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THE CHARACTERISTICS AND CLASSIFICATION OF
GENETIC SEQUENCES OF SOILS IN THE COASTAL PLAIN
SANDS OF EASTERN NIGERIA

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THE CHARACTERISTICS AND CLASSIFICATION OF GENETIC SEQUENCES OF SOILS IN THE COASTAL PLAIN SANDS OF EASTERN NIGERIA

By

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ABSTRACT

THE CHARACTERISTICS AND CLASSIFICATION
OF GENETIC SEQUENCES OF SOILS IN THE
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Fourteen soil profiles located within the Coastal Plain Sands geologic formation were investigated along a 126 km transect (Umuahia to Port Harcourt) traversing Imo and River States of Nigeria. Nine of the fourteen pedons were selected for more intensive studies that included their clay mineralogy, micromorphology, physical and chemical properties. Their characteristics were established and classification at the family level of all the pedons was made using the U.S. Soil Taxonomy. Approximate classification of the soils was made with the FAO/UNESCO Soil Map of the World Legend. Tentative series were proposed and tentatively correlated with established series used in Western Nigeria. Litho-, topo-, chrono- and climosequences of soils were established.

Data indicate soils vary from those with very little clay or silt in their deepest horizons sampled to soils relatively rich in silt and clay. Pedons developed on finer

materials have relatively more clay than those on coarse materials.

All the pedons have low cation exchange capacity and low base saturation.

The profiles are strongly to very strongly acid. Aluminum saturation percent is lower than 60% in most horizons.

In all the pedons the organic carbon and nitrogen contents are low and decrease with depth except in pedon 4 which has a subsoil maximum in the spodic horizon. Regression analysis shows significant relationships between organic carbon, nitrogen content and elevation.

Free iron oxides generally increase with depth in eight of the nine soils studied in more detail. The iron contents are lower in soils with udic and aquic moisture regimes than those with an ustic regime. In all the pedons, except the aquic regime soils, the amounts of free iron oxides seem to follow the same distribution pattern as the clay content within the same profiles indicating combined movement of iron and clay into the subsoil. Dithionite-extractable Al contents are lower in comparison with those of iron for pedons with ustic moisture regimes (pedons 1-3 and 7). Extractable Al contents are higher than Fe in pedons with udic and aquic moisture regimes, except in pedon 4 which has low extractable Al throughout and a marked accumulation of Fe in the Bhirm.

The phosphorus distribution shows that organic-P is the major form of P in these soils. The Fe-P form is relatively higher than Al-P and Ca-P in the ustic regime soils while Al-P and Ca-P are almost equally distributed in the aquic regime soils. Phosphorus fixation capacity of the soils increases with clay content.

The sand and coarse-silt fractions are predominantly composed of quartz. X-ray diffraction analysis of clay shows mainly kaolinite. Relatively older soils have more kaolinite than the younger soils.

Isotic and undulic plasmic fabrics characterize the micromorphology of most of the soils. Ferri-argillans are not very conspicuous in the soils.

Most of the ustic soils (pedons 1-3, 7 and 14) are classified as Typic Paleustults, fine-loamy and pedon 13 as Arenic Paleustult, coarse-loamy. Pedons 5 and 10 are classified as Typic Paleudults, fine-loamy. Pedon 12 is Typic Paleudult, coarse-loamy and Pedon 11 is Arenic Paleudult, coarse-loamy. Pedon 6 is an Oxic Dystropept, coarse-loamy.

The sandiest poorly-drained soil is classified as an Aeric Grossarenic Tropaquod. The somewhat poorly- and poorly-drained soils, pedons 9 and 8, are classified as Typic Paleaquult, coarse-loamy and Typic Tropaquult, fine-loamy, respectively. All of the fourteen pedons have siliceous mineralogy and isohyperthermic temperature regimes.

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Using the FAO/UNESCO World Soil Map Legend all the soils, except pedons 4 and 6, are classified as Dystric Nitosols. Gleyic Nitosols are proposed for pedons 8 and 9. Pedons 4 and 6 are classified as a Gleyic Podzol and a Dystric Cambisol, respectively.

DEDICATION

To my beloved father, George Ukoha Lekwa, who laid the foundation and contributed immensely for my success and achievement, but could not live to see the materialization of his efforts.

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INTRODUCTION

The Coastal Plain Sands occupy a significant area of the Eastern States of Nigeria. In origin they are fluvio-lacustrine and were laid down in a series of large shallow lagoons and lakes. With a rather schematic study of the soils, a generalized soil map of Eastern Nigeria was published in 1964. In this generalized soil map the soils of the Coastal Plain Sands are grouped under the Ferralitic soils (Jungerius, 1964).

