MINERALOGY AND PEDOGENESIS IN A SOIL CHRONOSEQUENCE ON A FLOODPLAIN, EASTERN NIGERIA

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ABSTRACT

Studies on soils of the floodplain of lower Niger river are scanty although this floodplain forms a very important agricultural resource base in Nigeria. The objective of this study is to provide comprehensive information on the characteristics of the soils with respect to their mineralogy and the effect of seasonal flooding on their properties. Five soil profiles located on a depositional sequence were studied. The soils are deep, poorly drained and fine to medium textured. Mottling and periodic waterlogging are prominent morphological properties and pedogenetic process. The dominant clay mineral is kaolinite, comprising more than 40% of the total clay minerals in the clay fractions. Other clay minerals are the interlayered vermiculites (IV) and smectite. Quartz and feldspars are also prominent in the fine-earth fraction. The prominence of gibbsite and kaolinite is postulated to originate from a direct transformation of feldspars from the up river with younger parent material. The occurrence of lepidocrocite, hematite and ferrihydrite is attributed to the high moisture regimes which favour the formation of lepidocrocite which, under favourable weathering conditions, give rise to hematite and ferrihydrites. The annual cyclic flooding and drying plays a significant role in the weathering, transportation and eventual redistribution processes of the minerals. Results obtained from this study will provide information on agrotechnology transfer.

Key words: Feldspar, Clay minerals, Land reclamation, Lepidocrocite, Moisture regime, Kaolinite

INTRODUCTION

The floodplain soils in West Africa occur abundantly across all agroecological zones and they are potentially viable areas for increased agricultural production in an environment where agricultural activities are constrained by several factors, notably limited water supply (Buri *et al.*, 2000). Although the floodplains form important agricultural resource bases in West Africa, very few studies have been done on them to understand their soil-related constraints to crop production. In the Niger river floodplain most of the studies on soils are on the upper and mid-streams parts of the river, in the arid and semi-arid zones (Bui and Wilding 1988; Ducloux *et al.* 1998). Some studies on the floodplain have concentrated on specific problems related to specific crops such as swamp rice. Narteh and Sahrawat (1999) discussed river flooding in West African soils and its effect on their electrochemical and chemical properties while Buri *et al.* (2000) tried

to trace the effect of zinc toxicity on rice planted in lowland valleys.

Very few studies exist on the soils of the lower Niger floodplain, which is characterised by heavy rainfall and a humid tropical environment (Jungerius and Levelt, 1964; Obi and Akamigbo 1981). The lower Niger river floodplain provides a very good example of a chronosequence in a humid tropical environment, where the degree of weathering and soil formation are very intensive. Harris *et al.* (1980) attributed mineralogical differences between soils developed in alluvium to time when the effects of other soil factors have been relatively constant.

. The aim of this research is to provide information for better management of the soils, for agronomic purposes. The specific objectives of this study are (i) to provide information on the morphology and the physico-chemical properties of the soils and (ii) to determine the pedogenic processes and mineral transformations in a floodplain chronosequence.

MATERIALS AND METHODS
Description of the area

The area is located between longitudes 6°42′ and 6°49′E and latitudes 5°56′and 6°03′N. The floodplain is more than 10 km wide. All land units within the floodplain are below 30 m a.s.l and have a slope gradient of less than 1%. Annual rainfall, which occurs from April to November, is 1800 mm, bimodally distributed with peaks in July and September and with a very high intensity (Monanu 1975). Annual flooding occurs during the period of maximum rainfall. The mean monthly temperatures vary between 25°C and 32°C with high insolation. The natural vegetation is mainly derived savannah, with some relicts of rainforest distributed in patches (Jungerius, 1964). The underlying geological materials are mainly recent alluvial deposits (Orajaka, 1975). These materials include soils detached from the upper land areas in arid and semi-arid zones of the sahel region of West Africa and carried downstream. The floodplain is mainly used for cultivation of swamp rice during the rainy season while root crops, maize and vegetables are planted during the dry period. Some areas remain fallow for long periods. Also in an attempt to boost agricultural production, irrigation projects are planned for the floodplain.

Field study

Five soil profiles were selected to constitute an east-west soil depositional sequence (Fig. 1), with each profile representing a different depositional stage of the river Niger. The oldest deposition, farthest from the present river-bed, which also includes colluvial materials from the upland, was identified as NFP/P1, followed by NFP/P2. The intermediate stage is represented by NFP/P3 while NFP/P4 and NFP/P5 are closest to the present river-bed (Fig. 1). Soils were described using the FAO (1977) guidelines. Sampling was done during the dry season (March), when the land was not submerged by floodwater. The soil samples were collected from the different pedogenic horizons of each profile, air-dried, sieved through a 2-mm mesh and analysed as described below.
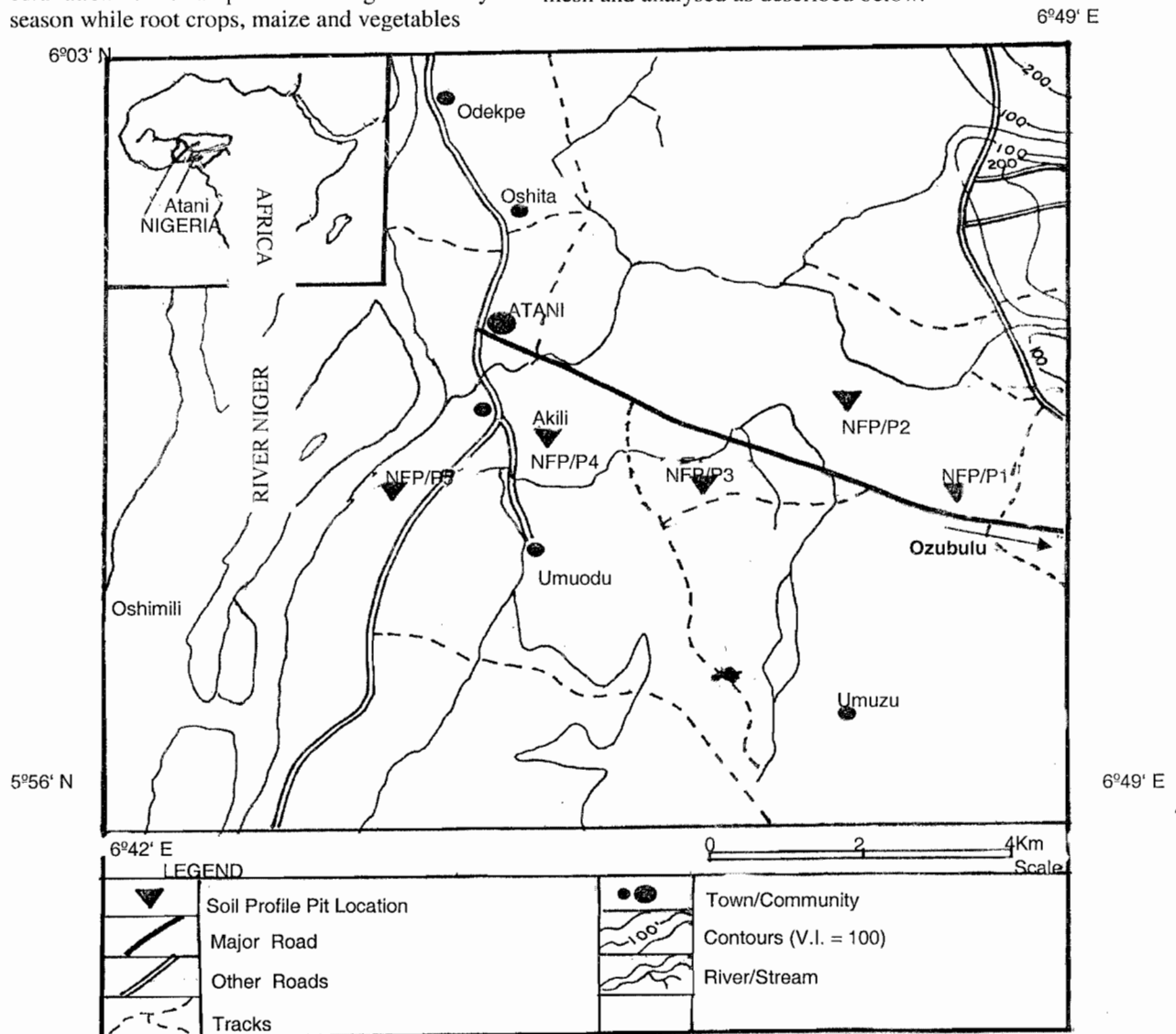

