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Genesis and classification of Wadi el-Sheikh soils, Beni Suef, Egypt.

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Abstract

The study examined some soils derived from calcareous and gypsiferous parent materials in Wadi el-Sheikh, opposite Al Fashn, Beni Suef, Egypt. The main objectives of this research were to study the relationship between clay minerals and physiographic units as well as the relative importance of key pedogenic processes in controlling clay mineralogy. Palygorskite, chlorite, illite, smectite, quartz and interstratified minerals were observed in soil samples, using XRD analyses. Gypsiferous soils showed more pedogenic palygorskite as compared to calcareous soils. Lithic Gypsicalcids and Calcigypsids, Typic Calcigypsids, Lithic Haplocalcids, Haplocalcids Calcic Haplosalids are the classification of the studied samples. Dissolution and transport of anhydrite from outcrops, is considered the main source of pedogenic gypsum in these soils. Micromorphological studies, of thin section observations indicated variable habits of gypsum crystals suggested a dynamic soil environment.

Key words: Clay minerals; Gypsum and Calcareous soils, arid climate , capability.

INTRODUCTION

The increasing population causes a huge pressure on the areas already inhabited and causes a decrease in area per capita. As a means to curb the problem and narrow the gap that exists between food production and consumption, the government adopted policies aiming at self-sufficiency in food production. This is accomplished by a horizontal extension of cultivated areas. Crop yield is a function of many interactive factors. The soil, as a medium for growing plants, is one of the main plant production factors. Therefore study of soil genesis, problems and limitations of calcareous soils - which, cover more than one million feddans (one faddan = 4200m^2) of agricultural soils and more than 30% of the desert soils in Egypt [1] - are very important aspects. The geology of the study area has been described [2] as Nummulites gizehensis-carrying beds of the base of the Mokattam formation can be followed for the entire length of this stretch. To the north of Minia at Samalut and Maghagha, these beds are followed by easily-weathered marls and shale beds. In this latter location the gizehensis beds are about 70m in thickness; they are followed by a group of variable strata that correspond to the building stone horizon of the Cairo neighborhood. Slightly to the north of Beni Suef the Mokattam formation become lithologically similar to that exposed in Cairo and includes the massive building stones.

It has long been recognized that clay minerals strongly influence the major physical and chemical properties of soils and, consequently, questions concerning the origin, distribution and formation of these minerals have assumed prominence in soil research [3]. In arid and semi-arid regions, palygorskite, smectite, chlorite, illite, kaolinite and vermiculite are the dominant clay minerals [4,5,6,7,8]. The percentage of palygorskite in soils is related to the gypsum content [8]. Gypsum is one the most common sulfate minerals, occurring in geologic deposits as well as a constituent of soils [9], where it is typically the dominant form of calcium sulphate [10]. Anhydrite ($CaSO_4$) is mainly associated with marine evaporates and is soon converted to gypsum upon exposure to environments normal to soils [11]. Pedogenic gypsum crystals can occur individually or in clusters (nodules and plugs) within the soil groundmass and pores [9]. Typically the crystals are silt-and-sand sized, euhedral to subhedral in habit, exhibiting forms including thin filaments, laths, lenticular, tabular pseudo-hexagonal and hexagonal, as well as prismatic [11, 12, 13, 14, 15]. The shape, size, and position of gypsum crystals, within the soil mass, have been used to determine their source [16, 17]. The objectives of this study were to investigate the relative importance of inheritance, transformation and neoformation in determining soil clay mineralogy, especially palygorskite; characterize the forms of pedogenic gypsum crystals in relation to geomorphic position; evaluate the relationship between landforms and clay mineralogy.

Wadi el-Sheikh area (Fig.1) is a strategic region located at the eastern bank of Nile River in, opposite Al Fashn, about 160 km southeast of Cairo. It is located between 31°00′ to 30° 58′ E longitude and 28° 53′ to 28° 58′ N latitude. The study area is bounded by the River Nile coast to the west. It covers about 30 km^2. This area is accessible and traversed by the upper eastern main road and desert tracks. Soil temperature regime of the study area is aridic, and the temperature regime is hyperthermic [18]. The study area is situated within the arid belt where sporadic rainfall may occur from time to time and accompained with torrential storms and flash floods. The climatic parameters indicate that the maximum rainfall is 2.5 mm mostly falls in November. Temperatures range from 5.5 to 12.3 °C during the winter, to between 25.4 and 37 °C during the summer, averaging about 21.8 °C over the year. Potential evapotranspiration averages about 12.7 mm annual, being most intense during the dry summer season [18].

