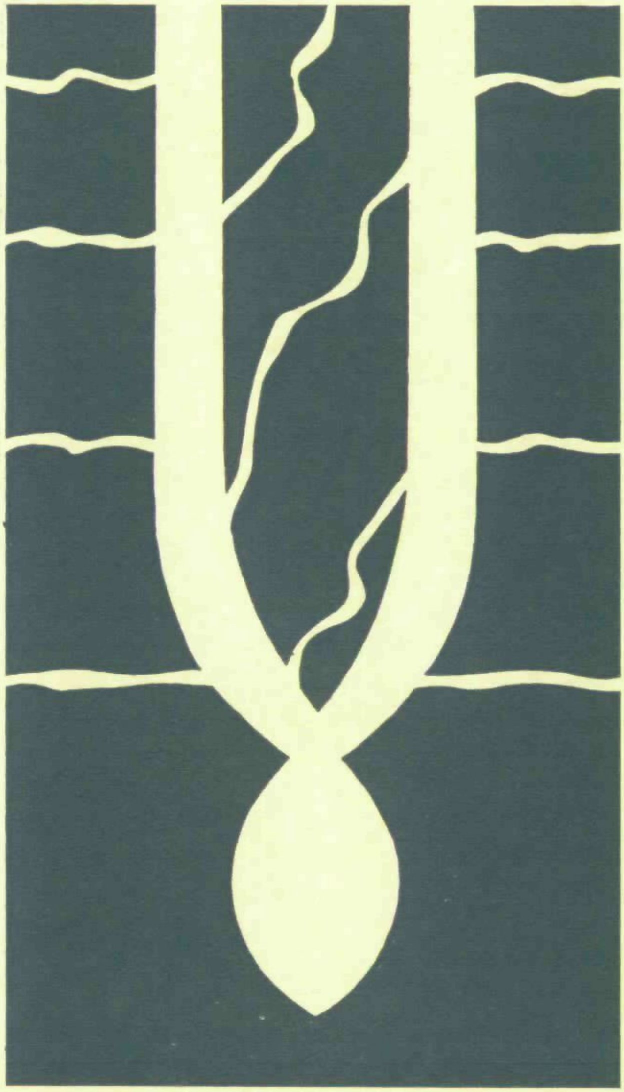
Soil Survey Papers No. 5

ANCIENT DUNE FIELDS AND FLUVIATILE DEPOSITS IN THE RIMA-SOKOTO RIVER BASIN (N.W. NIGERIA)



W. G. Sombroek
and
I. S. Zonneveld

Netherlands Soil Survey Institute, Wageningen

SOIL SURVEY PAPERS No. 5

ANCIENT DUNE FIELDS AND FLUVIATILE DEPOSITS IN THE RIMA-SOKOTO RIVER BASIN (N.W. NIGERIA)

Geomorphologic phenomena in relation to Quaternary changes in climate at the southern edge of the Sahara

W. G. Sombroek

and

I. S. Zonneveld

SOIL SURVEY INSTITUTE, WAGENINGEN, THE NETHERLANDS — 1971

Dr. I. S. Zonneveld was chief of the soils and land evaluation section of the Sokoto valley project and is at present Ass. Professor in Ecology at the International Institute for Aerial Survey and Earth Science (ITC) at Enschede, The Netherlands (P.O. Box 6, Enschede).

Dr. W. G. Sombroek was a member of the same soils and evaluation section and is at present Project Manager of the Kenya Soil Survey Project, which is being supported by the Dutch Directorate for International Technical Assistance (P.O. Box 30028, Nairobi).

CONTENTS

SUMMARY

This paper deals with geomorphologic features in aeolic and aqueous deposits in the northwestern part of Nigeria (Rima-Sokoto river basin), and their relation to climatic changes during the Quaternary.

Basic data, expressed on a coloured map 1 : 500,000, have been derived from aerial photographs, descriptions of soil profiles, vegetational and geological studies in the field, and chemical, physical, and mineralogical analyses in the laboratory, all forming part of a UNDP/FAO Soil and Water Resources Survey Project carried out between 1963 and 1966.

Kind of deposits

There are five different types of deposits of aeolic character. Four of these have a top in the fine sand fraction; they were deposited as dunes and are now partly denudated. Distinguished are:

- Sangiwa coversand formation, originally with transversal parabolic dune forms,
- Sokoto and Zurmi coversands with longitudinal dune forms,
- Illela coversands with fortress shaped dune forms,
- The fifth aeolic deposit, called Funtua, is a loess.
- Most aeolic materials were deposited by ENE winds.

There are fourteen different types of aqueous deposits, eight above the present floodplains, six inside them. Those above flood level are:

- High-terrace (Gusau and Bakolori) and sandy wash plain (Tureta) deposits, all three positioned relatively high.
- Main-terrace deposits (Rabah, Talata, Kaura-namoda), all three at intermediate level.
- Low-terrace deposits (Zazagawa and Bagudo), both relatively low but above the maximum flood level of the presentday rivers.

The sandy wash plain was formed by sheet-flood processes from the Sangiwa sands, the high terrace by a combination of sheet-flood and fluviatile action with loess as an important source of the sediment (especially Gusau).

The main-terrace deposits are mainly sandy and were formed by braiding rivers; locally a more meandering river system must have been active as well, resulting in more loamy materials (Talata). The Zazagawa low terrace is a clear sandy braiding river deposit, the loamy Bagudo again shows a bit more meandering river influence.

The six aqueous deposits that are in the presentday floodplains are the following:

- Argungu floe deposits, sandy deposits with a floe pattern orginated by a braiding river.
- Diggi park deposits, meandering river deposits of mainly silty character, at present with a rather high degree of alkalinity, and a park-like vegetative cover.
- Ambursa central and Tungantudo enclosed deposits, which have a lacustrine character and are clayey.
- Kurukuru and Gande micaceous deposits, having a sedimentology identical to the Diggi park ones, but of recent to sub-recent origin, with little or no alkalinity features, and a strikingly high content of micas.

It is apparent that in the early part of the Quaternary there was a rhythmic variation in aeolic and aqueous depositions, only partly separated by downcutting periods, whereas in the latter part there was a rhythmic variation between aqueous deposition and aqueous downcutting, only once interrupted by aeolic deposition.

Origin of the deposits

A study of the heavy minerals of the sand fractions in combination with the textural and geomorphological features revealed the following about the origin of the deposits.

The sandy deposits in the northwestern and central part of the survey area (Sangiwa, Tureta, Sokoto, Rabah, Zazagawa, Argungu and Illela sands) all come from the same original local sources, namely the more or less sandy Cretaceous and Tertiary sedimentary rocks, viz. the Gundumi, Gwandu II + III and particularly Rima formations. It is very likely that these sands developed for a good part one from the other, whether aeolic or fluviatile, the sorting of the sands becoming more and more refined. The fluviatile re-sorting, moreover, led to a gradual coarsening from fine sand to medium sand. Maximum transport distances were 50-75 km, although the distances are usually much less.

The sandy deposits in the southeastern subcatchment have also been derived locally; in this case weathering Crystalline basement material was involved, either directly (Zurmi) or indirectly (Kaura-namoda). The very fine sands, loams, and silt-rich clayey deposits occurring both on the river terraces and in the floodplains of the rivers that have their catchment in the Crystalline basement area (Bakolori, Talata, Bagudo, Diggi, Kurukuru and Gande) are all mainly derived, directly or indirectly and by longdistance transport, from weathering Crystalline basement materials.

The loessic deposits in the southeastern subcatchment area, however, derived from faraway sources of non-crystalline rocks to the north-east of the survey area, either directly (Funtua) or indirectly (Gusau).

The silt-poor clayey deposits in some of the floodplains of the northwestern subcatchment (Ambursa, Tungantudo) are derived from clayey sedimentary rocks mainly in the far north (Sahara), at that time a humid area.

Geomorphologic history

Absolute dating of the deposits could only be done tentatively, by comparison with neighbouring areas from where some absolute dating has been reported in literature. The following sediment-historical sketch can be given (for details see chapter 7 and 8 and Tables 7 en 8).

In a landscape mainly formed by pediplanations during the Early Pleistocene, aeolic sedimentation of poorly sorted sands (Sangiwa) in transversal dunes and loess (Funtua) took place during the Early Weichselien and possibly started already in the Eemien, under desert conditions. This was followed by erosion in a climate with irregular rainfall; a kind of pediplanation process (sheet floods) gave rise to a sandy „wash plain" (Tureta) and fluviatile deposits (Gusau, Bakolori). This period was followed by a return of desert conditions, still during the Weichselien, in which well-sorted sands were deposited as longitudinal dunes (Sokoto, Zurmi). A period of irregular rainfall, without any distinct rainy season, followed during the following part of the Weichselien. No renewed formation of sandy wash plain, from the Sokoto and Zurmi dune fields, took place; instead, mainly braiding-river sandy sediments were deposited.

Lowering of the erosion base — i.e. the Niger river, conditioned in the meantime by relative sea-level changes — was probably the cause of repeated incisions. First, the Gusau and Bakolori deposits were formed into terraces, after which by alternation of periods of incision and sedimentation, three groups of other terraces (Rabah-Kaura-Talata, Zazagawa-Bagudo and Argungu) were formed. Then a period with distinct wet seasons started, resulting in a meandering river system (Diggi). This was followed, probably in the beginning of the Holocene, by a very humid period when only heavy clays were deposited in lacustrine conditions (Ambursa and Tungantudo). During a relatively short period about the transition from Atlanticum to Subboreal, which was characterized by a climate with a long and pronounced dry season but no true desert conditions, a fleecy-cloudlike pattern of dunes was formed in the northernmost part of the area (Illela). These dunes are described as „fortress-shaped" dunes (chapter 4.5). A climate with a distinct wet season, causing a meandering river system, returned in early Subboreal times and still exists. There is a tendency for rivers to start braiding again, but whether climate is responsible, or devastation in the hinterland, is not known.

Comparison with neighbouring areas

The aeolic sedimentation features fit into a general pattern. The sequence of the aqueous deposits in the Sokoto area has a more restricted occurrence. A complete range is found along the middle and lower Niger River between Niamey and Lokoja, while an incomplete range exists along the fossil tributaries ("dallols") in Niger Republic, viz. the Maouri and the Bosso. A degree of correlation with the various deltaic and lacustrine deposits around Lake Chad can be observed.

Use of the data

Results may be of use to students of earth history in the semi-arid zones in general, but also to agronomists and engineers working on development planning in the same or similar areas.

There is a clear correlation between age and lithology of the sediments and the soils developed on them. Therefore land use and vegetation also show a strict correlation with the geomorphological forms. Because of this, the results obtained and published in this paper were a sound guideline during the interpretation process of aerial photographs. They allowed findings from detailed studies of a limited number of spots to be extrapolated quickly over the areas. It was thus possible to speed up substantially the work of the reconnaissance soil and land evaluation survey of the whole area (100.000 km^2) and the semi-detailed survey, scale 1 : 20,000, of the floodplains (300,000 ha). Some other applications of the results for land development are mentioned.

INTRODUCTION

In the relevant geomorphologic and pedologic literature, mention is made of Quaternary changes in climate in the present Sahara region and its southern fringes (URVOY, 1942; TRICART et al., 1957; ZIEGERT, 1969; GROVE and WARREN, 1968). The present paper gives an outline of the alternate occurrence of dune fields and riverine deposits of various ages in the northwestern part of Nigeria, which reflect most probably the above-mentioned climatic changes.

The data used for this paper were collected during the UNDP/FAO Soil and Water Resources Survey Project of the Sokoto valley. The authors were members of the team engaged in the soil survey and land classification part of this project.

In a period of three years, a group of three men, on the average, surveyed about 300,000 ha of river-bordering land at scale 1 : 20,000, while the whole catchment area of the Rima-Sokoto system, 10,000,000 ha, was mapped at scale 1 : 200,000. This was possible only by making the fullest use of aerial photo interpretation, and by applying the physiographic approach to surveying (c.f. VINK, 1967). Physiographic units characterized by land forms and vegetation patterns are the basic units in such an approach. Hence, the geomorphologic history of the area had to be studied carefully, to assure a logical basis for photo interpretation and mapping. This study pointed to an alternation in climatic conditions in both the Pleistocene and Holocene epochs. Description of the land forms, lithology, geomorphologic history and climatic change form the subject of this paper; the more "practical" data on soils and land classification can be found in the FAO report relative to the Project (FAO, 1969).

as "forest reserves". A long-time degeneration has nevertheless taken place on these sites, through century-long burning, wood picking and nomadic grazing.

Nearly everywhere the occurring trees and shrubs are leafless during the dry season. Both the poor grassy undercover of the semi-natural vegetation and the stubble of the arable fields are either grazed off by goats and cattle, or carried underground by termites. As a result, the land is a semi-desert at the end of the dry season, especially in the north-western part.

On the better soils, especially those near the rivers, *arable cropping* takes place. It ranges from long-fallow shifting cultivation to permanent wet-season cropping. Guinea corn, millets, groundnuts and cotton are the main crops. In the floodplains much rice is grown. Locally wheat, onions and tobacco are of importance.

The *population* totals about 3 millions. Towns and villages are concentrated alongside the main rivers, in the easternmost part of the area (Kaura Namoda - Funtua) and in a broad N-S running band in the western part (Illela - Sokoto - Jega). The settled population belongs mainly to the Sudan-negridic Hausa tribe, but its ruling class is formed largely by descendants of the Fulani, a tribe of presumably eastern mediterranean origin (JOHNSTON, 1967). A small portion of the population, belonging exclusively to an unmixed group of the Fulani tribe, has a nomadic way of life. Their cattle graze on poor soils covered with tree and shrub savannah during the wet season, on the stubble

Fig. 1. Aerial view of the rural settlement pattern in the relatively fertile area around Sokoto town, where the structural plateau of the Kalambaina-Dange level of fossil plinthite (laterite, LK) is overlain by a shallow layer of coversand of the Sokoto type. A vague longitudinal pattern of these coversands may be noticed by the alternation of brighter and darker strips from left-bottom to right-top on the photograph.

I. GENERAL GEOGRAPHY OF THE AREA

The area studied covers the whole of the Rima-Sokoto River basin in the north-western tip of the Federal Republic of Nigeria (North-West State, parts of North-Central State). This basin drains into the Niger river near the frontier with the Republics of Niger and Dahomey. Included in the study is a zone between the basin proper and the frontier with Niger Republic; this zone drains into the Niger River via the dallol Maouri just beyond that frontier. The region lies roughly between 4° and 8° E and 11.30° and 14.00° N. Its area is approximately 100,000 km² (38,500 cq. miles).

The presentday *climate* of the area is hot and semi-arid (type A_w in the Köppen classification). A pronounced dry season lasts from October till May, while the wet season is characterized by frequent and torrential rains of relatively short duration. The mean annual rainfall decreases gradually from south to north (1090 mm at Funtua, 965 at Gusau, 780 at Birnin kebbi, 710 at Sokoto and 600 mm at Illela). Most of the rain falls in the months of July and August, while in the period November to March the total precipitation is less than 10 mm. The monthly maximum temperatures are lowest in December and January (13°C) during which time a dust-carrying desert wind blows from the north-east. The maxima are highest in April (38°C), just before the advance of the rain front from the south. The monthly relative humidity is over 90 % in August, and only 10 to 30 % in December and January.

The *relief* as a whole is virtually flat, though from ground level scattered low table lands or steeply rising low hills strike the eye. Only in the southern part (the River Ka area) is the relief intensity often high. The altitude varies from about 250 m near the mouth of the Rima River to about 600 m at the upper reaches of the south-eastern tributaries.

Though the valley is named after the Sokoto River, the main component of the *hydrographic network* is the Rima River, formed by confluence of the Bunzuru and the Gagare. Downstream, the Sokoto, Zamfara and Ka Rivers join in. All these rivers have an enormous discharge during and immediately after the rainy season (about 700 m³/sec near the Niger River in September), but towards the end of the dry season the total flow diminishes to a trickle (about 6 m³/sec near the Niger River, less than 1 m³/sec near Argungu), and all active river channels can be crossed on foot. Non-permanent tributaries are the Shella and the Gawon Gulbi in the central part of the area, and the Maradi, Tarka and Goulbi o n'Kabba in the north-east, the latter two representing a fossil catchment sub-area in the present Sahara.

The *soils* of the uplands vary greatly. In the south-eastern part of the area shallow and somewhat imperfectly drained soils predominate. In the other parts the upland soils are mostly deep and well drained, but sandy, except where caps of indurated plinthite abound. Many of these upland soils have a strong tendency to become sealed superficially, resulting in a high run-off coefficient and sheet erosion.

The soils of the river terraces and floodplains vary strongly in characteristics and quality.

The *vegetation* is largely that of the so-called Sudan zone, which contains savannah woodland on the better soils and tree and shrub savannah on the poorer. Only in the extreme south-east (Funtua) is a relatively dense wooded vegetation belonging to the Guinea zone found; in the extreme north (Illela) the shrubby and thorny vegetation of the Sahel zone occurs. It is only on the poorest soils and far away from permanent sources of water that these natural vegetation types still cover extensive terrains, partly predominance of montmorillonite/vermiculite; 40-80 points to montmorillonite/vermiculite with some other components; 15-40 suggests either illite, chlorite, halloysite, allophanes or comparable amorphous colloids occurring singly, or mixtures of kaolinite with these and/or some montmorillonite; 3-15 indicates a strong predominance of kaolinite, and < 3 a predominance of crystalline sesquioxides.

CEC-values of clay fractions were calculated for all samples which had undergone a routine chemical analysis at the Northern Nigeria Soils Laboratory in Samaru/Kano. The values in Table 5 are the averages of usually large numbers of representative samples, and they therefore have a high degree of accuracy. During the calculation, it was assumed that the mineral fractions > 2 μ have no exchange capacity of any significance and that 1 % Carbon (representing the organic matter) accounts for 3.5 m.e. exchange capacity of its own (value obtained empirically at the Project laboratory).

The cation exchange capacity as determined on the fine earth (fraction < 2 mm) then gives the cation exchange capacity of the mineral clay colloids as follows:

$$\text{CEC-clay} = \frac{\text{CEC-soil} - 3.5 \times \%\ \text{C}}{\%\ \text{clay}} \times 100.$$

2.4 Soil profile morphometry

The soil profile morphometry, by indicating the mode and intensity of the action of the pedogenetic factors, provides clues to the type and age of the deposits and the weathering aggressiveness of former climates. Some morphometric features, moreover, may help to decide which type of deposit is concerned if other indications are absent or ambiguous.

In the field, one of the first indications of the type of soil development is provided by the *easiness of augering*. Acid sandy soils are easily penetrated, well structured clayey soils fairly easily, whereas very fine sandy to loamy soils with a poor structure and high alkalinity, especially when dry, can only be penetrated by strenuous efforts; the auger starts "singing" at being turned, without further penetration.

A particularly helpful phenomenon for distinguishing sandy deposits turned out to be the structure and structure stability of the soil surface, expressed in the degree of persistent *surface sealing*. Under the prevailing climate in the area, all more or less clayey soils have a tendency to become superficially sealed, i.e. compacted and encrusted, but tillage will usually overcome this phenomenon for a substantial period. Some soils, however, show a sealing that quickly re-establishes itself after tillage. This applies particularly to some sandy soils, notably those with poor grainsize sorting. Table 4 gives some quantification of the sealing phenomenon in sandy soils of the area, based on thin sections.

The *colour and colour sequence* indicate which pedogenetic processes have been most active, and the duration of such processes (cf. FAUCK, 1965). In general, mottling indicates the influence of ground water or stagnating surface water. Homogeneous colouring and a gradual vertical colour sequence indicate a soil formation under conditions of free drainage. The parent materials being comparable, then bright reddish colours in the subsoil or strong red mottling indicate that a ferralitic type of weathering (humid to subhumid tropical conditions) is or has been active for a considerable [1] time; yellowish or brownish colours or mottling would point to short weathering or continuous semi-arid or arid conditions.

[1] LENEUF and AUBERT (1960) calculated that the transformation of a granite layer up to 1 meter into a ferralitic soil takes at least 22 000 years.

by comparing all the collected data in a table (analogous with the establishment of plant-ecological associations of the Braun-Blanquet school) and taking into account groupings found in the relevant literature (a.o. CROMMELIN 1964). The following groups appeared: a) Zircon - Kyanite; b) Hornblende - Epidote - Andalusite, and c) a residual group that included Tourmaline and Staurolite.

Figures 24, A to D give the results.

It should be stressed that the above is an empirical approach only, and does not pretend to be a comprehensive petrological study.

The number of samples of several deposits was too small to give a reliable delineation of their occurrence in the triangle. Nevertheless, the place of most deposits in the triangle was sufficiently defined to deduce from which older deposits the various Quaternary sediments are derived, either directly or indirectly.

In the field, a first impression of the mineralogic composition can be obtained by estimating the frequency and size of mica flakes ($\sim$ Epidote - Hornblende association). Such flakes can be easily discerned with the naked eye or a pocket magnifier when the material is rubbed between the fingers. The presence or absence of mica flakes therefore constitutes an easy and reliable mapping criterion.

For the more or less clayey deposits, the type of *clay minerals* in the lower part of the soil profile gives important indications as to both the age and origin of the deposits. The presence of montmorillonite, for instance, often coincides with rich parent material, a juvenile character of soils, and/or semi-arid weathering. Illite goes often together with sub-humid temperate weathering. Well-crystallised kaolinite and crystalline iron and aluminium oxides indicate humid tropical weathering and/or old age and/or poor parent materials. "Poorly crystallised kaolinite", as determined below, may be considered intermediate between well-crystallised kaolinite and illite. Allophanes are usually associated with recent volcanic parent materials, and amorphous gels generally indicate that new minerals are forming — which infers a juvenile character of the parent material or recent changes in climate.

The composition of the clay fraction ($< 2\mu$) was studied in the following three ways, which together give a fairly reliable picture of the colloids concerned (Table 5).

a) X-ray diffraction and Differential Thermal Analysis. This method, applied to only 25 and 10 samples respectively, at the Royal Tropical Institute, reveals only the crystalline forms, qualitatively and semi-quantitatively.

b) Determination of the SiO_2, Al_2O_3 and Fe_2O_3 ratios (on molecular basis). This method provides information on both the crystalline and the amorphous components of the clay fraction, with the SiO_2/Al_2O_3 ratio in particular (Ki values) giving useful clues. Values higher than 3.0 indicate a predominance of montmorillonite/illite; 2.0 - 3.0 the presence of both montmorillonite/illite and kaolinite; values 1.6 - 2.0 normally the predominance of kaolinite; and values below this the presence of considerable percentages of gibbsite, allophanes or amorphous aluminum oxides. High Fe_2O_3 values (i.e. low Al_2O_3/Fe_2O_3 ratio) indicate the presence of iron oxides (either crystalline such as hematite, or amorphous) in an appreciable percentage. The above ratios were determined by total analysis (fusion followed by X-ray fluorescence) on the clay fraction of 25 samples at the Royal Tropical Institute.

c) Calculation of the cation exchange capacity of the clay colloids. This method too, provides information on both crystalline and amorphous forms, establishing the chemical activity of their surfaces. A CEC-clay of > 80 m.e./100 g indicates a strong (weathering and soil formation stage) of sediments, though it may be evident that certain sedimentological conditions may cause a deviation of this general (pedological) trend.

< 0.25	very low	(common in very old tropical sediments)
0.25-0.5	low	(common in old tropical sediments)
0.50-0.75	moderate	(common in old subtropical sediments)
0.75-1.00	high	(common in recent subtropical sediments)
1.00-1.50	very high	(common in recent temperate region sediments, fluviatile)
> 1.50	extremely high	(common in recent temperate region sediments, aeolic).

For some of the floodplain deposits the "siltiness", or the lack of it, is shown on texture triangles (Figs. 14, A to C).

Among the clayey floodplain deposits, some differences were found in the clay's degree of stabilization (physical ripening, cf. PONS and ZONNEVELD, 1965). This *ripening stage* indicates whether the sediment has been water-soaked since its deposition, or has been able to dry out, either fully or superficially. A laboratory indication of the degree of ripening is given by the so-called n-value ($n = \frac{A - 20 + 0.2\,(L + H)}{L + 3H}$ where A is the percentage of water in the soil in field condition, calculated on dry soil basis; L the percentage of clay, and H the percentage of organic matter i.e. organic carbon $\times$ 1.7). N-values below 0.7 indicate full physical ripening, values around 1.4 half-ripe conditions and values above 2.0 completely unripe conditions. In the field, rather reliable estimates can be obtained by squeezing the material through one's fist (for details cf. PONS and ZONNEVELD).

2.3 Mineralogy of the deposits

In sandy deposits the relative frequency of occurrence of the so-called *heavy minerals* provides information on the spatial origin of the deposits. It is well known that heavy mineral tend to occur in combinations that are mutually exclusive, making it possible to establish empirical mineral associations.

In view of this, samples of the Quaternary sediments, the pre-Quaternary deposits and the Crystalline basement rocks were selected and sent to the Royal Tropical Institute in Amsterdam for an analysis of their mineralogic composition. As a rule, only one fraction of each sample was analysed, that of the fine sand fraction, 100 - 250 μ. This was done because taking the predominant grainsize of each sample tends to distort the reliability of the results, as observed by e.g. CROMMELIN (1964), and exemplified by comparative analysis of all fractions of some of the samples from the study area. The results are given in Tables 2 and 3. This shows that there are six main heavy mineral associations concerned in the area:

(A) Tourmaline - Staurolite - Zircon
(B) Tourmaline - Kyanite - Zircon (with some Staurolite)
(C) Tourmaline - Sillimanite - Zircon (with some Andalusite)
(D) Tourmaline - Staurolite - Zircon (with some Epidote, Hornblende and Andalusite)
(E) Tourmaline - Hornblende, with Staurolite, Zircon, Epidote and Andalusite (mixed)
(F) Epidote - Hornblende.

The data can also be compared in so-called heavy mineral triangles. Such triangles require a grouping into three associations. These associations were established empirically, of deposition of the material. This distribution may be uniform or varied. When it is varied, the correlation with meso-relief features, if any, is described systematically.

If the deposits were sandy, the *various sand fractions* were compared as to their weight percentages. Such fractioning was executed on all grains smaller than 2000 μ, on an oven-dry basis, by dispersion with sodium hexametaphosphate and pre-treatment with hydrogen peroxide when organic matter was present. This was followed by separation of the sand fractions by means of sieving, and by determination of the clay fraction by pipette sampling. The following fractions are discerned:

2000 - 1000 μ: very coarse sand
1000 - 500 μ: coarse sand
500 - 250 μ: medium sand
250 - 100 μ: fine sand
100 - 50 μ: very fine sand
50 - 2 μ: silt
< 2 μ: clay.

The weight percentages are also compared graphically. In sedimentology, various methods are in use for such a graphical representation and for the systematic analysis of the resulting curves (cf. BOULET, 1964). It was found that a simple non-cumulative presentation on single logarithmic paper was sufficient to show the differences between the various sandy deposits in the study area.

If one clear top in such a curve is apparent, then a single origin of the sandy material may be assumed. Prominence of the medium to coarse sand fraction may point to braiding river deposits. Fine sands may point to coversand origin, very fine sands to loessic origin.

Many of the deposits under study showed a top in the fine sand fraction. Its pronouncedness however, when averages were taken of a number of representative samples of the deposit spread over the survey area, proved to be varied (Figs. 12, A to D). The following empirical classes of "sand sorting" are distinguished (weight of two adjacent subfractions with highest values, in percentage of the weight of all mineral particles > 2 μ):

— very well-sorted sands: > 80 %
— well-sorted sand: 70 to 80 %
— moderately sorted sand: 60 - 70 %
— poorly sorted sand: less than 60 %.

If the deposits are more or less clayey, special attention has to be given to the *silt/clay ratio.* It appeared that the various floodplain and terrace deposits differed substantially in this aspect. This silt/clay ratio depends on both sedimentological and weathering processes. In the area under study, major differences are probably mainly due to the latter process. Reference is made to VAN WAMBEKE (1962) who states that, in general, low values indicate strong pedogenetic weathering in a wet tropical climate. This weathering may have taken place in situ, in which case a low ratio indicates old age of the present surface of the deposit and includes a period with a wet tropical climate. It can also mean that the deposit is derived from highly pre-weathered sources (rego-genetic material), in which case the area of the source must have had a former wet tropical climate.

For heavy textures proper, i.e. materials with more than 40 % clay-sized particles, the following empirical classes of silt/clay ratio (in weight percentages) are distinguished; in parentheses the common occurrence of these ratios is given in relation to age

2. METHODS OF STUDY

For the characterization, mapping and the establishment of origin and relative age, especially of the Quaternary deposits, a number of criteria were used. These will be detailed below, as a record. The systematic description may, at the same time, benefit aerial photo interpretation, field survey, and laboratory analysis for any subsequent, more detailed surveys.

2.1 Geography of the deposits

The *spatial occurrence* of the deposits and the *form* of the outcropping areas give the first clue as to the type of sedimentation and subsequent erosion.

The *physiographic position* of the deposit in relation to other deposits — both horizontally and vertically — gives an indication of the spatial origin and the relative age of the material.

The *thickness* of the deposit and its spatial variation give an indication of the length of the period of sedimentation and/or the subsequent erosion.

The inherent *relief* gives an inference of the mode of deposition. A distinction is made between macro-, meso-, and micro-relief, as follows:

— Macro-relief refers to considerable differences in topography over great distances (differences in altitude of more than several meters over a distance of some hundreds to one thousand meters). Macro-relief takes into account the slope characteristics of the land (gradient, length, shape and pattern of slopes) and determines whether the land as a whole is level, undulating, rolling, hilly or mountainous. In general, the term applies to the result of orogenic and ancient erosional processes.

— Meso-relief refers to moderate differences in topography over rather short distances (differences in altitude of a half to a few meters over a length of ten to a few hundred meters). Meso-relief takes into account the local differences within the frame of the general. It describes details of topography in floodplains, tidal forelands, dune fields, etc. In general, the term applies to the results of sedimentation processes.

— Micro-relief refers to small differences in topography over short distances (differences in altitude of less than half a meter over distances of less than 10 m). Micro-relief describes such details as the gilgay pattern of terrains with montmorillonitic clays, termite mounds etc. In general, micro-relief is related to soil-forming processes, including soil biological activity.

Some forms of relief, when measured quantitatively, are intermediate, e.g. a pattern of high dunes. In the following, all relief forms due inherently to dune formation are grouped in the meso-relief category.

The presentday surface *drainage pattern* can also be instrumental in determining the age and origin of a deposit; it is particularly helpful in mapping from aerial photographs.

When aqueous deposits are concerned, the *level* above or below presentday high-water of nearby river channels, and the existence of sudden drops in level are indications of the relative age of the deposit.

2.2 Granulometry of the deposits

The grain-size distribution provides an important criterion for establishing the mode of the arable fields during the first part of the dry season, and in the floodplains during the latter part.

Through century-long practice, the use of renewable land and water resources is rather well organized within the scope of limited technical possibilities, and its pattern is consequently a fairly accurate reflection of the quality of these resources.

Fig. 2. Strong surface sealing on old coversands of the Sangiwa type causes high run-off and sheet erosion even on nearly level terrains. The natural vegetative cover is very poor and a groundcover of grasses does not appear till well into the rainy season.

The *textural differentiation* between topsoil (A horizon) and subsoil (B horizon) can also be indicative of the length and type of pedogenetic weathering. Soils on young sediments generally show little or no regular change in texture with depth. In such soils a micro-stratification, due to yearly oscillations in the sedimentation processes, is often still observable. A hot and humid climate would result ultimately in no, or only a very gradual, textural differentiation (ferralitisation); a climate with a pronounced dry season would result in strong differentiation (illuviation, ferrolysis). Semi-arid to arid climatic conditions again give little pedogenetic texture difference, but show an accumulation of salts and lime. With most climates, however, shallow ground water or stagnating surface water is liable to promote textural rearrangement. In sandy soils, pedogenetic textural differentiation may show either in a homogeneous slightly heavier texture, in micro-morphological clay coatings and clay bridges in the subsoil, as is the case with old coversands (cf. Table 4), or in several thin horizontal bands of heavier texture, so-called fibers, in the subsoil. The latter appear to be characteristic for some of the sandy river terrace soils (cf. Fig. 13).

Deductions from *profile characteristics* on pedological and paleopedological processes, especially *in relation to time*, may help explain the geomorphological situation, especially about periods of stability.

The extent and depth of eluvial horizons in subhumid conditions and the formation of plinthite under humid tropical conditions, where imperfect drainage prevailed, may give a clue to occurrence and duration of past environmental conditions.

Absolute dating with C^{14} is difficult in tropical soils due to the rapid decomposition of organic matter. In semiarid and arid conditions, however, calcareous accumulation layers may suit this method. However, no specimens suitable for C^{14} dating were found in the area.

The whole complex of profile morphometry and chemical and mineralogic data on the soils is reflected in the scientific *soil classification*. Mainly for the record, this is indicated in the following between brackets, using the scheme of D'HOORE (1964) as applied to his soil map of Africa, with some modifications. A provisional correlation is also made with the early versions of the new USA system of soil classification, commonly known as the "Seventh Approximation" (SOIL SURVEY STAFF, 1960). Recent, improved versions of the latter system (SOIL SURVEY STAFF, 1967), the legend of the FAO/UNESCO Soil-Map-of-the-World project (DUDAL, 1968), or the recent systems of French and Belgian soil scientists for tropical Africa (AUBERT, 1965; TAVERNIER AND SYS, 1965) became available only after completion of the survey in the area.

2.5 Vegetation, land use and termite features

Land use, natural vegetation, and the results of termite activity provide survey tools for recognizing geomorphological features both in the field and on aerial photographs.

The arrangement of the plant taxa and individuals into micro and macro patterns, plant communities and vegetation zones usually shows the integrated influences of soils, climate, hydrology, fauna and man, but in many cases they also provide an indication of the occurrence of geomorphological and lithological features.

Vegetation differences are described in terms of combination of species and/or structures of the vegetation in horizontal and vertical direction. Species are rarely recognizable as such on photographs of the scales used.

The horizontal pattern, however, often gives clear mapping criteria, while the vertical aspect, such as the difference between various types of arable fields and semi-natural vegetations, can be seen quite well in the stereoscopic image. Indirectly, conclusions can be made on the crop (e.g. cassava occurs in typically fenced plots, because the crop is still on the land during the dry season when the cattle and sheep roam freely around). During field inspection, more detailed information is gathered on natural species, crops and vegetation patterns.

In the area studied, most of the land use is still adapted to a low level of technology. So in their selection of arable fields, farmers have been strongly guided by the existing natural ecological conditions, and the resulting land use is, to a large extent, related to these ecological conditions. These in their turn show a close correlation with the geomorphological and lithological conditions. Since all these correlations are not absolute at any moment of time, one should use any indication with intelligence.

In the non-cultivated part of the area under study differences due to "anthropogenic" influence do exist, e.g. intensity of nomadic grazing, but the natural ecological condition is often clearly reflected in the vegetation differences.

Land use types

The following forms in land use and semi-natural vegetation were recognized:

Semi-permanent wet season cropping. The same plot is used every year in the wet season; it is bare in the dry season and may be fallow for a year from time to time. The plots may form one continuous arable area or may have a scattered distribution. The latter case usually indicates a disrupted pattern of ecological conditions of which only the suitable places (= usually non-sealing sandy soils) have been selected.

Tree-savannah, with a combination of shrubs and relatively low trees that do not form a close canopy. A variant of this is the termitaria landscape where trees only occur on top of the termite mounds (see below).
Savannah woodland, with very open tree canopy of medium high trees.
Riverine forest, a closed forest of rather high trees along floodplains and on some relatively old and high-lying parts of the floodplain proper. A subdivision has been made in these formations according to floristic composition.

Many parts of the floodplains have a mainly *herbaceous vegetation* (grasses, *Cyperaceae* etc.), the species composition depending on both the depth of flooding and the soil properties. Tufted grasses *(Vetiveria* spp.), for instance, are characteristic of shallowly flooded terrains with somewhat compacted and sodic micaceous soils. The low shrub "gumbi" (*Mimosa* sp.) is found specifically on those terrains, either shallowly or deeply flooded, that have soils of high chemical fertility (Vertisols; typic Juvenile soils on micaceous sediments).

A major non-edaphic difference in the semi-natural vegetation is that between the free-grazing areas and the so-called "forest reserves" where, even though bush fires are quite common a less intensive grazing is practised. Moreover, the reserves are not very old, so that inside the boundaries rather heavily devastated patches may occur. Finally, the major part of the forest reserves is deliberately planned in areas where very unfavourable conditions, even for forest, exist (edaphic conditioned shrub savannah, tree savannah, etc.).

On the basis of (floristic) vegetation differences the area as a whole can be roughly divided into two major phyto-climatic zones: in the north the so-called Sudan zone; in the south the Guinea zone (KEAY, 1959). In both, *Combretaceae* play a dominant role. The Guinea zone is characterized by a more luxuriant vegetation, which includes *Isoberlina doca* as an important key species. In not too disturbed areas on the deeper soils, woodlands occur in both zones: *Combretum nigricans* and *Anogeissus* woodland in the Sudan zone, and Anogeissus-Isoberlina woodland in the Guinea zone. In the Sudan zone the woodlands degrade more readily into savannah woodland, savannahs and lower stages.

Termite features

Another biogene feature influencing the landscape in the area is termite action. Various types of termite mounds are found, all showing a relation with the substratum.

Presumably, each termite species has its own preferred edaphic conditions. No termite taxonomic studies were undertaken, but an empirical correlation was established between the size and shape of the mounds and the soil properties, such as texture, chemical fertility and drainage condition. The following types of termitaria have been discerned (cf. Fig. 3):
umbrella-shaped mounds. These are about 50 cm high, and have a single or multiple, thin curved roof over a thick stilt. The type predominates on imperfectly drained acid sandy soils.
cathedral-shaped mounds. These are 2 to 4 m high, have several pointed tops and ribbed sides rising abruptly from the ground. The type is found on well-drained acid loamy soils.
nightcap-shaped mounds. These are 1 to 2 m high and have smooth sides but are somewhat lopsided, especially the upper part. The type is characteristic of imperfectly drained loamy soils of relatively high fertility and continuous subsoil seepage.

Shifting cultivation (wet season). Plots are used only temporarily and are left fallow for long periods before being cultivated again. In the region studied, this type is easily recognized as a mixture of bushpatches, clearly visible cultivated fields, and intermediate stages.
Irrigated all-season permanent cropping. Farms of this type are easily recognizable on aerial photographs taken in the dry season (as was the case with the air photos used). So far this type only occurs locally near areas with permanent water supply (e.g. springs of the Kalambaina formation).
Rice cultivation "on the floods" (wet season). In the floodplains the soil is tilled just before the flood and immediately after the first rain. Because the floods are often very irregular, it is not a real type of floating rice cultivation as in East-Asia. A major problem is that in the lower floodplain the floods are often earlier than the rainfall, because the rain starts earlier in the upper catchment. When that happens there is no possibility of tilling and sowing and the area remains fallow, or the floods come directly after or during the sowing and destroy the farmer's work.
Semi-permanent cultivation after the floods. Certain crops (e.g. cassava, gourds, tobacco, onions, occasionally wheat) are sown directly after the flood on some floodplain soils.

Crop sequences

With regard to the crops, four "crop-sequences" were distinguished: "heavy", "medium", "light" and "wet".

The most important crops in the *heavy sequence* are cotton, wheat and guinea corn; they occur on the heavier, deep, not too wet soils. The *medium sequence* comprises guinea corn, beans, groundnuts and some cotton, also cocoyams and vegetables (onions); this sequence is found on the non-sealing sandy soils with some water storage capacity. The *light sequence* is composed of millet, cowpeas, cassava and some groundnuts, and can be found on the poorest sandy soils. The *wet sequence* consists of rice and, locally, gourds and vegetables. Sugar cane and sweet potatoes are found only on areas with no long irregular flooding, e.g. floodplain edges.

Trees in arable fields

Trees always occur on the arable land. They have either been planted or are remnants of the former natural vegetation. They give the farmland a park-like character and provide an indication of the ecological conditions as well. The size of the trees in the semi-permanent cultivated plots shows a positive correlation with the favourableness of the site. In the park-like farm land it also shows some correlation with the broad climatic zones, which merge gradually into each other. In the northern area *Acacia albida* with its peculiar habit of having leaves in the dry season and being bare in the wet season is dominant in the arable fields. With decreasing latitude, *Parkia clappertonia, Butyrospermum parkii, Vitex doniana* and *Ficus* ssp. increasingly occur. However, the soil moisture storage conditions, influenced particularly by surface sealing, soil texture and soil depth, greatly obscure climatic differences.

Semi-natural vegetation

Differences in the semi-natural vegetation that can be easily recognized, even on airphotos, are the following:
Shrub-savannah, with low shrubs and a scattered grass and herb vegetation in-between,

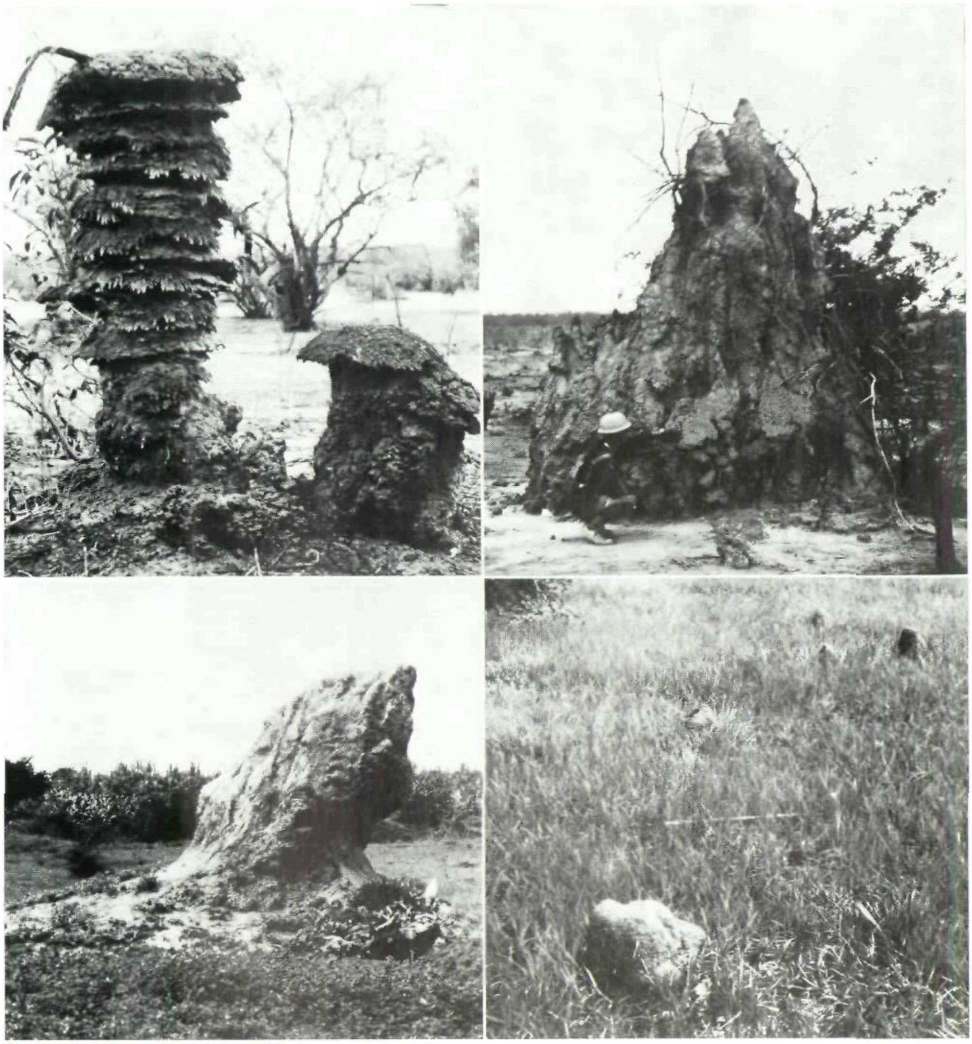


Fig. 3. Four different types of termite mounds, indicative of different soil properties.
a = umbrella type,
b = cathedral type,
c = nightcap type,
d = helmet-type.

helmet-shaped mounds. These are only about 20 cm high and largely half-spherical. They are found on well-drained acid sandy soils with a strong surface sealing.

