CHARACTERIZATION OF SOILS IN VARIOUS GEOMORPHIC UNITS OF THE BAKOLORI AREA IN SOKOTO STATE, NIGERIA

BY

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APRIL, 1987

DECLARATION

I hereby declare that this thesis has been composed by myself and that it is a record of my own research work. It has not been accepted in any previous application for a higher degree. All quotations are distinguished by quotation marks and the sources of information are specifically acknowledged by means of reference.

ODUNZE, A. C.

APRIL 1987

CERTIFICATION

This project report/thesis entitled Characterization of Soils in Various Geomorphic Units of the Bakolori Area in Sokoto State, Nigeria, by ODUNZE, AZUBUIKE CHIDOWE meets the regulations governing the award of the degree of Master of Science (M.Sc.) degree in Soil Science of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

Soils of five major geomorphic units recognized by Sombroek and Zonneveld (1971) in the Bakolori area of Sokoto State were studied with a view to finding out if geomorphic units can actually be translated directly into soil mapping units in the area. In pursuance of this objective, the morphological, physical, chemical and mineralogical characteristics of the soils were studied. The soils were also classified according to the U.S.D.A. Soil Taxonomy (Soil Survey Staff, 1975) and the FAO-UNESCO soil legend (1974).

The studies show that soils of the Bakolori area have formed in a climatic environment presently characterized by an annual rainfall of less than 1000mm and a mean annual air temperature of 28^{0}C. They occur under a dominantly grassland vegetation. Soil parent materials consist mainly of layers of aeolian and colluvial materials over old alluvium in the upland areas and mainly of recent alluvium and colluvium in the valley bottoms and levees of the Sokoto river.

The soils of the upland areas exhibit unstable, and weak structural development in the surface horizons and are susceptible to severe wind and water erosion. Soils of the crestal positions do not show any horizon development. However, those of the upper to lower slopes and terrace-plateau positions have weakly to strongly developed argillic

horizons. Soils of the levee areas are juvenile fluviatile deposits, showing distinct stratification of soil materials separated by fine bands of clay and organic matter.

Soil texture in upland areas varies from loamy sand to sandy loam over sandy loam to sandy clay loam, but in the levee areas, soil texture varies from sandy loam to loam over sandy loam, loamy sand, silt loam and even sand in the subsoil horizons. Soils of the backswamp and flood catchment areas have textures varying from sandy clay loam to clay over sandy clay loam, clay loam and clay.

Low to very low values of organic carbon, exchangeable cations and cation exchange capacity were recorded in the upland soils. Available phosphorus was generally low in the soils and soil pH indicates a strongly acid to slightly acid reaction in the upland soil units. Soils of the valley bottoms are slightly acid to neutral in reaction and have higher fertility status than their associated upland soil units.

Quartz and K-feldspars dominate the mineralogy of the sand fraction of soils of the entire area. Zircon, augite, ilmenite, magnetite, garnet, hornblende, rutile and tourmaline occurred as trace minerals in the sand fractions. However, among the soils of upland units biotite and hornblende and the above accessory minerals occurred in the sand fractions of Taleta loamy to clay main terrace unit. Also, soils of Kurukuru-Gande micaceous and Diggi Park units contain biotite and

and hornblende in addition to garnet, tourmaline, ilmenite, rutile, zircon and magnetite. Quartz, microcline, plagioclase and anorthite dominate the mineralogy of the silt fractions of soils of all the geomorphic units studied. All the soils of the area are kaolinitic, and illite is the only 2:1 lattice layer silicate clay common in all the soils. Also, smectite clays occurred in soils of the Diggi Park units located in the valley bottoms. Prominent pedogenic processes occurring in these soils include eluviation-illuviation of silicate clays and iron oxyhydroxides, kaolinization, illitization and mineral transformation processes, especially of illite into smectite in the Diggi Park and Kurukuru-Gande micaceous units.

According to the U.S.D.A. Soil Taxonomy, the soils of the Sangiwa cover sand on crestal positions are classified at the subgroup level as Typic Usterthent. Soils of Sangiwa cover sand on the upper slopes and Tureta sandy wash plain on mid and lower slope areas are classified as Oxic Paleustalf . while soils of the Telata loamy to clay main terrace unit are classified as Ultic Paleustalf. Soils of the Kurukuru-Gande micaceous unit are classified as Typic Ustifluvent while the backswamp phase of the Diggi Park unit is classified as Vertic Fluvaquent or Tropic Fluvaquent, and flood catchment phase of Diggi Park as Aeric Tropic Fluvequent. In the FAO-UNESCO soil legend, the soils of Sangiwa cover sand unit

on crestal areas are classified as Regosols. However, soils of Sangiwa cover sand on the upper slopes, Tureta sandy wash plain on both mid and lower slopes and Talata loamy to clay main terrace units are classified as Nitosols. The levee soils are classified as Fluvisols and the soils of the Diggi Park unit are classified as Gleysols.

DEDICATION

To Professor O. C. Onazi, formerly, Director, Division of Agricultural Colleges, Ahmadu Bello University, Zaria, currently Vice-Chancellor, University of Jos, Jos.

and

To ODUNZE's family; Ivy and Favour, for their various acts of friendliness, encouragements, assistence, insistence on high standards and dedication to academic excellence.

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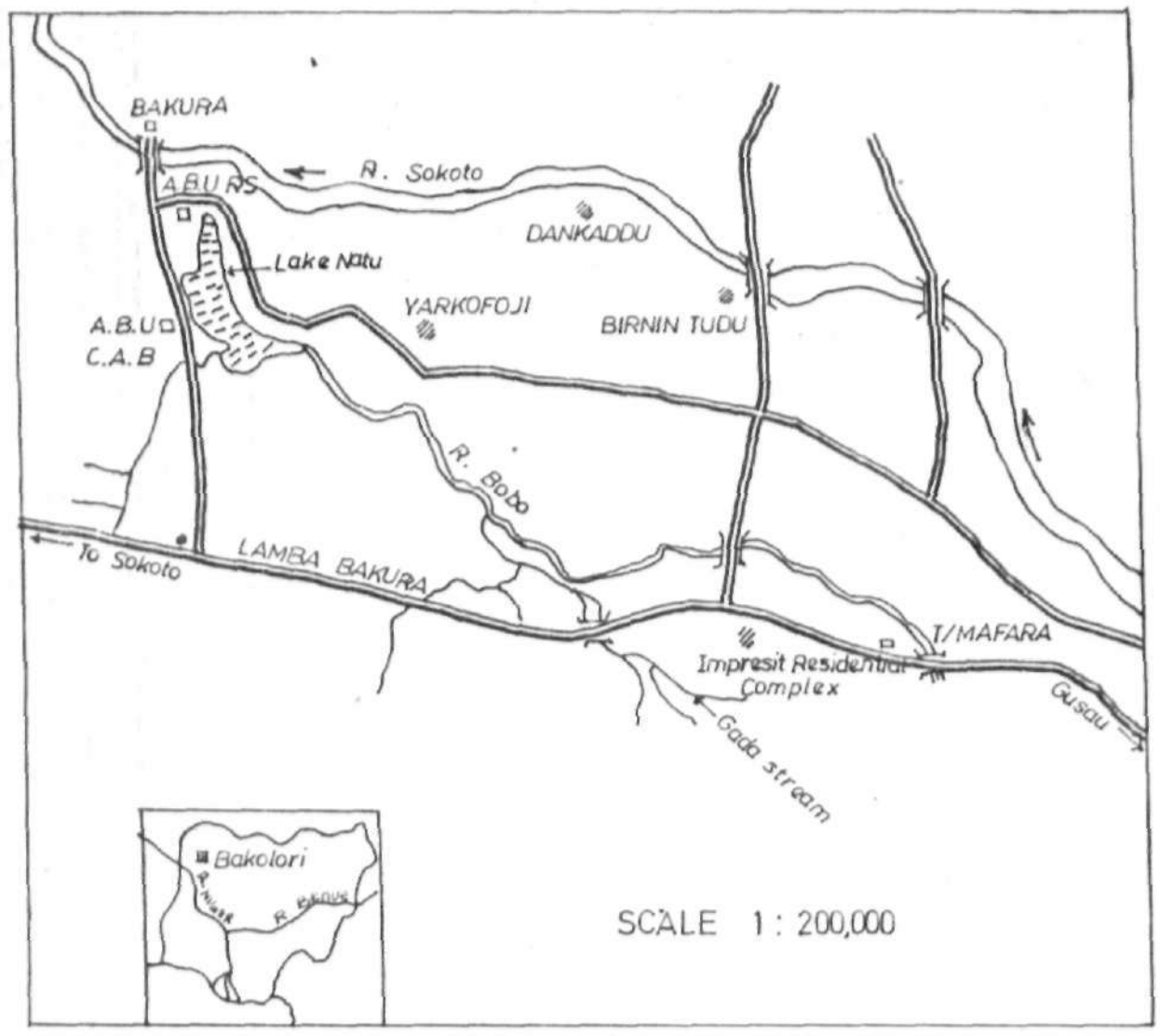
1. INTRODUCTION

Dakolori is an area lying between latitudes $12^{0}30^{'}$ and $13^{0}00^{'}$ North, and longitude $5^{0}30^{'}$ and $7^{0}00^{'}$ East, within Sokoto State, Nigeria. Major towns and villages within the area include Talata-Mafara, Birnin-Tudu, Lamba-Dakura and Dakura (Fig. 1).

Sokoto river and its major tributaries like the Dobo river, which drains the area has attracted the development of large scale irrigated agricultural projects and a few experimental farms in the area. Consequently, there is an increased pressure on land in the Dakolori area for agricultural, urban and forestry uses. It has, therefore, become essential to study the soils within the area more intensively, so as to ensure sound planning and decision making regarding the appropriate allocation of land for different purposes. The result of this study will hopefully provide information for future feasibility and design studies, for instance, engineering works related to irrigation development planning and expansion schemes in the area.

A team of FAO staff (1969) carried out a soil and water resource survey of the Sokoto valley which include Dakolori area. That soil study was mainly a reconnaissance level soil survey at a scale of 1:500,000. It led to the

FIG. 1 LOCATION MAP OF BAKOLORI STUDY AREA



conclusion that Bakolori area consists of two main types of soils namely:

i) "Older aqueous sandy to loamy deposits, and

ii) Younger aqueous micaceous very fine sands to loamy deposits".

Even more recent soil studies of the area (Impresit, 1974) do not appear to have gone beyond this level of generalization regarding the characteristics of the soils. However, Sombroek and Zonneveld (1971) in a geomorphological study of the ancient dune fields and fluviatile deposits in the Rima-Sokoto river basin of North-Western Nigeria, identified a number of geomorphic units within the basin. The present study touches on five of these geomorphic units. It is expected that the geomorphic units will be of help when a more detailed soil survey of the area shall be carried out. It is, therefore, among the purpose of this study, to find out if these geomorphic units can be used for grouping the soils together at various taxonomic levels, and also to find out if there is any significant difference in the mineralogy of the soils from the various geomorphic units. Or, to spell it out in details, the purpose of the present study is as follows:

a) To examine the morphological, physical, chemical, and mineralogical characteristics of soils

occurring within the five major geomorphic units mapped in the Bakolori area.

b) To find out if there is a relationship between the geomorphic units and soils they cover, and also if the geomorphic units already mapped by Sombroek and Zonneveld (1971) may aid in the future detailed mapping of soils of the Bakolori area.

c) To carry out a taxonomic classification of the soils according to the U.S.D.A. Soil Taxonomy (Soil Survey Staff, 1975) and the F.A.O./UNESCO Soil Legend (1974).

Chapter 2

LITERATURE REVIEW

2.1 Pedology and Geomorphology

Pedology can be defined as the science which considers the soil as a natural body and places minor emphasis on its immediate practical utilization. It studies, examines and classifies soils as they occur in their natural environment (Brady, 1974). Geomorphology on the other hand deals with the arrangement and differentiation of landforms and the processes that have been or are shaping them. The difference between pedology and geomorphology is rather blurred and, in many cases, highly artificial (Gerrard, 1981). However, pedology is concerned with the processes involved in soil formation, while geomorphology deals with the arrangement and differentiation of landforms and the processes that have been or are shaping them.

Ojanuga *et al*. (1976), in a study of the soils and stratigraphy of mid to lower slopes in the south western upland of Nigeria, stated that the most recent pedimentation of slopes and hence, the deposition of the youngest soil parent materials, is believed to have occurred about 2360 ± 120 years before the present; in confirmation to the claims of Daniels *et al*. (1971) that geomorphology involves the interpretation of landforms as records of

geologic history. However, Stiegeler (1976) referred to geomorphology as the study of evolution of landforms, excluding the major forms of the earth surface, such as mountain chains and ocean basins, but including the study of the relationships between structures and landforms. Geomorphology includes the inductive and deductive study of existing landforms from which the processes of their evoluation are inferred, as well as the measurements of actual processes operating and the inference of their ultimate influence on the landscapes on which they are acting.

Lepsch et al. (1977) noted that soil properties that are expressions of weathering indices are related to geomorphic surfaces. Also geomorphological and pedological processes interact on hill slopes, especially where the movement of soil and water is considered (Gerrard, 1981). Substantiating this assertion, Ojanuga et al. (1976) noted that pedogenic and geomorphologic studies along the mid to lower slopes of typical landforms in south western Nigeria revealed simple to complex stratification of pedisediments derived through cyclic erosional and depositional phenomena that evolved the inselberg landscape in the region. Hence, contemporary soils owe many of their major properties to depositional processes. According to Daniels et al. (1971), geomorphic surfaces may be depositional or erosional or both. It may be a level plain, a straight slope, or may have

a multicurvate or undulating configuration.

From the foregoing, it may be concluded that pedology is the science that studies the soils whose upper boundaries are the earth's surface and is concerned with the processes involved in soil formation, while geomorphology is the science that studies the evolution of landforms and their interpretation as records of geologic history; excluding the major forms of the earth surface, such as mountain chains and ocean basins.

2.2 Studies on Padogenesis-Geomorphic Relationships

Soil formation is the result of the interaction of various geomorphological and pedological processes. Geomorphological process may create destructive landforms, such as erosion surfaces, which have a great influence on soil types and distribution (Gerrard, 1981).

Daniels *et al.* (1971) while studying the relationship between geomorphology and soil morphology and genesis in north Carolina and Maryland, U.S.A., observed that geomorphologists and pedologists have an overlapping interest in the same object. Geomorphologists study the origin of the shape of the surface of the earth, the origin of the material, past climates, watertable regimes, outside additions such as dust and cyclic salts are also part of the geomorphic record. On the other hand, pedologists study soils in the

field and laboratory to understand how their characteristics came to be and also determine the importance of the characteristics - whether they are durable or transient. If the pedologist knows the history of the landscape in which his object, the soil occurs, he is in a better position to interprete and decipher many things that might seem either too easily obvious or strange and anomalous.

Geiger and Nettleton (1979) studied the properties and geomorphic relationships of some soils of Liberia, and noted that the properties of soils are related to their position in the landscape. Also, conclusions about soil genesis based on conventional analysis and conventional consideration of present soil-forming factors usually are improved when geomorphic and stratigraphic information are added (Daniels et al. 1971).

Lepsch et al. (1977) in a soil-landscape relation study in the occidental plateau of São Paulo, Brazil, agreed that there is a general relationship between geomorphic surfaces and soils. Differences in parent material can be related to geomorphic history of the site. Thus, the geomorphic work was found to be of great help in improving the conclusions about soil morphology and genesis. Also, an understanding of geomorphic relationships should prove useful in the operations of further detailed surveys in similar areas. Accordingly, Daniels et al. (1971) observed that the knowledge

about the history of a site, its relation to the surrounding landscape and especially the duration of its existence and exposure to various environments help to clarify our understanding of the soil.

Gerrard (1901), citing Tricart and Cailleux (1972), stated that the most important law of pedologic geomorphology is that chemical erosion is approximately proportional to the intensity of the soil-forming processes and that the normal evolution of soil is all the more advanced as one chemical erosion is restricted. Many soil forming processes are also geomorphological processes and the distinction between geomorphology and pedology was being blurred at the edges of the disciplines. However, pedology and geomorphology are vitally important in an interpretative sense, in association with other disciplines in deciphering the phases of development within the quaternary period (Gerrard, 1901). Consequently, Coleman and Fenton (1982) in a study of the stratigraphy and water table relationship of upland loess-derived soils in south central Iowa, stated that the depth to burried geomorphic surface and/or thickness on the flat and sloping areas decreases systematically with distance from the major area. As the depth to the buried geomorphic surface and loess thickness decreased and distance from the source area increased, the internal natural drainage of the more extensive soil become poorer and the depth to the water table increased.

From the above review, it can be seen that there is a close inter-relationship between the geomorphology of an area, and the morphology, composition, and development of the soils in that area. This means that the pedologist, by paying close attention to the geomorphology of an area, would be able to make more meaningful contributions about the the soils in that area. However, the review also indicates that a lot has still to be done before the full potential of a coordination of information from these two disciplines can be exploited effectively.

2.3 Use of Geomorphology in Soil Survey

Geomorphological maps provide information about the location of features formed by fluvial, glacial, fluvioglacial, volcanic, colluvial, tectonic, erosional and aeolian processes. It may also be possible to show the nature of the materials (Gerrard, 1981).

In soil surveys, soil scientists dig many holes in the landscape to make the delineations, and study soil colour, texture, structure, porosity, consistence, pH, organic matter, kinds of clay, and other profile characteristics. They combine these observations with their knowledge of geomorphology, topography, vegetation, land use and other landscape attributes to map different soil areas (Olson, 1981). Ranges in soil characteristics are also described for each soil map unit so that the variations from the "modal"

soil within each landscape unit can be isolated and identified. If large spots within a map unit are significantly different from the defined soil, those spots must be identified and mapped as separate soils if the differences are great enough to affect use and management of the area (Olson, 1981).

Geomorphological maps have been used extensively in various landuse and land management schemes. In Venezuela, geomorphological map was used to define areas of limited values for agriculture, thus, saving time and money on more detailed surveying (Gerrard, 1981).

It is apparent from the above review that while soil profile descriptions are of much interest to the soil surveyor, the nature of soil parent materials; i.e. fluvial, glacial, fluvio-glacial and aeolian, that affect soil characteristics and influences stability of the soils during erosion and landslides is of interest to the geomorphologist. Geomorphology, therefore, acts as a service arm to soil survey; providing information on the arrangement and differentiation of landforms and the processes that have been or are shaping them. Also geomorphological maps may be useful in reducing soil survey time and costs, by indicating the origin of the parent materials, and factors shaping the landscape under study.

Chapter 3

PHYSICAL SETTING OF STUDY AREA

3.1 Location and Extent

The Bakolori is bordered by Lamba-Bakura in the north Bakura town onthe north-east, Talata-Mafara in the south and by Birnin-Tudu in the south-east. The study area covers about 52,850 hectares, stretching a distance of 20km from Talata-Mafara town to Lamba-Bakura, along Zaria-Sokoto road; and about 15km towards Birnin-Tudu town. On the north-east and south-east borders is the Sokoto river; the main river draining the area (Fig. 1).

Details of the extent (ha.) and percentage composition of each of the geomorphic units covered in this study are shown in Table 1.

3.2 Geology and Geomorphology

The landscape of Bakolori area was mainly formed by weathering and erosion during the early Pleistocene epoch (Table 2). The study area is underlain by sedimentary rocks which in the terrace area are covered by clay grits, clays, sandstones, and pebble beds with coarse conglometrates at the base (Gundumi Formation). In the flood plain area, the sedimentary rocks are covered by alluvial deposits composed of gravel, sand, silt and clay layers (FAO, 1969, Kogbe, 1972).

Table 1: Extent and percentage composition of total area of selected geomorphic units studied in the area

Geomorphic Units	Extent (ha.)	% Composition
Sangiwa cover sand	17650.0	33.41
Tureta sandy "wash plain"	7900.0	14.94
Talata loamy-clay main terrace	17600.0	33.30
Kurukuru-Gande Micaceous	6100.0	11.54
Diggi Park	3600.0	6.81
	52850.0	100.00

The following five major geomorphic deposits were among others identified in this area by Sombroek and Zonneveld (1971).

i) Sangiwa cover sand deposits
ii) Tureta sandy "wash plain" deposits
iii) Talata loamy to clay main terrace deposit
iv) Diggi Park deposits
v) Kurukuru and Gande micaceous deposit

Aeolic sedimentation of poorly sorted sands in transversal dunes deposited in the early Pleistocene epoch (Table 2), resulted in one major deposit - the "Sangiwa cover sand". The Sangiwa cover sand is mainly fine sands, and must have been transported by saltation due to the influence of the east-north-east winds. The aeolic deposit was later led in

Table 2: Geologic and Geomorphic Time-scale of study Area (after Sombroek and Zonneveld, 1971).

	Rima-Sokoto Deposit (Bakolori Area)	Estimated age B.P.	European Equivalence	Era or Period
1.	Gande micaceous young levees and splays	0-1000	Sub-atlanticum	Holocene
2.	Kurukuru-micaceous terrace-like deposits	1000-1000	Sub-atlanticum	
3.	Kurukuru-micaceous old levees and splays	3200-4500	Sub-boreal	
4.	Diggi Park deposit	11,600	Weichselian	Pleistocene
5.	Rabah-Talata-Kaura main terrace	15,000		
6.	Tureta sandy "wash plain"	40,000		
7.	Sangiwa Cover sands	100,000	Eemien	

a climate with irregular rainfall; giving rise to a kind of planation process (sheet floods). This resulted in the development of the Tureta sandy "wash plain" and Talata loamy to clay main terrace deposits. The Tureta sandy "wash plain" deposits occur at a relatively higher plain above the present day rivers. They have been accumulated mainly by sheet erosion and accumulation. Talata loamy to clay main terrace is located on an intermediate level, and is formed on a flood plain at a time when the river water

level was high. Recent aqueous deposits of the study area are Diggi Park, and Kurukuru-Gande Micaceous deposits. The Diggi Park fluvial deposits were formed during a period with distinct wet season, during which the river meandered. Kurukuru-Gande micaceous deposits are also fluviatile and were formed from a sub-recent to recent meandering river system.

3.3 Relief, Drainage and Soils

The relief of the whole of the Bakolori area is virtually flat, although from the ground level, scattered low table lands or very gently rising high lands occur. The altitude of the area varies from about 250m near the bank of the Sokoto river to about 600m in the south-eastwards direction (Sombroek and Zonneveld, 1971).

Two major river bodies drain the Bakolori area. They are the Sokoto river and the Bobo river, the Sokoto river borders the north-east of the Bakolori area. It serves as the major natural drain of the area, and floods from the high lands empty into it. Sokoto river also serves to drain used and excess water from the Bakolori irrigation project, which is within the study area. The Bobo river drains mainly the higher land area. It flows along the old valleys and lowland areas of the study landscape.

In general, three main types of deposits have been

recognized in the Bakolori area; namely the aeolian deposits, the older aqueous deposits, and the younger aqueous deposits (FAO, 1969; Impresit, 1974). The aeolian and older aqueous deposits are mainly of sandy to loamy textures and are deep and well drained. Many of these upland soils have a tendency to become sealed superficially or capped, resulting in a high run-off coefficient, as well as sheet and wind erosion (Sombroek and Zonneveld, 1971). The younger aqueous deposits occur within the meandering river systems and consist of micaceous very fine sands to loam. In the backswamp areas of the meandering rivers, the soils are deep and poorly drained with clay, silt clay and clay loam textures (Impresit, 1974).

3.4 Climate

Data related to rainfall, temperature, wind speed, evapotranspiration, sunshine hours were collected from the Irrigation Research Station of the Ahmadu Bello University, Bakura. This data are summarized in Table 3 and covers 1982, 1983, 1984 and 1985. The mean monthly rainfall, evapotranspiration and air temperature for the area are also presented in Fig. 2.

The present day climate of the Bakolori area is hot and semi-arid. The dry season is very pronounced and lasts from October to May, while the wet season is often torrential and of short duration. In the area, there are two dominant air masses, the northerly dry harmattan winds which come from the

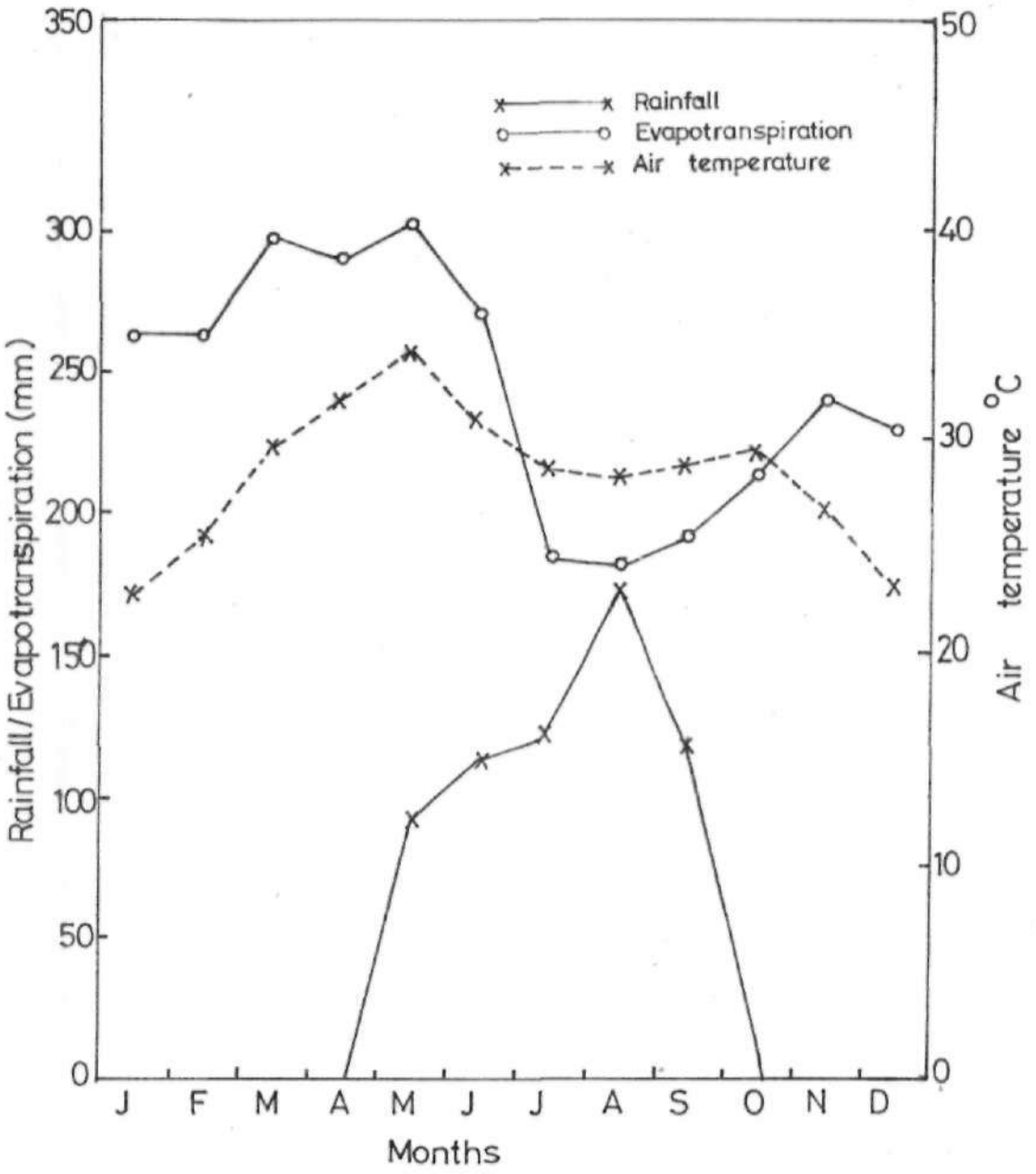


FIG 2. MEAN MONTHLY RAINFALL EVAPOTRANSPIRATION AND AIR TEMPERATURE FOR 1982-85 IN BAKOLORI AREA.

Table 3: Climatological data of the Oakolori area - 1982-1985

Year/Month	Sun-shine (hrs)	Wind speed (km)	Evapotrans-piration (mm)	Air Temp. ^{o}C	Rain-fall (mm)	% Annual Rainfall
1982						
January	8.21	134.62	247.3	24.0	-	-
February	5.90	148.81	238.2	25.7	-	-
March	5.22	134.55	333.1	30.5	-	-
April	6.10	148.14	297.6	33.95	0.2	0.0
May	6.17	161.79	295.4	33.65	59.9	9.2
June	6.50	168.29	305.7	29.95	72.4	11.1
July	6.70	94.29	150.7	27.60	134.1	20.5
August	10.34	90.60	178.1	27.60	264.8	37.8
September	12.60	101.90	168.6	27.80	104.1	15.9
October	6.80	81.90	174.5	29.70	33.9	5.2
November	6.70	106.80	218.7	24.85	-	-
December	7.00	122.90	229.0	23.75	-	-
Total	88.24	1502.59	2836.9	339.05	653.4	
Mean/an	7.4	125.3	236.4	28.25		
1983						
January	4.4	287.1	270.8	19.05	-	-
February	7.1	166.6	241.2	26.76	-	-
March	6.8	179.0	348.4	28.40	0.4	-
April	5.7	102.9	310.3	32.80	-	-
May	7.1	164.0	302.0	34.90	31.4	6.6
June	6.4	149.0	263.5	30.50	105.3	22.1
July	6.2	150.2	241.0	28.10	142.6	30.0
August	6.4	120.6	176.0	26.95	116.3	24.4
September	5.7	94.11	190.3	27.70	79.9	16.8
October	6.9	92.47	259.8	28.10	-	-
November	7.9	81.27	239.3	26.50	-	-
December	6.6	97.67	233.1	23.80	-	-
Total	77.2	1684.92	3083.7	333.56	475.9	
Mean/an.	6.43	140.41	257.0	27.79		

Table 3 (Contd.)