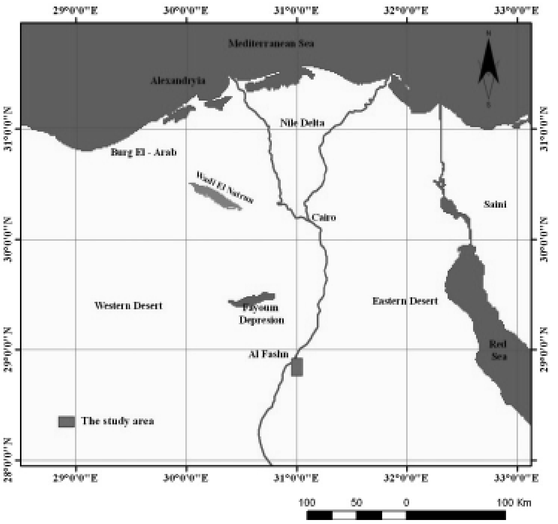

Figure 1 Location of the study area

MATERIALS AND METHODS

Seven profiles were selected to represent the different elevation in the study area. Digital Elevation Model (DEM) of the study area has been generated from the vector contour lines (Fig.2); Arc- GIS 9.0 software was used for this function. The elevation of the studied profiles varies from 69 m to 107 m a.s.l. (Fig.2). Soils were located using GPS and sampled using standard techniques [19] and classified to the subgroups according to Soil Survey Staff [20]. Particle-size distribution was determined by sieving and sedimentation, using the pipette method [21]. It is well known that gypsum, when present in large quantities, influences the physical behavior of soils, so its removal (during pretreatment) complicates the interpretation of particle-size distribution [9, 22]. Accordingly, in this study, particle-size distribution was not determined for some samples due to its containing substantial amounts of gypsum. Chemical measurements of organic carbon by potassium dichromate and ferrous sulfate 1N, total calcium carbonate ($CaCO_3$%) by calcemater , saturation percent (SP), soil pH in a saturated paste, electrical conductivity (EC) was determined in the saturation extract, gypsum ($CaSO_4{\cdot}2H_2O$) in 1-50 water extract and precipitation with acetone, cation exchange capacity (CEC) by ammonium acetate 1N pH 7.0 [23]. "ALES arid" software [24] is used in the study. The model based on available irrigation water (W), thermic conditions (C), effective soil depth (X), salinity (S), calcium carbonates (Ca) and gypsum content(G)

Separation of clay fraction was carried out by dithionite treatment and precipitate by magnesium chloride 1N [25, 26]. Four oriented separated clay samples were prepare in order to determine the clay mineral constituents. Four pretreatments made up for each: magnesium, glycolated , potassium and heat (at 550 C° for two hours) treatments. X-ray diffraction (XRD) patterns were obtained with a Siemens D500 diffractometer, using Fe-filtered Cukα radiation (35 kV, 20 Am), (λ=1.7999A°) and scanning speed of 2° 2 ∅ /min.

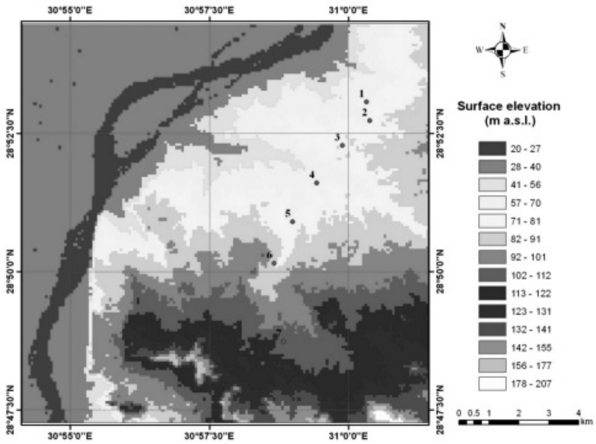

Figure 2 Location of the studied soil profiles**.**

Representative 7 undisturbed soil surface samples in boxes collected from the most soil layers. Normal (2×2 cm) thin sections prepared using a mixture of plastic material diluted by styrene and accelerated by catalizer. The impregnation has done under vacuum. The hardened material was cutground, polished and mounted on a petrographic slide. The thin sections examined by polarized microscope (Zeiss) and described mainly according to terminology explained by [27, 28]. Photographs of the distinguished features illustrated in the results.