Figure: 1 Location map of the studied area

Laboratory methods
Physicochemical methods

Particle size distribution of the <2-mm fractions was measured by the hydrometer method as described by Gee and Bauder (1986). Bulk density was determined by the clod method (Blake and Hartge, 1986). A modified form of the Richards saturation paste method (1954) was used to determine the saturation water percentage (WSP). In this method, ceramic crucibles of 80 cm^3 capacity with perforated base were used. The inner base of the crucible was covered with a filter paper to prevent loss of soil through the perforations. Soils were packed in the crucible through tapping. The process continued until the crucible was three-quarter full. The crucible was then transferred to a basin of water. About half the height of the crucible was under water and allowed to stand in the basin until the soil was saturated with water by capillarity through the porous base of the crucible.

Soil pH was measured in a 1:2.5 soil: distilled H_2O and 0.1 M KCl suspension. Organic carbon was determined by the Walkley and Black method, total nitrogen by micro-Kjeldahl method (Bremner, 1965), available phosphorus by the Bray II method (Bray and Kurtz, 1945) and exchangeable bases and acidity as described by Thomas (1982). Dithionite-citrate-bicarbonate extractable Fe, Al and Mn (represented as Fed, Ald and Mnd) were measured as described by Mehra and Jackson (1960) and oxalate extractable Fe, Al and Mn (represented as Feo, Alo and Mno) by the McKeague and Day (1966) method

Mineralogical methods

Clay minerals were determined by X-ray diffractometry (XRD) with a SIEMENS D500 diffractometer, using Ni-filtered CuKα-radiation after various pretreatments such as Mg-, Mg+glycerol-solvated, K-saturation, K+110°C, K+350°C, and K+550°C heating. Mineralogy of the fine-earth fraction was also determined by XRD on powdered samples. Semi-quantitative estimation of minerals and elements in the fine-earth fraction diffractograms were done using the computer package DIFFRAC AT V3.3 SIEMENS 1993. Differential thermal analysis (DTA) using STA 409EP NETZSCH equipment was used to measure semi-quantitatively the mineral compositions in the clay fractions. The

chemical composition of the fine-earth fractions was determined using SIEMENS SRS 200 X-ray fluorescence (XRF) equipment.

RESULTS
Physico-chemical properties

The particle size distribution of the soils is shown (Table 1). Depth distribution of clay follows an irregular trend in all profiles (Table 1) where it increased with depth and then decreased in the lower two horizons. Apart from profile NFP/P3, the values of silt fraction decreased with depth with the highest values always in the topsoil. These silt values are higher in these soils than most soils in the adjacent ecological zones (Igwe et al., 1995). Fine sand was the dominant fraction (42 to 78 % in all soils). These values decreased with depth but often increased at the Cg, Bg3 or the Bg4 horizons. In the coarse sand fraction of profile NFP/P1, values were almost uniform except in the horizon Bg2. In the other soil profiles, except horizon Cg of profile NFP/P2, low values of between 2 and 30 % were obtained indicating wide variation. The soils have medium to high bulk densities, ranging from 1.11 to 1.85 Mg m^{-3} without any trends or patterns. Soil water saturation percentage showed values of between 46.3 and 94.2 % for the soils with those of profile NFP/P3 having the highest water saturation percentage (Table 1).

Chemical data (Table 2) show that the soils are moderately acid, with NFP/P1 the most acid. In all the soils higher organic carbon (OC) content was obtained in the top horizons and decreased with depth, with the Ap-horizon of NFP/P1 having the highest value of 2.11 %. Also the values of total nitrogen and available phosphorus were low in the soils. The values for exchangeable Na^+ were between 0.09 and 0.20 $cmol_c$ kg^{-1} while those of exchangeable K^+ ranged from 0.10 to 0.21 $cmol_c$ kg^{-1}. Relatively high values were obtained for exchangeable Ca^{2+} in profiles NFP/P1, NFP/P2 and NFP/P3 but in profiles NFP/P4 and NFP/P5 high values were recorded in exchangeable Mg^{2+}. The CEC of the soils were between 2.8 and 9.4 $cmol_c$ kg^{-1} while exchangeable Al^{3+} was moderate to high, reflecting the low pH values. Generally, the soils are acid, low in organic carbon content, exchangeable bases and, cation exchange capacity.

Table 1. Some physical properties

Horizon	Depth (cm)	Clay	Silt	Fine sand	Coarse sand	WSP	Bulk density Mg m^{-3}
				----------%----------			
Profile NFP/P1 (Typic Tropaquepts or Dystric Fluvisols)*							
Ap	0-15	12	8	52	28	64.5	1.53
Bg1	15-30	20	6	50	24	46.3	1.11
Bg2	30-60	30	6	50	14	67.0	1.40
Bg3	60-93	22	4	48	26	69.3	1.62
BCg	93-130	20	4	48	28	54.5	1.31
Profile NFP/P2 (Typic Endoaquepts or Dystric Gleysols)							
Ap	0-16	14	4	78	4	84.3	1.54
Bg1	16-37	18	6	70	6	63.7	1.34
Bg2	37-64	18	4	74	4	66.4	1.68
Bg3	64-108	16	4	76	4	59.0	1.38
Cg	108-175	6	2	62	30	46.7	1.87
Profile NFP/P3 (Dystric Durochrepts or Dystric Gleysols)							
Ap	0-12	26	14	56	4	89.6	1.70
Bg1	12-27	34	10	48	8	81.1	1.54
Bg2	27-60	32	10	50	8	71.3	1.38
Bg3	60-80	34	12	42	12	75.1	1.50
Bg4	80-125	36	14	42	8	94.2	1.81
Profile NFP/P4 (Aquic Eutropepts or Eutric Gleysols)							
Ap	0-20	18	20	60	2	60.5	1.33
Bg1	20-43	24	16	54	6	54.4	1.66
Bg2	43-79	24	16	54	6	55.3	1.38
Bg3	79-106	20	14	60	6	53.6	1.79
Bg4	106-160	24	10	64	2	54.0	1.63
Profile NFP/P5 (Fluvaquentic Eutropepts or Eutric Fluvisols)							
Ap	0-23	12	18	68	2	76.5	1.78
AB	23-56	22	18	58	2	74.3	1.85
Bg1	56-84	22	20	56	2	72.3	1.84
Bg2	84-123	24	18	56	2	69.9	1.78
Bg3	123-170	16	16	66	2	71.5	1.85

Table 2. Soil pH, organic. carbon, exchangeable cations and cation exchange capacity (CEC)