Year/Month	Sun-shine (hrs)	Wind speed (km)	Evapotrans-piration (mm)	Air Temp. ^{o}C	Rain-fall (mm)	% Annual Rainfall
1984						
January	4.7	155.0	260.0	21.8	-	-
February	6.5	149.9	275.5	26.0	-	-
March	6.5	108.0	229.2	31.1	-	-
April	7.7	120.4	260.8	33.0	-	-
May	6.2	172.5	287.4	31.5	57.5	14.3
June	8.7	148.8	244.1	29.0	140.7	35.1
July	5.0	128.8	222.3	30.5	51.9	12.9
August	7.0	108.6	167.9	29.8	56.4	14.1
September	5.4	120.3	186.1	29.9	84.3	21.0
October	5.5	100.8	204.6	30.0	10.5	2.6
November	7.1	93.6	272.8	27.8	-	-
December	4.7	157.7	204.6	22.6	-	-
Total	75.0	1514.4	2815.3	353.0	401.3	
Mean/an.	6.25	126.2	234.6	29.42		
1985						
January	12.9	130.9	275.9	25.2	-	-
February	4.8	197.8	299.6	24.1	-	-
March	3.2	177.6	282.1	28.1	-	-
April	4.2	110.5	288.0	27.4	-	-
May	5.1	179.0	322.4	36.3	208.0	22.0
June	5.1	195.0	267.0	33.9	124.0	13.1
July	6.6	142.4	120.3	27.0	155.6	16.4
August	6.0	84.0	197.1	28.0	267.0	20.2
September	6.0	67.4	162.0	26.5	192.0	20.3
October	7.0	64.3	214.0	30.0	-	-
November	8.0	78.5	223.0	27.0	-	-
December	5.0	149.2	237.0	22.5	-	-
Total	73.9	1569.6	2888.4	336.9	946.6	-
Mean/an.	6.16	130.8	240.7	28.1		

(Source: Irrigation Research Station, A.B.U., Bakura, 1986).

Sahara and the south westerly monsoon winds of humid oceanic air (Kendrew, 1961; Griffith, 1971).

3.4.1 Rainfall

Bakolori area has marked wet and dry seasons. The rainy season normally begins in the month of May and ends in the month of September. Although mean annual rainfall fluctuates very much every year (Table 3), it can be generally said to be about 600mm (Irrigation Research Station, Ahmadu Bello University, Bakura, 1985). Yearly rainfall totals range between 400 and 946.6mm with a mean of about 607.3mm for the 1982-1985 period. The peak rainfall period is between June and August (Fig. 2). During the months of November to February, the area is subject to cool, dry north easterly winds (harmattan), which yield virtually no rain. In the months of March and April, the area becomes hot and very dry. Between the months of October and May, vegetative growth decreases drastically, such that scarcely is any vegetative cover left on the soil surface. Over this period, the soil solum dries out and pedogenetic processes are slowed down. From late May to September, the seasons change, as the moist southerly winds bring rains, vegetative activities start again, and the processes that develop the soil solum become rejuvenated. Soil moisture regime of the area is generally inferred to be aridic tropustic. Exceptions are those of the Kurukuru-Gande micaceous and Diggi Parks which have ustic

soil moisture regimes respectively.

Over the months of June, July and August, maximum amounts of rainfall are recorded. Mean rainfall over the periods June to August for 1982 to 1985 ranged from 58.8 to 76.5% of total annual rainfall. Average per cent rainfall for these months of peak rainfall is 22.13% for 1982 to 1985. Generally, mean monthly rainfall increases from 89.2mm in May, attains a peak of 171.6mm in August and decreases to 115.08mm in September (Fig. 2). This sequence agrees with that observed by Kowal and Knabe (1972) in the study area.

3.4.2 Temperature

Temperature is high in the study area, with mean annual values ranging between 270.0 and 30.0°C. Mean annual temperature for the period 1982 to 1985 averaged about 28.39°C. Air temperature usually drops during the peak rainfall months of June to August; attains a major drop during the harmattan months of December to February, and rises to a peak in the month of May, just before the rains begin (Table 4, Fig. 2). Average maximum temperature during the months of March, April and May is 34.0°C, but commonly ranges between 30.0 and 34.0°C. The soil temperature regime of the Bakolori area has been inferred to the isohyperthermic.

3.4.3 Evapotranspiration

Mean monthly values of evapotranspiration range between

a minimum of 150mm and 200mm in the months of July to September, to a maximum average of between 200 and 348.4mm between the months of September and June (Table 3). For the period 1982 to 1985, the monthly evapotranspiration in the Bakolori area is far in excess of monthly rainfall (Table 4, Fig. 2). Exceptions to this are during the months of August 1982 and in July, August and September, 1985. This means that in some years mean monthly precipitation may exceed monthly evapotranspiration, thus leaving excess soil water for plant use during the rainy season. However, total annual evapotranspiration ranges from 2815.3 to 3083.72mm with a mean of 2906.08mm. This means that despite the rainfall, cropping during the rainy season (May to September) will require supplementary irrigation, while dry season (October to April) cropping will require high to moderate irrigation frequency for most crops.

3.4.4 Radiation pattern

Generally, long sunshine hours per day/month are observed in the project area. Generally, mean annual sunshine hours range between 6.2 and 7.4 hours per day/month. A mean value for the period 1982 to 1985 of 6.56 hours/day/month of sunshine is obtained for Bakolori area (Table 3). Range of sunshine hours is between 4 and 12.9 hours/day/month in the area. This range of sunshine hours will adequately enhance viable photosynthetic activity during the cropping

season within the survey area.

3.5 Vegetation and Land Use

The survey area lies within the Sudan Savanna Zone (Keay, 1959). The vegetation is open savanna woodland on the better soils and trees and shrubs on the poorer ones.

The vegetation of the poorer soil area is greatly modified by cultivation, bush burning, tree felling for fire wood (Plate 10) and over-grazing. Nearly everywhere the trees and shrubs are leafless during the dry season (October to May). Both the poor grassy under cover of the semi-natural vegetation and the stubble of the arable fields are either grazed off by goats and cattle or are carried underground by termites (Sombroek and Zonneveld, 1971).

Most of the farming activities are carried out during the rainy season. On the better soils, especially those near the rivers, streams or flood catchment areas, arable cropping takes place. It ranges from long-fallow shifting cultivation to permanent wet-season cropping. Guinea corn, millet, groundnuts, cowpeas and cotton are the main crops commonly grown in the area. In the flood plains, and in the Bakolori irrigation areas, in addition to the crops listed above; rice, wheat and sugar-cane are also grown. During the dry season, major crops grown in the flood plains and in the Bakolori Irrigation Project area include potatoes, tomatoes,

onion, carrots, cabbages, water melon and spinnach. Upland areas are normally left fallow during the dry season.

Table 4: Mean monthly Rainfall, Evapotranspiration and air Temperature for 1982 to 1985 in Bakolori Area

Months	Rainfall (mm)	Evapotranspiration (mm)	Air Temperature ^{o}C
January	-	264	22.6
February	-	264	25.6
March	-	298	29.5
April	-	289	31.8
May	89.2	302	34.1
June	110.6	270	30.8
July	121.1	184	28.5
August	171.6	180	28.1
September	115.1	189	29.0
October	-	213	29.5
November	-	239	26.5
December	-	226	23.2
Total	607.6	2918	339.2
Mean			28.3



Plate 1 (a)

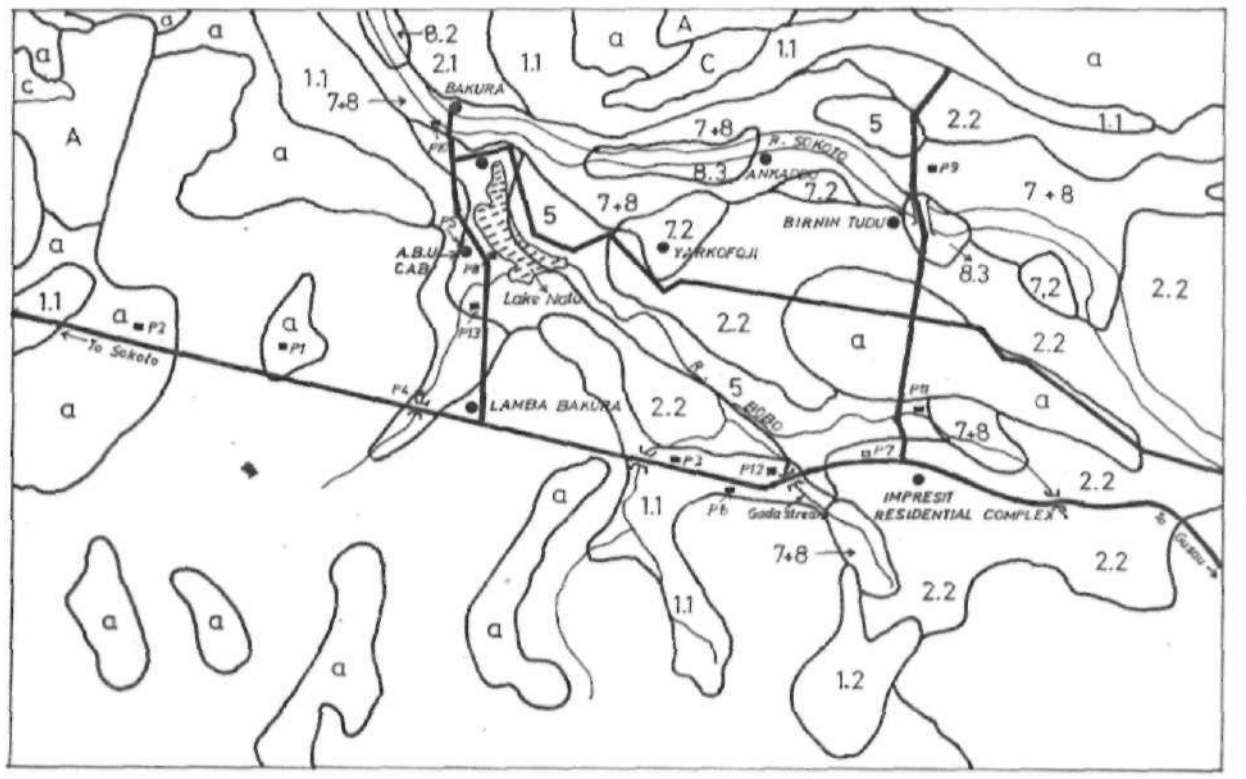
Tree felling operation and vegetation type in the Sangiwa cover sand unit



Plate 1 (b)

Surface capping typical of soils of the upland units (Tureta sandy "wash plain" unit).

FIG3. BASE MAP SHOWING MAJOR GEOMORPHIC UNITS STUDIED IN THE AREA.



SCALE 1: 200,000

LEGEND

STUDIED

- 7+8 Kurukuru and Gande micaceous fine sands, silt and clays undivided often basin lands.
- 5 Diggi Park sands loams and clays meandering river deposits.
- 2.2 Talata loamy to clayey main terrace.
- 1.1 Tureta sandy wash plain.
- a Sangiwa older cover sand.

NOT STUDIED

- A, C Thick and continuous cover sand
- C Sokoto younger cover sand
- 8.3 Gande micaceous fine sand and loams active point bars
- 8.2 Gande micaceous fine sands and loams active splays
- 7.2 Kurukuru micaceous fine sands and loams terrace like parts.
- 2.1 Rabah sandy main terrace
- 1.2 Bakolori loamy high terrace

Roads
Rivers
Geomorphic unit
P3 Profile pits
Settlement

Chapter 4

MATERIALS AND METHODS

4.1 Preparation of Base Map

Topographical maps, geological maps, geomorphological maps, land use maps and road maps covering the survey area were assembled and analyzed for the purpose of obtaining a background knowledge of study area, and to help in the detail planning of the field work. After obtaining the background knowledge of Bakolori study area, a number of traverses and auger observation points were selected to represent each of the mapped geomorphic units. These traverses and auger points are plotted on the base map before the field work started.

4.2 Field Studies

Soils occurring in each of selected five geomorphic units were examined in the field by augering at the pre-determined observation points. At each site, the soil was augered to a depth of 120cm, and described regarding the surface characteristics, vegetation, slope, soil depth, texture, drainage, moist soil colour, etc. Following the auger-point descriptions, approximate boundaries between the various geomorphic units within the area were confirmed. A minimum of two profile pits were then dug in each of the five geomorphic units; Sangiwa cover sand, Tureta sandy "wash plain", Talata loamy to clay rain terrace, Kurukuru-Gande

micaceous and Diggi Park deposits.

Each profile pit was described in the moist state of their full range of morphological characteristics. Soil description followed the pattern described in the Soil Survey Manual (Soil Survey Staff, 1951). except that the horizon designations are the ones of the revised version of May, 1981 (Guthrie and Witty, 1982). Following the field descriptions, soil samples were collected in soil bags for laboratory analyses.

4.3 Laboratory Studies

Soil samples were air-dried, ground and sieved to remove materials greater than the 2mm fraction. The following analyses of the less than 2mm fraction were carried out.

4.3.1 Particle size distribution

Particle size distribution was determined by the hydrometer method (Day, 1965). Sand, silt, and clay were determined with the aid of the Bouyoucos hydrometer using sodium hexametaphosphate as dispersing agent. Sizes and amounts of particles settling was determined by employing the progressive time interval of 40 sec, 1 min, 5 min, 1 hr, 3 hrs, 6 hrs and 8 hrs. Sand fractions were collected after decanting silt and clay, dried at 105^{0}C in an oven and sieved into the range of sizes 2-1 mm. 1-0.5 mm, 0.5-0.25 mm, 0.25-0.106 mm, 0.106-0.053mm, using a sieve set with

corresponding sizes.

4.3.2 Soil pH

Soil pH was determined potentiometrically on 1:1 soil to solution ratio using glass electrode and Coleman metric IV pH meter, in distilled water and 0.01 m calcium chloride ($CaCl_2$) solution.

4.3.3 Electrical conductivity

Electrical conductivity was determined on the soil extract made from a ratio of 1:2 soil to water paste. A conductivity meter was used for the determination following the Bower and Wilcox (1965) procedure. Correction was made for temperature at 25°C using the formula

$$EC_{25^oC} = \frac{EC_T}{1 + 0.02\ (T - 25^oC)}$$ where EC_{25^oC} is the electrical conductivity at 25°C.

EC_T = Determined electrical conductivity at laboratory temperature.

T = Temperature at which EC_T was determined.

4.3.4 Available phosphorus

Available phosphorus was determined by the Bray No. 1 method (Bray and Kurtz, 1945).

4.3.5 Organic carbon

Organic carbon was determined following the Walkley-Black method (Jackson, 1958). The method involved the

digestion of the soil organic matter by potassium dichromate ($K_2Cr_2O_4$) using concentrated sulphuric acid to increase the temperature and hasten the reaction. Per cent organic carbon was obtained using the formula:

$$\text{Org. carbon \%} = (\text{Blank titre} - \text{Actual titre}) \times \frac{0.3 \times m \times f}{\text{Grams of air dry soil}}$$

where m = Concentration of ferrous ammonium sulphate

f = Correction factor 1.33

4.3.6 Exchange acidity

Exchangeable acidity was determined by the leaching method described by Peech et al. (1962) using barium chloride-triethanolamine (Ba-TEA) solution adjusted to pH 8.2, and by the successive leaching of soil with IN KCl using 1:10 soil to solution ratio. Amounts of exchangeable H and Al in the leachates were determined by the titration procedure outlined by Mclean (1982).

4.3.7 Cation exchange capacity

Cation exchange capacity of soil sample was determined using three analytical procedures, namely, ammonium acetate (pH7.0) method decribed by Chapman (1965), sum of exchangeable metallic cations plus exchange acidity by the $BaCl_2$ - TEA (pH8.2) procedure of Chapman (1965), and the sum of exchangeable metallic cations plus exchange acidity

by IN KCl method of Mclean (1982). Cation exchange capacity of the clay fraction (CEC-clay) was determined by calculation, using the formula

$$\text{CEC-clay} = \frac{\text{CEC}_{\text{Soil pH}_7} - (3.5 \times \%C)\ 100}{\%\ \text{Clay}}$$

where % C = Per cent organic carbon of soil sample.

4.3.8 Exchangeable cations

Exchangeable Ca, Mg, K and Na were determined with IN NH_4OAc (pH7.0) using 1:10 soil : solution ratio. Calcium and magnesium in the filtrates were determined with a Perkin-Elmer model 2908 Atomic Absorption Spectrophotometer (AAS), while sodium and potassium in the filtrates were determined with a Gallenkamp Flame Analyzer (Chapman, 1965).

4.3.9 Per cent base saturation

Base saturation was calculated by dividing the total exchangeable metallic cations (Ca, Mg, K and Na) by the cation exchange capacity (CEC) obtained by the NH_4OAc, (pH7.0), sum of cations plus exchange acidity by the $BaCl_2$ - TEA (pH 8.2) and the sum of cations plus exchange acidity by IN KCl method.

4.3.10 Extractable iron and aluminium

Extractable iron and aluminium were determined by the sodium citrate, sodium bicarbonate and sodium dethionite (CBD) method described by Jackson (1962). It involved the complexing

of iron and aluminium oxides and hydroxides with sodium citrate and sodium hydrogen carbonate. The solution was heated and reduced with sodium dithionite. After centrifugation, iron contents of the soil extracts were determined at 248.3nm wave length in atomic absorption spectrophotometer, while aluminium was determined at 530nm wave length in a spectronic 20 colorimeter following a colour intensity developed after 2.0 hours.

4.3.11 X-ray diffraction analysis of the sand, silt and clay fractions

Soil samples collected from seven profile pits were subjected to mineralogical analysis. One profile each of Sangiwa cover sand, Tureta sady "wash plain", Talata loamy to clay main terrace, and Kurukuru-Gande micaceous deposits, and three profile pits of Diggi Park Unit were studied.

Soil samples studied mineralogically were first treated with hydrogen peroxide, and sodium citrate, sodium bicarbonate and sodium dithionite to remove organic matter and sesquioxide, contents of the soils. They were further dispersed using sodium hexametaphosphate solution. Sand, silt and clay fractions were separated after series of decantations and centrifugations.

Sand fraction of between 2 0 and 75um diameter range were separated by sieving. The sand particles were observed

under the petrographic microscope to identify minerals present in the particles. Magnetic minerals were first separated with a bar-magnet and also identified under the microscope.

Silt fractions were air-dried, ground into fine powder, put into X-ray diffraction sample holder for mineral identification. A Diano XRD 700 diffractometer which employed Ni-filter Cu Kv radiation was used. The diffraction tube was operated at 40Kv and 30 amp for all the samples. Instrument setting for the silt samples are as follows:

Scanning range	-	$8^{o}2\theta$ to $65^{o}2\theta$
Divergence slit	-	$1^{o}2\theta$
Receiving slit	-	0.2mm
Scatter slit	-	$1^{o}2\theta$
Scanning speed	-	$2^{o}2\theta$/min
Paper-speed	-	2cm/min

Clay fractions separated by siphoning at a progressive time interval were sedimented with magnesium acetate (MgOAc) salt, centrifuged, left to dry in the air, and ground into fine powder. The powdered clays were then divided into three for non-oriented, oriented and heated XRD sample analysis as discussed below.

Non-oriented-magnesium saturated clay samples

This powdered clay fraction was put in an XRD sample holder and the clay was scanned from $9^{o}2\theta/t_{p}$ to $60^{o}2\theta$ using a

Cu-tube. The following specifications were used:

Diversion Slit	-	1^{o}
Receiver Slit	-	0.2mm
Scatter Slit	-	1^{o}
Scanning speed	-	$2^{o}2\theta$/min
Paper speed	-	20mm/min

Oriented, magnesium saturated clay samples

0.1g Mg - saturated, air-dried, ground clay was homogenized in $5cm^3$ of demineralized water in a test tube. $1cm^2$ of the suspension was transferred into a ½ size clean microscope slide (2.6 x 4.6cm) by means of a pipette. This was allowed to dry overnight. The clay samples were scanned from $3^{o}2\theta$ to 20^{o}. Specifications used were:

Divergence slit	-	$½^{o}2\theta$
Receiving slit	-	0.2mm
Scatter slit	-	$¼^{o}2\theta$
Scanning speed	-	$1^{o}2\theta$/min
Paper speed	-	10mm/min

To obtain the oriented, magnesium-saturated, glycerol treated clay sample, one drop of glycerol was homogenized with clay suspension in the test-tube above. $1cm^3$ of this suspension was then transferred into ½ size microscope slide (2.6 x 4.6cm) with a pipette and allowed to air-dry over night. Instrument setting was as used for 'oriented, magnesium saturated clay".

Clay sample saturated with potassium chloride and washed out three times with ethanol, was air-dried, ground in a mortar and 0.1g of it was homoganized in 5cm^3 of deionized water. 1cm^3 of the suspension was transferred into ½ size microscope slide and allowed to dry over-night. Instrument setting was as in the case above.

After XRD analysis of the K-saturated air dry sample, the sample on the microscope slide was placed in an oven at 500 to 550^{0}C for one hour. After cooling to a temperature at which the slide can be handled with the finger, it was placed in the XRD sample holder for analysis. Instrument setting was as in the case of Mg-saturated clays.

Chapter 5

RESULTS AND DISCUSSION

Figure 3 presents the base map showing major geomorphic units in the Bakolori area. Five major geomorphic units designated Sangiwa Cover Sands, Tureta sandy "wash plain", Taleta loamy to clay main terrace, Kurukuru-Gande micaceous and Diggi Park units were selected in the survey area. An evaluation of morphological, physical, chemical and mineralogical characteristics of the soils of the project area as well as a summary of soil characteristics of each of the units selected in the area are discussed below.

5.1 Soil Morphological Characteristics

Soils around Bakolori area are either aeolian, alluvial, colluvial, or a mixture of these, in origin. The parent material deposits follow what appears like a toposequence, with aeolian deposits at the crestal positions, mixed aeolio-colluvium at upper and middle to lower slope areas, mixed aeolio-fluvial materials at terrace-plateaux, mixed colluvio-alluvium at backswamp valley areas of Bobo river and Gada stream, and flood-catchment areas; and mainly fluviatile soil materials at levee areas of the Sokoto river.

Soils of the crestal and upper slope positions having aeolian (pedons 1 and 2) and mixed aeolio-colluvial parent materials are those of Sangiwa cover sand. Those of the

middle (pedon 3) to lower (pedon 4) slope positions are the soils of Tureta sandy "wash plain" unit. Their soil parent materials are mainly mixed aeolio-colluvial in origin. Soils of the Talata loamy to clay main terrace unit (pedons 7 and 8) are plateau like terrace materials that are a mixture of aeolian and fluviatile deposits. At the levee areas bordering the banks of river Sokoto, recent fluviatile parent materials characterize soils of the Kurukuru-Gande micaceous unit. The valley bottoms, the backswamps and flood catchment phases of the Diggi Park unit are characterized by mixed colluvio-alluvial soil parent materials (pedons 11, 12 and 13).

A minimum of two profile pits were sunk in each of the five geomorphic units and described. Two representative (modal) profile pits, which show the range of morphological properties, are described below for each geomorphic unit. Soil descriptions follow the pattern described in the soil survey manual (Soil survey staff, 1951), except that the horizon designations are the ones of the revised version of May, 1981, (Guthrie and Witty, 1982). Soil descriptions are for the moist state of the soil unless otherwise stated.

The elevation of the study area is about 300m above sea level.

5.1.1 Sangiwa cover sand

Soils of the Sangiwa cover sands include very well-drained to excessively drained yellowish red (5YR 5/8) to red

(2.5YR 5/8) sandy loam to sandy loam soils with dark brown (7.5YR 4/4) to reddish brown (5YR 4/4) sandy loam surface horizons. The soils are deep and occupy crestal and upper slope positions of about 2% slope (nearly level). Typical profiles of the crestal phase show no distinct horizon differentiation. The soil parent materials mainly consists of aeolian deposits. Those of the upper slope phase are argillic, and weakly plinthic at between 130 and 180cm depth. Their parent materials are mixed aeolio-colluvial in origin.

Coarse fragments in the soils include quartz gravels which increased from surface to sub-soil horizons within a depth of 200cm. Iron concretion and nodule formations accounted partly for the high content of coarse fragments observed in the sub-soil.

The soils exhibit unstable, weak to moderate structure especially in the surface soil horizon, and are, therefore, very susceptible to erosion which is evident from the extensive capping and clay depletion of surface horizons (Plates 1b and 2).

There is hardly any observable evidence of pedogenic processes taking place in the soils of the crestal positions. However, the soils located on the gently sloping upper slope positions are argillic and show evidence of formation of few soft iron nodules and concretions in the subsoil horizons. Possibly, lateral movement of clay and Fe-oxyhydroxides from



Plate 2

Poor crop performance on capped soils in the upland soils units (Tureta sandy wash plain)

the crestal positions through underground seepage may account for the argillic horizons and the presence of the soft Fe-nodules. The soils of the Sangiwa cover sand occupy about 33.41% of the total project area (Table 1).

Influence of sheet erosion common on these soils is evident on the surface soils. Extensively capped soil surface and the reduced silt and clay contents of soils can possibly be attributed to wind and sheet erosion.

Soil pedons 1 and 2 which typify the soils of the Sangiwa cover sands are described below. Typical profile picture is shown as Plate 3.

Pedon 1

Date described	:	16/11/84
Location	:	13km from Lamba-Bakura, along Zaria-Sokoto road on the right hand side.
Geology	:	Aeolian deposits over highly weathered fluviatile basement sediments of the Cretaceous Gundumi Formation.
Soil Parent Material	:	Aeolian deposits over saprolites derived from sedimentary materials of the Gundumi Formation.
Geomorphology	:	Low dune landscape.

Topography : Crestal position; nearly level, 2% slope.

Vegetation/Land Use : Sudan Savanna - open woodland, not cultivated Combretum grass, shrubs and short trees.

Erosion : Moderate sheet erosion.

Drainage : Somewhat excessively well drained.

Surface characteristics: Extensive capping of soil surface.

Depth to water table : Very deep (below 200cm).

Depth to any impenetrable layer : Not encountered.

Horizon	Depth (cm)	Description
A	0-25	Dark brown (7.5YR 4/4) sandy loam; weak, medium, sub-angular blocky structure; slightly sticky (wet) very friable (moist), soft (dry); common, fine to mediur , pores; many, fine roots, many ant holes; gradual, smooth boundary.
AC	25-60	Yellowish red (5YR 5/8) sandy loam; weak, medium, sub-angular blocky structure; slightly sticky (wet), very friable (moist), slightly hard (dry); many fine to medium,

Horizon	Depth (cm)	Description
		pores; common, medium roots; many termite and ant mounds; many fine and medium quartz gravels; diffuse, smooth boundary.
C_1	60–150	Yellowish red (5YR 5/8) sandy loam; weak, medium, sub-angular blocky structure; slightly sticky (wet), very friable (moist), hard (dry); many medium . pores; few, medium roots; few termite and ant borrows; abundant quartz gravels, diffuse, smooth boundary.
C_2	150–200	Yellowish red (5YR 5/8) gravelly sandy loam; weak, medium sub-angular blocky structure; slightly sticky (wet), very friable (moist), hard (dry); many, medium roots; common iron concretions and nodules; haematite and quartz fragments; few termite and ant burrows; abundant, fine and medium quartz gravels.

Pedon 2

Date described	:	16/11/84
Location	:	About 8km from Lamba-Bakura, along Zaria-Sokoto road, on the left hand side.
Geology	:	Aeolian deposits over highly weathered fluviatile Basement sediments of the Cretaceous Gundumi Formation.
Soil Parent material	:	Aeolio-colluvial material over sedimentary saprolites of the Gundumi Formation.
Geomorphology	:	Dune landscape.
Topography	:	Upper slope, nearly level, 2% gradient.
Vegetation/Land Use	:	Fallow; old millet farm. Open Savanna woodland; common Combretum grasses and few short trees and shruds.
Erosion	:	Moderate sheet.
Drainage	:	Well drained.
Surface characteristics	:	Extensive capping (surface).
Depth to water table	:	Very deep (deeper than 180cm).
Depth to impenetrable layer	:	Not encountered.

Horizon	Depth (cm)	Description
Ap	0-30	Reddish brown (5YR 4/4)sandy loam; weak, medium, sub-angular blocky structure; slightly sticky (wet), very friable (moist), soft (dry); common medium, pores; many, medium and coarse roots; many ant holes; clear smooth boundary.
Bt_1	30-80	Red (2.5YR 5/8) sandy clay loam; weak to moderate, medium, sub-angular blocky structure; slightly sticky (wet), very friable (moist), slightly hard (dry); few, fine clay skins on ped faces and in pores; common, medium, pores; common, fine to medium roots; few, fine quartz gravels; few termite burrows; gradual smooth boundary.
Bt_2	80-130	Redish yellow (5YR 6/8) sandy clay loam; weak, medium, sub-angular blocky structure; sticky (wet), friable (moist), slightly hard (dry); few, thin clayskins in pores; common, medium, pores; few, fine roots; many medium iron-nodules; few fine to



Plate 3

A typical profile of the Sangiwa cover sand unit.

Horizon	Depth (cm)	Description
		medium quartz gravels; clear smooth boundary.
Btv	130-180	Yellowish red (5YR 5/8) sandy clay loam; moderate, coarse, sub-angular blocky structure; sticky (wet), firm (moist), hard (dry); common, thin clay skins in pores; few, medium, pores; abundant soft iron nodules; many, medium quartz fragments.

5.1.2 Tureta sandy "wash plain"

Soils of the Tureta sandy "wash plain" are grouped into mid and lower slope soil phases. One pedon each will be described to characterize each phase of the unit.

Soils of the middle slope phase (pedon 3) are well-drained yellowish red (5YR 5/8) to reddish yellow (7.5YR 4/8) sandy clay loam to sandy loam with dark brown (7.5YR 4/4) sandy loam surface horizons. These soils are deep and occupy mid slope (pediment) positions of 2% slopes. Typical pedon (pedon 3) shows argillic properties, indicating that clay lessivation is a distinct pedogenic process occurring in these soils. The soil parent material consists of a mantle of mixed loessial and colluvial deposits over sedimentary materials.

Soils of the lower slope phase (pedon 4) are moderately well-drained, strong brown (7.5YR 5/6) to light gray (5YR 7/1) sandy loam to sandy clay loam with reddish yellow (7.5YR 6/6) loamy sand surface horizon. These soils are deep and occupy lower slope positions of 6% slope. Typical pedons (pedon 4) show argillans on their ped surfaces and in pores. The soil parent materials in this phase consists of a mantle of mixed aeolio-colluvial material over sediments. The profile is characterized by gleying and hydromorphic mottling; as is observed between 142 - 190 cm depth of pedon 4.

Quartz fragments and soft iron nodules contained in soils of this unit account, for the coarseness of the pedons examined. The iron nodules are thought to have been solubilized and laterally transported ferrous iron oxides which was subsequently re-oxidized into ferric forms. The occurrence of these soft iron nodules increases with depth, and exists discretely. Few fine mica flakes which were observed in the pedons of this unit decreased with depth.

The soils exhibit unstable, week to moderate structure especially in the surface soil horizon, and are, therefore, very susceptible to erosion, which is evident from the extensive capping, gullies, and silt and clay depletion of the surface horizons. Wind erosion contributes immensely in the erosion of surface soil materials.

