Sand and Clay Mineralogical Composition in Relation to Origin, Sedimentation Regime, Uniformity, and Weathering Rate of Nile Terrace soils at Assiut, Egypt

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Abstract: The current study has been carried out in order to investigate the mineralogical composition of both sand and clay fractions in representative profiles of various Nile terrace soils located south Assiut barrages, and also to evaluate the origin, uniformity, sedimentation regime and weathering rate of these soils. Soil samples from each layer of nine profiles were taken and their sand fraction was subjected to grain-size analyses and the minerals of fine sand were examined by polarizing microscope as well as the clay fraction was subjected to the X-ray analysis. Very fine sand as a dominant mean size, moderately sorted and leptokurtic and very leptokurtic sediments characterize the soils of the youngest terrace soils on both Nile banks; however, the oldest Nile terrace soils soils on both sides as scarps are fine to very fine sediments and poorly to well sorted, platykurtic and mesokurtic. The sediments of youngest and oldest terraces are generally strongly coarse skewed (very negative skewed). The light minerals are the predominant content of the fine and very fine sand fractions of the various Nile terrace soils without any consistent trend of their distribution throughout the profiles. They could be ordered in the youngest and oldest terrace soils as quartz > feldspars > calcite, while they could be ordered as quartz > calcite > feldspars in the soils of the terrace bench or plain and the terrace rear suture on both sides. Opaques are the most abundant minerals in the heavy fraction of the studied soils. They are in similar amounts for the soils of the youngest and oldest terraces on both Nile sides. No clear pattern of the opaques distribution with soil depth, while they tend to increase in the direction away from the Nile bank. The non-opaque minerals include pyroxenes (augite, diopside, hypersthene and enstatite), epidotes, amphiboles (hornblend, actinolite and tremolite), zircon, garnet, rutile, tourmaline, monazite, staurolite, apatite and kyanite, arranged in a decreasing order of abundance. Irregular distribution of these minerals throughout the entire depth and the distance from the Nile on both sides is observed. The assemblages and frequencies of these heavy and light minerals in the studied soil samples suggest that the origin of these soils derived from different provenances. The variations in the percentages of these minerals throughout the soils depth and the distance between the Nile and the desret indicate multi sedimentation regimes. Concerning uniformity and weathering ratios, results show some variations between the profile layers of the studied Nile terraces and do not have any specific trend either with depth or among profile sites. Also no consistent trend of the weathering ratios with depth in the studied terrace soil profiles. Smectites are the most abundant clay mineral in all soil samples followed by kaolinite, mixed mica-smectite, vermiculite, sepiolite, palygorskite, chlorite, mixed mica-vermiculite, micas and then pyrophyllite. Quartz, K-feldspar, calcite and plagioclase are present in the clay fraction and arranged in a decreasing order of abundance. These minerals do not show any constant trend with depth in the studied soil profiles. The presence of these clay minerals in the studied soils is largely due to the detrital origin from the Ethiopian Plateau that mixed with the detrital materials derived from the sandstone and limestone plateaus surrounding the Nile river course during the transportation and precipitation of these Nile sediments.

Key words: Sand mineralogy, sedimentation regime, origin, uniformity, weathering ratios and clay minerals.

INTRODUCTION

The Neonile deposits are made up of silts and clays indistinguishable in aspect and composition from

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those, which were deposited over the land of Egypt by the modern Nile up to the very recent past. These deposits form the top layer of the flood plain of the modern Nile and are also found outside this plain in the form of benches that fringe the valley at elevations ranging from 1 to 12m above the modern flood plain. The Nile flood plain is mainly composed of mud and silt having thickness of about 9 meters. They consist of very finely divided mineral matter with fine sand and organic matter. The younger Neonile sediments of the valley and delta of the Nile have been accumulated since the Holocene forming continuous column of sediments (Said, 1981). The Nile river terraces on both sides of the valley formed from sediments belonging to the Pliocene and Pleistocene. The Pliocene sediments in the southern part of the valley between Kum-Umbu and Bani-Suwayf consist of conglomerates, gravel and sand; those are distributed in some parts of the valley between Pleistocene and Holocene sediments of the flood plain and the two scarps bordering the valley. The Pleistocene deposits consist of sand and gravel originating in the Red Sea mountains. Moreover, the formation of the river terraces is related to three main factors, namely changes in base level, changes in water volume and load and changes in the hydrographic system of the Nile (Abu Al-Izz, 1971). In the past, fertile volcanic muds carried by summer floods of the Nile have brought prosperity to Egyptian dynasties (Said, 1993; Stanley *et al*., 2003). Today, dams built in Egypt and Sudan for flood regulation, water supply and hydropower virtually stopped sediment transport to the sea. Rather than on the delta and fan, huge volumes of sediments accumulate today in reservoirs, resulting in a rapid loss of storage capacity on one side, and in ravaging erosion of deltaic cusps on the other (Stanley and Warne, 1998).

Minerals present in the sand fraction can be taken as criteria to infer the origin of soil parent materials (Abdel-Ghaphor, 1982). They, also, could be used as a tool to evaluate the uniformity and development of the soil profile and soil genesis, in terms of the degree of mineral weathering (Brewer, 1960; Bear, 1964; Sillanpaa, 1972). Studies of origin and uniformity of sediments and parent materials are generally more reliable when they are based on size fractions greater than 2μm, especially on the heavy mineral fractions because they contain the greatest number of mineral species in sediments and are most likely to be diagnostic for particular igneous rocks and sedimentary beds (Milner, 1962). Heavy mineral assemblages have been regarded as sensitive indicators of sediment source (Pettijohn *et al*., 1987; Nechaev and Isphording, 1993; Heroy *et al*., 2003; Garzanti and Ando´, 2007; Garzanti *et al*., 2008; Yang *et al*., 2009). The content and distribution of minerals in soils are good means to estimate the stability of minerals against the weathering processes that occur under different soil conditions (El-Shanawany, 1992). Minerals are indicators of the amount of weathering that has taken place and the presence or absence of particular minerals gives clues as to how soil is formed (Schultz, 1989). Moreover, knowledge of clay minerals is important to provide a clear indication of the role played by weathering processes (Miller and Donahue, 1992).

Mineralogical composition of sand and/or clay fractions as well as origin, uniformity and weathering rate of some Nile alluvial or terrace soils have been investigated by many researchers such as Elwan *et al*. (1980), Gewaifel *et al*. (1981), Noaman (1989), Faragallah (1995), Lotefy (1997), Amira and Ibrahim (2000) Amira *et al*. (2000), Farragallah and Essa (2004 & 2006), Behiry (2005) and Garzanti *et al*. (2006).

The objectives of this investigation are to identify soil minerals of the fine sand and clay fractions in the soil layers and to judge the weathering, the sedimentation regime, the origin and the uniformity of various Nile terrace soils, south of Assiut barrages, Assiut governorate, Egypt.

MATERIALS AND METHODS

Nine soil profiles were chosen to represent the different terraces on both sides of the Nile river on the cross section of the valley, south of Assiut barrages at Assiut, Egypt. Profiles 1 and 5 represent the very recent (youngest) Nile terrace soils in the eastern and western banks of the Nile stream, respectively. Profiles 2, 6 and 7 represent the succeeding terrace soils; profile 6 points to the recent terrace soils between very recent and old terraces in the western side only; profiles 2 and 7 are of scarps of flood plain soils that represent the oldest terrace in the eastern and western sides of the Nile river, respectively. Profiles 3 and 8 represent the terrace bench or plain soils that are located in the Nile valley-desert interference zone that they are close to the eastern and western desert, respectively. Profiles 4 and 9 represent the terrace rear suture soils that are present in the fringes of the eastern and western desert, respectively (Fig. 1).

Soil samples were collected from each layer of the studied profiles, air-dried, crushed, sieved with a 2 mm sieve and subjected to the physical and chemical analysis as given in Table (1). The particles-size distribution of the soil samples was performed according to Piper (1950) and Jackson (1973). Organic matter of the soil samples was determined using Walkely- Black method (Jackson 1973). Soil calcium carbonate was measured
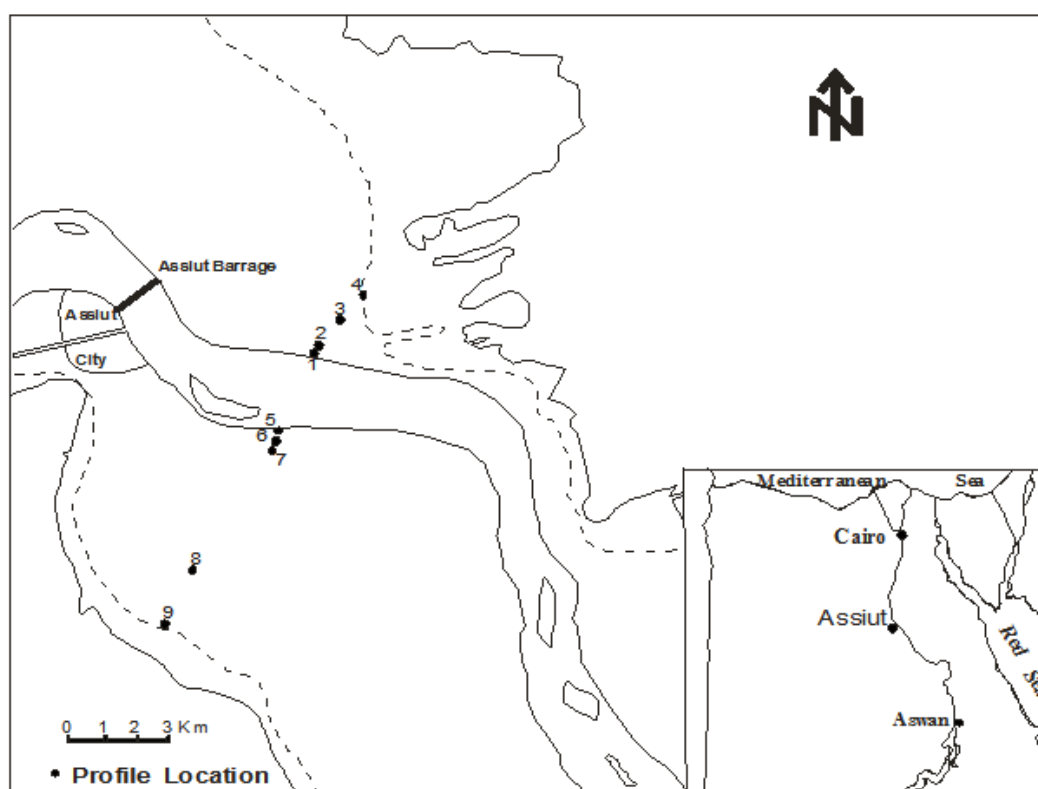
Fig. 1: Locations of the studied soil profiles representing the Nile terraces, south of Assuit barrages.

by the calcimeter method, according to Nelson (1982). Soil pH was measured in 1:1 water suspension of soil to water using a glass electrode as reported by Mclean (1982). The electrical conductivity was determined in the saturated soil paste extract using a conductivity meter. Soluble ions were also determined in the saturated soil paste extract according to Jackson (1973). The cation exchange capacity (CEC) of the soil samples was determined using NaOAC at pH 8.2 as a saturating solution and NH_4OAC at pH 7.0 as a displacing solution, and then sodium was measured by flamephotometer (Jackson, 1973).