Unlike the Western Region of Nigeria, much of the work that was done in soil survey in the Eastern part of Nigeria was lost during the Nigerian Civil War (1967-1970). The Land Resources Division of British Overseas Development was engaged by the Federal Government of Nigeria to carry out soils study of Central Northern Nigeria and some parts of the Northern region have been studied by the Soil Survey Staff of Ahmadu Bello University, Zaria. Owing to scarcity of soils data and trained soil scientists, an update of the soils map (1964) has not been done. Presently the Federal government is proposing to collect and collate soils data with the subsequent plan of drawing up a new soils map of the country.

One of the immediate tasks facing the few soil scientists is the diversity in soil classification systems viz. USDA (Soil Taxonomy), FAO/UNESCO, French, British, Dutch, etc. It is envisaged that the FAO/UNESCO system may be adopted to a certain degree and that this will be supplemented by the USDA (Soil Taxonomy) system. For this to be successful, a lot of soils correlation, characterization and classification is needed. This problem is most acute in the Eastern States of the country. Whiteside (1963) stressed the need for soil characterization in Eastern Nigeria. Inadequacy of soils data hindered a comprehensive field review/study during the soil correlation meetings in Eastern Nigeria (January 1973; June 1974; Lekwa, 1974).

The principal aim of the present study will be to provide some of the much needed data that are essential for understanding the genesis and the classification of soils derived from the Coastal Plain Sands. The scientific information acquired should not only be applicable to a considerable part of Eastern Nigeria, but also to other parts of Nigeria and of the tropics. An added advantage is that the area provides for research into the so-called "acid sands" of Nigeria. It has another advantage in that it is located close to a center of crops research, the National Cereals Research Institute of Nigeria, Amakama-Umuahia. Thus, the area is conveniently located for more extensive related agricultural research. Decisions involving the proper use and management of soils have a scientific basis when soil behavior is understood in relation to soil characteristics, the origin of these characteristics and the environment where the soils occur.

A broad classification of the soils of the area has been made as Ferralitic soils. Some soil scientists have classified them tentatively as Oxisols or Ultisols. The practical implications of this controversy contributed to the undertaking of this more complete characterization of some of the soils of the area. Fourteen profiles representative of the area were studied in the field. Nine of them were then sampled with the following objectives in mind:

1. To obtain the chemical, physical, mineralogical and micromorphological characterization of the soils.
2. To determine criteria needed for their classification using the U.S.D.A. Soil Taxonomy.
3. To provide basic information for future soil mapping and correlation programs in Nigeria.
4. To begin interpretation of the results for land use planning and crop research programs.

LITERATURE REVIEW

Soil genesis and classification advanced when concepts of landforms were applied to explain differences in soils and relationships between soils. In the developing countries soils data are often lacking or not collated. Great demands are being placed upon the soils of tropical Africa to meet the needs for food and fiber of a rapidly expanding population. Soil surveys which are fundamental to land use planning are lacking except for a few places where surveys of a reconnaissance type are available. Most of the existing soil surveys were not made with the intention of classifying the soils according to the USDA system of soil classification.

Genetic Sequences of Tropical Soils

The cocoa soils of Western Nigeria had been mapped and classified using the catena concept as a mapping unit. Milne (1935) in his original article on catena noted that the soil profiles changed along the traverse from the ridge crest to the stream in accordance with topography and Milne *et al*. (1935), in discussing a complex of soils in Tanzania hinted that the red earths may be relict soils, especially when associated with calcareous black clays. Milne *et al*.

recognized how landscape evolution can affect soils when they stated, "The great plateau lying behind the east-west facing ranges carry material which was graded down during a long process of peneplanation, and which therefore may:

--Retain characteristics impressed during its first weathering.

--Have acquired new ones as its profile developed under conditions of sluggish drainage and,

--Undergo a fresh adjustment to conditions of rejuvenated drainage following the elevation of the peneplain into plateau."

In Nigeria the constantly recurring succession of soils downslope from the red hilltop soils, through brown and yellow slope soils to the gray alluvial sands and clays will be very obvious to the agriculturist. The essence of the catena, therefore, is the spread of soil decomposition products across a topographic sequence, and their temporary hold up there in a dynamic phase of soils development.

Bushnell (1943, 1945) suggested terminology for specified groupings of catenas of soils:

--Chrono-catena for those differing in time of soil formation.

--Byndel for those differing in parent materials.

--Climo-catena for those differing in climate.

--Thermo-catena for those differing in the temperature component of climate.

--Hygro-catena for those differing in the moisture component of climate.

--Floro-catena for those differing in vegetation.

Jenny (1941) considers catenas of soils as differing in relief or topography, which includes in addition to degree of slope, shape of slope, convexity and concavity, length of slope, direction of exposure, and height of water table.