Apart from the above active termitaria, there are giant ones, which are apparently fossil, occurring in various stages of degradation, Their form is sombrero-shaped. These are about 3 m high with a basal diameter of up to 10 m, and are densely overgrown with shrubs and low trees. This causes them to show up on aerial photographs as *black dots*. At many places the mounds have apparently been partly or completely flattened by sheet erosion, resulting in round patches of about 20 m in diameter, which are strongly alkaline and devoid of vegetation. These show up on aerial photographs as *white dots*. Pronounced black-dot and white-dot patterns are characteristic of the imperfectly drained loamy to clayey soils of some of the pre-Quaternary deposits with only a very thin sand cover (for details cf. ZONNEVELD, DE LEEUW and SOMBROEK, 1971). Less striking variants of these fossil termitaria are found on some of the older fluviatile deposits (cf. Fig. 19).

2.6 Compilation of maps and cross-sections (Appendices 1 and 2)

The coloured map 1 : 500,000 of Appendix 1, containing the relevant geomorphologic and lithologic features of the study area, is a compilation of the un-coloured 1 : 200,000 soil and land form map of the original FAO report (FAO, 1969). This map was prepared from semi-controlled photo mosaics 1 : 100,000. Transferred to these photo mosaics and slightly generalized, were the lines of stereoscopic photo-interpretation of aerial photographs 1 : 40,000 (taken end of dry season, 1962), confirmed or modified by field check all over the area. For the main floodplains, the 1 : 40,000 photo-interpretation, in its turn, already comprised a generalization of earlier stereoscopic interpretation of photographs 1 : 10,000 (taken end of dry season, 1959), and a detailed field check. The present map therefore is the result of several generalizations and their accompanying reductions of the field patterns. Hence the map can not be used for detailed field studies, let alone for detailed planning. Its only purpose is to show the geomorphological and lithological pattern and genesis of the area. The mode of delineation of the various units is adapted to that purpose. The crinkly boundary lines of the Illela coversands, for instance, contrast with the broad elliptic boundary lines of the Sokoto coversands, reflecting the detailed pattern in the field, though not necessarily being geographically accurate.

The numbering of the grid on the coloured map coincides with that of the photomosaics 1 : 100,000, on which the numbering of field observations is based. The site of these (soil) observations, some of which appear in several of the tables in this paper, can therefore be roughly localized on the 1 : 500,000 coloured map; for detailed localization, however, the soil maps of the FAO report have to be consulted.

The cross-section of Appendix 1 is schematic. However, the altitudes and the dip of the various strata and plinthite levels are the result of careful identification as regards geomorphology and lithology, in a broad zone along the A-B line, of points whose altitudes are established on the newest geological and topographic maps.

Appendix 2 contains soil maps at 1 : 20,000 of two representative parts of the Rima-Sokoto main floodplain, copied directly from the semi-detailed soil map (21 sheets) of the FAO report, but with deletion of the detailed pattern of gullies and footpaths as well as the numbering and symbolic characterization of the field observations.

The cross-section of the floodplain is schematic. It combines the physiography of the Rima floodplain in the Argungu area (cf. soil map b) with that of the floodplain in the area just downstream of the confluence of the Sokoto and Rima Rivers (cf. soil map a) and the situation near Wurno, further upstream. The relative position of the various deposits, the depths of flooding and the land use and vegetation can therefore be considered representative of all situations between Kende (near the Niger River) and Sabon Birni (at the northern bend), as these are described in more detail in the FAO report.

To visualize the floodplain physiography completely, Appendix 2 should be in colour as well, but this was beyond the financial means of the publisher, as it was for FAO.

age (Campanian-Maestrichtian); their maximum thickness is 20 m. They consist of soft and plastic black shale with carbonaceous matter and iron sulphides, turning fissile and bluish gray on exposure, with formation of large gypsum crystals and aluminium sulphate nodules. Thin bands of marly limestone occur with these shales, which themselves alternate and grade laterally into sandy clays and mudstones. The surface of the deposits is capped with a sheet of plinthite (LM-LR).

e. The *Wurno deposits* are also of Late Cretaceous age (Maestrichtian); their maximum thickness is 35 m. Their composition is quite comparable to that of the Taloka deposits, to the extent that they cannot be separated where the Dukamaie deposits are absent (as is the case in the southern part of the area). Heavy mineral analysis of two samples showed a Tourmaline-Staurolite-Zircon association.

The three deposits Taloka, Dukamaie and Wurno together form the *Rima group,* which as a whole lies unconformably over the Gundumi-Illo deposits. The Rima deposits were laid down in conditions of shallow and quiet brackish waters (detritic, reducing milieu: marsh), while the Dukamaie represent a marine transgression proper. Outcropping non-indurated parts are very erosion-susceptible.

The soils of the non-indurated parts are rather sandy, often with a poor grain-size sorting (Fig. 12, A). The activity of the clay minerals is rather low (CEC 18-30 m.e.). The soil surface is prone to strong sealing. In many parts they bear hardly any vegetative cover and the susceptibility for sheet and gully erosion is very high (sandy Leached Red Kaolinitic soils/Normustults; sandy Red Ferruginous Tropical soils/ Vetustalfs).

f. The *Dange deposits* are of Early Tertiary age (Paleocene) and maximally about 20 m thick. They are marine deposits of coastal or estuarine origin and consist of attapulgitic clay-shales that are soft, well laminated ("schists papyracés"), bluish gray, somewhat gypsiferous and with calcium phosphate nodules; they are alternated by thin bands of limestone. Their area of outcropping is very limited, due for one thing to the presence of a protecting plinthite layer of the Kalambaina deposits.

g. The *Kalambaina deposits* are also of Early Tertiary age (Paleocene-Lower Eocene) and their thickness reaches a maximum of 25 m. They were deposited under conditions of a retreating sea without sedimentary additions of continental origin. At the base they consist of hard, white chalky nodular limestones, followed by slabby, white to pale yellow calcareous mudstones and pale gray clay-shales with bands of fissile calcareous mudstones. The upper shales have turned into a very extensive sheet of plinthite, forming a well-defined scarp at the eastern side (LK, Dange scarp). Heavy mineral analysis of two samples of Kalambaina-Dange deposits points to a Tourmaline-Kyanite-Zircon (+ Staurolite) association.

Because of the extensiveness of the plinthite of the Dange-Kalambaina formation, non-soils and shallow soils are predominant (Ironstone Crusts; Lithosolic Brown soil of ASTR [1]/lithic Haplorthent). The other sedimentary soils are often dark coloured and clayey, with high activity of the clay minerals (40-80 m.e. CEC) but rather low values (0.3-1.0) for the silt/clay ratios (Lithomorphic Vertisols/entic Grumustert; Brown Calcareous soils/entic Haplustoll).

h. The *Gwandu deposits* are also of Early Tertiary age (Middle to Upper Eocene) and reach maximally 350 m thickness. The deposits were laid down under continental, mainly lacustrine, conditions and consist of massive clays that are non-plastic and stained white; clayey grits that are variegated white, red and purple; and sandstones that

[1] ASTR = Arid and Semi-arid Tropical Regions.

Table 1. Legend of the pre-Quaternary geology of the Iullemmeden-Middle Niger basin.

Stratigraphy		northern part (Niger-Mali)					southern part: Niger		southern part: Nigeria	
Pliocene					—				—	
Miocene					—				—	
Eocene		Continental terminal	Ct3	300	grès argileux du Moyen Niger •			W2-3	Gwandu	Upper (III), Middle (II)
Eocene		Continental terminal	Ct2	20-50	argiles et sables à lignites •			W1	Gwandu	Lower (I)
Eocene		Continental terminal	Ct1	5-50	argiles et grès ferrugineux et laterites de l'Adrar Doutchi •			K	Kalambaina	
Eocene		Paléocène marin	eIII-VI	25	calcaires et marnes blancs et schistes papyracés		à Lockhartia	K	Kalambaina	
Paleocene		Paléocène marin	eIII-VI	20	calcaires et marnes blancs et schistes papyracés		à Operculinoïdes	D	Dange	
Late Cretaceous	Danian									
Late Cretaceous	Maestrichtian	Crétacé marin	Cr9-8	35	groupe de Azouac	grès fins de "Upper Sandstones"		R	Rima group	Wurno
Late Cretaceous	Campanian	Crétacé marin	Cr9-8	0-20	groupe de Azouac	marnes et calcaires jaunes de "Mosasaurus Shales" •		R	Rima group	Dukamaie
Late Cretaceous	Santonian	Crétacé marin	Cr9-8	120	groupe de Azouac	grès fins de "Lower Sandstones"		R	Rima group	Taloka
Late Cretaceous	Coniacian	Crétacé marin	Cr7	0-60	calcaires et argiles vertes de Zakak		Csc300 grés et argiles du Continental hamadien •	I / G	Gundumi	
Middle Cretaceous	Turonian	Crétacé marin	Cr6b	0-300	calcaires blancs		Csc300 grés et argiles du Continental hamadien •	G	Gundumi	
Middle Cretaceous	Turonian	Crétacé marin	Cr6a-5	0-30	grès et argiles glauconnieux des monts de Iguellala	à Nigericeras	Csc300 grés et argiles du Continental hamadien	G	Gundumi	
Middle Cretaceous	Cenomanian	Crétacé marin	Cr6a-5	0-30	grès et argiles glauconnieux des monts de Iguellala	à Neolobites	—		—	
Early Cretaceous		Continental intercalaire	Ci	300-1000	grès et argiles de Tégama	Farah	—		—	
Early Cretaceous		Continental intercalaire	Ci	300-1000	grès et argiles de Tégama	Echkar	—		—	
Early Cretaceous		Continental intercalaire	Ci	300-1000	grès et argiles de Tégama	El Rhas	—		—	
Early Cretaceous		Continental intercalaire	Ci	300-1000	grès et argiles de Tégama	Tiguedi	—		—	
Jurassic- Permian		Continental intercalaire	CiI	0-500	argiles de Irhazer		—		—	
Jurassic- Permian		Continental intercalaire	CiII	0-230	grès de Agadès		—		—	
Jurassic- Permian		Continental intercalaire	CiIII	0-180	arkoses de Izegouandane		—		—	
Early Paleozoic - pre Cambrian					socle cristallin		socle cristallin		Gwarian complex	

——— marine — — — partly marine • plinthite levels

The pebble beds in adjoining parts of Niger Republic, described by GREIGERT and POUGNET (1967) as Quaternary, seem in fact identical with the (basal) pebble beds of Gundumi.

A layer of plinthite occurs on top of the clays (LG), as well as on a level in the upper grits (LI-LG, see under b). The soils developed on these sediments are generally poor, with clay minerals of low activity (CEC-clay 5-20 m.e., rarely up to 40). The silt/clay ratios are rather low, varying between 0.3 and 0.7. The soils may be imperfectly drained (Gray or Leached Red Kaolinitic soils/Normustults; some Ironstone Crusts and Gravels).

b. The *Illo deposits* are the lateral equivalent of the Gundumi ones, but supposedly partly younger (cf. Nupe sandstone, "grès de Kandi" of Dahomey). The main components are: lower grits, which are white, friable, falsebedded, medium to coarse grained and with quartz pebbles, and sometimes with interbedding of white, blue or mottled clay; a thin layer (< 10 m) of pisolithic and nodular massive white hydrargyllitic clays; upper grits, which are friable and false-bedded, with subordinate layers of clay. Mineralogically the deposits seem to belong to the Tourmaline-Staurolite-Zircon association (Association A, 2 samples). A plinthite level occurs in the upper grits (LI-LG). The soils are largely comparable to those of the Gundumi deposits. Locally richer ones occur, having a CEC-clay of 20-30 m.e. (Red Ferruginous Tropical soils/Vetustalfs).

c. The *Taloka deposits* are of Late Cretaceous age (Santonian) and their maximum thickness is 120 m. They consist of sandstones that are consistently fine grained, quartzitic, white to grayish white or yellowish, and with interbedding of thin layers of soft mudstones.

d. The *Dukamaie deposits* (formerly "Mosasaurus shales") are also of Late Cretaceous

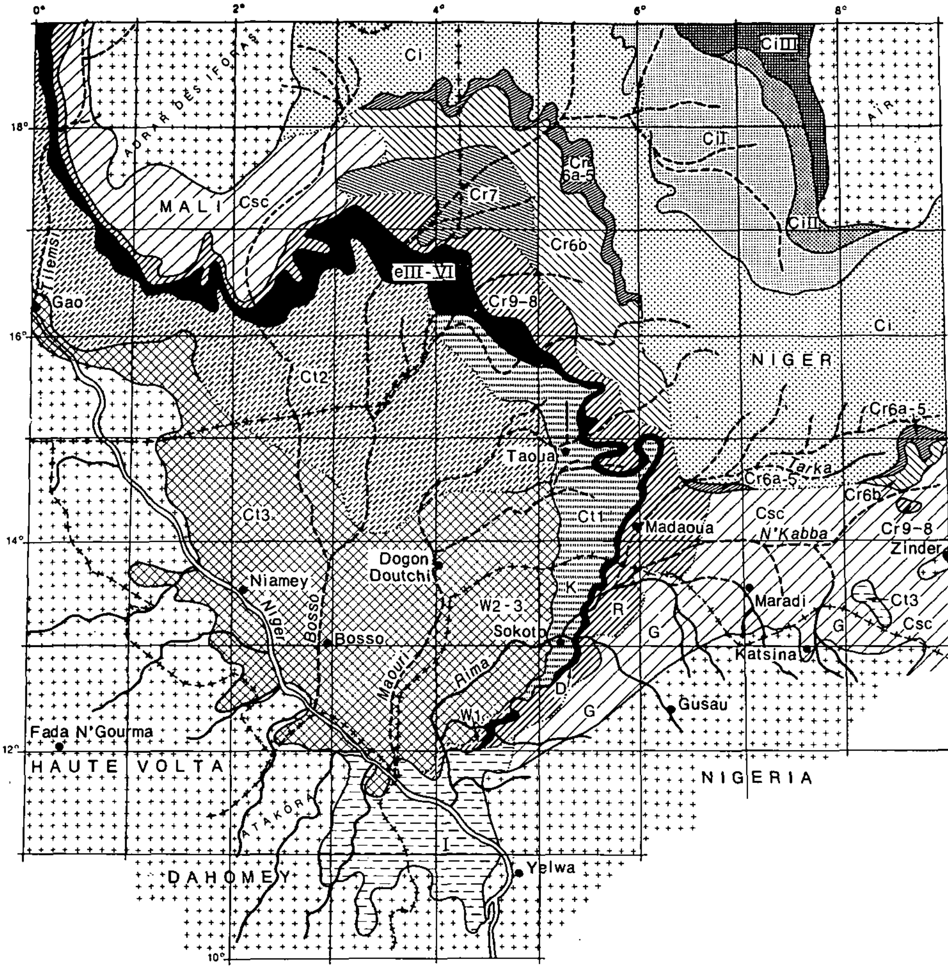


Fig. 4. Map of the pre-Quarternary geology of the Iullemmeden-Middle Niger basin. Legend is Table 1.

The descriptions of the strata as given below are mainly from Jones (1948), while reference is made to the corresponding nomenclature of Greigert (1966). The chronology is from the Kaduna Geological Department (geologic table of Haug). Table 1 gives a summary.

a. The *Gundumi deposits* are of Late Cretaceous age (Turonian; "Continental hamadien") with a maximum thickness of 300 m. They are continental deposits of fluviatile and lacustrine origin, derived from already highly weathered crystalline basement material. The main components are: poorly sorted basal conglomerates and hard arkoses; pebble beds, most numerous near the base; tough clays, normally dark grey, sometimes blue and purple; clayey grits, with a predominance of massive felspatic, illsorted, coarse to medium grained grits, often in a clayey matrix. Heavy mineral analysis of two samples points to an association of Tourmaline - Staurolite - Zircon, with some Epidote, Hornblende and Andalusite (association D).

3. PRE-QUATERNARY GEOLOGY AND GEOMORPHOLOGY

3.1 Geology

As shown on Fig. 4, the south-eastern half of the area is composed of a crystalline basement complex. The geologic data on this part have not yet been published, but provisional maps 1 : 250,000 are available at the Geologic Survey Department of Kaduna. The north-western half of the area — forming part of the Iullemmeden (Western Niger) basin, the centre of which lies in Niger Republic — has Late Mesozoic and younger sedimentary rocks at its surface. The small Nigerian part of this basin has been described and mapped by JONES (1948), while the main Niger part was done by GREIGERT (1966) with the help of aerial photographs. Most of the sedimentary area within Nigeria has recently been remapped — also with aid of aerial photographs — by the Geological Survey Department of Kaduna.

The *Crystalline basement complex* (Gwarian complex) consists of pre-Cambrian to Lower Paleozoic, igneous and metamorphic rocks. The oldest ones are pegmatites, granites and aplites, with inclusions of meta-gabbro and hornblende schists. The younger ones consist of either undifferentiated granites/granodiorites and migmatites, or Meta-sediments. The latter are considerably folded and faulted, and consist of psammitic and migmatitic rocks and (semi) pellitic schists and phyllites, with inclusions of ferruginous quartzites and Meta-conglomerates. Locally in the basement complex area, volcanic rocks (rhyolites, dacites and tuffs) occur; their age is uncertain. At scattered places near the eastern water divide, a street of indurated plinthite is found (LB on the map) probably identical with the ironstone strips between Katsina and Kazaure of GROVE and PULLAN (1963).

The heavy mineral association of the weathered surface layers is of the Epidote-Hornblende type. The soils tend to be shallow and somewhat imperfectly drained. Their clay-mineral activity, however, is fairly high (CEC = 30-60 m.e. per 100 g/clay). The silt/clay ratios may be elevated, varying from 0.5 to 1.7 (Rock outcrops and Lithosols; Yellowish Brown and Dark Reddish Brown Ferruginous Tropical soils/Vetustalfs; Semi-Hydromorphic soils/Argiustolls; some Vertisols/Grumusterts or Grumaquerts; some Solodized Solonetzes/mollic Natraqualf).

The *Cretaceous and Tertiary rocks* were deposited as sediments in a synclinal basin, active from the Late Cretaceous to the Early Tertiary. The deposits are mostly conformable and without folding, and show a regular slight dip of about 3.5 m per km to the NNW. In general, the various deposits are thickest in the north; they thin away towards the SW, to the extent that south of the lower Zamfara River the strata are very near to each other or even lacking. At the end of every sedimentation stage, or even every sub-stage, a sheet of plinthite developed, often over an extensive area (SOMBROEK, 1971) [1].

[1] In that paper it is explained that formation — though not necessarily the truncation and hardening — of the plinthite levels must have taken place at various times during the whole period of basin-sedimentation, and not afterwards as believed by e.g. JONES (1948) and also inferred by PULLAN (1969, Fig. 7.9). Proofs of this are the differential gentle dips of the various plinthite levels (cf. cross-section on Appendix no. 1) and the indications that a lower-level may continue below a higher-level plinthite. The latter was observed at some multiple scarps (cf. also Stereo-triplets of Figures 5 and 6) and in some geologic borings, e.g. those near Balle (GSN nos. 3051, 3053, 3054), Rabah (No. 2488) and Argungu (Nos. 2486 and 2488).

are white, medium to fine grained and with criss-cross bedding. As a whole the deposits are comparable to the Gundumi ones but there is a considerably higher portion of clay. The Gwandu deposits lie unconformably over the older deposits, in the south overstepping the Kalambaina, the Dange and even the Rima ones. Three levels of plinthite can be discerned (LW_0, LW_1, LW_2), dividing the deposits into three subformations. The lowest of these (Gwandu I) is edaphically somewhat richer than the two other subformations (Gwandu II + III) which are mainly kaolinitic in character. Because of finds of foraminiferes and fish bones, GREIGERT and POUGNET (1967) believe that the lowest 20-50 m were deposited under closed sea conditions. As regards heavy mineral composition, there seems to be a difference as well: The Gwandu II + III deposits would have a Tourmaline-Staurolite-Zircon association, the Gwandu I deposits a Tourmaline-Kyanite-Zircon (+ Staurolite) association (2 and 1 samples respectively).

Most of the sedentary soils are comparable to the poor soils of the Gundumi deposits. In some parts — probably largely concerning Gwandu I materials — the clay minerals are of a more active type (CEC-clay 25-50 m.e.) resulting in better soils (Yellowish Brown Ferruginous Tropical soils/Vetustalf). In both cases the silt/clay ratios are relatively low, namely 0.2-0.7.

3.2 Geomorphology

Most of the area of the Gwarian basement complex is nowadays virtually flat with only scattered inselbergs, mainly of porphyritic granites, standing out. Several erosion cycles must have been active, one of the first being that which resulted in the Gondwana peneplain (Jurassic). A general subsidence must have taken place in the Middle Cretaceous. The Gondwana surface was covered in the western and north-western parts with Gundumi-Illo sediments. After this, some uplift must have followed (unconformity of Rima group) followed by erosion, which resulted in a new plain: post-Gondwana pediplain. Shallow residues of Gundumi deposits are still present on the fringe of the basement complex, with little or no difference in level; apparently the Gondwana peneplain and the post-Gondwana pediplain are at about the same level in this area.

Deposition of Rima, Dange and Kalambaina sediments in the NW part followed (Late Cretaceous — Early Tertiary), when this area was at or below sea level. This changed to a continental environment when the Gwandu deposits were laid down. After the Middle Tertiary, the whole basin area was uplifted and sedimentation was replaced by considerable erosion. This resulted in a landscape with low tabular hills and scarps (abrupt differences in altitude up to about 50 m), due to the presence of the various erosion-resistant layers of indurated plinthite ("surfaces d'altération"), which had all formed during the Cretaceous — Tertiary, at moments of relative stability and imperfect drainage of the land (SOMBROEK, 1971). A period of stability during the Miocene caused new pediplanation of the basement complex area (African surface), still apparent from the fossil meanders of the Ka River.

At the end of the Tertiary a final shaping of the basement area must have taken place (Niger surface), during which the present courses of the main rivers formed.

The inselberg aspect on the basement area and the tableland aspect of the sedimentary area were preserved in their essence during the Quaternary, the area not being subject to any tectonic movement. Along the scarps and on the basement area some erosion continued; at other places deposition of aeolic or fluviatile materials took place. These portion of the Crystalline basement area, have been scarcely, if at all, described by geologists. During the present physiographic soil survey, therefore, new provisional names for each of these Quaternary sediments were devised.

Fig. 5. The older levels of indurated plinthite, constituting plateaus or scarps, each of them indentifiable with specific older sedimentary deposits: LG = plinthite scarps and hill rests of the Gundumi fm; LM-LR = plinthite scarps of the Rima group undivided; LM = plinthite plateau of the Dukamaie fm; LK = plinthite scarps and plateau of Kalambaina - Dange fm. For the symbols of the other mapping units cf. Appendix 1, (stereo-triplet E-W, scale 1 : 40,000, of an area 15 km north of Goronyo).

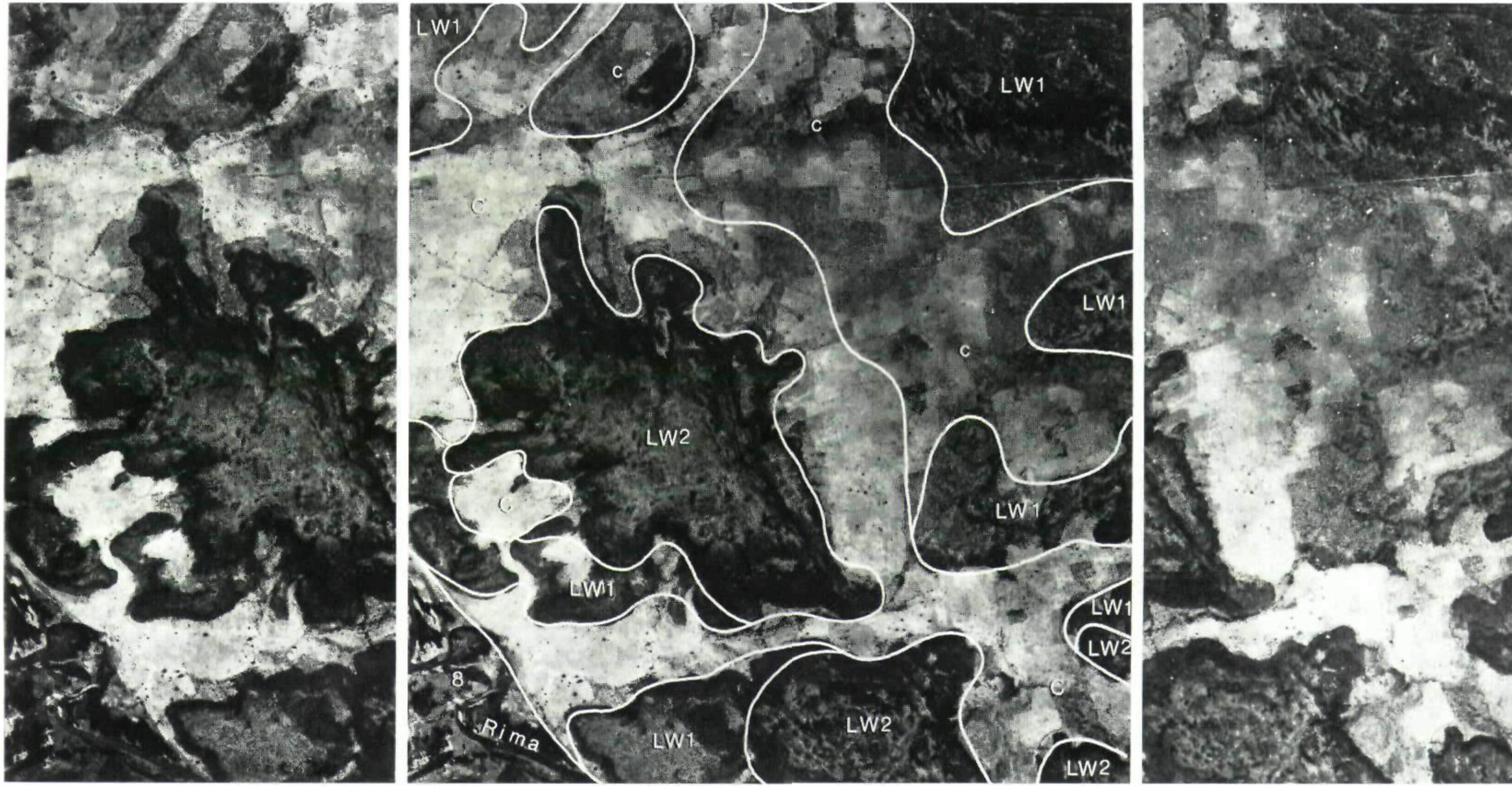


Fig. 6. The younger levels of indurated plinthite, constituting plateaus and scarps, each of them identifiable with specific younger sedimentary deposits: LW1 = plinthite scarp and plateau of the Middle Gwandu fm; LW2 = plinthite scarp and plateau of the Upper Gwandu fm. For the symbols of the other mapping units cf. Appendix 1.
(stereo-triplet E-W, scale 1 : 40,000, of an area 20 km east of Gande)

Fig. 7. Remnants of the youngest plinthite level (Upper Gwandu fm., LW2). In the foreground the crust has completely fallen apart due to erosion of the soft kaolinitic substratum. In the background the level can be seen intact, forming a tableland. Longitudinal strips of coversand (Sokoto type) have accumulated around the table lands and their remnants, and are characterized by arable land with sparse trees. They contrast with the poor low shrub savannah of Sangiwa coversand (centrally between the two hills) (west of Argungu).

Fig. 8. Illela type of coversands on top of the plinthite-capped plateau land (LK, the darker parts) of the Kalambaina deposits. The sands have a clear pattern of fortress-type dunes (hill-crests at foreground and background right). At the horizon two levels of Gwandu plinthite (LW1, LW2) can be discerned (near Illela).

Table 4. Micromorphological features of coversand and wash-plain soils (thin sections made by the Netherlands Soil Survey Institute, Wageningen)

Deposit and profile No.	Depth in cm	Plate No.	Clay bridges	Clay coatings	Variation in grain sizes	Dominant grain size	Open space %	Plant tissues	Iron concr.	Stratification
Sangiwa coversand	0- 4	3	(+)	++	++	+	15	++	–	+++
	4- 8	4	++	++	+	+	20	++	+	++
E5/1	26- 30	5	–	+	+	++	80	++	+	–
	60- 63	8	+++	+++	++	+	35	++	+	–
	100-103	6	++	+++	+	++	30	++	+	–
	158-162	2	–	–	++	++	40	–	–	–
Tureta wash-plain dep.	0- 3	2	–	–	–	++	80	++	–	+
	60- 61	9	+++	+++	+	++	30	++	+	–
E5/16	164-168	10	+++	+++	(+)	++	40	+	+	–
Sokoto coversand	0- 7	7	++	++	+	+	50	+++	+	(+)
	20- 27	10	++(+)	++	+	+	50	+++	++	–
D4/36	82- 86	12	+++	+++	+	+	50	+++	++	–
Illela coversand	0- 4	1	–	–	–	++	40	+++	+	+
	4- 15	3	++	++	–	+(+)	40	+++	++	+
F4/38	31- 51	4	++	++	+	++	40	++	+++	–

Explanation of symbols

Clay bridges and coatings: – = none, + = few, ++ = common, +++ = many
Variation in grain sizes: – = little, + = moderate, ++ = strong
Dominant grain size (in part of microscope image taken up): + = $<$ 1/10, ++ = 1/10-1/2, +++ = $>$ 1/2 of image
Open spaces (in % of microscope image): approximate estimations
Plant tissues: – = absent, + = few, ++ = common, +++ = many
Stratification in grain sizes: – = absent, + = weak, ++ = broken-up. +++ = clear

Table 3. Heavy minerals of three sand fractions separately [1] for some deposits (Soil Laboratory, Royal Tropical Institute, Amsterdam)

Profile number	Fraction (μ)	Opaque	Alterites	Zircon	Kyanite	Tourmaline	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Zoisite	Actinolite	Augite	Hypersthene	Spinel	Sillimanite	Andalusite	Epidote	Hornblende
Sangiwa coversands																					
E5/1	500-250	53	8	6	2	40	—	—	—	—	—	50	—	—	—	—	—	—	2	—	—
	250-100	61	5	18	5	60	—	1	—	—	—	14	—	—	—	—	—	—	1	1	—
	100- 50	74	2	57	10	16	—	11	—	—	—	6	—	—	—	—	—	—	—	—	—
E3/11	500-250	65	11	6	3	36	—	—	—	—	—	49	—	—	—	—	—	—	6	—	—
	250-100	69	9	25	5	50	—	5	—	—	—	14	—	—	—	—	—	—	1	—	—
	100- 50	58	9	70	3	6	—	13	—	—	—	8	—	—	—	—	—	—	—	—	—
D5/30	500-250	45	12	1	20	38	—	1	—	—	—	27	—	2	—	—	—	—	5	3	3
	250-100	51	7	5	21	38	—	2	—	—	—	9	—	1	—	—	—	—	1	10	13
	100- 50	49	13	18	27	15	—	14	—	—	—	9	—	1	—	—	—	1	4	7	4
Tureta washplain deposits																					
E5/16	500-250	31	27	—	22	49	—	1	—	—	—	28	—	—	—	—	—	—	—	—	—
	250-100	55	21	9	18	43	—	6	—	—	—	23	—	—	—	—	—	1	—	—	—
	100- 50	50	6	54	8	11	—	22	2	—	—	3	—	—	—	—	—	—	—	—	—
Zurmi coversands																					
D7/15	500-250	26	31	9	—	5	3	—	—	—	—	3	—	—	—	—	—	2	1	3	1
	250-100	42	9	34	1	34	6	1	—	—	—	8	—	—	—	—	—	—	1	7	8
	100- 50	53	2	65	1	14	—	14	—	—	—	2	—	—	—	—	—	—	—	2	2
D7/9	500-250	10	21	2	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	57	39
	250-100	15	13	3	—	1	—	—	—	—	—	—	—	3	—	—	—	—	—	29	64
	100- 50	31	3	6	—	3	—	2	—	—	—	—	—	2	—	—	—	—	—	34	53
Sokoto coversands																					
E3/48	500-250	31	42	2	—	8	—	—	—	—	—	12	—	—	—	—	—	—	—	—	—
	250-100	59	17	16	6	55	—	3	1	—	—	18	—	—	—	—	—	—	—	—	—
	100- 50	61	11	59	5	13	—	14	1	—	—	7	—	—	—	—	—	—	—	—	—
C3/79	500-250	66	26	2	44	22	—	5	—	—	—	22	—	—	—	—	—	—	5	—	—
	250-100	41	19	9	30	25	—	12	—	—	—	18	—	—	—	—	—	2	1	—	2
	100- 50	44	9	34	19	8	—	28	1	—	—	6	—	—	—	—	—	—	1	—	—
Illela coversands																					
F4/38	500-250	61	19	2	—	50	—	2	—	—	—	44	—	—	—	—	—	—	2	1	—
	250-100	57	4	40	6	40	—	3	—	—	—	9	—	—	—	—	—	—	1	—	—
	100- 50	44	7	73	—	17	—	6	—	—	—	4	—	—	—	—	—	—	—	—	—
F4/8	250-100	49	9	27	3	59	—	1	—	—	—	10	—	—	—	—	—	—	—	—	—
	100- 50	51	5	81	1	9	—	7	—	—	—	2	—	—	—	—	—	—	—	—	—
Bacita Estate samples																					
Bacita lowterrace sands (T5?)																					
	200- 50	77	—	16	4	26	—	2	3	—	—	41	—	—	—	—	—	2	2	3	1
Fanagun sands																					
	200- 50	57	7	37	5	17	1	3	2	—	—	6	1	—	—	—	—	2	1	15	5
Brung fine sands and loams																					
	200- 50	50	1	23	5	11	—	9	3	—	—	3	—	—	—	—	—	2	—	31	12
Egbungi heavy clays																					
	200- 50	75	2	27	1	13	—	5	2	—	1	38	—	—	—	—	—	—	—	9	2
Belle fine sands and loams																					
	200- 50	26	2	1	4	5	—	2	2	—	—	2	5	—	—	—	—	2	—	33	42

[1] Also the fractions 2000-1000 μ and 1000-500 μ were studied. All of them contained either no heavy minerals at all, or insufficient numbers to allow meaningful counting.

Table 2 (continued)

Profile number	Opaque	Alterites	Zircon	Kyanite	Tourmaline	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Zoisite	Actinolite	Augite	Hypersthene	Spinel	Sillimanite	Andalusite	Epidote	Hornblende
Illela coversands																				
F4/39	49	17	33	—	45	—	14	1	—	—	7	—	—	—	—	—	—	—	—	—
F4/28	53	9	50	2	31	—	9	—	1	—	2	—	—	—	—	—	—	5	—	—
E3/10	57	5	17	1	63	—	8	1	—	—	8	—	—	—	—	—	—	1	—	1
E3/6	52	21	26	2	52	—	2	—	—	—	14	—	—	—	—	—	—	1	—	3
F5/24	61	9	26	2	55	—	2	—	—	—	12	—	—	—	—	—	—	3	—	—
E4/89	59	11	36	4	40	—	—	—	—	—	19	—	—	—	—	—	—	—	1	—
F4/38	57	4	40	6	40	—	3	—	—	—	9	—	—	—	—	—	—	1	—	—
F4/8	49	9	27	3	59	—	1	—	—	—	10	—	—	—	—	—	—	—	—	—
Tureta washplain deposits																				
E3/41	52	9	36	9	35	—	4	1	—	—	15	—	—	—	—	—	—	—	—	—
F6/2	47	6	14	7	61	—	1	—	—	—	16	—	—	—	—	—	—	—	—	1
C3/44	50	7	10	37	20	—	17	1	—	—	13	—	—	—	—	—	—	1	1	—
E6/27	53	6	42	2	46	—	—	—	—	—	7	—	—	—	—	—	—	2	1	—
D2/12	56	9	40	3	29	—	5	—	—	1	16	—	—	—	—	—	1	4	1	—
E5/16	55	21	9	18	43	—	6	—	—	—	23	—	—	—	—	—	1	—	—	—
Gusau high-terrace deposits																				
D7/29	53	11	11	3	40	1	2	1	—	—	8	—	—	—	—	—	—	1	23	11
Bakolori high-terrace deposits: no analysis																				
Rabah main-terrace deposits																				
E4/57	58	11	26	10	45	—	1	—	—	—	14	—	—	—	—	—	—	—	—	4
C3/41	49	16	4	35	35	—	11	1	—	—	12	—	—	—	—	—	—	2	—	—
F5/20	43	6	36	—	50	—	2	—	—	—	11	—	—	—	—	—	—	—	1	—
D3/34	58	12	36	1	33	1	3	—	—	—	8	—	—	1	—	—	2	—	11	4
Kurukuru micaceous deposits																				
Wurno II	8	3	2	—	10	—	—	—	—	—	6	—	—	—	—	—	—	4	24	54
Wurno II	31	11	3	2	13	1	1	—	—	—	10	—	—	—	—	—	—	4	26	40
E6/35	5	2	—	—	2	—	—	—	—	—	3	1	3	—	—	—	—	6	20	65
SB1	17	3	2	2	6	—	—	—	—	—	—	1	2	—	2	—	—	8	13	64
Gande micaceous deposits																				
SK20	13	4	—	1	—	—	—	—	—	—	—	1	—	—	—	—	2	1	20	75
SK14	32	14	—	—	—	—	—	—	—	—	—	1	—	—	—	—	2	—	34	63

Table 2 (continued)

Profile number	Opaque	Alterites	Zircon	Kyanite	Tourmaline	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Zoisite	Actinolite	Augite	Hypersthene	Spinel	Sillimanite	Andalusite	Epidote	Hornblende
E5/27	65	10	21	1	54	—	3	1	—	—	17	—	—	—	—	—	—	3	—	—
D5/30	51	7	5	21	38	—	2	—	—	—	9	—	1	—	—	—	—	1	10	13
D5/93°	60	10	9	4	42	—	—	—	—	1	8	—	2	1	—	—	—	12	14	7
D5/65°	40	19	3	4	24	—	—	—	—	—	6	—	3	—	—	—	2	9	31	18
E6/7°	62	5	20	1	47	—	1	—	—	—	16	—	—	—	—	—	—	2	4	9
E3/44x	32	39	27	6	40	—	5	—	—	—	12	—	2	—	—	—	—	3	3	2
D3/26x	47	12	33	2	38	—	15	1	—	—	8	—	—	—	—	—	—	3	—	—
C2/3x	52	14	18	9	46	—	10	—	—	—	12	—	—	—	—	—	—	5	—	—
Sokoto coversands (o = shallow on Gwandu plinthite caps)																				
E5/30	60	5	28	4	49	—	6	—	—	—	12	—	—	—	—	—	—	—	1	—
E3/32	63	7	12	6	60	—	1	—	—	—	11	—	1	—	—	—	—	8	—	1
E3/48	59	17	16	6	55	—	3	1	—	—	18	—	—	—	—	—	—	—	—	—
C3/45a	55	15	3	15	40	—	10	—	—	—	22	—	—	—	—	—	1	9	—	—
B2/118	51	9	8	35	32	1	8	—	—	—	14	—	—	—	—	—	—	2	—	—
D3/18	41	40	16	20	39	—	4	1	—	—	14	—	1	—	—	—	—	4	—	1
D3/10	45	33	20	4	59	—	7	1	—	—	4	—	—	—	—	—	—	5	—	—
D2/5	59	5	18	10	45	—	5	—	—	—	10	—	1	—	—	—	—	9	—	2
C2/2	60	21	15	8	49	—	5	—	—	—	16	—	—	—	—	—	—	5	—	2
C3/79	41	19	9	30	25	—	12	1	—	—	18	—	—	—	—	—	2	1	—	2
D2/19	52	31	25	7	37	—	7	1	—	—	19	—	—	—	—	—	1	2	1	—
D4/36	66	6	21	5	49	—	—	—	—	—	15	—	1	—	—	—	—	6	1	2
D4/36	55	11	32	6	35	—	3	—	—	—	14	—	—	—	—	—	—	3	2	5
E4/87	62	21	31	11	37	—	2	1	—	—	17	—	—	—	—	—	—	1	—	—
E4/87	52	6	47	2	37	—	1	1	—	—	8	—	—	—	—	—	—	2	1	1
E4/11°	44	3	27	8	36	1	1	—	—	—	13	—	—	—	—	—	—	3	8	3
D4/23°	51	4	21	3	37	1	4	—	—	—	10	—	2	—	—	—	—	2	10	10
D3/2°	47	9	12	12	36	1	1	1	—	—	11	—	1	—	—	—	—	4	7	14
E3/26°	46	37	30	1	49	—	3	—	—	—	9	—	1	—	—	—	—	3	—	4
D4/28°	52	41	6	6	49	—	2	—	—	—	19	—	1	—	—	—	—	6	6	5
Zurmi coversands																				
D7/46a	51	6	22	2	21	—	2	—	—	—	2	—	1	—	—	—	1	—	19	30
C8/23	42	6	34	2	26	1	—	1	—	—	14	—	—	—	—	—	4	8	5	5
C6/6	29	6	7	—	4	—	—	—	—	1	4	—	—	—	—	—	—	4	75	5
D7/47a	45	9	8	1	9	1	—	—	—	—	6	—	—	—	—	—	—	1	63	11
D7/35	57	8	21	1	6	1	4	—	—	—	1	—	1	—	—	—	2	—	30	33
D7/13	62	19	59	—	7	5	—	—	—	1	—	1	—	—	—	—	—	—	18	9
B7/37	31	42	13	—	2	—	1	—	—	2	—	—	4	—	—	—	1	7	22	48
B7/37	47	14	18	—	2	2	—	—	—	5	—	1	2	—	—	—	—	6	35	29
B7/37	53	10	24	—	—	—	—	—	—	—	—	—	4	—	—	—	—	4	27	41
D7/15	42	9	34	1	34	6	1	—	—	—	8	—	—	—	—	—	—	1	7	8
D7/9	15	13	3	1	—	—	—	—	—	—	—	—	3	—	—	—	—	—	29	64