Grain-size analyses of the sand fraction were preformed by sieves to obtain different sand size fractions. The phi (Φ) values at 5, 16, 25, 50, 75, 84 and 95 % were obtained from the cumulative curves. The statistical size parameters, namely mean size (Mz), the sorting coefficient (So), skewness (Sk) and Kurtosis (K_G) were obtained according to Folk and Ward (1957). Samples of the fine and very fine sand fractions (0.25-0.063 mm) were separated into heavy and light minerals using bromoform (sp.g. 2.85). Mineral grains were mounted on glass slides using natural Canda Balsm (R.I 1.538). Systemic identification and area count of minerals were undertaken using a Zeiss polarizing microscope. These procedures were carried out according to Milner (1962), Brewer (1964) and Mange and Maurer (1992). The ratios between some ultra stable minerals were used to evaluate the uniformity, while the ratios between less stable and ultra stable minerals were used to evaluate the weathering values according to Haseman and Marshall (1945), Barshad (1964), Brewer (1964), Chapman and Horn (1968) and Hammad (1968).

The clay-size fraction (<2μ) was separated from the studied soil samples after removing the soluble salts and organic matter. Three treatments i.e., oriented air dried, glycolated and heated at 550°C were performed on each clay sample. The prepared clay samples were investigated using PHILLIPS X-ray diffractometer with CuKα radiation, 45 KV and 35 mA and scanning between 2θ of 4 and 40. The clay minerals were identified and their relative proportions were determined using the semi-quantitative peak area technique according to Schultz (1964), Jackson (1964), Whitting (1965), Mac Ewan (1968) and Carroll (1970).

Table 1: Some physical and chemical properties of the studied soil profiles that represent Nile terraces.

Profile No.	Depth (Cm)	Particle size distribution			Texture grade	O.M %	CaCO₃ %	pH (1:1)	EC_e dsm⁻¹	Soluble cations (meq/l)				Soluble anions (meq/l)			CEC meq/100g
		Sand%	Silt%	Clay%						Ca⁺⁺	Mg⁺⁺	Na⁺	K⁺	Cl⁻	HCO₃⁻	SO₄⁻	
1	0 - 15	41.9	35.23	22.91	Loam	1.9	3.89	8.03	0.91	5.74	2.46	0.28	0.43	3.56	1.8	3.5	34.9
	15 - 25	36.4	28.75	34.9	Clay loam	1.52	3.31	8.01	0.85	4.06	3.88	0.18	0.22	2.95	3.6	2.0	40.15
	25 - 35	41.3	34.77	23.94	Loam	1.89	2.48	8.12	0.66	4.28	1.83	0.23	0.17	2.66	2.25	1.5	30.86
	35 - 70	30.9	34.1	35.02	Clay loam	1.62	3.73	8.06	0.52	3.06	1.83	0.13	0.18	1.84	2.25	1.0	36.99
2	0 - 40	32	37.36	30.68	Clay loam	2.78	3.06	8.05	0.82	5.12	2.46	0.23	0.41	3.51	2.66	2.0	34.86
	40 - 70	36	32.84	31.25	Clay loam	1.79	2.48	8.22	0.98	6.12	3.28	0.3	0.15	2.66	3.6	3.5	42.93
	70 - 95	47.2	15.35	37.43	Sandy clay	2.09	4.97	7.83	1.17	8.2	3.06	0.34	0.13	3.81	4.05	4.0	36.56
	95 - 195	38.4	32.04	29.62	Clay loam	1.87	4.14	7.99	0.88	6.12	2.46	0.06	0.11	2.95	2.25	3.5	37.1
	195-235	32.4	42.87	24.73	Loam	1.98	3.31	7.95	0.63	4.28	1.64	0.34	0.09	2.66	2.66	1.0	38.4
3	0 - 35	60.4	20.8	18.81	Sandy loam	1.81	14.9	8.3	0.74	3.06	3.28	0.32	0.53	3.09	2.25	2.0	32.63
	35 - 55	68.9	9.85	21.24	Sandy clay loam	0.95	17.4	8.39	0.57	4.1	1.22	0.17	0.25	1.84	2.6	1.5	31.46
	55 - 70	86.4	2.68	10.91	Loamy sand	0.63	22.6	8.48	0.48	3.06	1.46	0.15	0.18	1.12	2.25	1.5	38.65
	70 - 150	87.5	4.11	8.4	Loamy sand	0.73	25.6	8.46	0.52	2.46	2.46	0.16	0.22	1.84	2.25	1.0	26.89
4	0 - 20	93.2	2.42	4.35	Sand	0.52	25.7	8.57	2.71	13.1	2.95	11.4	0.17	15.4	3.6	8.0	21.11
	20 - 35	74.5	10.1	15.41	Sandy loam	0.07	33.1	8.61	5.77	26.4	3.11	27.5	0.36	27.4	6.3	21	19.91
	35 - 150	43.6	51.06	5.3	Silt loam	0.87	29	8.17	1.44	10.7	2.64	1.29	0.18	8.82	2.25	3.5	21.16
5	0 - 20	40.1	37.76	22.17	Loam	2.36	2.48	8.15	0.98	5.88	3.34	0.37	0.37	5.33	2.66	2.0	33.66
	20 - 35	34.2	31.2	34.58	Clay loam	1.38	2.07	8.04	0.94	5.74	3.28	0.27	0.22	5.19	2.25	2.0	41.83
	35 - 65	40.5	34.58	24.96	Loam	1.34	1.66	8.14	0.57	2.44	2.46	0.6	0.12	2.55	1.8	1.5	34.14
6	0 - 45	40.5	29.77	29.73	Clay loam	2.42	2.07	8.29	0.99	4.28	4.88	0.7	0.09	4.12	3.6	2.0	37.1
	45 - 80	46.4	25.8	27.78	Sandy clay loam	1.76	2.48	8.24	0.88	4.88	3.28	0.51	0.18	3.09	4.05	1.5	37.35
7	0 - 40	41	28.74	30.29	Clay loam	2.75	3.48	7.81	1.27	7.84	4.1	0.54	0.21	6.39	3.6	3.0	36.25
	40 - 70	31.5	39.93	28.63	Clay loam	1.1	2.4	8.39	0.52	2.44	2.44	0.21	0.06	2.66	1.8	1.0	36.16
	70 - 120	42.4	34.04	23.53	Loam	1.81	4.97	8.26	0.95	5.56	3.28	0.27	0.08	3.12	4.05	2.0	34.01
	120-155	46	32.14	21.91	loam	2.34	1.66	8.3	0.81	6.72	1.22	0.24	0.1	3.09	4.5	1.0	37.12
8	0 - 50	62.8	6.63	30.57	Sandy clay loam	2.56	15.55	8.24	0.75	4.28	2.44	0.33	0.11	2.55	3.4	1.5	35.27
	50 - 70	84.9	2.24	12.91	Loamy sand	0.63	38.2	8.48	0.52	2.46	2.46	0.22	0.06	1.84	2.25	1.0	23.33
	70 - 85	91.6	3.25	5.18	Sand	0.42	41.4	8.55	0.91	5.44	2.46	1.02	0.1	3.49	3.45	2.0	23.97
	85 - 150	94.4	2.62	3.01	Sand	0.7	25.3	8.5	1.4	6.12	4.88	0.27	0.14	6.39	3.6	1.5	30.1
9	0 - 10	40.5	37.12	22.35	Loam	0.73	33.1	8.17	2.82	20.5	5.74	1.37	1.32	11	4.05	13	25.8
	10 35	93.1	2.35	4.61	Sand	0.59	45.6	8.09	3.61	29.5	4.1	1.24	1.47	5.49	3.6	26	19.24
	35 - 150	90.8	5.71	3.52	Sand	0.78	36.4	8.39	1.73	13.1	2.46	0.87	1.01	3.09	2.25	12	21.46

RESULTS AND DISCUSSIONS

Grain-size Analysis:

The grain-size distribution of sand fractions of the studied Nile terrace soil samples is present in Table (2) and graphically illustrated in Figure (2). It is shown that there are differences in the behavior of the grain-size distribution of the sand fractions in the eastern and western sides that may be due to the sedimentation regime. Cumulative curves of the sand fractions are plotted on semi-logarithmic graphs (Figure 3). Accordingly, main grain-size parameters i.e., mean size (Mz), the sorting coefficient (So), skewness (Sk) and Kurtosis (K) were calculated and are present in Table (3). The obtained data show that very fine sand as a dominant mean size and moderately sorted sediments characterize the soils of the youngest terraces on both Nile banks; however, the oldest Nile terrace soils on both sides as scarps are fine to very fine sediments and poorly to well sorted. Although the sediments transported by water or weathered in situ are usually poorly sorted (Inman, 1952), it is possible to get well sorted sediments transported by water across long distance (Folk and Ward, 1957; Elwan *et al*., 1980). Thus the sediments of youngest and oldest terraces are actually transported and deposited under Nile water action. These sediments are generally strongly coarse skewed and very negative skewed (Table 3 & Figure 4), indicating that water is the main factor affecting the formation and deposition of these soils. The youngest terraces on both Nile banks are generally leptokurtic and very leptokurtic, while the oldest ones are platykurtic and mesokurtic, indicating that the velocity fluctuations were restricted within the central 50% of the average velocity force having a greater length of time than normal. Moreover, cumulative curves of profiles 1, 2, 5, 6 and 7 in figure 3 exhibit visible heterogeneity soil materials.

The terrace bench or plain soils that are located in the Nile valley-desert interference zone and the terrace rear suture soils that are present in the fringes of the eastern and western deserts have fine to medium sand and poorly to moderately sorted sediments (Table 3 & Figure 4). The skewness values indicate that these soils are fine skewed (positively skewed) to strongly coarse skewed (very negatively skewed). Accordingly, both water and wind are the main factors affecting the formation and deposition of these soils. Considering kurtosis, the obtained data clarify that these soils are platykurtic to leptokurtic. Moreover, cumulative curves of profiles 3, 4, 8 and 9 in Figure 3 reflect mostly heterogeneity parent materials. It is clearly observed that values of mean size and kurtosis decrease, but sorting and skewness values increase toward the desert on both Nile sides (Figure 4).

Based on the aforementioned results, the soils of youngest and oldest terrace sediments are heterogeneous materials under one sedimentation regime that was mainly by Nile water. However, the terrace bench or plain soils and the terrace rear suture soils are heterogeneous materials under a multi sedimentation regime that aeolian, water-aeolian and water. The stratified condition observed in these soils is mostly due to depositional variations and/or the sedimentation regime.

Table 2: Grain-size distribution of sand fractions of the studied soil samples.