There is evidence of the development of argillic

horizons as indicated by the occurrence of clay skins in pores between 36 and 200cm depth in pedon 3, and between 70 and 100cm depth in pedon 4. Also the relative increase in the clay content of the Bt horizons (pedons 3 and 4) suggest that clay lessivation is a marked pedogenic process occurring in the soils of this unit. These soils occupy about 14.94% of the total project area.

Soils of Turete sandy "wash plain" geomorphic unit are described below and a typical pedon is shown in plate 4.

Pedon 3

Date described	:	13/11/84
Location	:	2km from Lamba-Bakura road junction, along Zaria-Sokoto road; on the right hand side.
Geology	:	Alluvium over weathered sediments of Basement materials.
Soil parent materials	:	Aeolio-colluvial material over saprolite derived from the Gundumi Formation.
Geomorphology	:	Strongly undulating landscape
Topography	:	Middle slope; gently sloping, 2% slope.
Vegetation/Land Use	:	Cultivated to millet, cowpea.

Erosion : Severe sheet erosion.

Drainage : Well drained.

Surface characteristics : Extensive capping and wind blown materials in the nearby slopes.

Depth to water table : Not encountered (deeper than 200cm).

Depth to any impenetrable layer : Not encountered.

Horizon	Depth (cm)	Description
Ap	0-36	Dark brown (7.5YR 4/4) sandy loam; weak, medium, sub-angular blocky structure; non-sticky (wet), very friable (moist), soft (dry); common, medium pores; common, fine to medium roots; many ant holes; clear, smooth boundary.
Bt_1	36-150	Yellowish red (5YR 5/8) sandy clay loam; moderate, medium, sub-angular blocky structure; slightly sticky (wet), friable (moist), slightly hard (dry); common, moderately thick clay skins in pores and ped surfaces; many medium to coarse, pores; common, medium roots; many fine, quartz gravels; few soft

		Fe-nodules; few vertical and continuous cracks (less than 1cm wide); deffuse, smooth boundary.
Bt_2	150-200	Reddish yellow (7.5YR 4/8) sandy loam; moderate medium, sub-angular blocky structure; slightly sticky (wet), friable (moist), slightly hard (dry); few, thin, clay skins in pores; common medium pores; few, medium roots; many, soft medium nodules and concretions, many, medium quartz gravels; few continuous, less than 1cm vertical cracks.

Pedon 4

Date described : 16/11/84

Location : 8km from Lamba-Bakuro, along Sokoto-Zaria road, on the left hand side.

Geology : Alluvium over sedimentary rock.

Soil parent materials : Aeolio-colluvial material over sedimentary saprolites derived from Gundumi Formation.

Geomorphology : Moderately to strongly undulating

Topography : Lower slope; gently sloping to sloping, 6% gradiant.

Vegetation/Land Use : Cultivated to millet.

Erosion : Moderate sheet erosion.

Drainage : Moderately well-drained.

Surface characteristics : Extensive capping of soil surface.

Depth to water table : Not encountered.

Depth to any impenetrable layer : Not encountered.

Horizon	Depth (cm)	Description
Ap	0-17	Reddish yellow (7.5YR 6/6) loamy sand; weak, medium, sub-angular blocky structure; slightly sticky (wet), very friable (moist), soft (dry); common, fine to medium, pores; common, fine roots; many, fine mica flakes and quartz fragments; many ant holes; clear smooth boundary.
BA	17-70	Strong brown (7.5YR 5/6) sandy loam; moderate, medium sub-angular blocky structure; slightly sticky (wet), friable (moist) hard (dry); common, fine to medium, pores; few fine roots; common, fine mica flakes and quartz fragments; common ant holes; clear, smooth boundary.



Plate 4

A typical profile of the Tureta sandy "wash plain" unit.

Horizon	Depth (cm)	Description
Bt	70-142	Strong brown (7.5YR 5/6) sandy clay loam; coarse, sub-angular, blocky structure; sticky (wet), firm (moist), hard (dry); common, thin, clay skin in pores; many medium, pores; few, tiny mica flakes; many, medium quartz fragments; few ant holes; diffuse, smooth boundary.
Btg	142-190	Light grey(5YR 7/1) sandy clay with many coarse, distinct, strong brown and brownish yellow (7.5YR 5/6) and (10YR 6/8) mottles; strong coarse, sub-angular blocky structure; sticky (wet), firm (moist), very hard (dry); common, moderately thick clay and Fe-oxyhydroxide clay skins in pores; many, medium, pores; many, medium soft iron nodules; few, very fine mica flakes.

5.1.3 Talata loamy to clay main terrace unit

Soils of the Talata loamy to clay main terrace unit include well to moderately well-drained yellowish red (5YR 4/8) to strong brown (7.5YR 5/8) sandy clay loam sub-soils with deep dark brown (7.5YR 4/4) sandy loam surface

horizons. The soils are deep and occupy terrace like plateau positions of 1% slope. Soil parent materials consist of a mantle of mixed loessial and sub-recent fluvial materials over sedimentary substratum.

Coarse fragments in the soils consist of quartz fragments which are more dominant in the subsoils. The soils exhibit unstable weak to moderate structures, especially in the surface horizon. This is evident from the slight capping of the surface soils, and very limited gullying associated with the geomorphic unit.

There is evidence of argillation as indicated by the occurrence of clay cutans on ped surfaces and a remarkable increase in clay content in the Bt horizons. This suggests that clay lessivation is a major pedogenic process within this unit. The Talata loamy to clay main terrace unit occupy about 33.3% of the total project area.

Typical soil profiles of the Talata loamy to clay main terrace unit (pedons 7 and 8) are described below:

Pedon 7

Date described : 24/11/84

Location : 100m away from Talata Mafara - Birnin/Tudu road junction; about 70m away from Birnin-Tudu road.

Geology	:	Old alluvium over sedimentary rocks of the Gundumi Formation.
Soil parent material	:	Mixed loessio-alluvium over sedimentary materials.
Geomorphology	:	Terrace-plateaux
Topography	:	Terrace-Plateaux, nearly level, 1% gradient.
Vegetation/Land Use	:	Fallow; old guinea corn plot; common Imperata sp and Combretum sp grasses.
Erosion	:	Slight sheet erosion.
Drainage	:	Well-drained.
Surface characteristics	:	Slightly capped.
Depth to water table	:	Very deep (below 210cm).
Depth to any impenetrable layer	:	Not encountered.

Horizon	Depth (cm)	Description
Ap	0-50	Dark brown (7.5YR 4/4) sandy loam; moderate, medium, sub-angular blocky structure; non-sticky (wet), very friable (moist), slightly hard (dry); common, fine to medium and horizontal pores; common fine and medium roots; few fine quartz fragments; common ant and termite burrows; clear wavy boundary.

Horizon	Depth (cm)	Description
Bt_1	50-90	Yellowish red (5YR 4/8)sandy clay loam; moderate, medium sub-angular blocky structure; slightly sticky (wet), friable (moist), slightly hard (dry), few, thin, Fe-oxhydroxide clay skins on pad surfaces; few fine quartz fragments; many ant burrows; few vertical cracks less than 1 cm wide; gradual, smooth boundary.
Bt_2	90-170	Yellowish red (5YR 5/8) sandy clay loam; moderate, medium, sub-angular blocky structure; slightly sticky (wet), friable (moist) slightly hard (dry); few thin clay and Fe-oxyhydroxide skins on ped surfaces; common, fine and medium, continuous pores; few fine quartz fragments and Fe-Mn concretions, few ants and rodent burrows; few fertical cracks; clear, smooth boundary.
C_1	170-210	Strong brown (7.5YR 5/8) sandy clay loam; moderate, medium, sub-angular blocky structure; slightly sticky

(wet), friable (moist), slightly hard (dry); common, fine continuous pores, few quartz fragments and Fe-Mn concretions.

Pedon 8

Date described	:	20/12/84
Location	:	About 6km along Lamba-Bakura to Bakura road, 70m into the right hand side of the road.
Geology	:	Old alluvium over sedimentary deposits of the Gundumi Formation.
Soil Parent material	:	Thin aeolian deposits over old Alluvium and saprolite of the Gundumi Formation.
Geomorphology	:	Terrace-Plateaux.
Topography	:	Terrace-plateau, nearly level, 1% gradient.
Vegetation/Land Use	:	Fallow, old millet farm.
Erosion	:	Slight sheet erosion.
Drainage	:	Very well drained.
Surface characteristics	:	Very slight capping.
Depth to water table	:	Very deep (below 210cm).
Depth to any impenetrable layer	:	Not encountered.

Horizon	Depth (cm)	Description
Ap	0-60	Dark brown (7.5YR 4/4) sandy loam; moderate, medium, sub-angular blocky structure; slightly sticky (wet), friable (moist), slightly hard (dry); common, fine and medium pores; common, fine and medium roots; common termite and ant mounts; clear, smooth boundary.
Bt_1	60-120	Strong brown (7.5YR 5/8) sandy clay loam; moderate, medium, sub-angular blocky structure; sticky (wet) firm (moist), hard (dry); common, moderately thick, clay skins on ped faces; common fine and medium, pores; few, fine, and medium roots; few soft iron nodules, few, fine quartz fragments and common Fe-Mn concretions; few ant burrows; clear, smooth boundary.
Bt_2	120-200	Yellowish red (7.5YR 5/6) sandy clay loam with few, fine, very pale brown 10YR 8/4) mottles; moderate, medium, sub-angular blocky structure; sticky (wet), firm (moist), hard (dry); few,

moderately thick, clay skins on ped faces and as colloidal stains; few, fine and medium pores; few soft Fe nodules; few fine quartz fragments and common Fe-Mn concretions; few tiny (less than 1cm wide) vertical cracks.

5.1.4 Kurukuru-Gande Micaceous Unit

Soils of this unit are generally moderately well drained dark brown (10YR 3/3), reddish yellow (7.5YR 7/6) to strong brown (7.5YR 5/8) with silt loam, loamy sand to sand textures. The surface horizons are deep, light yellowish brown (10YR 6/4) to brown (10YR 4/3) sandy loam to loam. The soils are deep, and are inferred to possess an ustic soil moisture regime because of the generally good internal drainage of the soils. These soils occupy the levees bordering the banks of the Sokoto river, and generally occur on slopes of 1% gradient. Typical pedons show fine clay bands and stratification of varied soil parent materials (Plate 5), as well as many fine and medium mica flakes. Soil parent materials consist mainly of recent fluviatile materials. Hydromorphic mottling is a common feature within the sub-surface horizons of the pedons examined.

The soils exhibit unstable, weak to loose structure in the entire profile. Influence of wind erosion is very reduced on this soil. There are no evidence of distinct

pedogenic processes as no diagnostic horizons appear to have developed, suggesting that the soils are still very young. Soils of this geomorphic unit belong to the recent aqueous terrace soils that gain fresh parent materials from river Sokoto during every rainy season when the river over-flows its banks. The seasonal nature of resh material deposited at these levee sites may account for the youthfulness of the soils. The geomorphic unit occupies about 11.54% of the entire project area (Table 1).

Pedons 9 and 10 typifying the soils of the Kurukuru-Gande micaceous units are described below.

Pedon 9

Date described	:	17/11/84
Location	:	About 15km along Bakolori-Birnin Tudu road from Talata Mafara - Sokoto road; 1km across river Sokoto bridge, on the right hand side at Birnin Tudu.
Geology	:	Recent alluvium of the Sokoto river.
Soil parent material	:	Recent fluvial micaceous deposits.
Geomorphology	:	Micaceous deposits on flat to nearly level flood plain (levee) of Sokoto river.

Topography	:	Levee, nearly level, 1% slope, valley bottom.
Vegetation/Land Use	:	Cultivated to sorghum, park land type vegetation in the Savanna.
Erosion	:	Slight sheet erosion.
Drainage	:	Moderately well-drained.
Surface characteristics	:	Micaceous, loose sandy surface.
Depth to water table	:	Deeper than 220cm in the dry season.
Depth to any impenetrable layer	:	Not encountered.

Horizon	Depth (cm)	Description
Ap	0-56	Light yellowish brown (10YR 6/4) sandy loam; weak, medium, sub-angular blocky structure; slightly sticky (wet), very friable (moist), loose (dry); few, medium, pores; common fine and medium roots; abundant, shiny yellow mica flakes, common ant mounds; abrupt, smooth boundary.
$2C_1$	56-100	Dark brown (10YR 3/3) silt loam; with many medium, distinct reddish brown (5YR 4/4) mottles; moderate to weak, medium, sub-angular blocky structure; sticky (wet) friable (moist), hard (dry); few, fine

		pores; abundant, shiny, yellow, and white mica flakes; few ants and termite mounds; abrupt, smooth boundary.
$3C_2$	100-200	Reddish yelow (7.5YR 7/6) loamy sand; weak, medium, platy structure; non-sticky (wet), loose (moist), Loose (dry); many fine pores; abundant, fine mica flakes; gradual smooth boundary.
$4C_3$	200-220	Strong brown (7.5YR 5/8) sand; single grained structure; non-sticky (wet), loose (moist)loose (dry); many medium and coarse, pores; abundant medium mica flakes.

Pedon 10

Date described	:	23/11/84
Location	:	About 15km from Lamba-Bakura, 1km away from Bank of Sokoto river in Bakura.
Geology	:	Young aqueous deposits.
Soil parent material	:	Recent fluvial micaceous deposit.

Geomorphology	:	Micaceous deposits on flat to gently sloping flood plain (Levee) of Sokoto river.
Topography	:	Levee, nearly level, 2% gradient.
Vegetation/Land Use	:	Cultivated to cowpea, Guinea corn, a park land type vegetation in the Sudan Savanna.
Erosion	:	Slight sheet erosion.
Drainage	:	Moderately well drained.
Surface characteristics	:	Micaceous fine sand surface.
Depth to water table	:	Deeper than 220cm in dry season.
Depth to any impenetrable layer	:	Not encountered.

Horizon	Depth (cm)	Description
Ap	0-30	Brown (10YR 4/3) loam; weak, medium, sub-angular blocky structure; slightly sticky (wet), friable (moist), soft (dry); common fine and medium, pores; common, fine medium roots; abundant, yellow and white shiny mica flakes; common, termite mounds, and rodent burrows; clear smooth boundary.
$2C_1$	30-80	Very pale brown (10YR 8/3) sandy loam; weak, fine, sub-angular blocky structure; non-sticky (wet), very

friable (moist), soft (dry) common, fine pores; common, fine, medium roots; common clay and organic matter bands; common, fine, medium mica flakes; abrupt, smooth boundary.

$2C_2$	80-110	Strong brown (7.5YR 5/8) sandy loam; moderate, medium, sub-angular blocky structure; slightly sticky (wet), firm (moist) slightly hard (dry); common, fine, medium, pores; few, medium and coarse roots; many, fine mica flakes; few rodent burrows; common clay and organic matter bands; abrupt, smooth boundary.
$3C_{2g}$	110-175	Very dark gray (10YR 3/1) sandy loam with few, fine, faint, strong brown (7.5YR 5/8) mottles; moderate, medium, sub-angular blocky structure; sticky (wet), firm (moist), slightly had (dry); common, fine, yellow shiny mica flakes; few tiny clay bands; abrupt, smooth boundary.



Plate 5

A typical profile showing Layering in the Kurukuru-Gande micaceous unit.

Horizon	Depth (cm)	Description
$4C_3$	175-220	Reddish yellow (7.5YR 7/8) sand; weak, fine, medium, single grained structure; non-sticky (wet), loose (moist), loose (dry); common, medium, coarse, pores; fine to medium, mica flakes; many fine, medium quartz fragments.

5.1.5 Diggi park unit

Soils of the diggi park geomorphic unit include poorly drained yellowish brown (10YR 5/4), yellowish red (5YR 4/6), brownish yellow (10YR 4/2) to grey (N5/0) sandy clay loam, clay loam and clay soils. They have dark brown (10YR 4/3) to dark yellowish brown (10YR 3/4) clay to sandy loam surface horizons. The soils are deep and are flooded during the rainy season. They have an aquic soil moisture regime. These soils occupy the valley bottoms of the study area and are usually located at backswamps of rivers and streams like the Bobo river and the Gada stream as well as the flood catchment areas and have slopes of less than 1% gradient. Typical pedons show numerous criss-crossing cracks on the soil surface less than 1cm wide. Soil parent material consists of alluvial deposits over sedimentary materials. Hydromorphic mottling and gleying were observed within the sub-surface horizons of the backswamp phase (pedons 11 and

12) of the Diggi Park unit. Slickensides were also noticed at a depth of about 190cm in pedons 11 and 12.

Coarse fragments in the soils include occasional fine manganese and iron nodules which increased in size and quantity with depth. The iron and manganese nodules are re-oxidized iron believed to have been derived mainly through underground seepage and partly due to erosion from the uplands. The iron nodules exist discretely and are not cemented together.

The soils exhibit moderate to strong structure especially in the surface horizons. They are hardly susceptible to either wind or sheet erosion and thus serve as a zone of accumulation of eroded fine soil materials from the uplands. This is reflected in the high content of extractable iron, silt and clay in the soils of this geomorphic unit (Tables 5 and 6). The soils also show evidence of hydromorophic mottling and gleying as dominant pedogenic processes occurring in them. This geomorphic unit occupy about 6.81% of the total project area.

Three pedons typifying soils of the Diggi Park geomorphic unit are described below. Two pedons (pedons 11 and 12) are described as typical of the backswamp phases, while pedon 13 is typical of flood catchment phase of the unit.

Pedon 11

Date described	:	17/11/84
Location	:	2km from Bekolori-Birnin-Tudu road junction; across Bobo river bridge, on the right hand side.
Geology	:	Colluvio-alluvial materials.
Soil parent materials	:	Recent alluvium over old colluvio-alluvial deposits.
Geomorphology	:	Deeply incised backswamps of the Bobo river.
Topography	:	Backswamp; nearly level, 1% slope (valley bottom).
Vegetation/Land Use	:	Sudan savanna Park land, cultivated to sorghum.
Erosion	:	Slight sheet erosion.
Drainage	:	Poorly drained.
Surface characteristics	:	Numerous cracks on the soil surface, less than 1cm in width.
Depth to water table	:	Not encountered.
Depth to any impenetrable layer	:	Not encountered.

Horizon	Depth (cm)	Description
Ap	0-32	Dark brown (10YR 4/3) clay, with many, medium, distinct yellowish and (5YR 5/8) mottles; strong, coarse, sub-angular blocky structure; sticky (wet), firm (moist), hard (dry); many, fine, pores; common, fine to medium roots; common, medium, soft Fe-nodules; few, fine mica flakes; common termite and ants mounds; common, vertical and oblique, 1cm wide cracks; clear, smooth boundary.
AC	32-80	Yellowish brown (10YR 5/4) clay; with few, fine and faint, yellowish red (5YR 5/8) mottles; strong, coarse, sub-angular blocky structure; sticky (wet), firm (moist), hard (dry); few, very fine roots; few fine iron and manganese nodules; few, tiny mica flakes; few vertical cracks, less than 1cm wide; abrupt, smooth boundary.
$2C_1$	80-110	Brownish yellow (10YR 6/6) sandy clay loam, with many medium distinct

		strong brown (7.5YR 5/8) mottles; strong, coarse, sub-angular blocky structure; slightly sticky (wet), friable (moist), hard (dry); many, medium soft Fe and Mn nodules; few fine mica flakes; few termite burrows; clear, smooth boundary.
$3C_{2g}$	110-155	Grey (N 5/0) clay loam; with many medium, distinct, strong brown (7.5YR 5/8) mottles; strong, coarse, sub-angular blocky structure; sticky and plastic (wet), firm (moist), hard (dry); common, medium, pores; many, medium, Fe and Mn concretions; few, fine mica flakes; common ant burrows; clear, smooth boundary.
$4C_3$	155-185	Dark greyish brown (10YR 4/3) clay with common, fine distinct strong brown (7.5YR 5/6) mottles; strong, coarse, sub-angular blocky structure; sticky (wet), firm (moist), hard (dry); few, medium, pores; few fine mica flakes; few slicknesides; few vertical cracks.

Pedon 12

Date described	:	17/11/84
Location	:	100cm off Gada stream bridge, 10km away from Talata Mafara/ Birnin Tudu road junction, along Zaria-Sokoto road, on the right hand side.
Geology	:	Alluvium over sedimentary materials.
Soil parent material	:	Recent over older alluvial deposit of Gada stream.
Geomorphology	:	Diggi Park on flat to gently sloping backswamp of Gada stream.
Topography	:	Backswamp; broad valley, less than 1% slope, level to nearly level.
Vegetation/Land Use	:	Sudan savanna park land; cultivated to sorghum, cassava, potato.
Erosion	:	Slight sheet; prominent freshly deposited soil parent material.
Drainage	:	Poorly drained; seasonally water-logged.
Surface characteristics	:	Fine, loose sandy surface.
Depth to water table	:	Not encountered (deeper than 190cm during dry season).
Depth to any impenetrable layer	:	Not encountered.

Horizon	Depth (cm)	Description
Ap	0-48	Brownish yellow (10YR 6/6) sandy loam; with many, medium, distinct, strong brown (7.5YR 5/8) mottles; weak, medium, sub-angular blocky structure; slightly sticky (wet), very friable (moist), soft (dry); many, medium, pores; many, medium roots; few, fine mica flakes; few rodent holes; clear very boundary.
$2Cg_1$	48-150	Grey (N5/0) clay; with many, coarse, distinct dark brown (7.5YR 4/4) mottles; strong, coarse, sub-angular blocky structure; very sticky (wet), firm (moist), very hard (dry); many, medium, pores; many, fine roots; few fine, mica flakes; few termite burrows; vigorous effervescence with H_2O_2; many vertical, oblique cracks; gradual, smooth boundary.
$2Cg_2$	150-190	Grey (N5/0) clay; strong, coarse, sub-angular blocky structure; sticky (wet), firm (moist), very hard (dry); common, medium,

pores; few, fine mica flakes; slight effervescence with H_2O_2; poorly developed slickensides on peds; many vertical cracks.

Pedon 13

Date described : 25/11/84

Location : 5km from Lamba Bakura; 50m away from Lamba-Bakura road on the left hand side.

Geology : Alluvium over basement rock materials.

Soil parent material : Recent loessio-colluvial mixed deposits over old alluvium.

Vegetation/Land Use : Sudan savanna park, land cultivated with guinea corn and cow-peas.

Geomorphology : Diggi Parks on flood catchment level to gently slopping valley bottom.

Topography : Flood catchment; nearly level 1.2% slope, valley floor.

Erosion : Slight sheet erosion.

Drainage : Poorly drained to moderately well drained (seasonally flooded).

Surface characteristics : Multiple criss-crossing cracks.

Depth to water table : Very deep (below 230cm in dry season.

Depth to impenetrable layer : Not encountered.

Horizon	Depth (cm)	Description
Ap	0-30	Dark yellowish brown (10YR 3/4) sandy clay loam; moderate, medium, sub-angular blocky structure; slightly sticky (wet); firm (moist), hard (dry); common, fine and medium, pores; many, fine and medium roots; many ant and rodent holes slight effervescene with H_2O_2; few, fine vertical cracks; clear, smooth boundary.
AC	30-60	Yellowish red (5YR 4/6) clay, moderate, mediu, sub-angular blocky structure; sticky (wet), firm (moist), slightly hard (dry); common, moderately thick Fe-oxyhydroxide strains on ped surface; few, fine and medium roots; common ants and rodent burrows; few vertical cracks less than 1cm wide, clear, smooth boundary.

$2C_2$	60-140	Dark brown (10YR 4/6) sandy clay loam; moderate, medium, sub-angular blocky structure, sticky (wet), firm (moist), slightly hard (dry); common fine and medium, pores; few medium, roots; few ant holes; slight effervescence with H_2O_2; few vertical cracks; clear, smooth boundary.
$3C_3$	140-230	Dark brown (7.5YR 4/6) sandy clay loam; strong, medium, sub-angular blocky structure; slightly sticky (wet), firm (moist) hard (dry); moderately thick clay skins in ped faces; common, fine and medium pores; few iron-concretions; few, fine quartz gravels; few vertical cracks.

5.2 Physical Characteristics

5.2.1 Particle-size distribution

The particle-size distribution data for soils of the various geomorphic units studied are presented in Table 5.

The data indicates that the top soils of all the geomorphic units (except the Diggi Park unit) are coarse textured, varying from loamy sand to sandy loam and loam. This finding is in line with the observation of Jones and Wild (1975) that over most of the savanna, soils are predominantly sandy, at least at the surface. The dominant sand size fraction in the soils is the very coarse (2.0 - 1.0mm) fraction. This may mean that the aeolian, alluvial and mixed aeolic-colluvial parent materials of the soils are rich in the very coarse sand fractions. It is possible that finer sand fractions may have been sorted out during erosion (water and wind), leaving mainly the very coarse sand fractions at the upland positions.

Soils of the Diggi Park unit located at the backswamps and in the flood catchment areas have top soils varying in texture from sandy loam to sandy clay loam and clay. Their sand fractions are more in the fine (0.25 - 0.1mm) and very fine (0.1 - 0.05mm) sand fractions. Possibly, these fine soil materials had been eroded from the upland positions and deposited at the valley bottoms.

Table 5: Particle Size Distribution of the Soils

Pedon	Horizon	Depth mm	VCS (2-1.0) mm	CS (1-0.5) mm	MS (0.5-0.25) mm	FS (.25-0.10) mm	VFS (.1-.05) mm	Total Sand (2-.05) mm	Silt (.05-.002) mm	Clay (≤.002mm)	Textural Classifications U:S.D.A.
					%						
		Sangiwa Cover Sands (Typic Ustorthent, coarse-loamy, mixed, isohyperthermic/Dystric Regosols).									
1	A	0-25	58.2	3.2	4.9	6.4	7.3	80.0	10.0	10.0	Sandy loam
	AC	25-60	51.2	2.8	7.6	7.8	8.6	78.0	4.0	18.0	Sandy loam
	C_1	60-150	61.2	10.8	3.2	3.4	3.4	82.0	4.0	14.0	Sandy loam
	C_2	150-200	55.6	1.2	6.6	7.0	7.6	78.0	4.0	18.0	Sandy loam
		Sangiwa Cover Sands (Oxic Paleustalf, fine-loamy, mixed, isohyperthermic/Dystric Nitosol)									
2	Ap	0-30	29.0	2.3	17.0	18.8	6.9	74.0	12.0	14.0	Sandy loam
	Bt_1	30-80	30.4	3.0	22.0	8.6	6.0	70.0	4.0	26.0	S/Cl. loam
	Bt_2	80-130	26.0	2.4	25.2	9.5	4.9	68.0	6.0	26.0	S/Cl. loam
	Btv	130-180	31.0	2.4	17.5	4.1	5.0	60.0	10.0	30.0	S/Cl. loam
		Tureta Sandy Wash Plain (Oxic Paleustalf, fine-loamy, mixed, isohyperthermic/Dystric Nitosol)									
3	Ap	0-36	31.8	13.8	9.0	10.0	11.4	76.0	10.0	14.0	Sandy loam
	Bt_1	36-150	30.2	5.0	12.4	12.8	13.6	74.0	6.0	20.0	S/Cl. loam
	Bt_2	150-200	22.6	4.6	15.9	16.0	16.9	76.0	6.0	18.0	Sandy loam
		Tureta Sandy Wash Plain (Oxic Paleustalf, fine-loamy, mixed, isohyperthermic/Dystric Nitosol)									
4	Ap	0-17	20.4	8.4	17.2	17.6	18.4	82.0	8.0	10.0	Sandy loam
	AB	17-70	19.4	4.2	14.3	15.3	16.8	78.0	12.0	18.0	Sandy loam
	Bt	70-142	19.8	4.8	9.7	10.8	11.7	56.0	10.0	34.0	Sandy loam
	Btg	142-190	17.0	2.8	9.2	11.0	12.0	52.0	12.0	36.0	Sandy loam

Foot Note: S/Cl. = Sandy clay

Table 5 (Contd.)

Pedon	Horizon	Depth cm	VCS (2-1.0) mm	CS (1-0.05) mm	MS (0.5-0.25) mm	FS (.25-0.1) mm	VFS (.1-.05) mm	Total Sand (2-.05) mm	Silt (.05-.002) mm	Clay (<.002mm) mm	Textural Classification U.S.D.A.
						%					
		Talata Loamy to Clay Main Terrace (Ultic Paleustalf, fine-loamy, mixed, isohyperthermic/Dystric Nitosol)									
7	Ap	0-50	32.2	14.0	10.6	11.4	11.8	80.0	6.0	14.0	Sandy loam
	Bt_1	50-90	33.4	11.6	9.7	10.5	10.8	78.0	4.0	20.0	S/Cl. loam
	Bt_2	90-170	34.4	8.6	7.6	8.5	8.9	68.0	6.0	26.0	S/Cl. loam
	C	170-210	17.4	6.4	12.2	12.8	13.2	72.0	6.0	22.0	S/Cl. loam
		Talata Loamy to Clay Main Terrace (Ultic Paleustalf, fine-loamy,mixed, isohyperthermic/Dystric Nitosol)									
8	Ap	0-60	29.6	10.2	6.0	12.2	20.0	78.0	6.0	16.0	Sandy loam
	Bt_1	60-120	27.0	10.0	5.0	11.0	17.0	70.0	6.0	24.0	S/Cl. loam
	Bt_2	120-200	27.8	10.6	5.6	10.5	15.5	70.0	6.0	24.0	S/Cl. loam
		Kurukuru-Gande Micaceous (Typic Ustifluvent, coarse-loamy mixed, isohyperthermic/Eutric Fluvisol)									
9	Ap	0-56	14.8	13.4	12.5	14.6	16.7	72.0	18.0	10.0	Sandy loam
	$2C_1$	56-100	1.2	0.8	8.0	5.0	11.0	26.0	54.0	10.0	Silt loam
	$3C_2$	100-200	6.8	34.6	12.5	13.5	14.6	82.0	10.0	8.0	Loamy sand
	$4C_3$	200-220	76.4	0.6	5.0	5.1	4.9	92.0	0.0	8.0	Sand
		Kurukuru-Gande Micaceous (Typic Ustifluvent, coarse-loamy, mixed, isohyperthermic/Dystric Fluvisol)									
10	Ap	0-30	5.0	3.2	8.6	11.6	17.6	46.0	36.0	18.0	Loam
	$2C_1$	30-80	1.6	3.8	8.0	19.5	41.1	74.0	16.0	10.0	Sandy loam
	$2C_2$	80-110	1.4	4.0	16.5	18.0	10.1	60.0	28.0	12.0	Sandy loam
	$3C_{2g}$	110-175	3.6	12.4	14.7	16.6	18.7	66.0	24.0	10.0	Sandy loam
	$4C_3$	175-220	66.6	10.6	5.2	5.0	4.6	92.0	0.0	8.0	Sand

S/Cl. = Sandy Clay

Table 5 (Contd.)

