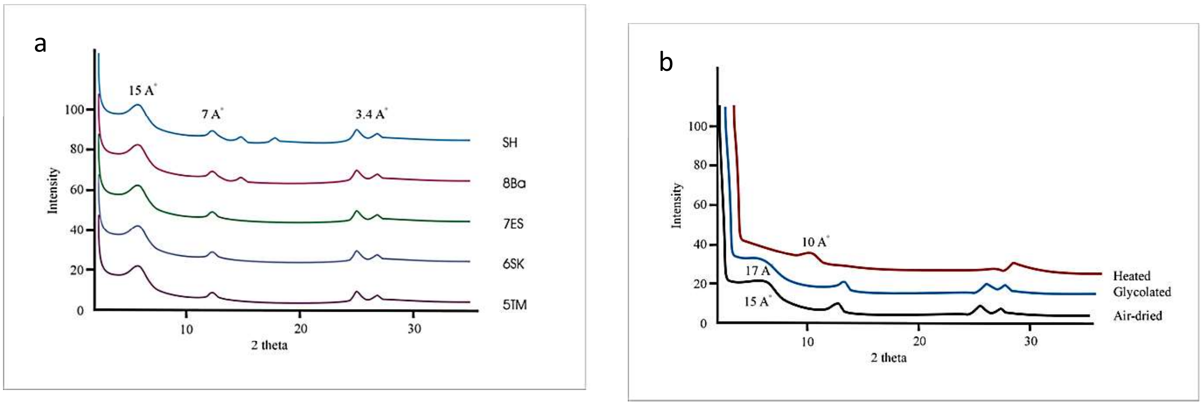

Fig. 5: a) Representative XRD patterns of the Nile soils in the Sohag Governorate Showing the similarity of their clay mineralogy (SH, 5TM, 6SK, 7ES and 8BA representing samples from Sohag, Tema, Sakolta, Elmaragha and Elbalina districts, respectively). b) Representative XRD patterns of the untreated, ethylene glycol solvated and heated clay fraction samples from the studied soil (black line: air-dried, blue line: glycolated, rose line: 550 °C heated).

There is proof of massive deforestation on the western portion of the plateau, which slopes in the direction of the Nile supports this claim (Blanford, 1869). According to Blanford's studies, basalt, trachyte, and dolerite are less common rocks that make up the base of the Abyssinian plateau than metamorphic rocks, sandstone, and limestone. On the Ethiopian plateau, muscovite, biotite, chlorite schists, trachyte and basalt were found, according to Levitte (1974). The majority of the clay-sized material that the Nile transported northward into Egypt before the construction of the High Dam originated from wadis rather than the river's headwaters in central Africa and the Ethiopian Plateau.

According to Hurst (1944) and Foucault and Stanley (1989), the Ethiopian highlands produced most of the Nile's sediment burden and at least 70% of its flow north of Khartoum. El-Attar and Jackson, 1973 stated that the clay that the Nile carried northward over Egypt before and immediately after the High Dam was built was primarily composed of smectite (70%), with small amounts of illite (10%) and kaolinite (25%).

Based on Butzer and Hansen, (1968); Weir et al., (1975); El Sabrouti, and Sokkary, (1982) Maldonado and Stanley, (1981), large amounts of smectite were carried with reference to the Nile Delta and nearby Egyptian shelf, originating mostly in Ethiopian volcanic terrains but also throughout the Holocene, semi-arid areas drained by the Atbara River and the Blue Nile Weathered basic volcanic rocks are the source of smectites. Pedogenic smectites can be created through deteriorated smectite, a straight forward transformation of other silicate minerals, or by precipitation from solution (complicated transformation) or through straight forward modification). Most frequently, they are found in soils from warm temperate climates to tropical wet and dry regions (De Visser, 1991). Potassium-bearing micas undergo a simple change to extendable 2:1 minerals (vermiculite and smectite) by swapping out the K in the interlayer with hydrated cations via layer and edge weathering (Fanning et al., 1989).

Table (3): Clay mineral composition of soils of the River Nile in the studied area (Sohag Governorate).