RESULTS

Soil morphological and physical characteristics: In general, soils of the study area have a weak or moderately fine to medium subangular blocky or massive structure (Table 1). Commonly the soils are medium to coarse texture in the upper horizons, passing through a smooth transition to a loamy, medium texture in the lower horizons.

Soil profiles from no.1 to 5 are shallow profiles, due the presence of very hard carbonate rocks. While, profiles no 6 and 7 are deep. There are a range of soil colors between 2.5Y, 7.5YR and 10YR. Due to containing substantial amounts of gypsum of sample of profiles 1 , 2 and subsurface layers of profile 3 the texture and structure of the some soil samples are not determined. Loamy, silty loam, silty clay loam and sandy loam are the dominant soil texture. Soil structures are fine or medium, weak or moderate granular, subangular blocky, angular blocky, single grains and massive. Soil consistence and layer boundary have been described as shown in Table (1). Both gypsum and carbonates were observed in profiles from 1 to 4, only in the latter was there evidence that secondary forms of both co-exist: carbonate in the form of thin filaments, powdery pockets and nodules, and gypsum in the form of thin filaments, crystals and nodules.

Soil chemical characteristics: As indicated in Table (2) the pH values (paste) of soils range from 7.7– 8.3, with greater values in the lower horizons.

Table (1) Morphological characteristics of the studies soil profiles

Location (GPS)	Horizon	Depth (cm)	Colour (Dry)	Texture	Structure	Consistence (Dry, moist; Wet)	Boundary
(Profile No.1)							
N.28°53′04″ E. 31° 00′ 20″	A1sk	0-10	2.5Y 8/4	-	-	so, fr, ns, np	cw
	A2sk	10-20	2.5Y 8/4	-	-	so, fr, ns, np	cs
	A3sk	20-25	10YR7/4	-	-	so, fr, ns, np	cs
	ACsk	25-30	7.5YR7 /2	-	-	so, fi, ms, mp	gs
	Cca	30-50	10YR7/4	-	-	h, fi, ms, mp	–
(Profile No.2)							
N.28°53′03 E. 31° 00′22″	A1sk	0–5	2.5Y 7/4	-	-	so, fr, ns, np	cs
	A2sk	5–10	2.5Y8/4	-	-	so, fr, ns, np	gs
	Cca	10-30	2.5Y 8/4	-	-	so, fr, ns, np	–
(Profile No.3)							
N.28°52′17″ E. 30°59′ 54″	A1sk	0–15	7.5YR7/2	L	1fgr	h, fr, ss, sp	cs
	A2sk	15–35	7.5YR7 /4	-	-	so, fr, ss, sp	gw
	CA	35-80	7.5YR 8/4	-	-	so, fr, ss, np	–
(Profile No. 4)							
N.28°51′36″ E.30°59′26″	Ask	0–10	10YR 7/3	SiL	1fm	h, fi, ms, mp	db
	Cca	10–20	10YR 7/4	SiCL	1fsbk	sh, fr, s, p	-
(Profile No. 5)							
N.28°50′54″ E. 30° 59′ 00″	AC	0-20	10YR 8/4	L	1fgr	h, fr, s, p	cs
(Profile No.6)							
N.28°50′09″ E. 30° 58′ 40″	Aca	0–40	10YR 8/4	SiL	2msbk	h, fr,ms, mp	cs
	AC	40-150	7.5YR 7/4	SCL	2msbk	h, fi, ms, mp	–
(Profile No.7)							
N.28°48′44″ E. 30° 58′ 50″	A1ca	0–30	10YR 8/3	SL	1fsg	h, fi, ns, np	cs
	A2ca	30-70	10YR 8/4	SL	1fm	sh, fi, ns, np	as
	AC	70-150	10YR 8/4	SL	1mm	sh, fi, ns, np	–

*Symbols used according to abbreviation given in Soil Survey Manual [23]

Organic matter content is very low (<0.5). Calcium carbonate ($CaCO_3$%) ranged between 20-51%. Saturation percent (SP%) ranged between 19-42%. The studied profiles content high amount of gypsium (6-53%) except profiles no.6 and 7 its content is <5%. Soils of profiles 1, 2 and 7 exhibited CEC of less than 10 meq /100g, while the others ranged up to 14.6 meq /100g. Of the seven profiles, profiles 3 & 4 and 5 & 6 demonstrated the largest CEC (Table 2). The studied soils are saline (EC > 4 dS/m) except the surface layer in profile no.6 (1.4 dS/m); and the deep layer in profile no. 7(2.4 dS/m) however, those containing detectable amounts of gypsum (profiles 1, 2, 3, and 4), exhibited EC greater than 10.3 dS/m.