Aldrich *et al*. (1956), Bushnell (1943), Soil Survey Staff (1951) and Ruhe (1960) have altered the concept of catena in recent years. Evaluating Milne's definitions of catena, Ruhe (1960) restated and redefined catenas as, "the sequence of soils encountered between the crest of a low hill and the floor of the adjacent swamp, the profile changing from point to point of this traverse in accordance with conditions of drainage and past history of the land surface . . . ." According to Ruhe (1960), two variants of catena can be distinguished in the field. In one, the topography was modeled by denudation or other processes, from a formation originally similar in lithological character. Soil differences were then brought about by drainage conditions, differential transport of eroded material, leaching, translocation, and redeposition of mobile chemical constituents. In the other variant, the topography was carved out of two or more superimposed formations which differ lithologically. Ruhe (1960) emphasized two principal points in the catena definition, namely, physiographic history and geomorphic evaluation of the landscape. This differs from Aldrich et al. (1956) definition, "a sequence of soils from similar parent material and of similar age in areas of similar climates but whose characteristics differ due to variation in relief and drainage."

The formulation of the catena concept by Milne (1935) was the result of a recognition that particular slope forms were associated with particular soil sequences. Milne proposed the idea as a mapping unit rather than as a taxonomic unit (Ruhe, 1960) and the subsequent elevation of it to taxonomic status was a recognition of the fact that the idea implied a real relationship between soil-forming processes and slope processes (Bushnell, 1943; Calton, 1954). As a mapping unit it has been constantly used for the mapping of soils of a number of areas in Africa (Ruhe, 1960).

Milne (1935) briefly showed that the soils of a catena are related to the erosion and deposition of sediment on a landscape in East Africa. There the landscapes in a fully developed terrain generally have common elements. Ruhe (1960) defined the slope-profile components as summit, shoulder, backslope, footslope and toeslope.

Nye (1954, 1955b) in a study of a toposequence without rock outcrops in Africa points out that "a study of only the vertical development of a profile omits half the picture. The lateral relationships and variations between corresponding horizons in the catenary successions of profiles equally deserve study. It is impossible to understand the formation of the profiles on the lower parts of the slope unless the formation of the upper slope-members is understood and the importance of such factors as lateral drainage and soil creep is appreciated."

Slope-soil relationships may be studied in at least two ways, either by the study of catenas, in which changes in soil characteristics from summit to valley bottom are related to variation in slope; or by examining planation surfaces and depositional features in relation to soils, thus relating soil development to erosional history. Pallister (1956) and Ollier (1959) used the former approach while the latter approach is exemplified by Mulcahy (1960).

Moss (1968) states that the assumption that the soils found on a particular surface will be older than those on a lower surface cannot be objectively supported. The surfaces, in terms of their formation, may not be of uniform age.

Dixey (1955) has pointed out the drawbacks of characterizing surfaces by the date of their initiation, and favors other methods, such as using the geological period of still-stand immediately prior to their disruption, or the age of the offshore deposits accumulated during the erosion of the surface. Pedologically, surfaces take time to develop and thus the soils with which they are associated may be of widely differing age. Ollier (1959) postulated that the correlation of the soils with surfaces in terms of age implies that processes of soil formation begin with the cutting of an erosion surface.

According to Moss (1968) the general rule seems to be that many different soils occur on the same surface, owing to the many different factors affecting soil formation. He stated that there is little relationship between surface age and soil age, owing to the confusion which surrounds the notation of age with reference to the geomorphic surfaces, the non-uniformity of the operation of weathering and erosion process over one surface, and the fact that many surfaces in Africa are formed, not on virgin rock, but on preweathered material.

Daniels *et al*. (1971) divided the geomorphic surfaces into two, depositional and erosional. On many landscapes, a surface can have depositional and erosional elements and the two elements are considered as one surface. They considered time zero of a geomorphic surface as the time when it was first exposed to subaerial weathering. They maintain that on an erosional surface, this would be when erosion at that point stopped; on a marine depositional surface, it would be when the ocean withdrew and exposed the sediments to subaerial weathering. Thus, the age of the geomorphic land surface and the associated soil is the same. The authors concluded that results about soil genesis based on conventional analysis and consideration of present soil-forming factors usually are improved when geomorphic and stratigraphic information is added.

Ollier (1959) pointed out that the connection between soils and geomorphology is most important in tropical soils; more so perhaps than in soils of temperate regions, where parent rock and parent material are often more nearly synonymous.

DeVillers (1965) considered that in tropical conditions climatic oscillation since the tertiary has been a prime factor in inducing cyclic erosion-deposition; thus, it seems more realistic to consider soil formation in terms of the cyclic rather than the steady-state concept. In the present study soil formation factors will be broadly treated to include climate, organisms, topography, time and parent materials (Jenny, 1941).