District	Village	Smectite%	I/S (R1) %	I/S(R0)%	WCI %	Kaolinite%	K/S(R0) %
Tema		58	19	9	2	4	8
Sakoulta	Awamia	66	8	8	4	11	3
Tahta	Nageeeldeek	57	14	8	6	8	7
	Sawammaa	56	17	14	4	7	2
Maragha		59	15	12	3	7	4
	Exsas	67	0	8	7	13	5
	Shandweel	61	15	3	5	10	6
	Elshaikh yousif	66	8	6	6	8	6
Sohag	Talawsat	71	0	9	3	6	11
Akhmim	Kolla	40	13	11	8	9	19
Elmanshah		47	25	9	8	11	0
Gerga	South Gerga	36	13	14	4	17	16
Elbalina		68	0	13	4	10	5
Dar Elsalam	Awlad elshaikh	40	13	11	3	27	6
Average		57	11	10	5	11	7

In the soils of the oldest and youngest terraces on both sides of the Nile, smectites range in abundance from moderate to greatly, according to El-Attar and Jackson (1973). On the outskirts of the desert, they are, nevertheless, scarce to moderately common in the terrace's back suture soils. The oldest and youngest Nile terraces' soil profiles show no overall trend of growing or decreasing smectites. The terrace rear suture on both sides of the desert's edge and the terrace bench in the Nile valley-desert interference zone's soils, they do, nevertheless, have a tendency to decline with depth. This pattern shows that maintained Smectite-rich Nile sediments make up the majority of the upper portion of these soils.

Given the aforementioned assertions, it is hypothesized that the minerals in the investigated soils were created in their original environment.

5. Smectite characterization:

In most of the tested soil samples, smectites with percentages ranging from 40% to 71% are the most common clay mineral (Table 3). The presence of smectite in relatively high concentrations and an increase in smectite content in the I-S minerals with small amounts of illite may indicate a loss of K from the clay mineral fraction of these soils under continuous-corn cropping practices, which predominated in Upper Egypt in the 1960s (Li and Sarah, 2003). All of the investigated soils have pure smectite, with the smectite 001-peak being broad and centered at around 15 Å (Fig. 5a). Montmorillonites with two layers of water molecules in the interlayer position and divalentcations have a d-value of 14–15 Å. Since it appears as a broad band at around 15 Å in the air-dried pattern, extends to approximately 17 Å with glycolation, and collapses to 9.6 Å with heating, it occurs as Ca-montmorillonite, according to Lim and Jackson (1986).

The peak is asymmetric to the low-angle, high-d-value side, indicating that there may have been mixed layering of illite with Ca and Mg as well as some Na in the interlayer position. The peak is still broad and is located at 17 Å after EG-solvation. Iron is the source of the high background since it scatters X-rays. According to Mamy and Gaultier (1976) and Reynolds (1992), the asymmetrical band (34-39 2Θ in Figure (6) represents a typical fully turbostratic stacking mode. Smectite (060, d = 1.503 Å, Fig. 6) has broad peaks, which is a sign of its dioctahedral structure (Brown and Brindley, 1980; Moore and Reynolds, 1997). Since different protoliths undergo pedogenesis under a variety of environmental conditions to produce the dioctahedral smectite group (montmorillonite, Al-rich beidellite), pure bentonite layers can also be produced by altering silicic volcanic ash under subaquatic conditions (Hodder et al. 1990; Naish et al. 1993).

By contrast, the trioctahedral variety (saponite) and Fe-rich dioctahedral end-members (nontronite).areoften formed through hydrothermal alteration and meteoric weathering of basalt(McMurtry et al., 1982; Parra et al., 1986, Güven, 1988; Chamley, 1989).

The dioctahedral range of smectites is occupied by the b_o parameter values (9.06-9.095 Å) obtained from the position of the 060 reflection in the non-oriented powder XRD patterns and their unit cells refinement. According the Scherrer method, Ca-montmorillonite species of smectites with crystallite sizes ranging from 2 to 4 nm is recorded. The Williamson-Hall method revealed a non-uniform strain that was too small, ranging from 0 to 0.002%. The crystallite thickness of the smectites found in this study is less than that of smectites reported by Mystkowsky et al. (2000) (3.4–7.3 nm), which could be related to the mineral species and occurrences of smectites. The smectite crystallite thickness is not reflective of the growth method; rather, it is connected to the characteristics of the layers themselves (Eberl et al., 1998). The crystallite thickness of illite/smectite is mainly depending on the lateral dimension of the layer (Mystkowsky et al., 2000 and Šucha et al., 1996).