Table 2 (continued)

Profile number	Opaque	Alterites	Zircon	Kyanite	Tourmaline	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Zoisite	Actinolite	Augite	Hypersthene	Spinel	Sillimanite	Andalusite	Epidote	Hornblende
Kaura-namoda main-terrace deposits																				
C7/	41	37	2	—	5	—	1	—	—	—	12	—	1	—	—	—	3	36	11	29
Zazagawa low-terrace deposits																				
F5/14	54	3	48	1	32	1	1	1	—	—	15	—	—	—	—	—	—	—	1	—
BK9	49	5	11	2	37	1	—	—	—	—	11	—	—	—	—	—	1	2	15	20
AR16	52	3	27	3	46	—	1	—	—	—	8	—	1	—	—	—	—	1	9	4
Bagudo low-terrace deposits																				
C3/39	39	27	2	15	34	—	5	1	—	—	6	—	—	—	—	—	1	11	23	2
C4/9	57	6	18	1	57	—	1	—	—	—	20	—	1	—	—	—	—	1	1	—
Argungu floe deposits																				
F5/11	46	2	20	2	30	1	—	1	—	—	10	—	1	—	—	—	2	4	11	18
AR9	56	4	12	—	23	1	—	—	—	—	10	—	2	—	—	—	—	6	17	29
BK2	43	5	13	—	31	—	—	—	—	—	5	—	3	—	—	—	—	12	15	21
F5/6	52	3	6	3	24	2	1	—	—	—	13	—	1	—	—	—	—	6	12	32
Diggi park deposits																				
BK16	41	5	8	1	18	—	1	—	—	—	9	—	2	—	—	—	1	5	15	40
AR11	47	6	7	1	21	—	—	—	—	—	2	—	—	—	—	—	1	2	15	51
E6/30	22	3	2	—	—	—	—	—	—	—	—	—	1	—	—	—	—	4	14	79
BK48	30	19	6	3	21	1	—	1	—	—	5	—	1	—	—	—	1	10	30	21
Ambursa central deposits																				
BK7	57	6	42	1	15	1	—	—	—	—	15	—	—	—	—	—	—	1	12	13
BK37	52	10	16	1	28	—	3	1	—	—	8	—	—	—	—	—	1	5	15	22
SK17	18	14	20	7	13	—	2	—	—	—	16	—	—	—	—	—	—	10	16	16
Tungantudo enclosed deposits																				
F4/20	56	11	22	—	57	—	—	—	—	—	15	—	—	—	—	—	—	6	—	—
Sangiwa coversands (o = shallow on Gundumi; x = shallow on Gwandu II + III)																				
E5/1	56	24	22	6	56	—	1	—	—	—	15	—	—	—	—	—	—	—	—	—
E4/100	54	13	21	11	45	—	2	—	—	—	19	—	—	—	—	—	—	2	—	—
E3/43	61	10	15	7	52	—	2	1	—	—	20	—	—	—	—	—	—	2	—	1
D2/4	55	17	19	10	47	—	6	—	—	—	14	—	—	—	—	—	—	4	—	—
F5/17	74	5	25	4	52	1	—	—	—	—	13	—	1	—	—	1	—	2	—	1
F6/4	76	3	26	1	58	—	1	—	—	—	12	—	—	—	—	—	—	2	—	—
C2/4	56	31	8	21	50	—	9	—	—	—	10	—	—	—	—	—	—	1	—	1
E3/11	69	9	25	5	50	—	5	—	—	—	14	—	—	—	—	—	—	1	—	—

Table 2. Heavy minerals of the fine sand fractions (100-250 μ)
(Soils Laboratory, Royal Tropical Institute, Amsterdam)

Profile number	Opaque	Alterites	Zircon	Kyanite	Tourmaline	Garnet	Rutile	Anatase	Brookite	Titanite	Staurolite	Zoisite	Actinolite	Augite	Hypersthene	Spinel	Sillimanite	Andalusite	Epidote	Hornblende
Crystalline rocks of basement																				
B5/29	48	5	3	—	3	—	—	—	—	—	1	—	—	—	—	—	—	1	81	11
C7/8	11	52	5	3	6	3	2	—	—	1	10	—	—	—	—	—	—	8	18	44
B7/37	41	13	32	—	4	—	27	2	—	1	2	—	—	—	—	—	—	1	15	16
B8/27	57	6	40	4	4	3	—	—	—	1	2	—	—	—	—	—	8	1	29	8
Meta-sediments of basement: no analysis																				
Gundumi sedimentary rocks																				
D5/22	62	19	4	2	75	—	5	—	—	—	8	—	—	—	—	—	—	4	1	1
D5/61	40	45	12	1	20	2	2	1	—	—	4	—	1	—	—	—	2	7	14	34
D5/14	57	11	13	4	43	1	1	—	1	1	12	—	5	—	—	—	—	3	8	8
D5/47	57	26	15	9	53	—	1	—	—	—	9	—	—	—	—	—	4	3	—	6
Illo sedimentary rocks																				
B2/2	73	11	22	11	36	1	13	—	—	—	14	—	—	—	—	—	1	1	1	—
B2/40	57	4	40	7	39	—	3	—	—	—	11	—	—	—	—	—	—	—	—	—
Rima sedimentary rocks																				
F5/2	61	17	36	2	43	—	1	1	—	—	14	—	—	—	—	—	—	—	1	2
C3/70	53	12	10	24	34	—	12	1	—	—	19	—	—	—	—	—	—	—	—	—
E4/104	46	9	36	6	34	—	7	—	—	—	16	—	—	—	—	—	—	1	—	—
Kalambaina + Dange sedimentary rocks																				
E4/96	58	5	44	3	33	—	3	—	—	—	12	—	—	—	—	—	—	3	2	—
C3/51	51	6	23	34	27	—	6	—	—	—	8	—	—	—	—	—	—	2	—	—
Gwandu I sedimentary rocks																				
B2/32	45	42	11	53	14	—	9	—	—	—	12	—	—	—	—	—	—	1	—	—
Gwandu II + III sedimentary rocks																				
E3/20	57	11	30	—	48	—	5	—	—	—	12	—	1	—	—	—	—	1	2	1
D2/11	54	23	13	4	57	—	3	1	—	—	18	—	—	—	—	—	—	2	2	—
Funtua loessic deposits																				
B8/33	49	25	10	—	20	1	1	—	—	—	4	—	7	—	—	—	30	16	7	4
Talata main-terrace deposits (o: within Tureta area)																				
D5/79	47	3	2	1	12	1	1	—	—	—	5	—	4	—	—	—	—	42	11	21
D6/73	57	26	6	2	19	—	1	—	—	—	4	—	3	—	—	—	3	12	34	16
E6/17°	43	6	37	2	33	—	2	—	—	—	16	—	1	—	—	—	—	—	7	1

in height with the slacks is about 10 m. The dune tops form a rather regular grid with some orientation NNW - SSE, thus forming the pattern of transversal parabolic dunes. Between 13°.13′ N and 13°.00′ N the pattern is the same, but the relief differences are only 2 to 3 m, and hardly observable from the ground. Below the 13°.00′ N parallel, no relief difference exists at all, though on the aerial photographs a "ripple" pattern is very apparent (cf. Stereo-triplet of Figure 9). This is caused by strong differences in the density of the vegetative cover, the reasons for which are amply discussed by ZONNEVELD, DE LEEUW and SOMBROEK (1971); apparently the original dune relief in these areas has been completely flattened through denudation and erosion (sheet flood and rill wash).

Thinner covers of the same deposits, often with some mixture of sedentary Gundumi or Gwandu material, are found in broad bands around the most characteristic parts, described above. These thin covers are often found on slightly sloping terrain, and the vegetation pattern is more dendritic than ripply, being testimony of the former occurrence of erosion gullies as well.

The present-day drainage pattern, though when seen from the air seemingly very dense because of the curious vegetation patterns, is actually irregular and very open (parallel "overprint" on dendritic).

The granulometric composition of the deposits shows a top in the fine sand fraction but not a very pronounced one (an average of 37 %); there are considerable percentages in the medium sand fraction (24 %) as well as in the very fine sand (15 %), silt (6 %) and clay (8 %) fractions. For an apparently aeolic deposit, the grain-size sorting is poor.

The mineralogic composition of the fine sand fraction is of the Tourmaline-Staurolite-Zircon type (11 samples); a few (4 samples) also have considerable percentages of Epidote, Hornblende and Andalusite.

In spite of their sandy character, the soils of the denudated or nearly denudated parts are extremely liable to surface sealing, showing up in greater compactness of the surface layer of the soil (cf. Table 4). In contrast to the situation with sealing soils of heavier texture, tillage has no beneficial effect because the very first rain showers that follow cause complete re-sealing. Its detrimental effect on emergence of seedlings and on rainwater storage makes rain-fed agriculture virtually impossible. Only in the northern most part, where the inherent relief still exists, is the sealing moderate to slight. Augering is easy once the sealed layer is passed. The soil profile has a brown to strong brown fine sandy topsoil, and the subsoil is a yellowish red to red loamy fine sand (mainly Red Acid Sand/Quarzipsamment). In the areas with a shallow coversand layer, the profiles are usually somewhat heavier in texture (Red or Yellowish Brown Leached Kaolinitic Soil/Normustult?).

Only in the northernmost parts does some wet-season shifting cultivation take place (mainly millets); the vast majority of the land with Sangiwa sand coverage has a very poor *Combretum nigricans* savannah woodland or tree savannah, though strongly varying in density as mentioned before.

4.3 The **Sokoto coversand deposits** (C or c; 15B; 7-1, 7-2, 7-3 or 7-5) found in the northwest-central part of the survey area; marked concentrations occur around Sokoto and Tambawal towns, and north of Lema. The deposits occur over wide stretches in the area of the Tertiary Kalambaina-Dange deposits, are more scattered in the area of the Tertiary Upper Gwandu deposits and occur very locally in the area of the Cretaceous Rima and Gundumi deposits. In all these areas the sands are very often found concentrated at the eastern and, in particular, the western side of elongated scarps or individual tablelands (these sides apparently constituting the windward and the lee-

4. THE AEOLIC DEPOSITS

Five different types of aeolic sediments have been recognized and mapped in the area of the Rima-Sokoto river basin. These are:

4.1 The **Funtua loessic deposits** (b; 13 B; 1-5) [1], found only at the south-eastern edge of the area, between Funtua and Ronka.

The deposits occur on some of the flattened parts of the Crystalline basement, sometimes being concentrated directly east or west of isolated or ridgy hills (windward and leeward respectively).

The present thickness of non-displaced material is usually less than 2-3 m; only in some original gully-fillings is the coverage substantially thicker.

The deposits have no inherent relief; the mode of sedimentation apparently covered any minor irregularities of the original surface, and the result is a flat landscape. In the present-day occurrences some mixing with other materials (Zurmi coversands; sedentary basement material) can often be established. Apparently considerable covering, erosion and re-deposition has taken place in times subsequent to the original sedimentation.

The loess-covered parts have shallow drainage ways with a dendritic pattern; these, however, do not serve the most central and flattest parts, which are consequently waterlogged in the rainy season.

The granulometric composition of what seems to be the most pure of the deposits shows a high percentage of the very fine sand fraction (40-55 %); there are also considerable percentages of silt (15-20 %) and clay (15-30 %).

The heavy mineral association of the fine sand fraction shows a unique richness of sillimanite (1 sample only). Augering is fairly easy. The surface layer is considerably sealed when a natural vegetative cover is present, but stays friable for long time after tillage. If not imperfectly drained, the soil profiles have a brown very fine loamy sand to sandy loam top, grading into a strong brown to reddish brown or yellowish red very fine sandy clay loam subsoil (Red, Reddish Brown or Yellowish Brown Ferruginous Tropical soil/Vetustalf).

Apart from the waterlogged parts, the loess-covered areas are intensively cultivated during the wet season, with cotton, yams and guinea corn. If not cropped, a relatively luxuriant woodland prevails.

4.2 The **Sangiwa coversand deposits** (A or a; 13A; 6-2 or 6-3) found in the central-north-eastern part of the area (Isa, Lamba-tureta) and in the north-western part (Tangaza, Argungu).

The deposits occur uniformly over wide stretches of most of the flattened parts of the areas with either the Cretaceous Gundumi or the Tertiary Gwandu (II +III) deposits either at shallow depth or outcropping. They are not notably concentrated on the eastern or western sides of tablelands.

The present-day thickness of the deposits varies from less than 1 m to 10 à 15 m.

Only in the extreme north (above the 13°.30′ N. parallel) do the most characteristic parts of the deposits have an inherent meso-relief. It consists of low, hummocky dunes in a dense pattern; the distance between the dune tops is about 200 m and their difference

[1] The first group of symbols refers to the map accompanying this paper, the second and third groups to the geological scheme and the reconnaissance soil mapping legend respectively of the original FAO report (FAO, 1969).

ward sides respectively). When they occur together with Sangiwa deposits they are clearly covering these (cf. Stereo-triplet of Figure 10).

The present-day thickness varies between 5 and 40 m near scarps and in narrow valleys, and between 0.5 and 5 m on plains and flat structural plateau parts.

The inherent meso-relief, very apparent in the extreme WNW of the area, consists of long and broad low ridges in a ENE-WSW direction. They are 500 - 5000 m long, 200 - 1000 m wide, and 5 - 20 m high except on the plateau parts where the height is 1 - 3 m. Longitudinal dunes (seifs) must be concerned; locally their development from large parabolic dunes can still be traced. In narrow valleys between the Dange or Lower + Middle Gwandu scarps (LK, LW_0-LW_1) this dune pattern is vague or absent. This may be due partly to a different mode of deposition, but certainly also to considerable colluvation after deposition.

The drainage pattern is rather dense and dendritic in the valleys, open and vaguely parallel elsewhere.

The granulometric composition shows a higher top in the fine sand fraction (43 %) than the Sangiwa deposits, while there is more medium sand (28 %), but less very fine sand (10 %) and silt (3 %). The sand is therefore moderately to well sorted. The sometimes relatively high percentages of clay (10 %) are probably due to an influence of the samples from colluviated materials where admixture with some material of the clay-shales of the Dange formation is common.

The mineralogic composition of apparently pure deposits is of the Tourmaline-Staurolite-Zircon type (20 samples).

The surface layer of the soils shows no sealing. Augering is very easy. The profiles mostly have a brown sandy topsoil over a yellowish red sand to loamy sand subsoil (Yellowish Red Acid Sand/Quarzipsamment). Where in contact with the Kalambaina-Dange formations, the subsoil is reddish brown (in the case of shallow covers on top of the Kalambaina plinthite cap) or yellowish brown (in the case of colluviated fillings of the narrow valleys between the Dange scarp): Reddish or Yellowish Brown soil of ASTR/Haplargid.

The terrains with Sokoto sand coverage are being used nearly everywhere for shifting cultivation (millets + cowpeas), or — in the case of contact with the Kalambaina-Dange formation — for permanent wet season cultivation (millets + cowpeas, some guinea corn, some cassava). The parcels in the latter case are strewn with tall trees of useful species, notably the *Acacia albida*. The few uncultivated parts have a rather homogeneous savannah woodland with *Combretum nigricans* and *Anogeissus*.

4.4 The **Zurmi coversand deposits** (D or d; 16A; 1-1 and parts of 1-2) found in the eastern part of the area, notably near Kaura-namoda and Zurmi.

They occur over wide and rather continuous stretches on flattened parts of the Crystalline basement, with a slight tendency to concentrate at either the eastern or western side of isolated or ridgy hills.

Their present thickness varies from about 10 m to less than 0.5 m; the configuration and drainage pattern shows that in many parts denudation and erosion must have carried off and redeposited part of the original coverage.

The inherent meso-relief of these coversands is small. Height differences — observable only with difficulty in the field — are maximally 2-3 m over distances of more thans 500 m, in N-S direction only. Apparently largely denudated longitudinal dunes, running ENE-WSW, are concerned; vague remnants of parabolic dunes can be observed locally on the aerial photographs.

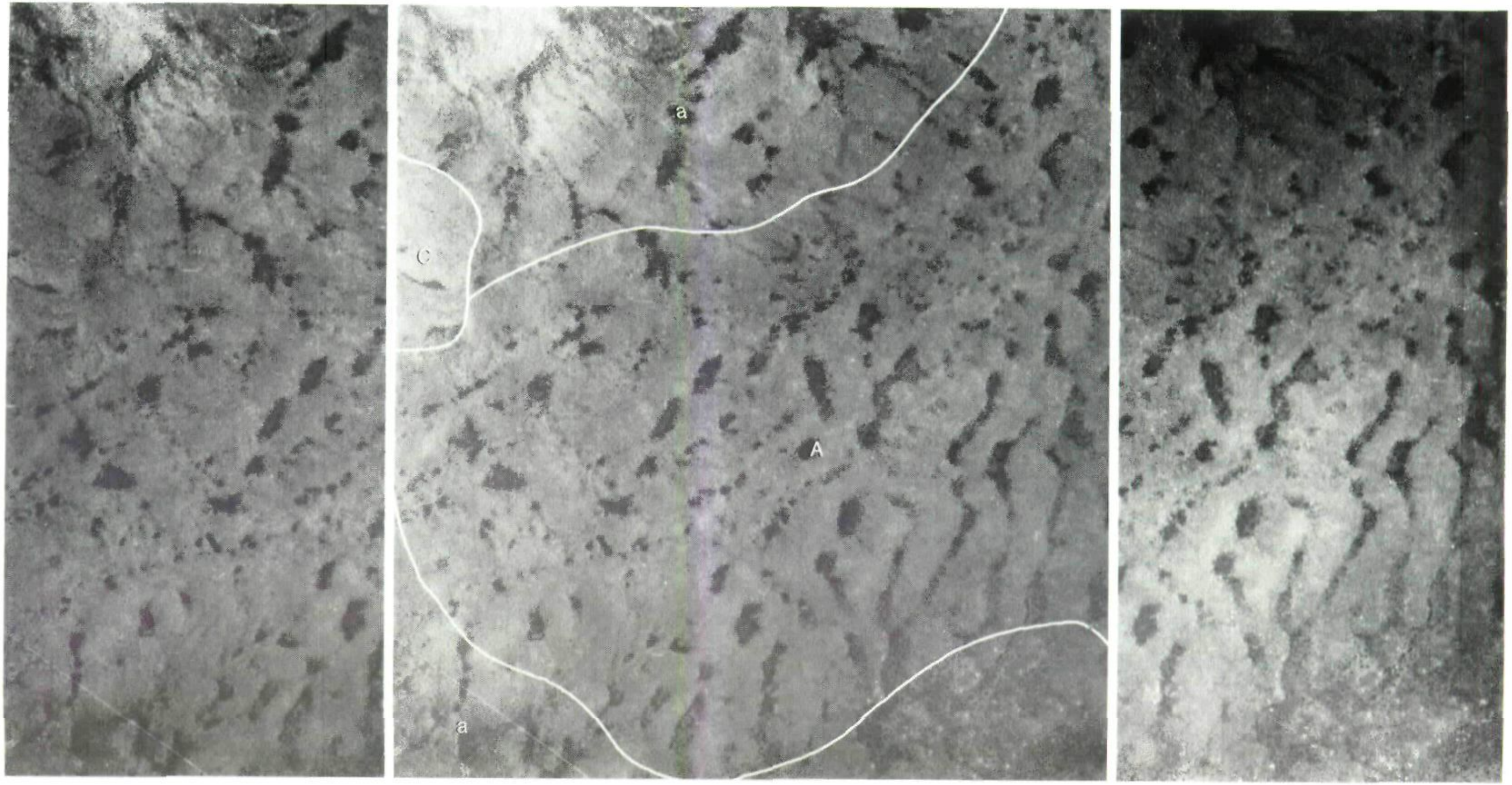


Fig. 9. The ripply vegetation pattern of pseudo dunes and gullies of the denudated Sangiwa coversands (A), a relic of low transversal dunes. For the symbols of the other mapping units cf. Appendix 1.
(stereo-triplet E-W, scale 1 : 40,000, of an area 25 km south of Dange).

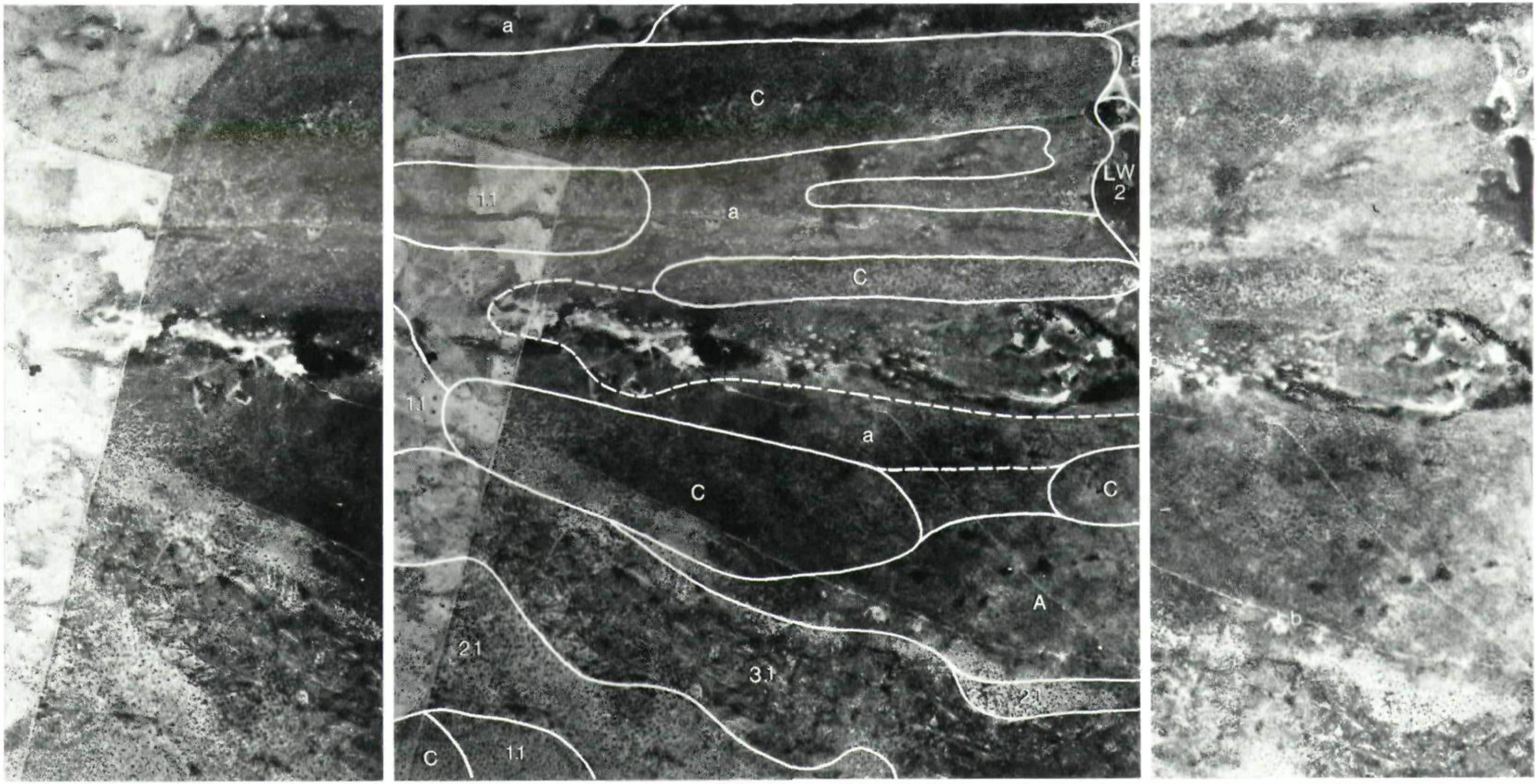


Fig. 10. The elongated pattern of the low longitudinal dunes of the Sokoto coversands (C). For the symbols of the other mapping units cf. Appendix 1. (stereo-triplet E-W, scale 1 : 40,000, of an area 25 km north of Lema)

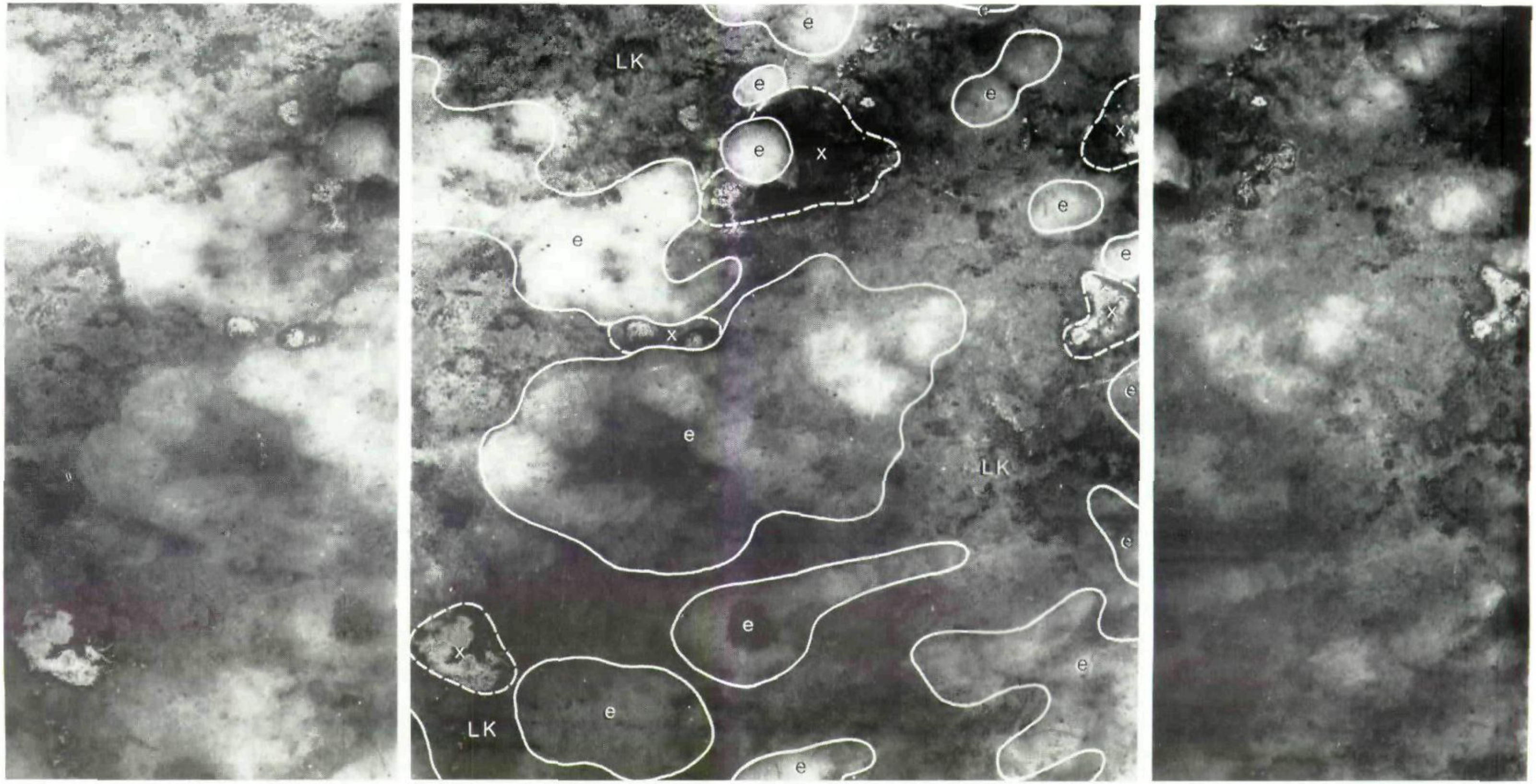
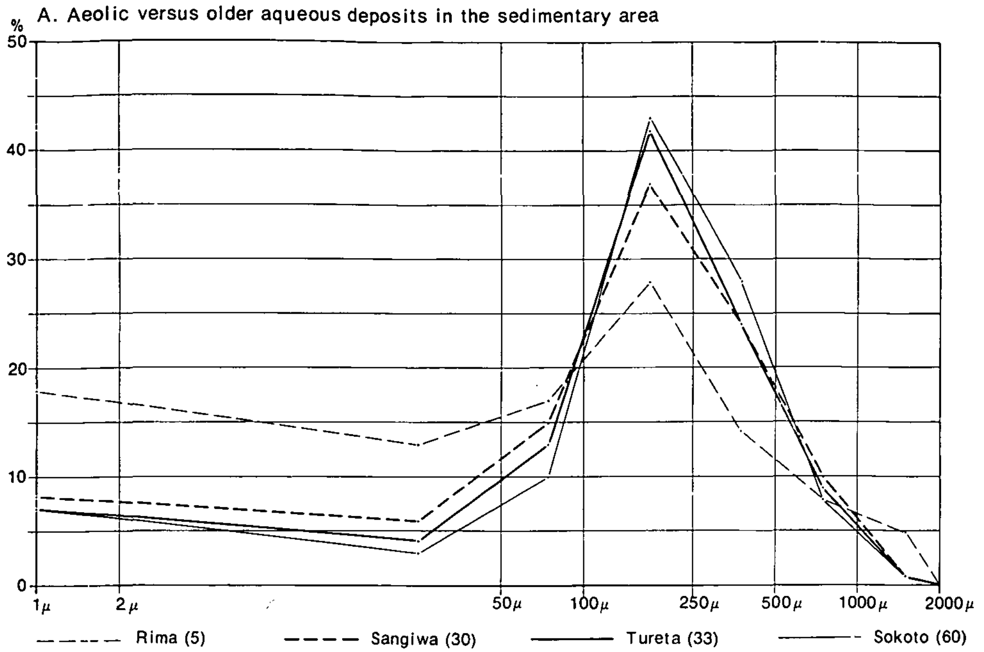


Fig. 11. The fleecy-cloud pattern of the fortress-shaped dunes of the Illela coversands on the Kalambaina structural plateau (e). In between the plinthite-capped parts of this plateau (LK), are small and shallow depressional parts with non-plinthitic fertile soils (x).
(stereo-triplet E-W, scale 1 : 40,000, of an area 25 km west of Illela)



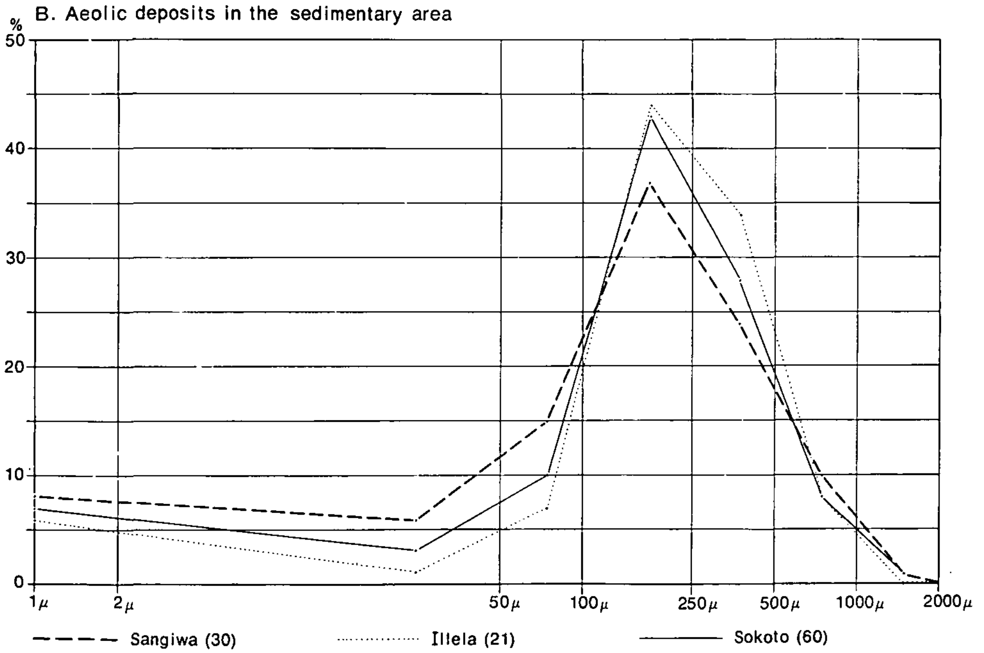


Fig. 12. (A to D) Graphical comparison of the grain-size distribution of various Quarternary deposits.

The terrains with Tureta deposits are often under wet-season shifting cultivation (millets + cowpeas, some groundnuts). The original vegetation, still preserved in narrow outliers of the plain within forest reserve boundaries, is comparable with that of the Sokoto coversands: rather homogeneous Combretum nigricans- Anogeissus woodland. In many places, grazing has degraded it into tree-savannah with a grassy surface cover of rather good grazing quality.

5.2 The **Bakolori loamy high-terrace deposits** (1.2; 15A; 9-2) are found only very locally (Maradun, Maru).

The deposits occur in narrow bands along the middle reaches of only a few of the main rivers, both in the Crystalline basement area and at the transition with the sedimentary area. The deposits are not found on those parts of the crystalline area where Zurmi coversands abound; apparently these are of a younger age than the Bakolori deposits, and cover them. The thickness of the deposits is variable.

The macro-relief in between the gullied parts is flat; there is no noticeable meso-relief and the level above the highwater of the rivers is several tens of meters. The bands are 1-3 km wide, but considerably dissected, to the extent that isolated patches, rather far from the river bed, are often concerned whose edges are often scarplike, with substantial gullies. Thus, the deposits form low table-lands on top of the Crystalline basement. Apparently erosion has considerably diminished the original extent of the deposits, and is still continuing.

Texturally, the deposit is usually a fine sandy loam, but with no consistently clear top in the fine sand fraction.

Mineralogically, the deposits were not analysed, but field observation shows the presence of micas in small amounts. Data on the composition of the clay fraction are lacking.

Surface sealing is not persistent. Augering is fairly easy; the profiles have a dark yellowish brown loamy sand topsoil over a yellowish brown to reddish brown sandy loam subsoil (Reddish Brown or Yellowish Brown Ferruginous Tropical soil/Vetustalf).

The terrains are largely in use for permanent wet-season cropping (cotton, guinea corn).

5.3 The **Gusau loessic high-terrace deposits** (1.3; 13C; 9-3) are also found only very locally (Gusau).

The deposits occur as narrow bands along some of the main rivers (Sokoto, Gagare) in the Crystalline basement area, upstream of the Bakolori deposits. Like the Bakolori deposits, they are not found where coversands abound. They do, however, have a physiographic association with the Funtua loess deposits, from which they appear to have developed by colluvial and alluvial valley filling.

The thickness of the deposits varies with the depth of the original valleys.

The macro-relief is flat or slopes very gently towards the river, and the level above high water of the rivers is similar to that of Bakolori deposits. Another similarity between the two deposits is that the bands are considerably dissected, locally forming low tablelands with substantial active gullying at the scarps.

The granulometric composition is a very fine sandy loam (50 % very fine sand, 10 % silt, 20 % clay). The fine sand fraction of one sample showed a mixed mineralogic composition: Tourmaline-Hornblende, with some Staurolite, Epidote and Andalusite. No micas could be observed in the field. The clay fraction consists of poorly crystallised kaolinite and iron oxides, with SiO_2/Al_2O_3 about 2.5, and cation exchange capacity 30-40 m.e.

The surface of the soil seals slightly but not persistently. Augering is fairly easy.

5. THE OLDER AQUEOUS DEPOSITS

A number of sandy to loamy deposits have been recognised and mapped, arranged as depositional terraces or terrace-like plains alongside the main drainage ways. They are described in the following:

5.1. The **Tureta sandy wash-plain deposits** (1.1; 14; 9-1) [1] are found throughout the northwestern half of the survey area (Kebbe, Lamba tureta, Gandi, Isa, Sabon Birni, Argungu, Binji, north of Lema).

The deposits occur in broad bands, along both the permanent rivers and minor, ephemeral streams in the sedimentary part of the area, notably where the Gundumi and Middle/Upper Gwandu formations have been mapped. The deposits are found only rarely in the area of the Illo, Rima, Dange, Kalambaina and Lower Gwandu formations and do not occur at all on the Crystalline basement area.

Physiographically, the occurrence is largely associated with that of the Sangiwa sands; in these parts the deposits are usually found as wide and uninterrupted fingery bands, with smooth lines of transition to the Sangiwa deposits; apparently the Tureta deposits are younger than the Sangiwa ones. Where Sokoto and Illela sands occur in substantial expanse. Tureta deposits are either absent or occur interruptedly and with irregular lines of transition (e.g. north of Lema). Apparently the Tureta deposits are older than the Sokoto and Illela sands and are largely covered by them.

The thickness of the deposit is uncertain; it probably varies from a few meters to 40 or more.

The macro-relief of the deposits is flat, but the plain as a whole has a very gentle slope towards the rivers. The width of the bands varies from less than 1 km to about 10 and their level above the highwater of the rivers from 10 to 30 m, the higher figures applying to the larger rivers. Within the general flatness, there is locally a meso-relief, consisting of surface irregularities over distances of maximally 100 m and a few meters height. They have the form of low dunes (e.g. near Isa) or of blow-outs/deflation holes (e.g. near Zazagawa). At the boundary with the surrounding landscape the changes in height are usually very gradual, but in the Sangiwa sand area there is occasionally a low scarp (terrace slope).

Geomorphologically, the deposits have a "wash-plain" character (cf. Chapter 7, and Zonneveld, de Leeuw and Sombroek, 1971). The drainage pattern is open dendritic; characteristically, many interruptions occur, and many of the smaller drainage ways that come from Sangiwa coversand or Gundumi and Gwandu outcrops stop dead upon entering the area of the Tureta deposits.

The granulometric composition of the Tureta sands has a clear top in the fine sand fraction (42 %); the percentage of medium sand is rather low (24 %), while the percentages of the very fine sand, silt and clay fractions are in between those of the Sangiwa and Sokoto coversands (13, 4 and 7 % respectively); the sand is therefore moderately sorted.

The mineralogic composition of the sand fraction is of the Tourmaline-Staurolite-Zircon type (6 samples).

The surface of the soils shows little sealing, although where the bands form narrow strips in between Sangiwa sands, the sealing may be moderate. Augering is easy. The profiles have a brown to strong brown sandy topsoil over a yellowish brown or reddish brown loamy sand subsoil (Brown and Red Acid Sand/Quarzipsamment).

[1] See note on page 31.

The drainage pattern is fairly dense and dendritic.

The granulometric composition again shows a clear top in the fine sand fraction (43 %), with only 12 % in the medium sand fraction, but rather high percentages in the finer fractions: very fine sand 24 %, silt 5 %, clay 9 %. The deposits are therefore only moderately sorted.

The mineralogic composition of the fine sand fraction shows a predominance of a Epidote-Hornblende type (11 samples), strikingly different from that of the other coversands.

The surface layer of the soil seals, but not as strongly as that of the Sangiwa sands; it apparently has no adverse effect on vegetation and crops. Augering is easy. Where the deposits are thick enough (> 1.5 m) the profiles have a brownish yellow to yellowish brown loamy subsoil of loamy sand to sandy loam (Yellowish Brown soil of ASTR/Haplargid). Where the deposits are shallower, the underlying weathered crystalline rocks have apparently contributed significantly to the soil formation (Yellowish Brown Ferruginous Tropical soil/Vetustalf).

The terrains have, for a good part, permanent wet-season cultivation, with groundnut as the prominent cashcrop. Parts within forest reserve boundaries have *Anogeissus* woodland or, in the south, *Anogeissus-Isoberlina* woodland. Parts in shifting cultivation have degradation stages to shrub-savannah (e.g. with *Terminalia*)

4.5 The **Illela coversand deposits** (E or e; 21A; 8-1, 8-2 or 8-3), found only in a small area north of Sokoto town, near the frontier with Niger Republic (Raka, Illela, Gada).

The deposits occur as a continuous cover near tableland outcrops of the Middle Gwandu, as discontinuous stretches running roughly E-W on plateau land of the Kalambaina formation, and as patches near plinthite outcrops of the Upper Gwandu and the Dukamaie formations. In the latter case the patches tend to be concentrated at the eastern or western side of isolated tableland hills or scarps.

The thickness varies from 0.5 m in the slacks of the dunes on the Kalambaina plateau land to more thans 30 m near scarps of the Middle or Upper Gwandu.

These coversands have a prominent inherent meso-relief. It consists of groups of small, somewhat ellipsic dunes, which are 400-500 m long (E-W), 300-400 m wide (N-S) and 10-20 m high; the dune tops tend to be flat or even saucer-shaped. The grouping results in a pattern of "fleecy clouds" on aerial photographs (cf. Stereo-triplet of Figure 11). This pattern may have developed from longitudinal dune chains which were re-shaped into "fortress" dunes (cf. SCHELLING, 1955). A drainage pattern hardly exists.

The granulometric composition shows a very clear top in the fine sand fraction (44 %), a considerable percentage of the medium sand fraction (34 %), and very low percentages of the very fine sand, silt, and clay fractions (7, 1, and 6 % respectively). The sands are therefore well sorted.

The mineralogic composition is of the Tourmaline-Staurolite-Zircon type (8 samples).

The soil surface does not have any degree of sealing. Augering is very easy. The soils on the thicker deposits have rather reddish profiles in the area of the Gwandu deposits (Yellowish-Red Acid Sand/Quarzipsamment), but those in the area of the Kalambaina and Dukamaie deposits are more yellowish brown (Yellow and Brown Acid Sand/Quarzipsamment). Shallow deposits in the latter areas have more reddish brown profiles (Reddish Brown Soil of ASTR/Haplargid).