Horizon	Depth (cm)	pH H$_2$O	pH KCl	OC	TN	Na$^+$	K$^+$	Ca^{2+}	Mg^{2+}	Al^{3+}	CEC	Avail. P mg kg^{-1}
				----%----					-cmol$_c$ kg^{-1}-			
Profile NFP/P1												
Ap	0-15	5.1	4.0	2.11	0.148	0.12	0.13	0.9	0.5	0.7	2.8	12.0
Bg1	15-30	4.9	3.9	0.76	0.056	0.12	0.13	1.1	0.1	1.2	3.5	9.6
Bg2	30-60	4.7	3.9	0.76	0.050	0.10	0.11	1.3	0.7	2.5	6.0	8.4
Bg3	60-90	5.1	3.9	0.32	0.023	0.10	0.11	1.0	0.6	4.0	6.9	9.6
BCg	90-130	4.9	3.8	0.32	0.020	0.09	0.10	0.9	0.4	2.0	3.9	12.0
Profile NFP/P2												
Bg1	16-37	5.2	4.0	1.08	0.060	0.14	0.16	0.9	0.5	2.9	5.7	12.0
Bg2	37-64	5.4	4.1	0.32	0.025	0.15	0.16	1.0	0.5	2.5	5.5	9.6
Bg3	64-108	5.5	4.1	0.24	0.020	0.15	0.17	1.2	0.4	2.0	5.4	8.4
Cg	108-175	6.0	4.2	0.12	0.010	0.14	0.16	1.1	0.3	0.4	2.5	13.2
Profile NFP/P3												
Ap	0-12	5.3	4.3	1.52	0.096	0.15	0.15	1.1	0.4	1.0	3.8	14.4
Bg1	12-27	5.5	4.4	0.68	0.046	0.15	0.17	1.0	0.3	0.7	3.0	12.0
Bg2	27-60	5.8	4.4	0.40	0.026	0.16	0.17	1.0	0.2	0.8	3.0	13.2
Bg3	60-80	5.8	4.2	0.28	0.015	0.13	0.15	1.0	0.3	1.3	4.1	13.2
Bg4	80-125	5.8	4.1	0.32	0.020	0.13	0.15	1.0	0.2	2.8	6.1	14.4
Profile NFP/P4												
Ap	0-20	5.6	5.0	1.52	0.097	0.15	0.16	1.6	3.2	0.7	6.2	26.4
Bg1	20-43	5.4	4.1	0.56	0.036	0.15	0.16	1.5	4.0	0.8	6.9	14.4
Bg2	43-79	5.6	4.1	0.32	0.023	0.15	0.16	1.6	2.1	2.2	8.0	13.2
Bg3	79-106	5.7	4.7	0.12	0.010	0.14	0.15	0.9	2.2	2.0	6.8	10.8
Bg4	106-160	6.3	4.1	0.20	0.010	0.13	0.14	0.9	2.3	1.9	6.7	12.0
Profile NFP/P5												
Ap	0-23	5.7	4.0	1.52	0.096	0.13	0.14	2.9	3.6	1.2	2.4	14.0
AB	23-56	5.6	4.2	0.48	0.34	0.12	0.23	3.0	2.1	1.2	6.2	13.2
Bg1	56-84	5.7	4.2	0.42	0.015	0.15	0.19	2.5	3.5	0.3	5.6	13.2
Bg2	84-123	5.9	4.9	0.32	0.015	0.13	0.2	3.0	2.2	0.3	6.1	13.2
Bg3	123-170	5.7	4.0	0.20	0.023	0.16	0.14	3.0	1.9	1.3	6.7	12.0

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Mineralogical and chemical composition
Mineralogy of the fine-earth fraction

Table 3 presents a qualitative valuation of the mineral components of the fine-earth fraction obtained from XRDs. The dominant mineral is quartz followed by orthoclase feldspar. The clay minerals identified were kaolinite, smectite, mica-related minerals and some vermiculite. Hematite, lepidocrocite and gibbsite were also found in the XRD of powdered samples of the fine-earth (Fig. 2). Small amounts of birnessite were identified in profile NFP/P3 while trace amounts were observed in profiles NFP/P4 and NFP/P5.

Table 3. Qualitative evaluation of the mineral content of the fine-earth fraction

Horizon	QUA	KAO	ILL	VER	SME	HEM	MAG	LEP	DIA	GIB	BIR	FEL
					MINERALS*							
					Profile NFP/P1							
Ap	+++	++	(+)	+	(+)	+	(+)	+	+	++	-	++
Bg1	+++	++	(+)	+	+	+	(+)	+	+	++	-	++
Bg2	+++	++	(+)	+	+	+	(+)	+	+	++	-	++
Bg3	+++	++	(+)	+	+	+	(+)	+	+	++	-	++
BCg	+++	++	(+)	+	(+)	+	(+)	+	+	++	-	++
					Profile NFP/P2							
Ap	+++	++	(+)	+	(+)	+	(+)	+	+	++	-	++
Bg1	+++	++	(+)	+	+	+	(+)	+	+	++	-	++
Bg2	+++	++	(+)	+	+	+	(+)	+	+	++	-	++
Bg3	+++	++	(+)	+	(+)	+	(+)	+	+	++	-	++
Cg	+++	++	(+)	+	+	+	(+)	+	+	++	-	++
					Profile NFP/P3							
Ap	+++	++	+	+	+	++	-	++	+	++	+	++
Bg1	+++	++	+	+	+	++	-	++	+	++	+	++
Bg2	+++	++	+	+	+	++	-	++	+	++	+	++
Bg3	+++	++	+	+	+	++	-	++	+	++	+	++
Bg4	+++	++	+	+	+	++	-	++	+	++	+	++
					Profile NFP/P4							
Ap	+++	++	+	+	(+)	+	-	++	+	+	(+)	++
Bg1	+++	++	+	+	+	+	-	++	+	+	(+)	++
Bg2	+++	++	+	+	+	+	-	++	+	+	(+)	++
Bg3	+++	++	+	+	+	+	-	++	+	+	(+)	++
Bg4	+++	++	+	+	+	+	-	++	+	+	(+)	++
					Profile NFP/P5							
Ap	++++	++	+	+	+	+	-	++	+	+	(+)	++
AB	+++	++	+	+	+	+	-	+	+	+	(+)	++
Bg1	+++	++	+	+	+	+	-	+	+	+	(+)	++
Bg2	+++	++	+	+	+	+	-	+	+	+	(+)	++
Bg3	+++	++	+	+	+	+	-	+	+	+	(+)	++

* QUA=quartz; KAO= kaolinite; ILL= illite; VER= vermiculite and related minerals; SME= smectite; HEM= hematite; MAG= maghemite; LEP= lepidocrocites; DIA= diaspore; GIB= gibbsite; BIR= Birnessite; FEL= felspars