General clay mineralogy of soils: A description of x-ray pattern obtained for the clay sample of the surface layer of profiles 1, 2, 3 and 4(Fig.3). The results indicate the dominance of smectite in these soils, in comparison to profiles 1, 2 and 4 in which illite was most abundant (Fig. 3) and moderate quantities of palygorskite were found too.

Palygorskite and appreciable amounts of mica and smectite in the clay fraction are found in some similar soils in Egypt [29]. All profiles contained small quantities of interstratified minerals, and measurable amounts of quartz.

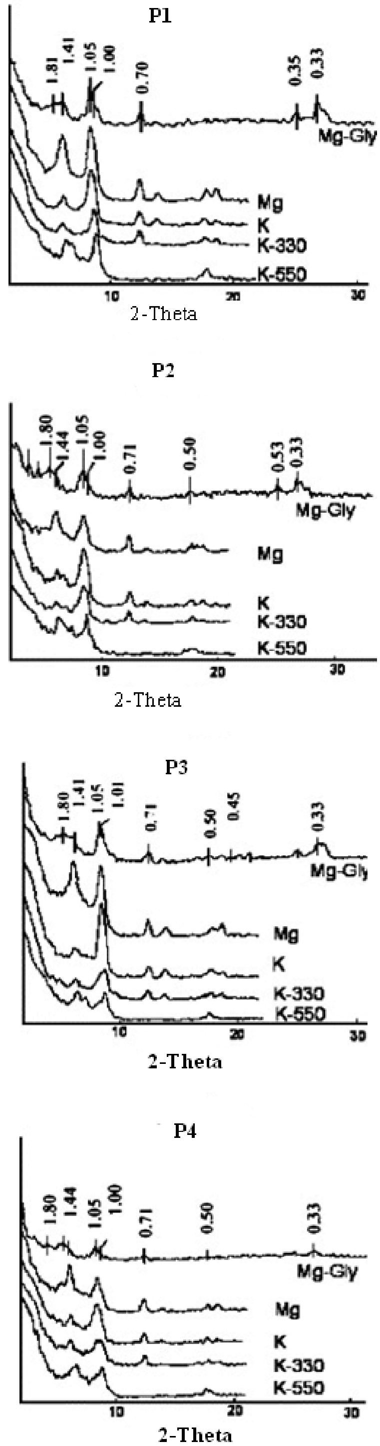

Figure 3: X-ray patterns of the studied soil samples.