Profile No.	Depth (Cm)	Very coarse 2.0 –1.0 mm	Coarse 1.0 - 0.5mm	Medium 0.5-0.25mm	Fine 0.25-0.125mm	Very fine 0.125-0.063mm	Total %
1	0 - 15	1.92	1.64	1.26	3.59	33.44	41.85
	15 - 25	0.06	0.21	0.36	3.86	31.85	36.35
	25 - 35	3.36	2.76	2.34	5.31	27.53	41.30
	35 - 70	0.23	0.11	1.63	9.15	19.77	30.88
2	0 - 40	0.42	0.22	0.84	23.92	6.55	31.95
	40 - 70	4.72	3.50	2.42	0.45	24.86	35.95
	70 - 95	0.95	0.10	1.24	19.47	25.46	47.22
	95 - 195	2.08	5.75	5.04	7.63	17.85	38.35
	195 - 235	0.16	0.52	0.85	13.47	17.40	32.40
3	0 - 35	2.95	5.86	12.95	15.31	23.34	60.40
	35 - 55	2.83	6.95	15.74	19.17	24.22	68.91
	55 - 70	0.65	2.56	5.68	16.69	60.83	86.41
	70 - 150	3.37	5.70	10.29	12.55	55.57	87.49
4	0 - 20	9.29	15.62	30.29	21.52	16.50	93.23
	20 - 35	6.75	8.65	18.47	12.98	27.64	74.49
	35 - 150	3.33	8.93	17.06	7.20	7.11	43.63
5	0 - 20	0.80	0.77	0.91	2.27	35.31	40.07
	20 - 35	0.33	1.49	2.97	14.29	15.14	34.22
	35 - 65	0.31	1.45	0.91	2.39	35.40	40.46
6	0 - 45	0.04	0.31	1.77	4.72	33.65	40.50
	45 - 80	0.34	0.87	2.77	6.01	36.42	46.41
7	0 - 40	0.03	0.27	0.04	5.91	34.73	40.98
	40 - 70	0.02	0.44	0.24	2.88	27.88	31.45
	70 - 120	0.19	0.08	0.04	6.25	35.87	42.43
	120 - 155	8.18	8.48	5.34	6.45	17.52	45.96
8	0 - 50	0.06	2.18	7.53	32.38	20.64	62.80
	50 - 70	12.41	11.45	22.43	5.81	32.77	84.88
	70 - 85	10.39	11.13	22.57	12.08	35.40	91.57
	85 - 150	9.98	37.31	32.29	11.20	3.59	94.37
9	0 - 10	0.10	0.19	0.47	15.40	24.37	40.53
	10 35	18.80	25.60	22.48	17.81	8.36	93.05
	35 - 150	15.42	23.36	24.03	18.45	9.52	90.78
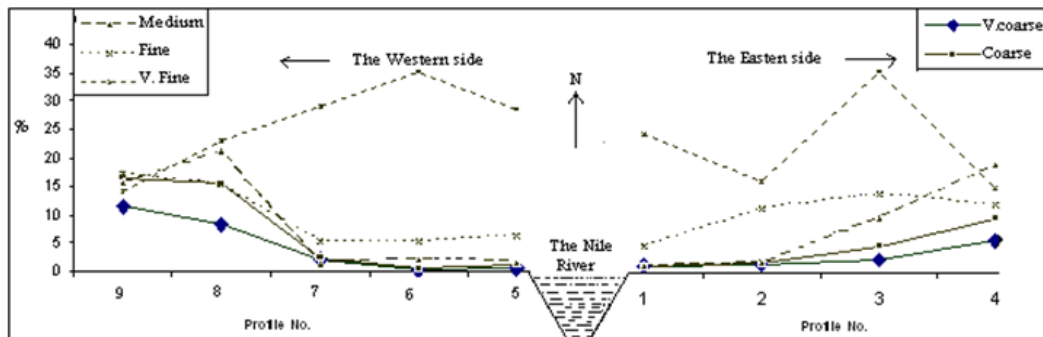
Fig. 2: Grain-size distribution of sand fractions in the soil profiles with distance from the Nile border to the desert on both sides.
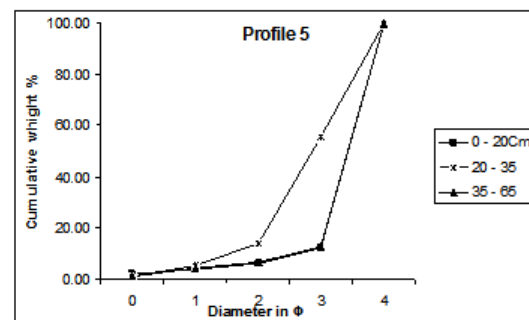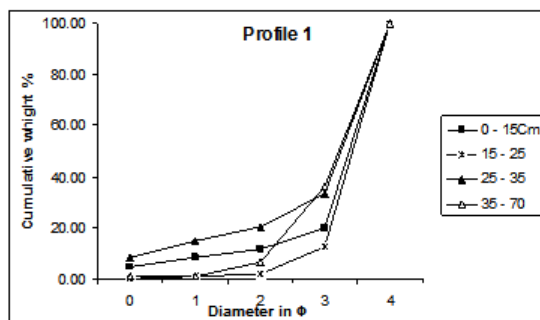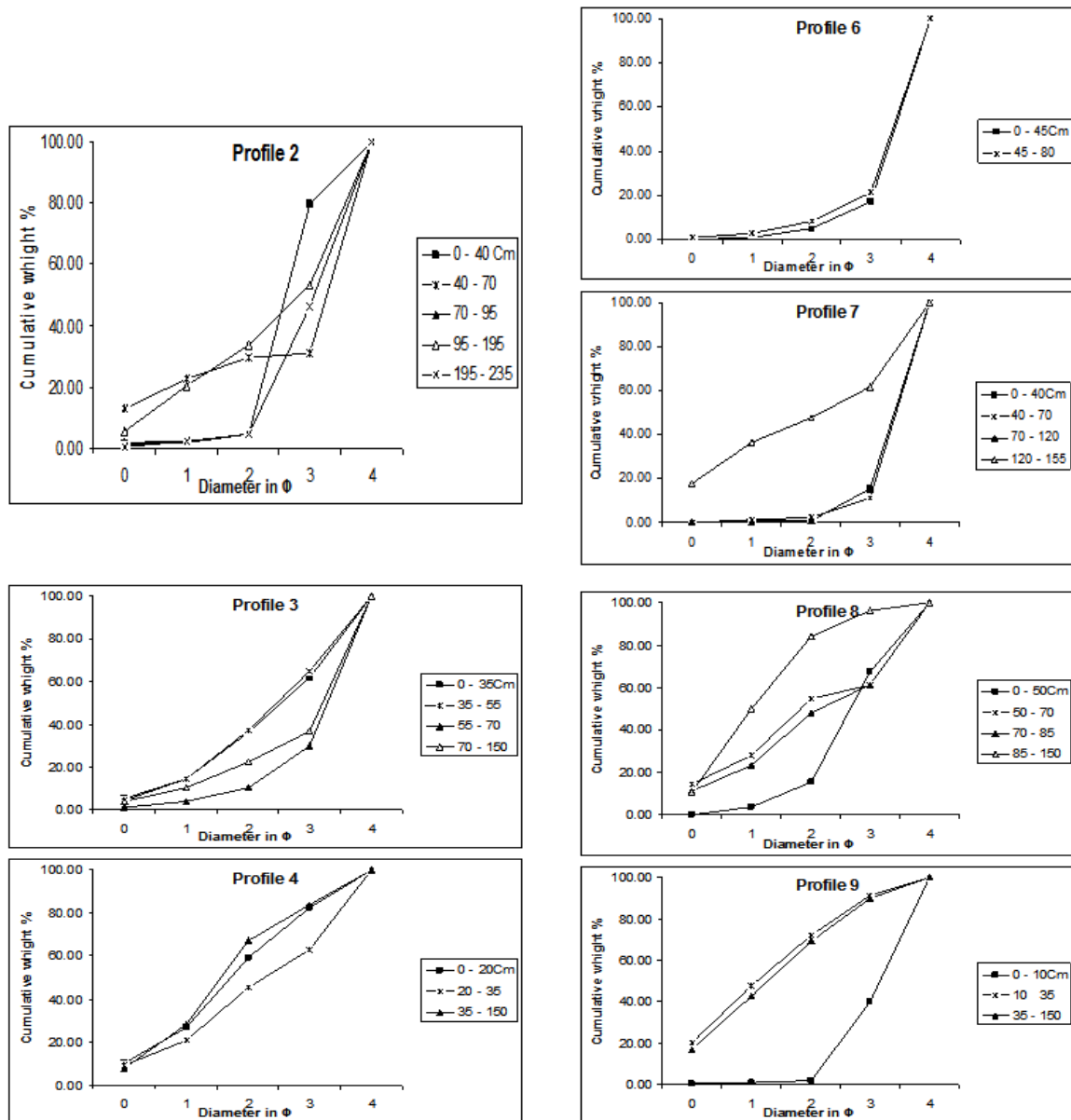
Fig. 3: Cumulative frequency curves of sand fractions of the studied soil profiles.

Table 3: Statistical measures of the grain size distribution of the studied soil samples.

Profile No	Depth Cm	Mz	So	Sk	K_G	Nomenclature
1	0 - 15	3.36	0.88	-0.59	2.28	V. fine sand; moderately sorted; strongly coarse skewed; very leptokurtic
	15 - 25	3.51	0.43	-0.37	1.04	V. fine sand; well sorted; strongly coarse skewed; mesokurtic
	25 - 35	2.80	1.32	-0.68	1.4	Fine sand; poorly sorted; strongly coarse skewed; leptokurtic
	35 - 70	3.17	0.65	-0.29	0.91	V. fine sand; moderately well sorted; coarse skewed; mesokurtic
2	0 - 40	2.66	0.48	0.23	1.28	Fine sand; well sorted; fine skewed; leptokurtic
	40 - 70	2.53	1.6	-0.77	0.74	Fine sand; poorly sorted; strongly coarse skewed; platykurtic
	70 - 95	3.07	0.62	-0.08	0.83	V. fine sand; moderately well sorted; near symmetrical; platykurtic
	95 - 195	2.44	1.35	-0.46	0.74	Fine sand; poorly sorted; strongly coarse skewed; platykurtic
	195 - 235	3.07	0.62	-0.07	0.83	V. fine sand; moderately well sorted; near symmetrical; platykurtic
3	0 - 35	2.43	1.22	-0.26	0.86	Fine sand; poorly sorted; coarse skewed; platykurtic
	35 - 55	2.39	1.18	-0.20	0.86	Fine sand; poorly sorted; coarse skewed; platykurtic
	55 - 70	3.21	0.77	-0.48	1.26	V. fine sand; moderately sorted; strongly coarse skewed; leptokurtic
	70 - 150	2.89	1.14	-0.60	1.03	Fine sand; poorly sorted; strongly coarse skewed; mesokurtic