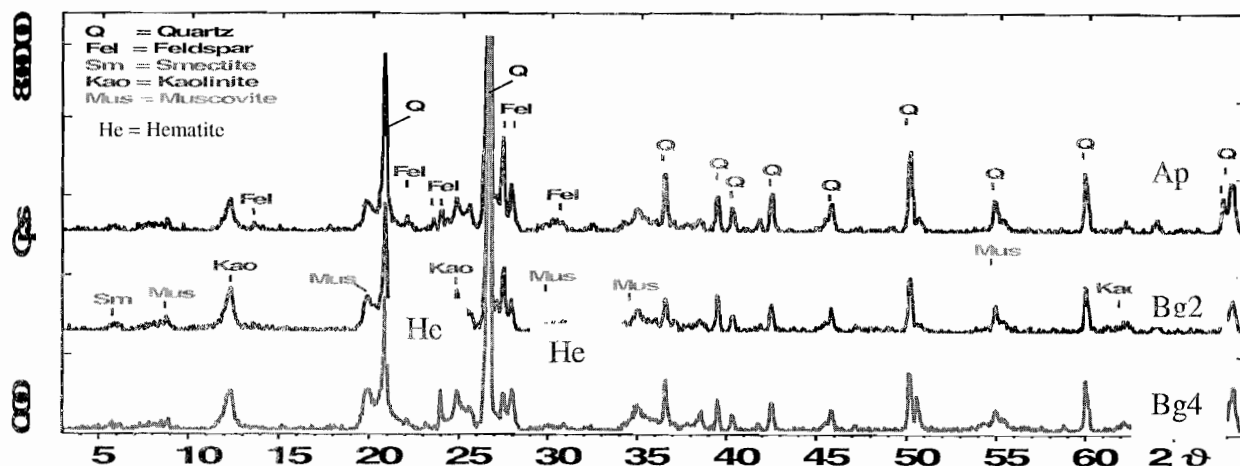+++=abundant; ++ common; += few; (+)= trace; -=not detected
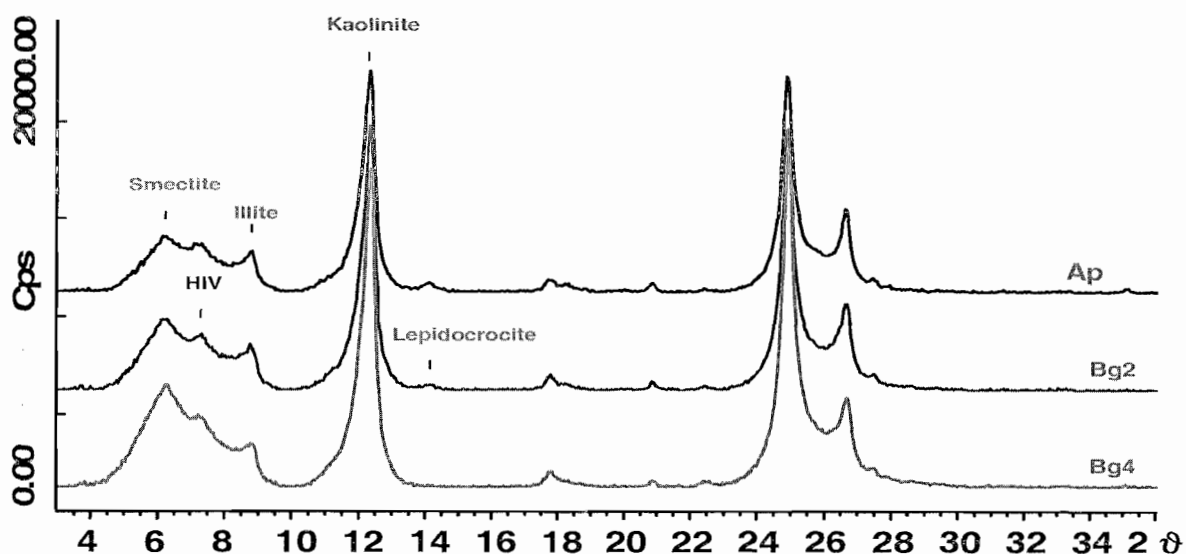

Fig 2. Typical Powder XRD from NFP/P3

Fig. 3. Typical XRD of Mg- treated oriented clay fraction from NFP/P3

In the fine-earth fractions, SiO_2 was the dominant total elemental oxide, followed by Al_2O_3 and Fe_2O_3 (Table 4). Total K_2O was higher than MgO, Na_2O and CaO. TiO_2 values were generally higher than those of ZrO_2. The values of total P_2O_5 and MnO were low but relatively higher in profile NFP/P3. The dithionite-extractable Fe (Fed) ranged from 4.12 to 59.07 g kg^{-1} with highest values occurring in profile NFP/P3. The values of ammonium oxalate-extractable Fe (Feo) were between 0.77 and 13.72 g kg^{-1}. Generally, the values of total Fe (Fet) the highest followed by Fed except in Ap horizon of profile NFP/P3. Similar trend was also obtained in Al where total (Alt) > Ald > Alo (Table 5). However, Alo was found to be higher only in Ap-horizons of NFP/P1, NFP/P2 and horizon Bg3 of profile NFP/P5. The values of both Mnd and Mno were low in most profiles except profile NFP/P3. In general, there seemed to be high total, dithionite and oxalate soluble Fe, Al and Mn in profile NFP/P3.

The calculated Fed/clay ratio for the fine-earth (Table 6) indicated a general trend of high values within the first two upper horizons or three horizons and then decreased towards the bottom of the profiles. However, profiles NFP/P4 and NFP/P5 did not follow this trend but showed fluctuations in their values. The Fed/Fet and Feo/Fed mole ratios showed values of less than unity. In most cases higher values were obtained for Fed/Fet ratio than their corresponding Feo/Fed (Table 6). Also Ald/Alt ratios were low, with values ranging from 0.009 to 0.277, while higher values of between 0.032 and 1.60 were obtained for Alo/Ald ratio. Very high significant correlation coefficients were obtained between clay and Fet, Fed, Alt and Ald (r = 0.84, 0.80, 0.84 and 0.77) respectively. Fet, on the other hand, correlated positively and significantly with Fed and Alt (r = 0.87, and 0.92), respectively. Total Fe, therefore, may also be in association with the total Al on the clay surfaces. The Si/Al mole ratios, calculated on total element bases, were between 2.80 and 10.99 (Table 6). This narrow Si/Al ratio for most horizons is an indication of the dominance of kaolinite and other highly weathered minerals over other clay minerals (Blume and Schwertmann 1969). The highest Si/Al ratio value of 10.99 was in Cg horizon of profile NFP/P2.

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Table 4. Total elemental distributions in the fine-earth fractions

Horizon	Depth (cm)	Na$_2$O	MgO	P$_2$O$_5$	Al$_2$O$_3$	SiO$_2$	K$_2$O	CaO	TiO$_2$	MnO	Fe$_2$O$_3$	ZrO$_2$	LOI
						------%------							
					Profile NFP/P1								
Ap	0-15	0.13	0.40	0.07	8.30	77.23	1.30	0.13	0.67	0.01	1.59	0.04	5.3
Bg1	15-30	0.12	0.49	0.06	11.17	73.29	1.27	0.14	0.85	0.01	2.45	0.04	6.9
Bg2	30-60	0.09	0.75	0.07	17.40	64.40	1.39	0.15	1.23	0.02	4.84	0.04	11.9
Bg3	60-93	0.09	0.45	0.05	11.64	70.58	1.02	0.10	0.62	0.01	2.37	0.03	7.6
BCg	93-130	0.08	0.38	0.04	9.92	72.62	1.03	0.09	0.52	0.01	1.85	0.03	6.6
					Profile NFP/P2								
Ap	0-16	0.52	0.57	0.10	11.45	69.18	2.55	0.39	1.16	0.04	2.49	0.11	7.8
Bg1	16-37	0.52	0.59	0.07	12.50	69.48	2.56	0.36	1.24	0.03	3.00	0.11	5.9
Bg2	37-64	0.58	0.60	0.06	12.52	70.37	2.75	0.37	1.33	0.02	3.14	0.11	5.5
Bg3	64-108	0.67	0.57	0.05	12.00	68.96	2.84	0.43	1.21	0.02	3.44	0.11	4.8
Cg	108-175	0.41	0.30	0.06	6.13	76.41	1.69	0.28	0.49	0.01	1.13	0.09	1.6
					Profile NFP/P3								
Ap	0-12	0.42	0.91	0.22	15.33	62.48	2.56	0.42	1.64	0.08	6.11	0.06	12.8
Bg1	12-27	0.35	1.03	0.26	17.06	57.69	2.41	0.43	1.68	0.17	8.23	0.05	13.2
Bg2	27-60	0.32	1.09	0.25	18.68	54.86	2.37	0.44	1.72	0.31	8.68	0.05	14.1
Bg3	60-80	0.27	1.11	0.20	19.57	54.71	2.21	0.39	1.73	0.33	8.48	0.04	15.0
Bg4	80-125	0.32	1.03	0.16	18.42	56.41	2.12	0.39	1.57	0.11	7.49	0.05	13.6
					Profile NFP/P4								
Ap	0-20	0.73	0.70	0.16	12.24	68.44	3.16	0.61	1.32	0.07	3.46	0.11	7.6
Bg1	20-43	0.52	0.91	0.13	15.00	62.87	2.87	0.41	1.65	0.09	5.98	0.09	8.7
Bg2	43-79	0.59	0.86	0.11	14.71	64.41	2.97	0.44	1.43	0.07	5.31	0.10	6.9
Bg3	79-106	0.66	0.78	0.11	13.77	65.08	2.98	0.47	1.29	0.08	5.12	0.11	5.8
Bg4	106-160	0.66	0.83	0.10	14.20	65.09	2.98	0.48	1.22	0.04	4.33	0.12	5.6
					Profile NFP/P5								
Ap	0-23	0.89	0.77	0.12	12.43	67.50	3.13	0.85	1.16	0.08	3.64	0.14	6.1
AB	23-56	0.62	1.04	0.23	17.13	62.30	2.74	0.70	1.46	0.08	5.83	0.10	9.1
Bg1	56-84	0.57	1.12	0.26	17.64	59.25	2.71	0.82	1.48	0.09	6.16	0.09	10.3
Bg2	84-123	0.69	1.12	0.17	18.22	60.79	2.86	0.80	1.51	0.07	5.75	0.09	9.0
Bg3	123-170	0.81	0.98	0.12	15.18	66.74	3.00	0.84	1.32	0.05	4.62	0.11	6.3