Pedon	Horizon	Depth cm	VCS (2-1.0) mm	CS (1-0.5) mm	MS (0.5-0.25) mm	FS (.25-0.1) mm	VFS (.1-.05) mm	Total Sand (2-.05) mm	Silt (.05-.002) mm	Clay (< .002mm) mm	Textural Classification U.S.D.A.
						%					
		Diggi Park (Vertic Fluvaquent, fine-clayey, montmorillonitic, isohyperthermic/Eutric Gleysol)									
11	AP	0-32	6.6	2.8	4.5	7.5	10.6	32.0	28.0	40.0	Clay
	AC	32-80	6.2	0.7	4.1	5.0	10.0	26.0	30.0	44.0	Clay
	$2C_1$	80-110	20.0	5.8	11.9	13.4	14.9	66.0	14.0	20.0	S/Cl. loam
	$3C_{2g}$	110-155	6.8	1.4	6.4	8.0	1.4	34.0	30.0	36.0	Clay loam
	$4C_3$	155-185	3.4	0.2	3.0	2.0	5.4	14.0	34.0	52.0	Clay
		Diggi Part (Tropic Fluvaquent, fine-loamy, mixed, isohyperthermic/Dystric Gleysol)									
12	Ap	0-48	16.6	9.6	10.4	11.0	14.4	62.0	24.0	14.0	Sandy loam
	$2Cg_1$	48-150	2.0	0.4	3.6	3.0	5.0	14.0	38.0	48.0	Clay
	$2Cg_2$	150-190	2.0	0.0	0.0	8.0	10.0	20.0	26.0	54.0	Clay
		Diggi Part (Aeric Tropic Fluvaquent, fine-loamy, mixed, isohyperthermic/Eutric Gleysol)									
13	Ap	0-30	17.0	5.6	9.6	11.2	12.6	56.0	16.0	28.0	S/Cl. loam
	AC	30-60	3.0	2.0	4.0	11.0	12.0	32.0	24.0	22.0	S/Cl. loam
	$2C_2$	60-140	12.8	2.0	9.7	11.8	13.9	50.0	22.0	28.0	S/Cl. loam
	$3C_2$	140-230	6.2	1.6	8.9	12.8	16.7	46.0	20.0	34.0	S/Cl. loam

NB: VCS represents very Coarse Sand FS represents Fine Sand CS represents Coarse Sand

VFS " " Fine Sand MS " Medium Sand S/Cl. = Sandy Clay

dominated the soil texture, especially at the surface horizons. Mean sand content for the surface horizon of these soils is about 77%, with a range of 70 to 82%. Within the sand fractions, the very coarse (2-1.0mm) sand fractions were dominant. Their values ranged from 19 to 58%, with a mean of about 34% in the top soil, and from 17 to 61% in the deeper horizons. Possibly, the soil parent materials deposited at these sites are rich in the very coarse sand fractions; and most of these being more resistant to weathering and erosion, have remained in place. The textures of these upland soils are mainly sandy loam or loamy sand at the surface, over sandy loam or sandy clay loam at sub-surface horizons.

Soils of the Kurukuru-Gande micaceous unit (levee soils) also have high amounts of sand which appear to increase with depth. At the surface horizons, mean value is about 59%, with a range of 46 to 72%. The soil texture varies between sandy loam and loam at the surface horizons, over variable textures of slit loam, loamy sand, sandy loam and even sand in the sub-surface horizons. Possibly, these sand fractions are freshly water-deposited and have not been weathered yet.

Soils of the Diggi Park unit have moderate amounts of sand dominated by the fine (0.25-0.1mm) and very fine (0.1 - 0.5mm) fractions. In the surface horizons, the values range from 25.0 to about 47.0%, with a mean of about 35.0%.

This may be interpreted to mean that the erodible fine and very fine sand fractions dominated the soil parent materials deposited in these valley bottoms on which these soils were developed.

The dominance of coarse sand fractions in the soils of Sangiwa cover sand, Tureta sandy "wash plain", and Talata loamy to clay main terrace is thought to have resulted from the influence of both wind and sheet erosion commonly occurring within these geomorphic unit areas. The position of these units within the landscape appears to encourage the removal of the fine particles by run off water or wind action, leaving mainly the very coarse sand fractions. Sangiwa cover sands are located at the crests and upper slope positions, Tureta sandy "wash plain" at mid and lower slope positions, and the Talata loamy to clay main terrace are located at the plateau-lake terrace positions in the Bakolori area.

Silt fraction: Generally, silt contents of soils of the Sangiwa cover sand, Tureta sandy "wash plain", and Talata loamy to clay main terrace (upland soils) are low. The highest amounts occur at the surface horizons and ranged from 4 to 12%, with a mean of about 9.0%. Possibly most of the silt contained in these soils have either been transformed into clays or eroded to the valley bottom. The silt fraction and the 2:1 layered silicate clay

minerals contained in soils of the valley areas (Diggi Park units) are greater than those in the Upland areas (Tables 5 and 10).

Soils of the Kurukuru-Gande micaceous unit have a remarkably high silt content especially in the surface horizons (Pedons 9 and 10). The values range from 18 to about 36%, with a mean of about 27% at the surface horizon, and from trace amounts to 54% in the sub-soils. Possibly, the high amount of silt content may indicate that the fluviatile soil parent materials deposits are rich in silt, most of which have as yet not undergone any meaningful pedogenesis or transformation, to clay size minerals.

Soils of the Diggi Park unit equally have high silt content, which appear to increase with depth. In the top soil, the values range from 16 to about 30%, with a mean of about 24%. It is possible that the silt may have been eroded from upland areas, and accumulated downslope. Silt content of the sub-soil horizons ranged from 14 to 38% with a mean of about 28%.

Clay fraction: Clay contents of soils within the upland positions are low in the surface horizons, but increase with depth. The range of clay in these soils is from 10 to 18%, with a mean of about 14.3% at the surface horizons, while in sub-soil the range is from 14 to 36%, with a mean of about 25%. Clay lessivation or eluviation-

illuviation processes may account for the increasing clay contents at the sub-soil horizons, especially the B horizon.

In the levee soils, though clay contents are low, the highest amounts are contained at the surface soils horizons. Over the entire horizons of the pedons examined (Pedons 9 and 10), the range of clay content is from 8 to 20%, with a mean of about 12%. However, at the surface horizons, values range from 10 to 18%, with a mean of about 14%. Possibly, the process of sedimentation; through which these soil parent materials have undergone, could be held responsible for the low clay content of soils of this unit.

Soils of the Diggi Park unit have high amounts of clay which appear to increase with depth, though not in any discernible order. Clay contents at the surface horizons range from 14 to 44%, with a mean of about 30%. Possibly, mineral transformation and neoformation processes from primary soil minerals to clay as well as sedimentation of colluvial clays, may account for this high amounts of clay in this soil unit.

5.3 Chemical Characteristics

Tables 6 and 7 present data on chemical characteristics of the soils. These include soil pH, electrical conductivity of the soil extract at 25^{o}C, organic carbon, available phosphorus, exchange acidity, exchangeable cations, cation

exchange capacity, base saturation, extractable iron and aluminium, and exchangeable sodium percentage.

5.3.1 Soil reaction

Soil pH values for the surface horizons of soils of the upland area range between 4.6 and 5.9 with a mean of about 5.4 in water and also range from 3.9 to 5.3, with a mean of about 4.4 in 0.01M$CaCl_2$ solution. These ranges in soil pH indicate very strongly acid to moderately acid soil reaction. This generally strong to moderately acid soil reaction observed in the upland soils (Sangiwa cover sand, Tureta sandy "wash plain", and Talata loamy to clay main terrace) is attributed to loss of bases (Table 8), especially Ca and Mg, to erosion (mainly sheet or gully), leaching, poor vegetative cover, nature of parent material and low return of bases to the surface soil layers (Plates 1a, 1b and 2).

Soils occurring on the levees (Kurukuru-Gande micaceous unit) have a moderate to slightly acid soil reaction at the surface horizon. Soil surface pH range from 5.7 to 6.2 with a mean of about 6.0 in water, and between 5.3 and 5.5, with a mean of about 5.4 in 0.01M $CaCl_2$ solution. This slightly higher pH in the uppermost soil horizons of the levee soils may be attributed to the accumulation of exchangeable bases derived from weathered mica, annual flooding, plant roots and litter decomposition.

Table 6: Soil pH, Organic Carbon, available phosphorus, Electrical Conductivity and Extractable Iron and Aluminium of the pedons studied.

Pedon	Horizon	Depth	pH		$EC_{25}{}^{o}C$	Org. Carbon	Extract. Fe^{2+}	Extract. Al^{3+}	Avail. P
			H_2O	$CaCl_2$					
		cm			mmhos/cm	%		Meq/100g	ppm
	Sangiwa Cover Sand (Typic Ustorthent, coarse-loamy, mixed isohyperthermic/Dystric Rogosol)								
1	A	0-25	5.7	4.7	0.39	0.13	1.48	0.08	0.00
	AC	25-60	5.4	4.0	0.29	0.02	2.29	0.08	0.70
	C_1	60-150	5.1	4.1	0.39	0.07	3.32	0.08	4.62
	C_2	150-200	5.2	4.0	0.29	0.40	2.64	0.09	2.45
2	Sangiwa Cover Sand (Oxic Paleustalf, fine loamy, mixed isohyperthermic/Dystric Nitosol)								
	Ap	0-30	5.0	4.0	0.49	0.11	3.30	0.10	4.90
	Bt_1	30-80	5.1	3.8	0.29	0.07	5.54	0.10	1.05
	Bt_2	80-130	4.6	3.7	0.59	0.03	4.64	0.08	0.00
	Btv	130-180	4.4	3.8	0.88	0.03	6.21	0.10	0.70
3	Tureta Sandy Wash Plain (Oxic Paleustalf, fine-loamy, mixed, insohyperthermic/Dystric Nitosol)								
	Ap	0-36	4.6	3.9	0.49	0.10	2.68	0.07	6.30
	Bt_1	36-150	4.8	4.0	0.49	0.03	0.71	0.08	2.45
	Bt_2	150-200	5.1	4.2	0.39	0.40	6.79	0.09	1.40
4	Tureta Sandy Wash Plain (Oxic Paleustalf, fine-loamy, mixed, isohyperthermic/Dystric Nitosol)								
	Ap	0-17	5.5	4.5	0.39	0.50	0.79	0.08	6.30
	AB	17-70	4.9	4.0	0.39	0.06	4.11	0.09	0.70
	Bt	70-142	5.2	4.0	0.59	0.06	7.14	0.19	0.00
	Btg	142-190	5.3	4.3	0.24	0.03	1.07	0.22	0.00

Table 6 (Contd.)

Pedon	Horizon	Depth	pH H_2O	pH $CaCl_2$	$EC_{25}{}^{o}C$	Org. Carbon	Extract. Fe^{2+}	Extract. Al^{3+}	Avail. P
		cm			mmhos/cm	%		Meq/100g	ppm
7	Talata Loamy to Clay Main Terrace (Ultic Paleustalf, fine-loamy mixed, isohyperthermic/Dystric Nitosol)								
	Ap	0-50	5.9	4.8	0.39	0.11	3.57	0.00	14.40
	Bt_1	50-90	6.1	5.2	0.49	0.14	10.71	0.00	0.70
	Bt_2	90-170	6.2	4.4	0.78	0.06	12.32	0.00	0.00
	C	170-210	5.7	4.5	0.88	0.05	10.71	0.00	0.00
8	Talata Loamy to Clay Main Terrace (Ultic Paleustalf, fine-loamy, mixed, isohyperthermic/Dystric Nitosol)								
	Ap	0-60	5.8	5.3	0.59	0.13	3.93	0.00	1.40
	Bt_1	60-120	6.4	5.8	0.78	0.06	6.25	0.00	0.00
	Bt_2	120-200	7.4	6.7	0.29	0.07	7.32	0.00	0.00

Table 6 (Continued)

Pedon	Horizon	Depth	pH		$EC_{25}{}^{o}C$	Org. Carbon	Extract. Fe^{2+}	Extract. Al^{3+}	Avail. P
			H_2O	$CaCl_2$					
		cm			mmhos/cm	%			ppm
9	Kurukuru-Gande Miscaceous (Typic Ustifluvent, coarse-loamy, mixed, isohyperthermic/Eutric Fluvisol)								
	Ap	0-56	5.7	5.3	3.73	0.06	1.96	0.16	0.00
	$2C_1$	56-100	6.4	5.6	1.06	0.13	1.07	0.10	0.00
	$3C_2$	100-200	6.5	5.9	0.78	0.00	0.89	0.10	0.00
	$4C_3$	200-220	6.6	6.0	0.59	0.02	0.71	0.16	0.00
10	Kurukuru-Gande Micaceous (Typic Ustifluvent, coarse-loamy, mixed, isohyperthermic/Dystric Fluvisol)								
	Ap	0-30	6.2	5.5	0.78	0.11	5.36	0.00	1.40
	$2C_1$	30-80	6.5	5.7	0.49	0.02	1.79	0.00	0.00
	$2C_2$	90-110	5.6	4.8	0.49	0.04	5.00	0.00	0.70
	$3C_{2g}$	110-175	6.7	5.9	0.79	0.02	1.79	0.00	0.00
	$4C_3$	175-220	6.8	6.0	0.59	0.01	3.21	0.00	4.20
11	Diggi Park (Vertic Fluvaquent, fine-clayey, montmorillonitic, isohyperthermic/Eutric Gleysol)								
	Ap	0-32	5.7	5.1	1.89	0.36	8.93	0.20	0.70
	AC	32-80	6.2	5.3	1.37	0.17	21.43	0.09	0.70
	$2C_1$	80-110	7.9	6.7	3.33	0.05	4.64	0.18	2.45
	$3C_{2g}$	110-155	7.8	6.6	3.43	0.12	8.93	0.40	0.70
	$4C_3$	155-185	7.3	6.7	4.41	0.16	23.16	0.10	0.70

Table 6 (Continued):

Pedon	Horizon	Depth	pH H_2O	pH $CaCl_2$	$EC_{25}{}^{o}C$	Org. Carbon	Extract. Fe^{2+}	Extract. Al^{3+}	Avail. P
		cm			mmhos/cm	%		Meq/100g	ppm
12	Diggi Park (Tropic Fluvaquent, fine-loamy, mixed, isohyperthermic/Dystric Gleysol)								
	Ap	0-48	6.6	5.9	0.29	0.06	3.75	0.10	0.00
	$2Cg_1$	48-150	5.7	4.7	0.59	0.31	15.89	0.00	0.00
	$2Cg_2$	150-190	5.8	4.9	0.20	0.10	15.89	0.16	0.70
13	Diggi Park (Aeric Tropic Fluvaquent, fine-loamy, mixed, isohyperthermic/ Eutric Gleysol)								
	Ap	0-30	5.1	4.5	0.69	0.13	14.11	0.00	0.00
	AC_1	30-60	5.3	4.6	0.29	0.46	21.43	0.00	1.40
	$2C_2$	60-140	5.2	4.4	0.69	0.18	16.61	0.00	1.15
	$3C_2$	140-230	5.1	4.2	0.39	0.08	16.96	0.00	0.00

In the Diggi Pork unit, scil pH range from 5.1 tn 6.6 and has a mean of about 5.8 in water at the surface horizons, uhile in Q.01M $CaCl_2$ the range is from *k.5* to 5.9, with a mean of about 5.1. These soila can be said to have a range in soil pH uhich is between strongly acid to neutral in reaction. However, soil pH of pedon 11 increased with depth. Its value ranges from 5.7 to 7.9 in the entire profile, and has a mean of about 7.0 in water. This soil reaction lies within a range of moderately acid to slightly alkaline. The increasing trend of pH values in the 3ub surface horizons of this soil unit may indicate o gradunl build-up of salts within the profile. This moderate to a slightly alkaline soil reaction trend is thought to have resulted from accumulation of exchangeable bases, especially Ca and Na derived from colluviol soil parent materials as well as the influence of high ovapotranspirntiun, and cation adsorption capacity of clays; especially the 2:1 lattice clay minerals contained in the sub~soil3.

5.3.2 Electrical conductivity (EC_{2t}-On) and Exchangeable sodium percentage ESP)

Data related to electrical conductivity and exchangeable sodium percentage are presented in Table 6 and 8, respectively.

Electrical conductivity values obtained in the soils of

the upland units are generally less than 1 mmhos/cm. These values are far less than the 4 mmhos/cm critical limit for salt affected soils (Brady, 1974). Hence, these soils do not contain a concentration of soluble salts high enough to seriously hamper the growth of most plants. Also, the exchangeable sodium percentage of these upland soils is generally low to moderate, ranging from 3.6 and 10.9%, with a mean of about 7.5% at the surface horizon, and a range of from 3.6 to 11.7% in the sub-soil. This low to moderate range of exchangeable sodium percentage contained in these upland soils appears to confirm that these soils do not have salinity problems since the ESP values are much less than the 15% critical limit for sodic soils (Israelsen and Hansen, 1962).

Soils of the Kurukuru-Gande micaceous units (Levee soils) have electrical conductivity values that are equally low, generally being less than 1.0 mmhos/cm. However, in pedon 9, electrical conductivity values are as high as 3.73 and 1.06 mmhos/cm in the Ap and $2C_1$ horizons, respectively. These fairly high EC_{25C}^{0} values may be attributed to the influence of the high seasonal water table of the soils, and the excessive evapotranspiration in the area. Also, the exchangeable sodium percentage content of soils of this unit is generally very low. However, soils of pedon 9 which had relatively high EC_{25C}^{0} values also have ESP values that are as high as 14.6%.

The high values of EC and ESP in the Levee soils indicates a gradual build-up of a soluble sodium salts at both the surface and sub-soil horizons of the soils. The fact that these soils have electrical conductivity and exchangeable sodium percentage values close enough to the critical limits of 4 mmhos/cm and 15%, respectively, may strongly indicate that these soils can be salt affected if not carefully managed, especially under irrigated agricultural use.

Soils of the Diggi Park units (Pedons 11, 12 and 13) have a range of EC_{25C} values from 0.29 to 1.89 mmhos/cm at the surface horizons, with a mean of about 0.91 mmhos/cm. Though soils of this unit have low electrical conductivity values at the surface horizons, soils of pedon 11 have values that increase with depth to a maximum of 4.41 mmhos/cm. Electrical conductivity values in this pedon range from 1.37 to 4.41 mmhos/cm, with a mean of 2.29 mm hos/cm for the entire profile. This increasing trend of EC_{25C} values at the sub-horizons may indicate a build-up of soluble salts in the sub-soil. This could be attributed to the influence of perched water table positions in these soils, high rates of evapotranspiration in the area, accumulations of eroded soil materials from the uplands, as well as adsorption of salts by clays. Paliwal (1972) in a study of Indian soils observed that accumulation of salts increased with increasing clay content.

Regarding the exchangeable sodium percentage value of the Diggi Park, soils of pedon 11 increased with depth to a maximum of 15.8%. The ESP values in this pedon range from 6.7 to 10.4% in the surface horizons, and from 13.6 to 15.8% in the sub-soil horizons. In pedons 12 and 13, the ESP values range from 1.5 to 7.0% in the entire profile examined, indicating a low exchangeable sodium percentage range. The moderate to high exchangeable sodium percentage values of pedon 11 indicates that the soils are increasingly sodic with depth. This might have resulted from reduced percolation and excessive evapotranspiration (Hagen et al., 1968, Paliwal, 1972). This level of accumulation of soluble sodium salts in the soils of pedon 11 may hamper proper growth of most crops.

5.3.3 Organic carbon

Organic carbon data are presented in Table 6. Generally, soils of the Bakalori area contain very low amounts of organic matter. In the soils of the Sangiwa cover sand, Tureta sandy "wash plain", and Tolata loamy to clay main terrace (upland soil units), values range from 0.02 to 0.5%, with a mean of about 0.12% at the surface horizons. Generally in these soils, organic carbon contents tend to decrease with increasing soil depth. The low organic carbon content of the soils may be attributed to erosion, over graving by livestock, and annual bush burning which is rampant in the area.

In the levee soils (Pedons 9 and 10), organic carbon content ranges from 0.06 to 0.11%, with a mean of about 0.09% at the surface horizon, but decreased irregularly even to trace amounts in the subsurface horizons. It is thought that poor vegetative cover, low return of organic matter due to over grazing by cattle and goats, and annual bush burning, especially before cultivation are responsible for this very low organic carbon contents of the soils.

Soils of the Diggi Park unit equally have low range of organic carbon contents. They range from 0.6 to 0.46 per cent with a mean of about 0.24% at the surface horizons, but decreased with depth. It is thought that the slight increase in organic carbon content in these soils can be attributed to the better vegetative cover (Plate 6) and more return of organic matter (in form of plant roots and litter decomposition). Also, the long period of waterlogging may cause a reduction in the rate of organic matter mineralization, hence leaving a relatively high organic matter content in these soils.

5.3.4 Available phosphorus

Available phosphorus data is presented in Table 6. These reveal that available phosphorus in soils of the upland units range from trace amounts to as much as 14.4 ppm in the surface horizons, with a mean of about 4.34 ppm. Apart from pedon 12, which has the highest values of available



Plate 6

Crop performance in the Diggi Park Unit

(Flood-Catchment Phase)



Plate 7

Landscape position (Terrace-Plateau) and
vegetation in the Talata-loamy to clay
Main Terrace Unit

phosphorus in the subsurface horizons (C_1 and C_2), the surface horizons often have the highest amounts of available phosphorus, followed by a sharp decrease in the B and C horizons. This sequence of distribution of available phosphorus in profiles of well-drained upland soils of the savanna region was observed by Esu (1982). He attributed the relatively higher amounts of available phosphorus in the surface horizons of the soils to the generally higher contents of organic matter in the surface horizons of the soils.

The low content of available phosphorus in the upland soils may be attributed to the influence of sheet erosion, wind erosion, poor vegetation, bush burning and nature of parent material. Many researchers, including Jones and Wild (1975), Acquays and Oteng (1972), reported that loss of top soil through erosion involves loss of phosphate.

Soils of the Kurukuru-Gande micaceous unit (Levee soils) have very low values of available phosphorus. Values range from trace amounts to 1.40 ppm in the surface horizon, with a mean of about 0.7 ppm. In the subsurface layers, value as high as 4.20 ppm are obtained in pedon 10, though a sharp fall in available phosphorus occurred between the Ap and the C_3 horizons of the pedon. Possibly the fluviatile parent materials deposited at these buried layers contain relatively higher values of available phosphorus.

In the Diggi Park unit, available phosphorus values range from trace amounts to 1.40 ppm, with a mean of about 0.56 ppm in the surface horizons. Relatively higher values of available phosphorus are obtained at the subsurface layers of pedons 11 and 13. This increase in available phosphorus is attributed to the fact that these colluvial soil parent materials may have been deposited at a time when the phosphorus rich top soils of the uplands were eroded.

The generally low range of available phosphorus in the soils of the study area is attributed to the influence of sheet erosion, bush burning, poor vegetative cover, and phosphate impoverished parent materials.

5.3.5 Extractable iron and aluminium

Results of the total extractable iron and aluminium oxides determined for the soils are presented in Table 6.

Soils of the Sangiwa cover sands, Tureta sandy "wash plain", and Talata loamy to clay main terrace contain low amounts of extractable iron and aluminium oxides. Extractable iron oxides range from 1.48 to 4.11% with a mean of about 2.89%. In all the pedons examined in these upland geomorphic units, the surface horizons generally contain relatively low total extractable iron oxides, while the sub-soil horizons often contain much higher amounts. This trend indicates that the translocation of dissolved Fe from

the surface to the sub-soil horizons is a major pedogenic process in the soils. Awujoola (1979) and Malgwi (1979) observed similar trends in the depth distribution of Fe_2O_3 in the soils they studied, and attributed the high contents in the B horizons of the well-drained soils to translocation of dissolved Fe coupled with increased precipitation of iron oxide during the dry season. Also, in these upland geomorphic units, extractable Al^{3+} ranges from trace amounts to 0.1 meq/100g soil, with a mean of about 0.06 meq/100g soil.

In the levee soils (Kurukuru-Gande micaceous unit) the highest amounts of extractable Fe oxides are contained in the upper horizons of the soils. Values obtained range from 1.96 to 5.36%, with a mean of about 3.66% in the surface horizons. These values appear to decrease with depth. Total extractable iron oxide values in the sub-soil horizons range from 0.71 to 5.0% with a mean of about 1.8%. The generally low extractable iron percentage obtained in these soils appear to indicate that low amounts of extractable iron is contained in the fluviatile soil parent material from which the soils are presumed to be derived. Total extractable alluminium oxides of soils of this unit range from trace amounts to 0.16 meq/100g soil in the surface horizons, with a mean of about 0.08 meq/100g soil. Lower values were recorded in the sub-soil horizons of the soils.

Relatively high amounts of extractable iron oxides were

recorded in soils of the Diggi Park unit relative to soils of the upland units. Values obtained in the surface horizons range from 3.75 to 21.43%, with a mean of about 13.93%. The high amounts of extractable Fe-oxides obtained in these soils may be attributed to accumulation of eroded fine iron rich soil materials from soils of the upland areas. The irregular distribution of extractable iron oxides with depth tend to suggest that much of the Fe in the soils were inherited from the upland soil units by erosion and underground lateral seepage. Values of extractable aluminium oxide obtained in soils of this unit are low. They range from trace amounts to 0.20 meq/100g soil, with a mean of about 0.08 meq/100g soil. It is possible that aluminium oxides in these soils have been depleted and used for clay formation by neoformation such that only trace amounts of extractable Al is left in the soils. Such clays that may have formed in these soils include kaolinite, illite, and smectite (Table 11 and Figs. 12 to 15).

5.3.6 Exchange acidity

Data on exchange acidity by $BaCl_2$-trienthanolamine and 1NKCl procedures are presented in Table 7.

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Values of exchange acidity by 1NKCl method are generally low and range from trace amounts to 0.70 meq/100g soil, with a mean of about 0.24 meq/100g soil in the surface horizons of the upland soils. In the sub-soil horizons,

values range from 0.4 to 0.7 meq/100g soil indicating that exchange acidity values for these soils increase with soil depth.

In the soils of the Kurukuru-Gande micaceous and Diggi Park units, exchange acidity values obtained ranged from 0.05 to 0.4 meq/100g soil, with a mean of about 0.12 meq/100g soil in the surface horizons. In the sub-soil horizons, exchange acidity values range from 0.05 to 0.5 meq/100g soil. The exchange acidity determined by 1NKCl for all the soils of the study area was very low. The low exchangeable Al present in these soils reflect their generally slight acid nature, because at pH 5.5 to 6.0, the exchangeable aluminium in tropical soils is known to precipitate out of the soil solution as insoluble gibbsite (Sanchez, 1976).

5.3.7 Exchangeable cation

The data on exchangeable cations and total exchangeable bases are presented in Table 7.

Relatively low to very low amounts of total exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) are present in the well-drained to somewhat excessively drained soils of the upland units (Sangiwa cover sand, Tureta sandy "wash plain", and Talata loamy to clay main terrace). In the surface horizons of these soils, values range from 0.74 to 4.65 meq/100g soil with a mean of about 2.64 meq/100g soil, and from 1.93 to

Table 7: Exchangeable cations and Exchange Acidity of the pedons studied.

Pedon	Horizon	Depth cm	Exchangeable Cations Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Al^{3+}	H^{+}	Total Exch. Base	Exchange Acidity KCL	BaCl-TEA
			Meq/100g Soil								
		Sangiwa Cover Sand Unit									
		(Typic Ustorthent, coarse-loamy, mixed, Isohyperthermic/Dystric Regosol)									
1	A	0-25	1.8	0.1	0.22	0.66	0.00	0.05	2.78	0.25	3.6
	AC	25-60	1.7	0.1	0.13	0.37	0.20	0.10	2.30	0.30	2.6
	C_1	60-150	1.6	0.0	0.12	0.37	0.30	0.10	2.09	0.40	3.2
	C_2	150-200	1.9	0.1	0.13	0.4	0.20	0.20	2.53	0.40	2.8
2	(Oxic Paleustalf fine-loamy mixed, isohyperthermic/Dystric Nitosol)										
	Ap	0-30	1.6	0.1	0.14	0.41	0.30	0.15	2.25	0.45	0.8
	Bt_1	30-80	1.6	0.0	0.26	0.70	0.70	0.15	2.68	0.85	4.4
	Bt_2	80-130	1.9	0.1	0.31	0.83	0.65	0.10	2.76	0.75	6.0
	Bt_v	130-180	1.9	0.1	0.22	0.54	0.20	0.30	2.76	0.50	5.0

Table 7 (Contd.): Exchangeable cations, Exchange Acidity of the pedons studied.

Pedon	Horizon	Depth cm	Exchangeable Cations Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	H^+	Total Exch. Base	Exchange Acidity KCL	BaCl-TEA
			Meq/100g Soil								
		Tureta Sandy Wash Plain Unit									
		(Oxic Paleustalf, fine-loamy, mixed, isohyperthermic/Dystric Nitosols)									
3	Ap	0-36	0.3	0.0	0.13	0.31	0.05	0.00	0.54	0.05	2.4
	Bt_1	36-150	1.5	0.1	0.12	0.30	0.60	0.10	1.92	0.70	4.0
	Bt_2	150-200	1.9	0.1	0.13	0.31	0.00	0.10	2.44	0.10	3.6
		(Oxic Paleustalf, fine-loamy, mixed, isohyperthermic/Dystric Nitosol)									
4	Ap	0-17	1.8	0.1	0.13	0.37	0.00	0.20	2.40	0.20	2.0
	AB	17-70	1.8	0.1	0.17	0.42	0.50	0.20	2.49	0.70	3.6
	Bt	70-142	2.4	0.6	0.23	0.47	0.40	0.20	3.70	0.60	5.6
	Bt_g	142-190	3.5	0.9	0.39	0.62	0.10	0.20	4.49	0.30	4.6

Table 7 (Contd.): Exchangeable bases, Exchange Acidity of the pedons studied.