Rook (1961) classified soil forming processes under these groups: disintegration of primary minerals, decomposition and synthesis of organic compounds, solution and peptization, precipitation and coagulation, ion exchange dynamics of liquid phase and heat. Simonson (1959) summarized these processes as additions, losses, translocations, and transformations.

Interaction of these processes under tropical conditions gives rise to many different soils. Ferralization is the common end product where age or drainage conditions are not limiting factors. Ferralization can occur in place, or materials can be preweathered and transported, or both; supporting a two-cycle theory for tropical soils in many areas (Ollier, 1959). According to Stepanov et al. (1967), ferralization is associated with a profound decomposition of primary minerals, accumulation of sesquioxides, and paucity of other elements.

The type of humus or humic compounds that are prevalent have a very important role in soil genesis and evolution. Tricart and Coilleux (1965) state that fulvic acids are the most prevalent in red tropical soils; prehumic and humic acids are destroyed by bacterial action. The pH, C/N ratios, kind of organic matter originally present, and microorganisms are factors associated with the type of humus present in soils.

Thorp and Smith (1949) modified the 1938 Soil Classification Scheme by grouping the Red Podzolic with the Yellow Podzolic soils, under the great soil group Red-Yellow Podzolic soils, and included the Yellow Lateritic soils within the Reddish-Brown Lateritic great soil group. Bennema (1963) related the red and yellow soils of the tropics to latosols and indicated that South America and Africa represent the greatest concentration of latosols in the world. The principal characteristics of these soils are:

- --Indistinct horizon differentiation
- --Absence or scarcity of silicate clay skins
- --Low CEC due to absence or near absence of 2:1 lattice clay minerals
- --Red, yellow or brown colors of subsurface horizons
- --Absence of well-developed blocky or prismatic structure
- --Deep sola
- --Consistence in moist state; very fiable or friable
- --High porosity and high permeability
- --Low base status in the whole profile
- --Relatively high anion exchange capacity and high P-fixation power
- --Relatively low amounts of exchangeable aluminium due to the low effective base exchange capacities of the clays present
- --High resistance to gully erosion due to their porous structure and deep sola.

Aubert (1964) summarized the characteristics of Ferralitic soils as follows:

- --Low content of primary minerals
- --High content of hydroxides, especially iron, aluminium, manganese and titanium. Low ratios of silica/sesquioxide or silica/alumina.

--Colloidal materials are characterized in most weathered horizons by hydrates and hydroxides of iron, aluminium, and titanium

--Low silt and humus content

--Very small changes in temperature at depth (50 cm) during the year.

According to Bennema (1963) red and yellow soils are typical in uplands of subhumid regions of the tropics. Color is related in many cases to the different parent materials in which the soils formed. Red soils are associated with initially higher contents of ferromagnesian minerals than in red-yellow soils. Reddish soils are, on the average, lower in silica than the brownish soils and are related in the tropics to old surfaces.

Nature and Significance of Iron in the Soil

In studies of soil classification and genesis it would seem essential to differentiate between the free oxides formed as products of weathering and those inherited from the parent material. The portion of the total iron in a soil occurring as hydrous oxides, uncombined with layer silicate structures, and which is reductant-soluble is designated as free iron. These oxides occur as coatings on mineral grains, and possibly as intergrowths with the clay minerals. The iron in these oxides was released from the silicate lattices upon the weathering of the minerals.

Rankama and Sahama (1949) state that most of the iron in igneous rocks occurs in the lattices of pyroxenes, amphiboles, and ferromagnesian micas. Sand size fragments of these minerals are found in soils, and since they are relatively unstable (Goldrich, 1938) it can be assumed that they weather and release the lattice iron during the period of soil formation.

Halvorson (1931) discussed the relation of carbon dioxide pressure and pH to the solubility of iron compounds. He stated that very little iron remained in solution above pH 6.5. Olson (1947) found iron solubility in soils to be related not only to pH, but also to the amount of free iron oxides present. Thus iron movement could occur more readily at a given pH in a soil with more free iron oxides.

Rankama and Sahama (1949) state that iron is capable of forming complexes with organic matter, and that these complexes are capable of movement as colloidal sols. Starkey and Halvorson (1927) indicate that iron can remain in solution as organic compounds at higher pHs than it can as inorganic compounds, since the organic compounds are less ionized. Franzmeier (1962) presents a thorough review of the proposed methods of iron movement, including organic and inorganic colloidal complexes and ionic solutions.