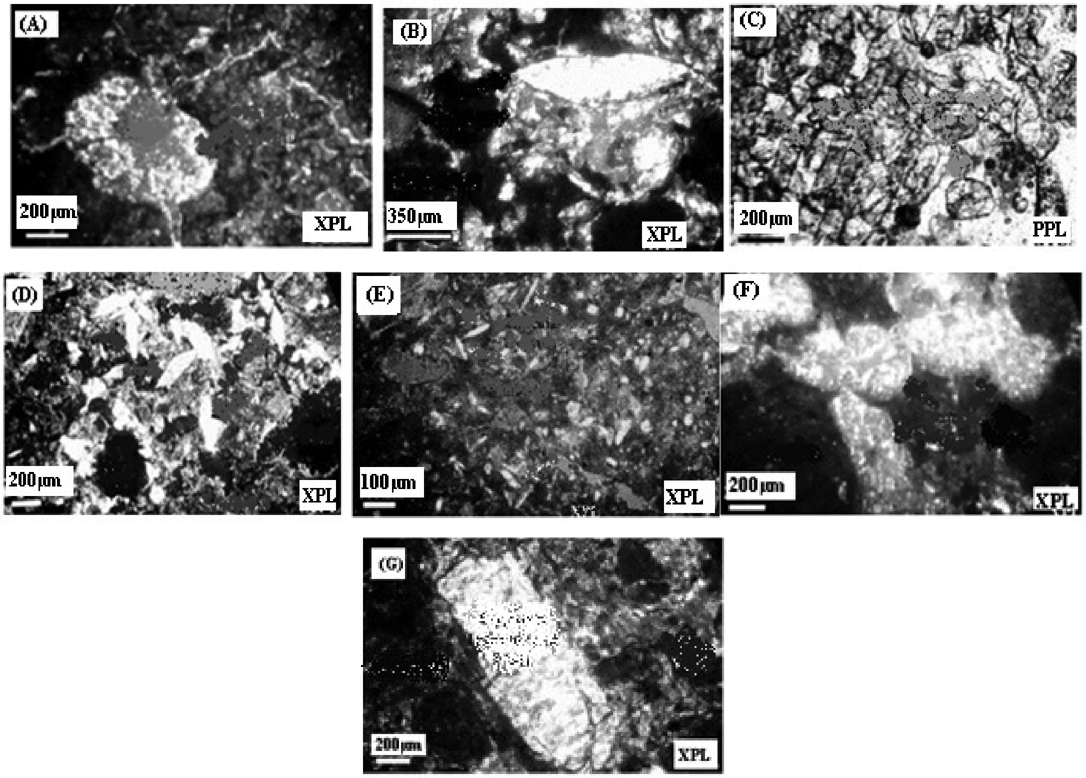

Figure 4: Thin sections of some studied soil horizons.

General micromorphological properties: The studied samples are yellowish brown, rarely laminated. The groundmass is argillaceous, mostly silty, and slightly sandy in local places (Fig 4c,e and g). Iron oxide occurs as scattered small spots, and irregular patches impregnating the argilleceous groundmass. While it fill fissures as inherited materials and coat a few fibrous of gypsum occasionally (Fig.4 a, c and e). Calcite crystals constitute a part of the groundmass in the studied soils. Scattered fine to medium-grained subrounded to subangular quartz grains are embedded in argillaceous groundmass of the investigated thin sections. The channels, vughs and planar voids are recorded in (Fig 4b). Typic dense incomplete infilling by gypsum is rich profile no.6 (Fig. 4f). Profile 1, formed on the piedmont plain, contains gypsum throughout the profile (Table 2). Within the surface horizon, gypsum occurs as infilling and coating of large voids and channels with preferred orientation; no lenticular gypsum and interlocked gypsum plates were noticed in this horizon (Fig. 4a).

Profile no.2 (Fig 4b) formed on a plateau, contains both calcareous and gypsiferous parent materials. Gypsum and calcium carbonate accumulate in soils according to their relative solubility and over time they concentrate at the depth of leaching. Field observation of this profile showed secondary gypsum as thin filaments, nodules and small needle-like crystals. The horizon of this profile show random lenticular gypsum, in soil mass and oriented gypsum microcrystals, coating voids and channels. Finer texture (smaller pore spaces) of this horizon causes smaller sizes of lenticular gypsum crystals. Profile no. 3 (Fig. 4c) small amounts of prismatic gypsum are found in the investigated horizon of surrounded with round and pseudo-hexagonal gypsum crystals in large voids. Gypsum interlocked plates show solution pits, suggesting dissolution process. A clear relationship between the size of pore space in soil mass and dimensions of lenticular crystals is noted in profile 4 and 5 (Figs. 4d and e). Growth of gypsum crystals in voids and channels continues until space becomes limiting causing crystals to interlock and lose some of their forms. In the absence of gypsum nodules and massive indurated horizon, this profile represents a moderate accumulation of pedogenic gypsum. Round or pseudo-hexagonal gypsum microcrystals are observed as coating or infilling in larger voids, while most of lenticular gypsum crystals are formed in small voids of soil mass of profile no.6 (Fig. 4f). This may indicate that supersaturated gypsum soil solution remains longer in smaller voids (larger water retention), hence lenticular gypsum crystals form larger voids exhibit round or pseudo-hexagonal gypsum microcrystals. Thin section observation of profile no.7, (Fig.4g) show medium to very large random lenticular and granular gypsum crystals that have completely infilled planar voids and channels as well as interlocked gypsum in some parts.

DISCUSSION

The occurrence of gypsum in these soils appears to be related to proximity to the local outcrop of Mokattam Formation [2], since only profiles from 1 to 4 contained measurable amounts of this mineral. Though the possibility of aeolian redistribution cannot be discounted, the dissolution of anhydrite form these outcrops, solution transport and subsequent precipitation is considered the main mechanism for gypsum neoformation. In the gravelly alluvial fans and hill slopes, gypsum typically occurs as indurate gypsum crust on the soil surface; the low water infiltration of these soils, favors its accumulation.