Pedon	Horizon	Depth cm	Exchangeable Cations						Total Exch. Base	Exchange Acidity	
			Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Al^{3+}	H^{+}		KCL	BaCl-TEA
			Meq/100g Soil								
		Talata loamy to Clay Main Terrace Unit									
		(Ultic Paleustalf, fine-loamy, mixed isohyperthermic/Dystric Nitosol)									
7	Ap	0-50	3.4	0.8	0.14	0.31	0.00	0.10	4.65	0.10	3.8
	Bt_1	50-90	2.8	0.3	0.18	0.34	0.00	0.05	3.62	0.05	3.4
	Bt_2	90-170	1.9	0.1	0.39	0.34	0.00	0.05	2.69	0.05	4.8
	C	170-210	2.1	0.2	0.34	0.39	0.00	0.10	3.03	0.10	5.0
		(Ultic Paleustalf, fine-loamy, mixed isohyperthermic/Dystric Nitosol)									
8	Ap	0-60	2.9	0.1	0.16	0.37	0.00	0.10	3.53	0.10	4.4
	Bt_1	60-120	3.4	0.3	0.19	0.37	0.00	0.50	4.26	0.50	3.0
	Bt_2	120-200	4.4	0.4	0.28	0.40	0.00	0.50	5.48	0.50	25.0

Table 7 (Contd.)

Pedon	Horizon	Depth cm	Exchangeable Cations Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Al^{3+} Meq/100g	H^{+} Soil	T_{otal} Exch. Base	Exchange Acidity KCL	BaCl-TEA
			Kurukuru-Gande Micaceous Unit								
9	(Typic Ustifluvent, coarse-loamy, mixed, isohyperthermic/Eutric Fluvisol)										
	Ap	0-56	1.8	0.1	0.15	0.41	0.00	0.05	2.46	0.05	2.0
	$2C_1$	56-100	3.7	0.2	0.12	0.35	0.00	0.05	4.37	0.05	4.8
	$3C_2$	100-200	1.9	0.1	0.13	0.39	0.00	0.05	2.52	0.05	2.0
	$4C_3$	200-220	2.0	0.1	0.10	0.31	0.00	0.05	2.51	0.05	1.0
	(Typic Ustifluvent, coarse-loamy, mixed isohyperthermic/Dystric Fluvisol)										
10	Ap	0-30	3.2	0.3	0.17	0.35	0.00	0.05	4.02	0.05	25.0
	$2C_1$	30-80	1.8	0.7	0.12	0.30	0.00	0.05	2.92	0.05	24.4
	$2C_2$	80-110	2.6	0.1	0.15	0.35	0.00	0.05	3.20	0.05	4.6
	$3C_{2g}$	110-175	2.1	0.8	0.13	0.31	0.00	0.05	3.34	0.05	4.4
	$4C_3$	175-220	1.7	0.0	0.12	0.31	0.00	0.05	2.23	0.05	1.4

Table 7 (Contd.): Exchangeable base and Exchange Acidity, Data Sheet

Pedon	Horizon	Depth cm	Exchangeable Cations Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Al^{3+}	H^{+}	Total Exch. Base	Exchange Acidity KCL	BaCl-TEA
			Meq/100g Soil								
			Diggi Park Unit								
11	(Vertic Fluvaquent, fine-clayey, montmorillonitic, isohyperthermic/Eutric Gleysol)										
	Ap	0-32	5.0	1.5	0.32	0.70	0.00	0.05	7.53	0.05	8.4
	AC	32-80	9.8	1.3	1.00	2.52	0.00	0.05	14.62	0.05	9.2
	$2C_1$	80-100	4.8	0.9	0.52	1.48	0.00	0.05	7.70	0.05	1.6
	$3C_{2g}$	100-155	14.5	0.7	1.33	3.70	0.00	0.05	20.23	0.05	4.0
	$4C_3$	155-185	19.5	1.1	1.67	4.35	0.00	0.05	26.62	0.05	8.4
12	(Tropic Fluvaquent, fine-loamy, mixed isohyperthermic/Dystric Gleysol)										
	Ap	0-48	2.9	0.3	0.14	0.34	0.00	0.05	3.68	0.05	1.6
	$2Cg_1$	48-150	5.4	0.8	0.41	0.88	0.00	0.15	7.49	0.15	12.0
	$2Cg_2$	150-190	5.7	0.8	0.52	1.61	0.00	0.05	8.63	0.05	9.2
13	(Aeric Tropic Fluvaquent, fine-loamy, mixed, isohyperthermic/Eutric Gleysol)										
	Ap	0-30	2.8	0.5	0.18	0.38	0.00	0.40	3.96	0.40	6.6
	AC	30-60	4.4	0.8	0.23	0.37	0.00	0.20	5.80	0.20	11.6
	$2C_2$	60-140	2.8	0.4	0.19	0.39	0.00	0.40	3.78	0.40	7.0
	$3C_3$	140-230	3.0	0.5	0.22	0.37	0.00	0.50	4.09	0.50	8.6

26.62 meq/100g soil in the sub-soil horizons. Generally in the pedons examined, exchangeable bases increased with depth with maximum values often occurring in the Bt horizons. The low exchangeable bases in the surface horizons of the upland soils may be due to leaching losses, eluviation of bases into the underlying lower B and C horizons, and plant root uptake of bases.

Also in the upland soil units, the amounts of exchangeable Ca^{2+} in the surface horizons range from 0.3 to 3.4 meq/100g soil, with a mean of about 1.9 meq/100g soil, but values increased from 1.5 to 4.4 meq/100g soil in the sub-soils. Exchangeable Mg^{2+} values range from trace amounts to 0.8 meq/100g soil, with a mean of about 0.15 meq/100g soil in the surface horizons. Also, very low to trace amounts of Mg^{2+} were obtained in the sub-soil horizons. Exchangeable K^{+} values ranged from 0.13 to 0.22 meq/100g soils, with a mean of about 0.15 meq/100g soil in the surface horizons. Sub-soil values ranged from 0.12 to 0.39 meq/100g soil. Exchangeable sodium values obtained for all the horizons of the upland units range from 0.31 to 0.83 meq/100g soil, and are considered moderate relative to the other bases in the soils.

The total exchangeable bases of soils of the upland units present a sequence of occurrence similar to Ca> Na> K> Mg. The predominance of Ca over the other cations in

these soils may be due to the fact that of all the exchangeable cations, Ca^{2+} is the least easily lost from soil environments (Brady, 1974). Also, the dominance of Na^{+} over K^{+} and Mg^{2+} in these soils is attributed to the influence of the high rate of evapotranspiration in the area or that plagioclase feldspers weather to release Na in the soils.

In the levee soils (Kurukuru-Gande micaceous unit), exchangeable bases are distributed **irregularly** within the pedons examined. This may be due to the fluvial nature of the parent materials from which the soils are derived. However, over the surface horizons values for total exchangeable bases range from 1.8 to 3.2 meq/100g of soil with a mean of about 2.5 meq/100g of soil. Exchangeable Ca^{2+} was also the most dominant cation in the soils.

Over the entire horizons of pedons examined in the Diggi Park unit, total exchangeable bases varied between 3.68 and 26.62 meq/100g soil. In these soils, as was the case with the upland soils, exchangeable bases tend to increase in the subsurface horizons. Calcium ions were predominant over all other bases in the pedons. The range of Ca^{2+} ions in the pedons (11, 12 and 13) is from 2.8 to 19.5 meq/100g soil in all the horizons sampled in this unit. Values ranging from 2.8 to 9.8 meq/100g soil with a mean of about 4.98 meq/100 soil were obtained in the

surface horizons, and from 2.8 to 19.5 meq/100g soil in the sub-soil horizons. The general trend shown by the distribution of the exchangeable bases is Ca > Na > Mg > K. The dominance of Na^+ over K^+ ions may indicate a gradual build-up of soluble sodium salts in soils of this unit.

In general, the relatively low contents of exchangeable cations in the soils of the upland units and Kurukuru-Gande micaceous unit may be related to the nature of the parent material, loss due to erosion and leaching. The predominance of Ca over the other cations in these soils, especially in the subsurface horizons, may be due to the occurrence of exchange sites in soils which show affinity for Ca^{2+} (Beckett, 1965) or due to the fact that of all the exchangeable cations (Ca, Mg, K, Na), calcium is the least easily lost from soil environments (Brady, 1974). In the Diggi Park unit the low to high range of exchangeable bases may be attributed to accumulation of eroded soil materials with greater adsorptive capacity from the upland areas, increased adsorption by clays, especially in the sub-soils and the inherent fertility of the soils.

5.3.8 Cation exchange capacity

Cation exchange capacity (CEC) was determined by three methods; namely, the effective CEC or ECEC (by 1NKCl extraction), the sum of cations (by $BaCl_2$-TEA buffered at pH 8.2), and by the ammonium acetate (NH_4OAc-CEC at pH 7) method.

Data for cation exchange capacity is presented in Table 8. The results presented reveal that the magnitude of the CEC depends upon the method used.

In the upland soil units, values for CEC by sum of cation (pH 8.2) range from 3.05 to 8.45 meq/100g soil, with a mean of about 5.57 meq/100g soil in the surface horizons, while values for the NH_4OAc-CEC vary between 3.4 and 10.4 meq/100g soil with a mean of about 5.33 meq/100g soil, also in the surface horizon. Cation exchange capacity values by ECEC method vary between 0.79 and 4.75 meq/100g soil with a mean of about 2.89 meq/100g soil. This result confirms the trend that CEC by the Σcations> NH_4OAc-CEC> ECEC as observed by Esu (1982), and Awujoola (1979).

In the Kurukuru-Gande micaceous unit (Levee soils), CEC values by sum of cations vary between 4.46 and 29.02 meq/100g soil, with a mean of about 16.74 meq/100g soil in the surface horizon. Also, values obtained by the NH_4OAc-CEC procedure range from 2.8 to 8.0 meq/100g soil, with a mean of about 5.40 meq/100g soil; while values of ECEC vary between 2.51 and 4.07 meq/100g soil with a mean of about 3.29 meq/100g soil in the surface horizons.

For soils of Diggi Park unit CEC by Σcation (at pH 8.2) values vary between 5.28 and 23.82 meq/100g soil, with a mean of about 14.60 meq/100g soil; while NH_4OAc-CEC values range from 7.2 to 24.2 meq/100g soil, with a mean of

about 15.0 meq/100g soil in the surface horizons. Values of ECEC vary from 3.73 to 14.67 meq/100g soil with a mean of about 7.27 meq/100g soil. Results in this unit confirm that values of ECEC is the least among the three methods used.

The discrepancy between the sum of cations and ECEC determination has been explained by Sanchez (1976) as resulting from increase in pH dependant negative charges measured by $BaCl_2$-Triethanolamine at pH 8.2. Also, soils whose exchange sites are accounted for mainly by kaolinite, halloysite, and sesquioxides have pH-dependent negative charges. The x-ray diffraction analysis of the silt and clay fractions of soils of Bakolori area reveals that the soils contain high amounts of kaolinite clays (Figs. 4 to 15), low to moderate amounts of oxides and hydroxides of iron, and very low to trace amounts of oxides and hydroxides of aluminium (Table 6). The soils, therefore, have the capacity to exchange more H^+ at pH 8.2 than at lower pH. The difference between the NH_4OAc-CEC and ECEC has also been attributed to the increase in pH (Sanchez, 1976).

Sanchez (1976) suggested that the measurement that determines more accurately the total charge at the actual soil pH involved leaching with a neutral unbuffered salts such as KCl determined at the pH of the soil, which is called effective CEC by Coleman and Thomas (1976). They argued that the ECEC more accurately reflects what is

Table 8: Cation Exchange Capacity (CEC), Base Saturation and Exchangeable sodium percentage of the pedons studied.

Pedon	Horizon	Depth cm	Cation Exchange Capacity pH7.0 (Meq/100g Soil)	Cation Exchange Capacity pH8.2 (Meq/100g Soil)	Cation Exchange Capacity ECEC (Meq/100g Soil)	Clay meq/100g Clay	Base Saturation pH7.0 (%)	Base Saturation pH8.2 (%)	Base Saturation ECEC (%)	ESP
			Sangiwa Cover Sand Unit							
1	(T_{Vmic} Ustorthent, coarse-loamy, mixed, isohyperthermic/Dystric Regosol)									
	A	0-25	6,4	6,38	2.83	59.4	43.4	43.6	98.2	10.3
	AC	25-60	4.8	4.90	2.60	26.3	47.9	46.9	88.5	7.7
	C_1	60-150	3.4	5.29	2.49	15.3	61.5	39.5	83.9	10.9
	C_2	150-200	10.0	5.33	2.93	47.8	25.3	47.5	86.4	4.0
2	(Oxic Paleustalf fine-loamy mixed, isohyperthermic/Dystric Nitosol)									
	Ap	0-30	4.4	3.05	2.70	28.7	51.1	73.8	83.3	10.3
	Bt_1	30-80	6.0	6.96	3.51	22.1	42.7	36.8	72.9	11.7
	Bt_2	80-130	8.6	8.76	3.51	32.7	32.1	31.5	78.6	9.7
	Bt_v	130-180	9.0	7.76	3.26	30.0	30.7	35.6	84.7	6.0

NB: ECEC = Effective Cation Exchange Capacity

Cation Exchange Capacity (CEC),

Table 8 (Contd.): Base Saturation and Exchangeable sodium percentage of the pedons studied.

Pedon	Horizon	Depth cm	Cation Exchange Capacity pH7.0	pH8.2	ECEC	Clay	Base Saturation pH7.0	pH8.2	ECEC	ESP
			Meq/100g Soil			Meq/100g Clay	%			
			Tureta Sandy Wash Plain Unit							
3	(Oxic Paleustalf, fine-loamy, mixed, isohyperthermic/Dystric Nitosol)									
	Ap	0-36	4.6	3.14	0.79	30.4	16.09	23.6	93.67	6.7
	Bt_1	36-150	4.8	5.92	2.62	23.5	40.00	32.4	73.28	6.3
	Bt_2	150-200	5.0	6.04	2.54	20.0	48.80	40.4	96.06	6.2
4	(Oxic Paleustalf, fine-loamy, mixed, isohyperthermic/Dystric Nitosol)									
	Ap	0-17	3.4	4.40	2.60	16.5	70.59	54.6	92.3	20.9
	AB	17-70	6.2	6.09	3.19	33.3	40.16	40.9	78.10	6.8
	Bt	70-142	8.0	9.3	4.30	23.0	46.25	29.8	86.10	5.9
	Bt_g	142-190	8.6	9.39	5.09	23.6	55.70	51.0	93.10	7.2

Table 8 (Contd.): Cations Exchange Capacity, Base Saturation and Exchangeable Sodium Percentage of the pedons studied.

Pedon	Horizon	Depth	Cation Exchange Capacity				Base Saturation			ESP
			pH7.0	pH8.2	ECEC	Clay	pH7.0	pH8.2	ECEC	
		cm	Meq/100g Soil			Meq/100g Clay	%			
		Talata loamy to Clay Main Terrace Unit								
7		(Ultic Paleustalf, fine loamy, mixed, isohyperthermic/Dystric Nitosol)								
	Ap	0-50	8.4	8.45	4.75	57.2	55.36	55.0	97.89	3.7
	Bt_1	50-90	7.8	7.02	3.67	36.6	46.41	51.6	98.63	4.4
	Bt_2	90-170	9.4	7.49	2.74	35.0	28.62	35.9	98.18	3.6
	C	170-210	5.4	8.03	3.13	23.7	56.11	37.7	96.81	7.2
8		(Ultic Paleustalf, fine-loamy, mixed, isohyperthermic/Dystric Nitosol)								
	Ap	0-60	10.4	7.93	3.63	55.2	33.94	44.5	97.25	3.6
	Bt_1	60-129	8.8	7.26	4.76	35.8	48.41	58.7	89.50	4.2
	Bt_2	120-200	10.8	30.48	5.98	50.74	50.74	18.1	91.64	3.7

Table 8 (Contd.):

Pedon	Horizon	Depth	Cation Exchange Capacity				Base Saturation			ESP
			pH7.0	pH8.2	ECEC	Clay	pH7.0	pH.8.2	ECEC	
		cm	Meq/100g Soil			Meq/100g Clay	%			
		Kurukuru-Gande Micaceous Unit								
		(Typic Ustifluvent, coarse-loamy, mixed, isohyperthermic/Eutric Fluvisol)								
9	Ap	0-56	2.8	4.46	2.51	25.9	87.86	55.2	98.01	14.6
	$2C_1$	56-100	6.0	9.17	4.42	27.7	72.83	47.7	98.87	5.8
	$3C_2$	100-200	2.8	4.52	2.57	35.0	90.00	55.8	98.05	13.9
	$4C_3$	200-220	6.8	3.51	2.56	84.1	36.91	71.5	98.05	4.6
	(Typic Ustifluvent, coarse-loamy, mixed isohyperthermic/Dystric Fluvisol)									
10	Ap	0-30	8.0	29.02	4.07	42.3	50.25	13.9	98.77	4.4
	$2C_1$	30-60	8.4	27.32	2.97	83.3	34.76	10.7	98.32	3.6
	$2C_2$	60-100	10.0	7.80	3.25	82.2	32.0	41.0	98.46	3.5
	$3C_{2g}$	110-175	3.6	7.74	3.39	35.3	92.78	43.2	98.53	8.6
	$4C_3$	175-220	9.6	3.53	2.18	119.5	22.19	60.3	97.71	3.2

Table 8 (Contd.): Cation Exchange Capacity (CEC), Base Saturation and Exchangeable Sodium Percentage Data Sheet.

Pedon	Horizon	Depth	Cation Exchange Capacity				Base Saturation			ESP
			pH7.0	pH8.0	ECEC	Clay	pH7.0	pH8.0	ECEC	
		cm	Meq/100g Soil			Meq/100g Clay	%			
		Diggi Park Unit								
11	(Vertic Fluvaquent, fine-Clayey, montmorillonitic, isohyperthermic/Eutric Gleysol)									
	Ap	0-32	10.4	15.92	7.57	22.9	72.31	47.2	99.34	6.7
	AC	32-80	24.2	23.82	14.67	53.6	60.41	61.4	99.34	10.4
	$2C_1$	80-100	10.1	9.30	7.75	49.1	77.00	82.8	99.36	14.8
	$3C_{2g}$	110-155	24.0	24.23	20.28	65.5	84.29	83.5	99.75	15.8
	$4C_3$	155-185	32.0	35.02	26.67	60.2	83.19	76.0	99.81	13.6
12	(Tropic Fluvaquent, fine-loamy, mixed isohyperthermic/Dystric G_{leysol})									
	Ap	0-48	22.6	5.28	3.73	159.9	16.28	69.7	98.66	1.5
	$2Cg_1$	48-150	21.4	19.49	7.64	42.3	35.0	38.4	98.4	4.1
	$2Cg_2$	150-190	23.0	17.83	8.68	42.0	37.52	48.5	99.42	7.0
13	(Aeric Tropic Fluvaquent, fine-loamy, mixed isohyperthermic/Eutric Gleysol)									
	Ap	0-30	7.2	10.56	4.36	24.1	55.0	37.5	90.83	5.3
	AC	30-60	10.0	17.40	6.00	40.9	54.72	33.3	96.67	3.5
	$2C_2$	60-140	14.2	10.78	4.18	48.5	26.62	35.1	90.43	2.8
	$3C_3$	140-230	9.0	12.69	4.59	25.6	45.44	32.2	89.11	4.1

happening in the soil. Awujoola (1979) and Malgwi (1979) have however pointed out that the ECEC method is not likely to represent field conditions of soils in the Zaria area, and that an under-estimation of the CEC of soils is likely to result if the ECEC method is used in routine analysis for soil classification purposes. They further argued that ECEC represents CEC under soil pH conditions, but that soil pH conditions are likely to change with water content or saturation of the soils. They both recommended the use of the NH_4OAc-CEC method for estimating the CEC of soils in the Zaria area and for similar soils.

Generally, the lowest CEC values were recorded; especially, in the surface horizons of the well-drained to somewhat excessively drained upland soils owing to their low clay and perhaps low organic matter contents. Cation exchange capacity values however increased in the B horizons due to the high clay contents in such horizons. The highest CEC values were contained in the pedons of Diggi Park unit. In this unit also, lowest CEC values were recorded mainly in the surface horizons while values increased; particularly, in the gleyed B and C horizons. This relatively higher CEC values may be due to the presence of significant amounts of 2:1 layer silicate clays, notably smectite (Figs. 10 and 11; 12 and 13) which are present in pedon 10 of the Kurukuru-Gande micaceous and pedons 11 and 12 of Diggi Park units. However, in pedon 10, highest CEC values were obtained

in the surface horizons, and values rather decreased at the subsurface layers, possibly indicating a higher accumulation of 2:1 layer silicate clay minerals in the surface soils.

Cation exchange capacity of clay fractions in the upland soil units range from 16.5 to 59.4 meq/100g clay, with a mean of 38.4 meq/100g clay in the surface horizons. In the sub-soil horizons, values ranged from 15.3 to 50.7 meq/100g clay. In the levee soil units, CEC-clay values range from 25.9 to 42.3 meq/100g clay with a mean of 34.1 meq/100g clay in the surface horizons, and from 27.7 to 119.5 meq/100g clay in the sub-soil horizons. Generally, values appear to increase with depth, and values as high as 119.5 meq/100g clay was obtained in the deeper horizons. Also in the Diggi Park unit, CEC-clay values range from 22.9 to 159.9 meq/100g clay in both the surface and in all the sub-soil horizons of the unit. A mean of 86.8 meq/100g clay was obtained in the surface horizons.

In general values of CEC-clay range from 15.3 to 59.4 meq/100g clay in all the horizons of the upland soil units indicating a dominance of the kaolinite and illite clay minerals in the pedons (Sombroek and Zonneveld, 1971). This was confirmed further by the results of XRD analysis of the clay separates of the soils (Table 11, Figs. 5 to 9). Also, the range of CEC-clay values for soils of both the Kurukuru-Gande micaceous and Diggi Park units (22.9 to 159.9 meq/100g

clay) indicate the presence of expanding 2:1 layered (Smectite) clay minerals in addition to kaolinite and illite clays in soils of these units. This also confirms the findings from the x-ray analysis of the clay fractions (Table 11, Figs. 10 to 15).

5.3.9 Base saturation

Base saturation per cent as calculated for the three methods is variable and is dependent on the method used (Table 8). Generally, the base saturation by ECEC gave the highest values (72.9 to 99.8%). The sum of cations gave the the least values (10.7 to 83.5%). Base saturation by NH_4OAc gave values slightly higher than those obtained by sum of cations in most cases and values vary between 16.09 and 90.00% in all the horizons examined.

In soils of the upland areas (Sangiwa cover sand, Tureta "sandy wash" Plain and Telata loamy to clay main Terrace) base saturation (NH_4OAc pH 7) tends to be higher in the surface horizons than in the B horizons. Exceptions to this trend are found in pedons 4 and 8 in which values increased with depth of profiles. Malgwi (1979) attributed the high base saturation of the surface horizons in the Samaru area to cation addition to the soil surface from the harmattan dust. The low base saturation in the horizons immediately underlying the surface horizon represent regions of maximum eluviation of bases, while the gradual increase in base

saturation in the deeper sub-soil horizons may be due to the accumulation of leached cations. The low base saturation of the surface horizons of pedons 4 and 8 may indicate that these are zones of eluviation, in which the bases have been leached to sub-surface horizons.

In soils of the Kurukuru-Gande micaceous unit, base saturation (NH_4OAc) values were equally high in the surface horizons. Higher values were however recorded between 100 and 200cm within the profiles (pedons 9 and 10). This layer appear to represent the zone of accumulation of deposited materials that are high in bases. Base saturation values obtained in this zone range from 90 to 93%. It is also observed that there is no regular sequence in the distribution of base saturation values in the sub-horizons of the soils. Values in the entire profile range from 22 to 93%, and from 50 to 88% at the surface horizons.

Soils of the Diggi Park unit have base saturation (by NH_4OAc) values ranging from 16 to 84% in all the horizons. Surface horizon values range from 16 to 72%, with a mean of about 52%, and sub-soil values range from 35 to 84%.

5.4 Mineralogical Characteristics

Figures 4 to 15 show x-ray diffractograms of the clay (< 2 um) fractions of representative pedons of each of the five geomorphic units studied in the area. Tables, 10 and

11 present data related to semi-quantitative estimation of the mineralogy of the sand (0.25 - 0.075 mm), silt (0.05 - 0.002 mm) and clay ($<$ 0.002 mm) fractions. A detailed discussion of the mineralogy of the three soil separates (Sand, Silt and Clay) is given below.

5.4.1 Mineralogy of the sand fraction

The results of the petrographic analysis of the sand fraction of representative pedons for each of the geomorphic units are presented in Table 9.

The results show that quartz and K-feldspars together dominate the mineralogy of the sand fraction of all the pedons of all the geomorphic units. They often constitute more than 80% of the mineral in the sand fraction. Next in importance to quartz and K-feldspar is muscovite which has at least 3 to 10% composition in all horizons of the pedons examined.

In the upland soil units, only the Talata loamy to clay main terrace unit contain biotite and hornblende, while soils of the Sangiwa cover sands and the Tureta sandy wash plain units did not contain any relatively easily weathered minerals. This might mean that the soils of the Talata loamy to clay main terrace are less weathered than its associates in the upland areas. All the upland soil units contain accessory resistant minerals such as zircon, ilmenite, magnetite and garnet, except that the Talata

loamy to clay main terrace soils had in addition rutile, tourmaline and kyanite.

The levee soils (Kurukuru-Gande micaceous) contain the highest amounts of micaceous minerals among all the soils studied in the area, though in relative abundance, they are of 10 - 30% composition relative to other minerals. The abundance of micaceous minerals in this soil unit may be due to the fluvial origin of the soil parent material which may have been transported from a mica rich area (Sombroek and Zonneveld, 1971). Other minerals which occurred in trace amounts in the soils include augite and resistant minerals such as zircon, magnetite, garnet, rutile and tourmaline.

Soils of the Diggi Park unit (backswamp and flood catchment areas) in addition to quartz, feldspars and muscovite and biotite, also contained trace amounts of resistant minerals such as zircon, ilmenite, magnetite, garnet, rutile and tourmaline.

In general, it appears that the levee soils contain the highest amount of weatherable minerals, followed by soils of the backswamp and floodcatchment areas. The soils of the upland units perhaps because of their aeolian origin are rather inert and impoverished in weatherable minerals except the soils of the Talata loamy to clay main terrace unit.

Table 9: Estimated Mineral Contents of the Sand Fraction (250-75 um) of the Pedons Studied.

Pedon	Horizon	Depth	Quartz + K-Feld	Musc.	Biot.	Zir.	Aug.	Ilme.	Magne.	Gar.	Hornb.	Rut.	Tourm.	Kyan.
		cm	%											
			Sangiwa Cover Sand Unit											
1		(Typic Ustifluvent, coarse-loamy, mixed, isohyperthermic/Dystric Regosol)												
	A	0-25	xxx	(x)	-	tr	tr	tr	tr	tr	-	-	-	-
	AC	25-60	xxxx	x	-	-	tr	tr	tr	tr	-	-	-	-
	C_1	60-150	xxxx	(x)	-	tr	-	tr	tr	-	--	-	-	-
	C_2	150-200	xxxx	(x)	-	tr	-	-	tr	-	--	-	-	-
			Tureta Sandy Wash Plain Unit											
4		(Oxic Paleustalf, fine-loamy, mixed, isohyperthermic/Dystric Nitosol)												
	Ap	0-17	xxx	x	-	-	-	tr	tr	tr	-	-	-	-
	AB	17-70	xxxx	x	-	tr	-	tr	tr	tr	-	-	-	-
	Bt	70-142	xxxx	x	-	tr	-	tr	tr	tr	-	-	-	-
	Btg	142-190	xxxx	(x)	-	tr	-	tr	tr	tr	-	-	-	-
			Talata loamy to Clay Main Terrace Unit											
7		(Ultic Paleustalf, fine-loamy, mixed isohyperthermic/Dystric Nitosol)												
	Ap	0-50	xxx	x	(x)	tr	-	tr	tr	-	tr	-	-	-
	Bt_1	50-90	xxxx	(x)	(x)	tr	-	tr	tr	tr	tr	tr	tr	-
	Bt_2	90-170	xxxx	(x)	tr	tr	-	tr	tr	tr	tr	tr	tr	-
	C	170-210	xxxx	(x)	tr	tr	-	-	tr	-	-	tr	tr	-

*Symbol of quantities of minerals:- non detected; tr, trace; (x) 0.5-3; +, 3-10; xx, 10-30; xxx, 30-80; xxxx, >80%

**K-Feld, Potash Feldspar; Musc, Muscovite; Biot, Biotite; Zir, Zircon; Aug., Augite; Magne, Magnetite; Gar, Garnet; Hornb, Hornblende; Rut, Rutile; Tourm, Tourmaline; kyan, kyanite.

Table 9 (Contd.): Estimated Mineral Contents of the Sand Fractions (250-75 um) of the Pedons Studied

Pedon	Horizon	Depth	Quartz + K-Feld	Musc.	Biot.	Zir.	Aug.	Ilme.	Magne.	Gar.	Hornb.	Rut.	Tourm.	Kyan.
		cm	%											
			Kurukuru-Gande Micaceous Unit											
			(Typic Ustifluvent, coarse-loamy, mixed, isohyperthermic/Eutric fluvisol)											
9	Ap	0-56	xxxx	xx	xx	tr	tr	-	tr	tr	-	tr	tr	-
	$2C_1$	56-100	xxxx	xx	x	tr	tr	-	tr	tr	-	tr	tr	-
	$3C_2$	100-200	xxxx	x	xx	tr	tr	-	-	tr	-	tr	tr	-
	$4C_3$	200-220	xxxx	x	xx	tr	-	-	tr	-	-	tr	tr	-
			Diggi Park - Backswamp Phase											
			(Vertic Fluvaquent, fine-clayey, montmorillonitic, isohyperthermic/Eutric Gleysol)											
11	Ap	0-32	xxx	x	x	-	tr	tr	-	-	tr	-	tr	tr
	AC	32-80	xxxx	(x)	x	tr	tr	tr	tr	tr	tr	-	tr	tr
	$2C_1$	80-110	xxxx	(x)	(x)	tr	tr	-	-	tr	-	-	-	tr
	$3C_{2g}$	110-150	xxxx	(x)	(x)	tr	tr	tr	tr	-	tr	-	-	-
	$4C_3$	155-185	xxxx	tr	tr	tr	-	tr	tr	tr	tr	-	tr	tr
			(Tropic Fluvaquent, fine-loamy, mixed, isohyperthermic/Dystric Gleysol)											
12	Ap	0-48	xxxx	x	(x)	tr	-	-	tr	-	tr	-	tr	-
	$2C_{g1}$	48-150	xxx	(x)	tr	tr	-	-	tr	tr	tr	-	tr	-
	$2C_{g2}$	150-190	xxx	(x)	(tr)	tr	-	-	tr	tr	tr	-	tr	-
			Diggi Park - Flood Catchment Phase											
			(Aeric Tropic Fluvaquent, fine-loamy, mixed, isohyperthermic/Eutric Gleysol)											
13	Ap	0-30	xxxx	x	-	tr	-	tr	tr	-	-	tr	tr	-
	AC	30-60	xxxx	(x)	-	tr	-	tr	tr	tr	-	tr	tr	-
	$2C_2$	60-140	xxxx	x	-	tr	-	tr	tr	tr	-	tr	tr	-
	$3C_3$	140-230	xxxx	x	-	tr	-	tr	tr	tr	-	tr	tr	-

5.4.2 Mineralogy of the silt fractions

Results of x-ray diffraction analysis (XRD) of the silt fraction of soils (Table 10) show that for all the geomorphic units, quartz, kaolinite, microcline and plagioclase dominated the mineralogy of the silt fractions. The quartz content of the silt fraction constituted a maximum of about 80%, and showed strong peaks at 3.34Å and 4.26Å Kaolinite with a strong peak at 7.17Å varied between 10 and 30%, and microcline and plagioclase with distinct peaks at 3.24Å and 3.20Å ,respectively, constituted as much as 10% each in composition.