Table 3: Continue

4	0 - 20	1.74	1.29	0.01	0.99	Medium sand; poorly sorted; near symmetrical; mesokurtic
	20 - 35	2.18	1.4	-0.16	0.81	Fine sand; poorly sorted; coarse skewed; platykurtic
	35 - 150	1.69	1.23	0.13	1.06	Medium sand; poorly sorted; fine skewed; mesokurtic
5	0 – 20	3.53	0.57	-0.49	1.73	V. fine sand; moderately well sorted; strongly coarse skewed; very leptokurtic
	20 - 35	2.87	0.84	-0.17	1.11	Fine sand; moderately sorted; coarse skewed; leptokurtic
	35 - 65	3.52	0.61	-0.50	1.87	V. fine sand; moderately well sorted; strongly coarse skewed; very leptokurtic
6	0 - 45	3.46	0.53	-0.42	1.27	V. fine sand; moderately well sorted; strongly coarse skewed; leptokurtic
	45 - 80	3.36	0.66	-0.49	1.41	V. fine sand; moderately well sorted; strongly coarse skewed; leptokurtic
7	0 - 40	3.48	0.44	-0.34	0.99	V. fine sand; well sorted; strongly coarse skewed; mesokurtic
	40 - 70	3.52	0.42	-0.37	1.06	V. fine sand; well sorted; strongly coarse skewed; mesokurtic
	70 - 120	3.48	0.44	-0.34	0.98	V. fine sand; well sorted; strongly coarse skewed; mesokurtic
	120 - 155	1.91	1.64	-0.23	0.62	Medium sand; poorly sorted; coarse skewed; very platykurtic
8	0 - 50	2.72	0.77	-0.02	1.14	Fine sand; moderately sorted; near symmetrical; leptokurtic
	50 - 70	1.86	1.59	0.01	0.7	Medium sand; poorly sorted; near symmetrical; platykurtic
	70 - 85	2.07	1.49	-0.12	0.77	Fine sand; poorly sorted; coarse skewed; platykurtic
	85 - 150	1.06	0.94	0.12	1.11	Medium sand; moderately sorted; fine skewed; leptokurtic
9	0 - 10	3.16	0.58	-0.13	0.81	V. fine sand; moderately well sorted; coarse skewed; platykurtic
	10 - 35	1.16	1.31	0.09	0.86	Medium sand; poorly sorted; near symmetrical; platykurtic
	35 - 150	1.30	1.31	0.05	0.89	Medium sand; poorly sorted; near symmetrical; platykurtic
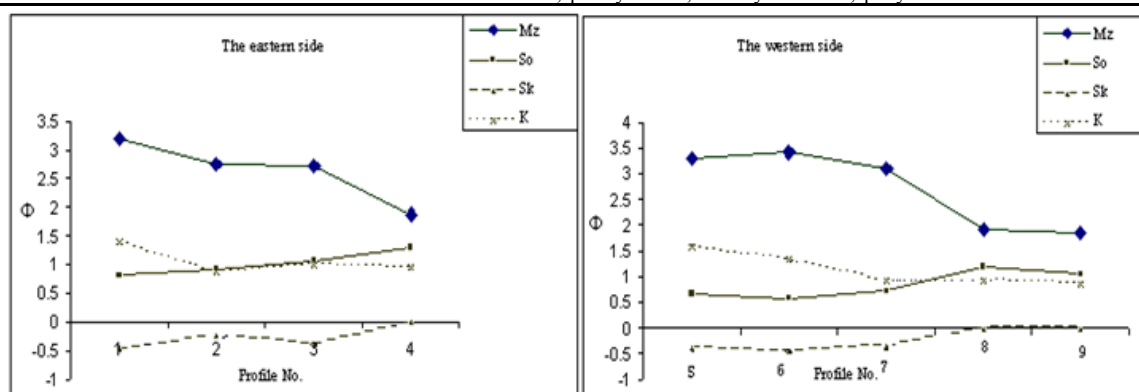
Fig. 4: The distribution of grain size parameters in the soil profile on both sides of the Nile river.

Mineralogical Composition of the Sand Fractions:

The fine and very fine sand fractions (0.25-0.063 mm) of the studied terrace soils have been separated into the light and heavy minerals as shown in Table (4). The light minerals are predominant in the studied factions with a range of 92.20 to 99.53 %, without any consistent trend of their distribution throughout the profiles. The highest amounts of the light minerals are obtained for the terrace bench or plain soils in the Nile valley-desert interference zone and for the terrace rear suture soils in the fringes of the eastern and western desert. This may be attributed to the aeolian action and/or the decrease in the water energy far from the Nile stream in these soils. However, the contents of heavy minerals in the fine and very fine sand fractions of the investigated soil samples are relatively low (0.47 to7.88 %), without a specific pattern of distribution with depth (Table 4). The highest levels of the heavy minerals are found in the youngest and oldest terrace soils, which contain similar amounts. Index figure values (heavy/light minreals x 100), are also relatively low and range from 0.47 to 7.54 %. Moreover, their distribution within each soil profile does not have any specific trend. This reflects the heterogeneity of parent sediments and the young nature of soil development.

1- Light Minerals:

Percentages of minerals and their distribution in the light fraction of the fine and very fine sand of the studied soil samples are listed in Table 5. The light minerals could be ordered in the youngest and oldest terrace soils as quartz > feldspars > calcite, while they could be ordered as quartz > calcite > feldspars in the terrace bench or plain soils and the terrace rear suture soils on both Nile sides. Quartz is the main constituent in the light minerals of all studied soil samples with a rang of 51.20 - 98.52%. The highest amounts of quartz (93.06- 98.52%) are found in the youngest and oldest terrace soils but the lowest ones (51.20 - 88.54 %) are in the soils of the terrace bench or plain and the terrace rear suture on both Nile sides. On the other hand, calcite mineral is ranked in high levels for the terrace rear suture soils on both sides (Figure 5) with a range of 24.21 to 48.19%, followed by the terrace bench or plain soils (9.18-34.96%), and then the oldest terrace

Table 4: Percentages of heavy and light minerals and index figure in the fine and very fine sand fractions of the studied soil samples.

| Profile No.	Depth (Cm)	Weight of fine&v.fine sand (gm)	Heavy minerals		Light minerals		Index figure
			Weight (gm)	%	Weight (gm)	%	
1	0 - 15	18.5160	0.6514	3.52	17.8646	96.48	3.65
	15 - 25	17.8552	0.6009	3.37	17.2543	96.63	3.48
	25 - 35	16.4208	0.7526	4.88	15.6682	95.42	4.80
	35 - 70	14.4570	0.2095	1.45	14.2475	98.55	1.47
2	0 - 40	15.2309	0.3824	2.51	14.8485	97.49	2.58
	40 - 70	12.6533	0.6330	5.00	12.0203	95.00	5.27
	70 - 95	22.4642	0.3438	1.53	22.1204	98.47	1.55
	95 - 195	12.7388	0.8930	7.88	11.8458	92.99	7.54
	195 - 235	15.4378	0.2294	1.49	15.2084	98.51	1.51
3	0 - 35	19.3218	0.1168	0.60	19.2050	99.40	0.61
	35 - 55	21.6930	1.1708	5.40	20.5222	94.60	5.71
	55 - 70	38.7614	0.2132	0.55	38.5482	99.45	0.55
	70 - 150	34.0624	0.3362	0.99	33.7262	99.01	1.00
4	0 - 20	19.0125	0.3456	1.82	18.6669	98.18	1.85
	20 - 35	20.3084	0.3798	1.87	19.9286	98.13	1.91
	35 - 150	7.1540	0.5578	7.80	6.5962	92.20	8.46
5	0 - 20	18.7901	0.8126	4.37	17.9775	95.68	4.52
	20 - 35	14.7143	0.9179	7.56	13.7964	93.76	6.65
	35 - 65	18.8953	0.6570	3.48	18.2383	96.52	3.60
6	0 - 45	19.1842	0.6798	3.54	18.5044	96.46	3.67
	45 - 80	21.2186	0.9688	4.57	20.2498	95.43	4.78
7	0 - 40	20.3214	0.9253	4.58	19.3961	95.45	4.77
	40 - 70	15.3763	0.9225	6.33	14.4538	94.00	6.38
	70 - 120	21.0572	0.9783	5.08	20.0789	95.35	4.87
	120 - 155	11.9829	0.8800	7.35	11.1029	92.66	7.93
8	0 - 50	26.5129	0.1237	0.47	26.3892	99.53	0.47
	50 - 70	19.2932	0.8145	4.22	18.4787	95.78	4.41
	70 - 85	23.7409	0.8954	3.77	22.8455	96.23	3.92
	85 - 150	7.3922	0.4500	6.08	6.9422	93.91	6.48
9	0 - 10	19.8865	0.1299	0.65	19.7566	99.35	0.66
	10 35	13.0862	0.3715	2.84	12.7147	97.16	2.92
	35 - 150	13.9865	0.3788	2.71	13.6077	97.29	2.78

Table 5: Percentages of minerals and their distribution in the light fraction of the fine and very fine sand of the studied soil samples

Profile No.	Depth (Cm)	Quartz	Feldspars				Calcite
			Plagioclase	Orthoclase	Microcline	Total	
1	0 - 15	95.77	3.01	0.55	0.55	4.11	0.12
	15 - 25	95.85	2.56	0.96	0.64	4.15	0.00
	25 - 35	93.24	4.66	0.93	1.17	6.76	0.00
	35 - 70	97.72	1.63	0.33	0.33	2.28	0.00
2	0 - 40	97.13	1.58	0.53	0.53	2.63	0.24
	40 - 70	98.52	0.99	0.25	0.25	1.48	0.00
	70 - 95	98.21	0.79	0.39	0.39	1.57	0.22
	95 -195	96.15	2.88	0.32	0.64	3.85	0.00
	195-235	97.05	1.69	0.84	0.42	2.95	0.00
3	0 - 35	88.54	0.64	0.32	0.32	2.27	9.18
	35 - 55	84.91	0.37	0.37	0.37	1.10	13.99
	55 - 70	81.52	0.18	0.18	0.00	0.36	18.12
	70 - 150	82.10	1.31	0.16	0.00	1.48	16.42
4	0 - 20	67.02	0.27	0.27	0.27	0.80	32.17
	20 - 35	66.84	0.53	0.27	0.27	1.07	32.09
	35 - 150	55.28	0.25	0.25	0.25	0.75	43.97
5	0 - 20	95.00	4.00	0.50	0.25	4.75	0.25
	20 - 35	97.22	2.22	0.28	0.28	2.78	0.00
	35 - 65	96.62	1.93	0.97	0.24	3.14	0.24
6	0 - 45	98.04	1.31	0.33	0.33	1.96	0.00
	45 - 80	98.04	1.12	0.56	0.28	1.96	0.00
7	0 - 40	95.95	2.35	0.85	0.21	3.41	0.64
	40 - 70	95.99	3.14	0.52	0.35	4.01	0.00
	70 - 120	93.06	3.61	1.53	0.72	5.86	1.08
	120-155	97.40	0.97	0.65	0.32	1.95	0.65
8	0 - 50	82.52	0.65	0.32	0.32	1.29	16.18
	50 - 70	64.50	0.27	0.27	0.00	0.54	34.96
	70 - 85	65.07	0.66	0.22	0.00	0.88	34.05
	85 - 150	73.21	0.45	0.23	0.00	0.68	26.12

Table 5: Continue

	0 - 10	74.74	0.84	0.21	0.00	1.05	24.21
9	10 35	66.11	0.23	0.00	0.23	0.47	33.42
	35 - 150	51.20	0.30	0.00	0.30	0.60	48.19