Numerous workers have devised methods for the removal of iron oxides from the surfaces of mineral grains without disrupting their crystal lattices. Most of these procedures were devised with the objectives of cleansing the clay particles to sharpen the x-ray patterns rather than that of the quantitative determination of the oxides removed. Paddick (1948) used a solution of thioglycolic acid to extract the free iron oxides from calcareous soils. The thioglycolic acid also formed a color complex with the iron thus permitting the quantitative determination of the iron extracted by a colorimeter. Jackson (1956) used diluted HCl as an extractant, and determined the amount of iron removed colorimetrically, using orthophenanthroline to develop the color. Kilmer (1960) used a solution of sodium hydrosulfite as an extractant and determined the iron extracted by titration with potassium dichromate. This procedure is rather complex but is reported to give consistent results.

Free iron is determined usually by the dithionite method. This does not distinguish between hydrated iron oxide weathering products and crystalline primary iron oxides (Deb, 1949; Mitchell, Farmer and McHardy, 1964). Deb (1949) reviewed several of the extraction and determinative procedures including those developed by Tamm, Jung, Scarseth and Allison, Dion and Truog. He found a great deal of variability in the amount of iron removed from the same soil by the various methods. Deb devised his own extraction procedure using sodium thiosulfite as an extractant under conditions of low temperature and pH. Mehra and

Jackson (1960) used the same extractant but buffered the system to pH 7.3.

Schwertmann (1964) tested acid ammonium oxalate as an extractant of iron oxides and found that in darkness it dissolved only x-ray amorphous oxides. Lundblad (1934) showed that this reagent was useful in differentiating certain classes of soils. Extraction with acid ammonium oxalate has frequently been used to provide an estimate of the (x-ray) amorphous fraction of ferric oxides in soils (Schwertzmann, 1964) and to evaluate soil profile genesis (McKeague and Day, 1966; Blume and Schwertzmann, 1969).

In the tropics the oxides and hydrous oxide of iron and aluminium in both crystalline and amorphous forms are among the major components of soils. A small portion of Fe and Al is also present in soils in the form of organic complexes. According to Juo _et al_. (1974) approximate differentiation among these three forms of Fe and Al in soils can be made by selective extraction methods.

The profile distribution of the various forms of Fe and Al has been used as a criterion in interpreting soil formation processes in the temperate region (McKeague and Day, 1966; Blume and Schwertzmann, 1969). Working on some Nigerian soils derived from sandstones, Ashaye (1969) studied the relationships between clay content and the acid-oxalate-extractable Fe and Al. He found that the relationships were not significant. However, he concluded that the amount and nature of the various forms of Fe and Al oxides and organic complexes may greatly influence the physical and chemical properties of the soils.

The presence of amorphous Fe and Al oxides may modify certain soil properties such as anion sorption, surface charge, specific surface area, swelling, and aggregate formation (McIntyre, 1956; Sumner, 1963; Sherman et al., 1964; Acra and Weed, 1966; Greenland et al., 1968). Sherman et al. (1964), pointed out that drying at elevated temperature causes the amorphous Fe and Al oxides to dehydrate and subsequently shift to a system of greater crystallinity. They also reported some evidence showing that the loss of amorphous materials in tropical soils as a result of dehydration and crystallization resulted in significant changes in certain chemical and physical properties of the soil, such as, the decrease in cation-exchange capacity and the increase in both bulk density and particle density of the soil.

Mehra and Jackson (1960) compared four common extracting procedures. They presented data indicating the magnitude of the variation between methods as shown in Table 1.

The very existence of so many methods for the determination of free iron oxides would indicate that none of them is completely satisfactory. Apparently, each method removes only a certain group of iron compounds.

Table 1.--Data showing variation between methods of iron extraction (Mehra and Jackson, 1960).

Soil or Mineral	Percentage of Iron Oxides		
	Mehra and Jackson	Truog	Deb
Miami B	1.0	2.5	1.5
Vermiculite	4.5	6.0	4.2
Nontronite	0.5	2.9	2.8
Glauconite	0.8	0.6	0.7
Nontronite (fine)	0.2	7.9	8.0
Vermiculite (fine)	6.3	10.3	7.8

Values obtained using any of these methods must, therefore, be considered relative, rather than absolute.

Clay Mineralogy

Clay mineralogy studies constitute an important phase in the characterization of soils, soil genesis, and the classification of soils. Directly or indirectly they reflect clay content and clay composition. Keller (1970) observed that clay minerals are the result of the reactive response of geologic materials to the energies characterizing certain environments over time. Clays found in soils result either from the inherited clays present in the parent material or from the synthesis of clay in the soil profile.

Specific processes by which clay minerals are formed are direct crystallization from solution, replacement, crystallization from a colloidal gel, and weathering of non-layered silicates. According to Keller (1970), argillation includes the following factors: temperature, pressure, pH, eH, concentration of metallic ions, H_4SiO_4 and/or hydrated SiO_2 polymers, concentration of Al^{+3} to $Al(OH)_4$ and/or hydrated aluminum hydroxides, polymorphs of SiO_2 and complex soluble compounds of silica and/or alumina.