Most of the land is in use for shifting cultivation (millets + cowpeas), but parts of the Gwandu area have a woodland vegetation similar to that of the Sokoto sands.

The profiles have a brown very fine loamy sand to sandy loam topsoil over a reddish brown of yellowish red very fine sandy clay loam subsoil (Reddish Brown Ferruginous Tropical soil/Vetustalf).

5.4 The **Rabah sandy main-terrace deposits** (2.1; 16BR; 10-1) are found throughout the northwestern half of the survey area (e.g. Katami, Gandi).

They occur in relatively narrow bands (1-2 km) along all of the permanent rivers and a few of the larger ephemeral streams in the sedimentary part of the area, starting at some distance from the Crystalline basement. Only where the rivers cut through the plinthite caps of the Middle/Upper Gwandu formation are the bands absent. The deposits are often physiographically associated with the occurrence of the Tureta wash plain, but they also occur in the areas with accumulation of Sokoto coversands (except where these are recently colluviated); in both cases there are smooth lines of transition. Where Illela coversands occur, however, the deposits are either absent or present only interruptedly and with irregular lines of transition (e.g. near Tangaza). Apparently the Rabah deposits are younger than the Tureta and Sokoto deposits, but older than the Illela ones.

The thickness of the deposits varies, probably from a few meters to about 20 m.

The terrains are mainly used for permanent wet-season cropping, comprising the medium crop sequence. Cotton is an important cash crop.

The terrains have a flat macro-relief. There is a well-marked height difference of several meters at the contact with the Tureta deposits (terrace slope). The level of the terrains is about 3-4 m above the high water of the rivers. Some meso-relief, the result of past wind action, is apparent in the northernmost area, near the occurrence of Illela coversand.

The granulometric composition of the Rabah terrace deposits is somewhat coarser than that of the Tureta ones. Along with fine sand (41 %), there is a considerable percentage of medium sand (30 %), while the percentages of very fine sand, silt and clay fractions are somewhat lower (10, 3 and 5 % respectively). The sands are thus wellsorted.

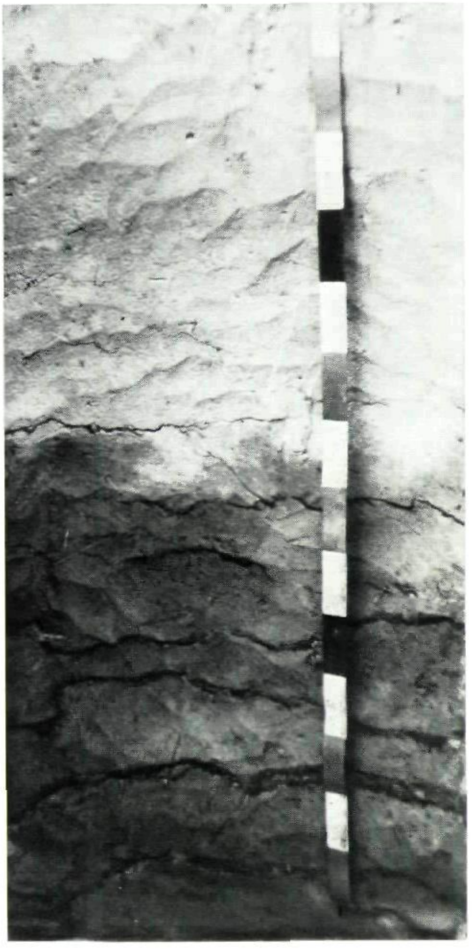
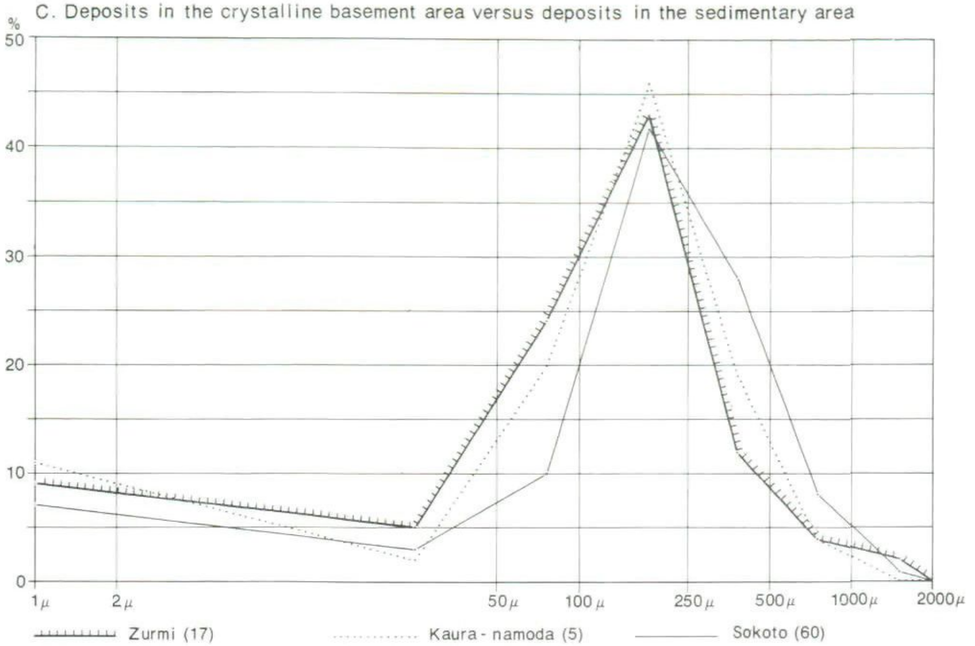
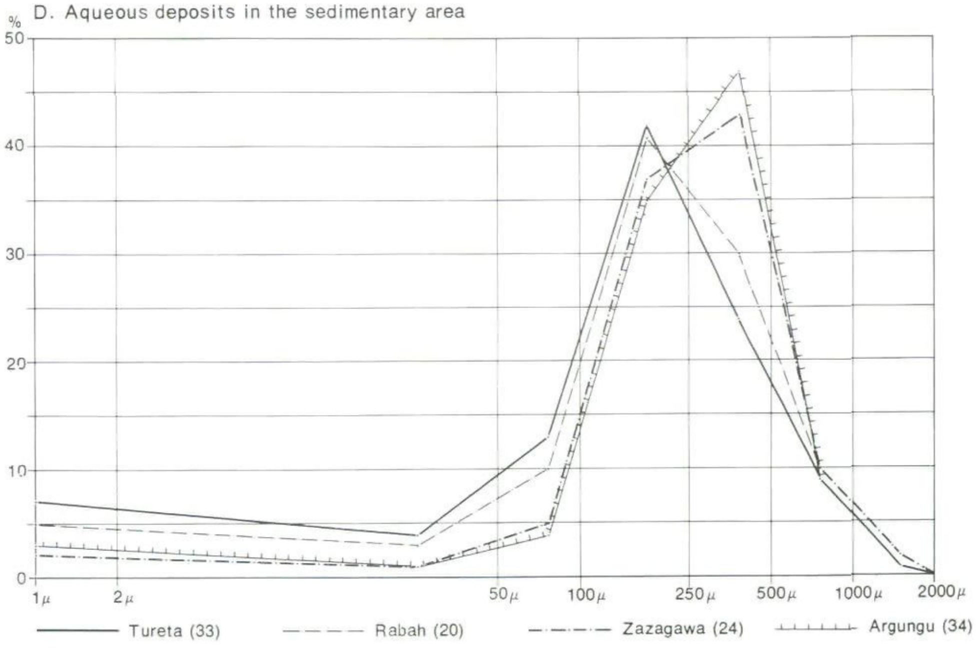


Fig. 13. Soil profile on the Rabah terrace. Yellowish Brown soil of Arid and Semi-Arid Tropical Regions/Haplargid, with banded clay accumulations in the subsoil ("fibers").


C. Deposits in the crystalline basement area versus deposits in the sedimentary area
%
50
40
30
20
10
0
1μ
2μ
50μ
100μ
250μ
500μ
1000μ
2000μ
Zurmi (17)
Kaura - namoda (5)
Sokoto (60)


D. Aqueous deposits in the sedimentary area
%
50
40
30
20
10
0
1μ
2μ
50μ
100μ
250μ
500μ
1000μ
2000μ
Tureta (33)
Rabah (20)
Zazagawa (24)
Argungu (34)

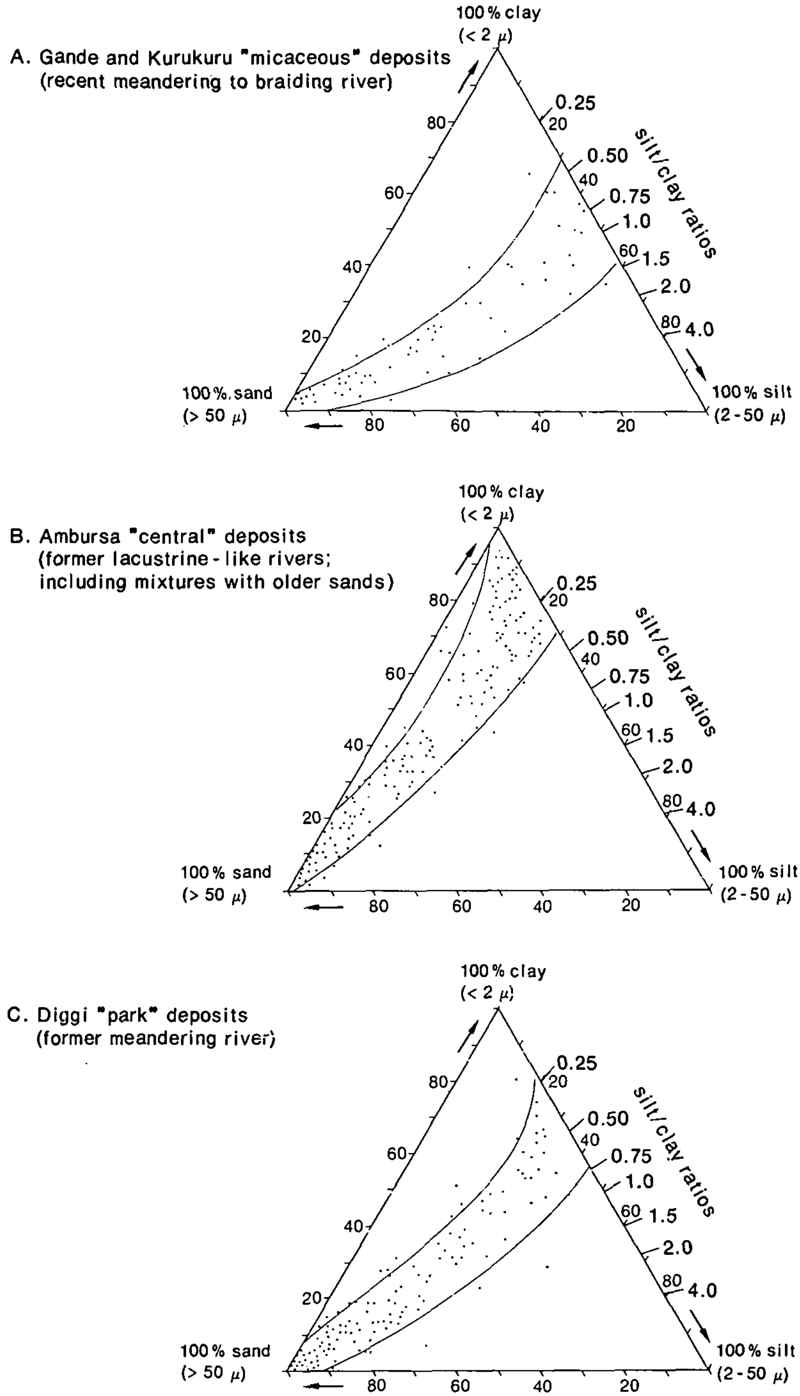


Fig. 14. (A to C) Triangular comparison of the grain-size distribution of some clayey aqueous deposits.

The surface does not seal. Only where — on the lowest parts — some admixture with other sediments has taken place, sealing may be faint to moderate. Augering is very easy. The profiles on the highest parts have a brown or dark grayish brown sandy topsoil over a pale yellowish sandy subsoil (Yellow Acid Sand/Quarzipsamment). At some depth the profiles of the lower parts have a thin (25-50 cm) bleached layer of very pale brown sand, below which some clay accumulation may have taken place (Weakly Bleached Hydromorphic soil/aeric Aquipsamment or aeric Albaqualf).

The land use is more intensive than on the Zazagawa deposits, one reason for this being the better hydrological conditions. The highest, non-flooded parts have a near-permanent wet season cropping of millets + cowpeas. Intermediate parts, just at the high water level (the channels proper), are normally not cultivated, but the lowest flattened parts have considerable rice-growing, with sand-adapted varieties.

The natural vegetative cover of the lowest flattened parts seems to be mainly grasses, which are only a little or not at all tufted. The intermediate and some of the high parts have a regularly distributed rather open woody vegetation, the palm *Borassus* often being a notable component. Fossil or active termite mounds are either absent or very low (the latter occurring in the flattened low parts).

Note: No loamy equivalent of the Argungu floe deposits has been found in the eastern tributaries of the Rima — which might be expected in view of the supposed correlation between the Zazagawa sandy deposits and the Bagudo loamy low-terrace ones.

6.2 The **Diggi park deposits** (5; 19; FP; P1 and P2) are found in the floodplains all over the northwestern half of the survey area (Isa, Sabon Birni, Goronyo, Talata-mafara, Argungu, Diggi, Gummi, Bunza, Dakin Gari).

Concerned here are the floodplains of all main rivers, including the presently ephemeral lower Maradi, whose catchments extend to well within the Crystalline basement area.

The deposits are not found in the floodplains of minor rivers, nor in the fossil floodplains of the Tarka, Goulbi o n'Kabba and Dallol Maouri, which all come from the Sahara area.

The deposits occur as either fairly continuous stretches or in broken units, the latter either immediately around Argungu floe patches or groups of patches, or discrete from them.

Where the deposits are underlain by floe sediments their thickness is probably not more than 3 m anywhere in the Rima floodplain, while it may be slightly more in the Crystalline basement tributaries, where floe sediments are absent.

The macro-relief is flat, but there is considerable meso-relief, though it differs from that of the Argungu floe deposits in that there are rather homogeneous and wide (250-500 m), relatively high stretches of somewhat sinoidal form (former river levees); locally they have a fig-leaf form and contain shallow creeks resembling veins (crevasses with crevasse splays), e.g. opposite Argungu. Within these high stretches, or rather bounding them, are elongated and often curving depressions (length 100-1000 m or more, width 50-100 m, depth 2 m or more) breaking the gentleness of the relief. These are former meander channels, either with channel fill or forming oxbow lakes. Alternating with the levees are rather extensive regular lower parts (parts of former basin lands).

Apparently sediments of a former meandering river system are concerned, laid down after a period of down-cutting and erosion of the floe deposits.

The height of the former levees and splays is 0-35 cm below normal high water, that of the basin land parts (when non-eroded or -covered) about 60-80 cm below. As

6. THE YOUNGER AQUEOUS DEPOSITS

In the areas commonly regarded as the floodplain ("fadama") of the rivers, a number of different deposits have been recognised and mapped. A detailed discussion of their pedological, hydrological and agro-ecologic conditions will be given in a forthcoming paper. The following description contains only those data that enable the deposits to be recognised and that allow their origin and age to be established. Appendix 2 gives a schematic cross-section of the main floodplains, as well as some examples of the detailed physiographic patterns (cf. also Stereo-pairs of Figures 15 to 18).

6.1 The **Argungu floe deposits** (4; 18; FS; S1, S2 and S3) [1] are found in the floodplains at the northwestern edge of the survey area (north of Goronyo, Gande, Argungu, Birnin Kebbi, Bunza). In fact, the deposits occur only in the Tarka and Goulbi o n'Kabba fossil floodplains and in the Rima floodplain downstream of their confluence. The surface occurrence may be either continuous stretches, groups of patches, or single patches of raised ground within the main floodplain. On aerial photographs these patches seem to float like bright ice-floes on a dark sea of other deposits (cf. Stereo pair of Figure 15), hence the name.

There is a clear physiographic association with the Zazagawa deposits; if in contact, the two deposits are separated by a fall in level of 1.5-2 m (terrace slope).

The thickness of the deposits is probably less than 10 m in most places.

The macro-relief is understandably flat, but there is much meso-relief: shallow channels in a rather dense braiding pattern, 0.5-1.0 m deep, 30-200 m wide, 100-400 m apart; also whole stretches may occur at this depth or even slightly lower, the channels, in particular, being etched with many subparallel narrow drainage ways. Apparently the channels of an original braiding river pattern formed the starting point for erosion during a period of river downcutting, the lowest parts being levelled off again by some subsequent sedimentation. In the Tarka, there is less gullying; on the other hand, some effects of past wind action can be observed (very low dunes; cf. nearness to the Illela coversand area).

The level of the highest, non-eroded parts is 30 to 100 cm above normal high water of the river — locally small villages have been built —, the level of the lowest parts 20 to 50 cm below it. In general the relative levels are slightly higher upstream than downstream. South of Diggi, for instance, the non-eroded parts are only a little, or not at all, above the high water level.

In fact, for the Argungu deposits, one should rather speak of "lowest terrace" than of a floodplain component.

The granulometric composition of the pure deposit (thus excluding the superficial layer of the lowest, levelled-off parts) is characterized by a high percentage of medium sand (47 %), somewhat less fine sand (35 %), and verv low percentage of very fine sand, silt, and clay (4, 1 and 3 % respectively). The sand is therefore somewhat coarser and, at the same time, even better sorted than the Zazagawa sands.

Mineralogically, the sand belongs to the association E: Tourmaline - Hornblende, with Staurolite, Zircon, Epidote and Andalusite (4 samples). Characteristically, during field examinations, no flakes of micas could be found.

[1] See note on page 31. The fourth group of symbols refers to the semi-detailed soil mapping of the original FAO report, as well as to the mapping symbols of Appendix 2.

The remaining woody vegetation, too, is very poor; locally the *Borassus* palm occurs in fair quantity.

5.8 The **Bagudo loamy low-terrace deposits** (3.2; 17B; FL2 and FL3) are found in the NE-SW axial part of the survey area (Gummi, Niger River).

They occur in bands along the main rivers just downstream of where they enter the sedimentary area from the Crystalline basement. Their extension is particularly broad (bands 5-10 km wide) along the middle Zamfara River and along the Niger; along the Sokoto their occurrence is restricted to a patch north of Bakura, while at the confluence of the Bunzuru and the Gagare they are even absent. Physiographically, the deposits are associated with the Talata deposits, though as a whole occurring slightly further downstream. Where in horizontal contact with either Talata or Rabah deposits, they are separated by a low scarp (terrace slope) of 3-5 m.

The thickness of the deposits is not known; it probably does not exceed 10 m.

The macro-relief is flat and the level of the terrain is only 1 m or even less above the high water level of the river. Locally, shallow and brief flooding takes place, though stagnant rain water is mainly concerned. On the other hand, the parts along the Zamfara locally have slightly raised patches, probably remnants of Talata deposits. The parts along the Niger near the upland have some bands that are slightly lower than the general level (apparently former basin lands), as well as some irregularly meandering gullies which form the presentday drainage pattern.

The granulometric composition of the deposits is mostly a fine to very fine sandy loam, to loam or sandy clay loam. Along the Niger and along the Rima near its confluence with the Niger, some sandy parts occur, which are similar to the Zazagawa deposits. On the other hand, clays to clay loams (with only a fair silt content: silt/clay about 0.4) occur as well in these areas, namely in the above mentioned former basin land parts. The clays are fully stabilized (ripe).

In its mineralogical composition the fine sand fraction seems intermediate between the Tourmaline-Staurolite-Zircon type and the Epidote-Hornblende type (type E, only 2 samples). Tiny mica flakes, in small quantity, can be observed in the field at some depth. The clay fraction consists of moderately crystallised kaolinite and some iron oxides, with SiO_2/Al_2O_3 ratio about 2.4, and a CEC of 20-35 m.e.

The soil surface has a strong tendency to seal, except on the raised patches. Augering is difficult. The soil structure is poor to fair and the drainage imperfect. The profiles show considerable illuviation of clay-sized particles, nearly obliterating any original sedimentary stratification; the topsoil is mostly a gray brown very fine sandy loam, the subsoil a light brownish gray clay loam with common mottles of yellowish brown/yellowish red; in the subsoil Na^+ may have accumulated (Mesotrophic Mineral Hydromorphic soil/vetustalfic Ochraqualf and aeric Natraqualf).

The land use is rectricted to some patchy growing of rice, while the slightly raised patches may have guinea corn. Most of the terrains have a covering of savannah woodland, relatively rich in species (*Acacias*). The trees and the shrubs are often clustered either on top of active, or around eroding and deserted, tall termite mounds (2-3 m high, 5 m wide). This gives a black-dot pattern on the aerial photographs ("dotted terrace").

At the side of the river a gullying scarp often occurs, sometimes even interrupting the bands; frequently found between this scarp and the present floodplain are strips with outcropping Crystalline basement or redeposited Zurmi sands. Apparently a substantial part of the Kaura-namoda deposits have been eroded in the course of time.

The granulometric analysis shows a distinct top in the fine sand fraction (40 to 50 %).

Mineralogically, the deposits may be of the Epidote-Hornblende type (only 1 sample). In the field they can easily be distinguished from the Rabah sands by the presence of flakes of micas.

The surface does not seal, or hardly so. Augering is very easy. The profiles consist of a yellowish brown fine sandy topsoil over a strong brown fine sandy subsoil, the latter, like the Rabah soil profiles, containing fibers (10-15 % clay; Yellowish Brown soil of ASTR/Haplargid).

The terrains are fully in use for semi-permanent wet-season cropping (groundnuts, millets, locally guinea corn).

5.7 The **Zazagawa sandy low-terrace deposits** (3.1; 17A; FL1) are found only in the northwestern part of the survey area (north of Goronyo, Argungu, Birnin Kebbi).

The deposits occur along the Goulbi o n'Kabba and the Tarka, and along the Rima River downstream of the confluence of these fossil tributaries as far as its confluence with the Zamfara. In Niger Republic, the main part of the Dallol Maouri, a fossil tributary of the Niger river, seems to be filled with these deposits as well.

Usually, rather broad bands are concerned (2-4 km). They are often physiographically associated with the Rabah deposits, from which they are separated by a low scarp (terrace slope) of 3 m or so.

The level above the high water of the rivers is about 2-3 m.

The thickness of the deposits is not known; it probably varies from 5 to 30 m or more.

The macro-relief is flat and the level is about 2 m above the high water of the river, if present. There is a meso-relief of shallow fossil gullies or channels (1 m deep, 50-100 m wide) in an open braiding pattern (about 200-1000 m apart). Locally, some deformations of the terrain surface, due to past wind action, are found (low dunes across Argungu; low dunes and blow-outs near Salami).

The present drainage pattern follows some of the fossil gullies.

The granulometric composition of the deposits is characterized by high percentages of both the fine and the medium sand fractions (37 and 43 % respectively); there is little or no very fine sand, silt, or clay (5, 1, and 2 % respectively). The sand is therefore somewhat coarser and at the same time even better sorted than that of the Rabah terrace.

Mineralogically the fine sand fractions belongs to the association D: Tourmaline-Staurolite-Zircon, with Epidote, Hornblende and Andalusite. In the field no traces of micas can be found.

The surface of the soil has no sealing at all. Augering is very easy. The profiles of the normal terrain parts have a dark brown sandy topsoil over a light yellowish brown to very pale brown sandy subsoil; fibers are either absent or few and very thin (Brown Acid Sand/Quarzipsamment). The gullies have profiles that are bleached to a considerable depth (white sand), without an accumulation horizon below (Strongly Bleached Hydromorphic soil/Aquipsamment). External drainage in these parts is imperfect to poor; the lowest parts are even marshy.

The terrains are in use for cropping, but extensively, taking the form intermittent wet-season cropping of millets + cowpeas only. The gullied parts, if not covered with a marsh vegetation, sometimes have cassava or sweet potatoes.

Table 5 (continued)

Profile no.	Soil classification unit	SiO_2 weight %	Fe_2O_3 weight %	Al_2O_3 weight %	$\frac{SiO_2}{Al_2O_3}$ molair	$\frac{Fe_2O_3}{Al_2O_3}$ molair	Clay minerals according to X ray diffraction (* DTA as well)	CEC-clay (milli-equivalent; average for the classification unit)
Gusau high-terrace deposits								
C7/14	– Reddish Brown Ferruginous Tropical Soil on unconsolidated parent material	46.0	7.40	30.9	2.53	0.15	*poorly cryst. kaolinite + iron oxides (10-30 %)	30-40
Talata main-terrace deposits								
D6/73	– Yellowish Brown Ferruginous Tropical Soil on unconsolidated parent material	46.4	6.85	31.8	2.48	0.14	poorly cryst. kaolinite + iron oxides (10-30 %)	20-30 (50)
Bagudo low-terrace deposits								
C3/39	– Mesotrophic Mineral Hydromorphic Soil on loamy riverine sediments	45.5	7.45	32.6	2.37	0.15	moderately cryst. kaolinite + some iron oxides (⩽ 10 %)	20-35
Diggi old meandering river deposits								
BK48	– Eutrophic Mineral Hydromorphic Soil on clayey riverine sediments	48.8	7.42	28.1	2.96	0.17	poorly cryst. kaolinite + iron oxides (10-30 %)	± 42 (BK48 and AR12)
AR12	– Eutrophic Mineral Hydromorphic Soil on clayey riverine sediments	47.8	7.67	29.6	2.75	0.16	*poorly cryst. kaolinite + iron oxides (10-30 %)	
Ambursa lacustrine deposits								
BK7	– Vertisolic Hydromorphic Soil on clayey lacustrine sediments	46.3	8.55	29.6	2.66	0.18	poorly cryst. kaolinite + some iron oxides (⩽10 %)	± 38 (BK7 and BK37)
BK37	– Vertisolic Hydromorphic Soil on clayey lacustrine sediments	47.7	7.78	28.2	2.88	0.17	poorly cryst. kaolinite + some montmorillonite	
Ambursa lacustrine deposits, lime-enriched								
BK17	– Topomorphic Vertisol on clayey lacustrine sediments	49.8	6.56	27.1	3.12	0.15	poorly cryst. kaolinite + montmorillonite	50-55
Tungantudo semi-lacustrine deposits								
F4/20	– Topomorphic Vertisol on clayey lacustrine sediments	46.5	10.44	24.8	3.19	0.27	poorly cryst. kaolinite + montmorillonite	± 70
Kurukuru + Gande young meandering river deposits								
W II	– Slightly Matured Juvenile Soil on sandy to loamy riverine sediments	47.7	7.78	28.8	2.82	0.17	poorly cryst. kaolinite + iron oxides (10-30 %)	± 50 (W II and SK21)
SK21	– Typic Juvenile Soil on clayey riverine sediments	47.8	7.90	28.9	2.82	0.18	poorly cryst. kaolinite + iron oxides (10-30 %)	

Table 5. Composition of the clay fractions of B horizons of soil profiles from various parent materials

Profile no.	Soil classification unit	SiO_2 weight %	Fe_2O_3 weight %	Al_2O_3 weight %	SiO_2/Al_2O_3 molair	Fe_2O_3/Al_2O_3 molair	Clay minerals according to X ray diffraction (* DTA as well)	CEC-clay (milli-equivalent; average for the classification unit)
Crystalline basement complex								
B5/29	– Mineral Semi-hydromorphic Soil on cryst. rock, intergrading to Solodized Solonetz	50.2	7.84	26.4	3.23	0.19	poorly cryst. kaolinite + montmorillonite	30-60
C7/8	– Yellowish Brown Ferruginous Tropical Soil on acid crystalline rocks	47.3	6.54	32.0	2.51	0.13	*poorly cryst. kaolinite + iron oxides (10-30 %)	30-45
C6/61A	- Reddish Brown Ferruginous Tropical Soil on ferromagnesian-rich rocks	35.7	8.98	24.0	2.53	0.24	*poorly cryst. kaolinite + haematite	—
Crystalline basement complex + Zurmi coversand								
B7/37	– Yellowish Brown Ferruginous Tropical Soil on acid crystalline rocks: A horizon	48.5	6.66	29.6	2.79	0.14	poorly crystallised kaolinte + iron oxides (10-30 %)	30-45
	B horizon	47.0	7.52	30.5	2.62	0.16		
	C horizon	48.5	7.61	29.6	2.79	0.16		
Gundumi formation								
D5/22	– Modified Gray Kaolinitic Soil	48.3	4.20	36.2	2.27	0.07	*well cryst. kaolinite	17-30
Illo formation								
B2/2	– Red Ferruginous Tropical Soil on unconsolidated parent material	44.3	7.54	33.6	2.24	0.14	*moderately cryst. kaolinite + some haematite	20-30
Dange-Kalambaina formation								
E4/96	– Lithomorphic Vertisol on calcareous rocks	50.3	9.51	22.0	3.89	0.28	*montmorillonite + poorly cryst. kaolinite	45-55 (
Kalambaina formation + Sokoto coversand								
D4/23	– Dark Brown Soil of ASTR on unconsolidated parent material	48.5	4.50	27.1	3.04	0.11	poorly cryst. kaolinite + montmorillonite	40-50
Gwandu II + III formation								
E3/16	– Leached Red Kaolinitic Soil	51.7	3.73	35.1	2.51	0.07	*well cryst. kaolinite	5-20
Gwandu II + III formation + Sangiwa coversand								
E3/44	– Leached Yellowish Brown Kaolinitic Soil	47.5	4.20	36.6	2.21	0.07	well cryst. kaolinite	15-20
Funtua loess								
B8/33	– Reddish Brown Ferruginous Tropical Soil on unconsolidated parent material	44.1	8.93	31.3	2.39	0.18	moderately cryst. kaolinite + some iron oxides (< 10 %)	30-40
B8/27	– Yellowish Brown Ferruginous Tropical Soil on unconsolidated parent material	44.1	9.23	31.9	2.35	0.18	*poorly cryst. kaolinite + some haematite	30-45

The mineralogic composition of the fine sand fraction is of the Tourmaline-Staurolite-Zircon type (4 samples).

The surface of the soil does not have any sealing. Augering is very easy. The majority of the profiles has a yellowish brown sandy topsoil over a light brown sandy subsoil; the latter almost always shows thin horizontal darker bands of some clay accumulation (about 12 %), the so-called fibers (Yellowish Brown soil of ASTR/Typic Quarzipsamment to Haplargid).

The terrains are virtually everywhere in use for permanent wet season, cropping (millets + cowpeas, guinea corn, some cassava).

5.5 The **Talata loamy to clayey main-terrace deposits** (2.2; 16 BT; 10-2, 10-3 and 2-6) are found in the NE-SW axial part of the survey area (Isa, Talata-mafara, Gummi).

They occur in rather broad bands (1-4 km) along the main rivers and some of the minor ones just at, or somewhat downstream of, their entrance into the sedimentary area from the Crystalline basement. The deposits are physiographically associated with the Bakolori deposits, though occuring as a whole slightly more downstream.

The thickness of the deposits, the lateral expanse and the micro-relief are comparable with those of the Rabah deposits, into which they merge further downstream. There is little or no meso-relief. The level above the high water of the rivers is 5-10 m, the higher values occuring more upstream.

Most of the deposits are a sandy loam (30-50 % fine sand, 10-30 % very fine sand, 2-10 % silt, 6-20 % clay), but in some parts, often those farthest away from the rivers, they may be clayey (35-40 % clay) with a silt/clay ratio about 0.8, and with full physical ripening. Mineralogically, the fine sand fraction of the loamy deposits belongs to the Tourmaline-Staurolite-Zircon type (Isa, one sample), or to the Epidote-Hornblende type (Talata-mafara, 2 samples). Its clay fraction consists of poorly crystallised kaolinite and iron oxides, with a SiO_2/Al_2O_3 ratio about 2.5 and a cation exchange capacity varying between 20 and 30 (occasionally up to 50) m.e.

The surface has little sealing, except for the clayey parts where sealing may be strong though not always persistent. Augering is fair to difficult. The profiles in the loamy areas have a good structure and have a yellowish brown loamy sand topsoil over a reddish brown sandy loam to sandy clay loam subsoil (Reddish or Yellowish Brown Ferruginous Tropical soil/Vetustalf). The profiles in the clayey parts, however, are imperfectly drained and have a bad structure (Semi-hydromorphic Yellowish Brown Ferruginous Tropical soil/aquic Vetustalf and Solodized Solonetz/Natraqualf).

Most of the clayey areas have a poor savannah woodland or shrub savannah vegetation. The loamy terrain parts — which form the bulk of the unit — are intensively cropped during the wet season (guinea corn, some cotton). Those parts along the Sokoto River have been selected for a major irrigation development scheme.

5.6 The **Kaura-namoda fine sandy main-terrace deposits** (2.3; 16BK; 11-1) are found only in the east-north-eastern part of the survey area (Kaura-namoda, Zurmi).

They occur in fairly broad bands (1-4 km) along the main rivers where these cross the area of the Zurmi coversands on the Crystalline basement. The bands have smooth lines of transition to the coversands, except where the latter have been redeposited. Apparently the Kaura-namoda deposits are younger than the Zurmi sands.

The thickness of the deposits is probably everywhere less than 10 m.

The macro-relief is approximately flat; the meso-relief also. The level above the high water of the rivers is about 10 m.

with the floe deposits, there are slight differences in level between the upstream and downstream parts [1].

The granulometric composition of the levee parts is a fine to very fine loamy sand to loam, that of the basin land parts a clay rather rich in silt (cf. Fig. 14; silt/clay = 0.5-0.6). The clay is stabilized (ripe).

Mineralogically, the fine sand fraction is of the Epidote-Hornblende type (type F, 5 samples). In the field, few to commonly occurring tiny flakes of micas can be observed in several of the lower layers. The clay fraction consists of poorly crystallised kaolinite and iron oxides, with SiO_2/Al_2O_3 ratio about 2.7 and a CEC of about 42 m.e.

The surface of the levee and splay parts (P1) seals strongly, that of the basin land parts (P2) slightly. On the latter surface cracking is faint to moderate. Augering is very difficult on the levee soils ("singing" auger), and difficult to fair on the basin land soils. The soils of the levees usually have a very bad structure (cloddy columnar), with accumulation of sodium in the subsoil. The profiles show a dark grayish brown topsoil over a light brownish gray subsoil with many medium-sized and distinct mottles of yellowish brown: this subsoil is usually heavier in texture than the topsoil, but the sedimentary stratification is not yet completely erased by pedogenetic processes (Solonetz/aeric Natraqualf or natric Haplustalf). The soils of the former basin lands have a fair structure and normally an insignificant accumulation of sodium. The profiles show a dark to very dark gray clayey topsoil with common fine distinct mottles of yellowish brown over a dark gray to gray clayey subsoil with many medium-sized distinct mottles of yellowish brown to strong brown (Eutrophic Mineral Hydromorphic soil/normustalfic mollic Ochraqualf, possibly natric).

The levee parts are virtually not used for cropping, but the basin land parts support rice growing, of relatively fair yields only. Many parts of the basin land are in fallow of tall, non-tufted grasses and tall herbs; only very low trees and shrubs occur. The levee parts, in contrast, have a relatively dense coverage of trees of many species (notably *Acaccia* spp.), *Borassus* palms and shrubs. Their ground cover consists largely of tall, often tufted grasses (*Vetiveria* sp.). High and apparently mostly active termite mounds are of common occurrence (2-4 high, 3 m diam.), having only little clustering of trees and shrubs. The scenery of the Diggi park deposits (high ground with arboreous cover [2], intersected with oxbow lakes and alternated with grassy lower ground) reminds one of a well laid-out urban park, hence the name.

6.3 The **Ambursa central deposits** (6.1; 20; FC: C2 to C7) are found in the floodplains at the northwestern edge of the survey area (Kware, Augi, Birnin Kebbi). In fact, the deposits occur only in the Rima River, south of its "confluence" with the fossil Tarka, and in minor strips in the Tarka valley itself.

Either continuous broad stretches are concerned, underlain by floe or park-over-floe deposits, or elongated narrow bands in between areas of outcropping floe or park deposits. When occurring at the edge of the floodplain, these bands are often interrupted by lobes of sandy upland. The deposits are apparently younger than the park deposits, and were laid down in an extensive floodbasin resulting from erosion of both park and floe sediments during a slight down-cutting period of the river. The lobes at the edges

[1] At the confluence of the Rima and the Niger rivers, a band of deposits occur that are apparently partly Argungu, partly Diggi; the pattern, however, is so intricate that separation on a small-scale map is impossible.

[2] In the Argungu Birnin-Kebbi area the aspect is largely destroyed by indiscriminate large-scale ploughing by Government Agencies in 1958-1959.