(nil-1.08%) as well as the youngest terrace soils (nil-0.25%). Feldspars are present in small amounts (0.36-6.86%) and occur in the forms of plagioclase, orthoclase and microcline. The feldspar contents in the studied soils show the order of the youngest terraces > the oldest terraces > the terrace bench > the terrace rear suture (Figure 5).The dominance of quartz is mostly related to its resistance to weathering and the disintegration during the multicyclic processes of sedimentation. Also, the presence of feldspars could indicate that the prevailing weathering during soil formation was not enough to cause a complete decay of these minerals (Hassona *et al.*, 1995).
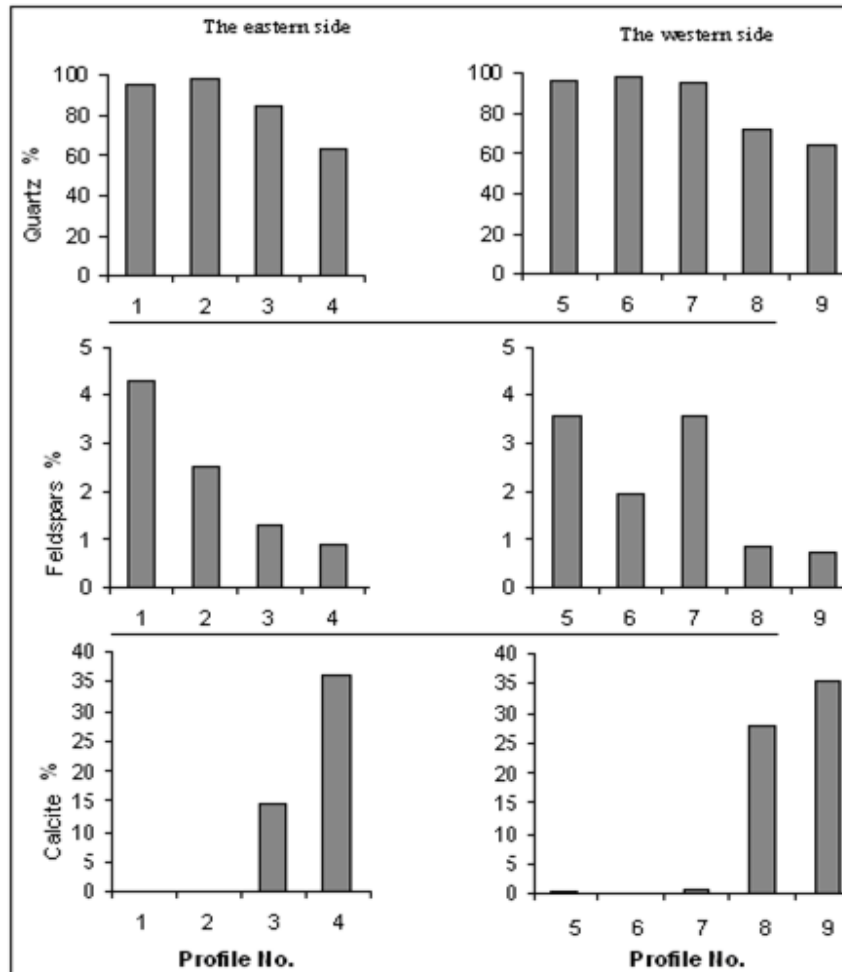
Fig. 5: The distribution of light minerals means on both Nile sides.

2- Heavy Minerals:

The microscopic inspection of the studied Nile terrace soils samples shows that the heavy minerals include both opaque and non-opaque minerals. Opaques are the most abundant minerals throughout the different samples with a range of 34.48 to 62.83% of the total heavy fractions (Table 6). They are in similar amounts for the soils of the youngest and oldest terraces on both Nile sides, lay in a range between 34.48 and 54.89 % of the total heavy fraction. Opaque minerals are found in the highest levels of the total heavy fraction in the soils of the terrace bench and the terrace rear suture (Table 6). No clear pattern of the opaques distribution with soil depth, while they tend to increase in the direction away from the Nile bank.

Table 6: Percentages of minerals and their distribution in the heavy fraction of the fine and very fine sand of the studied soil samples.

Profile No.	Depth (Cm)	Opaques	Pyroxenes					Epidotes	Amphiboles				Sphene	Rutile	Garnet	Zircon	Tourmaline	Monazite	Staurolite	Biotite	Apatite	Kyanite
			Aug.	Diop.	Hyper.	Enst.	Total		Horn.	Actin.	Trem.	Total										
1	0 - 15	46.47	8.18	0.37	1.86	0.74	11.15	17.10	5.58	0.74	1.12	7.43	2.23	0.74	0.74	0.37	0.37	1.12	1.12	9.29	1.49	0.37
	15 - 25	53.79	6.99	0.29	0.29	0.29	7.87	17.60	7.92	0.88	0.88	9.68	1.88	0.29	0.29	0.59	0.00	0.59	0.29	3.88	2.38	0.88
	25 - 35	50.67	11.66	0.90	0.90	1.35	14.80	8.97	6.73	2.69	2.24	11.66	2.24	0.90	0.90	0.45	1.35	0.90	4.04	1.35	0.9	
	35 - 70	43.42	12.50	0.66	0.00	1.97	15.13	19.08	6.58	1.97	1.32	9.87	5.26	1.32	0.66	0.66	0.66	0.66	2.63	0.00	0.00	
2	0 - 40	39.39	10.91	1.21	1.82	1.82	15.76	12.12	7.88	1.21	0.61	9.70	7.27	1.21	2.42	1.21	1.21	1.21	0.61	6.06	1.21	0.61
	40 - 70	53.13	3.91	0.78	1.17	1.95	7.81	7.81	5.47	1.17	1.17	7.81	2.34	1.56	1.17	1.17	1.56	1.17	0.78	11.72	1.56	0.39
	70 - 95	39.77	7.39	0.57	0.57	1.14	9.66	14.77	5.68	0.57	1.14	7.39	3.98	1.14	1.70	1.70	0.57	2.84	1.14	11.36	2.27	1.70
	95 - 195	47.3	7.43	0.68	0.68	0.68	9.46	13.51	6.76	1.35	2.03	10.14	3.38	1.35	1.35	0.68	0.68	2.03	0.68	6.76	2.03	0.68
	195-235	54.55	5.45	0.00	0.00	0.91	6.36	16.36	6.36	0.91	0.91	8.18	1.82	0.91	0.91	1.82	0.91	2.73	0.91	4.55	0.00	0.00
3	0 - 35	54.95	10.99	0.00	1.10	2.20	14.29	8.79	6.59	1.10	1.10	8.79	2.20	1.10	4.94	0.55	1.10	1.10	1.10	0.00	0.00	1.10
	35 - 55	58.39	8.76	0.73	1.46	3.65	14.60	9.49	5.84	2.19	2.19	10.22	0.73	2.19	0.73	0.73	0.00	0.73	0.73	0.73	0.00	0.73
	55 - 70	40.27	11.41	3.36	2.01	3.36	20.13	16.78	6.71	4.03	2.01	12.75	2.01	2.68	3.36	1.34	0.00	0.00	0.67	0.00	0.00	0.00
	70 - 150	41.24	7.22	2.06	4.12	3.09	16.49	13.40	10.31	5.15	2.06	17.53	3.09	2.06	3.09	2.06	0.00	1.03	0.00	0.00	0.00	0.00
4	0 - 20	62.83	8.38	0.00	1.05	0.00	9.42	7.85	6.28	2.62	1.57	10.47	2.09	0.52	1.57	2.62	1.05	0.00	1.05	0.00	0.00	0.52
	20 - 35	62.83	8.90	1.57	1.05	0.00	11.52	9.95	4.71	1.05	0.00	5.76	2.62	2.62	2.09	1.57	0.52	0.00	0.52	0.00	0.00	0.00
	35 - 150	54.64	10.93	1.09	0.55	1.64	14.21	9.84	9.29	2.73	1.09	13.11	1.09	1.09	0.55	2.73	1.09	0.55	0.55	0.00	0.55	0.00
5	0 - 20	34.48	12.32	0.99	2.46	0.99	16.75	21.67	14.78	1.97	0.99	17.73	2.46	0.99	0.49	0.49	0.49	0.99	0.49	1.97	0.49	0.49
	20 - 35	44.64	8.93	0.89	0.89	0.89	11.61	8.93	6.25	0.89	0.89	8.04	5.36	1.79	0.89	0.89	0.89	2.68	1.79	8.93	1.79	1.79
	35 - 65	42.25	12.68	1.41	0.85	0.56	15.49	18.59	8.45	1.41	1.69	11.55	1.69	0.56	0.28	0.56	0.00	0.56	0.28	5.63	1.69	0.85
6	0 - 45	46.15	11.54	1.92	1.54	1.54	16.54	15.38	7.69	0.38	1.15	9.23	1.92	0.38	0.77	1.54	0.00	0.77	0.38	5.77	0.38	0.77
	45 - 80	44.22	5.03	3.02	2.51	3.02	13.57	13.57	7.54	4.02	2.51	14.07	5.03	0.50	0.29	2.22	0.00	1.51	0.00	5.03	1.01	0.00
7	0 - 40	41.37	8.99	5.40	1.44	2.88	18.71	12.59	10.79	2.16	1.08	14.03	3.60	1.44	0.36	2.16	0.00	0.72	0.36	3.60	0.72	0.36
	40 - 70	47.7	10.86	1.64	0.66	0.33	13.49	13.16	9.87	0.66	0.99	11.51	3.29	0.99	0.33	1.97	0.66	1.64	0.99	2.63	0.99	0.66
	70 - 120	54.89	5.26	0.00	0.00	1.32	6.58	11.89	6.58	0.00	0.00	6.58	7.89	1.32	1.32	2.63	0.00	1.32	0.00	6.58	0.00	0.00
	120-155	50	6.25	1.25	0.63	1.25	9.38	9.38	9.38	1.25	1.88	12.50	3.75	1.25	0.63	2.50	0.00	0.63	0.63	9.38	0.00	0.00
8	0 - 50	62.21	11.52	0.46	0.00	0.92	12.90	9.22	5.99	0.46	0.00	6.45	2.76	1.84	0.00	2.30	0.46	0.00	0.00	0.92	0.92	0.00
	50 - 70	61.48	5.33	0.82	4.10	0.00	10.25	9.84	4.51	1.23	0.00	5.74	2.05	1.23	4.10	2.46	1.23	1.23	0.00	0.00	0.00	0.41
	70 - 85	50	11.00	2.00	4.00	2.00	19.00	7.00	3.00	0.00	0.00	3.00	7.00	4.00	7.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00
	85 - 150	57.88	4.82	0.32	1.29	1.61	8.04	17.68	4.18	0.00	0.32	4.50	3.22	2.57	2.25	1.93	1.29	0.00	0.00	0.64	0.00	0.00
9	0 - 10	45.59	9.12	1.52	0.91	1.22	12.77	12.16	9.42	1.52	3.04	13.98	3.04	2.74	2.13	3.04	1.52	0.91	0.61	0.61	0.30	0.61
	10 35	51.81	10.36	0.78	3.89	0.52	15.54	9.84	7.77	2.07	0.52	10.36	2.07	1.04	0.78	3.11	2.59	0.78	1.04	0.52	0.52	0.00
	35 - 150	62.22	7.56	0.00	1.78	0.44	9.78	4.44	4.89	1.78	1.33	8.00	4.44	1.78	4.00	3.56	0.89	0.44	0.44	0.00	0.00	0.00

The non-opaque minerals include pyroxenes, epidotes, amphiboles, zircon, garnet, rutile, tourmaline, monazite, staurolite, apatite and kyanite, arranged in a decreasing order of abundance (Table 6). Pyroxene minerals are the dominant in the non-opaque minerals and mainly composed of augite (3.91 – 12.50%), and then diopside (0 - 5.40%), hypersthene (0 - 4.12%) and enstatite (0 - 3.65%). Results obtained reveal that no specific patterns of pyroxene distributions with both soil depth and distance from Nile banks toward the eastern and western desert (Table 6 and Figure 6). Epidotes are the second most abundant group of non-opaques with a range between 4.44 and 21.67% without any clear trend throughout the profiles, but decrease far away from the Nile stream (Table 6 and Figure 6). The amphiboles are the third most predominant group of non-opaques. They are present as hornblend, actinolite and tremolite with range from 3.00 to 17.73 % without obvious differences among the studied terraces. The abundance of these relatively unstable minerals i.e. pyroxenes epidotes and amphiboles suggests that these soils are young and weakly developed and/or recent deposition (Gewaifel *et al.*, 1981; Faragallah, 1995; Amira, 2000; Faragallah and Essa 2004).