Kaolinite has been reported as the major mineral in the clay fraction of Ultisols. Clay minerals may be indicative of environmental conditions if they are formed *in situ* as a response to such environments. In the tropics kaolinite tends to be produced when H^+ concentration is high relative to metal ions, and when the aluminium concentration is high. Keller (1970) relates kaolinite formation to a high Al:Si ratio, high H^+ concentration and low Na^+, Ca^{++}, Mg^{++} and Fe^{+++} concentrations. The synthesis of kaolinite is restricted to a pH of about 4.5. This means a soil and climate where Ca^{++}, Mg^{++}, Na^+ and K^+ are removed freely and H^+ ions are supplied abundantly by acids or by dissociation of water.

DeKimpe and Gastuche (1960) concluded that kaolin appears in acid soils of low base saturation. Kaolinite is more stable in acid weathering conditions since the

2:1 minerals are less resistant to acid attack than the 1:1 species.

According to Mohr and Van Baren (1954) the main process of alteration in the tropics is desilication or kaolinization (Jackson, 1965). More intense and protracted weathering of parent rocks and soils under conditions of wet and dry seasons has resulted in further enrichment of sesquioxidic components giving free iron oxides, kaolinite (DeVillers, 1965) and halloysite (and frequently gibbsite) in clays of Ultisols (Jackson, 1965).

From well-oxidized (alternately wet and dry climates) and intensively leached soils of the tropics, the element silicon has frequently been severely depleted enriching the clay in hydrous oxides of Al, Ti, Fe and Mn during the Quaternary. Jackson (1965) called this process laterization or intensive desilication. The results of this process is an accumulation of hydrous oxide clays and TiO_2-rich residues (Jackson et al., 1948; Jackson and Sherman, 1953).

Tamura et al. (1955) in Hawaii showed that under alternating wet and dry climatic cycles, iron oxides are stabilized and accumulated. They found that in the Low Humic Ferruginous Latosols the Maui soil has a high hematite content in the A horizon and gibbsite in the B whereas in the Kanai soil goethite and hematite are predominant in the B horizon.

According to Frink and Peech (1962) gibbsite is the thermodynamically stable phase of $Al(OH)_3$ at room temperature and pressure. Fripiat et al. (1954) concluded that under savanna conditions grasses remove Si, thus increasing the tendency to concentrate alumina in the soil and giving rise to a higher gibbsite content when compared to soils under other vegetation.

Free gibbsite can appear through weathering when leaching rates are rapid and the supply of silica is limited. In Hawaii areas that are continually wet or alternatingly wet and dry for periods of time long enough to allow removal of silica, the soils contain either hydrated alumina and Al-Fe gel material, or laterite and gibbsite if a dry period has been involved. Iron oxides are probably the most common of the accessory minerals in clays (Mitchell et al., 1964). The name "limonite" has often been used for amorphous, hydrated iron oxides with composition Fe_2O_3 n H_2O or with a molecular formula such as $2Fe_2O_3 \cdot 3H_2O$ (Wada and Harward, 1974). The monohydrates of ferric oxide "goethite" and the anhydrous oxide hematite are the crystallized mineral forms found in soils, but hydrated ferric oxide gels and anhydrous Fe oxides are also known to occur in soils (Mitchell et al., 1964). Many of these materials exist as coatings on other particles (Jones and Uehara, 1973) rather than as discrete units.

Segalen (1971) working with metallic oxides and hydroxides in soils of the warm and humid areas of the world found that:

--Near the Equator, goethite is the dominant iron mineral. Iron is always outside the clay mineral structure which is essentially kaolinite.

--In the tropical zone, goethite and hematite are common and amorphous materials are ferruginous or manganic. The former are very often responsible for the red colors of the soils.

--In the subtropical zone, goethite, associated with amorphous products, appears to be the dominant iron mineral. The iron content is high.

Description of the Study Area

The land-mass of former Eastern Nigeria (now broken into four states viz. Imo, Anambra, River and Cross River States) extends from 4°15'N to 7°05'N, and from 5°32'E to 9°16'E. It thus occupies very much of a humid, tropical location. For three of its four sides, the physical boundaries of the area are reasonably well defined. The 400 km shoreline along the Gulf of Guinea, while it comprises a confused complex of sandy, barrier beaches, lagoons, creeks and swamps, nevertheless forms a clear-cut southern boundary to the Eastern states. On the west, the Niger River and its distributaries, culminating in the vast and intricate drainage network of the Niger Delta, serves to delimit the boundary between the Eastern states and Bendel state.