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Table 5. Total (t), dithionite-citrate (d) and oxalate (o) extractable Fe, Al and Mn in the fine earth fraction

Horizon	Depth (cm)	Fet	Alt	Mnt	Fed	Ald	Mnd	Feo	Alo	Mno
		--g kg⁻¹---								
					Profile NFP/P1					
Ap	0-15	11.1	44.0	0.093	4.82	1.12	0.013	2.35	1.79	0.009
Bg1	15-30	17.1	59.1	0.101	8.84	2.20	0.010	3.21	1.11	0.006
Bg2	30-60	33.8	92.0	0.131	15.61	4.86	0.011	2.87	2.17	0.003
Bg3	60-93	16.6	61.6	0.082	15.40	2.70	0.010	3.30	1.30	-
BCg	93-130	12.9	52.5	0.064	10.13	2.80	0.009	2.50	1.19	0.001
					Profile NFP/P2					
Ap	0-16	17.4	60.6	0.273	4.87	1.09	0.069	3.24	1.45	0.055
Bg1	16-37	21.0	66.1	0.196	10.02	1.80	0.019	3.38	1.74	0.012
Bg2	37-64	22.0	66.3	0.176	12.53	1.43	0.007	1.72	0.83	0.005
Bg3	64-108	24.1	63.5	0.166	15.22	1.34	0.007	1.06	0.50	0.004
Cg	108-175	7.9	32.5	0.108	5.14	0.90	0.019	0.77	0.29	0.009
					Profile NFP/P3					
Ap	0-12	42.7	81.1	0.642	14.12	2.88	0.239	13.72	2.26	0.313
Bg1	12-27	56.9	90.3	1.315	52.63	2.60	1.168	7.56	1.42	0.730
Bg2	27-60	60.7	98.9	2.383	59.07	3.28	1.948	7.13	1.45	1.600
Bg3	60-80	59.3	103.6	2.580	57.72	3.65	2.008	4.83	1.47	1.328
Bg4	80-125	52.2	97.5	0.860	48.30	2.58	0.460	2.89	1.12	0.278
					Profile NFP/P4					
Ap	0-20	24.2	64.8	0.512	12.96	0.98	0.423	2.57	0.94	0.198
Bg1	20-43	41.8	79.4	0.703	33.14	2.48	0.673	2.47	1.60	0.123
Bg2	43-79	37.1	77.9	0.558	26.69	2.02	0.518	1.86	1.44	0.208
Bg3	79-106	35.8	72.9	0.630	20.65	1.21	0.593	1.70	1.03	0.223
Bg4	106-160	30.3	75.1	0.307	21.09	1.79	0.295	1.11	0.85	0.040
					Profile NFP/P5					
Ap	0-23	25.5	65.8	0.592	13.13	1.07	0.570	3.00	0.65	0.250
AB	23-56	40.8	90.6	0.612	22.16	2.02	0.443	6.76	1.95	0.230
Bg1	56-84	43.1	93.4	0.606	24.66	2.11	0.647	6.91	1.45	0.322
Bg2	84-123	40.2	96.4		27.84	1.61	0.450	6.41	1.13	0.260
Bg3	123-170	32.3	80.3		21.05	0.76	0.417	4.27	0.79	0.117

Fet, Alt, Mnt = Total Fe, Al, Mn; Fed, Ald, Mnd = dithionite Fe, Al, Mn; Feo, Alo, Mno = oxalate Fe, Al, Mn

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Table 6: Fed/clay, Fe_d/ Fe_t, Fe_o/ Fe_d, Al_d/Al_t, Al_o/Al_d and Si/Al mole ratios of the fine-earth fraction.

Horizon	Fe_d/Clay	Fe_d/Fe_t	Fe_o/Fe_d	Al_d/Al_t	Al_o/Al_d	Si/Al
			Profile NFP/P1			
Ap	0.04	0.43	0.49	0.03	1.60	8.20
Bg1	0.04	0.52	0.36	0.04	0.51	5.80
Bg2	0.05	0.46	0.18	0.05	0.45	3.27
Bg3	0.07	0.93	0.21	0.04	0.48	5.36
BCg	0.05	0.79	0.25	0.05	0.43	6.47
			Profile NFP/P2			
Ap	0.04	0.28	0.67	0.02	1.33	5.34
Bg1	0.06	0.48	0.34	0.03	0.97	4.91
Bg2	0.07	0.57	0.14	0.02	0.58	4.96
Bg3	0.10	0.63	0.07	0.02	0.37	5.07
Cg	0.09	0.65	0.15	0.28	0.03	10.99
			Profile NFP/P3			
Ap	0.02	0.33	0.97	0.04	0.78	4.08
Bg1	0.16	0.93	0.14	0.03	0.55	3.38
Bg2	0.19	0.97	0.12	0.03	0.44	2.94
Bg3	0.17	0.97	0.084	0.04	0.40	2.80
Bg4	0.13	0.93	0.06	0.03	0.43	3.66
			Profile NFP/P4			
Ap	0.07	0.54	0.20	0.02	0.96	4.94
Bg1	0.14	0.79	0.07	0.03	0.65	3.70
Bg2	0.11	0.72	0.07	0.03	0.71	3.86
Bg3	0.10	0.58	0.08	0.02	0.85	4.17
Bg4	0.09	0.70	0.05	0.02	0.48	4.05
			Profile NFP/P5			
Ap	0.11	0.52	0.23	0.02	0.61	4.79
AB	0.10	0.54	0.31	0.02	0.97	3.21
Bg1	0.11	0.57	0.28	0.02	0.69	2.97
Bg2	0.09	0.54	0.30	0.02	0.70	2.95
Bg3	0.11	0.53	0.25	0.01	1.04	3.89

Clay mineralogy and soil classification

X-ray diffractometry (XRD) patterns of the clay fraction from selected horizons of a selected profile are presented in Fig. 3. These XRD patterns exhibit well-defined diffractions at 0.72 nm, indicating kaolinite as the dominant clay mineral. The 2:1 clay minerals present were illite at 1.0 nm, illite/smectite mixed layered at between 1.0 and 1.4 nm. Interlayered vermiculite (IV) occurred at 1.4 nm while smectite was observed at 1.8 nm. The diffraction peaks found between 1.0 and 1.4 nm in Mg-saturated samples shifted to 1.8 nm after the samples were solvated with glycerol, indicating the presence of smectite in various quantities in the soils. After various heat treatments, all the diffraction peaks collapsed to 1.0 nm, indicating the absence of halloysite and chlorite. In general, more kaolinites were detected in profiles NFP/P1 and NFP/P2 than those closer to the river. Also, more smectites were obtained from the soil profiles nearer the river than those towards the upland.