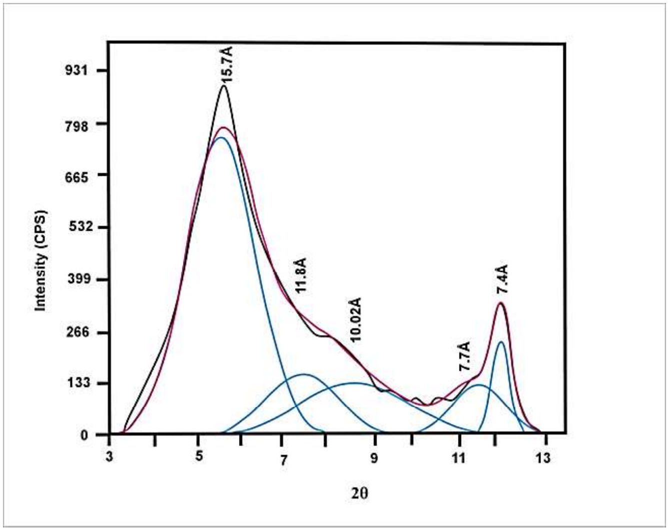

Fig. 6: Decomposition of background - subtracted XRD patterns of the studied (Elmaragha sample,7ES).
(15.7 Å) = Smectite,
(11.8 Å) = ordered smectite /illite mixed-layer mineral (R1),
(10.2 Å) = Well crystalline illite
(7.7Å) and (7.4Å) =Randomly ordered kaolinite-smectite mixed layer mineral (K/S R0)

6. IR Investigations of smectite

Infrared spectroscopy (IR) is a rapid, easy, and reasonably priced technique that provides helpful supplementary information on the crystal chemistry of clay minerals. Clay minerals have a complex connection with the IR spectrum that has only been partially understood. The IR spectra of the studied soils were measured in transmittance between 400 and 4000 cm^{-1} to study their structural composition. As in the XRD analyses, the IR spectra of the bulk samples of these soils reveal noticeable mineral similarity along the studied area (Fig.4).

The splitting of IR band is generally due to presence more than one type of hydroxyl bonds with different absorption frequencies. IR bands with frequencies vary from 3615 to 3622 cm^{-1} and from 911 to 918 cm^{-1} are represented as diagnostic bands of dioctahedral smectites (Caille`re et al., 1982 and Watanabe et al.,1992) that may be originated by stretching (ν), deformation (δ) and vibrations within hydroxyls configuration (AlAl-OH, Farmer, 1974). The IR bands smectites (montmorillonite) are influenced by their octahedral cation substitutions phenomena. Al^{3+} is the most dominant in octahedral sheets which is substituting by Mg^{2+} and Fe^{3+}cations. Whereas, in the tetrahedral sheet, Si^{4+} and Al^{3+} are mostly common cations (Reid-Soukup and Ulery, 2002).IR band of 3620 cm^{-1} frequency which characterized by stretching vibrations of OH structural groups is recorded in all samples of studied soils that indicates the dominance of Al^{+3} of. Additionally, another band (912 cm^{-1}, Tables 4, 5 and Fig.6) can be supported by the dominance Al^{+3} in montmorillonite octahedral sheets (Madejova and Komadel, 2001).

A shoulder near 878 cm^{-1} frequency on the infrared peak at 912 cm^{-1} frequency suggests deformation modes. AlFe (III)OH units (Russel et al. 1970 and Farmer, 1974). Observations of structural Fe (III) in octahedral sheets of smectite of the examined samples, as opposed to tetrahedral sheets, and the presentation of a stretching vibration band of Si-O at 1034 cm^{-1} frequency are in excellent agreement with the findings of Goodman et al. (1976). An increase in the quantity of tetrahedral Fe (III) can cause the Si-O stretching band to move to a lower frequency (~1000 cm^{-1}) (Bouna et al., 2012). The investigated soils' infrared spectra lack the IR band at ~825 cm^{-1} frequency, which is thought to be a distinctive band of $(Fe (III))_2OH$ unit deformation vibrations. This finding suggested that smectite from the investigated soils could not be distinguished from nontronite. (Fialips et al., 2002 and Madejova´ et al. 2009).