In the silt fractions of the upland, levee, and Diggi Park soil units, muscovite, biotite, and traces of geothite were obtained. Within the upland areas, soils of the Talata loamy to clay main terrace unit contain more easily weathered mineral like biotite up to 3%. However, within the entire study area soils of the Kurukuru-Gande micaceous unit contained more of the easily weathered minerals like plagioclase (10%), muscovite (30%), and biotite (30%) in the silt fraction. Among soils of the Diggi Park unit, the soils of the backswamp (pedons 11 and 12) contained about 3% biotite, 10% muscovite, and about 30% plagioclase, while soils of the flood catchment areas (pedon 13) did not contain biotite.

Generally, all the soil fractions of the pedons examined

contained plagioclase and the silt fractions of the levee soils contained in addition more biotite than the silt fractions of the other pedons studied. Like in the sand fraction, mica was also dominant in the silt fraction of the levee soils. This finding may indicate that soils of the Kurukuru-Gande micaceous units are less weathered than those of the upland and Diggi Park units.

5.4.3 Mineralogy of the clay fractions

X-ray diffractograms of the clay fractions of soils of the study area are presented in figures 4 to 15. Table 11 presents the semiquantitative estimate of minerals contained in the clay separate.

In all the soils, kaolinite 7.17Å) and illite (10.3Å) dominated the mineralogy of the clay fractions. Kaolinite was as much as 30-80% and illite was between 10 and 30% in composition. However, soils of the backswamps of the Diggi Park unit contained as much as 30 - 80% smectite clays; with a distinct peak at 15.0Å (Fig. 12). About 3% of smectite clay was estimated in the levee soils (Kurukuru-Gande micaceous unit). Possibly, the smectite clays of these units may have resulted from either transformation of mica into the 2:1 clay minerals or from clay neoformation. All the pedons also contained quartz, with distinct peaks of 3.34Å and 4.26Å, Fe-oxyhydroxides, and microcline.

Table 10: Semiquantitative estimation of mineral contents of silt fractions (0.05-0.002 mm) of the Pedons Studied.

Pedon	Horizon	Depth cm	Quartz	Microcline	Plagioclase	Muscovite	Biotite	Goethite	Haematite	Kaolinite
						%				
		Sangiwa Cover Sands Unit								
		(Typic Ustorthent coarse-loamy, mixed, isohyperthermic/Dystric Regosol)								
1	A	0-25	xxx	(x)	x	-	-	-	-	x
	AC	25-60	xxx	(x)	x	-	-	-	-	xx
	C_1	60-150	xxx	tr	(x)	-	-	-	-	xx
	C_2	150-200	xxx	(x)	x	-	-	-	-	xx
		Tureta Sandy Wash Plain Unit								
		(Oxic Paleustalf, fine-loamy, mixed, isohyperthermic/Dystric Nitosol)								
4	Ap	0-17	xx	(x)	(x)	x	-	tr	tr	x
	AB	17-70	xx	(x)	(tr)	x	-	tr	tr	xx
	Bt	70-142	xxx	tr	x	tr	-	-	tr	xx
	Btg	142-190	xxx	tr	(x)	(x)	-	tr	tr	x
		Talata loamy to Clay Main Terrace Unit								
		(Ultic paleustalf, fine-loamy, mixed isohyperthermic/Dystric Nitosol)								
7	Ap	0-50	xxx	x	x	(x)	(x)	tr	-	x
	Bt_1	50-90	xxx	(x)	x	(x)	(x)	tr	-	xx
	Bt_2	90-170	xxx	(x)	(x)	(x)	tr	tr	-	xx
	C	170-210	xxx	(tr)	(x)	tr	-	-	-	x

*Symbol of semiquantitative estimate of mineral:-, non detected; tr, trace (< 0.5); (x), 0.5-3; x, 3-10, xx, 10-30; xxx, 30-80; xxxx, > 80%.

Table 10 (Contd.): Semiquantitative estimation of mineral contents of silt fractions (0.05-0.002 mm) of the Pedons Studied.

Pedon	Horizon	Depth	Quartz	Microcline	Plagioclase	Muscovite	Biotite	Goethite	Haematite	Kaolinite
		cm				%				
			Kurukuru-Gande Micaceous Unit							
			(Typic Ustifluvent, coarse-loamy, mixed, isohyperthermic/Eutric Fluvisol)							
9	Ap	0-56	xxx	(x)	x	xx	xx	-	-	x
	$2C_1$	56-100	xxx	(x)	x	xx	xx	-	-	xx
	$3C_2$	100-200	xxx	(x)	(x)	xx	x	tr	-	xx
	$4C_3$	200-220	xxx	(x)	(x)	xx	x	tr	tr	x
			Diggi Park - Backswamp Phase							
			(Vertic Fluvaquent, fine-clayey, montmorillonitic, isohyperthermic/Eutric Gleysol)							
11	Ap	0-30	xx	x	x	x	(x)	-	-	x
	AC	30-80	xx	(x)	xx	x	(x)	tr	-	xx
	$2C_1$	80-110	xxx	(x)	x	x	tr	tr	-	x
	$3C_{2g}$	110-155	xx	x	(x)	(x)	tr	-	-	xx
	$4C_3$	155-185	xx	(x)	(x)	(x)	tr	tr	-	x
			(Tropic Fluvaquent, fine-loamy, mixed, isohyperthermic/Dystric Gleysol)							
12	Ap	0-48	xxx	(x)	x	x	tr	-	-	x
	$2Cg_1$	48-150	xx	(x)	x	x	tr	tr	-	xx
	$2Cg_2$	150-190	xx	(x)	(x)	(x)	tr	tr	-	x
			Diggi Park - Flood catchment phase							
			(Aeric Tropic Fluvaquent, fine-loamy, mixed, isohyperthermic/Eutric Gleysol)							
13	Ap	0-30	xxx	(x)	x	x	tr	tr	-	x
	AC	30-60	xxx	(x)	xx	x	-	tr	-	xx
	$2C_2$	60-140	xx	(x)	x	x	-	tr	-	x
	$3C_3$	140-230	xxx	(x)	x	x	-	tr	-	x

The quartz content of the upland soils ranged from 3 to 30%. But in the soils of the Kurukuru-Gande micaceous units quartz composition was as much as about 30 - 80%, and in the Flood catchment soils of the Diggi Park unit, quartz content was about 30%.

Low levels of microcline (about 3%) was obtained in the clay fractions of all the pedons. However, in soils of the Kurukuru-Gande micaceous and Diggi Park units, about 10% mica was obtained. In general, therefore, soils of the Bakolori area contain kaolinite clay as the only identifiable 1:1 layer clay mineral. This clay mineral appears to increase with depth (Figs. 4, 6, 8 and 10), and attains a maximum accumulation between 50 and 180cm deep in the upland soil units. Possibly, kaolinite clay minerals may have been transported along with the aeolian soil parent materials in the upland area. Also, it is thought that kaolinization may account for the increasing clay content with depth in the upland soils while kaolinite clay minerals may have been transported along with eroded soil materials from the upland area into the Diggi Park units. Illite clays appear to be the most dominant 2:1 lattice clay mineral in all the soils of the pedons examined. Possibly, mica transformation to illite may account for the presence of illite clay minerals in the soils.

Table 11: Semiquantitative estimation of minerals contained in clay fractions ($\leq$ 0.002 mm) of the Pedons Studied.

Pedon	Horizon	Depth	Quartz	Microcline	Plagioclase	Mica	Kaolinite	Illite	Smectite
		cm				%			
		Sangiwa Cover Sand Unit							
		(Typic Ustorthent, coarse-loamy, mixed, isohyperthermic/Dystric Regosol)							
1	A	0-25	x	-	-	-	xx	-	-
	AC	25-60	x	(x)	-	-	xxx	-	-
	C_1	60-150	x	(x)	-	-	xxx	xx	-
	C_2	150-200	x	(x)	-	(x)	xx	xx	-
		Tureta Sandy Wash Plain Unit							
		(Oxic Paleustalf, fine-loamy, mixed, isohyperthermic/Dystric Nitosol)							
4	Ap	0-17	(x)	(x)	-	-	xx	x	-
	AB	17-70	(x)	(x)	-	-	xxx	xx	-
	Bt	70-142	(x)	(x)	-	-	xxx	xx	-
	Btg	142-190	(x)	(x)	-	-	xx	x	-
		Talata loamy to Clay Main Terrace Unit							
		(Ultic paleustalf, fine-loamy, mixed, isohyperthermic/Dystric Nitosol)							
7	Ap	0-50	(x)	(x)	-	(x)	xx	xx	-
	Bt_1	50-90	(x)	(x)	-	-	xxx	xx	-
	Bt_2	90-170	x	-	-	(x)	xx	xx	-
	C	170-210	x	-	-	(x)	xx	xxx	-

*Symbol of semi-quantitative estimate of minerals:- non, detected; tr, trace ($\leq$ 0.5); (x), 0.5-3; x, 3-10; xx, 10-30; xxx, 30-80; xxxx, $>$ 80%.

Table 11 (Contd.): Semiquantitative estimation of minerals contained in clay fractions (≤ 0.002 mm) of the Pedons Studied.

Pedon	Horizon	Depth	Quartz	Microcline	Plagioclase	Mica	Kaolinite	Illite	Smectite
		cm				%			
		Kurukuru-Gande Micaceous Unit							
		(Typic Ustifluvent, coarse-loamy, mixed, isohyperthermic/Eutric Fluvisol)							
9	Ap	0-56	xx	-	-	x	xx	x	-
	$2C_1$	56-100	xxx	(x)	-	x	xxx	xx	(x)
	$3C_2$	100-200	xx	-	-	x	xxx	xxx	(x)
	$4C_3$	200-220	xxx	-	-	x	xx	xx	(x)
		Diggi Park - Backswamp Phase							
		(Vertic Fluvaquent, fine-clayey, montmorillonitic isohyperthermic/Eutric Gleysol)							
11	Ap	0-32	x	(x)	(x)	-	xx	xx	x
	AC	32-80	x	-	-	x	xx	xxx	xx
	$2C_1$	80-110	x	-	-	x	xx	xxx	xxx
	$3C_{2g}$	110-155	x	(x)	-	(x)	xx	xx	xxx
	$4C_3$	155-185	x	-	-	x	xx	xx	xx
		(Tropic Fluvaquent, fine-loamy, mixed isohyperthermic/Dystric Gleysol)							
12	Ap	0-48	x	(x)	(x)	-	xx	xx	xx
	$2Cg_1$	48-150	x	-	-	x	xxx	xxx	xxx
	$2Cg_2$	150-190	x	(x)	-	x	xx	xxx	xx
		Diggi Park - Flood catchment Phase							
		Aeric Tropic Fluvaquent, fine-loamy, mixed, isohyperthermic/Eutric Gleysol)							
13	Ap	0-30	xx	(x)	-	x	xx	xx	-
	AC	30-60	xx	-	-	(x)	xxx	xxx	-
	$2C_2$	60-140	xx	-	-	x	xxx	xxx	-
	$3C_3$	140-230	xx	-	-	-	xxx	xxx	-

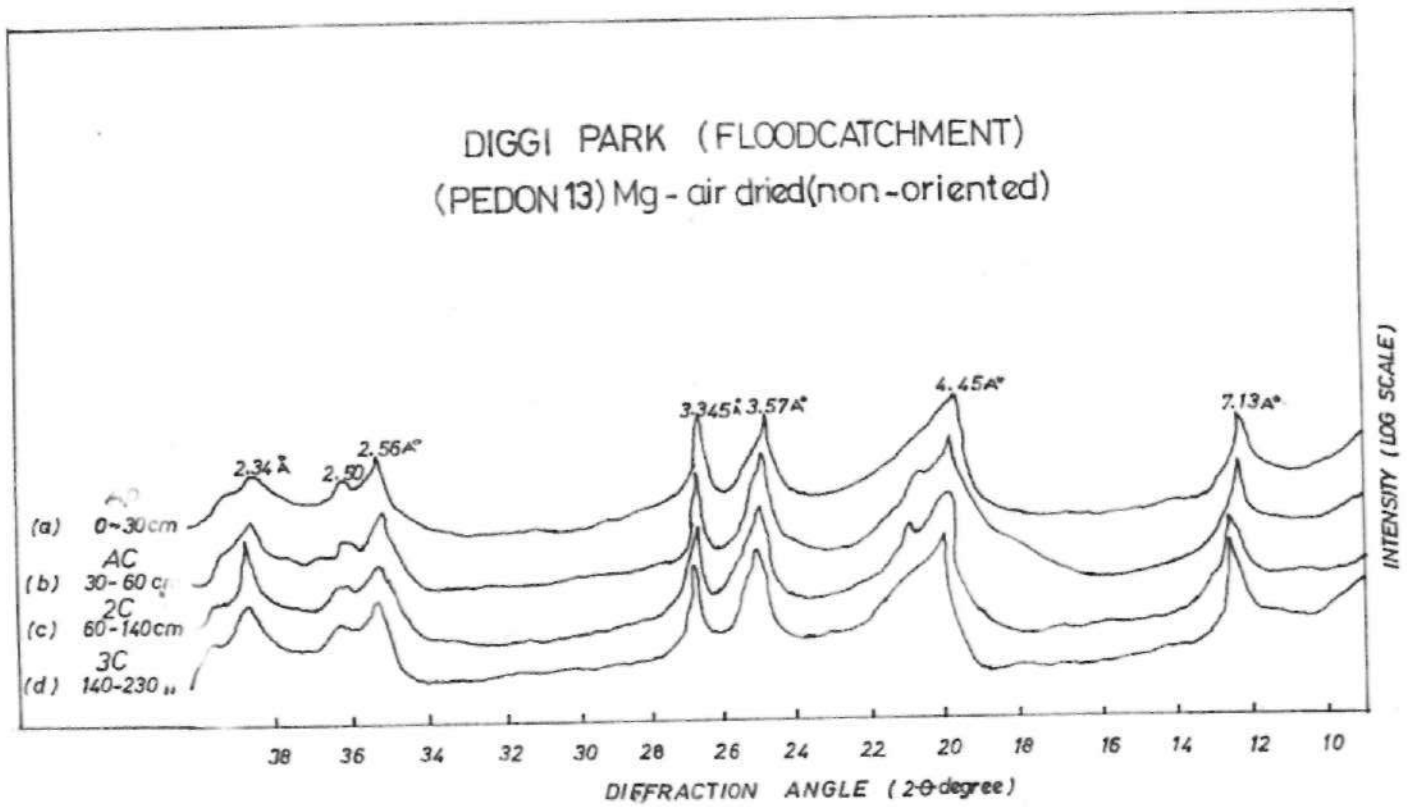


FIG. 15 X-RAY DIFFRACTOGRAMS OF CLAY

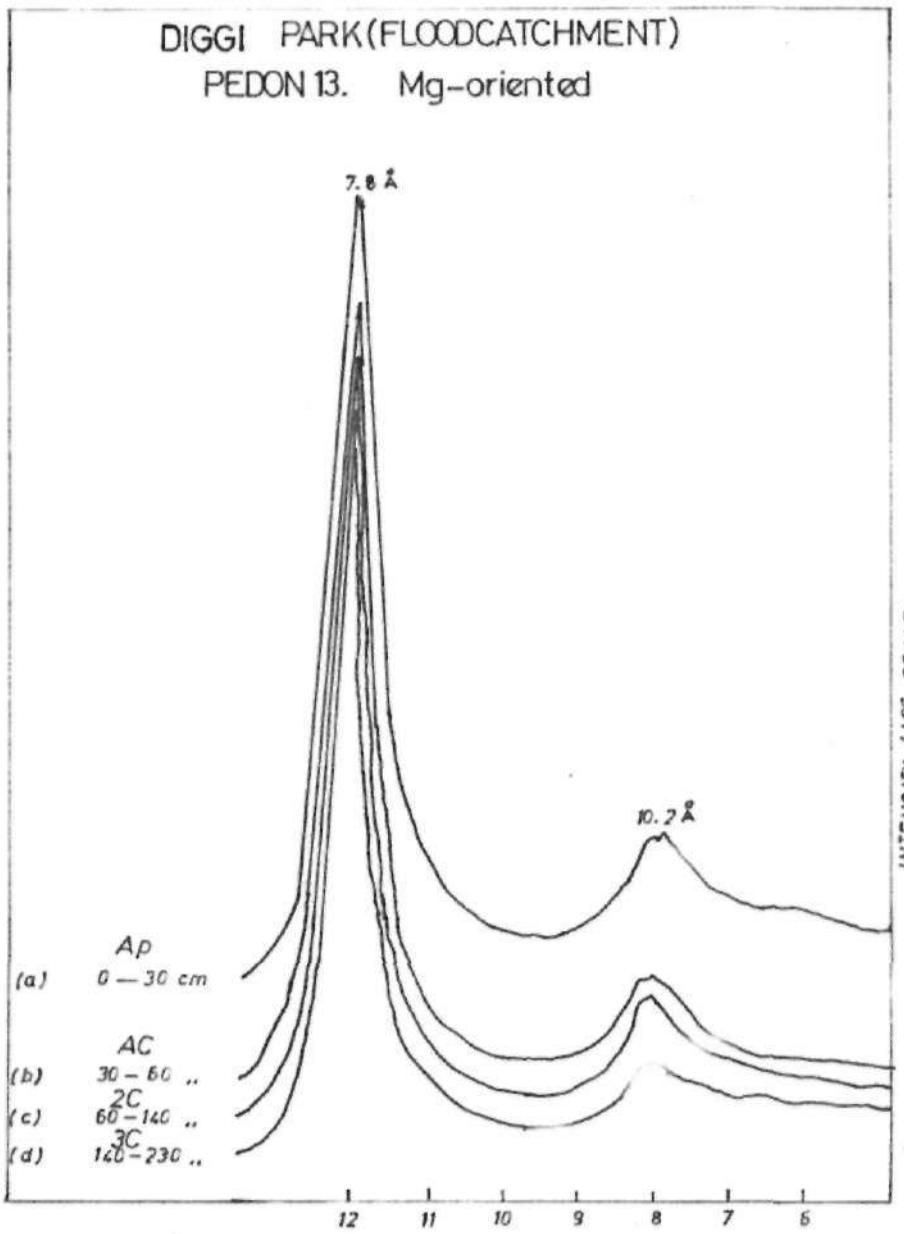


FIG 14. X-RAY DIFFRACTOGRAMS OF CLAY

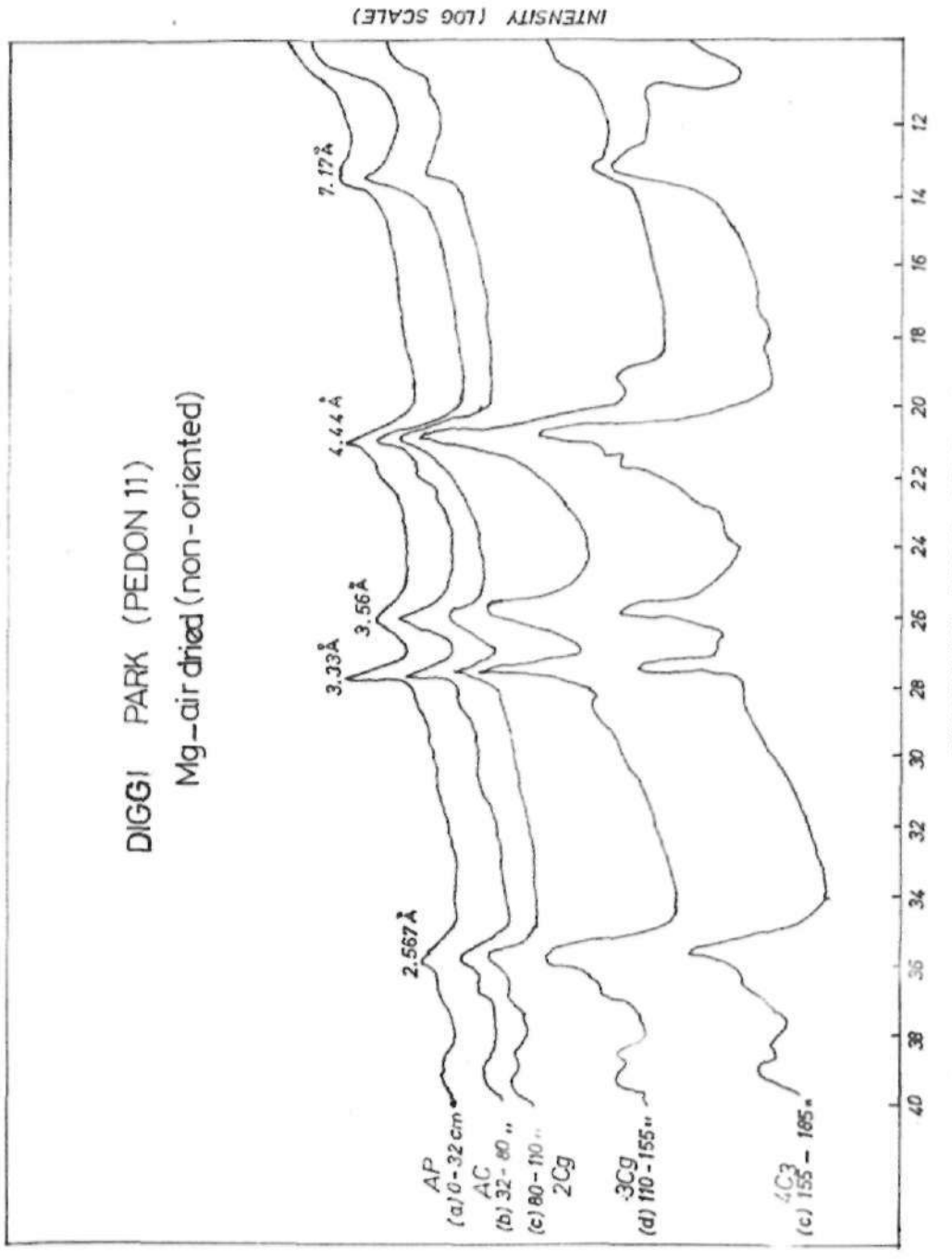
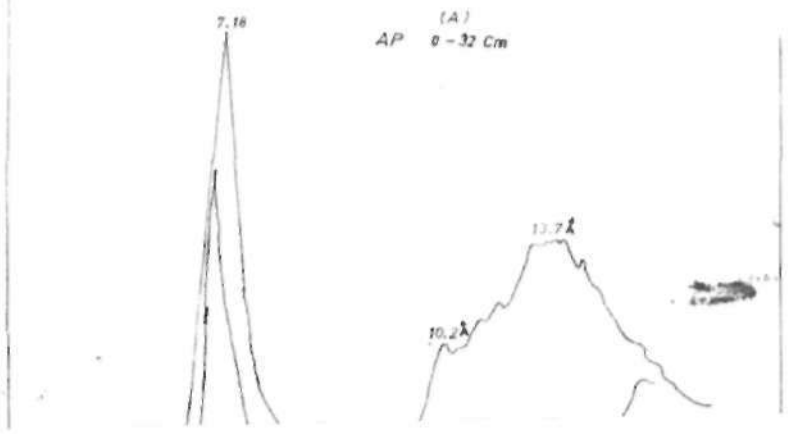