The Coastal Plains of Eastern Nigeria comprise the entire area adjacent to the coast line along the southern edge of the country. Thus they embrace not only substantial portions to the south of former Eastern Nigeria but also parts of the Mid-Western state (now Bendel State) including Benin Division. These plains extend from Port Harcourt northwards for more than 104 km. It is adjoined by the Oban Hills in the Cross River State while the Kukuruku hills adjoin it at its western boundary.

The Coastal Plain Sands or Benin Sands is a geological formation and does not embrace the entire geographical area defined above, the portion excluded being the narrow southern tip of the geographical coastal plain generally referred to as the mangrove swamps of the Niger Delta, an area south of an imaginary line running approximately East-West across Port Harcourt. It embraces much of former Owerri Province, Benin, and the northern areas of former Rivers and Calabar Provinces (Figures 1 and 2).

Climate.--The Eastern States of Nigeria experience a high intensity of solar radiation throughout the year because of their latitudinal location. Daylight hours are nearly constant from month to month; as far north as Nsukka, the difference between the shortest and longest day is only forty-eight minutes. This ensures a steady

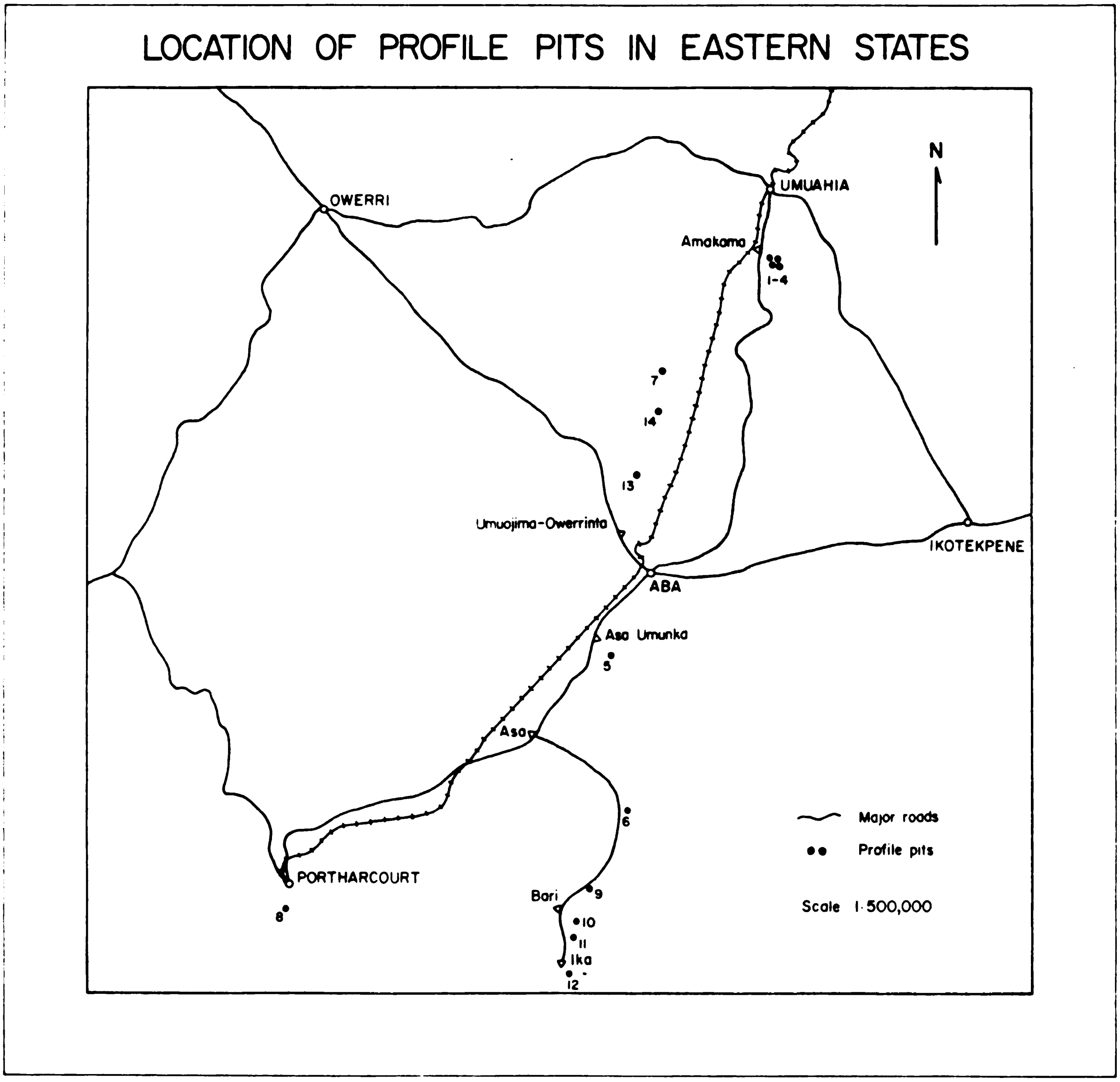


Fig. 1.--Location of profile pits in the Eastern States.