Typically, the infrared bands of the kaolinite group at frequencies of 3698 and 3620 cm^{-1} are utilized as diagnostic signs. Kaolinite exhibits four distinct O-H group vibration and stretching zones, ranging from 3620 to 3700 cm^{-1}(Gadsden, 1975; Watanabe et al. 1992 and Madejova and Komadel, 2001).Because of hydrogen bonding with the oxygen in the next layer, there are in-phase vibrations along the inner surface OH groups in kaolinite (Madejová, 2003).The majority of the analyzed soil samples have infrared bands (IR bands) in the 3692–3697 cm^{-1} frequency range, with additional bands at 3620, 1000, 912, and 528 cm^{-1} frequencies (Tables 4,5 and Fig. 6). These bands were linked to kaolinite that was accurately identified using XRD charts (7.2Å, Table 6 and Fig.7). The presence of kaolinite is suggested by the faint infrared bands at frequencies of 794 and 754 cm^{-1}(Wilson, 1994).

In accordance with the acquired XRD data, the illite of the examined soils exhibits distinctive infrared bands at frequencies of 3620, 3357, 912, 797, 527, and 461 cm^{-1}(Saikia and Parthasarathy, 2010). The investigated soils' illite/smectite mixed-layer (I/S) exhibits distinctive infrared bands at frequencies of 909 and 912 cm^{-1}. The (I/S) IR bands are being used as additive components (Russell, 1987).

The non-clay minerals (quartz) have IR bands at 794 and 777, 754 and 690 cm^{-1} (Russell, 1987). Carbonate minerals (calcite) is appeared at the bands 1435, 876, and 872 cm^{-1} (white, 1971). Feldspar is recorded at bands 1146, 1090, 1034, 1011, 790, 588, 533 and 464 cm^{-1}. The IR broad band which is centered at 1636 cm^{-1}frequency sometimes overlapped with at 1680 and 1650 cm^{-1}bands (Tables 4,5 and Fig.6) due to deformation modes of water coordinated to interlayer cations and in the hydration sphere of cations, respectively (Frost et al.,2002).

CONCLUSIONS

By using advanced techniques (X-ray diffraction, infrared spectroscopy, studies, and software) to accurately characterize and quantify clay minerals of the River Nile soils in the Sohag Governorate, Egypt, some significant results have been achieved.

The bulk and clay mineralogies of these soils are nearly similar throughout the districts of Sohag Governorate.

The phyllosilicates (25-56%) and feldspars (21- 43 %) are the principal minerals of the bulk mineralogy with remarkable amounts of quartz (10-22%) and calcite (6-12%).

The clay fraction mineralogy comprises smectite, kaolinite, illite (poorly and well crystalline), ordered smectite /illite mixed-layer mineral (R1), randomly ordered smectite /illite mixed layer minerals (R0) and kaolinite /smectite mixed layer minerals (K/S).

From 40% to 71%, smectites (Ca-montmorillonite species) are the clay minerals found in the majority of the soil samples under study. Its asymmetrical band (34-39 2θ) represents a stacking mode that is often entirely turbostratic.

Smectite's wide peaks (060, d = 1.503 Å) reveal its dioctahedral nature. The dioctahedral smectite group, which includes montmorillonite and Al-rich Beidellite, is produced under a variety of environmental conditions by the pedogenesis of protoliths. The dioctahedral range of smectites is occupied by the bo parameter values (9.06-9.095 Å) obtained from the position of the 060 reflection in the non-oriented powder XRD patterns and their unit cells refinement.

From the Scherrer method, the Ca-montmorillonite species with crystallite sizes range from 2 to 4 nm. Their non-uniform strain of these crystallites deduced from Williamson-Hall method vary from 0 and 0.002%. The crystallite thickness (2-4 nm) of the smectites found in this study is lower than the reported crystallite thickness (3.4-7.3 nm) of smectites in literature, which could be attributed to the mineral species and occurrences of these smectites. The thickness of the smectite.

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