These results indicate that the formation of lenticular gypsum crystals occurs in a longer time. The lenticular habit of gypsum also indicates high Ca/SO_4 ratios of the soil solution and relatively high temperatures during its growth [30, 31]. High Ca / SO_4 ratios are due to the presence of Ca^{+2} ions released by carbonate minerals or by the dissolution of gypsum.

Simple transformation of illite to smectite may play a major role in decreasing illite content at soil. The calcareous environment, high in Mg and Si mobility, may create favorable condition for the formation of smectite through transformation. The results of the current research indicate that inheritance and transformation from other minerals are the main pathways for the occurrence of smectite in the studied soils. Illite is a main precursor mineral for the formation of smectite in soils. Palygorskite is another possible precursor mineral for smectite formation in arid environments. The results indicate that there is a reverse correlation between smectite and palygorskite in the studied profiles. Smectite might be expected to form pedogenically high in Si and Mg concentration, low lying topography and poor drainage conditions [32]. The condition in the studied profiles is not favorable for the neoformation of smectite (relatively good drainage and low humidity of soils). Trace to moderate content of quartz is observed in clay fraction of the studied soils. More content of this mineral is found in clay fraction of soils of gravelly alluvial fans and hill slopes. The results of the current study cannot support the possible mechanisms in soil solution for pedogenic formation of palygorskite. Regardless of the particular mechanism, the solution chemistry with respect to Mg, silica, Al and pH will control palygorskite crystallization [33]. Although both calcareous and gypsiferous soils can provide buffered alkaline media with necessary anions and cations for palygorskite crystallization but characteristics of the solution chemistry of the gypsiferous soils may result more favorable medium for this purpose. Further studies are needed in order to compare the effects of these media on pedogenic formation of palygorskite.

Classification of the soils: The investigated soil profiles could be classified [20] as the following on subgreat group levels:

1. Lithic Gypsicalcids: These include soils represented by profile no.1.
2. Lithic Calcigypsids: These include soils represented by profile no.2
3. Typic Calcigypsids: These include soils represented by profile no.3.
4. Lithic Haplocalcids: These include soils represented by profiles no.4 and 5.
5. Calcic Haplosalids: These include soils represented by profiles no.6 and 7.

Capability classification of the investigated soils: In the capability classification using Arid ALES land evaluation system, the following parameters are comprise: available irrigation water (W), thermic conditions (C), effective soil depth (X), salinity (S), calcium carbonates (Ca) and gypsum content(G). According to the obtained values the following degrees of capability are distinguished.

Low capability class (C3): presented by soil profiles no.6 and 7. Soils of this class are barren, moderately appropriate thermic conditions. Plant available water is high. The irrigation water sources in this class are the ground water and River Nile. Soils in this class (C3) have no limitations with profile depth. Salinity is varying from 1.4 to 20.2 dS/m. Gypsum content is <4%. Calcium carbonate content is high (23-39%).

Very low capability class (C4): presented by soil profile no.3. Soils of this class are barren, moderately appropriate thermic conditions. The irrigation water sources in this class are the ground water and River Nile. Soils in class (C4) have slight limitation with profile depth. Salinity is very high (>16 dS/m). Gypsum content is ranged from 6-53%. Calcium carbonate content is very high (39-48%).

Extreme limitations capability class (C5): Soils of class (C5) are not suitable for agriculture prepossess, for the following reasons: Its salt content is very high. There are salt or limestone layer in subsurface layer as in profiles no. 1, 2, 4 and 5. There are gypsum and/or calcium carbonate limitations as in profiles no. 2, 4 and 5.

CONCLUSIONS

Palygorskite, chlorite, illite, smectite, quartz, and interstratified minerals are the major clay minerals in the studied soil profile samples. The results suggest that large amount of smectite is inherited from the marl formations, although some may be the product of transformation of illite and also palygorskite weathering. Neoformation of palygorskite as a result of calcite and gypsum precipitation seems to be a major pathway for the occurrence of this mineral in the studied soils. Gypsiferous soils showed more pedogenic palygorskite compared to calcareous soils. Micromorphological observations show variable habits of gypsum crystals in different physiographic units, suggesting a dynamic soil environment. Some of the study area could be moderately suitable for cultivation for certain crops tolerant for calcium carbonate under applications of fertilizers with acidic physiological effect. High soil salt content can be reducing by leaching to certain level by River Nile irrigation water supply. While areas not-suitable for agricultural purpose due to the severe mentioned limitations must be excluded.

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