FIG. 13 X-RAY DIFFRACTOGRAMS OF CLAY

141
DIGGI PARK (PEDON II)
Oriented clay



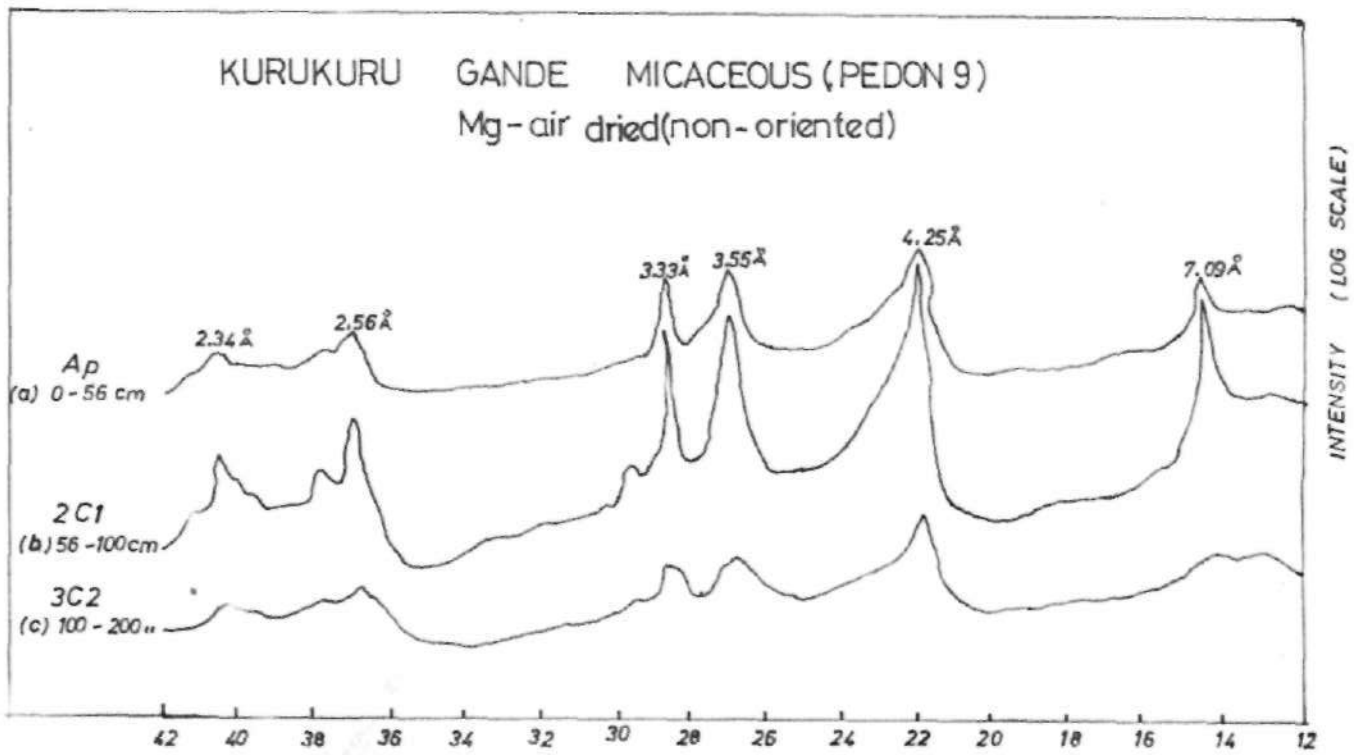


FIG 11. X-RAY DIFFRACTOGRAMS OF CLAY

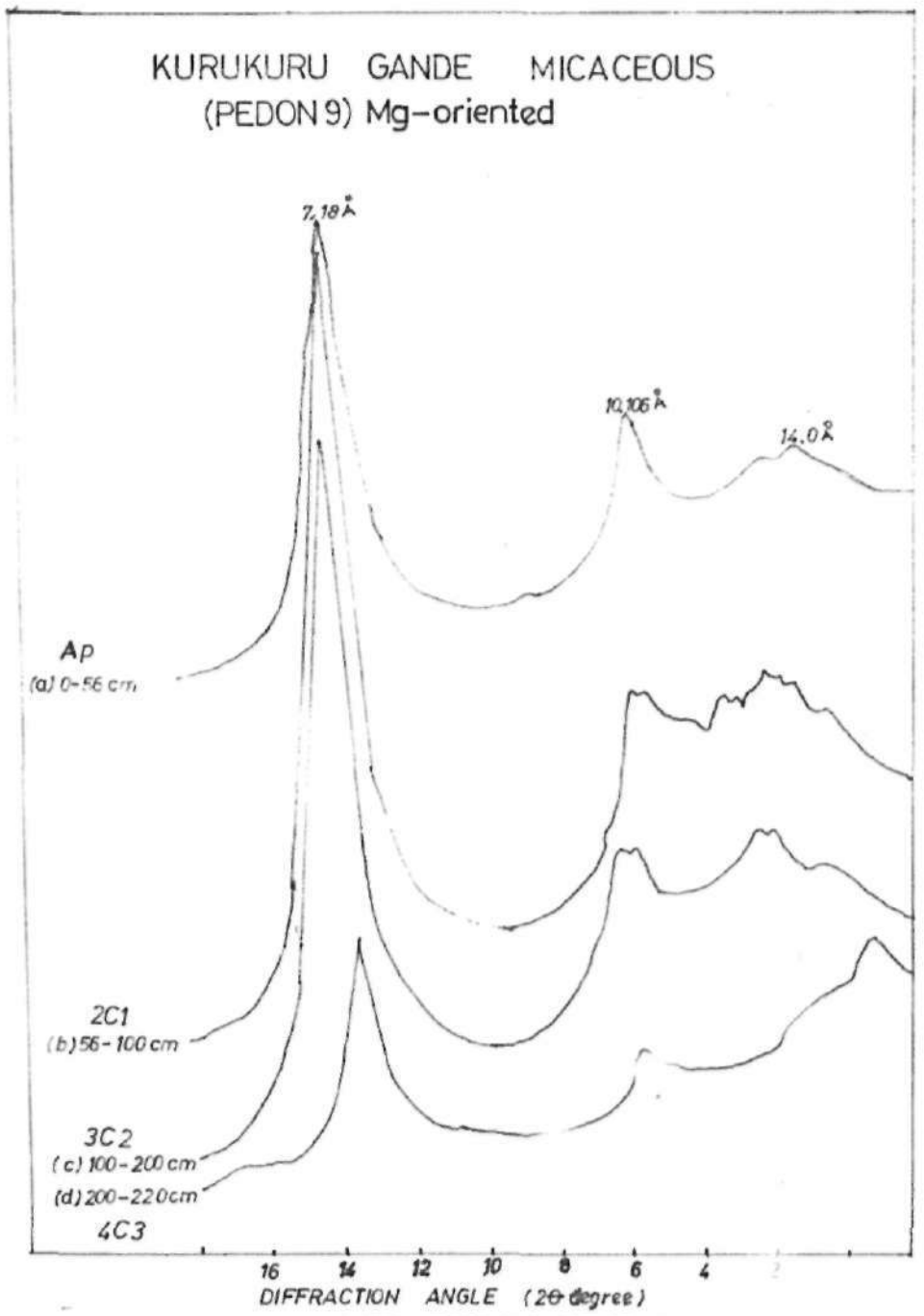


FIG 10. X-RAY DIFFRACTOGRAMS OF CLAY

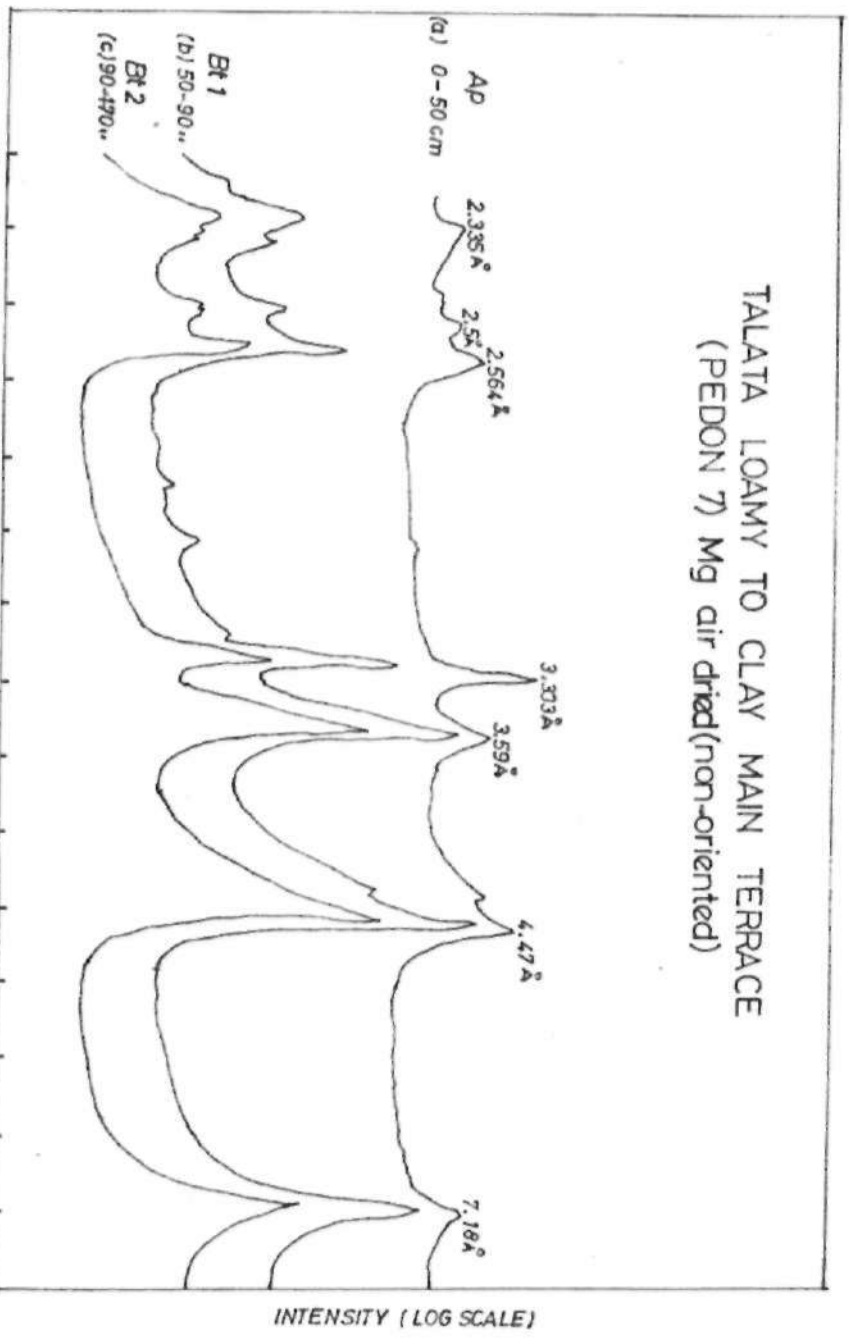


FIG 9. X-RAY DIFFRACTOGRAMS OF CLAY

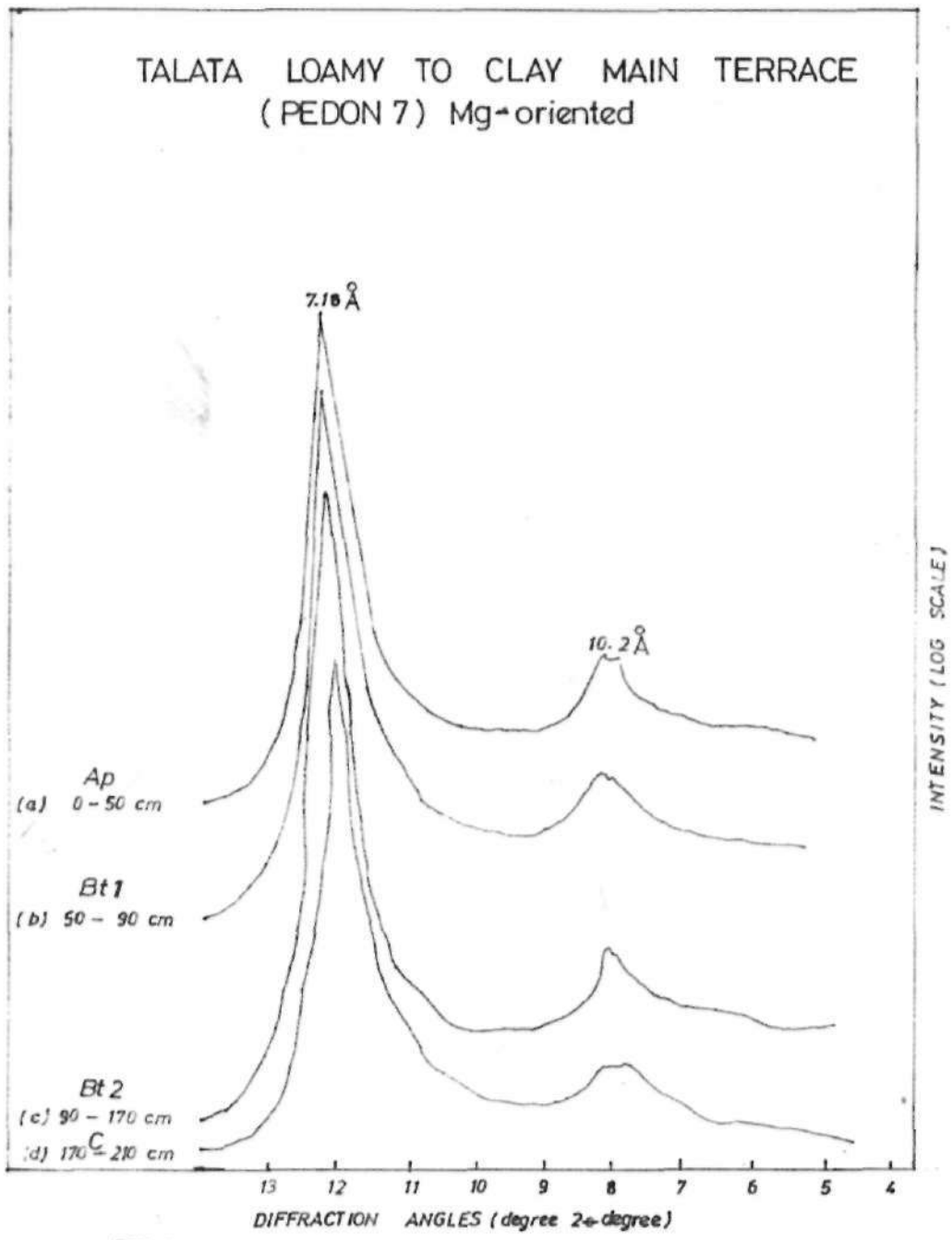


FIG 8. X-RAY DIFFRACTOGRAMS OF CLAY

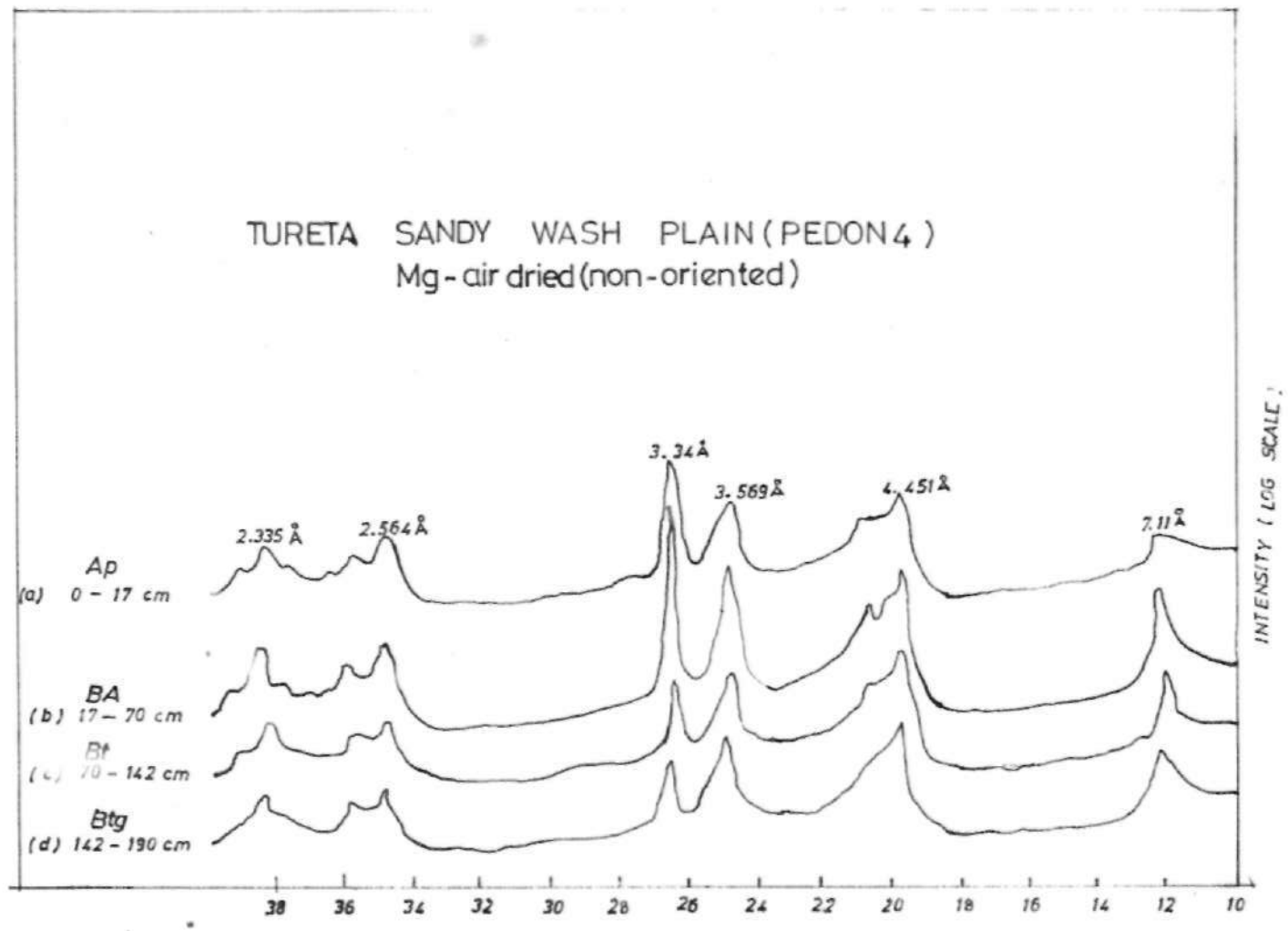


FIG 7. X - RAY DIFFRACTOGRAMS OF CLAY

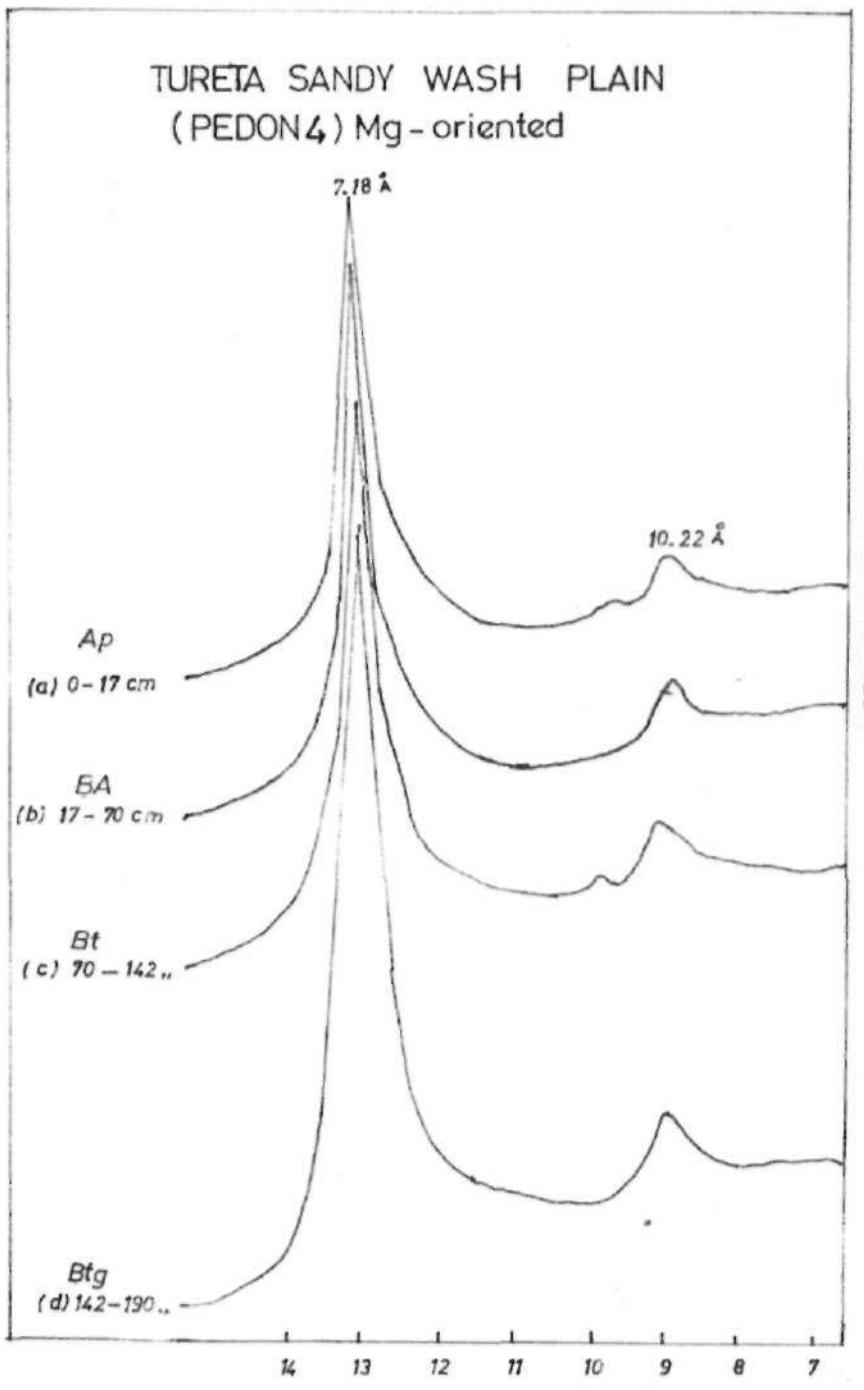


FIG 6. X-RAY DIFFRACTOGRAMS OF CLAY

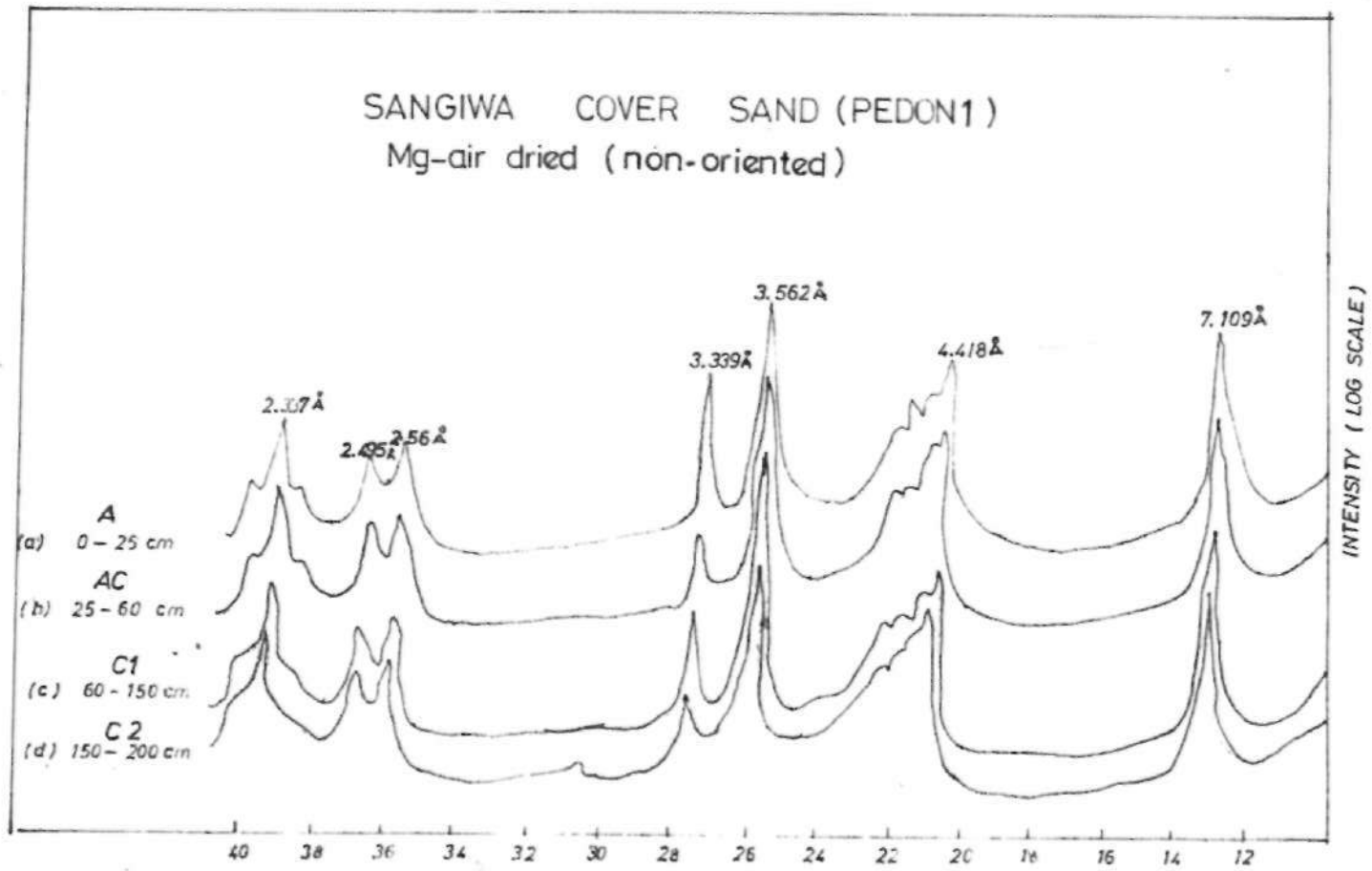


FIG. 5 X-RAY DIFFRACTOGRAMS OF CLAY

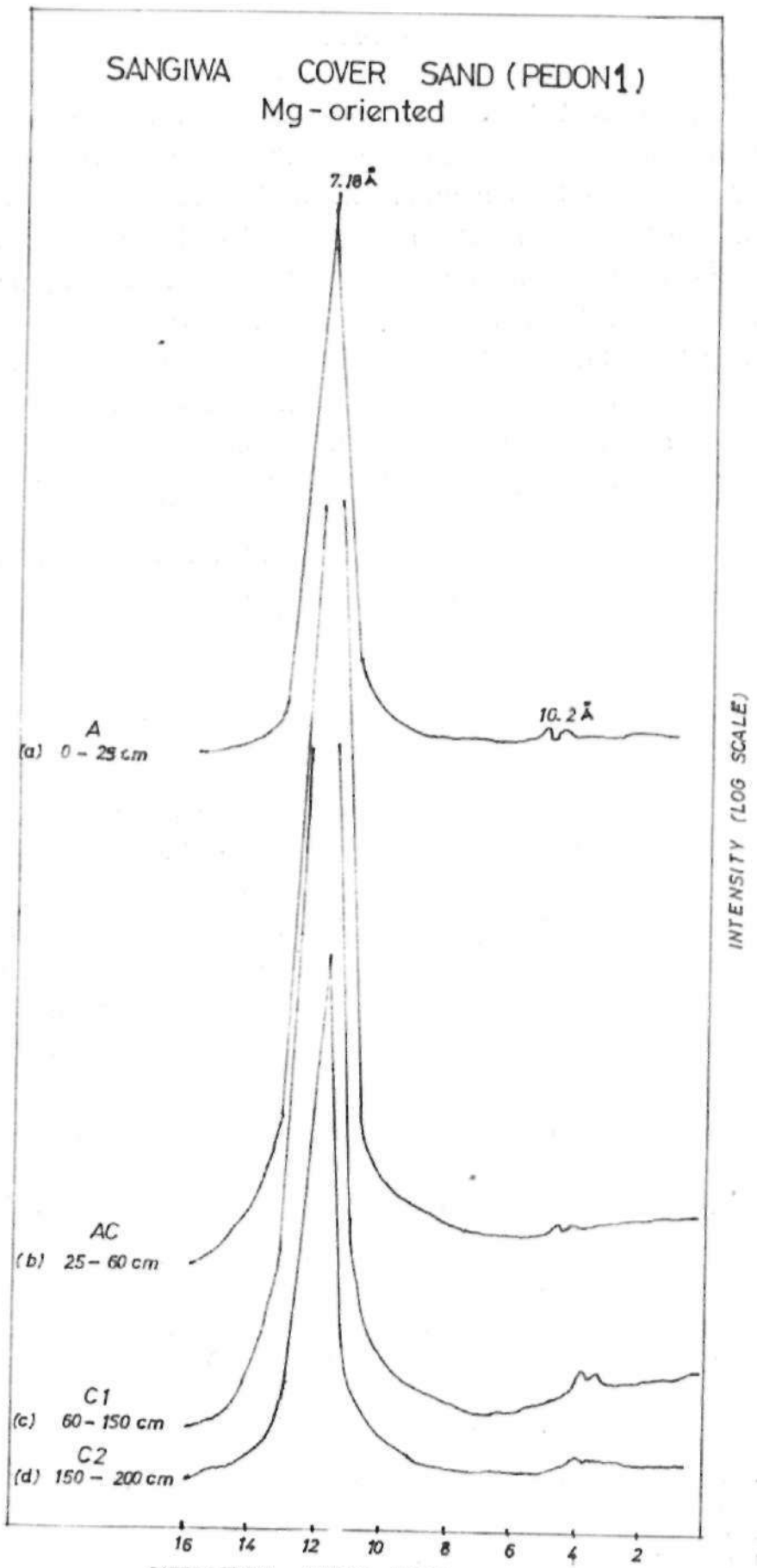


FIG 4 X-RAY DIFFRACTOGRAMS OF CLAY

5.5 Summary of Soil Characteristics

5.5.1 Sangiwa cover sand

Soils of Sangiwa cover sand geomorphic unit consist of flat to gently sloping, well-drained to somewhat excessively drained soils of crestal positions whose parent material consist of aeolian deposits over sedimentary materials. The soils consist of dark brown (7.5 YR 4/4) to reddish brown (5YR 4/4) sandy loam top soils over yellowish red (5YR 5/8) sandy loam or sandy clay loam sub-soils. Surface horizons have weak soil aggregates that are often crusted (plates 1(b) and 2) and very susceptible to both wind and water erosion when the crusted surfaces are broken either by cultivation or livestock traffic. The generally weak surface aggregates of soils of the Sangiwa cover sand unit can be attributed to the low clay and organic carbon contents and to the predominance of kaolinite in the clay fraction (Jones and Wild, 1975).

Soils of this geomorphic unit do not appear to have been cultivated. They are however extensively grazed by cattle and goats during and after the rainy season, and the few trees are felled for firewood (plate 1a), thus converting the area to open savanna woodland vegetation. Crusted surface soils tend to impede infiltration of water and aeration, hence increasing runoff following rain storms. It may also restrict seedling emergence.

Quartz plus potash feldspars are the dominant minerals in the sand fraction. Silt fractions are dominated by quartz, kaolinite, plagioclase and microline. Clay fractions of this unit are dominated by kaolinite, quartz and illite.

5.5.2 Tureta sandy "wash plain"

Soils of the Tureta sandy wash plain geomorphic unit belong to the group of soils located on mid and lower pediment slope positions of the landscape. They are well-drained to moderately well-drained soils formed from an admixture of aeolian deposits and colluvial materials over sedimentary materials of the Gundumi Formation. The soils of the unit consist of reddish yellow (5YR 4/6) to reddish brown (2.5YR 3/6) sandy loam or loamy sand surface horizons over strong brown (7.5YR 5/6) to light grey (5YR 7/1) sandy loam to sandy clay loam sub-soil horizons. The soils are deep and cultivated mainly to millet during the rainy season. The soils are characterized by severe capping and are easily susceptible to both wind and water erosion (plates 2 and 1b).

The vegetation of the area consists of open savanna wood-land. Extensive grazing by cattle and goats, bush burning during land preparation for cultivation and tree felling for firewood are commonly witnessed on the soils of this unit.

The mineralogy of the sand fraction of the soils of this geomorphic unit shows dominance of quartz plus potash feldspar.

Garnet, zircon, and ilmenite occur as trace minerals, possibly suggesting the colluvial origin of the soil parent materials of the unit. Silt fractions are dominated by quartz, kaolinite, plagioclase, muscovite and microcline. Goethite, haematite and magnetite occur only as trace minerals. The presence of such weatherable minerals like plagioclase and mica in soils of this geomorphic unit may mean that the soils still have some amount of weathering potential. Clay fractions are dominated by kaolinite, illite and quartz.

5.5.3 Talata loamy to clay main terrace

These soils occupy the terrace-plateau positions of the Bakolori area. The soils are thought to originate from an admixture of aeolian and alluvial deposits over terrace soil materials. These soils are generally well-drained, deep and slightly capped. They have dark brown (7.5YR 4/4) sandy loam top soil horizons over yellowish red (7.5YR 5/6) to strong brown (7.5YR 5/8) sandy clay loam sub-soil horizons.

Soils of this geomorphic unit are generally extensively cultivated mainly to millet, sorghum, cowpea and groundnut. The soils are very poor in organic carbon content, and this may account for the weak surface soil aggregates as well as the low inherent fertility of the soils. Though soil surfaces of the soil show very weak capping characteristics, many gully sites abound in the area, indicating that the soils of this unit are susceptible to

gully erosion.

The mineralogy of the sand fraction is dominated by quartz, potash feldspars, muscovite, biotite, hornblende, rutile, zircon, ilmenite, garnet, tourmaline and magnetite. The silt fractions consist of quartz, kaolinite, plagioclase microline, muscovite, biotite and goethite. The abundance of such weatherable minerals as plagioclase, microcline, biotite and hornblende in these soils may indicate that the soils are young and highly weatherable. X-ray diffraction analysis of the clay fraction of the soils show kaolinite and illite are the dominant clay minerals, in addition to other minerals like microcline and quartz.

5.5.4 Kurukuru-Gande micaceous unit

Soils of this geomorphic unit belong to the group of soils termed "fadama" soils. They are moderately well-drained and usually waterlogged for a considerable part of the rainy season. The soils occupy levee positions bordering the banks of river Sokoto. The soil parent materials are fluviatile in origin; having been gained from alluvial materials of the Sokoto river. The soils consist of light yellowish brown (10 YR 6/4) to brown (10 YR 4/3) sandy loam to loam surface horizons over reddish yellow (7.5 YR 7/8) to strong brown (7.5 YR 5/8) single grained, sandy subsurface horizon. Surface soils of this geomorphic unit are mica rich, the soils are very weakly capped, and during the dry season the

water table is beyond 200cm depth.

Vegetation of the area consists predominantly of tall trees and short grasses. The soils are cultivated to millet, sorghum, cowpea, potatoes and groundnut.

The mineralogy of the sand fractions of this unit shows abundance of quartz plus potash feldspars, biotite, muscovite, hornblende and traces of ilmenite, augite, garnet, tourmaline, zircon and magnetite. The silt separatesare also dominated by quartz, kaolinite, plagioclase, microcline, muscovite and biotite. Haematite and goethite occurred as trace minerals. The abundance of such weatherable minerals as biotite, hornblende and plagioclase, in these soils suggests that the soils still possess moderate weathering potential. The profiles could be said to be immature, as it presents a clearly stratified, non homogenized layer of freshly deposited soil parent materials, only separated by fine clay bands (Plate 5). Clay fractions of soils of this unit is dominated by kaolinite and illite clays. Smectite occurred at less than 3% composition. It is thought that the smectite may have resulted from mica transformations. The entire profile is quartz rich.

5.5.5 Diggi Park Unit

Soils of the Diggi Park geomorphic unit are also termed "fadama" soils. They are generally poorly drained,

waterlogged for a considerable part of the year and are located at depressional sites; either as backswamps of rivers and streams like Bobo river and Gada stream, or as flood catchment plains.

The backswamp phase of soils of the Diggi Park unit (pedons 11 and 12, Figs. 12 and 13) contain very recent alluvial deposits over sedimentary materials of the Gundumi Formation. Soil surfaces of this phase show numerous cracks, strong aggregates and soils may be said to be only slightly eroded, if at all. These soils have dark brown (10YR 4/3) to brownish yellow (10YR 6/6) clay to sandy loam surface horizons over dark greyish brown (10YR 4/3) to grey (N 5/0) clay sub-soil horizons. During the dry season, the watertable may recede beyond 150cm depth.