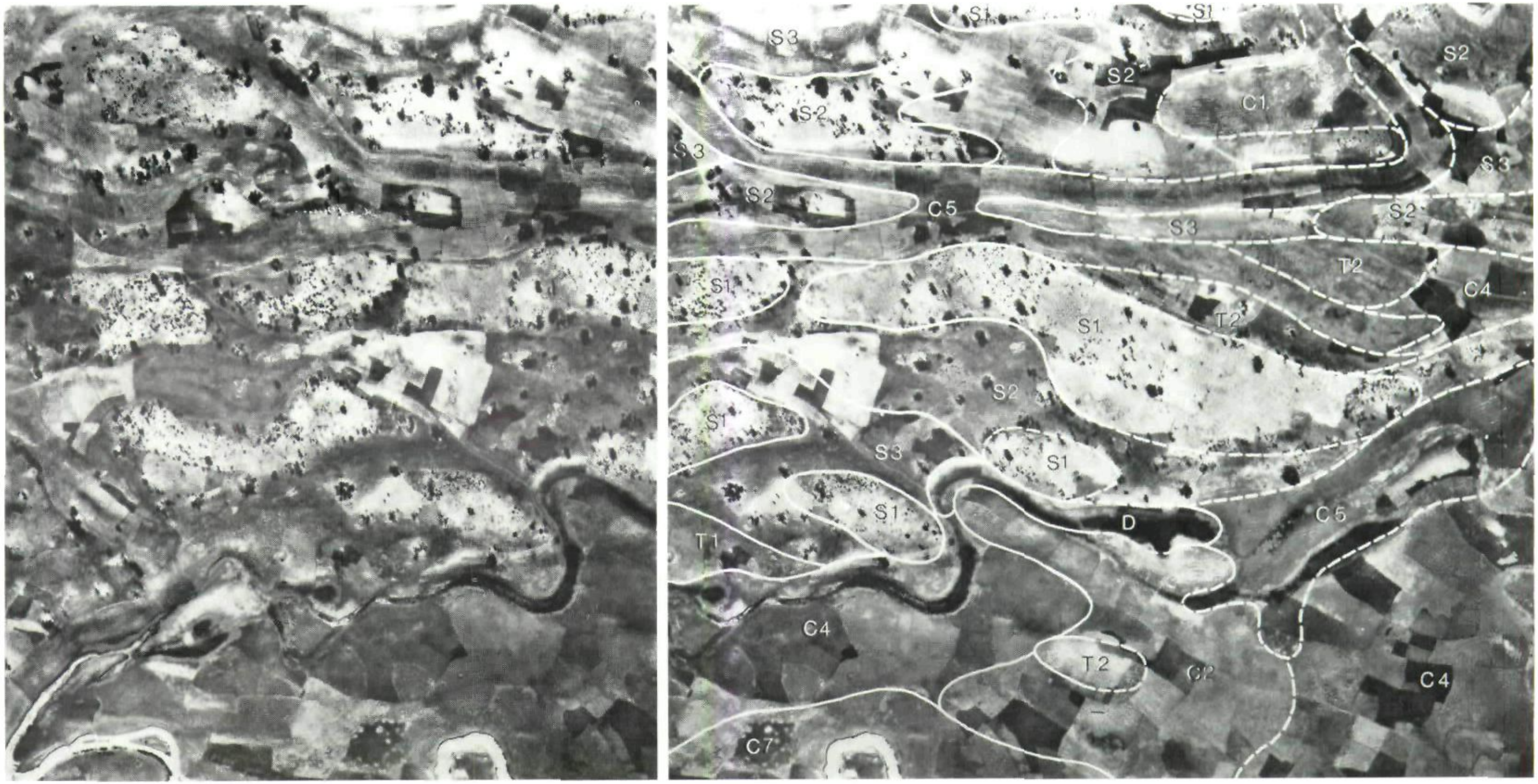


Fig. 15. The floe-like pattern of non-eroded parts (S1), shallowly eroded parts (S2), and low, flattened stretches (S3) of the Argungu deposits, of braiding river origin. For the other mapping symbols cf. Appendix 2.
(stereo-pair NE-SW, scale approx. 1 : 10,000, of a floodplain part near Argungu, centre of Map b. of Appendix 2)

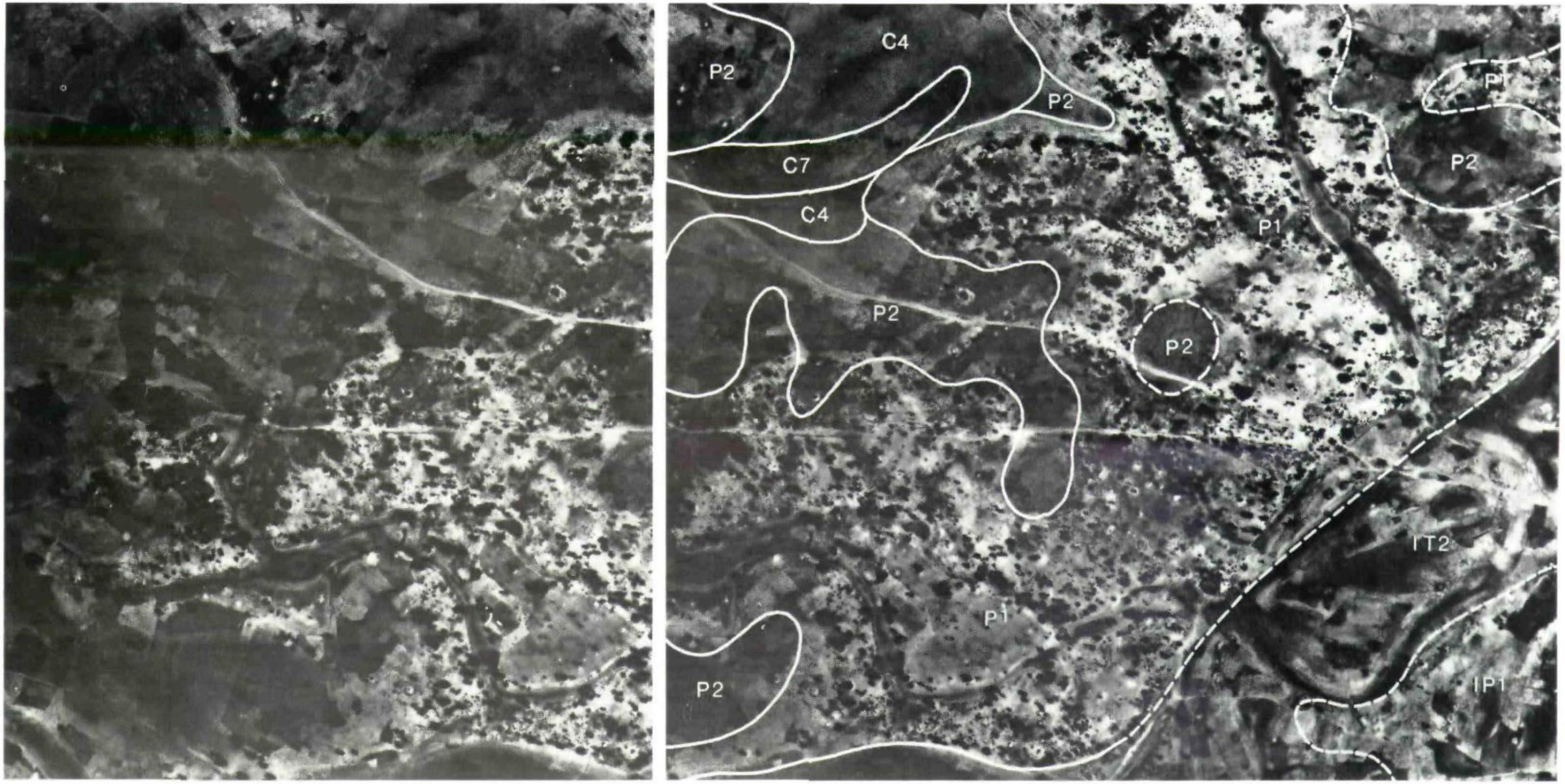


Fig. 16. The park-like vegetation of the Diggi deposits, of meandering river origin, showing former levees and splays (P1) and former basin lands (P2). For the other mapping symbols cf. Appendix 2.
(stereo-pair NE-SW, scale approx. 1 : 10,000, of a floodplain part near Argungu, top-right of Map b. of Appendix 2)

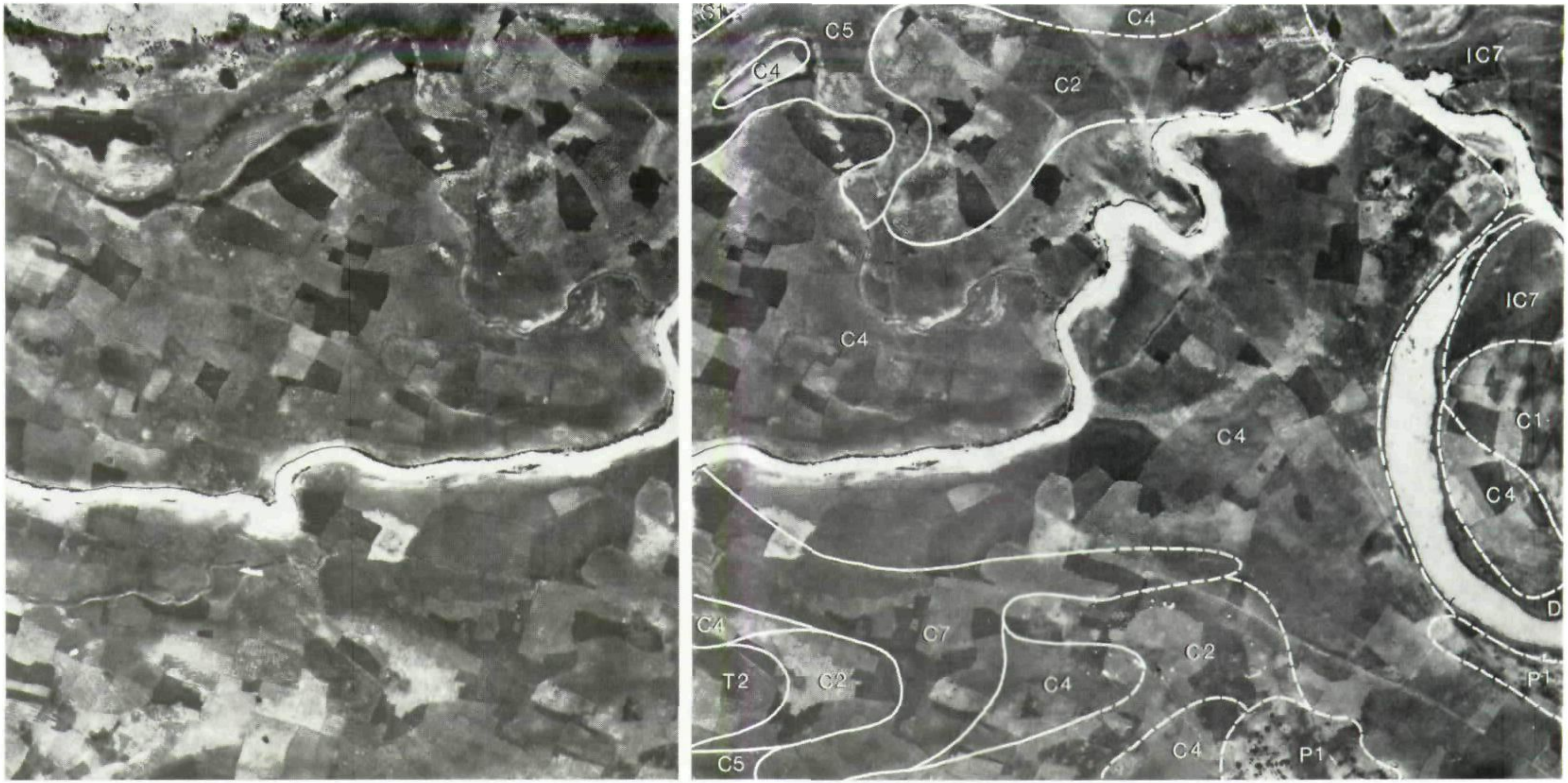


Fig. 17. The extensive level floodplain parts (C1 to C7), constituted by Ambursa deposits, of lacustrine origin. The presentday river channels, carrying sediment-poor water in these areas, cross the terrains without a banding of levees. For the other mapping symbols cf. Appendix 2.
(stereo-pair NE-SW, scale approx. 1 : 10,000, of a floodplain part near Argungu, top-centre of Map b. of Appendix 2)

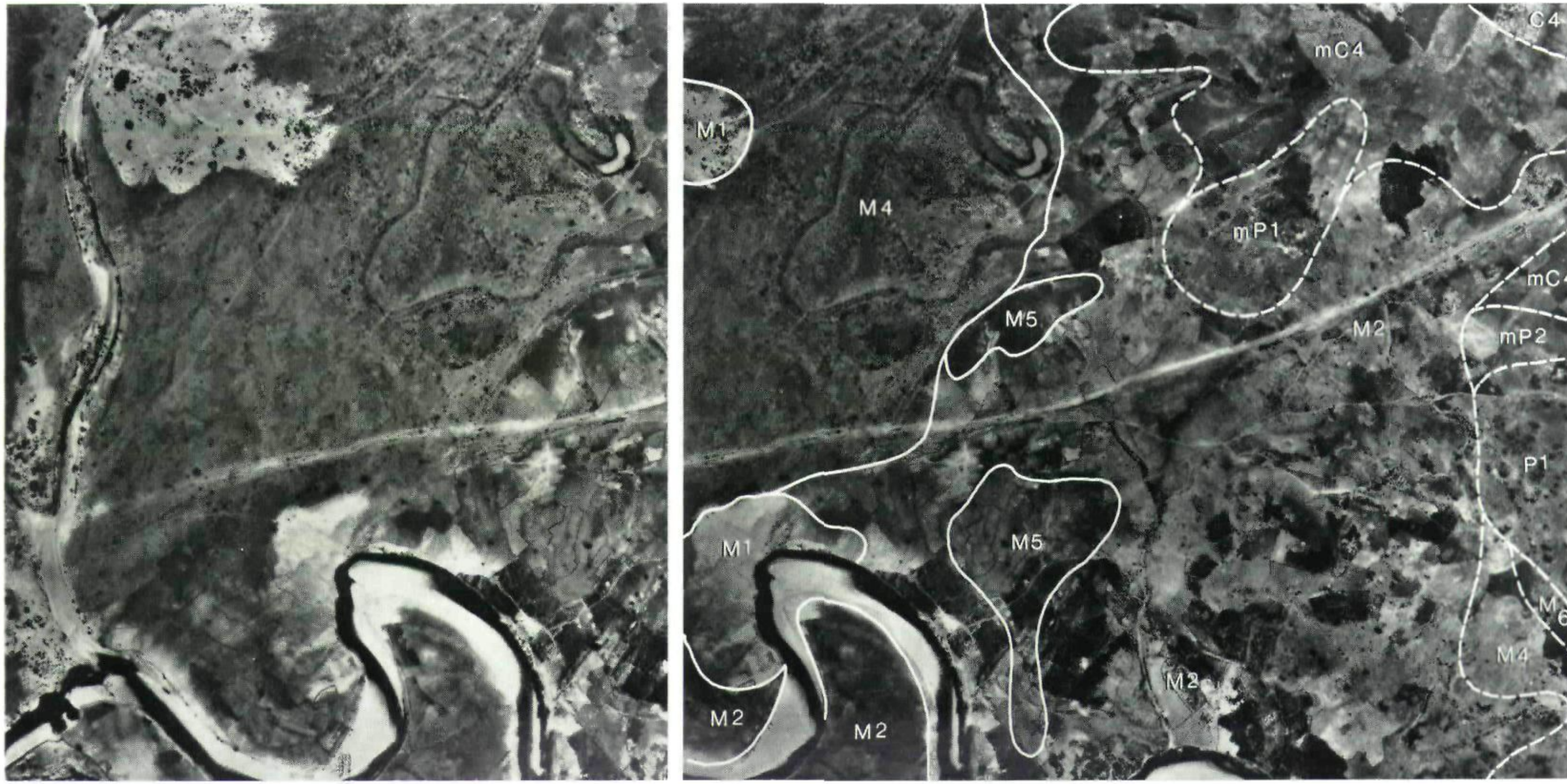


Fig. 18. The irregular meso-relief of the various units and phases (M1 to M6) of the Kurukuru-Gande micaceous deposits, the result of presentday meandering-river activity in stretches with sediment-rich water. For the other mapping units cf. Appendix 2.
(stereo-pair N-S, scale approx. 1 : 10,000, of a floodplain part near Sokoto town, bottom-centre of Map a. of Appendix 2)

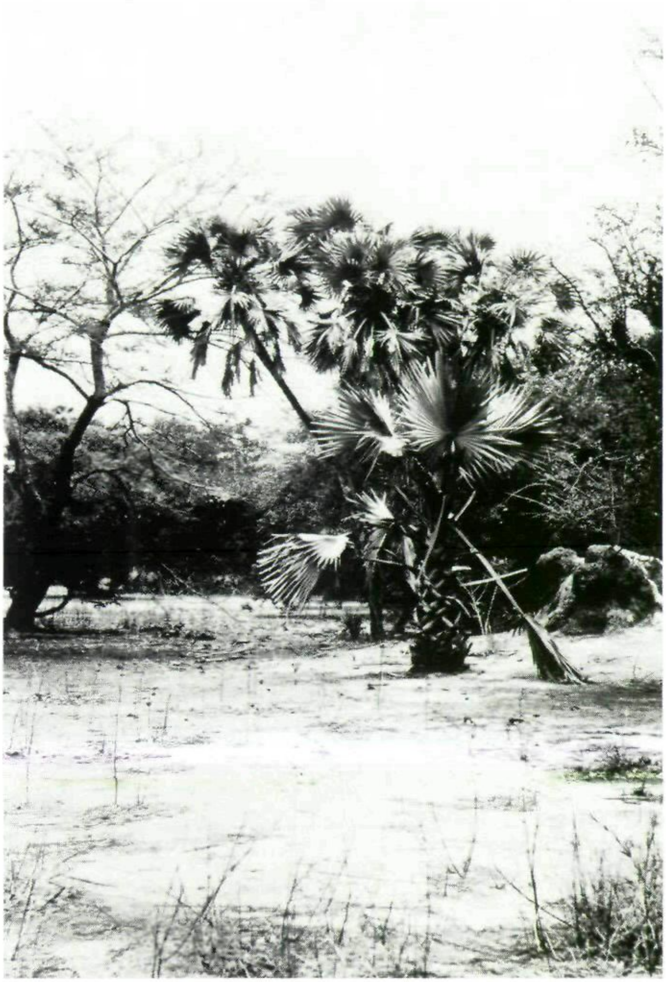


Fig. 19. The scenery of floodplain parts with a coverage of Diggi "park" deposits. The poor soil conditions allow a typical vegetation to be conserved. Noteworthy is the largely fossil termite mound at the right, partly overgrown with thick bush, partly levelled by sheet erosion (near Argungu).

are apparently colluvial and alluvial fans of a period after the Ambursa deposition (in fact, this colluviation is still continuing, notably where Illela, Sokoto and Wurno/Taloka sands abound). The name "central" was coined because of the central geographical position of the deposits.

The thickness of the deposits varies from 0.3 to 2 m only.

The meso-relief is characteristically flat over large distances. The only interruptions are formed by slightly raised patches (i.e. patches with floe or park deposits near or at the surface) circular or elliptic and with very gentle slopes, or by scattered small elliptic depressions (50 and 100/200 m). When crossing Ambursa deposits, the irregularly bending and branching presentday stream channels have no banding of levees or splays, nor do they carry any appreciable load of sediments.

Fig. 20. View of floodplain parts with a coverage of Ambursa "central" deposits, showing the general flatness of the terrains and the absence of any arboreous vegetation. A patch with rice straw, in the foreground, is followed by a burned stretch, part of which is being hoed for rice cropping during the next flood season (north of Birnin Kebbi).

Fig. 21. A part of the floodplains with last-year deposition of Gande "micaceous" sediments in the form of splays, with its typical irregular mesorelief and coverage by "gumbi" shrubs (*Mimosa* sp.) (west of Sokoto-town).

Fig. 22. Succession of floodplain deposits of different age on the bank scour of a river channel. The upper layer, partly horizontally stratified, consists of the very fine sandy to loamy Gande "micaceous" deposits. The middle layer, with a well-developed prismatic soil structure, is formed by Ambursa "central" deposits. The whitish layer under it consists of medium sands of the Argungu "floe" deposits (near Gande).

The level of the terrains varies from 60 to about 120 cm below normal high water, with some variation upstream and downstream. These differences in level usually occur very gradually; only the lowest parts may sometimes be separated from the other terrain parts by a fairly sudden drop of a few decimetres.

The granulometric composition of the deposits is very regularly clayey, and is further characterized by low percentages of silt (silt/clay ratio $\leqslant 0.3$). The lowest strata, c.q. the whole thickness of the deposit at the highest level (slightly raised patches), are often a sandy clay (40-50 % clay sized, frequently with a noticeable admixture of floe and sometimes also park elements). The middle strata, comprising most of the deposit at the main, intermediate terrain levels, are clays proper (50-70 % clay sized), and the upper strata, confined largely to the lowest terrain levels, are heavy clays (70-90 % clay sized). The clays are stabilized (ripe), except in the ponds. The regularity in the relief and in the granulometric composition indicates that concerned here is a former sedimentation in very quiet waters, i.e. lacustrine like, which condition was particularly pronounced towards the end of the period.

Mineralogically the fine sand fraction — which may in fact belong to the floe deposits! — belongs to the mixed association E: Tourmaline — Hornblende, with Staurolite, Zircon, Epidote and Andalusite (4 samples). The clay fraction consists apparently of poorly crystallised kaolinite and some montmorillonite, SiO_2/Al_2O_3 being about 2.8, and the cation exchange capacity (CEC) only fairly high: about 38 m.e./ 100 g clay.

The surface of the soils does not seal. The heavier parts show considerable cracking, and there is a very faint micro-relief of gilgay. The augering is fairly easy. The profiles consist of a dark gray to very dark gray clayey topsoil with common fine distinct mottles of yellowish red, grading into a gray clayey subsoil with many medium sized and distinct mottles of yellowish brown to strong brown. Especially when the clay layer is shallow, the first part of the sandy substratum is bleached (gray brown to pale brown) and is followed by a mottled gray layer of 20-40 cm thickness with clear pedogenetic clay accumulation (about 20 %), before the yellowish brown (floe) sand proper is reached (Vertisolic Mineral Hydromorphic soils/vertic or mollic Ochraqualfs). Where seepage water from calcareous rock (Dange, Kalambaina and Dukamaie deposits) enters, or entered, the floodplain, e.g. near Kware, the soils have more active clay colloids (more montmorillonite; SiO_2/Al_2O_3 ratio 3.1; CEC = 50-55 m.e. per 100 g clay), which shows up in a strong cracking and often a subdued gilgay pattern of micro-relief; the clayey part of the soil profiles is then very dark gray throughout, and the subsoil contains carbonate concretions (Topomorphic Vertisols/vertic Argiaquolls).

The terrains with Ambursa central deposits are rather intensively used for traditional rice growing. Locally, with primitive irrigation, the calcareous variants sustain dry-season cropping of tobacco, onions, and other vegetables. Fallows contain tall, non-tufted grasses and wild rice on the higher parts, while short grasses, rushes and stolonic aquatic plants prevail on the lower. The natural vegetative cover is also grassy. Trees and shrubs are absent, except for the low "gumbi" shrub (*Mimosa* sp., an indication of high fertility) on the calcareous variant. Termite mounds do not occur, except for very low flattened ones on the slightly raised patches.

6.4 The **Tungantudo enclosed deposits** (6.2; 21B; FK) are found only in the NNW tip of the survey area (Gwadabawa - Illela, Binji, Gada).

The deposits occur in enclosed flat depressions within the uplands, with no, or only partial, drainage outlets. The form of these depressed flats is irregular, due to the presence of dunes of the Illela coversands. Apparently the latter have partly overblown the Tungantudo deposits, which therefore must be older.

The thickness of the deposits is probably nowhere more than a few meters. Often a layer of fossil indurated plinthite (of the Kalambaina formation, LK) underlies the deposit at less than one meter.

The macro-relief is flat, but there is some meso-relief, especially near Illela in the north: broad bands of slightly raised terrain alternate with extensive lower parts, the latter comprising nearly all of the land in the southern part. The raised terrains, apparently former levees, contain river channels at their centre which are fossil and largely silted-in. Scattered Illela dunes may be found on top of these levees. The lower parts are apparently former basin lands. During the wet season, the levee parts are not or only slightly submerged while the basin land parts are submerged — with rainwater — to about 100 cm. There is all-year-round seepage from an aquifer below the plinthite cap of the Kalambaina formation (locally from one of the Lower Gwandu), and even springs may be concerned (Tungantudo village).

The granulometric composition of the basin land parts is a clay or heavy clay, with an appreciable percentage of silt (silt/clay = 0.4-1.0). The clays are fully stabilized (ripe). The levee parts have fine sandy loam to clay loam textures. The fine sand fraction of one sample contains a Tourmaline-Staurolite-Zircon association. Clay minerals are poorly crystallised kaolinite and montmorillonite, and the SiO_2/Al_2O_3 ratio is correspondingly high (about 3.2) as is the cation exchange capacity (about 70 m.e. per 100 g clay).

The heaviness and the richness of the sediments makes a correlation with the Ambursa deposits logical, but the levee and the basin land pattern, though subdued, excludes pure lacustrine sedimentation conditions.

The surface of the soil does not seal. Augering is fairly easy. Basin land parts even have a crumbly surface with deep cracking. Its profiles have a dark brown clayey topsoil without mottling, over a very dark gray brown subsoil of clay or heavy clay, with some mottling of brownish yellow only in the lower part. Carbonate concretions are common, as is mycelium-like soft lime (Topomorphic Vertisols/Grumustert). The levee profiles have a dark grayish brown, fine sandy loam to sandy clay loam topsoil and a dark brown clay loam subsoil, or a yellowish brown sandy loam to sandy clay loam subsoil (Dark Brown soil of ASTR/grumustertic Haplustalf to aquic Argiustoll). The substratum under both levee and basin land profiles often contains snail shells and gypsum crystals, unless plinthite is shallow.

The terrains are only partly under cultivation, but wherever wet season drainage is possible the crop variety on both the levee and the basin land parts is large. If a dry-season water supply happens to be available, the crops are irrigated onions and wheat, cotton, guinea corn and tobacco.

The natural vegetation consists of reeds on the lowest parts, Typha species at seepage sites, low grasses and the shrub "gumbi" (*Mimosa* sp.) on the intermediate parts, and a dense forest of *Acacia* species on the better drained parts.

6.5 The **Kurukuru and Gande micaceous deposits** (7.1 to 8.3; 22 + 23; FM a.o.; M1 to M6) are found in the floodplains all over the survey area, except at the northwestern edge.

The deposits occur in the floodplains of all of the tributaries whose catchments extend to within the Crystalline basement, as well as in the floodplain of the Niger River (which crosses crystalline parts further upstream in Niger Republic). Relatively narrow strips are concerned within the Crystalline basement area, and wide bands within the sedimentary area. Only in the lower Maradi are the deposits absent. In the Rima floodplain the deposits occur only over some distance immediately downstream of the entrance of the mentioned tributaries, the sedimentation front moving several hundreds of meters still further downstream each year.

In the mentioned floodplain parts the micaceous deposits overlie central, park, and even floe deposits, their thickness varying from less than 1 m to more than 5.

The meso-topography and the level are varied. There are stable rather flat parts occurring in curving bands and fig-leaf shaped patches, containing inactive river channels and creeks, and flooded to about 50 cm depth (old levees and splays: 7.1; M4 of Appendix 2). Other stable parts are flat over extensive distances, locally covering the old levees and relatively high lying, a few decimetres above normal high water (terrace-like parts: 7.2; M3). Other stable parts, occurring in fig-leaf or fingery shaped patches, have a rather irregular topography; they partly overlie the old levees or cut through the terrace-like parts, and are flooded about 30 cm (younger splays: 8.1; M2). Again, other and rather high patches occur, which have a very irregular mesorelief; the form of these patches is largely fingery and they have a dense irregular pattern of still active, branching-out creeks; the flooding varies from 20 to 100 cm depth. These active youngest splays and their crevasses (8.2; M1) are still largely lacking on photographs of 1960, but were very prominent during the field survey in 1963-1964 (cf. Fig. 23). Other non-stable relatively high parts occur in the floodplain parts just downstream of

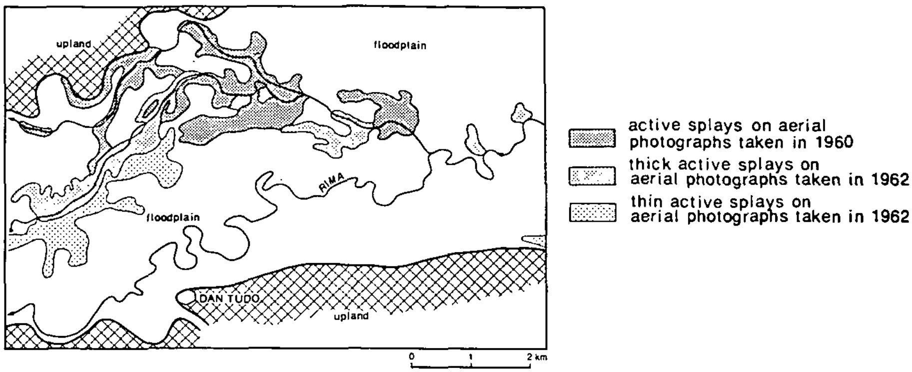


Fig. 23. Progress of Gande sedimentation in the Rima floodplain near Dan Tudo (between Kurukuru and Sabon Birni).

the Crystalline basement area; they have a meso-relief of slightly curving, narrow high and low strips, running subparallel (active point bars: 8.3), as a whole only a few decimetres below normal high water.

Along with all these relatively high-level parts there are also open or enclosed, extensive or small, low terrains, usually rather flat, and flooded on the average to about 100 cm (basin land parts, from old to present: 7 + 8; M5 and M6).

The spatial occurrence of the various subunits is illustrated in Appendix 2 but the pedogenetic and reclamative implications will be discussed in a forthcoming paper. The above suffices to conclude that concerned here is an apparently recent and still continuing sedimentation of a meandering river system, at present with a tendency to deteriorate into braiding. Sedimentation started after the lacustrine period of the Ambursa deposits, with no initial downcutting phase of the rivers (at least not in the main Rima floodplain). The older phases (M3, M4, parts of M5 and M6) have been grouped as Kurukuru deposits, the younger ones (M1, M2, parts of M5 and M6) as Gande deposits.

The granulometric composition of all relatively high-lying parts (old levees and splays, terrace-like parts, younger splays, present splays, present point bars) is a very fine loamy sand to loam (see diagram of Fig. 14), interspersed with thin layers or lenses of more or less clayey material. The basin land parts have clay loams to clays, characterized by high percentages of silt (20-40 %, silt/clay = 1.0). On the older terrain parts the clays are stabilized. On the younger parts, however, the clays are still in the process of consolidation (non-ripe or half ripe; n-values of 1.0-2.0).

Mineralogically, the fine sand fraction is of the Epidote-Hornblende type (6 samples). In the field, large quantities of relatively large flakes of micas can be observed in the sandy layers, hence the name "micaceous". In the clayey layers, tiny flakes of micas are of common occurrence. The clay minerals consist of poorly crystallised kaolinite with iron oxides, corresponding with only rather high SiO_2/Al_2O_3 ratios (about 2.9) and rather high cation exchange capacities (CEC about 50 m.e./100 g clay).

With the exception of the old levees and splays, there is no surface sealing, and augering is easy to very easy. Cracks in the clayey parts are small, except for the superficial and temporary ones related to the ripening process. The sandy to loamy deposits have brown to gray brown topsoils and brown to very pale brown subsoils, both mostly without mottling. There is normally little or no clay illuviation, the sedimentary macro-stratification and often also the micro-stratification still being very apparent (Typic, Slightly or Moderately Matured Juvenile soils/aquic Haplortents, partly haplustalfic). The clayey deposits have gray brown topsoil with some mottling of strong brown to yellowish red, and brown subsoils with some mottling of yellowish brown to yellowish red. Here, too, sedimentary stratification is clear (Typic or Slightly Matured Juvenile soil/aquic Haplortent, partly normustalfic, or Hydraquent).

The land use is varied and often intensive. The younger or present splays and point bars often have tobacco, vegetables, gourds, cassava, and rice growing, the terrace-like parts guinea corn, cotton, and cassava. The old levees and splays, however, are little used; only some rice is grown. The younger basin land parts frequently have rice growing, but also some tobacco and gourds, while the older ones have only rice.

Neither the younger and present splays nor the younger basin lands have any tree growth, but the low shrub "gumbi" (*Mimosa* sp.) is frequent. The older basin lands have less gumbi coverage, but a few trees; the terrace-like parts commonly have tall trees *(Parkia, Acacia albida)*. The old levees and splays have few to commonly occurring low trees and shrubs, low termite mounds, and a grassy cover that is characteristically tufted (*Vetiveria* sp.). In fact, the latter formation is in all aspects intermediate between the micaceous deposits proper and the levee parts of the park deposits.

There are, to be complete, several parts in the various floodplains whose characteristics do not completely correspond to the sets of characteristics of any deposit described above. Such parts are, in fact, the result of intricate alternation of deposition and erosion (see legend of Appendix 2: units T1, T2 and C1; units I-; units M-). They are in the present context of little or no significance, but they are quite important for detailed reclamation planning.

7. GEOMORPHOLOGY OF THE QUATERNARY DEPOSITS AND CLIMATE

7.1 Modes of deposition

The foregoing descriptions allow the following conclusions to be drawn.

There are five different types of deposits which, because of their geography and granulometry, are undoubtedly aeolic in character. Four of these — Sangiwa, Sokoto, Zurmi and Illela — have a top in the fine sand fraction; they can be denominated as "coversands" or "drift" and must have been transported by saltation, mostly by ENE winds. Accumulation has taken place as dune fields, which have afterwards been denutated or deformed to a smaller or larger degree. The Sangiwa type of coversand has transversal parabolic dunes, the Sokoto and Zurmi types have longitudinal dunes (seifs), and the Illela type fortress-shaped dunes.

Te fifth type of aeolic deposits has a top in the very fine sand fraction; instead of forming a dune pattern, it has accumulated rather regularly over broad stretches in the southeast of the area. These Funtua deposits can be denominated as loessic, and must have been transported high through the air by ENE winds.

There are eight different types of deposits which, because of their geography, must be aqueous in character, forming terraces or terrace-like units alongside the floodplains of presentday or former rivers. Three of these deposits are positioned relatively high above the presentday rivers: "high-terrace" and "washplain" deposits (Gusau, Bakolori and Tureta); three are at intermediate level: "main-terrace" deposits (Rabah, Talata, Kaura-namoda); two are at a relatively low level, just above the local high water level: "low-terrace" deposits (Zagawa, Bagudo).

The over-all granulometry of these deposits, the lateral variation in granulometry, and the geography allow deductions to be made as to the type of aqueous accumulation: the Tureta deposits have accumulated mainly by sheetflood action; the Bakolori and Gusau deposits have accumulated by sheetflood and fluviatile action, the latter possibly from a meandering regime. The other deposits are all fluviatile: the Rabah deposits are from a braiding regime, the Kaura-namoda deposits probably from a braiding regime, the Talata deposits from a meandering to braiding regime. The Zazagawa deposits have been deposited by a braiding river regime, the Bagudo deposits by a meandering to braiding regime.

There are six different types of deposits in the presentday floodplains, all aqueous in character. Of these, the Argungu floe deposits are fluviatile, from a former braiding river system; the Diggi park deposits are also fluviatile, but from a former meandering system. The Ambursa central deposits are lacustrine, from former lake-like conditions in part of the main floodplain, which progressively became more pronounced (three phases). The Tungantudo enclosed deposits are also largely lacustrine, from former lake-like conditions in an area without external drainage, but for a part also fluviatile, from a former vaguely meandering river system. The Kurukuru and Gande micaceous deposits are fluviatile, from a sub-recent to recent meandering river system, with one or more phases of a more braiding nature.

7.2 Relative age of the deposits

The following conclusions can be drawn from the earlier descriptions:

— The Sangiwa coversands are older than the Sokoto coversands, which in their turn are older than the Illela coversands.
— The Zurmi coversands are younger, at least in part, than the Funtua loess.
— The Tureta washplain deposits are younger than the Sangiwa coversands, older than the Sokoto coversands.
— The Gusau high-terrace deposits are younger than the Funtua loess, older than the Zurmi coversands.
— The Bakolori high-terrace deposits are older than the Zurmi coversands.
— The Rabah main-terrace deposits are younger than the Sokoto coversands, older than the Illela coversands.
— The Talata main-terrace deposits are younger than the Bakolori deposits — formed after a downcutting period — and of the same age as the Rabah deposits.
— The Kaura-namoda main-terrace deposits are younger than the Zurmi coversands.
— The Zazagawa low-terrace deposits are younger than the Rabah deposits, and separated by a down-cutting period.
— The Bagudo low-terrace deposits are younger than the Talata deposits, separated by a downcutting period, and of the same age or younger than the Zazagawa deposits.
— The Argungu floe deposits are younger than the Zazagawa deposits, and separated by a downcutting period.
— The Diggi park deposits are younger than both the Argungu and the Bagudo deposits, and separated by a slight downcutting period.
— The Ambursa central deposits — three phases — are younger than the Diggi park deposits, and separated by a slight downcutting period.
— The Tungantudo enclosed deposits are older than the Illela coversands, probably of the same age as the Ambursa deposits.
— The Kurukuru micaceous deposits — two phases — are younger than the Ambursa deposits, but not separated by a downcutting period.
— The Gande micaceous deposits are younger than the Kurukuru deposits, and possibly separated by a slight downcutting period. Gande deposits are still being formed at present.

This leads to the scheme of table 6.

It is clear that in the earlier part of the Quaternary there was a rhythmic variation in aeolic and aqueous deposition, only partly separated by downcutting periods, whereas in the latter part there was a rhytmic variation between aqueous deposition and aqueous downcutting, only once interrupted by aeolic deposition.

Before an attempt is made to correlate this with climatic variations, the sources of the various deposits will be traced.

7.3 Sources of the deposits

For the benefit of the discussion a distinction is made between:
a) the *southeastern subcatchment,* covering the area of outcropping Crystalline basement rock; b) the *central subcatchment,* covering the area of sedimentary rock drained by the Maradi, the Rima till Kurukuru, the Sokoto, the Gawon Gulbi, the Zamfara, and the Ka; c) the *northwestern subcatchment,* covering the area of sedimentary rock drained, either now or formerly, by the Tarka, the n'Kabba, the Kware, the Maouri, the lower Shella, and the Rima between Kurukuru and is confluence with the Zamfara (cf. stage 0 of Appendix 3).

Table 6. Relative age of the Quaternary deposits in the Rima-Sokoto River basin.

Age	(North)western area	Transitional area	(South)eastern area
young		Gande micaceous deposits	
		?> Kurukuru micaceous deposits	
	Illela coversand		
	Tungantudo encl. dep.....Ambursa central dep.		
	?>	Diggi park deposits	
	> Argungu floe deposits	Bagudo low terrace	
	> Zazagawa low terrace		
	> Rabah main terrace — — — — —	Talata main terrace	Kaura main terrace
	> Sokoto coversand	......	Zurmi coversand
	Tureta wash plain	Bakolori high terrace	Gusau high terrace
old	?> Sangiwa coversand	......	Funtua loess

Explanation of signs: — — — — aeolic, ———— aqueous

– – – – – – – – same age, ... probably same age

> river downcutting, ?> slight or questionable river downcutting

The data on grain-size distribution, heavy-mineral composition of the sand fraction, and clay-mineral composition allow the following conclusions to be made.

The *Funtua* loessic deposits have a Tourmaline-Sillimanite-Zircon association. Such an association is not found in any of the other formations in the area, including the Crystalline basement on which the Funtua loess has been deposited. To conclude only on this basis that the deposit originated from sources far outside the survey area would normally hardly be justified because only one sample is concerned. Yet, the grain-size distribution (clear top in the very fine fraction) indicates transport over great distances (high in the air, in contrast with the saltation-type of transport of the coversands). Considering the old age of the deposits, the clay-mineral activity seems relatively high when compared with that of the older Quaternary sediments of local origin (see below), which also points to extraneous origin. In view of the vague ENE-WSW alignment, Cretaceous or Tertiary strata in the Chad sedimentary basin are likely to be the source of the Funtua loess. (PIAS (1970) mentions that the sediments of the first Chari-delta, south of Lake Chad, are relatively rich in sillimanite!).

The *Sangiwa* coversands have mostly a Tourmaline-Staurolite-Zircon association of minerals. Such an association occurs also in most sedimentary rocks. The association of the Crystalline basement rocks, however, is completely different, namely Epidote-

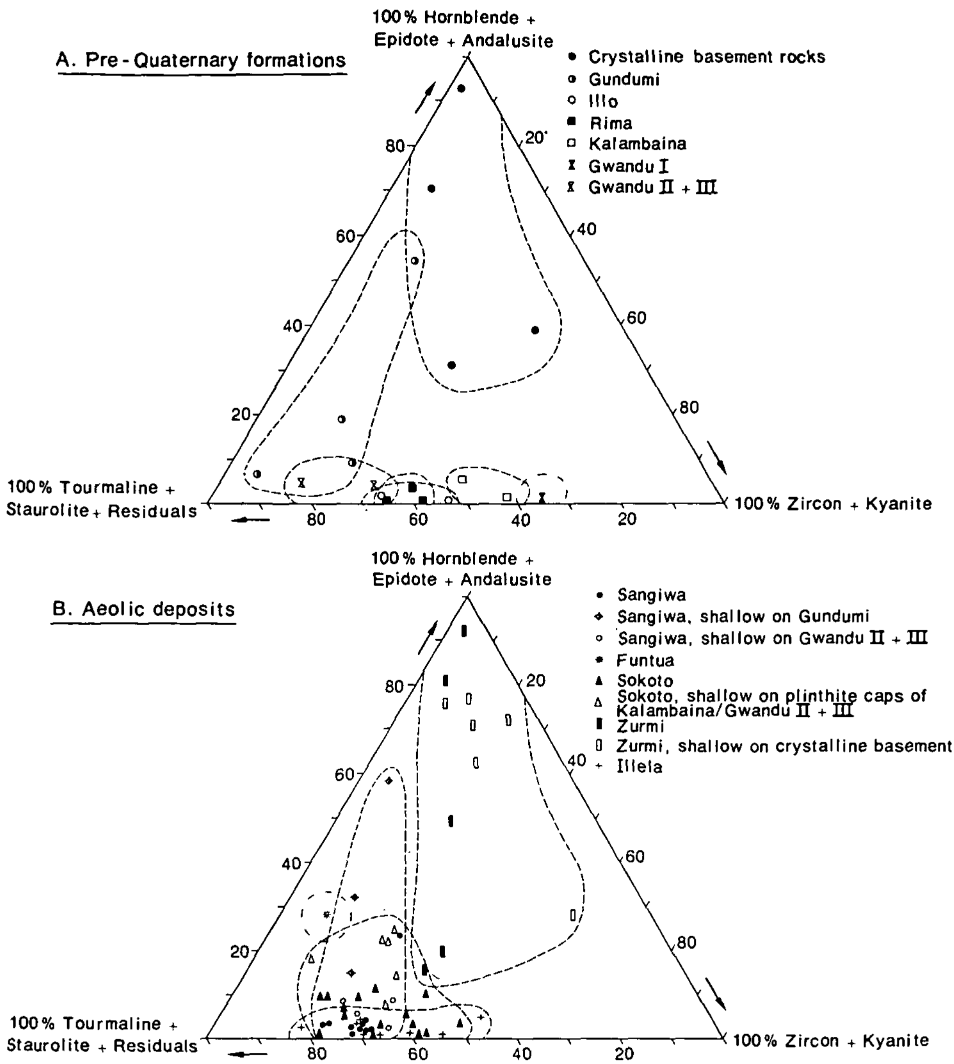
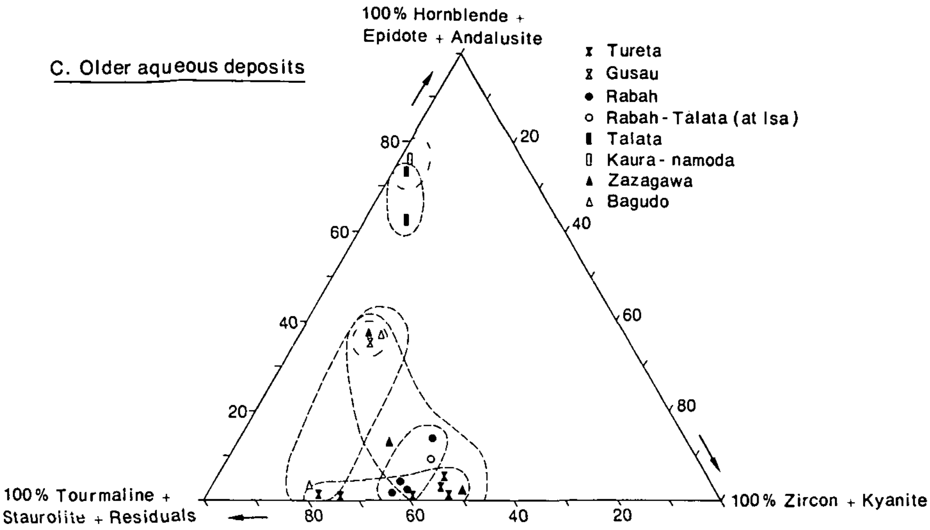
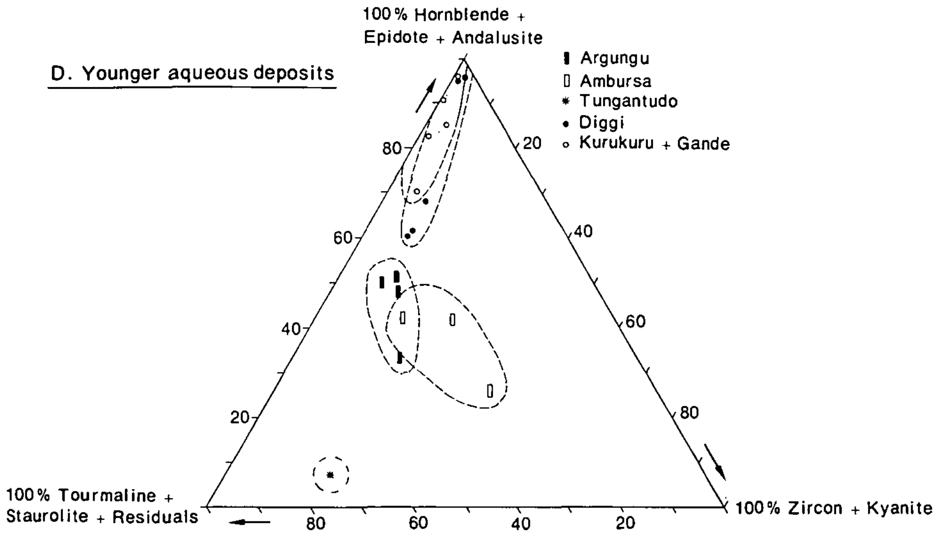


Fig. 24. (A to D) Triangular comparison of the heavy mineral composition of pre-Quaternary formations and Quaternary deposits.

Hornblende. Origin of the Sangiwa sands from weathering basement materials can therefore be excluded. When comparing in detail the heavy mineral composition of Sangiwa with the various sedimentary rocks (cf. triangles of Fig. 24), it is apparent that a close relation exists with the mineral composition ("triangle blot") of Gundumi and Gwandu II + III, and a partial overlapping with the Rima triangle blot.