The differential thermal analysis (DTA) confirmed the dominance of kaolinite in most of the soils (Fig. 4). Endotherm at the relatively low temperature of between 470 and 495°C also is an indication of the presence of kaolinite. Gibbsite was always showing a small endotherm peak at 265°C. Mackenzie (1972) observed that gibbsite and bayerite yield endotherm peaks in the range from 250 to 550°C. Fig 5 shows the scanning electron micrograph (SEM) of grains of fine sand and silt fractions. Figs 5A displays rounded smooth grains indicating evidence of fluvial transport of materials. Also Fig 5B orthoclase feldspars are shown undergoing dissolution weathering while Figs 5C-E are silt grains showing aggregated kaolinite particles being exfoliated. It is of interest to note the flat arrangements and the morphology of kaolinite minerals. The soils were classified according

to Soil Taxonomy (1996) and approximate classes of FAO/UNESCO (1988) (Table 7). Information from clay mineralogy will be used to classify the soils up to the family level of generalization.

Table 7. Summary of classification of the soils

| Profile	USDA Soil Taxonomy (1996)	FAO/UNESCO (1988)
NFP/P1	Typic Kandiaqult; loamy, kaolinitic, Isohyperthermic	Dystric Fluvisols
NFP/P2	Typic Endoaquepts; loamy, mixed, I sohyperthermic	Dystric Gleysols
NFP/P3	Dystric Durochrepts; loamy, mixed, Isohyperthermic	Dystric Gleysols
NFP/P4	Aquic Eutropepts; loamy, mixed, Isohyperthermic	Eutric Gleysols
NFP/P5	Fluvaquentic Eutropepts; loamy, mixed, isohyperthermic	Eutric Fluvisols
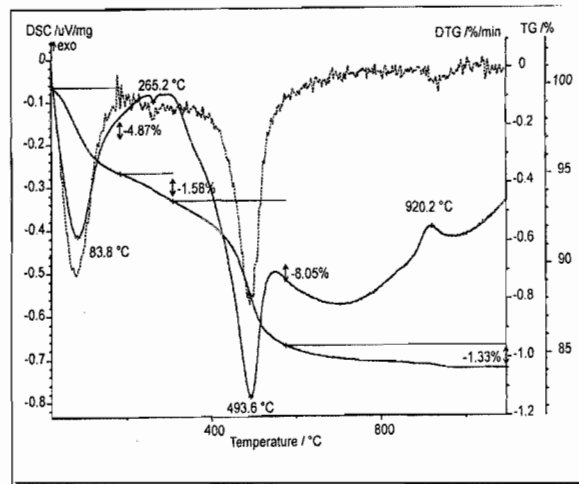
Fig. 4. Differential thermal analyses (DTA) of a typical clay sample from the soils from Bg2 Profile NFP/P3

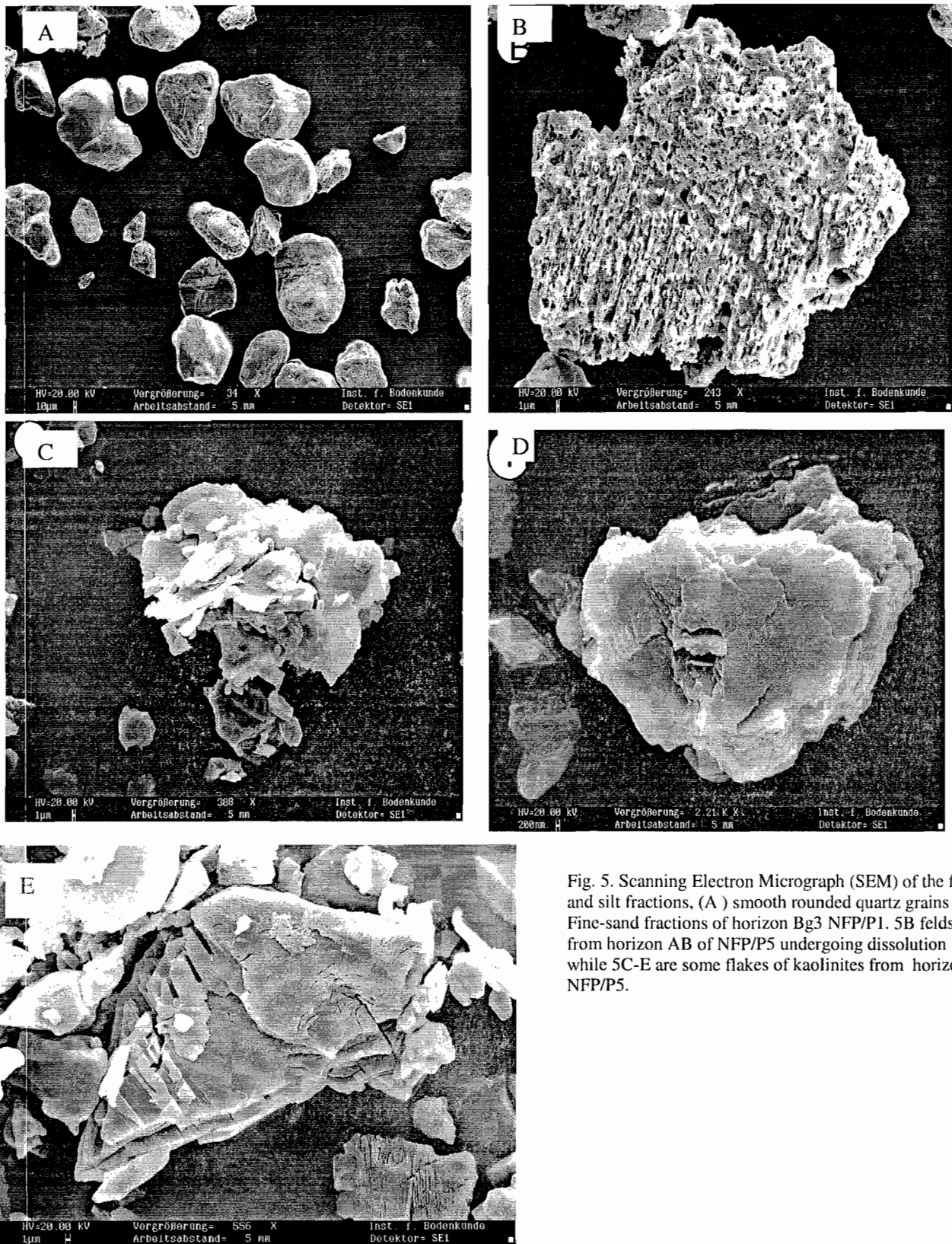Igwe C.A, Ekebosi, G.O, Zarei, M and Stahr, K

Fig. 5. Scanning Electron Micrograph (SEM) of the fine-sand and silt fractions, (A) smooth rounded quartz grains from the Fine-sand fractions of horizon Bg3 NFP/P1. 5B feldspar ineral from horizon AB of NFP/P5 undergoing dissolution eathering, while 5C-E are some flakes of kaolinites from horizon Bg2, NFP/P5.