The relatively high resistant minerals including sphene, rutile, garnet and zircon are found in all the studied terrace soil samples as relatively moderate amounts (0.73-7.89%, 0.29-4.00%, 0.29-7.00% and 0.55-3.56%, respectively), with irregular distribution throughout the entire depth and the distance from the Nile (Table 6 and Figure 6). However, tourmaline, monazite, stauralite, and kyanite are present in most samples of the studied soils with small to very small amounts as they constitute 0.00 to 2.59%, 0.00 to 2.84%, 0.00 to 1.79%, and 0.00 to 1.79%, respectively. It appears from Table (6) that the presence of biotite and apatite minerals is mainly recorded in the youngest and oldest terrace soils with a range up to 9.29 and 2.38%, respectively. The presence of the resistant minerals in the studied soils may be ascribed to their primary assemblage in parent materials that have been formed by different sedimentary sources.

Soil Origin and Sedimentation Regime:

Studies of the origin of sediments and parent materials are generally more reliable when based on size fractions greater than 2 μm, especially on the "heavy minerals" fraction because they contain the greatest number of mineral species in sediments and are most likely to be diagnostic for particular igneous rocks and sedimentary beds (Milner, 1962). The assemblages and frequencies of heavy and light minerals in the studied soil samples as shown in Tables 5 and 6 suggest that the origin of these soils derived from different provenances. The occurrence of quartz in a very high content could reflect the acidic igneous rocks and also feldspars as orthoclase and microcline but feldspars as plagioclase indicate the basic igneous origin (Pettijohn, 1975 ; Blatt, 1992). Calcite suggests their derivation from lime-rich surrounding as sedimentary origin (Osman, 1996). The presence of iron oxides in a relatively high content suggests the possibility of enrichment with iron-rich minerals from a basic source rock, as proposed by Shendi (1990). The occurrence of ferro- and calcium-
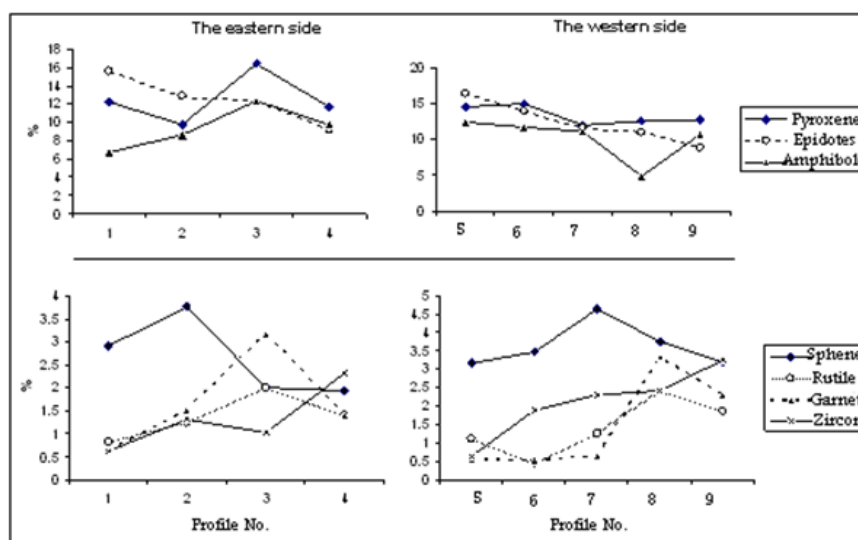
Fig. 6: The distribution of some heavy minerals in the soil profiles on both Nile sides.

magnesium- silicate minerals, such as epidotes, amphiboles and pyroxenes in pronounced amounts, and the ultra-stable minerals such as sphene, rutile, zircon, garnet and tourmaline with lesser amounts of monazite, staurolite, biotite, apatite and kyanite could indicate igneous and/or metamorphic sources (Milner, 1962). The presence of opaques, pyroxenes and rutile reflect basic igneous rocks; sphene, zircon, apatite represent the acidic igneous rocks; epidotes represent the metamorphic rocks and amphiboes, biotite, tourmaline as well as garnet represents igneous and/or metamorphic rocks (Pettijon, 1975; Friedmen and Sanders, 1978; Nechaev and Isphording, 1993). It could be concluded that the studied soils are precipitated from Nile sediments, which are derived from the igneous and metamorphic rocks of Ethiopian Plateau (Said, 1981). Calcite suggests their derivation from lime-rich plateau surrounding the Nile valley.

Concerning the sedimentation regime of the studied soils, there are some variations between the layers of the different Nile terrace soils as indicated from the particle size distribution (Tables 1 and 2), the statistical size parameters (Table 3), cumulative curves (Figure 3) and the distribution of light and heavy minerals (Table 6). These variations indicate that these soils were stratified and/or mostly formed under multi sedimentation regimes. The soil stratifications of the youngest and oldest Nile terraces could be attributed to the variable water conditions occurred during their transportation and sedimentation together with the effect of the paleo-topography.

Uniformity and Weathering Ratios:

The distribution patterns of some minerals that are identified as relatively high resistant to weathering and persist for a long time such as zircon, rutile and tourmaline throughout a soil profile can indicate soil uniformity. So, the ratios between resistance minerals (zircon, rutile and tourmaline) were used for the evaluation of soil profile uniformity and maturity (Haseman and Marshall, 1945; Barshed, 1964; Brewer, 1964; Chapman and Horn, 1968). The assumption ratios Zr/R, Zr/T and Zr/R+T are calculated and given in Table 7. Results show some variations between the profile layers of the studied Nile terrace soils and do not have any specific trend either with depth or among profile sites. This indicates that the soil materials forming the different beds are of different origins and are derived from different sources or from a parent material of heterogeneous nature.

Regarding the assessment of the efficiency of weathering processes and, consequently, soil development, the ratios between the most susceptible weathered minerals (amphiboles, pyroxenes and biotite) and the ultrastable ones (zircon and tourmaline) are used (Hammad, 1968). Computed weathering values throughout the studied soil profiles from the ratios A+P/Zr+T, H/Zr+T and B/Zr+T are present in Table 7. The obtained values indicate that no consistent trend of the weathering ratios with depth in the studied terrace soil profiles; this may be attributed to the fact that these soils had multi-origin or formed due to multi-sedimentation regimes. The weathering ratios, in some cases, are relatively lower in the surface than in the subsurface layer. This could suggest a slight role of weathering in the surface layer. The relatively high values of weathering ratios in most cases, especially in the surface layers, could be due to the continuous contamination with fresh sediments of different nature.

Table 7: Uniformity and weathering ratios of the studied soil samples.

Profile No.	Depth (Cm)	Uniformity ratios			Weathering ratios		
		Zr/R	Zr/T	Zr/R+T	A+P/Zr+T	H/Zr+T	B/Zr+T
1	0 - 15	0.50	1.00	0.33	25.11	7.54	12.55
	15 - 25	2.03	0.00	2.03	29.75	13.42	6.58
	25 - 35	1.00	2.00	0.67	19.60	4.99	2.99
	35 - 70	0.50	1.00	0.33	18.94	4.98	1.99
2	0 - 40	1.00	1.00	0.50	10.52	3.26	2.50
	40 - 70	0.75	0.75	0.38	5.72	2.00	4.29
	70 - 95	1.49	2.98	0.99	7.51	2.50	5.00
	95 - 195	0.50	1.00	0.33	14.41	4.97	4.97
	195-235	2.00	2.00	1.00	5.33	2.33	1.67
3	0 - 35	0.50	0.50	0.25	13.99	3.99	0.00
	35 - 55	0.33	0.00	0.33	34.00	8.00	1.00
	55 - 70	0.50	0.00	0.50	24.54	5.01	0.00
	70 - 150	1.00	0.00	1.00	16.51	5.00	0.00
4	0 - 20	5.04	2.50	1.67	5.42	1.71	0.00
	20 - 35	0.60	3.02	0.50	8.27	2.25	0.00
	35 - 150	2.50	2.50	1.25	7.15	2.43	0.00
5	0 - 20	0.49	1.00	0.33	35.18	15.08	2.01
	20 - 35	0.50	1.00	0.33	11.04	3.51	5.02
	35 - 65	1.00	0.00	1.00	48.29	15.09	10.05
6	0 - 45	4.05	0.00	4.05	16.73	4.99	3.75
	45 - 80	4.44	0.00	4.44	12.45	3.40	2.27
7	0 - 40	1.50	0.00	1.50	15.16	5.00	1.67
	40 - 70	1.99	2.98	1.19	9.51	3.75	1.00
	70 - 120	1.99	0.00	1.99	5.00	2.50	2.50
	120-155	2.00	0.00	2.00	8.75	3.75	3.75
8	0 - 50	1.25	5.00	1.00	7.01	2.17	0.33
	50 - 70	2.00	2.00	1.00	4.33	1.22	0.00
	70 - 85	0.75	0.00	0.75	7.33	1.00	0.00
	85 - 150	0.75	1.50	0.50	3.89	1.30	0.20
9	0 - 10	1.11	2.00	0.71	5.87	2.07	0.13
	10 35	2.99	1.20	0.86	4.54	1.36	0.09
	35 - 150	2.00	4.00	1.33	4.00	1.10	0.00

Zr = Zircon   R = Rutile   T = Tourmaline   A = Amphiboless   P = Pyroxines   H = Hornblend   B = Biotite

According to the above-mentioned results and discussion, it could be concluded that the studied soils are stratified and are of multi-origin and/or formed under multi-depositional regimes and apparently cause the heterogeneity of the soil material. Also, these soils are pedologically young and are weakly developed. This is the result of the prevailing arid climate that keeps the chemical changes at the minimum. Similar results are found by Elwan et. al. (1980), Noman (1989), Lotfy (1997), Amira (2000) and Faragallah and Essa (2004 and 2006).