When the sites of the individual Sangiwa samples are traced, it appears moreover that those from an area with Gwandu outcrops show more heavy mineral affinity with the Gwandu II + III blot on the triangle, whereas those from an area with Gundumi outcrops show more affinity with the Gundumi blot. This applies particularly to the





samples collected from relatively shallow Sangiwa layers. In the latter case one might imagine some later admixture of minerals from the substratum, either horizontally by sheet-flood erosion or vertically by termite activity. The analysed samples, however, were a careful selection from a large group, taking into account the grain-size and other characteristics. The correlation, also for the samples of thick layers, is so clear that one can conclude that the presentday coversands have developed from the local Gundumi and Gwandu II + III strata respectively, not from faraway sources. The spatial concentration of the coversands in Gundumi and Gwandu areas and the relatively poor sand sorting (Fig. 12) support the above conclusion that only limited horizontal transport has taken place, maximally 25 km or so.

Seen in this light, the absence of sands of Sangiwa age in the Kalambaina-Dange and

Gwandu I areas is understandable. They are too clayey and too well protected by plinthite caps to form a local source of coversand. The area of Illo outcroppings — which are at least in part sandy — was probably largely beyond the climatic zone that induced coversand formation. The restricted occurrence of Sangiwa coversands in the area of Rima outcrops — the strata of which as a whole are even sandier than Gundumi or Gwandu — is without doubt due to subsequent very strong erosion in these areas, which still continues at present.

The *Tureta* sandy washplain deposits have a Tourmaline-Staurolite-Zircon heavy-mineral association, but more uniform than the Sangiwa coversands from which they must be derived, judging from the physiographic association. On the triangle the centre of the Tureta blot has moved from Sangiwa towards Rima and Illo. Apparently, at the washplain formation, Sangiwa sands were mixed with materials from underlying strata, notably the Rima sands. The grainsize distribution, too, points to such a mixed origin: if only Sangiwa sands had been involved in aqueous erosion and redeposition at short distance, this would have resulted in lower silt and clay percentages, which is not the case (Fig. 12).

The *Gusau* high-terrace deposits are physiographically and granulometrically more or less associated with the Funtua loess. Their origin from the latter, with some admixture of weathering Crystalline basement material, is likely. The mineral assemblage of the one analysed sample of Gusau deposits, though lacking sillimanite, does not contradict a mixed origin.

The clay percentages and silt/clay ratio are both somewhat lower, but the clay minerals seem comparable. The number of analyses on which the averages of these values are based, are too few to warrant definite conclusions.

The *Bakolori* high-terrace deposits, because of their loamy rather than loessic character and their occurrence away from presentday Funtua deposits, must have developed mainly from weathering Crystalline basement materials. No heavy mineral analysis to support this was executed, nor are there any data on the clay mineral activity.

Like Sangiwa and Tureta, the *Sokoto* coversands as a whole have a Tourmaline-Staurolite-Zircon association. Here, too, the centre of the mineral blot in the triangle has moved towards Rima and Illo. This would indicate that at least part of the Sokoto sands has derived directly from these two types of sedimentary rocks. The spatial occurrence of the Sokoto sands seems to confirm this: though some are found associated with the Sangiwa deposits (the extreme northwest) and some with the Tureta deposits (near Tureta; blow-outs), their main occurrence is west of the strongly eroding Rima sand outcrops. If the aeolic transport were identical to that of the Sangiwa, origin mainly from Rima sands would imply poor granulometric sorting. Yet the sorting is even better than that of the Tureta. This points to a secondary character of the Sokoto sands (resedimentation of Sangiwa or Tureta sands, and of Rima and Illo colluvium) and/or to repeated aolic deposition and erosion over a relatively long period with stronger and more regular winds. In agreement with this supposition are the longitudinal character of the dunes, the thickness of the accumulations near the plinthite scarps and their occurrence on the plinthite plateaus far west of these scarps. Maximal transport distance seems to have been 50-75 km.

The origin of the Sokoto sands from either Sangiwa, Tureta, Rima or Illo is even more clearly established if one compares individual samples in a particular sub-area on their heavy mineral assemblages; the same holds for the granulometry. In general, all sands in the northern part are slightly coarser than those in the southern part, but since the samples used for the various grain-size graphs are in one instance somewhat concentrated in the north (e.g. Sangiwa), and in another in the centre or the South (e.g. Sokoto), differences between the various deposits tend to become obscured by the averaging. Short-distance comparison of grain-size of Rima, Sangiwa, Tureta and Sokoto reveals a distinct increase in the grain sorting.

The *Zurmi* coversands, while having about the same pattern of deposition as the Sokoto sands, have a grain-size distribution which is more to the very fine sand side than is that of the Sokoto sands, pointing to a different source. They have indeed a completely different mineral association: Epidote-Hornblende. On the triangle a complete superimposure with the heavy mineral blot of the crystalline rocks occurs. Without doubt, the Zurmi coversands, too, are the result of relatively short-distance aeolic transport, but in this case from weathering Crystalline basement materials — in the northern part possibly via a stadium of "pre--Zurmi" coversands dating from the Sangiwa period.

Judging from their physiographic position, the *Rabah* sandy main-terrace deposits will have originated from the Tureta deposits and locally from the Sokoto deposits. Their heavy mineral associations are also comparable, but the centre of the Rabah triangle blot is somewhat further removed from the basis of the triangle than is the Tureta one.

The grain-size peak at the fine sand fraction is slightly more pronounced than that of either Tureta or Sokoto, reflecting the fluviatile re-sorting.

The physiographic position of the *Talata* loamy to clayey main-terrace deposits (just downstream of the Bakolori deposits; along those rivers with a catchment in the Crystalline basement area; pattern of meandering river deposits) make it likely that the main source of the sediments has been weathering Crystalline basement materials, either directly or via the Bakolori stage. Two of the three samples analysed on heavy minerals do indeed show a resemblance to the Crystalline basement — Epidote-Hornblende association (and Andalusite) — although the presence of some Tourmaline points to some admixture with Gundumi and/or Tureta influence. That Tureta sediments were the source of the sandy component of the deposit seems beyond doubt for the third sample, which was taken relatively far downstream within a broad band of Tureta (near Isa). In the area of the confluence of the Rima and Niger, Illo influence is likely. The grain-size distribution of the sand fraction of these relatively heavy textured deposits gives fewer additional indications as to the source than does the silt/clay ratio (0.8) and the clay-mineral composition (CEC 20-30), but the absence of the latter data for the Bakolori deposits prevents comparison.

In view of their physiographic position, the *Kaura-namoda* fine sandy main-terrace deposits are likely to have derived mainly from the Zurmi coversands. The one sample with heavy-mineral analysis has an Epidote-Hornblende association, quite comparable with the Zurmi (and the Crystalline basement) association and their triangles blots, except for the absence of Zircon. Also the grain-size distribution is comparable with that of the Zurmi coversands, taking into account some extra sorting by the fluviatile action. There can be little doubt that the Kaura-namoda deposits have developed from the Zurmi coversands, possibly with some admixture of fresh weathering products of Crystalline basement.

The *Zazagawa* sandy low-terrace deposits have Tourmaline-Staurolite and Zircon as main heavy minerals, though some Epidote and Hornblende is also present in two of the three samples. As a whole, this is still rather comparable to the association of the Rabah deposits from which the Zazagawa must have derived, in view of their physiographic relation and the short-distance transport involved (braiding river). The braiding-river deposition also explains why the top of the grain-size distribution has shifted to the medium sand fraction. Very fine sand, silt, and clay percentages are clearly lower than for the Rabah deposits, which also provides evidence of renewed fluviatile sorting.

At first sight, the presence of Epidote and Hornblende would indicate Crystalline basement or Gundumi influence, but this is impossible in view of the short-distance transport; furthermore, the sample with the highest percentages of these minerals is from the Birnin Kebbi area, very far away from Gundumi or Basement. A likely explanation is that the Zazagawa sands have derived in part from slightly pre-weathered deeper layers of fluviatile sands, laid bare during the preceeding downcutting period. As in all other fluviatile sediments, the Zircon and Kyanite components tend to disappear in the fine sand fraction.

The *Bagudo* loamy low-terrace deposits have a mineral association partly comparable to that of the Crystalline basement or Gundumi, partly to that of Tureta and Rabah. This seems to confirm the evidence, already indicated by the physiographic position, that the source of the Bagudo deposits has been a mixture of Talata-Rabah, Gundumi and Crystalline basement rock (or Meta-sediments in the case of the river Zamfara and Ka — from which, however, no heavy minerals were determined). The broad expanse of Bagudo deposits along the Niger River is likely to have developed both from the Crystalline hinterland in Niger Republic and Upper Volta (meandering river deposits, hence large-distance transport possible) and from the more locally occurring Illo sedimentary rocks or its derivates. The relatively low silt/clay ratio and the relatively low clay-mineral activity point to considerable weathering and pre-weathering.

The *Argungu* floe sands must be derived largely from the Zazagawa deposits and indirectly from the Rabah deposits, in view of their close geographic association. The heavy-mineral association has moved even further from the Zircon-Kyanite side of the triangle towards the Epidote-Hornblende side. Yet, since Crystalline basement or Gundumi as partial direct source is almost impossible (faraway, while only short distance transport must have been involved), it is more logical to assume the infuence of local deeper sand layers, not earlier subjected to pedogenesis, with Zircon and Kyanite disappearing in the fine sand fraction by the renewed fluviatile action. The grain-size distribution, at any rate, points to further coarsening and at the same time further sorting, under the influence of renewed braiding-river action on the older fluviatile sediments.

The *Diggi* park sands, loams and silt-rich clays have a well defined Epidote-Hornblende mineral association, clearly related to the Crystalline basement and its derivates (Zurmi, Kaura-namoda, partly Talata). The disappearance of the Zircon-Kyanite components, at least in the fine sand fraction, would be due to fluviatile action. Derivation of the Diggi deposits from Crystalline basement materials is strongly supported by their presence only in those rivers which have a catchment in this basement. The clear meandering river deposition will, moreover, have allowed long-distance transport. In addition, the very fine sand fraction — hardly present in the sediments derived from the sedimentary rocks — is rather high, as is the silt/clay ratio.

Also the clay-mineral composition (CEC about 42 m.e.) points to origin of the deposits from the Crystalline basement, rather than from the sedimentary deposits like Gundumi and Gwandu (cf. Table 5).

For the *Ambursa* central clays, the heavy-mineral assemblage is in the centre of the triangle. The percentage of sand, however, is very small and, in fact, should concern locally reworked older sediments at the start of the lacustrine sedimentation (and some subsequent biological homogenisation). These older sediments should be mainly Argungu floe and some sandy Diggi park materials (cf. detailed cross-section of Appendix 2). Indeed, the Ambursa blot in the triangle shows some affinity with the Argungu blot.

Much more revealing is the almost entire absence of the silt fraction. This excludes origin from the silt-rich Crystalline basement materials. In fact, the geographic occurrence of the Ambursa only in the Rima and the Tarka indicates that the clayey material must have come solely from the fossil Sahara sub-catchment. The clay minerals are relatively poor (CEC about 38 m.e.), making it unlikely that the relatively rich marine Kalambaina-Dange and Dukamaie shales and limestones are the source (though these have caused local enrichment through seepage water, cf. Chapter 6.3). More likely the "grès et argiles de Tégama" of the "Continental Intercalaire" south of Agadèz are involved (cf. Table 1 and Fig. 4). Because of this continental character, the clay components should be relatively poor. No data on the silt content of these Tégama deposits, which should be low to lend support to the hypothesis, have been encountered in literature. The lacustrine conditions must have allowed gradual transport of such clays in dispersed condition over the very great distances concerned. In this connection it is noted that at least part of the lacustrine deposits of the second episode of Lake Chad have derived from the Tibesti area, some 800 km from the presentday lake (SERVANT, 1969).

The *Tungantudo* enclosed deposits are rather comparable with the Ambursa deposits. Their source, however, could be less faraway in view of the vague meandering aspect in the northern part. The somewhat higher silt/clay ratios and the richer aspect of the clay minerals all support the idea that the source must have been the relatively nearby "Cretacé-Marin" and "Paleocène Marin" (Kalambaina-Dange and Dukamaie, possibly also Gwandu I). The one sample analysed for heavy minerals in the fine sand fraction has a Tourmaline-Staurolite-Zircon association. Locally reworked Sokoto coversands — as an admixture — must be concerned, c.q. Gwandu II + III deposits or derivates (the latter applying, for instance, to the patches of Tungantudo-like material near Tangaza).

The *Illela* coversands have a very clear Tourmaline-Staurolite-Zircon association of heavy minerals. Development from the older deposits in and around the Tarka and n'Kabba (Sangiwa, Tureta, Rabah, Argungu, Zazagawa) is not likely because some of these deposits contain appreciable percentages of Epidote and Hornblende and lower percentages of Zircon. Blow-outs in these parts are, moreover, not so apparent, that they can account for the enormous total amount of Illela sands. For the same reason, origin from the few Rima outcrops in this area is unlikely. The clear mineralogic resemblance between Illela and Sokoto sands makes it logical to assume local deformation of Sokoto longitudinal dunes originally occurring in the area. This also confirms the supposition of Chapter 4.5 as to the mode of formation of the fortress shape of dunes. The Illela aeolic transport therefore must have involved even shorter distances than during the Sokoto and Gundumi periods. Maximally 2-5 km seems to have been the case and the wind direction would have been varied, possibly with a predominance of N-S. In the process of aeolic transformation the little silt and clay still present must have blown off, causing a still sharper peak in the fine sand fraction (the appreciable percentage of the medium sand fraction is not anomalous when it is taken into account that the Sokoto sands in the northern part are slightly coarser than the average for the whole survey area — on which average the Sokoto graph is based).

If the above deduction is correct, the Tungantudo deposits should occur locally as a sheet between Illela sand and Sokoto sands — which still has to be confirmed by deep augering.

The *Kurukuru* and *Gande* micaceous deposits, finally, like the Diggi park deposits, have a clear to very clear Epidote-Hornblende association of heavy minerals in their fine sand fraction. Their origin from weathering Crystalline basement materials is very logical, and this is supported by the high percentage of very fine sand, the high silt/clay ratio, the clay mineral composition, the presentday occurrence of the deposits only in those rivers with a catchment in the Crystalline basement, and the pattern of sediment-load of the river waters in the rainy season.

The fact that Kurukuru and especially Diggi deposits still have some Tourmaline and Staurolite may indicate a slight admixture from sandy deposits in the northwestern and central subcatchments, but this may be equally due to somewhat more weathering of Epidote and Hornblende after deposition.

When we *compare the mineral composition* of aeolic and fluviatile depositions *in relation to time sequence,* we see that in the aeolic sequence there is a gradual disappearance of the few original Epidote-Hornblende-Andalusite group. The reverse tendency can be observed in the fluviatile sequence.

Accepting that Epidote, Hornblende and Andalusite are more susceptible to pedogenetic weathering, the above difference in trend may well be the consequence of a difference in erosion of former deposits. In aeolic transport, the more weathered superficial layers are decapitated, hence the remaining material contains higher percentages of more easily weatherable minerals than the transported material. In fluviatile transport, both the relatively thin superficial layer and substratum layers are transported, the latter still containing the original content of easily weathering minerals. Surfaces of younger fluviatile deposits, where pedogenetic weathering has been less, therefore contain higher percentages of Epidote-Hornblende-Andalusite. The Zircon-Kyanite components of the heavy minerals in the fine sand fraction have a tendency to disappear in any fluviatile deposition. This also applies, and particularly, when long distance transport by meandering rivers form the Crystalline basement area is involved (cf. e, below). It is likely that in the *very* fine sand fraction, the Zircon-Kyanite components do not diminish very much. The fluviatile action may, in fact, cause these particular mineral particles in particular to wear down more strongly, resulting in smaller grain-sizes. The data of the Tureta sample in Table 3 seem to support this supposition; unfortunately no other aqueous deposits were analysed for heavy minerals in all sand fractions.

Although the number of samples per deposit analysed for heavy mineral content was often very small and inadequate to calculate statistical averages the data together with supporting evidence from physiography, grain-size distribution, silt/clay ratios and clay mineral activity, allow conclusions to be drawn regarding the source of the various Quaternary deposits. These conclusions may be summarized as follows:

a) The sandy deposits in the northwestern and central part of the survey area (Sangiwa, Tureta, Sokoto, Rabah, Zazagawa, Argungu and Illela sands) all come from the same original sources, namely the local, more or less sandy, sedimentary rocks, viz. Gundumi, Gwandu II + III, and particularly Rima (Taloka and Wurno) formations.

b) The majority of these sands, whether aeolic or fluviatile, probably developed one from the other, the sorting of the sands becoming increasingly refined in the process. The fluviatile re-sorting, moreover, led to a gradual coarsening from fine to medium sand.

c) There is a gradual mineralogical disappearance in the aeolic sequence of the few original Epidote-Hornblende-Andalusite minerals. In the sequence of fluviatile sediments there is a reverse tendency.

d) The sandy deposits in the southeastern subcatchment have derived from the locally occurring weathering Crystalline basement materials, either directly (Zurmi) or indirectly (Kaura-namoda).

e) The very fine sands, loams and silt-rich clayey deposits occurring both on the river terraces and in the floodplains of the rivers with a catchment in the Crystalline basement area (Bakolori, Talata, Bagudo, Diggi, Kurukuru and Gande) are all derived, directly or indirectly, from weathering Crystalline basement materials, with only locally an admixture of materials from sedimentary rocks.

f) The loessic deposits in the southeastern catchment are derived from faraway sources of (non-crystalline) rocks to the east of the survey area, either directly (Funtua) or indirectly (Gusau).

g) The silt-poor clayey deposits in some of the floodplains of the northwestern catchment (Ambursa, Tungantudo) are derived from clayey sedimentary rocks, mainly from far north of the survey area.

This may be the proper place to refer to similar lithostratigraphical findings in Northwest Europe, especially in The Netherlands, as regards the sources and spreading mechanisms of desert aeolic deposits (ZAGWIJN, 1956, VAN DER HAMMEN, 1951; MAARLEVELD and VAN DER SCHANS, 1955; SCHELLING, 1955; CROMMELIN, 1964). These findings describe three main coversand depositions in the periglacial area, dating from the last (cold) desert period of the Würm glaciation. There is a clear analogon in the sequence of type of sediments and erosion. The oldest coversand, formed during the "pleniglacial", is ill sorted and has been flattened to a very smooth relief. As regards time of deposition, it is related to loess deposits in the south of The Netherlands and in Belgium (compare the Sangiwa sands and the Funtua loess). The so-called young coversand, separated from the older sands by the "Bölling" level, has more relief and consists of reasonably well sorted sands (geomorphologically quite comparable to the Sokoto sands). On top of the young coversand, well sorted aeolic sands occur locally, with a very strong relief ("regional" aeolic sands, etc., of various younger ages). The type of dunes may vary from parabolic dunes to fortress-shaped dunes (compare the Illela sands).

Another clear analogon is presented by CROMMELIN (1964) who proved that vertically there is a clear mineralogical correlation between the three types of aeolic sands reported in The Netherlands. He concludes, just as we do in the present paper for the Nigerian area, that the younger sands are rather locally derived from the older ones and that no longdistance transport of more than a few kilometers will have taken place. With the above comparison, however, we do not mean to suggest that there is also an absolute time-stratigraphical correlation (cf. Chapter 8).

7.4 Sketch of the Quaternary sedimentologic history of the area. With the mode of deposition, the relative age, and the source of the various Quaternary deposits largely established, it is possible to envisage the sedimentologic history of the area. The sketches of Appendix 3 show the various stages. A summary is given below for each stage, mentioning, too, the likely characteristics of the climate at the time. More detailed discussions on these climates and the effect of changes are given in Chapter 7.5.

For the moment, the timing of the stages is uncertain. It is supposed that Stage 1 is somewhere in the Pleistocene. The genesis before that time is discussed under Stage 0.

Stage 0: After the youngest period of plinthite formation (LW2), a relative uplift of the area, including the sedimentary part, took place. This was followed by a period of tectonic stability with strong erosion and pediplanisation, during which large valleys were formed and the plinthite levels of various ages were exposed, causing their hardening ("cuirassing") if this had not occurred before. The main courses of the larger present-day rivers, both ephemeral or permanent, were established in all subcatchments. There is no evidence of any aeolic sedimentation in those times. If any occurred, the materials have been either completely removed or buried under younger sediments.

To supply the rivers with such a strong downcutting force and to cause the land surfaces to be erosion-susceptible — little or no vegetation — the climate of these times must have been characterized by at least periodical *torrential rainfalls concentrated in a very short period of the year* and possibly very erratic over the years: semi-desert climate. Pedogenesis under these circumstances will have been very slight and would have been overtaken by rock disintegration forming sand rather then silt and clay and by erosion processes in most places anyway.

Stage 1: In the central and north-western subcatchment the *Sangiwa coversands* were deposited as fields of transversal dunes. The materials were derived from local, more or less sandy, sedimentary rocks (Gundumi, Rima and Gwandu II + III) and were transported over small distances by ENE winds. Winds were not strong enough for the sand to climb the scarps and the sand-sorting was poor.

Although coversands may also have been deposited in the northern tip of the south-eastern subcatchment ("pre-Zurmi", derived from local disintegrating Crystalline basement rocks), the main part of the south-eastern subcatchment received rather regular accumulations of desert dust from extensive desert land sources faraway to the ENE. These accumulations formed the *Funtua loess*.

To allow aeolic erosion and deposition of fine sands, the central and northern parts of the area must have been devoid of any vegetation. In the south-eastern part, a sparse, probably grassy vegetation will have been able to consolidate incoming loess particles against wind erosion.

Rainfall must have been absent in most of the area, but slight and fairly regular (?) in the south-eastern part. Better soil conditions in this part may also have been of influence. A true *desert climate* will have prevailed in the main part, a *climate with minor rainfall* in the south-east, both parts having moderate ENE winds. Pedogenesis will have been very restricted during this time and only dry rock disintegration may have occurred, providing sand as finest material.

Stage 2: In the central and north-western catchments the Sangiwa dunefields were denudated by sheetfloods, and the erosion products — locally mixed with those of underlying sedimentary rocks, notably Rima — were deposited as *Tureta sandy wash-plain deposits* in broad valleys alongside the main rivers and numerous tributaries.

It is most probable that at the same time the Funtua loess deposits in the southeast were being severely eroded, the erosion material being re-deposited somewhat lower down as *Gusau deposits* (nowadays forming high-terrace remnants).

Erosion products from non- (or only slightly) loess-covered parts of the Crystalline basement were deposited elsewhere, in general slightly more downstream of the Gusau deposits: *Bakolori deposits*.

The aqueous erosion and deposition implies that rainfall must have occurred in considerable quantities, but not regularly enough to maintain a protective vegetative cover, not even in the loessic areas with their relatively favourable soil conditions. Hence the climate will have been characterized by *rather high, peaky or irregular precipitation,* comparable to that of Stage 0. In view of the widespread erosion, the net result of pedogenesis will have been slight.

Stage 3: The sandy surface materials in the north-western subcatchment were taken up by strong ENE winds and redeposited quite some distance further, locally after climbing plinthite scarps and wandering further over the smooth plinthite plateaus, as longitudinal dune fields: *Sokoto coversands*. These sandy surface materials are either Sangiwa or Tureta materials, but for a good deal also colluvia from Rima sands, accumulated as pediments at the feet of its plinthite-covered scarps in the previous period.

The near-absence of Sokoto sands in the central subcatchment is remarkable; a plausible explanation has not yet been found.

At the same time, in practically all of the south-eastern catchment, sandy surface materials (pre-Zurmi coversands, sandy weathering and disintegration products of crystalline rock, local admixtures of loessic materials) were being moved by the same ENE winds and shaped into longitudinal dunes, though less pronounced than the Sokoto ones: the moderately sorted *Zurmi coversands*. The near-absence of these coversands directly west of the boundary line between basement and sedimentary rock should be due, at least in part, to the presence of the Meta-sedimentary high ridge of Maru, with its steep and irregular topography acting as a barrier. South-east of Katsina, mainly east of the survey area, the Zurmi longitudinal dunes cover a low plinthite plateau (LB) in a clear striplike pattern (cf. PULLAN, 1969).

No loessic equivalent to the Sokoto and Zurmi sands has been found. If anywhere, it should occur south of the survey area.

To have allowed extensive wind erosion and coversand deposition as dunefields over large parts of the whole survey area, this must have been devoid of vegetation. Climatically the period will have been characterized by *pronounced desert* conditions with strong ENE winds. Pedogenesis at this time will have been non-existent.

Stage 4: In the northeastern and central subcatchment, a fluviatile erosion and downcutting phase was accompanied or immediately followed by aqueous deposition of either well sorted fine sands, the *Rabah deposits,* or loamy to clayey materials, the *Talata deposits*. The Rabah fine sands, found along the rivers in most of the sedimentary area, derive mainly from adjoining higher positioned Tureta washplain deposits; the Talata deposits, found only near the boundary with the Crystalline basement, derive mainly from weathering or disintegrated basement surface materials either directly or indirectly, notably via the Bakolori deposits. Variable degrees of admixture took place with materials of Gundumi or Illi sedimentary rocks or some Tureta sands (at Gummi, Niger river and Isa respectively).

In the southeastern catchment much aqueous erosion must have been taking place during this period. Deposition of these products along the Sokoto, Zamfara and Ka rivers will have been slight (no remnants of a main terrace are found nowadays). The Gagare, Bunzuru and Maradi rivers, however, passing through Zurmi coversand areas, were apparently carrying such a load of these fine sandy materials that redeposition as *Kaura-namoda deposits* occurred.

The river regimes at the time were probably mainly braiding in the Crystalline basement area, transforming into meandering on entering the sedimentary plain, while lower down, especially in the northwestern catchment, they once again became the braiding type.

To allow substantial aqueous erosion, fluviatile downcutting and fluviatile deposition as outlined, rainfall must have been rather high but at the same time the vegetative cover will have afforded little protection. Climatically therefore the period must have had *rather high precipitation,* but with the rains *falling in peaks or rather irregularly,* though not as much so as at Stage 2.

Pedogenesis will still have been limited.

Stage 5: In the northwestern subcatchment a renewed fluviatile downcutting phase was accompanied or immediately followed by aqueous deposition of very well sorted fine to medium sands under a braiding river regime. These *Zazagawa deposits* derived mainly from earlier aqueous deposits nearby, notably the Rabah deposits.

Probably at the same time, loamy aqueous deposits were being laid down, also after a downcutting phase, in the central subcatchment near the boundary with the Crystalline basement. These *Bagudo deposits* were deposited under a largely meandering river regime and were derived from Gundumi or Illo deposits and/or weathering products of the Crystalline basement, mainly its Meta-sedimentary part. In the more downstream part of the central subcatchment, Zazagawa-like deposition may have taken place — remodelling of Rabah deposits — but it is not found at the surface nowadays.

Also in the southeastern catchment erosion must have prevailed over deposition; no low-terrace-like deposits are found in this area nowadays in mappable expanses.

The changes in river hydrology, vegetation, and therefore also the climate should be about comparable to those of Stage 4: having *rather high precipitation, falling in peaks and/or irregularly.*

Pedogenesis was limited.

Stage 6: In the northwestern subcatchment a renewed fluviatile downcutting was followed by deposition of very well sorted medium to fine sands under a braiding river regime. These *Argungu floe deposits* derived mainly from earlier fluviatile deposits nearby, i.e. the Zazagawa ones.

No traces of Argungu-like deposits are found nowadays in the river floodplains of the central catchment; nor are there any more loamy equivalents near the basement area. It is, however, not unlikely that Bagudo deposits, even if deposited in Stage 5, were remodelled at this time, albeit incompletely. The erosional meso-relief features on the Bagudo low-terrace deposits may have originated by such a remodelling.

Climatic conditions must have had about the same characteristics as in Stages 4 and 5: *substantial, but irregular precipitation.* The southeast was probably regularly moist during the latter part of the period, with better vegetative cover (little or no sediments).

Pedogenesis was limited.

Stages 7: No changes took place in most of the northwestern catchment. In the Rima river and in all tributaries in the central catchment coming from the Crystalline basement, a downcutting phase — not very agressive in the Rima itself — was accompanied and followed by deposition of very fine sands, loams, and silt-rich clays under a meandering river regime. The *Diggi park deposits* derived by long-distance transport from eroding weathering products of the Crystalline basement area.

In the southeastern catchment itself sedimentation, if any, was probably slight, because no remnants are found nowadays.

The similarity with the presentday erosion and sedimentation pattern indicates that climatic conditions must have been comparable to, if not slightly moister than, those of today: semi-arid, with a *pronounced rainy season of relatively regular precipitation.* The vegetative cover must have been sufficiently dense to have buffered run-off and large-scale erosion, but there must have been a strong enough difference between dry and rainy seasons to allow the picking up and transport of a considerable load of the finer materials at the start of the rains.

Little or no water entered the rivers from the north-western and central subcatchments. Rains falling in areas with non-sealing sands like Sokoto sand infiltrated into the ground directly. In areas with sealing sands like the Sangiwa sands rains caused some sheetflood, and infiltrated upon reaching more permeable areas (Talata or Rabah deposits). Soil formation will have been substantial in those areas not subject to erosion.

Stage 8: Slight fluviatile downcutting was followed by sedimentologically quiet times. Only in the Tarka and the Rima, and north of Gwadabawa, were relatively silt-poor clays deposited: *Ambursa and Tungantudo deposits.* They derived from far-away northern sources and were deposited in conditions that were becoming more and more lacustrine-like.

Apparently rainfall was high and regular all over the area, causing a dense vegetation which effectively prevented erosion and sediment transport. Only those rivers which originated in significantly dryer areas far north — the presentday Sahara — contained dispersed clayey materials in their gentle waters. A barrier at Kende, near the confluence of the Rima and the Niger, prevented a further lowering of the erosion base of the river system, and swampy conditions prevailed allowing the dispersed clay to settle as a smooth blanket on top of the lower-lying Argungu and/or Diggi park deposits. Pottery fragments found just below this blanket near Wurno, indicate that at least temporary human habitation had occurred shortly before this time. Unfortunately, because of lack of decoration, no absolute dating of these fragments was possible.

A *humid and presumably hot climate* must have prevailed. It causes intensive pedogenesis to kaolinite clay minerals on the uplands, but the period was apparently too short to form proper ferralitic soils. As mentioned in chapter 2.4, transformation of 1 m of granite into ferrallitic soil under a per-humid and hot climate needs, according to LENEUF and AUBERT (1960), at least 22,000 years. The farthest that weathering of Crystalline basement materials in our area progressed during the humid period concerned is apparently up to the stage of Ferruginous Tropical soil.

Stage 9: Local wind erosion resulted in deformation of the non-sealing Sokoto coversands in a part of the northwestern catchment: *Illela coversand,* partly overblowing the earlier Tungantudo deposits. In the other parts, deformation of the Sokoto sands was restricted to colluviation by wind and water in places of steepest accumulation; it resulted in local burying of older aqueous deposits like the Rabah ones alongside the lower Gulbi and the Shella, and like the Ambursa deposits in the Tarka.
Note: Coversand deformation and colluviation processes are still continuing to some degree nowadays, and they may also have occurred in earlier stages (Nos. 4, 5 and 6).

The fortress aspect of the Illela dunes would indicate the presence of vegetation remnants (cf. SCHELLING, 1955, on the origin of such dunes in The Netherlands) and varying wind directions. This, and the fact that the Illela dunes occur only in the north of the area, would indicate that climatic conditions at the time were *not completely arid: a very short and/or irrigular wet season* probably occurred.

Stage 10: Erosion took place in the southeastern subcatchment and the resulting very fine sands, loams, and silt-rich clays accumulated in the floodplains of the major rivers in the central subcatchment. These *Kurukuru and Gande micaceous deposits* were laid down under a meandering river regime, with at least one temporary shift to more braiding conditions (terracelike parts, mapping unit 7.2). This sedimentation is still in full swing today, having filled-in only part of the Rima floodplain and there covering the Ambursa deposits and most parts of the Diggi park deposits. The climatic conditions of today must have started at this stage, interrupted by at least one spell of more erratic rainfall. The presentday deterioration to braiding, however, is most likely due to the intensive direct or indirect human influence (agriculture, burning, overgrazing), possibly combined with a tendency towards a "dryer" climate.

A rough estimate can be made of the start of Stage 10: In 1963 the Rima River at Sabon Birni carried about 0,7 million m^3 of sediment. Just upstream of its confluence with the Sokoto, the Rima contained hardly any sediment: i.e. all deposition took place between Sabon Birni and Sokoto. Estimated from the soil survey data, the total of deposited Kurukuru and Gande micaceous sediments for this stretch are 520 million m^3. If we assume the most improbable — that erosion suddenly started at full strength and that sediment transport remained constant — we would arrive at a period of $\frac{520}{0.7} = 750$, say between 500 and 1,000 years.

However, the assumption of a constant sediment-transport figure is obviously wrong. From a period of no sedimentation in Stage 9 to one of distinct sedimentation in Stage 10, a gradual increase is much more likely to have occurred. Moreover, the destruction of vegetation by overgrazing and burning is at present very strong and is probably much greater now than it ever was before.

It seems likely from the map image that the average age of the tongue of the micaceous sediments of the Sokoto River, passing the town Sokoto, is less than the average of similar sediments in the Rima River between Sabon Birni and Wurno. The latter tongue contains also fewer recent splays. The progress of the micaceous sediments can be observed yearly, if not daily.

The data suggest that the sedimentation downstream, i.e. the most recent, was more rapid than that upstream. This indicates an accelerating sedimentation process, which is now faster than ever before.[1] We may conclude from the Rima figures that the sediment tongue passed Sabon Birni more than 500 to 1,000 years ago[2]. If we take into account that before the tongue of micaceous sediments passed Sabon Birni, an equal but probably greater length of time must have elapsed, then the beginning of Stage 10 can be estimated at roughly several thousand years ago.

7.5 Periods of geomorphodynamic activity and stability, and related changes in climate

Introduction

Students of geomorphology and related sciences agree on the principle of changes of climate during the Quaternary in the temperate zones (glacials and interglacials) and

[1] The sediment load in 1963 for the area of the Sokoto River downstream of Sokoto bridge was 1.2 million m^3 per year. The total amount already laid down is 100 million m^3. This indicates its occurrence over a period of about a century. It is interesting that during the beginning of the famous Fulani empire, the fertile sediment tongue of the Sokoto River passed the place where the first sultan Bello established his capital in the first decade of 1800.

[2] Near Sabon Birni is the site of the old capital of the Haussa state Gobir: Alkawala. The micaceous tongue may also have passed there during the establishment of the city.

in the tropical regions (pluvials and interpluvials), but controversy surrounds the correlations between glaciations and pluvials. We will not review the whole of the extensive literature on this subject but will mention only some headlines that are important for our study.

In older literature, mainly before 1960, one often finds the supposition that glacials would coincide with pluvials. More recent studies, however, (e.g. BERNARD, 1962; BISHOP, 1962; MICHEL, 1970; ELOUARD et al., 1969) show it to be more probable that glaciations have at least in the present equatorial zones a counterpart in dry climates (interpluvials). A simple shift of the intertropical conversion zone during glacials towards the south would explain this easily. It implies that somewhere between the dry (interpluvial) zone in the south and the cool glaciation zone in the north an area would exist where the western winds, now causing high rainfall in western Europe, then would cause a humid climate. There is indeed evidence for this phenomena in North Africa (compare the displuvials of BERNARD, 1962). The occurrence in Senegal of arid landforms later submerged by sea level pleads in favour of a correlation between glaciations and dry periods in the more equatorial regions (MICHEL, 1970 also oral VERSTAPPEN).

Some discrepancies exist in literature also regarding morphodynamic activity in relation to climate. Certainly it is a much too simplified hypothesis to suppose that pluvials would give mainly fluviatile erosion and interpluvials mainly deposition.

For the central Sahara (Fezzan-Tibesti) ZIEGERT (1969) found a rhytmic alternation of incision/erosion phases and accumulation phases, separated by periods of stability. The periods of stability would date from interpluvials — pure desert conditions — the accumulation phases from pluvials, and the incision/erosion phases from displuvials. Such an alternation of isopluvials and displuvials, separated by interpluvials, would also have occurred in the area under study (about 12°N).

Recently, ROHDENBURG (1970) gave a critical review of various opinions on the relation between climate and cyclic erosion and sedimentation, and propounded a hypothesis for causes of geomorphologic instability from the ecological point of view, considering rainfall in relation to run-off, vegetation, rock weathering and soil formation. He first pointed out that discussion of the subject is hampered because the actualistic principle of study cannot properly be applied. The present gives no clear clue to the past, because in all presentday climates, whether humid or arid, there is a relative geomorphologic stability. For instance, loess deposition of any extent occurs nowhere at present; neither are there any large areas subject to coversand deposition; nor is pediplanation a major landforming factor . Where some degree of geomorphologic activity exists, this is clearly due to intense human interference in the ecosystem, especially in the vegetative cover. From his own observations in south-east Nigeria (RHODENBURG, 1969, 1970) and from references, he concludes that areas with relatively moist climates must have had a lower precipitation in the past, but one more regularly distributed over the year than at present. In contrast, areas with a relatively arid climate must have had a higher precipitation in earlier times but one very unevenly distributed over the year.

From the above it may be concluded that while periods of geomorphodynamic activity may have alternated in the past with those of stability, they are not necessarily correlated with periods of different total annual precipitation. Most activity may, in fact, have taken place during the change-over from one type of climate to another, as may be illustrated by the following example (after RHODENBURG, 1970).

Suppose a morphodynamic period of stability exists; rather high rainfall, distributed regularly over the year, stimulates the growth of a dense vegetative cover and deep soil weathering. Now, the climate changes gradually with the onset of a dry season of ever-increasing intensity, marked by lower total annual rainfalls. The vegetation becomes less luxuriant because physiological drought is being felt, and it is less resistant to unfavourable environmental factors like fires and animals. The vegetative cover of the soil surface becomes incomplete and the bare patches are liable to superficial sealing due to the direct impact of raindrops, causing soil dispersion. During the most extreme showers, run-off is substantial and erosion and redeposition starts causing pediplanation. It may happen that not enough loose surface material is available for redeposition nearby. The erosion then results in local incision, while only far downstream does sedimentation take place. With the increase of the dry season, the process gathers momentum until a certain optimum of morphodynamic activity is reached. At a certain stage the total precipitation has diminished so much that the periods of run-off are so brief and/or the amounts of run-off water so small that very little material is being transported. In the meantime, vegetation may have become very scanty or even absent. Gradually, water erosion peters out and a period of relative stability starts. If, after rains have ceased altogether, strong winds occur and much loose material happens to be left on the surface, aeolic erosion and deposition may take place, representing a new period of morphodynamic activity. After a shorter or longer period, precipitation will be on the increase again. Wind erosion stops and, after a time of water erosion, a new period of stability is gradually attained, with a dense vegetative cover and deep weathering.

In this one cycle of climate change, several periods of stability and activity have occurred. In the example chosen, events may have been induced by a simple shift of the average position of the zone of intertropical conversion. More intricate climatic cycles will give an even more complex result as to the sequence of geomorphodynamic processes.

Periods of stability cannot, of course, be traced on morphodynamic features, but rock weathering and soil formation during these times vary from practically nil (pure desert conditions) to very intensive (per-humid conditions). Paleopedological studies may therefore provide an insight (see chapter 2.4).

With the above in mind, the sequence of geomorphologic features and the probable differences in precipitation in the area of study can be schematized (Table 7). The absence of C^{14} data from the area (fossil carbon, shells, etc.) prevents any absolute dating. Nor are there any artifacts identifiable with human industries of known age. The occurrence and length of periods of stability can only be guessed at because only few data on paleosols are available (the plinthite levels are all pre-Quaternary). It is therefore only by comparison with neighbouring areas (cf. Chapter 8) that some degree of absolute dating is possible.

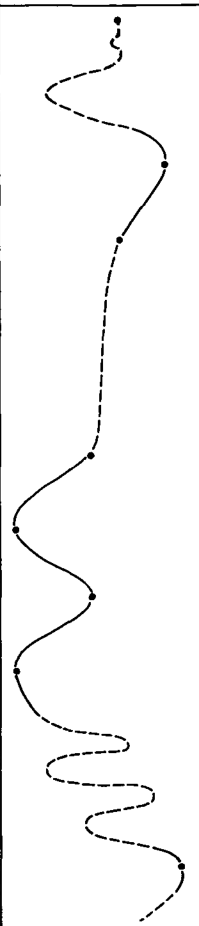
A major correlation problem is still presented by the sequence of three braiding river deposits in the sedimentary part of the area, each at a lower level, with marked terrace formation through incision but without apparent interruption by aeolic activity (Stages 4, 5, and 6). The repeated incision prior to deposition at lower level can have three causes:

a) Local tectonic upheaval: "tectonic terraces". Though the sedimentary area was not subject to any remarkable tectonic uplift during the Quaternary, a slight and hardly detectable one all through the period (as an aftermath of the main uplift in the Late Tertiary?), would automatically cause incision of the rivers, if the base level of the catchment — the Niger River at Bagudo — remained the same or was raised less. In such a case, however, downcutting would have been continuous rather than rhythmical.

Moreover, no correlation would exist with the terraces along the Niger itself — whereas there seems to be an obvious correlation (cf. chapter 8.2).

b) Changes in base level of the Rima and ultimately of the Niger: "thalassostatic river terraces". The level of the Niger river, even as far upstream as at Bagudo, may have oscillated under the influence of the general sea-level oscillations related to the various ice-ages (transgressions and regressions by glacio-eustatic sea-level changes, cf ZEUNER, 1959 and other authors). Upstream downcutting, as in the Rima-Sokoto system, could be related either to high sea levels (shortening of the Niger longitudinal profile, hence more erosional force), or to low sea levels (lowering of the erosion base of the Niger

Table 7. Probable changes in precipitation and geomorphodynamic activity in the area studied.