DISCUSSION

Morphology and physico-chemical properties

The soils are formed on alluvium, deposited over different periods of time. The gleying process, low pH and higher silt content of the soils closer to the river were attributed to the seasonally fluctuating water regime in the soils. Brinkman (1977) observed that these characteristics occurred in landscapes that were seasonally inundated or waterlogged during rainy seasons. Some researchers (Harris et al., 1980; Obi and Akamigbo, 1981) described soils under sedimentary influence to be fine grained. With maturity these soils tend to have thicker fine-textured horizons over the subsoil and in most cases overlying a sandy substrata as obtained in profile NFP/P2. There seem to be lateral movement of clay and enrichment of organic matter and Fe in solution from both the river Niger and from the upland from the directions of profiles NFP/P1, NFP/P2 and their redistribution on the soils of NFP/P3 (Table 1). A number of researchers (Sommer and Stahr, 1996; Sommer and Schlichting, 1997) working in other regions, described this kind of phenomenon as accumulation-chrono catena process. In this situation clay and silt may have accumulated with time due to dissolution processes of alkali-feldspartic pedogenic materials. The soils generally show moderate structural development in most horizons, except in profile NFP/P3 where the subsoil is massive and reflected in the high bulk density which may also be due to gleying, accumulation of materials by lateral movement of both ground and flood water. The landscape position of profile NFP/P3 is the lowest, thus taking delivery of all the materials from the adjacent soils.

The organic carbon (OC) content is low in all the soils. Buri et al. (2000) indicated that soils within the West African subregion, including floodplain soils, were relatively low in organic materials and inherent fertility. The soils are acidic, low in basic cations and CEC (Table 2) and developed over parent materials that are low in K, Mg, Ca and high SiO_2, Al_2O_3 and Fe_2O_3 contents (Table 4). The parent materials are alluvial sands and mud, very rich in quartz and some TiO_2. Also, the low levels of nutrients in the soils may be due to fixation of the nutrients, high mineralization of organic matter because of high temperature and high and intensive rainfall leading to leaching of nutrients.

Dynamics of oxides and hydroxides

Iron oxide (Fe_2O_3) was prominent in these soils, both as lepidocrocite, hematite and some maghemite (Table 3). The dominance of crystalline forms of Fe over amorphous forms (Table 5) may have been due to the age of these soils or the age of the sediments in which these soils formed. Schwertmann and Kämpf (1983) showed that crystalline iron forms are widely distributed in all climatic regions and prevail in alternating reducing and oxidizing conditions such as those of the soils being studied. The mobile Fe^{2+} moves to better aerated sites where it becomes oxidized to form lepidocrocite. The presence of lepidocrocite in the soil was assessed by Blume and Schwertmann (1969) by use of Feo/Fed ratio. A ratio of 0.2 or less is indicative of the formation of lepidocrocite. In these soils, Feo/Fed ratio for most fine-earth fraction was less than 0.2, showing the formation of lepidocrocite. The higher Feo/Fed ratios observed in profiles NFP/P1, NFP/P2, NFP/P3 and NFP/P4 suggest rapid redox process in these horizons of the four soils.

The high Si level in the soil favours the formation of ferrihydrite from lepidocrocites under waterlogged condition. Carlson et al. (1980) observed that such a range of Si concentration is quite common in natural waters. Kodama and Schnitzer (1977) remarked that lepidocrocite would normally be the weathering end product under alternate reduction and oxidation conditions. The presence of lepidocrocite suggests changes in the redox conditions, such as could be associated with seasonal flooding.

The lower Fed/clay ratio in almost all the Ap horizons of the soil profiles except in profile NFP/P5, was speculated to be the result of long periods of waterlogging of these soils, dissolution of Fe oxides and their eventual removal from the soil. Blume and Schwertmann (1969) reported that with a long annual wet period, as is the case in the study area, Fed/clay ratio minimum occurred in the topsoil. They attributed this process to lateral removal of Fe in solution. Again the significant positive correlation coefficients (r=0.84; 0.80) between clay, Fet and Fed, respectively further suggested the close relationship between crystalline Fe and clay. Also the higher Fed/Fet ratio was an indication that the soils and the parent materials were highly weathered irrespective of the time of present sediment deposition. In these soils the sediments and the parent materials, though recent in deposition would have undergone intensive weathering from the upland, which would explain the occurrence of advanced

weathering products such as kaolinite, crystalline Fe and Al in the soils.

The occurrence of gibbsite has been observed in many tropical soils. It is unlikely that this mineral had formed in these relatively young soils. Most probably the gibbsite had been formed in the soils of the watershed of the river Niger, subsequently eroded and carried downstream. They are collected from the inland basins where the conditions are favourable for their production thus giving rise to high levels of Al_2O_3 (Table 4). Hsu (1989) suggested that the primary Al silicate weathering to gibbsite is governed by the intensity of leaching when flooding recedes which is affected by rainfall, temperature, parent material, topography, water table, vegetation and time. Therefore, the high rainfall regime in both the studied area and the adjacent areas where the sediments are transported from might be a factor in the formation of gibbsite. In conclusion, some of the gibbsite may have been formed in the soils of the upland areas (NFP/P1 and NFP/P2) and transported to soils of lowland areas toward the river. This transportation process may have taken place in association with clay. This proposition is supported by the high correlation coefficients (r=0.84 and 0.77) between clay and Alt and Ald respectively.

The occurrence of Mn, both as total (Mnt) or dithionite/oxalate extractable forms, especially in profiles NFP/P3, NFP/P4 and NFP/P5, is attributed to the gleying process. The moisture saturation percentage was at maximum in profile NFP/P3 and that was the highest occurrence of birnessite. The moderate to high Si/Al ratio on tops and the lowest horizons of the soils show that these horizons accumulated lots of weakly to unweathered materials due to deposition on the top soil and apparent diagenesis of sediments and unconsolidated materials beneath the profile. Birkeland (1999) affirmed that decrease in Si/Al ratio in soils and clay minerals indicated weathering in a leaching environment and that values close to 2 or less show complete alteration of the original rock.

Clay mineral formation

Kaolinite, being the dominant clay mineral, may have been neoformed in the soils or inherited from transported sediments parent material. Feldspars are relatively abundant in the fine-earth fractions and transform directly to kaolinite and gibbsite (Eswaran and Bin, 1978). Another possible genesis of the kaolinite in these soils was through the resilication of gibbsite in which Si is known to accumulate and recombine

with Al resulting in the formation of kaolinite. Kittrick (1970) remarked that this process is further aggravated under percolating ground water. The fluctuating water table and the seasonal flooding were postulated to intensify the recombination process of Si and Al, which were high in the soil, to form kaolinite.

Smectite, which is more abundant in the profiles towards the river, may have been transported. Some earlier researchers (Jungerius and Levelt, 1964; Dixon, 1989) noted that under conditions similar to the studied soils, smectite was a significant component of soils transported from areas with warmer and drier climates. However, Borchardt (1989) remarked that poorly drained soil conditions, such as the soils studied, often support the formation and preservation of smectite. Therefore, it is possible that some smectite in the soils closer to the river (NFP/P3, NFP/P4 and NFP/P5) were formed within the soils in addition to those transported. This does not rule out the possibility of neoformation of smectite in the other soil profiles. Again, the relatively high Si/Al ratio in BCg and Cg horizons of profiles NFP/P1 and NFP/P2 respectively, (Table 6), support the theory of neoformation of smectite in soil solution given adequate supply of Mg^{2+}, Ca^{2+}, Fe^{3+}, and Na^+. These soils are low in illite. This is because illite, as a weathering product of micas, disintegrated under strong weathering condition to form vermiculites and smectites (Ojanuga, 1973; Fanning et al., 1989). The relative abundance of feldspar in the fine-earth may have been the source of the vermiculites.