The vegetation of the area within this geomorphic unit is rich with numerous tall and huge trees and Imperata grasses, giving a picture of a parkland in the Sudan savanna zone. The area is cropped to rice, sugar cane, sorghum (Plate 6) and wheat.

The mineralogy of sand separates of this phase of the Diggi Park unit is dominated by quartz plus potash feldspar, muscovite, biotite and hornblende. Zircon, garnet, tourmaline and magnetite occurred as trace minerals. Silt fractions consist of quartz, kaolinite, microcline, plagioclase, hornblende, and muscovite. The abundance of

weatherable minerals like hornblende, biotite, muscovite, plagioclase, and microcline in these soils means that the soils still have a high degree of weathering potentials.

The flood catchment phase of the Diggi Park unit (pedon 13, Figs. 14 and 15) are derived from recent fluvial materials over older alluvio-colluvial materials. Their surfaces exhibit numerous cracks and strong aggregates and water table is beyond 230cm depth during the dry season, though the soil surfaces are waterlogged during the rainy season. Soils of this phase are dark yellowish brown (10YR 3/4) sandy clay loam surface horizons and dark brown (7.5YR 4/6) sandy clay loam sub-soil horizons.

The vegetation of the area is parkland type, having many trees and tall grasses (e.g. Imperata sp) and shrubs. The area is cultivated to sorghum, rice, wheat and sugarcane.

The sand fractions of this phase of Diggi Park unit did not contain biotite and hornblende which are contained in the other phase of Diggi Park geomorphic unit examined. Silt fractions also show dominance of quartz, kaolinite, plagioclase, muscovite, microcline and goethite; and did not contain biotite. The abundance of moderately weatherable minerals like muscovite and microcline over the readily weatherable minerals like plagioclase in the soils of this gemorphic unit give an indication of the extent of weathering to which soils of the unit is subjected. Clay

fractions contain kaolinite, illite, quartz and microcline.

5.6 Soil Classification

The soils in the study area are classified according to both the U.S.D.A. Soil Taxonomy (Soil Survey Staff, 1975) and the FAO/UNESCO soil legend (1974). A summary of the classification of the pedons investigated is presented in Table 11. The differentiating characteristics that are used for the classification include morphological, physical, chemical and mineralogical soil properties that are considered important in both systems of classification.

5.6.1 Classification according to Soil Taxonomy

In classifying the soils according to the U.S.D.A. Soil Taxonomy, the lowest category into which the soils are fitted is the FAMILY. It is pertinent to add that the moisture regimes of the soils around Bakolori area have been inferred to be aridic tropustic (ustic) and aquic following information obtained from climatological data (Table 4 and Fig. 2) of the area. Soils inferred to have aridic tropustic soil moisture regime include those of Sangiwa cover sand, Tureta sandy "wash plain", and Talata loamy to clay main terrace geomorphic units. Soils of the Kurukuru-Gande micaeceous unit are inferred to have ustic soil moisture regime, while those of the Diggi Park geomorphic unit which are usually seasonally waterlogged are inferred to

have an aquic soil moisture regime. The soil temperature regime for the entire Bakolori also is inferred to be isohyperthermic.

Sangiwa cover sand unit: Soils of the Sangiwa cover sand deposits vary from those with largely undeveloped profiles (pedon 1) to those with weakly developed argillic horizons (pedon 2).

The undeveloped or weakly developed soils have no diagnostic horizons except for an ochric epipedon. They, therefore, fit closely into the order of Entisols, and being developed in recent aeolian deposits fit into the suborder of Orthents. In addition, since the soils have an aridic tropustic (ustic) soil moisture regime, an isohyperthermic soil temperature regime, and a conductivity of the saturation extract that is less than 2mmhos/cm at 25°C in all subhorizons up to a depth of 2m, they are further classified in the great group of Ustorthents. The soils are classified at the subgroup level as Typic Ustorthents because they are deep, sandy loams located on extensive crestal positions of less than 2% slope.

Soils of the Sangiwa cover sand units which are located on crestal positions (pedon 1) have more than 15 per cent by weight of materials coarser than fine sand particles, and less than 18 per cent clay in the fine earth fraction. They can, therefore, be said to belong to the "coarse-loamy"

particle-size class. These soils also have less than 40 per cent of any one mineral other than quartz or feldspar, and can, therefore, be classified as having a "mixed" mineralogical class. This phase of the Sangiwa cover sand is classified at the family level as Typic Ustorthent, coarse-loamy, mixed, isohyperthermic.

Pedon 2 which represents soils of Sangiwa cover sand located on upper slope positions have ochric epipedons, and weak argillic sub-surface horizons. The argillic horizons have a dominant hue of 5YR, a colour value moist of 4 and above, and have a base saturation of 35% or more (by sum of cations at pH 8.2) at a depth of 1.8m below the soil surface. The soils are, therefore, classified as Alfisols. The soils also have an aridic tropustic (ustic) soil moisture regime, and an isohyperthermic soils temperature regime, and can be classified as Ustalfs. And because the soils do not have lithic or paralithic contact within 1.5m of the surface, and have a clay distribution such that the percentage of clay does not decrease by as much as 20 per cent of the maximum within a depth of 1.5m from the soil surface, they can be classified further into the great group of Paleustalfs. These soils have cation exchange capacity (CEC) of less than 24 meq/100g clay in the major part of the argillic horizons, and are classified into the subgroup of Oxic Paleustalfs.

Soils represented by pedon 2 have more than 15 per cent of the sand fractions coarser than fine sand fractions (0.25 - 0.1 mm) and also have a clay content within the 18 to 36% range in the fine earth fraction. They can, therefore, be classified into the fine loamy particle-size class. They also have less than 40 per cent of any one mineral (Table 8, 9 and 10) other than quartz or feldspars in the fine sand fraction (0.25 - 0.1 mm). They fit into the mixed mineralogy class. The soils are, therefore, classified at the family level as Oxic Paleustalf, fine-loamy, mixed, isohyperthermic.

Tureta sandy "wash plain" unit: Soils of Tureta sandy wash plain geomorphic unit occupy the mid-slope (pedon 3) to lower slope (pedon 4) positions within the soilscape of the study area.

Soils of this unit have an ochric epipedon, and generally possess weak to strongly argillic Bt horizons. Pedons 3 and 4 have an epipedon that is both massive and hard when dry, and have an aridic tropustic (Ustic) soil moisture regime. Also, pedon 4 has a hue in the Bt horizon of 5YR, and a colour value (moist) of 5, and both pedons have a base saturation by sum of cations greater than 35 per cent at a depth of 1.8m below the soil surface. The two pedons are, therefore, classified into the order of Alfisols, and the sub order Ustalfs. The argillic horizons of these two pedons do not have a lithic or paralithic contact within

1.5m of the surface, and have a clay distribution such that the percentage of clay does not decrease by as much as 20 per cent of the maximum within a depth of 1.5m from the soil surface. They can, therefore, be classified further in the great group as Paleustalfs. The CEC clay (by calculation) of the pedons are less than 24 meq/100g and so they are classified into the sub-group Oxic Paleustalfs.

The soils have more than 15 per cent of the sand fractions coarser than fine sand (0.5-0.1 mm), and also have a clay content within the 18 to 36% range in the fine earth fraction. They can, therefore, be classified as having a fine-loamy particle-size class. They also have less than 40 per cent of any one mineral other than quartz and feldspar in the fine sand fraction (0.25-0.1 mm), (Tables 9, 10 and 11) and, therefore, fit into the mixed mineralogy class. They can, therefore, be classified at the family level as Oxic paleustalf, fine-loamy, mixed, isohyperthermic.

Talata loamy to clay main terrace unit: Soils of this geomorphic unit (pedons 7 and 8) have an ochric epipedon and are argillic. Pedon 7 has a dominant colour hue of 5YR, value of 4 (moist), and about 43.8 per cent base saturation (by sum of cations) in the Bt_1 and Bt_2 horizons which are about 1.8m below the soil surface. Pedon 8 has about 38.4% average base saturation (by sum of cations within the depth of 1.25m below the upper boundary of the argillic horizon. Soils of both pedons have epipedons that are massive and

hard when dry, and have an aridic tropustic (ustic) soil moisture regime and they are, therefore, classified as Alfisols. They can, therefore, be classified into the sub-order Ustalfs based on the soil temperature regime. These soils do not have a lithic or paralithic contact within 1.5m of their surfaces, and have a clay distribution pattern such that the percentage of clay does not decrease by as much as 20 per cent of the maximum within a depth of 1.5m from the soil surface; they can, therefore, be classified further into the great group Paleustalfs. These soils also have base saturations (by sum of cations) that is less than 75 per cent in all the argillic horizons, and the CEC-clay is greater than 24 meq/100g in the major argillic horizons. They can be fitted into the sub-group Ultic Paleustalfs.

The soils also have more than 15 per cent (by weight) of sand fractions coarser than fine sand in the fine sand fraction (.25 - .1mm). The clay contents fall within the acceptable range of 18 to 36%, and so the soils can be classified into the fine-loamy particle-size class. In addition, they have less than 40 per cent of any one mineral other than quartz or feldspars in the sand fraction (Table 8) and are, therefore, classified into the mixed mineralogy class. The soils of this geomorphic unit have, therefore, been classified into the family Ultic Paleustalf, fine-loamy, mixed, isohyperthermic.

Kurukuru-Gande micaceous unit: Soils of the Kurukuru-Gande micaceous deposits typified by pedons 9 and 10 represent the largely undeveloped soils of fluviatile origin, with no identifiable diagnostic horizons other than an ochric epipedon. They, therefore, fit closely into the order of Entisols. These soils do not have a lithic or paralithic contact within 25cm of the soil surface, are on 1% slopes, and have organic carbon content that decreases irregularly with depth. The soils show soil strata composed mainly of sandy loam, loamy sand and sand arrangements, they have textures of loamy very fine sand or finer in some sub-soil horizons below the Ap horizon, and are not permanently saturated with water to have the characteristics associated with wetness that are defined for Aquents. They, therefore, fit into the sub-order "Fluvents". The soil moisture regime is ustic and the soil temperature regime is isohyperthermic. Hence, these soils are classified into the great group, Ustifluvents. The soils do not have mottles within 50cm of the surface, but have less than 35 per cent clay in horizons that total 50cm in thickness. They, therefore, fit in the sub-group of Typic Ustifluvents.

The soils contain more than 15 per cent (by weight) of sand particles coarser than fine sand fraction, and less than 18 per cent clay in the fine-earth fraction, and can, therefore, be classified into the coarse loamy particle-size class. Also, they contain less than 40 per cent of any one

mineral other than quartz or feldspars in the sand fraction, they, therefore, fit into the mixed mineralogy class. Soils of the Kurukuru-Gande micaceous deposit can, therefore, be classified at the family level as Typic Ustifluvent, coarse-loamy, mixed isohyperthermic.

Diggi Park Unit: Soils of the Diggi Park geomorphic unit are largely undeveloped alluvial and colluvial deposits of backswamps (pedons 11 and 12) and flood catchment areas (pedon 13).

Soils of this unit have an ochric epipedon and no other identifiable diagnostic subsurface horizon. They can, therefore, be classified into the order Entisols. These soils lack gilgai, wedge shaped natural structural aggregates, and slickensides at a depth between 25cm and 1m. They are saturated with water at sometime of the year, have textures finer than loamy fine sand in all sub-horizons, but pedons 11 and 12 have within 50cm depth from the soil surface mottled horizons and a moist chroma of zero. Pedon 13, however, has no mottles, but has a moist colour value of less than 4 within 50cm of the surface. Soils of this unit are, therefore, classified into the sub-order Aquents. The entire soils of the Diggi Park geomorphic unit have an organic carbon content that decreases irregularly with depth and textures finer than loamy fine sand in all sub-horizons between the Ap and 1m. They, therefore, fit into the great group Fluvaquents.

Pedon 11 has cracks at some periods in most years that are about 1cm wide at a depth of 50cm, which extend upward to the soil surface horizon. They have more than 35% clay in horizons that total more than 50cm in thickness, and have an Ap horizon having a moist colour value of 4, and are therefore, classified into the sub-group Vertic Fluvaquents. However, pedon 12 has an Ap horizon that has a moist colour value of more than 4, and an isohyperthermic soil temperature regime and are, therefore, classified into Tropic Fluvaquents at the sub-group level. Also, soils of pedon 13 are fluvaquents that are not mottled, and do not have a chroma (moist) of less than 6 in all sub-horizons between the base of the Ap and 75cm depth. They are, therefore, fitted into the sub-group of Aeric Tropic Fluvaquents.

Pedon 11 contains 30 through 52% clay in the fine-earth fraction and, therefore, belongs to the fine-clayey particle-size class. Also, it contains a mixture that has more montmorillonite than any other clay mineral. It fits closely into the montmorillonitic mineralogical class. The soils can, therefore, be classified at the family level as Vertic Fluvaquent, fine-clayey, montmorrillointic, isohyperthermic.

Pedon 12 contains by weight, 15% or more fine sand (0.25 - 0.1 mm) or coarser, and 18 through 34% clay in the

fine-earth fraction. It can be classified into the fine-loamy particle-size class. Also, it contains a mixture of clay minerals that have no one clay mineral greater than the other by weight, it can, therefore, be classified into the mixed mineralogical class. These soils can, therefore, be classified into the family Tropic Fluvaquent, fine-loamy, mixed, isohyperthermic.

Pedon 13 (flood catchment) has 22 to 34% clay, more than 15% sand particles coarser than fine sand fractions, and can be classified into the fine-loamy particle-size class. Also, the soils have less than 40% of any one mineral other than quartz and feldspars in the sand fraction, and fit into the mixed mineralogical class. The soils can, therefore, be classified at the family level as Aeric Tropic Fluvaquent, fine-loamy, mixed, isohyperthermic.

5.6.2 Classification according to the FAO/UNESCO Soil Legend

Sangiwa cover sand: Soils of Sangiwa cover sand vary between undeveloped (pedon 1) and weakly argillic (pedon 2) soils.

Soils of pedon 1 represent weak or undeveloped and unconsolidated soil materials of recent aeolian deposits. They have no horizons other than an ochric horizon, lack characteristics which are diagnostic for Vertisols and Andosols and lack high salinity. They are, therefore,

classified as Regosols. These soils have a base saturation (by NH4OAc) of less than 50 per cent at least between 20 and 50cm from the soil surface and can, therefore, be classified further as Dystric Regosols.

Pedon 2 represents soils having argillic B horizons with a clay distribution where the percentage of clay does not decrease from its maximum amount by as much as 20 per cent within 150cm of the surface. Since the soil moisture regime is ustic, they can, therefore, be classified as Nitosols. The soils also have a base saturation of less than 50 per cent (by NH4OAc) in, at least, a part of the argillic B horizon within 125cm of the surface, and lack a high organic matter content in the B-horizon. They are, therefore, classified further as Dystric Nitosols.

Tureta Sandy Wash Plain Unit: Soils of the Tureta sandy wash plain (pedons 3 and 4) have argillic B horizons with a clay distribution where the percentage of clay does not decrease from its maximum amount by as much as 20 per cent within 150cm of the surface. The soils have ochric epipedons, lack plinthite within 125cm of the surface, and have an aridic tropustic (ustic) soil moisture regime. They are therefore, classified as Nitosols. These soils are further classified as Dystric Nitosols because the base saturation is less than 50 per cent (by NH4OAc) in at least a part of the argillic B horizon within 125cm of the surface, and the soils lack high organic matter content in the B horizon.

Talata Loamy to Clay Main Terrace Unit: Soils of the Talata loamy to clay main terrace unit (pedons 7 and 8) are soils having argillic B horizons with a clay distribution pattern such that the percentage of clay does not decrease from its maximum amount by as much as 20 per cent within 150cm of the soil surface. The soils have ochric epipedons, lack plinthite within 125cm of the surface, and have aridic tropustic (ustic) soil moisture regime. They, therefore, are classified as Nitosols. In addition, the soils have a base saturation of less than 50 per cent (by NH4OAc) in at least a part of the argillic B horizon within 125cm of the surface, and lack high organic matter content in the B horizon, and can be classified further as Dystric Nitosols.

Kurukuru-Gande micaceous unit: Soils of this geomorphic unit (pedons 9 and 10) are developed from recent fluviatile deposits having no diagnostic horizons other than an ochric A horizon. Their organic matter content decreases irregularly with depth, and the polypedons receive fresh materials at regular intervals. The soil profiles show fine stratification (plate 5) and can be classified as Fluvisols. However, they have a base saturation (by NH_4OAc) of more than 50 per cent between 20 and 50cm from the soil surface. The soils are not calcareous, lack sulphuric horizon and sulfidic horizon and sulfidic material within 125cm of the surface. They can be classified further as Eutric Fluvisols. But

pedon 10 has a base saturation (by NH_4OAc) of less than 50 per cent in at least a part of the soils between 20 and 50cm from the surface, equally lack sulfuric horizon and sulfidic materials within 125cm of the surface, and have, therefore, been classified further as Dystric Fluvisols.

Diggi Park Unit: These soils (pedons 11, 12 and 13) are formed from unconsolidated materials of recent alluvial deposits, showing hydromorphic properties within 50cm of the surface, having no diagnostic horizons other than an A horizon and a cambic B horizon, and lacking characteristics which are diagnostic for Vertisols. They can, therefore, be classified into the soils unit of Gleysols.

Pedons 11 and 13 belong to the group of Gleysols having a base saturation (by NH_4OAc) of 50 per cent or more, at least, between 20 and 50cm from the surface, but which are not calcareous. They lack plinthite within 125cm of the surface and are, therefore, classified as Eutric Gleysols. Pedon 12 represents the group of Gleysols having a base saturation (by NH_4OAc) of less than 50 per cent at least between 20 and 50cm from the surface. It can, therefore, be classified further as Dystric Gleysols.

Table 11: Summary of classification of the Pedons studied in the Bakolori area

Geomorphic Unit	Pedon	U.S.D.A.	FAO/UNESCO
Sangiwa cover	1	Typic Ustorthent, coarse-loamy, mixed, isohyperthermic.	Dystric Regosol
" "	2	Oxic Paleustalf, fine-loamy, mixed, isohyperthermic.	Dystric Nitosol
Tureta sandy "wash plain"	3	Oxic Paleustalf, fine-loamy, mixed, isohyperthermic.	Dystric Nitosol
" "	4	Oxic Paleustalf, fine-loamy, mixed, isohyperthermic.	Dystric Nitosol
Talata loamy to clay main terrace	7	Ultic Paleustalf, fine-loamy, mixed, isohyperthermic.	Dystric Nitosol
" "	8	Ultic Paleustalf, fine-loamy, mixed, isohyperthermic.	Dystric Nitosol
Kurukuru-Gande micaceous deposit	9	Typic Ustifluvents, coarse-loamy, mixed, isohyperthermic.	Eutric Fluvisol
" "	10	Typic Ustifluvent, coarse-loamy, mixed, isohyperthermic.	Dystric Fluvisol

Table 11 (Contd.)

Geomorphic Unit	Pedon	U.S.D.A.	FAO/UNESCO
Diggi Park	11	Vertic Fluvaquent fine-clayey, montmorillonitic, isohyperthermic.	Eutric Gleysol
" "	12	Tropic Fluvaquent, fine-loamy, mixed, isohyperthermic.	Dystric Gleysol
" "	13	Aeric Tropic Fluvaquent, fine loamy, mixed, isohyperthermic.	Eutric Gleysol

Chapter 6

SUMMARY AND CONCLUSIONS

Soils occurring in five major geomorphic units of the Bakolori area were studied with a view to finding out if the various geomorphic units recognized by Sombroek and Zonneveld (1971) can also be used as a basis for separating the soils in the area. Also, the study was intended to classify the soils according to the U.S.D.A. Soil Taxonomy (Soil Survey Staff, 1975) and the FAO-UNESCO soil legend (1974). In pursuance of these objectives, the following investigations were conducted:

i. A general assessment of the physical setting of the study area.
ii. A study of the morphological, physical, chemical and mineralogical characteristics of the soils within the five selected geomorphic units.
iii. A taxonomic classification of the soils according to the U.S.D.A. Soil Taxonomy and FAO-UNESCO Soil legend.

Regarding the general assessment of the physical setting of the study area, Bakolori is located in the Sudan savanna region of Nigeria. It is situated between latitudes $12^{0}30'$ and $13^{0}00'$ North and longitude $5^{0}30'$ and $7^{0}00'$ East, in the south-eastern part of Sokoto State. The project area covers a total of 52,850.0 hectares. The underlying

geology is the Gundumi Formation (FOA, 1969; Sombroek and Zonneveld, 1971; Kogbe, 1976). The soil parent materials consist of layers of aeolian materials over sediments of old alluvium at the crestal positions, admixtures of aeolian and colluvial materials over alluvial sediments at upper, mid and lower slope positions and a thin mantle of aeolian materials over thick sedimentary alluvial terrace material at the terrace-plateau areas. In the valley bottoms (Blackswamp and floodcatchment areas), soil parent materials consist of mixed aeolio-colluvial materials over alluvium. In the levee areas soil materials are mainly recently deposited fluviatile materials. The soil temperature regime in the entire area is isohyperthermic, and the soil moisture regime is aridic tropustic in the upland areas, Ustic in the Levee areas, and aquic in the backswamp and flood-catchment areas.

The five major geomorphic units identified by Sombrock and Zonneveld (1971) as Sangiwa cover sand, Tureta sandy "wash plain", Talata loamy to clay main terrace, Kurukuru-Gande micaceous and Diggi Park units were studied to determine their morphological, physical, chemical and mineralogical properties. Sangiwa cover sand unit is located at crestal and upper slope positions, Tureta sandy "wash plain" at mid and lower slopes, Talata loamy to clay main terrace at terrace-plateau positions, Kurukuru-Gande micaceous at the levees of the Sokoto river, and Diggi Parks

at the backswamps and flood catchment areas. Soils of Sangiwa cover sand, Tureta sandy "wash plain", and Talata loamy to clay main terrace units are well to moderately well drained upland soils, but soils of the Kurukuru-Gande micaceous are moderately well-drained Levee soils, while soils of the Diggi Park units are somewhat poorly drained to poorly drained valley bottom soils.

Morphologically, the upland soils exhibit unstable and weak structural development in the surface horizons and are very susceptible to wind and water erosion. Their surfaces show strong to moderate capping after the rains. Soils of Sangiwa cover sand at crestal positions (pedon 1) show only little horizon development. They are essentially layered aeolian deposits. However, soils of the Sangiwa cover sands on the upper slopes and soils of the Tureta sandy wash plain and the Talata loamy to clay main terrace located on the middle to lower slopes, and the terrace-plateau positions, respectively, have developed argillic horizons, as evidenced by the occurrence of clay skins in the Bt horizons. Levee soils of the Kurukuru-Gande micaceous units are of recent fluviatile parent materials. They show no distinct horizon development but (pedons 9 and 10) exhibit fine stratification of layered soil materials separated by bands of fine clay and organic matter. Soils of the Diggi Park unit are also derived from recent alluvium of the Bobo river, Gada stream, and fluvial flood catchment materials. They show strong

gleying and iron and mangnese oxide nodule formation. Soils of the study area are generally deep.

Particle size analysis indicates that soils of Sangiwa cover sand have mainly sandy loam surface horizons, over sandy loam or sandy clay loam sub-surface horizons. The well developed argillic soils of Tureta sandy wash plain and Talata loamy to clay main terrace units have sandy loam surface horizons, and sandy clay loam sub-soil horizons. Soils of Kurukuru-Gande micaceous units have sandy loam or loamy sand top soils over sandy sub-soil horizons. Also, colluvio-alluvial soil materials of the Diggi Park units have varying textures of clay, sandy clay loam, and sandy loam surface horizons, over clay and sandy clay loam sub-soils.

Soil drainage and the position on the landscape appear to have a direct influence on the fertility status of the soils. For example, total exchangeable bases, cation exchange capacity (CEC-soil NH_4OAc), extractable iron, base saturation (pH 7) and soil pH appear to increase from the crestal and upper slopes, to mid and lower slopes, with the highest values usually obtained in the soils of the valley bottom. This trend may be attributed primarily to erosion, which may have transported soil materials from crestal and upper slopes, and deposited them at the valley bottoms. Cummulation of these eroded soil materials possibly occur in the Diggi Park unit areas. However, bush burning,

extensive grazing, removal of crop residues for feeding livestock and for fencing and tree felling for firewood may have exacerbated the generally poor fertility status of soils of the upland areas. It is possible that the good vegetative cover, and the activities of beneficial soil micro-organisms have also contributed to the high fertility level of soils of the valley bottoms.

The x-ray diffraction analysis of the sand, silt and clay fractions of the soils shows that quartz plus K-feldspars dominate the mineralogy of the sand fractions. Trace amounts of zircon, garnet, ilmenite and magnetite were identified in the sand fractions of all soils examined. Soils of Talata loamy to clay main terrace differed from those of its associated upland units by containing hornblende, tourmaline, in addition to the above-mentioned accessory minerals. Sand fractions of soils of the Kurukuru-Gande micaceous and Diggi Park units also contain hornblende, tourmaline and augite in addition to zircon, garnet, ilmenite and magnetite. It is possible that the presence of weatherable minerals in the soils of Talata loamy to clay main terrace, Kurukuru-Gande micaceous and Diggi Park units may mean that they are less weathered than soils of Sangiwa cover sand and Tureta sandy "wash plain". Regarding the mineralogy of the silt fractions, quartz, microcline, plagioclase, muscovite and kaolinite dominated the mineralogy of all the samples examined. However, silt fractions of soils of the Talata loamy to clay

main terrace, and Kurukuru-Gande micaceous units contained biotite in addition to those already enumerated above. The clay fractions of the soils are dominated by kaolinite though illite appears to be the only 2:1 lattice layer silicate clay mineral common in all the soils studied. Smectites were, however, identified in soils of the Kurukuru-Gande micaceous and Diggi Park units. It is possible that smectification by neoformation occurred in pedon 11 which represent soils of the Diggi Park unit, while mica transformation to smectite may account for the smectite clays that are present in pedon 9 which represents soils of the Kurukuru-Gande micaceous unit. Generally, soils of the Bakolori area can be said to be moderately weathered as they still possess some amounts of weatherable minerals.

The soils were classified using the U.S.D.A. Soil Taxonomy (Soil Survey Staff, 1975) and the FAO-UNESCO soil legend (1974). In the upland areas, soils of the Sangiwa cover sand on the crestal position are classified as Typic Ustorthents, coarse-loamy, mixed, isohyperthermic at the family level of the U.S.D.A. Soil Taxonomy and as Dystric Regosol in the FAO-UNESCO system. Soils of the Sangiwa cover sand on the upper slope positions (pedon 2) and Tureta sandy "wash plain" on both middle and lower slope positions are classified at the family level as Oxic Paleustalf, fine loamy, mixed, isohyperthermic in the U.S.D.A. Soil Taxonomy and as Dystric Nitosol in the FAO-UNESCO soil legend. Sombrock and

Zonneveld (1971) classified soils of the Sangiwa cover sand and Tureta sandy "wash plain" as Red acid sand/Quartzi-psamment. From this study, it is found that soils of the Sangiwa cover sand on crestal positions have not developed any horizons, and are, therefore, different from those of the upper, mid and lower slope positions (Tureta sandy wash plain unit) that have argillic horizons. Soils of the Sangiwa cover sand on crestal areas are, therefore, Entisols, but lacks enough quartz fragments necessary for a Quartzipsamment classification proposed by Sombroek and Zonneveld (1971). It is also thought that Sombroek and Zonneveld (1971) may have wrongly enclosed the upper slope soils into the Sangiwa cover sand unit, as they have properties that more appropriately fit into the Tureta sandy wash plain unit.

Soils of the Talata loamy to clay main terrace are classified at the family level as Ultic Paleustalf, fine-loamy, mixed, isohyperthermic in the U.S.D.A. Soil Taxonomy and Dystric Nitosols in the FAO-UNESCO soil legend. Sombroek and Zonneveld (1971) classified these soils as Reddish or Yellowish Brown Ferruginous Tropical Soil/aquic Vetustalf and Solodized Solonetz/Natraqualf. It is observed that neither the EC_{25^oC} or the exchangeable sodium percentage content of soils of this unit meet the critical limit of 4 mmhos/cm and 15%, respectively, required for a sodic soil and will, therefore, not be a solodized solonetz or Natraqualf. Also, the soil moisture regime of the area is aridic tropustic and not aquic.

Soils of the Kurukuru-Gande micaceous units may be considered a geomorphic unit having freshly gained fluviatile soil materials. Soils of this unit are rightly called "micaceous" by Sombroek and Zonneveld (1971) because they contain more than 50% by weight of mica (biotite plus muscovite) materials. These soils are classified at the family level in the U.S.D.A. Soil Taxonomy (Soil Survey Staff. 1975) as Typic Ustifluvent, coarse-loamy, mixed, isohyperthermic, and as Eutric Fluvisols in the FAO-UNESCO soil legend. These soils were classified as Typic, slightly or moderately matured Juvenile soils/aquic Haplorthents, partly haplustalfic by Sombroek and Zonneveld (1971). Soils of this unit have an ustic moisture regime and not aquic. However, the soils are juvenile and mostly immature. They are rightly classified by Sombroek and Zonneveld (1971) as Entisols.

Soils of the Backswamp phase of the Diggi Park unit are classified as Vertic Fluvaquent, fine-clayey, montmorillonitic, isohyperthermic (pedon 11) and Tropic Fluvaquent, fine-loamy, mixed, isohyperthermic (pedon 12) at the family level of the U.S.D.A. Soil Taxonomy. They are also classified as Eutric Gleysols (pedon 11) and Dystric Gleysols (pedon 12) in the FAO-UNESCO system. This means that even within the Diggi Park unit of the backswamps, enough differences exist between them to warrant their being considered different soil units. Soils of the Flood Catchment areas type of the Diggi Park

unit (pedon 13) are classified as Aeric Tropic Fluvaquent, fine-loamy, mixed, isohyperthermic at the family level of the FAO-UNESCO soil legend. This phase of the Diggi Park unit have properties that differ from those of the Backswamp types, though they are valley bottom soils whose materials are gained mainly through colluvio-alluvial deposition. Soils of pedon 11 have $EC_{25}{}^{o}{}_{C}$ and ESP values that attained the critical limits of 4 mmhos/cm and 15%, respectively, for a sodic soil at between 80 and 155cm sub-horizon levels. This depth range at which the horizons may be said to be sodic may not qualify the entire soils to be classified as Natraqualf or Solonetz (Sombroek and Zonneveld, 1971). However, their ascertion that the moisture regime within the unit is aquic while the surface horizons have ochric epipedons are true.

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