Stage	*Deposits and estimated age*	Total annual precipitation very low ⟶ very high	Regularity of precipitation	*Characteristic features*	*Type of geomorpho dynamic activity*
10	Kurukuru - Gande micaceous deposits		distinct wet season	meandering rivers, soil formation	water action
9	Illela coversand		erratic, distinct and long dry season	local dune (de) formation	wind action
8	Ambursa - Tungantudo lacustrine deposits 9 - 10.000 BP		regular, no distinct seasons	lacustrine rivers, intensive soil formation	shortlasting stability
7	Diggi park deposits		distinct wet season	meandering rivers; soil formation	water action
6	Argungu floe deposits		irregular	braiding rivers	water action
5	Zazagawa - Bagudo low-terrace deposits		irregular	mainly braiding rivers	water action
4	Rabah - Tatata - Kaura main-terrace deposits		irregular	mainly braiding rivers	water action
3	Sokoto - Zurmi coversands 15-20.000 BP		erratic, if any	dune formation	wind action
2	Tureta - Bakolori - Gusau washplain and high-terrace deposits 30-40.000 BP		irregular	mainly sheetwash	water action
1	Sangiwa - Funtua coversand and loess		erratic, if any	dune formation	wind action
0	(Structural plateaus, main valleys and rivers)		probably varied	erosion and pediplanation	water and wind (?) action
00	Youngest plinthite level (LW2)		regular, probably no distinct seasons	intensive soil formation	stability

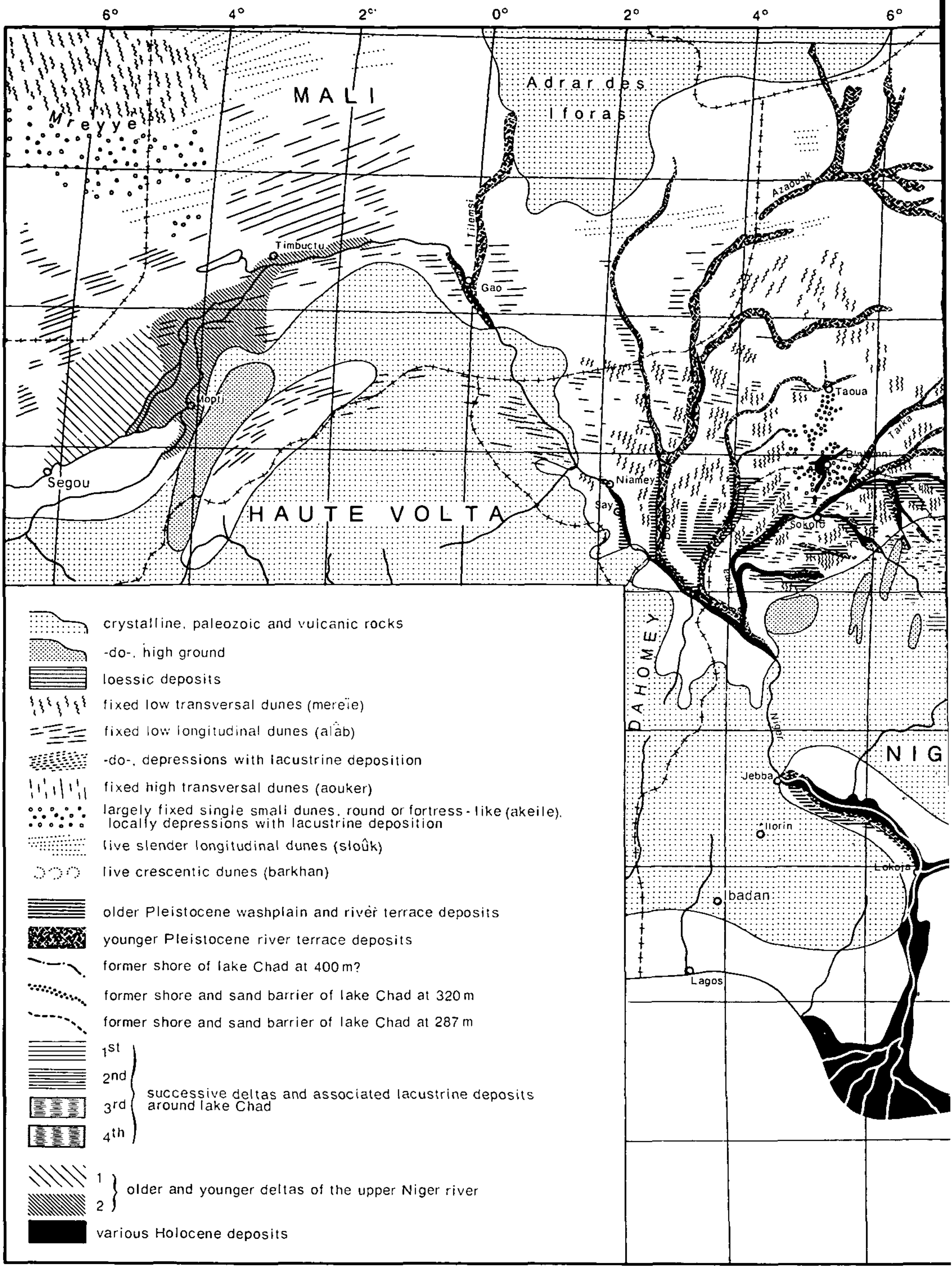
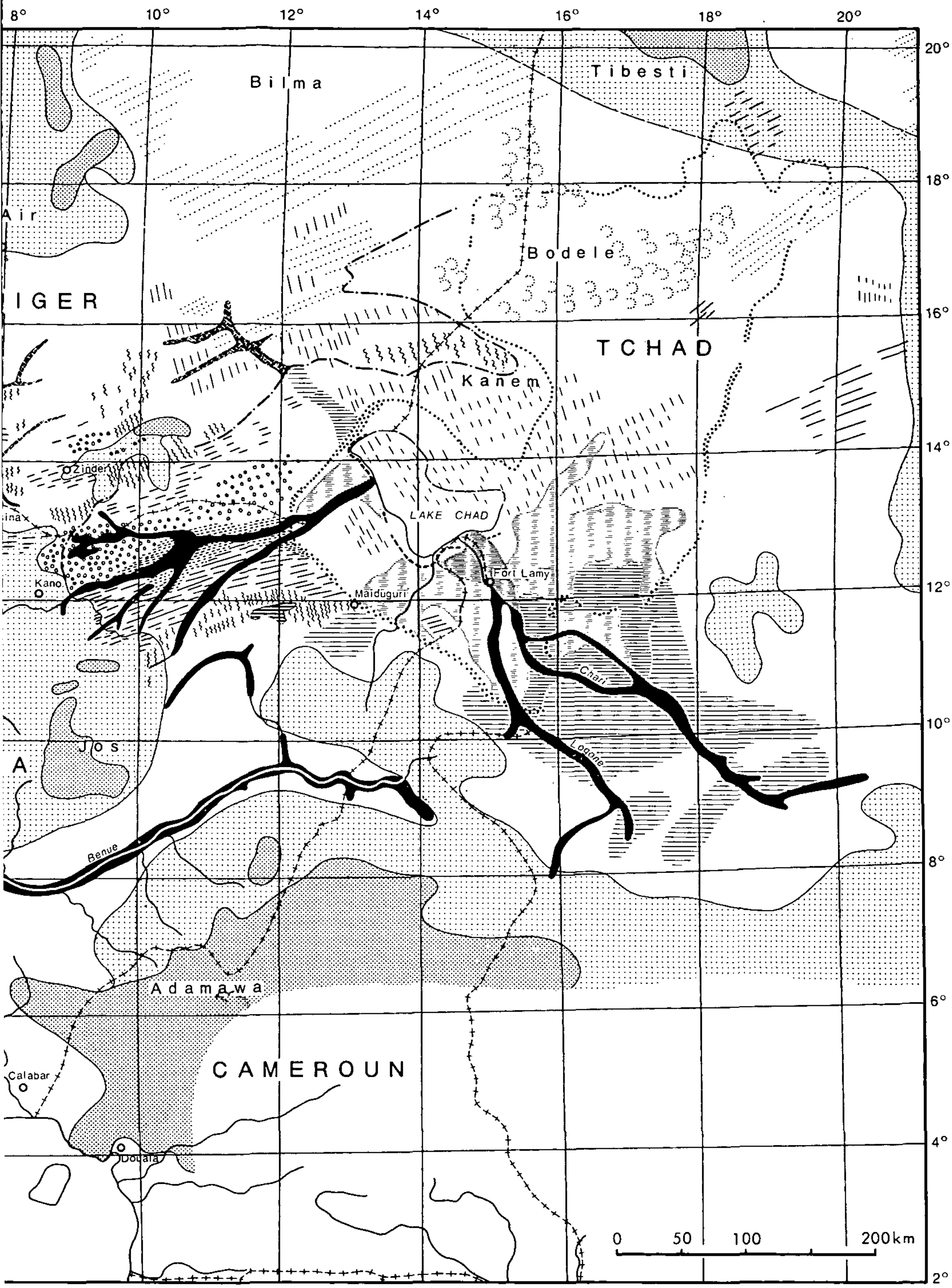


Fig. 25. Sketch map showing the occurrence of various Quaternary aeolic and aqueous deposits in the Nige



d area of West-Africa (compiled from various maps and reports; very tentative).

without much lengthening of the profile). With this reasoning, the Rima-Sokoto system would have formed an inherent part of the Middle and Lower Niger, and would have followed its downcutting in relation to sea-level changes, until an erosion-resistant sill (at about the level of the Ambursa deposits) was reached, preventing further downcutting. From geological observations, the presence of such a sill near Kende (at the confluence of the river Ka) seems indeed likely.

c) .Changes in climate: "climatic terraces". Incision and accumulation may be due purely to local changes in climate, either the transition from a humid climate to one with a distinct dry season (see above) or the transition from an arid climate to one with peaky and erratic rainfall. Whatever the kind and whatever the critical phase, if changes in climate were the sole cause of the repeated downcutting and valley filling in the Sokoto area, there would seem to be no reason for these processes to have taken place at a lower level each time, at least not for the downstream parts. It seems therefore more logical to assume that changes in both climate and the erosion base of the lower Niger river (whether or not conditioned by sea-level changes) have caused the rhythmic and progressive downcutting of the Rima-Sokoto river system, possibly helped by some gentle upheaval of the area. More definite conclusions can be drawn by comparison with river terrace systems of neigbouring areas.

River catchments which have no direct or indirect connection with the ocean are, for instance, the Kano and Hadejia systems, draining into Lake Chad. Since the sources of sediments are quite comparable with those of the Rima-Sokoto system, they would constitute an ideal object of study as regards the origin of downcutting and valley filling. However, no such features are reported for the Hadejia area (cf. Chapter 8). The gradual sinking of the Chad basin area during the Quaternary must have caused any older river downcutting and accumulation to be buried under these sediments.

In contrast, the Niger River, down to its confluence with the Benue, has several river terraces that can be related to changes in sea level (BUSER, cf. Chapter 8) and at the same time show strong similarity with the Sokoto ones.

Therefore, it can be concluded that a relative lowering of the base level, of a certain rhythmic chracter, is a major, if not the sole, cause of the repeated incisions.

8. COMPARISON WITH NEIGHBOURING AREAS

In recent years a number of publications have appeared on dune fields, river terraces and lacustrine deposits in various countries of the African sub-Sahara fringe. WARREN (1966) studied the Goz area east of Jebel Marra in Sudan republic. PIAS (1968) and SERVANT (1969) have given systematic information on the Quaternary history of the Lake Chad area as a whole, GROVE (1958) and PULLAN (1964) on its western part in particular. The southwestern part of Niger republic and the adjoining part of Upper Volta were studied most recently by GAVAUD and BOULET (1964 et seq.). The terraces along the Niger river inside Nigeria, from its confluence with the Rima to its confluence with the Benue, were studied by BUSER (1964). The Middle Niger area, mainly within Mali Republic, was covered by BLANCK (1968), the southeastern and central part of Mauretania (West Africa's "empty quarter") by MONOD (1958), the Senegal basin area most recently by MICHEL (1970). VOÛTE (1962) studied the geological and morphological evolution of Niger and Benue river valleys. Papers on the whole presentday Sudan and Sahel zone of Africa are from FAURE (1967), GROVE and WARREN (1968), and on the Guinea and forest zone by ROHDENBURG (1969, 1970). Earlier and other authors are mentioned in the present text and the reference-list.

8.1 The coversands

In our efforts to correlate the Sokoto findings, which are presented below, we have not worked chronologically, but rather with those links that seem most definite.

The longitudinal dunes of the Sokoto coversands (and most likely also those of Zurmi) are in every way comparable with, and thus probably of the same age as, the fixed longitudinal dunes, orientated largely ENE-WSW, that are reported for the Katsina area and the Nigerian part of the Chad basin by GROVE and PULLAN (1963), those in the middle Niger area between Timbuktu and Niamey reported by BLANCK (1968) and TRICART (1965), those between Niamey and Zinder mapped as "erg recent" by BOCQUIER and GAVAUD (1964), BOULET, BOCQUIER and GAVAUD (1965) and GAVAUD (1966) and those in Senegal reported by SEDAGRI (1969). They are variously called "red dunes" (WORRAL, 1969), "ancient erg" (GROVE, 1958), "first erg" (PIAS, 1970) and "elb" (pl. "alâb", MONOD, 1958). Their age, checked by C14 analysis, should be 15,000-20,000 BP [1], when a pronounced arid period must have prevailed all over the Sudan zone; it would coincide with the Ogolien II regression of Senegal (MICHEL, 1970), which is linked to the European Würm glacial (Weichselien).

Other deposits that can be definitely related with findings of surrounding areas are the Ambursa and Tungantudo lacustrine-like deposits. They should form part of a whole pattern of lacustrine sediments as described by FAURE (1967) in the present Sahel zone and beyond, to which also the clayey deposits of the Mega-Chad (3rd lacustrine transgression, beach level 320) belong. The age of these lacustrine deposits, well defined because of the abundance of molluscae, is between 9,000-10,000 BP (SERVANT, 1969), when the climate was relatively very humid.

The Illela coversands, which are at least for a major part younger than the Ambursa deposits and concern in fact a reworking of older dune fields, are comparable with the

[1] BP = before present, i.e. 1950.

Table 8. Tentative correlation of Quaternary aeolian and aqueous deposits in sub-Saha parts of W. Africa.

SENEGAL (Sedagri 1969; Michel 1970 et par lettre)	MIDDLE NIGER (Blanck 1968; Boulet, Gavaud 1966 et seq)	Stage	RIMA SOKOTO (this paper)	suggested climati characteristics
(dépôts fluviatiles actuels)	(dépôts actuels)	10	Gande micaceous young levees and splays	rel. high rainfall, distinct wet season (minor oscillations
			Kurukuru micaceous terrace-like deposits	
deuxième remblai sableux			Kurukuru micaceous old levees and splays	
dunes jaunes	(cornes de croissant)	9	Illela coversands (akeile)	low rainfall, erratic
?				
argiles fluviatiles	flat argileux, argiles de decantation	8	Ambursa and Tungantudo fluvio-lacustrine deposits	high rainfall, regular
premier remblai sableux	dépôts meubles de terrasse	7	Diggi park deposits	rel. high rainfall, distinct wet seaso
		6	Argungu floe deposits	fair rainfall, irregular
		5	Zazagawa - Bagudo low terrace deposits	
	niveau inferieur	4	Rabah - Talata - Kaura main terrace deposits	
dunes rouges	erg recent	3	Sokoto - Zurmi coversands (alâb)	very low or no rainfall
graviers sous berge, pedogenese sans cuirassement et bas glacis et basse terrasse	niveau superieur	2	Tureta sandy wash plain, Bakolori - Gusau high terrace deposits	fair rainfall, irregular
erg ancien de Ferlo	erg ancien	1	Sangiwa coversands (mereïe) and Funtua loess	very low or no rainfall
cuirassement et calcaire lacustre		0	Pediplanation after Upheaval	variable
moyen glacis et moyenne terrasse				
cuirassement				
haut glacis et haute terrasse				

phase of local dune formation e.g. the small dunes of the second erg in Mali which are irregularly orientated N-S and may form "cornes de croissants" on top of the longitudinal dunes (Blanck, 1968), the new dunes on lacustrine deposits (in their turn overlying older dunes) in the Aklé area northwest of Timbuktu (Urvoy, reported by Grove, 1958), and the small dunes of the recent erg of Senegal (SEDAGRI, 1969). They are called variously "yellow dunes", "recent erg", "third erg" (Pias) and "aklé" (pl. "akeile",

LOWER NIGER (Buser 1966; Higgins 1968)		CHAD BASIN (Unesco 1969; Pias 1968; Servant 1969)	estim. age B.P. (various authors)	marine trans/ regressions (Elouard 1969)	European sequences	
(Belle)	Niger floodplain deposits	present lake-level and presentday erg (>16°N, slouk, barkhans)	0		Sub atlanticum	Holocene
			1 000			
		lake-level 287-290, 4th Chari-delta, subactual clayey and alluvial series	1 800			
			3 200		Subboreal	
		third erg (>12°N)	4 500	Taffolien regr.		
			5 500	Noakchottien tr.	Atlanticum	
Egbunge)		lake level 320, 3 rd Chari-delta, recent clayey series	7 300		Boreal / pre-Boreal	
(Brung)			11 600			
Fanagun)		second erg (> 12°N, Kanem)			Weichselien	Pleistocene
T5 terrace, 3-10 m + sands and clays		lake levels 400-370-350, old fluvio-lacustrine series (2 nd Chari-delta?)				
T4' terrace, 15-20 m + ands with little gravel						
		first erg (> 10°N)	15 000	Ogolien II regression		
T4 terrace, 30-35 m + non-cemented gravel		lake level 400, 1 st Chari-delta, reworking of older deposits	20 000 / 40 000	Inchirien transgression	?	
?		? erg du Manga (?) ?	100 000	Ogolien I regression	Eemien / Saalien	
T3 terrace, non-cemented gravel ?			200 000	Aïoujien	Holsteinien	
?			300 000	Akcharien	Elsterien	
T2 terrace, consolidated gravel ?			500 000 / 700 000	Tafarien	Cromerien	
?			900 000		Menapien	

MONOD). They should date from a brief and not very extensive arid period that must have occurred somewhere between 8,000 and 4,000 BP. More precisely, the period would be contemporanous with the pre-Flandrien/Taffolien regression (SERVANT, 1969; GAVAUD, 1968) immediately following the well-dated Noakchottien transgression of 5,000-6,000 BP (BOULET, GUICHARD and VIEILLEFON, 1971). Comparison of our mapping pattern in the Illela area with those of BOULET, BOCQUIER and GAVAUD (1965) in the area of Birni n'Konni-Taoua (Maradi sheet of Niger Republic) does suggest that their series Dan Gona i.e. "sols ferrugineux lessivés en fer typique sur sables éoliens" and especially their "sols ferrugineux non-lessivés typiques sur sables éoliens" also belong to this phase of dune (de)formation, though Boulet c.s. still group these units with the "ergs anciens".

In contrast to the Sokoto and Illela coversands, only little mention is made of Sangiwa-like dune fields. GROVE (1958), however, reports them for the area south of Maiduguri and Azare in NE Nigeria and CLAYTON (1966) for the Gummi area (which is inside our survey area). A good part of the "erg anciens" of BOCQUIER, GAVAUD and BOULET in Niger republic and Upper Volta — including a large part of their "formation sableuse du moyen Niger", with its reticulated vegetation pattern — should be comparable to the Sangiwa type.

MONOD (1958) has reported similar patterns for the Mreyyé area of central Mauretania: low mounds or long undulations of a few meters relief, hardly detectable on the ground, wave length 200 m, orientated NNW-SSE, compacted sands.

They are therefore called "mreyyé" (pl. "mereïe") by GROVE. Their age is uncertain, since they do not figure in the schemes of PIAS, MICHEL etc. In our very tentative scheme of Table 8 we suggest an age of Ogolien I. [1]

Two other types of dunes, which have not been found in the Sokoto area, are reported in several countries, one of these types being the large and prominent fields of fixed transverse dunes with high relief (40-50 m), occurring directly northeast of the present Lake Chad, their bottoms locally flooded or covered with lacustrine clays (Kanem, second erg of PIAS, 1968). Similar red and high transverse dunes are reported for the Aouker area about 700 km west of Timbuktu in Mauretania (GROVE and WARREN, 1968). They would be older than the Illela dunes, younger than the Sokoto dunes, and therefore possibly following the Rabah, Zazagawa and Argungu fluviatile deposits, or dating from a dry spell between these depositions. The mobile dunes in the living ergs north of the present Sahel zone seem to be mainly longitudinal, but more slender, less regular,and less continuous than the alâb; they are sometimes called "silk" (pl. "slouk").

8.2 The river terraces and floodplain deposits

With the Ambursa and Illela deposits dated, the calculations of chapter 7.4, Stage 10 for the youngest fluviatile deposits in the Sokoto area (Kurukuru and Gande micaceous systems) seem to be reasonable: at least 2,000-3,000 years of sedimentation is in line with the dating of the last arid period (Illela). For both Chad and Senegal, minor oscillations of geomorpho-dynamic activity due to changes in climate in the last 5,000 years are reported (cf. also BUTZER, 1966). The fourth lacustrine transgression of Chad (3200-1800 BP, PIAS, 1968) may coincide with a sedimentation interval between the older and the younger Kurukuru deposits. The younger ones, terrace-like, would be related to a somewhat drier spell between 1800 and 1000 BP.

[1] The correlations of Ogolien I and Inchirien with the North European glacials and interglacials are left open in the scheme of Table 8. Assuming a correlation between glacials and interpluvials, the sequences would suggest the Inchirien to coincide with the Eemien, and the Ogolien I with the Saalien. However, this is not in accordance with the available absolute datings. If these are correct, a correlation of the Inchirien with an early Weichselien interglacial would be more likely. The Sangiwa sands would be early Weichselien in that case. A pluvial correlating with the Eemien would be missing, then.

More problematic is the correlation with findings elsewhere of the Sokoto river terraces and older floodplain deposits (high-terrace, main-terrace, low-terrace, floe deposits, park deposits — all separated by a phase of incision of the riverbeds).

River terraces are known for the Senegal river basin, where incision is directly linked to low sea levels (MICHEL, 1970, SEDAGRI, 1969). Before the formation of the red dunes, here two relatively old and cuirassed erosion surfaces and accompanying terraces had formed, as well as a non-cuirassed gravelly low terrace, which would date from the Inchirien marine transgression of 40,000-30,000 BP (?). This gravelly low terrace seems equivalent to the Tureta wash-plain c.s. (though comparison with the Chad data would point to 50,000 BP for this deposit — see chapter 8.3). Apart from a subsequent "alluvionnement" with fluviatile clays during a very humid climate, i.e. the Ambursa equivalent, there is only one valley filling ("premier remblai") in the period between the red dune formation and their transformation into yellow dunes. This valley filling will have been transformed into a terrace at the end of the Late Würm (low sea level) and may be equivalent to the Zazagawa and/or Argungu deposits. A second "remblai sableux", if laid down after the yellow dune period, may be equivalent to the terrace-like Kurukuru micaceous deposits of Sokoto, but may also be older (MICHEL, by letter).

For the Middle Niger and its fossil tributaries like the Tilemsi, several erosion surfaces and associated terraces are reported. BLANCK (1968) noted for the area Timbuktu-Niamey: a) two Early Quaternary cuirassed formations "en étages", being either "glacis" (= erosion surface) or "remblai" (= accumulation surface), b) one younger, non- or only partly, cuirassed glacis-terrace before the red dune formation (∾ Sokoto dunes), c) only one "high terrace" between the red dune and the yellow dune formation (∾ Illela dunes). BOULET et al. (1966), however, in their report on the soil survey of the south-west of Niger Republic (sheet Niamey), mention, for the Niger River between Say and Gaya (confluence with the Dallol Maouri), a sequence remarkably comparable to the Sokoto-Rima situation (the scale of the survey not permitting separate mapping):

— "flat argileux", consisting of black or gray silt-poor clays (∾ Ambursa),
— "depots meubles de terrasse", only partly flooded, 1-4 m above the flat argileux and consisting of: a) clayey fine sands and fine sandy clays, compact and partly alkaline (∾ Diggi), b) grey or yellow coarse sands (∾ Argungu) and c) reddish fine (?) sands (∾ Zazagawa).
— "niveau inférieur" of medium sands, 8-10 m above high-water (∾ Rabah),
— "niveau supérieur" of fine sands, 15-17 m above high-water (∾ Tureta).

Similar sequences are mentioned for two fossil northern tributaries, although in the Dallol Bosso ("association de Azouak") Diggi-like sediments are lacking, while in the Dallol Maouri, neither Diggi nor Ambursalike deposits are present. The Ambursa-like deposits in the Azouak association ("argiles de décantation") are supposedly derived from Cretaceous clays, far to the north (> 350 km). This fits perfectly with the conclusions for the Sokoto area.

If we now compare the Sokoto findings and those of BOULET with those of VOÛTE (1962) and BUSER (1964) for the Benue and the lower Niger River in Nigeria, we seem to have a possibility of dating the fluviatile deposits. VOÛTE gives the first outline of the various land surfaces along these rivers and of the thickness of the fluviatile sediments. The presence of deeply buried valleys forms a normal feature of these rivers, proving the influence of eustatic sea-level variations. Taking a synchronism of pluvials, glaciations and low sea levels as his basic principle, VOÛTE concludes that the upper terraces in the Niger-Benue valleys, e.g. those of 50 m alt. and 100-110 m alt. near Onitsha, were formed between the Kamasian (∾ Mindel ∾ Pluvial II) and the Kanjeran

(∾ Riss ∾ Pluvial III). The middle terraces, e.g. the 30-35 m alt. one at Onitsha, would have been formed between the Kanjeran and the Gamblian (∾ Würm ∾ Pluvial IV); the lowest terraces, e.g. 22-24 alt. near Onitsha, between the Gamblian and the Nakuran.

In the stretch between Yelwa (some 100 km downstream of the confluence of the Rima-Sokoto system) and Lokoja (at the confluence of the Benue) BUSER found six river terraces:
T1: highest level, consisting of conglomerates with ferruginous cement.
T2: level of 50-250 m⁺ (i.e. above the presentday river), characterized by consolidated gravel beds.
T3: level of 35-170 m⁺, very extensive and characterized by non-cemented gravel beds.
T4: like T3 but at a constant level of 30-35 m⁺.
T4′: constant level of 15-20 m⁺, consisting of sands with very little gravel.
T5: constant level of 3-10 m⁺, consisting of sands and clays without any gravel.
The first three terraces would have been formed when a barrier (sill) of Cretaceous sandstone still existed at Lokoja; their levels would therefore reflect former lake-like conditions of the Niger rather than following the level of the presentday Niger course as is the case for the latter three, when the still had been worn down. Like VOÛTE, BUSER assumes that erosion, causing incision, took place during pluvials; accumulation, ultimately causing terrace formation, took place during interpluvials. Pluvials would, moreover, coincide with the European glacials (see discussion below). The T1 level would be of Tertiary Age, the T2 of the Cromerien interglacial, the T3 level of the Holsteinien interglacial, the T4 of a Weichselien (Würm) interstadial and the T5 of Early Holocene age. Archeological findings in the T4 terrace confirm a Sangoen age.

Surveys by NEDECO (1961) and HIGGINS (1968) have shown that the Niger floodplain itself has a complex composition as well. Personal observations at Bacita Sugar Estate (downstream of Jebba) in 1971 revealed a strong similarity between the Niger floodplain deposits and the younger aqueous deposits of the Rima-Sokoto system. With the HIGGINS groupings shown in parentheses, the floodplain at Bacita consists of:
a) non-flooded terrains with medium to coarse sands without micas; flat if not eroded; permeable Acid Sand soils ("Fanagun sand bank").
b) little-flooded terrains with slightly micaceous very fine sands, loams, and clays; irregular meso-relief; often Alkali soils ("Brung").
c) flooded terrains with silt-poor clays; flat; Vertisol-like soils (parts of "Egbungi").
d) flooded terrains with strongly micaceous very fine sands, loams and silty clays ("Belle").
The similarity with the Sokoto sequence, namely a) Argungu, b) Diggi, c) Ambursa and d) Kurukuru/Gande, is apparent. Even the heavy mineral associations seem rather comparable (Table 3).

As regards the terraces, the stretch Bagudo-Yelwa should also be studied to establish beyond a doubt the correlation with the Rima-Sokoto terraces. It seems likely, however, that BUSER's T5 level can be compared with the Zazagawa + Bagudo low-terrace, his T4′ level with the Rabah main-terrace, and his extensive T4 level with the Tureta washplain and high-terrace associates.

In view of the discussion in Chapter 7.5, VOÛTE's and BUSER's suppositions as regards the correlation of glacials and pluvials and the interpluvial age of all terrace deposits seem too simplistic (cf. also the criticism of MICHEL, 1969). If we assume, however, that pluvials would correlate more with interglacials, and that at least a part of accumulation also took place in the pluvials or at least in transitional periods, the dating of VOÛTE and BUSER could be not far from the truth. Anyhow, it does indeed seem logical to assume that the three younger levels of BUSER, apparently having the ocean as base level, were incised during the most recent glaciation (Weichselien), under the influence of a stepwise lowering of the sea level.

For the Hadejia river area in the western part of the Chad basin, no river terraces are reported. PULLAN (1962, 1969) mentions only an older and a younger floodplain, both slightly below the level of the longitudinal dunes (Sokoto-like red dunes). The older floodplain seems comparable to the Diggi park deposits, the younger with the Kurukuru-Gande micaceous deposiits. For the Kano river area located, within the Crystalline basement area west of PULLAN's Hadejia region, at least one terrace is known, but mapping in this area has only just started.

8.3 Regional comparison of absolute ages

An attempt to correlate the Sokoto valley fillings with the various Chari deltas directly south of Lake Chad seems interesting (UNESCO 1969, PIAS 1968) [1]. Assuming, as before, that the third lacustrine transgression of Chad — lake level 320 — coincides with the Ambursa lacustrine deposits of the Sokoto area, then also the third delta should be of Ambursa age. The first delta, coinciding with the first lacustrine transgression — lake level 400; 50,000 BP? — was formed before PIAS's first erg, which should be equivalent to the Sokoto coversands of longitudinal dunes. The Tureta sandy wash-plain, and associated high-terrace deposits (Bakolori-Gusau) preceding these coversands in the Sokoto area, may therefore be contemporaneous with the first Chari delta. For the time of the second lacustrine transgression of Lake Chad — lake level (400-) 370-350; 20,-30,000 BP, and succeeding the first erg — PIAS mentions an old fluvio-lacustrine series which seems the same as UNESCO's second Chari delta. These deposits may coincide with the Rabah-Talata-Kaura main-terrace deposits of the survey area. They might, however, also be compared with both the Rabah main-terrace, the Zazagawa low-terrace, the Argungu floe and even the Diggi park deposits, because no other depositions are mentioned for the Chad basin between those of the second transgression and the third Chari delta (of Ambursa age).

This correlation cannot, however, hold good as regards absolute dating. Whilst the first erg of longitudinal dunes should be of the Ogolien II regression (15,-20,000 BP) of Senegal, the younger second Chad lacustrine transgression would date from 20,-30,000 BP! This apparent basic discrepancy in absolute chronology between Chad and Senegal has not been solved by the authors.

From this comparison of the Sokoto findings with neighbouring areas, it may be concluded that its aeolic deposits fit into a general pattern.

The sequence of aqueous deposits of the Sokoto areas has a more restricted occurrence. The full range seems to occur along the middle and lower Niger River between Niamey (Niger Republic) and Lokoja (Nigeria), and an incomplete range along the fossil tributaries in Niger Republic viz. the Dallols Maouri and Bosso. The Sokoto sequence of aqueous deposits shows at least a degree of correlation with the various deltaic and lacustrine deposits around Lake Chad.

[1] The data on shorelines and deltas around the present Lake Chad on the sketchmap of Fig. 25 are copied from the UNESCO maps. Comparison with PIAS' maps shows that his Deltas 2 and 3 are identical with UNESCO's Deltas 3 and 4. It also seems that PIAS'S first delta is contemporaneous with lake level 370-350 rather than with that of 400.

The comparisons made allow a generalized map and a correlation table to be presented (Fig. 25, Table 8). It should be stressed that both map and table are very tentative. The position in the table of the various Chad deposits is particularly uncertain. C^{14} datings and paleopedological observations from the survey area itself, further comparison with studies in neighbouring areas, and particularly personal exchange of information would considerably enhance the reliability of the correlations and add to the insight into the Quarternary geomorphodynamic-climatic history of the Sahara-West Africa transitional zone.

9. SOME APPLICATIONS FOR LAND DEVELOPMENT

The mainly geomorphological study described in this paper was not a separate entity. As mentioned in the Introduction, the information was gathered as a basis for mapping and evaluating the land of the area for agricultural development. As in most reports to be used by development planning authorities, the scientific considerations at the basis of the various surveys (climate, hydrology, geology, topography, soils, vegetation, land use) either do not occur in the official report on the project or do so in a very abbreviated form. This prompted the authors to decide on a separate elaboration of the geomorphologic features and history of the area. The data, set out systematically, may contribute to the advancement of knowledge of the geomorphodynamic-climatologic history of sub-Sahara West-Africa. At the same time, the study has a number of practical applications, which will be described in brief.

9.1 Speeding-up of land and soil surveys

In modern land and soil surveys, making full use of aerial photograph interpretation, delineation of landforms is one of the main mapping tools. This holds true particularly if the approach to the survey is physiographic; in that case the framework of the mapping legend is composed principally of landforms along with some other readily recognizable physiographic elements, like flooding conditions and vegetations. But even when mapping on a soilprofile morphometric/taxonomic basis, one must be able to recognize the various landforms if one is to use aerial photographs exhaustively. Soils and landforms are intimately related, but only the latter can be seen on photos. Landforms, in their turn, can only be satisfactorily delineated and subdivided as to their pedological significance, if one knows the geomorphologic history of the area. At the start of a survey, therefore, it seems sensible to devote even substantial time to unveiling this history. The seemingly "lost" time at the start will be more than recompensed by the more rapid, more reliable, and more comprehensive mapping during the main part of the survey.

This holds true for reconnaissance surveys as well as for more detailed surveys. An example is provided by the semi-detailed surveys of most of the floodplains in the area under study (300,000 ha). Once the geomorphologic composition and history was sorted out in a few well-chosen sample areas (Wurno, Argungu), the survey of all other floodplain areas became relatively easy, nearly routine. This was only possible, of course, because field observations were chosen in strict accordance with a preceding photo interpretation that took full account of the geomorphologic history. If a rigid grid system were to have been applied for this floodplain survey (as initially insisted upon by the project management), it would have been taken much longer and its accuracy and interpretative value would have been far inferior.

Reconnaissance or detailed soil surveys in neighbouring areas of known, or surmised, identical geomorphologic history and source of deposits can also draw much benefit from this basic knowledge. An example is the (semi) detailed survey of the Niger floodplain between Jebba and Lokoja, for the establishment of estates for commercial sugarcane production. Now that a strong similarity has been revealed between the geomorphologic history of this area and that of the Rima-Sokoto system (page 96), it should be possible, for instance, to delineate quickly and reliably those floodplain parts with sodic features (Diggi park deposits, Brung). Such features have presented unexpected, and therefore very costly, hindrances to the realization of the Bacita sugar estate (breaking of machinery, instability of irrigation channels, poor yields).

9.2 Extrapolation of geological and hydrological observations

The evaluation of the geological, and especially the *hydrogeological aspects* of development in an area can draw with much advantage on the knowledge of the geomorphologic pattern and history because it allows extrapolation of the data of relatively few boreholes Involved here are not only the expected occurrence of stable basis and building materials for roads, dams, and other major engineering works, but also delineation, use, and potential of aquifers. An example is the UNESCO study on the hydrogeology of the Lake Chad basin. It made ample use of geomorphologic-pedologic features and their history — including the various coversands with their differential hydrologic behaviour — in arriving at a comprehensive evaluation of the groundwater potential and recharge in the Chad basin.

The evaluation of *surface hydrology,* too, can benefit from the geomorphologic features and their history. Run-off and erosion measurements can be extrapolated, and the different sediment loads between hydrological stations along the floodplains can be correlated with sedimentation patterns. In fact, the immediate reason for starting the FAO project for the Sokoto valley area was the observation (LEDGER, 1961) that at some sites (Isa, Wurno, south of Sokoto town) the riverine erosion and sedimentation seemed to deteriorate rapidly (splays, pointbars, bank scouring), which was attributed to accelerated erosion in the upper catchment due to acute overgrazing and over-cultivation. The unravelling of the sedimentation history in the floodplain, however, has shown that these riverine processes are inherent features of a type of sedimentation that has been in progress for several thousands of years, though the processes may be increasing in strength nowadays (page 84).

A sound knowledge on the sedimentation characteristics in the different sections of the main Rima-Sokoto floodplains can be of much advantage at the construction and upkeep of the various small irrigation schemes envisaged or already realized. The existing Wurno polder, for instance, is located precisely at an active sedimentation "front".

9.3 Facilitation of detailed irrigation and drainage planning

The physiographic approach to the soil survey in the floodplains and associated terraces, and the conclusions derived as regards geomorphologic composition and history, should be of substantial help in the detailed design of irrigation schemes in the areas, whether as polders or otherwise.

Within the restricted time allotted for the survey, this approach came nearest to answering the original government demand that the maps produced could be used directly for design at farm level.

When detailed topographical maps are being compiled for canal lay-out, due account should be taken of the relation: physiographic soil mapping unit — height above/below flooding. A limited number of geodetic survey lines in the floodplains — the measuring points accurately identified on aerial photographs — will then allow reliable contour maps to be drawn, with intervals sufficiently small (1-2 feet) to allow even the design of the tertiary network of irrigation and drainage channels. How the inherent presentday land pattern of the various deposits should be taken into account is illustrated by the following: In areas without active sedimentation like the Argungu area (Maplet *b* of Appendix 2) the various river channels normally flow through the topographically lowest parts (often units of the Ambursa central system), without any natural levees alongside the channel. Extrapolation lines of geodetic survey points can therefore either disregard these channels or should curve gently upstream. In areas with active sedimentation like the Sokoto town area (Maplet *a* of Appendix 2) river channels normally flow through the topographically highest parts because of the formation of levees and splays alongside the channels. In this case the extrapolation lines of geodetic survey points should curve substantially downstream when nearing a river channel.

Other irrigation design criteria, too, such as infiltration rates, soil storage capacity, need for canal lining, feasibility of levelling etc., can and should be strictly related to the physiographic pattern.

A knowledge of the geomorphological build-up of the floodplains can greatly speed up and improve *drainage studies* (survey of the extent of the drainage problem, study of its causes, establishing the drainability of the terrains). Actual flooding conditions, actual or expected areas of seepage, the occurrence of impermeable layers, the thickness and horizontal extent of layers suitable for subsoil drainage, the degree of subsidence through physical ripening, etc., are all aspects that should be studied in geomorphological context.

The FAO project has indeed resulted in the design of a number of major floodplain polders — for flood protection, drainage, and irrigation — on the basis of the semi-detailed physiographic soil maps.

9.4 Guidelines for soil conservation and improvement

The insight obtained into the history of the various sediments allows predictions to be made as to the behaviour of their soils under different management, thus permitting specific trials.

An example is the differential degree of *surface sealing* of the various sandy deposits, while other soil characteristics and properties may be the same. For the strongly sealing sands (Rima sands, Sangiwa coversands) it is highly unlikely that rain-fed arable crops or pastures can be established. Without expensive soil improvement measures like green manuring, cover crop growing, and frequent tillage, these soils will always be prone to sealing, will be unable to admit substantial parts of the rainfall and will always have substantial sheet erosion. In contrast, the slightly or non-sealing sands (Sokoto coversands, various river-terrace deposits) can be used agriculturally with little or no effort. The same difference applies to re-afforestation, as borne out by trials of the Government Forestry Department. Re-afforestation trials with the normally easily grown Neem tree (*Azadirachta* sp.) have been very successful on non-sealing sands, but a failure on the sealing sands, even after elaborate trials on planting techniques, mulching, tillage etc.

The fact that there are similar types of sediments of different ages, and therefore different soils, allows conclusions to be drawn on trends and speed of *soil formation* and *soil deterioration*, agronomically speaking, under natural conditions. This, in its turn, helps to predict hazards of soil deterioration under artificial conditions, notably irrigated agriculture. One example will illustrate this: The sequence of Bagudo low-terrace deposits, Diggi park deposits, Kurukuru micaceous deposits, Gande micaceous deposits, concerns meandering river deposits of approximately identical pattern (levees and basin lands) and identical composition (very fine sand and silt-rich micaceous sediments derived

largely from Crystalline basement materials). Their age ranges from the Late Würm to the present, a period of about 12,000 years. The following aspects of pedogenetic weathering, soil profile formation, and agronomic deterioration are more and more apparent with increasing age:
— the micro-stratification disappears and the macro-stratification becomes diffuse,
— the physical ripening of the clay becomes complete,
— the porosity decreases (increased compaction) and the effective moisture storage capacity is less,
— a concentration of organic matter in the topsoil (A1 horizon) takes place,
— a subsoil horizon of illuvial clay accumulation (B horizon) develops, especially when heavy textures are concerned (basin lands),
— concurrently sodium accumulates in the subsoil, especially when lighter textures are concerned (levees),
— the soil surface becomes prone to sealing,
— the hydromorphic character of the soil profile becomes more pronounced (lower values for matrix colour, more mottling, more Manganese concretions),
— the chemical activity of the clay fraction decreases. In the light texture range the decrease in cation exchange capacity is from 60-55 m.e. (M1 and M2 units), via 50 (M3), 46(M4) and 48(P1), to 35-20 m.e. (Bagudo); in the heavy texture range the decrease is from 45-50 m.e. (M5, M6), via 42 (P2), to 35-20 m.e. (Bagudo),
— the mica content in the soil samples decreases,
— the silt content decreases (silt/clay ratios decreasing from 1.0 to 0.5 for the heavy textures).

Under intensified agricultural use, notably irrigation without adequate management measures like (subsoil) drainage, the above processes of apparent deterioration are likely to speed up substantially. Indeed, the presently favourable Juvenile soils (notably Units M1 to 3) of several minor government irrigation schemes are showing signs of structure decline and strong salinization after only a few years of use (strong capillary rise in the very fine sands and loams). Though such salinity may be overcome by several years of systematic leaching, the sodium component apparently tends to remain in the soil profile with further deterioration of soil structure as a result.

Therefore deep drainage right from the start of any irrigated agriculture on the micaceous sediments is of paramount importance.

Even the identification of the various *plinthite levels* and the determination of their ages have a direct practical significance (apart from speeding up the soil and hydrological surveys). The recognition that they are all pre-Quaternary [1] implies that none of the climates of the Pleistocene and the Holocene, including the presentday type, are apt to induce any plinthite formation. The conclusion that irreversible deterioration of the land through plinthite formation — "laterisation", of frequent occurrence in the more humid tropics — is not a hazard in the area surveyed, constitutes an important over-all consideration for land management.

[1] Unless the un-covering of old levels by accelerated erosion is concerned.

ACKNOWLEDGMENTS

The authors wish to express their thanks to the Federal Nigerian Government and the Food and Agriculture Organization of the United Nations (FAO) for their permission to publish the data assembled during their participation in the UNDP/FAO Sokoto Valley Project (NIR. 3).