CONCLUSION

The soils are deep, acid, low in bases and organic carbon. The low cation contents are a reflection of the nature of the parent materials, which were also low in these elements. High rainfall and the flooding incidence, resulting in reducing conditions, may have contributed in the low availability of the nutrients. Gleying process and mottling with Fe/Mn concretions, observed in the soils, are the effect of fluctuating water table. The movement of Fe and Al oxides in solution and eventual oxidation-reduction process were thought to be one of the causes of the gleying processes in the soil.

The dominant clay mineral is kaolinite. High levels of feldspar may have contributed to high Al oxide and kaolinite because these two minerals were direct transformation products of feldspar. While some kaolinite may be neoformed in the floodplain, some of this clay mineral have been also transported. The smectites detected may

have formed in-situ in addition to those that were transported in the parent materials from drier areas. Also the low values of illite are explained from the point of view of their rapid disintegration to form vermiculites and smectites. In conclusion, the annual flooding, high water table of these soils and the near level landscape in the floodplain may have combined to influence the weathering and subsequent soil formation processes of the floodplain.

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REFERENCES

Birkeland, P.W. (1999). Soils and geomorphology. 3rd edition. Oxford University Press, NY, 430 pp.

Blake, G.R. and Hartge, K.H. (1986). Bulk density In A. Klute (Ed), Methods of soil analysis Part 1, American Society of Agronomy, Madison, WI pp. 363-382.

Blume, H. P. and Schwertmann, U. (1969). Genetic evaluation of profile distribution of aluminum, iron and manganese oxides. Soil Sci Soc. Amer. Proc. 33: 438-444.

Borchardt, G. (1989). Smectite. In Dixon, J.B. and S.W. Weed (eds.) Minerals in soil environments, Soil Sci. Soc. Amer, Madison, WI pp. 675-728.

Bray, R.H. and Kurtz, L.T. (1945). Determination of total, organic and available forms of phosphorus in soils. Soil Sci. 59: 39-45.

Bremner, J.M. (1965). Total nitrogen. In C.A. Black (Ed), Methods of soil analysis Part II. Amer. Soc. Agron. 9, Madison, WI pp. 1149-1178.

Brinkman, R. (1977). Surface-water gley soils in Bangladesh: Genesis. Geoderma, 17: 111-144

Bui, E.N. and Wilding, L.P. (1988). Pedogenesis and mineralogy of a Halaquept in Niger (West Africa). Geoderma, 43: 49-64.

Buri, M.M., Masunaga, T. and Wakatsuki, T. (2000). Sulfur and zinc levels as limiting factors to rice production in West Africa lowlands. Geoderma 94: 23-42.

Carlson, L., Vuorinen, A., Lahermo, P. and Touvinen O.H. (1980). Mineralogical, geochemical and microbiological aspects of iron deposition from ground water. Environ. Bio-geochem. Int. Symp., Canberra.

Dixon, J.B. (1989). Kaolin and serpentine group minerals. In: Dixon, J.B., Weed, S. B. (Eds),Minerals in soil environments. Soil Sci. Soc. Amer., Madison, WI pp. 467-525.

Ducloux, J., Guero, Y. and Fallavier, P. (1998). Clay particle differentiation in alluvial soils of southwestern Niger (West Africa). Soil Sci. Soc. Amer. J. 62: 212-222.

Eswaran, H. and Bin. W.C. (1978). A study of a deep weathering profile on granite in peninsular Malaysia: 3. Alteration of feldspars. Soil Sci. Soc. Amer. J. 42: 154-158.

Fanning, D.S., Keramidas, V.Z., and El-Desoky, M.A. (1989). Micas. In: Dixon, J.B. and Weed, S.B. (Eds), Minerals in soil environments. Soil Sci. Soc. Amer., Madison, WI pp 551-634.

FAO, (1977). Guidelines for soil profile descriptions (2nd edn.), Rome, 66 pp.

FAO, (1988). Soil map of the world revised legend. World soil resources report 60, Rome, 119 pp.

Gee, G.W. and Bauder, J.W. (1986). Particle-size analysis.In Klute, A. (Ed), Methods of soil analysis, Part 1, Amer. Soc Agron 9; Madison, WI pp 91-100.

Harris, W.G., Iyengar, S.S., Zelazny, L.W., Parker, J.C., Lietzke, D.A. and Edmonds W.J. (1980). Mineralogy of a chronosequence formed in New River alluvium. Soil Sc. Soc. Amer. Journ. 44: 862-868.

Hsu, P.H., (1989). Aluminum oxides and oxyhydroxides. In: Dixon, J.B. and Weed, S.B. (eds), Minerals in soil environments. Soil Sci. Soc.Amer., Madison, WI pp 331-378.

Igwe, C.A., Akamigbo, F.O.R. and Mbagwu, J.S.C. (1995). Physical properties of soils of southeastern Nigeria and the role of some aggregating agents in their stability. Soil Sci. 160: 431-441.

Jungerius, P.D. (1964). The soils of eastern Nigeria. Pub. Serv. Geolog. de Luxemburge 14: 185-196.

Jungerius, P.D. and Levelt, T.W.M.1(964). Clay mineralogy of soils over sedimentary rocks in eastern Nigeria. Soil Sci., 97: 89-95.

Kittrick, J.A. (1970). Precipitation of kaolinite at 25°C and 1 atm. Clays & Clay Miner.18; 261-267.

Kodama, H. and Schnitzer, M. (1977). Effect of fulvic acid on the crystallization of Fe(III) oxides. Geoderma, 19: 279-291.

Mackenzie, R.C. (1972). Soils. In R.C. Mackenzie (ed). Differential thermal analysis. Vol. 2 Academic Press Ltd., New York pp 267-297.

McKeague, J.A. and Day, J.H. (1966). Dithionite and oxalate Fe and Al as aids in differentiating various classes of soils. Canadian J. Soil Sci., 46: 13-22.

Mehra, O.P. and Jackson, M.L. (1960). Iron oxide removal from soils and clays by a dithionite-citrate system buffered with sodium bicarbonate. Clay Miner. 7: 317-327.

Monanu, P.C. (1975) Rainfall In G.E.K. Ofomata (ed), Nigeria in maps, Eastern States. Ethiope Publishers, Benin-City, Nigeria. Pp 25-26

Narteh, L.T. and Sahrawat, K.L. (1999). Influence of flooding on electrochemical and chemical properties of West African soils. Geoderma 87: 179-207.

Obi, M.E. and Akamigbo, F.O.R. (1981). Water relations of the soils of the Niger-Anambra floodplains of southeastern Nigeria. Catena, 8: 285-298.

Ojanuga, G.E. (1973). Weathering of biotite in soils of humid tropical climate. Soil Sci. Soc. Amer. Proc. 37: 644-646.

Orajaka, S.O. (1975). Geology. In G.E.K. Ofomata (ed), Nigeria in maps, Eastern States. Ethiope Publishers, Benin-City, Nigeria pp 5-7.

Richards, L.A. (1954). Diagnosis and improvement of saline and alkali soils. USDA Handbook, No.60.

Schwertmann, U. and Kämpf, N. (1983). Oxidos de ferro jovens em ambientes pedogeneticos brasileiros. Rev. Bras Cienc. Solo 7: 251-255.

Sommer, M. and Schlichting, E. (1997). Archetypes of catenas in respect to matter- a concept for structuring and grouping catenas. Geoderma 76: 1-33.

Sommer, M. and Stahr, K. (1996). The use of element:clay ratios assessing gains and losses of iron, manganese and phosphorus in soils of sedimentary rocks on a landscape scale. Geoderma 71: 173-200.

Soil Survey Staff. (1996). Keys to soil taxonomy. 7th Edition. US. Dept. of Agric., Washington DC.

Thomas, G.W. (1982). Exchangeable cations. In: A.L. Page (ed), Methods of soil analysis, Amer. Soc. Agron. Madison, WI Part 2 pp. 159-165.