Mineralogical Composition of the Clay Fraction:
    Semi-quantitative measurements of the identified minerals and their relative abundance with depth in the clay fraction of the studied soil samples are given in Tables (8 and 9). X-ray diffraction (XRD) patterns of the clay fraction of the youngest and oldest Nile terrace soils are shown in Figures 7 to 10. Clay mineral distributions throughout the studied soil profiles are illustrated in Figure 11.
    Smectites are the most abundant clay minerals in all soil samples with percentages ranging from 14.79 to 52.73%. They are mainly moderate to much abundant in the soils of the youngest and oldest terraces on both Nile sides. However, they are little to moderate abundant in the soils of the terrace rear suture on the desert fringes. There is no general trend for increasing or decreasing smectites throughout the soil profiles of the youngest and oldest Nile terraces. However, they tend to decrease with depth in the soils of the terrace bench in the Nile valley-desert interference zone and the terrace rear suture in the fringes of the desert on both sides. This trend suggests that the upper part of these soils is largely made up of preserved Nile sediments that rich in smectites (El-Attar and Jackson, 1973).
    Kaolinite occurs as the second abundant clay mineral with amounts varying from 4.49 to 11.40%, followed by mixed mica-smectite (1.18-14.15%), vermiculite (0.0-8.34%), chlorite (1.66-6.36%), sepiolite (1.36-5.46%), palygorskite (0.68-4.34%), mixed mica -vermiculite (0.0-5.68%), micas (0.54-3.34%) and pyrophyllite (0.28-1.25%). Their relative abundances are generally traces to little in all investigated soil samples, particularly in the soils of the youngest and oldest Nile terraces. These minerals do not show any constant trend with depth

Table 8: Semi-quantitative measurements of the identified minerals in the clay fractions of the studied soils.

Profile No.	Depth (cm)	Smectites	Kaolinite	Mixed micas-sme.	Vermiculite	Chlorite	Sepiolite	Palygorskite	Mixed micas-verm.	Micas	Pyrophyllite	Quartz	K-Feldspar	Calcite	Plagioclase
1	0 - 15	27.44	6.51	5.66	6.79	6.36	3.11	2.12	2.26	1.41	0.28	20.23	12.16	4.24	1.41
	15 - 25	35.28	6.24	2.99	7.46	6.11	2.71	2.04	1.90	0.54	0.41	12.08	15.06	4.48	2.71
	25 - 35	40.76	6.24	13.42	0.00	2.58	3.20	3.10	1.55	2.06	0.31	10.94	9.29	4.13	3.30
	35 - 70	33.76	7.77	12.41	0.00	1.94	2.37	3.45	1.40	3.34	0.65	12.94	11.87	4.31	3.78
2	0 - 40	25.72	6.24	11.11	4.99	5.87	2.00	3.12	1.87	2.75	1.25	16.48	13.48	3.50	1.62
	40 - 70	28.97	4.49	11.90	7.34	6.35	2.48	2.48	1.69	2.78	1.09	10.89	12.80	5.26	1.49
	70 - 95	29.74	7.03	12.25	5.72	4.58	2.29	0.98	1.14	1.96	0.65	14.05	13.07	4.90	1.63
	95 - 195	33.37	8.58	3.22	4.29	3.97	3.22	3.00	2.36	0.54	0.43	13.95	14.81	6.44	1.82
	195-235	40.63	8.34	2.94	8.34	3.34	3.93	2.36	2.75	2.06	0.98	10.60	7.75	4.51	1.47
3	0 - 35	31.50	6.76	2.71	5.31	4.64	2.90	3.86	2.22	0.97	0.48	12.56	5.80	18.36	1.93
	35 - 55	21.60	6.00	10.84	3.69	2.92	5.46	4.23	5.38	1.54	0.77	9.45	3.38	20.75	4.00
	55 - 70	25.81	5.60	2.55	3.90	4.58	1.70	2.72	1.70	0.85	0.85	9.00	3.40	35.65	1.70
	70 - 150	16.63	5.65	7.36	3.41	2.67	5.22	3.94	4.80	1.17	0.75	8.00	3.84	33.05	3.52
4	0 - 20	19.24	10.87	7.90	5.11	4.18	3.72	3.07	2.79	2.51	0.46	10.22	3.90	24.16	1.86
	20 - 35	21.61	10.59	14.15	3.98	3.22	2.54	5.68		0.85	0.68	10.59	3.22	16.53	1.53
	35 - 150	19.39	11.40	1.18	6.35	5.17	4.00	4.70	2.59	1.18	0.82	10.58	5.05	25.85	1.76
5	0 - 20	38.17	5.65	3.14	6.27	5.20	2.51	1.61	1.88	1.70	0.45	15.23	11.65	4.75	1.79
	20 - 35	36.35	6.04	1.89	5.41	4.15	3.27	2.14	2.52	2.77	0.63	16.35	9.06	7.17	2.26
	35 - 65	39.05	7.91	4.82	6.27	4.82	2.89	3.86	1.93	0.48	0.48	12.05	7.71	5.30	2.41
6	0 - 45	22.41	6.11	13.45	7.33	5.70	2.44	1.79	2.77	2.44	0.41	15.16	11.74	6.60	1.63
	45 - 80	31.62	5.78	8.83	6.42	4.82	2.73	2.89	4.09	2.65	0.64	14.85	8.83	4.25	1.61
7	0 - 40	30.76	4.66	2.00	5.99	4.79	1.86	1.33	1.60	1.60	0.67	19.44	14.65	7.99	2.66
	40 - 70	34.38	4.76	2.72	0.00	3.67	1.36	0.68	0.82	0.68	0.68	22.42	15.90	9.24	2.72
	70 - 120	23.51	6.97	11.06	7.71	6.32	3.35	2.23	2.79	3.07	0.56	15.80	10.32	4.37	1.95
	120-155	34.61	6.92	11.36	0.00	4.55	1.86	1.76	0.00	2.07	0.41	19.32	11.47	3.82	1.86
8	0 - 50	52.73	7.58	2.96	0.00	1.66	2.37	0.95	0.00	0.83	0.59	12.80	7.70	7.46	2.37
	50 - 70	40.86	5.69	3.49	6.50	4.55	3.09	2.27	2.60	2.19	0.41	7.72	3.01	14.46	3.17
	70 - 85	34.42	8.82	12.68	0.00	1.68	2.27	3.36	0.00	2.10	0.34	6.80	1.34	23.51	2.69
	85 - 150	26.47	8.60	10.02	4.73	3.78	1.98	1.89	3.78	0.95	0.38	6.43	1.89	27.41	1.70
9	0 - 10	24.53	7.95	1.69	2.88	3.55	3.38	2.20	3.05	1.35	0.68	17.94	5.41	22.84	2.54
	10 35	21.49	9.06	1.90	2.92	2.34	2.19	1.90	1.90	1.02	0.44	15.64	5.85	31.43	1.90
	35 - 150	14.79	10.17	9.52	4.16	3.70	2.59	4.34	2.22	1.66	0.74	13.40	4.53	25.97	2.22

Table 9: Relative abundance of the identified minerals in the clay fraction of the studied soils

Profile No.	Depth (cm)	Smectites	Kaolinite	Mixed micas-sme.	Vermiculite	Chlorite	Sepiolite	Palygorskite	Mixed micas-verm.	Micas	Pyrophyllite	Quartz	K-feldspar	Calcite	Plagioclase
1	0 - 15	moderate	little	little	little	little	traces	traces	traces	traces	traces	little	little	traces	traces
	15 - 25	moderate	little	traces	little	little	traces	traces	traces	traces	traces	little	moderate	traces	traces
	25 - 35	much	little	little	traces	traces	traces	traces	traces	traces	traces	little	little	traces	traces
	35 - 70	moderate	little	little	traces	traces	traces	traces	traces	traces	traces	little	moderate	traces	traces
2	0 - 40	moderate	little	little	traces	little	traces	traces	traces	traces	traces	moderate	moderate	traces	traces
	40 - 70	moderate	traces	little	little	little	traces	traces	traces	traces	traces	little	little	little	traces
	70 - 95	moderate	little	little	little	traces	traces	traces	traces	traces	traces	little	little	traces	traces
	95 - 195	moderate	little	traces	traces	traces	traces	traces	traces	traces	traces	little	moderate	little	traces
	195-235	much	little	traces	little	traces	traces	traces	traces	traces	traces	little	little	traces	traces
3	0 - 35	moderate	little	traces	little	traces	traces	traces	traces	traces	traces	little	little	moderate	traces
	35 - 55	moderate	little	little	traces	traces	little	traces	little	traces	traces	little	little	moderate	traces
	55 - 70	moderate	little	traces	traces	traces	traces	traces	traces	traces	traces	little	little	moderate	traces
	70 - 150	moderate	little	little	traces	traces	little	traces	traces	traces	traces	little	little	moderate	traces
4	0 - 20	moderate	little	little	little	traces	traces	traces	traces	traces	traces	little	little	moderate	traces
	20 - 35	moderate	little	little	traces	traces	traces	traces	little	traces	traces	little	traces	moderate	traces
	35 - 150	moderate	little	traces	little	little	traces	traces	traces	traces	traces	little	little	moderate	traces
5	0 - 20	moderate	little	traces	little	little	traces	traces	traces	traces	traces	moderate	little	traces	traces
	20 - 35	moderate	little	traces	little	little	traces	traces	traces	traces	traces	moderate	little	little	traces
	35 - 65	moderate	little	traces	little	little	traces	traces	traces	traces	traces	little	little	little	traces
6	0 - 45	moderate	little	little	little	little	traces	traces	traces	traces	traces	moderate	little	little	traces
	45 - 80	moderate	little	little	little	little	traces	traces	traces	traces	traces	little	little	traces	traces
7	0 - 40	moderate	traces	traces	little	traces	traces	traces	traces	traces	traces	moderate	moderate	little	traces
	40 - 70	moderate	traces	traces	traces	traces	traces	traces	traces	traces	traces	moderate	moderate	little	traces
	70 - 120	moderate	little	little	little	little	traces	traces	traces	traces	traces	moderate	little	traces	traces
	120-155	moderate	little	little	traces	traces	traces	traces	traces	traces	traces	moderate	little	traces	traces
8	0 - 50	much	little	traces	traces	traces	traces	traces	traces	traces	traces	little	little	little	traces
	50 - 70	much	little	traces	little	traces	traces	traces	traces	traces	traces	little	little	little	traces
	70 - 85	moderate	little	little	traces	traces	traces	traces	traces	traces	traces	little	traces	moderate	traces
	85 - 150	moderate	little	little	little	traces	traces	traces	traces	traces	traces	little	traces	moderate	traces
9	0 - 10	moderate	little	traces	traces	traces	traces	traces	traces	traces	traces	moderate	little	moderate	traces
	10 35	moderate	little	traces	traces	traces	traces	traces	traces	traces	traces	moderate	little	moderate	traces
	35 - 150	little	little	little	traces	traces	traces	traces	traces	traces	traces	little	little	moderate	traces

much: >40%;   moderate: 15-40%;   little: 5-15%;   traces: <5.

in the studied profiles. Quartz (6.43-22.42%), K-feldspar (1.34-15.90%), calcite (3.50-33.05%) and plagioclase (1.41-4.00%) are present in the clay fraction and arranged in a decreasing order of abundance. The relative abundance of K-feldspar is little to moderate in the soils of the youngest and oldest Nile terraces, but, in the soils of the terrace bench and the terrace rear suture, it is traces to little. However, the highest values of calcite are found in the soils of the terrace bench and the terrace rear suture, where its relative abundance is moderate, while it is traces to little in the soils of the youngest and oldest Nile terraces. Plagioclase is traces abundant in all studied soils but quartz ranges from little to moderate abundant. No clear trend for distribution of these minerals with depth in the studied soil profiles.