Thanks are also due to the Federal Survey of Nigeria (Lagos) for its permission to print some aerial photographs, to the Ministry of Agriculture and Natural Resources of the Nigerian North-West State for its willingness to supply information on recent studies, and to the Geological Survey of Nigeria (Kaduna) for supplying data from unpublished geological maps, cross-sections and boreholes.

The authors are indebted to the Netherlands Soil Survey Institute (STIBOKA, Wageningen) for its willingness to draught text figures and appendices and to publish the paper as a whole, and to the International Institute for Land Reclamation and Improvement (ILRI, Wageningen) and the International Institute for Aerial Survey and Earth Science (ITC, Enschede) for allowing them to make use of facilities in writing and editing the paper.

Personal thanks are due to Dr. A. Jongerius (STIBOKA, Wageningen) for his micromorphological analysis of the sealing sands, and to Miss Dr. B. J. Sira of the Institute for Anthropobiology of the Utrecht University for her examination of pottery fragments. Valuable help and many constructive comments were given by various present or former members of the Institute for Agricultural Research of Zaria, Nigeria, of whom particular mention should be made of Messrs. K. Klinkenberg and P. N. de Leeuw. The same applies to Prof. Dr. G. C. Maarleveld (STIBOKA, Wageningen), Mr. P. Michel, Université Louis Pasteur, Strasbourg and Prof. Dr. H. Th. Verstappen (ITC, Enschede).

Above all, the authors wish to thank both the expatriate staff of the UNDP/FAO team for their friendly companionship, and the Nigerian counterpart staff of the Irrigation Department of the former Ministry of Agriculture of Northern Nigeria for their invaluable contribution to a smooth and pleasant execution of the project activities. Particular mention should be made of the other senior staff members of the soils team: Messrs. J. Dewis, K. Bhattacharyya, J. Doorenbos, R. J. M. Crul and Mallam Abdullahi Bauchi, and the junior staff members: Mallams Umaru and Basira, and Messrs. Moses Wende, Tom C. Crane, Yakubu Alabi, Johnson W. Ojuola, Joshua A. B. Luyomi, Stephen Okpe, Cyril Daudu, Paul Osapinla and David Umuela.

The remembrance will always be cherished of the general kindness and hospitality of the proud peoples of Haussaland, both in the towns and in the most remote hamlets and fields, which made the authors' stay in the country such a great experience.

REFERENCES

AUBERT, G. 1965 Classification des sols. Tableaux des classes, sous-classes, groupes et sous-groupes de sols utilisés par la section pédologie de l'ORSTOM. Cah. ORSTOM, Série Pédologie *3* (3).

BAWDEN, M. G., D. M. CARROLL and P. TULEY 1968 North-East Nigeria Project. Preliminary descriptions of Land Systems. D.O.S. Land Resources Division, London. 250 pp. - maps.

BERNARD, E. A. 1962 Interprétation astronomique des pluviaux et interpluviaux du Quaternaire africain. Actes 4e Congr. panafr. de Préhist. et de l'Etude du Quaternaire. Léopoldville 1959: 67-95.

BISHOP, W W. 1962 Pleistocene chronology in East Africa. Advanc. Sci. *75:* 491.

BLANCK, J. P. 1968 Schéma d'évolution géomorphologique de la vallée du Niger entre Tombouctou et Labbezanga (Rép. du Mali). Bull. ASEQUA *19-20:* 17-26.

BOCQUIER, M. and M. GAVAUD 1964 Etude pédologique du Niger Oriental. Rapport général, Tôme I et II; Carte pédologique de reconnaissance 1 : 500.000, feuille Zinder. ORSTOM, Dakar-Hann.

BOULET, R. 1964 Etude pédologique du Niger Central. Rapport général; Carte pédologique de reconnaissance 1 : 500.000, feuille Maradi. ORSTOM, Dakar-Hann.

BOULET, R. 1967 Nouveaux arguments en faveur de l'existence de deux ergs d'âges différents dans la zone sahéllienne de l'Afrique occidentale (Haute Volta). Actes 6e Congr. panafr. de Préhist. et de l'Etude du Quaternaire. Dakar 1967.

BOULET, R., M. BOCQUIER and M. GAVAUD 1965 Etude pédologique du Niger Occidental. Rapport général, Tôme I, II et III; Carte pédologique de reconnaissance 1 : 500.000, feuille Niamey. ORSTOM, Dakar-Hann. 6500/283.

BOULET, R., E. GUICHARD and J. VIEILLEFON 1971 Observations pédologiques et leur rélation avec les faits géomorphologiques dans le delta du Sénégal. Comparaison avec les observations effectuées au Niger. Bull. ASEQUA *29:* 99-110.

BUTZER, K. W. 1961 Climatic change in arid regions since the Pliocene. In: Stamp, L.D. History of land use in arid regions. UNESCO, Paris, p. 31-51.

BUTZER, K. W. 1966 Climatic changes in the arid zone of Africa during early to mid-Holocene times. In: World climate from 8000 to 0 BC. Royal Meteorological Society, London.

BUSER, P. 1964 Der Einfluss von Paläostrukturen auf die Entwicklung der Entwässerungssysteme West-Afrikas und die Quaternärgeschichte des Niger-Benue Stromgebietes. Z. der deutschen geol. Gesellschaft, Hannover *116* (3): 651-674.

CLAYTON, W. D. 1966 Vegetation ripples near Gummi (Nigeria). J. Ecol. *54:* 415-417.

CROMMELIN, R. D. 1964 A contribution to the sedimentary petrology and provenance of Young Pleistocene coversand in the Netherlands. Geologie en Mijnbouw *43* (9): 389-402 (Also: Boor en Spade *14:* 138-151, 1965).

D'HOORE, J. L. 1964 The soil map of Africa at 1 : 5.000.000. Explanatory report and map sheets. Commission for Technical Cooperation in Africa CCTA. Interafrican Pedological Service Joint Project no. 11 publ. *93*. Lagos. 209 pp.

DUDAL, R. 1968 Definitions of soil units for the soil map of the world. FAO/ UNESCO World Soil Resources Report *33*, Rome.

ELOUARD, P., H. FAURE and L. HEBRARD 1969 Quaternaire du littoral mauritanien entre Nouakchott et Port Etienne. Bull. ASEQUA *23:* 15-24.

FAO 1969 Soil and Water Resources survey of the Sokoto Valley, Nigeria; Final Report Volume 5: Soil Survey and land classification. FAO/SF: 67/NIR 3.

FAUCK, R. 1965 Traces d'influences paléoclimatiques dans les sols d'Afrique Occidentale Bull. ASEQUA *5-6:* 23-25.

FAURE, H. 1966 Evolution des grands lacs sahariens à l'Holocène Quaternaria *8:* 167-175.

FAURE, H 1967 Une importante période humide du Quaternaire supérieur du Sahara. Bull. Inst. fr. Afr. noire, A, *29* (2): 851-852.

GAVAUD, M. 1957 Interprétation chronologique des systèmes de sols des dunes fixées du Niger Méridional. Actes 6e Congr. panafr. de Préhist. et de l'Etude du Quaternaire. Dakar 1967.

GAVAUD, M. 1967 Esquisse de l'histoire des sols du Niger centre et ouest méridional. Bull. ASEQUA *14-15:* 24-27.

GAVAUD, M. 1968 Les sols bien drainés sur matériaux sableux du Moyen-Niger. Essay de systematique régional. Cah. ORSTOM, Serie Pédologie *6*, 3-4.

GREIGERT, J. 1966 Descriptions des formations crétacées et tertiaires du bassin des Iullemmeden. Carte géologique „Le Bassin des Iullemmeden" 1 : 1.000.000. Publ. Dir. Mines et Géol. no. 2. Rep. du Niger.

GREIGERT, J. and R. POUGNET 1967 Essai de description des formations géologiques de la République du Niger. Mémoires du Bureau de Recherches Géologiques et Minières. *48*, 236 pp.

GROVE, A. T. 1958 The ancient erg of Hausa land and similar formations on the south side of the Sahara. Geogr. J. *124* (4): 528-533.

Grove, A. T. and R. A. Pullan 1963 Some aspects of the Pleistocene paleogeography of the Chad basin. In: Flowell, F.C. and Bourlière, F. (editors): African Ecology and Human Evolution. Publs. Anthrop. Viking Fund, *36:* 230-245. Also: Samaru Miscellaneous Papers *4.*

Grove, A. T. and A. Warren 1968 Quaternary landforms and climate on the southside of the Sahara. Geogr. J. *134:* 194-208.

Higgins, G. M. 1968 Soils and related surface phenomena near Bacita. Samaru Research Bull. *88,* Zaria, Nigeria (Also: Niger. J. Sci. *1:* 205-215).

Johnston, H. A. S. 1967 The Fulani empire of Sokoto. Oxford University press, London. 310 pp.

Jones, J. B. 1948 The sedimentary rocks of Sokoto Province. Geological Survey of Nigeria Bull. 8.

Keay, R. W. J. 1959 An outline of Nigerian vegetation. Federal Government Printer, Lagos.

King, L. C. 1962 The morphology of the earth. Study and synthesis of a world scenery. Oliver and Boyd, Edinburgh.

Klinkenberg, K. and G. M. Higgings 1968 An outline of Northern Nigerian soils. Nig. J. of Science *2* (2): 91-115.

Ledger, D. C. 1961 Recent hydrological change in the Rima basin, Northern Nigeria. Geogr. Journal *27* (4): 477-487.

Leneuf, N. and G. Aubert 1960 Essai d'évaluation de la vitesse de ferralitisation. 7th Intern. Congr. Soil Science, Madison USA *5* (31).

Maarleveld, G. C. and R. P. H. P. van der Schans 1961 De dekzandmorfologie van de Gelderse Vallei. Tijdschr. Kon. Ned. Aardrijksk. Gen. *78* (1): 22-34.

Michel, P. 1969 Les grandes étappes de la morphogénèse dans les bassins des fleuves Sénégal et Gambie pendant le Quaternaire. Bull. Inst. fr. Afr. noire, A, *31* (2): 293-324.

Michel, P. 1970 Chronologie du Quaternaire des bassins des fleuves Sénégal et Gambie, Essai de synthèse. Bull. ASEQUA *25:* 53-64, Bull. ASEQUA *26.*

Michel, P. 1969 Les depôts du Quaternaire de la vallée intérieure du Niger, d'après H. Buser. Bull. ASEQUA *21:* 55-57.

Monod, T. 1958 Majâbat al-Koubrâ. Contribution à l'étude de l'Empty Quarter ouest Saharien. Mémoire Inst. fr. Afr. noire *52:* 141-150.

Monod, T. 1963 The Late Tertiary and Pleistocene in the Sahara and Adjacent Southerly Regions. p. 117-229 of "African Ecology and Human Evolution". Viking Fund Bulletin in Anthropology 36 (Howell, H. C. and F. Bourliere ed.).

NEDECO 1961 Niger Dams Project. Part 7, Irrigation and Agriculture. Nedeco, The Hague and Balfour Beatty & Co., London, Report to the Government of Nigeria.

PIAS, J. 1967 Chronologie du depôt des sédiments tertiaires et quaternaires dans la cuvette Tchadienne. C. R. Ac. Sc. Paris. Série D. *21*. 2432.

PIAS, J. 1968 Contribution à l'étude des formations sédimentaires tertiaires et quaternaires de la cuvette Tchadienne et des sols que en dérivent. Cah. ORSTOM, Série Pédologie *6* (3-4): 367-378.

PIAS, J. 1970 Caractérisation de paléosols de la cuvette Tchadienne. Bull. ASEQUA *25:* 23-37.

PONS, L. J. and I. S. ZONNEVELD 1965 Soil ripening and soil classification. Initial soil formation in alluvial deposits and a classification of the resulting soils. Intern. Inst. for Land Recl. and Improvement. Publ. *13.*

PULLAN, R. A. 1962 A report on the reconnaissance soil survey of the Nguru-Hadeija-Gumel area. Bull. *18* Soil Survey Section, Ministry of Agriculture, Northern Region, Nigeria.

PULLAN, R. A. 1964 The recent geomorphological evolution of the south-central part of the Chad basin. J. West African Sc. Ass. *9* (2): 115-139.

PULLAN, R. A. 1969 The soil resources of West-Africa. In: Thomas M. F. and Whittington, G. W. (editors): Environment and land-use in Africa. Methuen & Co., London.

PULLAN, R. A. 1970 The soils, soil landscapes and geomorphological evolution of a meta-sedimentary area in Northern Nigeria. Univ. of Liverpool, Dept. of Geography. Research Paper *6.*

ROHDENBURG, H. 1969 Hangpedimentation und Klimawechsel als wichtigste Faktoren der Flächen und Stufenbildung in den wechselfeuchten Tropen an Beispielen aus Westafrika, besonders aus dem Schichtstufen Land Südost-Nigerias (with a summary: Slope Pedimentation and Climatic change as Principal Factors of Planation and Scarp Development in Tropical Africa). Göttinger Bodenkundliche Berichte *10:* 57-152. Also: Z. F. Geomorph. N. F. *14:* 58-78 (1970).

ROHDENBURG, H. 1970 Morphodynamische Aktivitäts- und Stabilitätszeiten statt Pluvial- und Interpluvialzeiten. Eiszeitalter u. Gegenwert. *21:* 81-96.

SCHELLING, J. 1955 Stuifzandgronden (with a summary: Inland-dune sand soils). Detailed reports of the forest research station TNO, Wageningen. *2* (1): 1-58.

SEDAGRI 1969 L'utilisation de la géomorphologie pour la cartographie des sols. Application à la vallée et au delta du Fleuve Sénégal. Bull. ASEQUA *23:* 43-56.

SERVANT, M. 1969 Etat actuel des recherches stratigraphiques sur le Quaternaire dans les pays-bas du Tchad. Bull. ASEQUA *22:* 105-111.

SIEFFERMAN, G. 1968 Variations climatiques au Quaternaire dans le Sud-Ouest de la cuvette Tchadienne. Bull. Serv. Carte Géol. Als. Lorraine.

SOIL SURVEY STAFF 1960 Soil classification, a comprehensive system. Seventh approximation. USDA, Soil Conservation Service.

SOIL SURVEY STAFF 1967 Supplement to soil classification system (7th approximation). USDA, Soil Conservation Service.

SOMBROEK, W. G. 1971 Ancient levels of plinthisation in N.W. Nigeria. In: Yaalon D. H. (editor) Paleopedology; origin, nature and dating of paleosols. Intern. Soc. of Soil Science and Israel University Press, 329-338.

TAVERNIER, R. and C. SYS 1965 Classification of the soils of the Republic of Congo (Kinshasa). Pédologie no. spec. *3:* 91-136.

TRICART, M. J., P. MICHEL and J. VOGT 1957 Oscillations climatiques Quaternaires en Afrique Occidentale. Univ. de Strassbourg, Inst. de Géogr. et Centre de Géogr. Appliqué (Comm. V congr. INQUA, Madrid-Barcelona).

TRICART, M. J. 1965 Rapport de la mission de réconnaissance géomorphologique de la vallée moyenne du Niger. Mém. Inst. fr. Afr. noire *72.*

UNESCO 1969 Synthèse hydrologique du Bassin du Lac Chad (PNUD/UNESCO REG. 71). Rapport technique présentant les principaux résultats des opérations.: Draft report. Various printed maps (Institut Géografique National, Paris).

URVOY, Y. 1942 Les Bassins du Niger. Etude de géographie physique et de paléographie. Mém. de l'Inst. fr. de l'Afrique noire *4.*

VAN DER HAMMEN, T. 1951 Late Glacial flora and periglacial phenomena in the Netherlands. Leidse Geol. Med. *17,* 71 pp.

VAN WAMBEKE, A. 1962 Criteria for classifying tropical soils by age. J. Soil Sc. *13* (1): 124-132.

VAN ZINDEREN BAKKER, E. M. 1967 Upper Pleistocene stratigraphy and ecology on the basis of vegetation changes in sub-Saharan Africa. In: Background to evolution in Africa, by Bishop W. W. and Desmond Clark, J. (ed.). The Univ. of Chicago Press. pp. 125-147.

VINK, A. P. A. 1957 Physiographic systems in soil surveys. Anal. Edafol. Agrobiol. (Madrid) *26:* 159-169.

VOÛTE, C. 1962 Geological and morphological evolution of the Niger and Benue valleys. Actes 4e Congrès panafr. de Préhist. et de l'Etude du Quaternaire. Léopoldville 1959, Section I, 189-207. (Annales Museum de Tervueren).

WARREN, A. 1966 The Qoz region of Kordofan. Thesis. Cambridge Univ Library.

WORRALL, G. A. 1969 The Red Sands of the Southern Sahara. Bull. ASEQUA *21:* 36-39.

ZAGWIJN, W. H. 1956 Eolische zanden. In: Pannekoek (editor) Geologische geschiedenis van Nederland. Staatsdrukkerij, The Hague.

ZEUNER, F. 1959 The Pleistocene period. Its climate, chronology and faunal successions. Hutchinson Scientific and Technical Co., London.

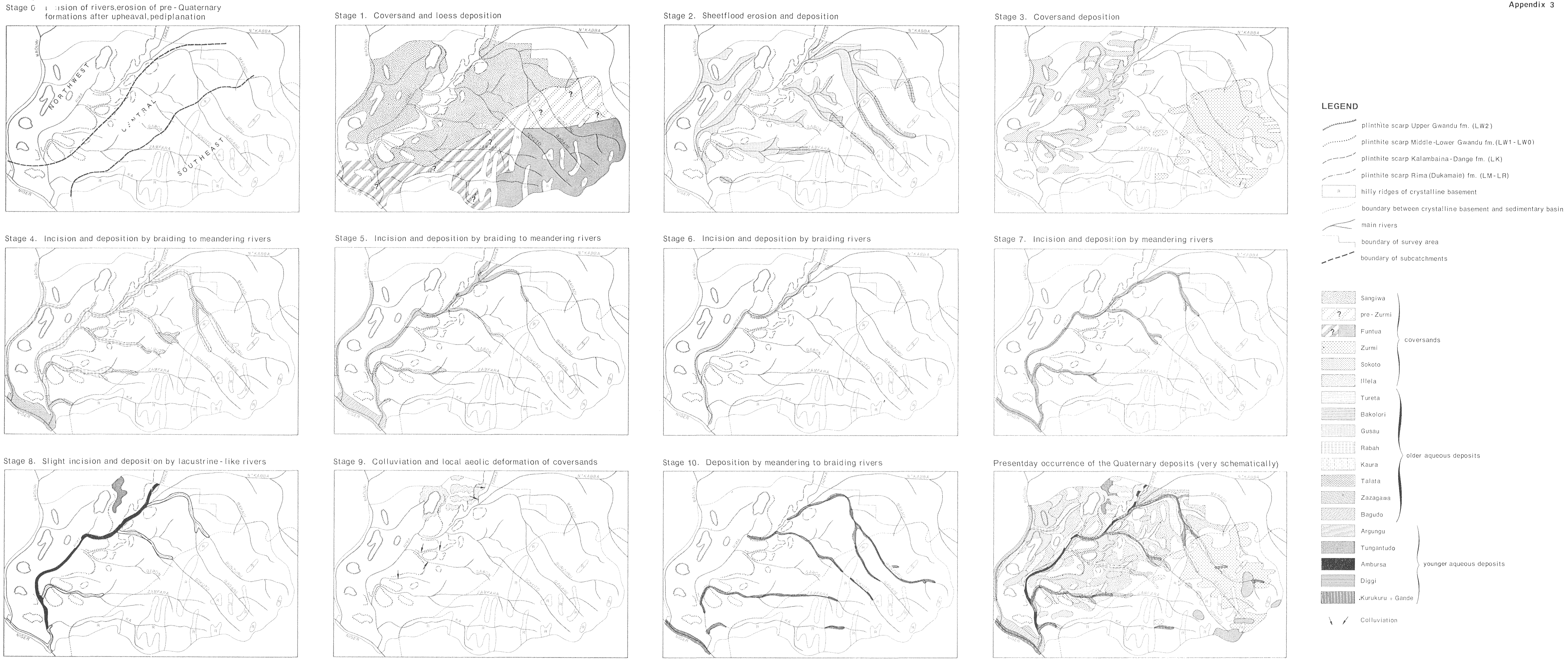
ZIEGERT, H. 1969 Pleistocene Climatic changes and human industries in the central Sahara (Eastern Fezzan and Northern Tibesti). Bull. ASEQUA *22:* 38-46.

ZONNEVELD, I. S., P. N. DE LEEUW and W. G. SOMBROEK 1971 An ecological interpretation of aerial photographs in a savannah region in Northern Nigeria. ITC Publ. *B63*. Enschede, Holland.

Sketch maps showing the various stages of the Quaternary history of the Rima - Sokoto river basin

Sombroek W.G. and I.S. Zonneveld (1971)
"Ancient dune fields and fluviatile deposits in the Rima - Sokoto river basin (N.W. Nigeria)"

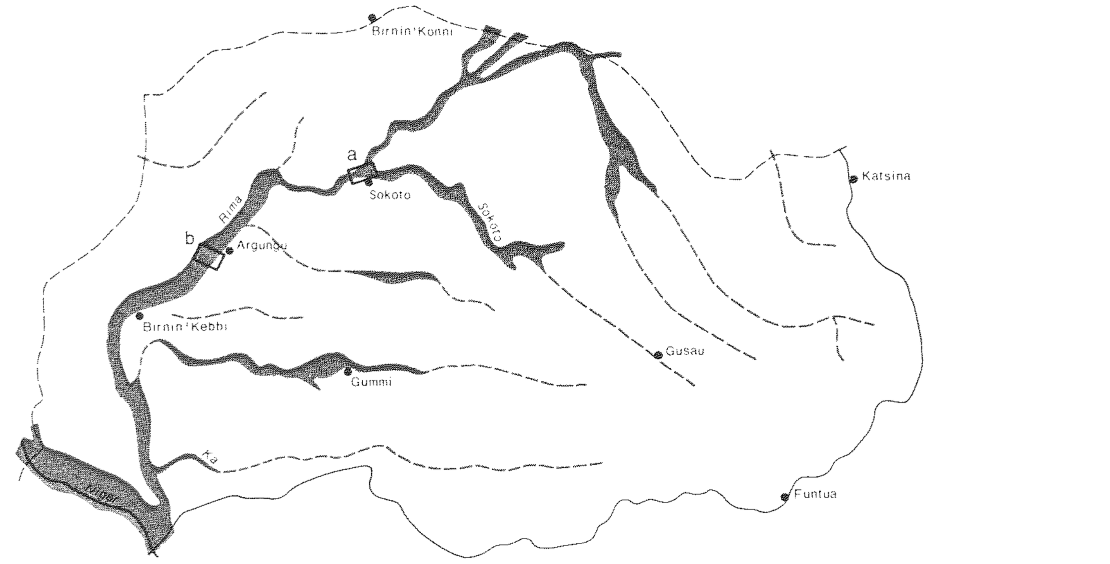
Appendix 3



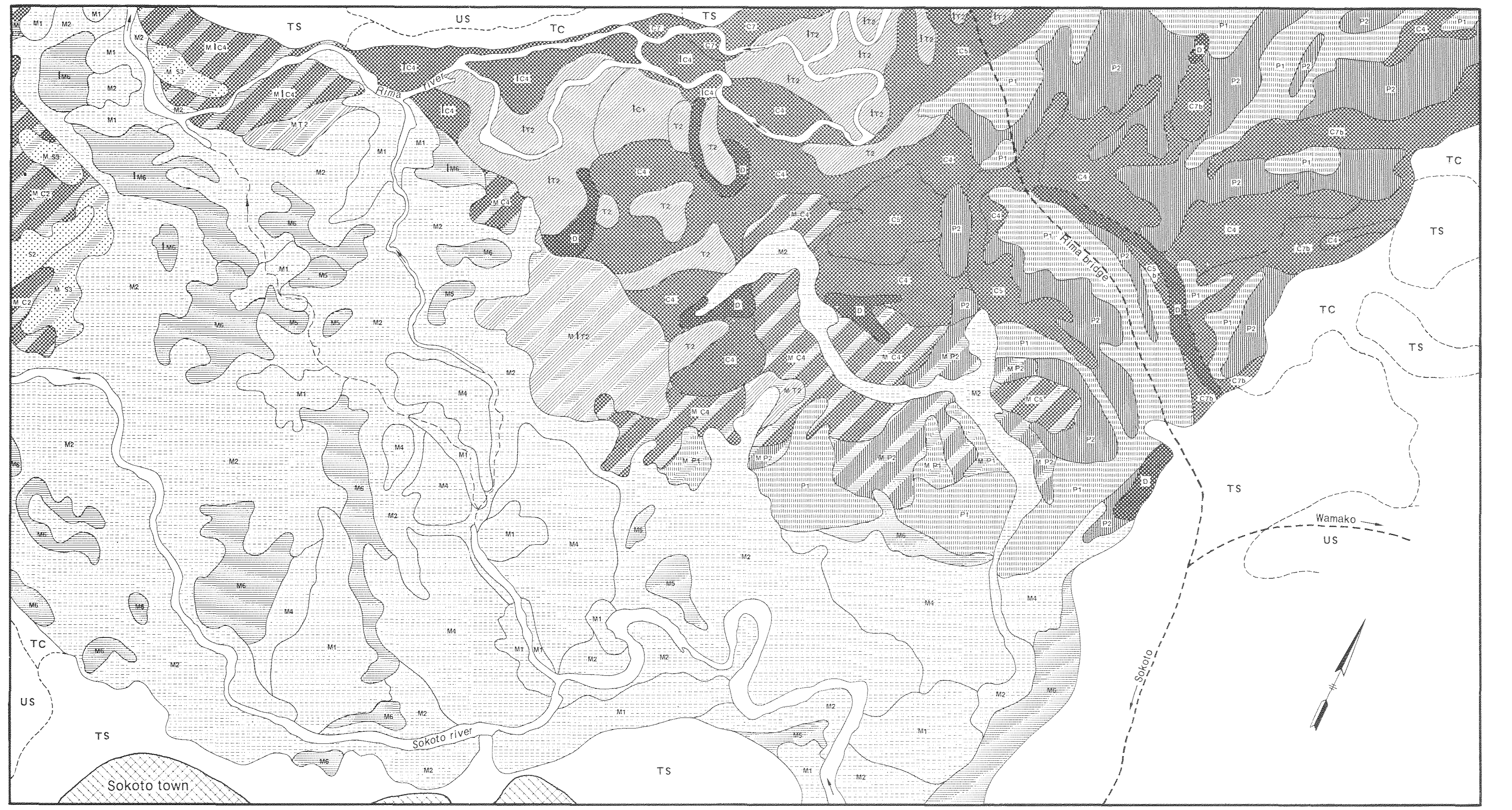
Physiography of the Rima - Sokoto floodplains

Sombroek W.G. and I.S. Zonneveld (1971)
"Ancient dune fields and fluviatile deposits in the Rima - Sokoto river basin (N.W. Nigeria)"

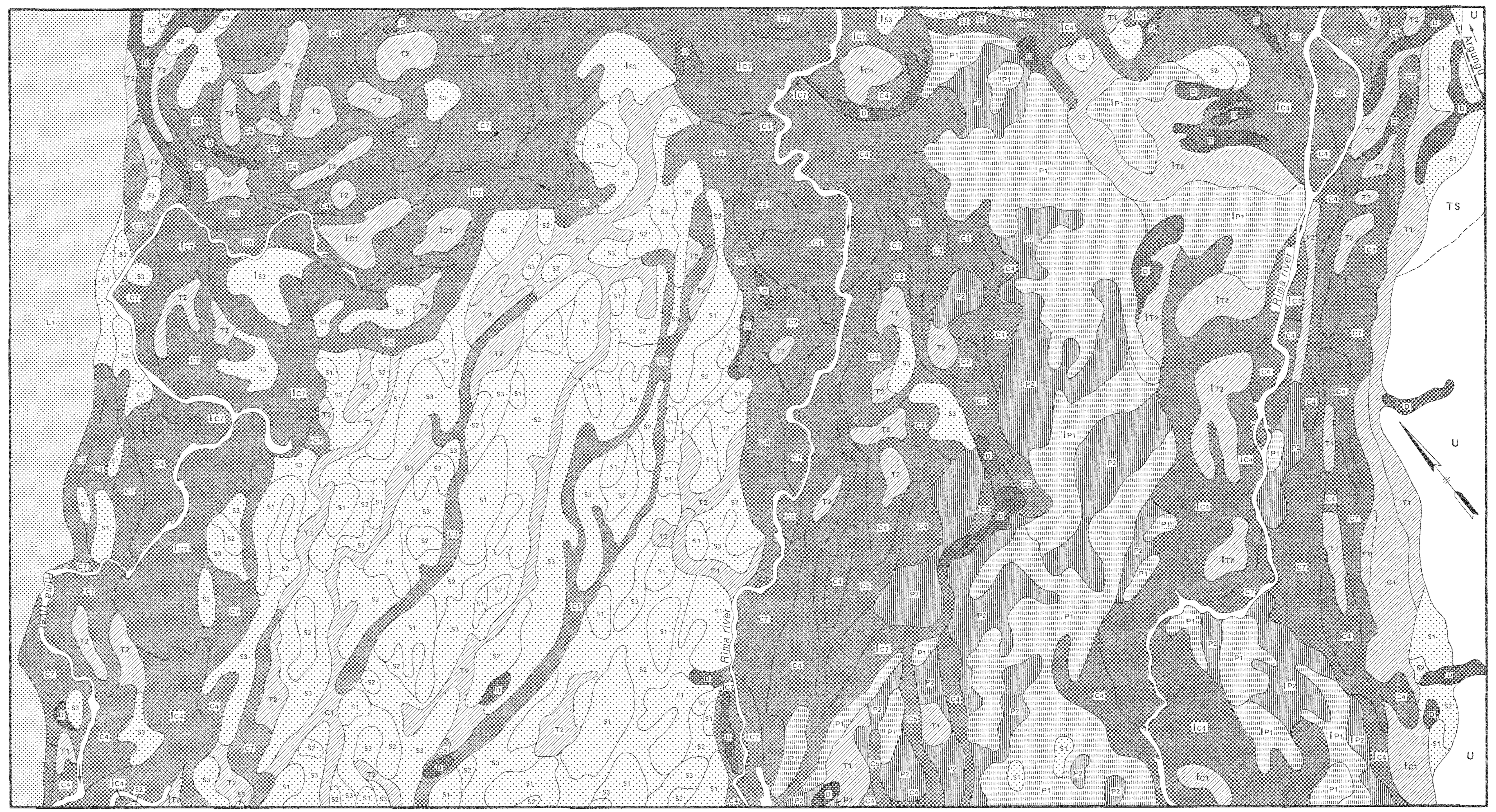
Appendix 2



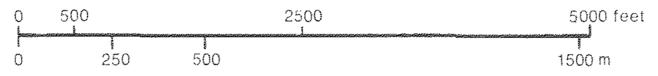
a) SOIL PATTERN IN A FLOODPLAIN AREA WITH PRESENTDAY SEDIMENTATION (confluence of the Sokoto and Rima rivers)



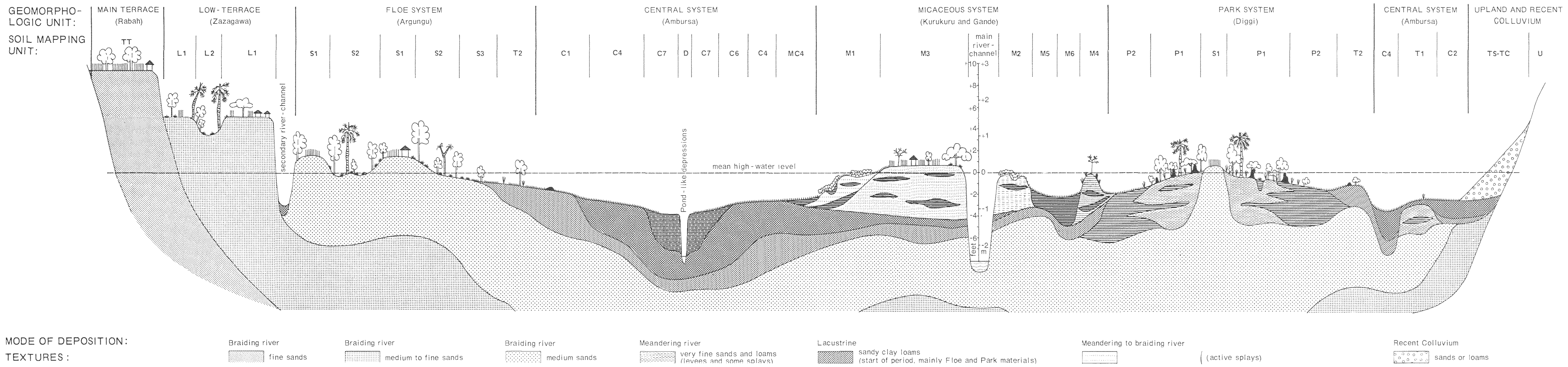
b) SOIL PATTERN IN A FLOODPLAIN AREA WITHOUT PRESENTDAY SEDIMENTATION (Rima river near Argungu)



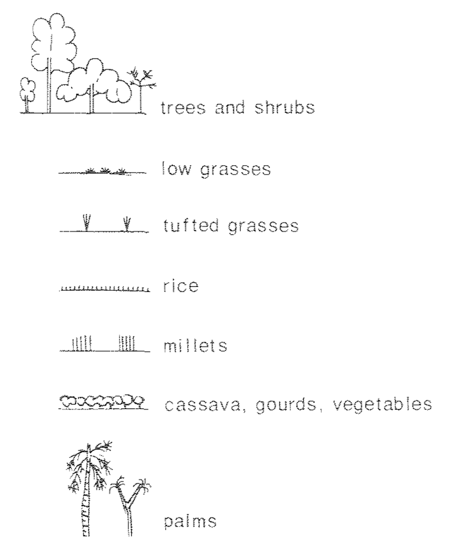
scale 1:20 000



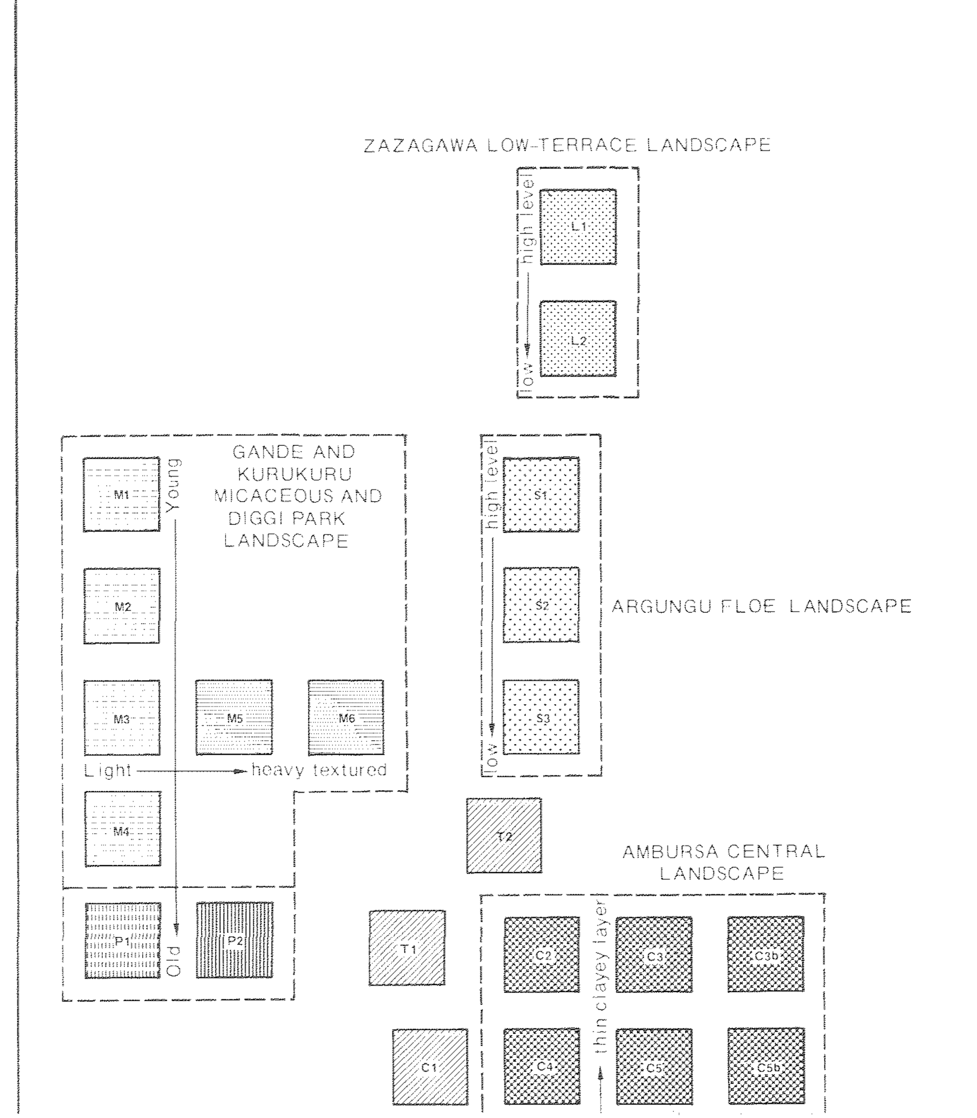
SCHEMATIC CROSS - SECTION OF THE RIMA FLOODPLAIN (textural differentation due to pedogenesis not indicated)



SURFACE FEATURES



RELATIONSHIP BETWEEN LEGEND UNITS



SOIL PROFILE TAXONOMY OF LEGEND UNITS

ACID SANDS and BLEACHED HYDROMORPHIC SOILS

L1 Brown Acid Sands, very well sorted, of riverine sediments

L2 *Strongly Bleached Hydromorphic Soils on sands of riverine sediments*

S1 Yellow Acid Sands, very well sorted, of riverine sediments

S2 Weakly Bleached Hydromorphic Soils on sands or loamy sands of riverine sediments

S3 Association of Weakly Bleached Hydromorphic Soils on sands or loamy sands of riverine sediments and Weakly Bleached Hydromorphic Soils on sandy loams of riverine sediments

NON - BLEACHED HYDROMORPHIC SOILS and HALOMORPHIC SOILS

P1 Solonetz on very fine loamy sands to clay loams of riverine sediments, with inclusion of Moderately Matured Juvenile Soils on ditto sediments

P2 Eutrophic Hydromorphic Soils on clays of riverine sediments, with inclusion of Vertisolic Hydromorphic Soils on ditto sediments

T1 Association of Solonetz on very fine loamy sands to clay loams of riverine sediments, and Eutrophic Hydromorphic Soils on sandy clay loams or on clays of riverine sediments

T2 Association of Solodized Solonetz and Eutrophic Hydromorphic Soils on sandy clay loams of riverine to lacustrine sediments, and Weakly Bleached Hydromorphic Soils on sandy loams of riverine sediments

C1 Eutrophic Hydromorphic Soils on sandy clay loams of riverine to lacustrine sediments, with inclusion of Solodized Solonetz on ditto sediments

VERTISOLIC HYDROMORPHIC SOILS and TOPOMORPHIC VERTISOLS

C2 Vertisolic Hydromorphic Soils on sandy clays to clays of lacustrine sediments, Shallow phase

C3 Vertisolic Hydromorphic Soils on heavy clays of lacustrine sediments, Shallow phase

C3b Topomorphic Vertisols on heavy clays of lacustrine sediments, Shallow phase

C4 Vertisolic Hydromorphic Soils on sandy clays to clays of lacustrine sediments, Medium deep phase

C5 Vertisolic Hydromorphic Soils on heavy clays of lacustrine sediments, Medium deep phase

C5b Topomorphic Vertisols on heavy clays of lacustrine sediments, Medium deep phase

C6 Vertisolic Hydromorphic Soils on sandy clays to clays of lacustrine sediments, Deep phase

C7 Vertisolic Hydromorphic Soils on heavy clays of lacustrine sediments, Deep phase

C7b Topomorphic Vertisols on heavy clays of lacustrine sediments, Deep phase

JUVENILE SOILS

M1,M2 Typic Juvenile Soils on micaceous very fine loamy sands to loams of riverine sediments

M3 Slightly Matured Juvenile Soils on micaceous very fine loamy sands to laoms of riverine sediments, with inclusion of Moderately Matured Juvenile Soil on ditto sediments

M4 Moderately Matured Juvenile Soils on micaceous very fine loamy sands to clay loams of riverine sediments, with inclusion of Solonetz as well as Slightly Matured Juvenile Soil, both on ditto sediments

M5 Typic Juvenile Soils and Slightly Matured Juvenile Soils, both on micaceous clay loams to *clays of riverine sediments, Shallow phase*

M6 Typic Juvenile Soils and Slightly Matured Juvenile Soils, both on micaceous clay loams to clay of riverine sediments, Deep phase

D Association of Typic Juvenile Soils and Juvenile Soils with non-ripe horizons at shallow depth, both on clay loams to heavy clays of riverine or lacustrine sediments

UNDIFFERENTIATED SOIL COMPLEXES

IC4 etc. Complex of soils with that/those of mapping unit C4, etc. being dominant, and usually irregular meso relief

MP1,MC4, etc. Soil or soils comparable to that/those of mapping unit P1, C4, etc. but with shallow cover (thinner than 30 cm) of recent clay to clay loam deposits of similar character as those of the Typic Juvenile Soils. In conjunction called Rejuvenated Hydromorphic Soils and Rejuvenated Vertisols on riverine or lacustrine sediments

THE UPLANDS BORDERING THE FLOODPLAIN (Short land form description only)

U lower-level plateau land

US scarp below lower-level plateau land

SERIES SOIL SURVEY PAPERS

No. 1. *Jongerius, A.* and *G. Heintzberger:* The preparation of mammoth-sized thin sections. 1964 — Dfl. 3.—

No. 2. *Jager, A.* and *W. J. M. van der Voort:* Collection and preservation of soil monoliths from sandy soils and ripened clay soils above and below the water table. 1966 — Dfl. 2.—

No. 3. *Broek, J. M. M. van den* and *L. van der Waals:* The Late Tertiary Peneplain of South Limburg (The Netherlands). Silicifications and fossil soils; a geological and pedological investigation. 1967 — Dfl. 2.—

No. 4. *Brinkman, R.* and *L. J. Pons:* A pedo-geomorphological classification and map of the Holocene sediments in the coastal plain of the three Guianas. 1968 — Dfl. 9.50

No. 5. *Sombroek, W. G.* and *I. S. Zonneveld:* Ancient dune fields and fluviatile deposits in the Rima-Sokoto river basin (N.W. Nigeria). 1971 — Dfl. 14.50