The clay minerals are generally formed from the weathering of different rock types and under specific climatic conditions. Smectites are inherited from the weathering of basic volcanic rocks. Pedogenic smectites can form by precipitation from solution (complex transformation) or by simple transformation of other silicate
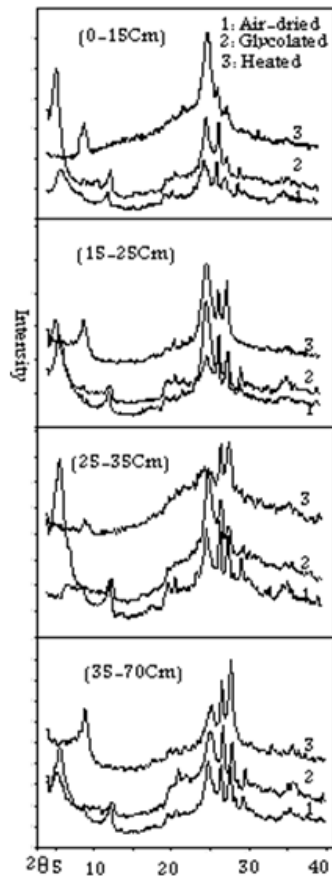
Fig. 7: X-ray diffractograms of the clay ftaction of profile 1.
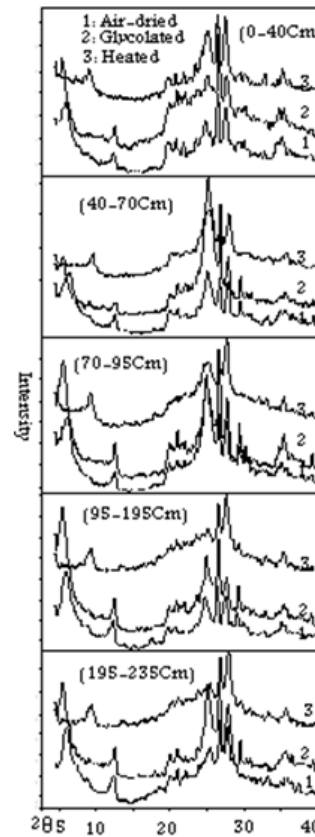
Fig. 8: X-ray diffractograms of the clay ftaction of profile 2.

minerals (degraded smectite). They are most commonly formed in the soils of tropical wet- and- dry to warm-temperate climates (De Visser, 1991). Potassium-bearing micas alter to expansible 2:1 minerals (smectite and vermiculite) by replacement of the K in the interlayer with hydrated cations through a simple transformation by both layer and edge weathering (Fanning *et al*., 1989). The occurrence of mixed layers in soils can most often be ascribed to incomplete rock weathering (De Visser, 1991). Formation of interstratified minerals might be due to hydrothermal transformation, weathering involving partial removal of interlayer K of micas. Reversibly uptake of K and formation of brucite or gibbsite interlayers in vermiculite and smectite form interstratified layers (Sawhney, 1989). Kaolinite is derived from nearly all types of igneous, metamorphic and sedimentary rocks if rainfall is frequent and water flow and hydrolysis are sufficiently strong under tropical to subtropical climate (De Visser, 1991). Kaolinite forms in the lithologic environment from feldspars and, to a lesser extent, micas in sandstones (Rossel, 1982). Vermiculite is originated from weathering and low temperature hydrothermal alteration of basic igneous rocks. It is most common in humid temperate and mountainous regions (De Visser, 1991). Vermiculite is most often reported to be transformed from muscovite, biotite, or chlorite (Douglas, 1989). Most mica minerals in soils are mainly primary as they are inherited from sedimentary and metamorphic rocks. Dominance of micas indicate an essentially physical weathering, found in cool or hot, dry regions and in mountainous regions (De Visser, 1991). Sepiolite and palygorskite minerals are believed to form mainly in calcareous crusts of semi-arid to arid regions (De Visser, 1991). Pyrophyllite is occasionally formed as detrital clay mineral in the argillaceous fraction of the paleosols and intercalated sediments**.** Mica (illite) and chlorite result from the erosion of plutonic and metamorphic rocks preserved from the noticeable chemical weathering at low hydrolysis in cool to temperate-dry climates.

From the previous discussion, it is obvious that the presence of these clay minerals in the studied soils is largely due to the detrital origin from the Ethiopian Plateau that mixed with the detrital materials derived
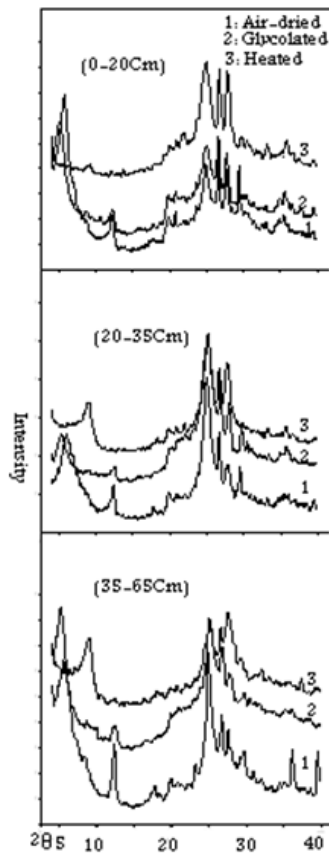
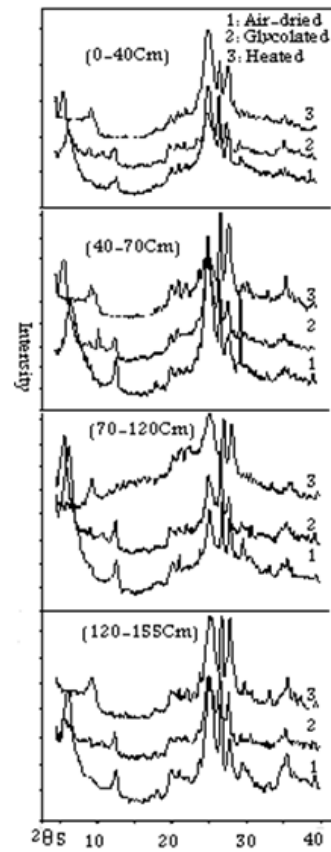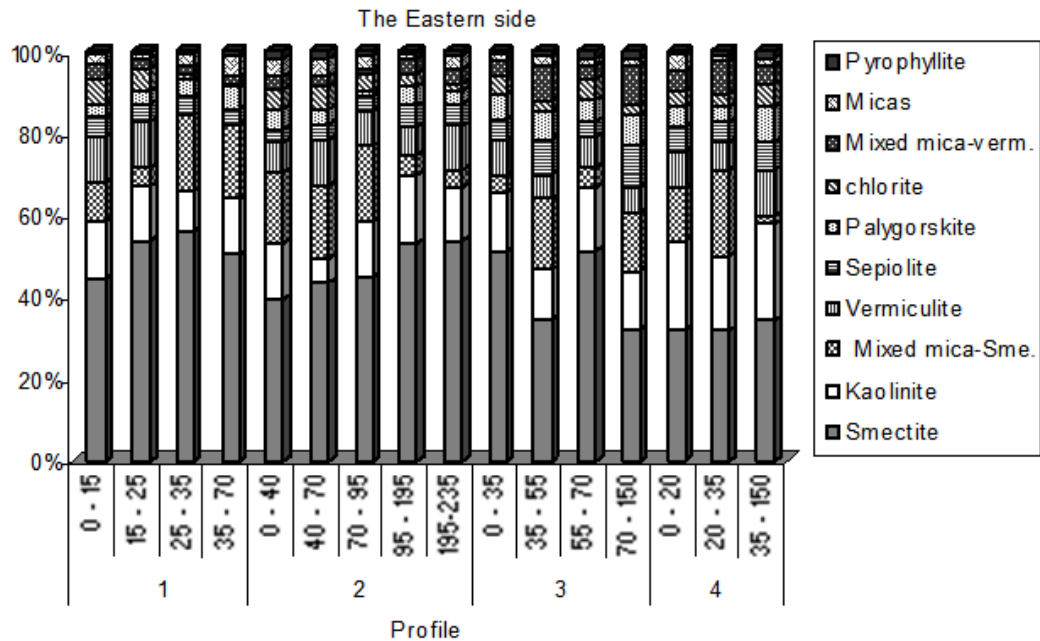**Fig. 9:** X-ray diffractograms of the clay ftaction of profile 5.

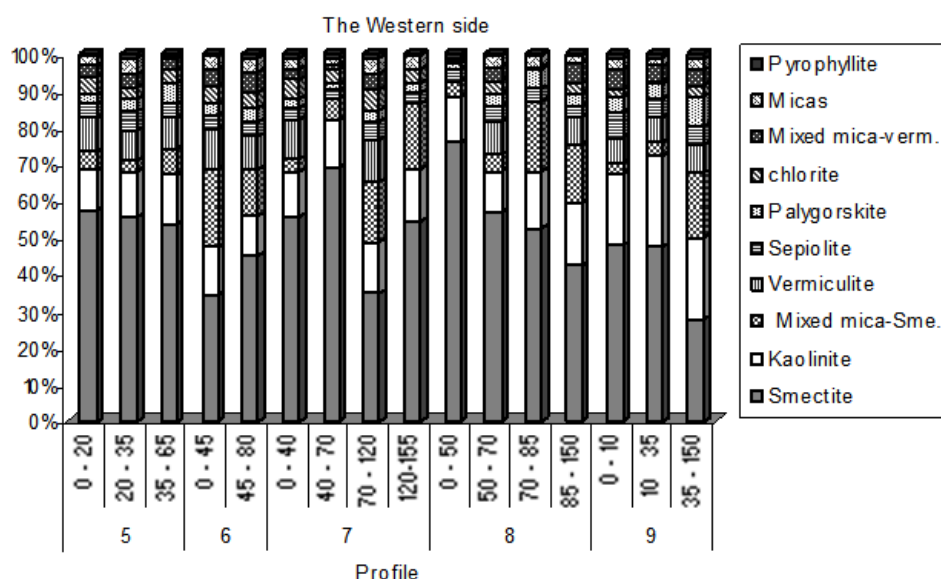**Fig. 10:** X-ray diffractograms of the clay ftaction of profile 7.

Fig. 11: The distribution of clay minerals throughout the studied soil profiles and the distance from the Nile to the desert on both sides.

from the sandstone and limestone plateaus which surrounding the Nile river course during the transportation and precipitation of these Nile sediments. Presence of micas and feldspars minerals in all studied soil samples emphasizes that these soils are young in the pedological viewpoint and less weathered (Fanning *et al.*, 1989). These findings coincide with those reported by Elwan *et al.*, (1980), Said (1981) and Faragallah and Essa (2004 and 2006).

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