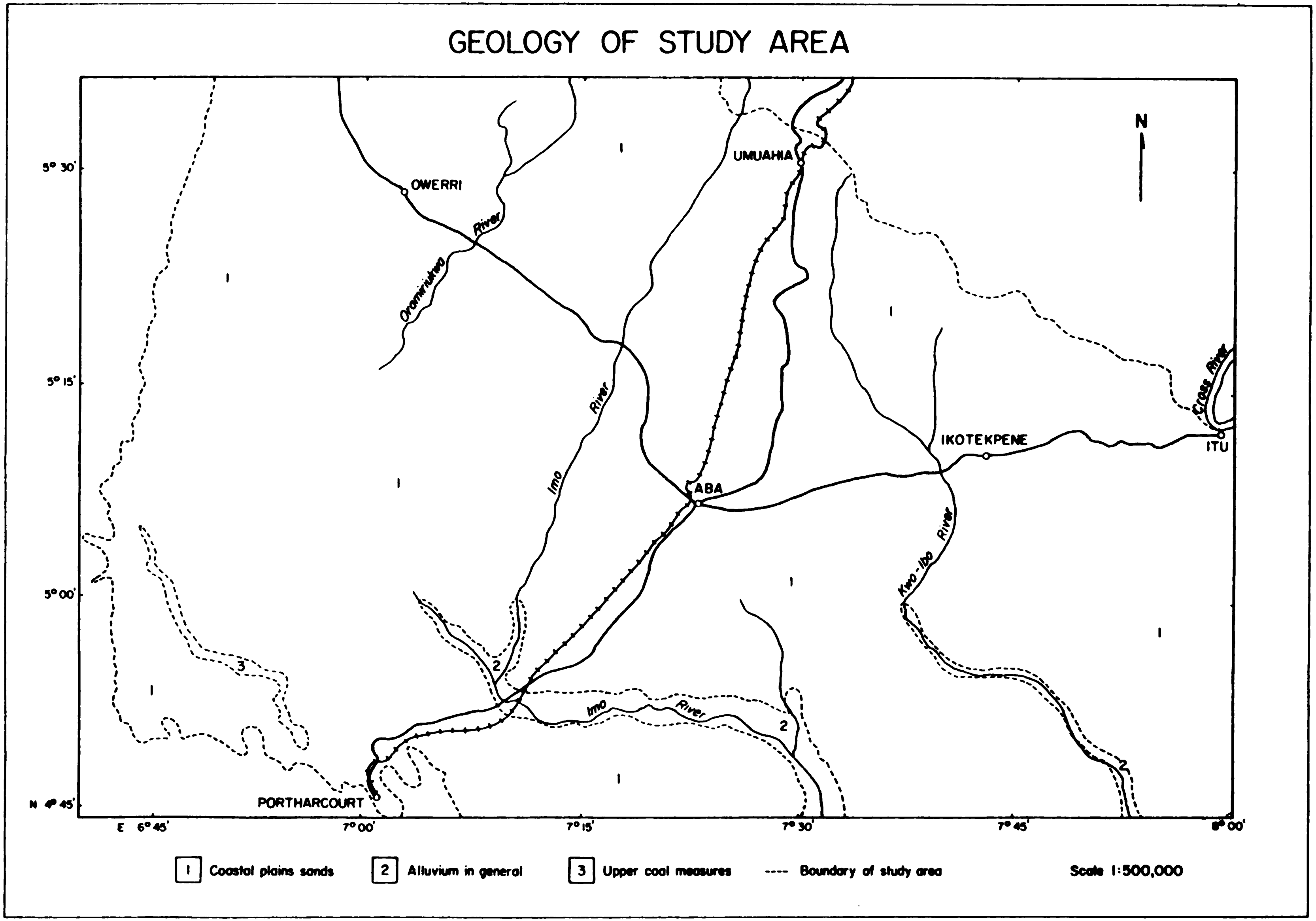


Fig. 2.--Geology of the study area.

input of solar energy although absorption, scattering and reflection due to the earth's atmosphere may modify the actual amounts of solar radiation received at ground level.

Air temperatures within the region are predictably high the year round. Mean annual temperatures are everywhere above 24°C (75°F) although they do not exceed 29°C (85°F) (Figure 3). Mean minimum temperatures do not fall below 18°C (65°F) while mean maximum temperatures do not exceed 32°C (90°F). The hottest months of the year are February and March, and the coldest month is usually August (Figure 4). February and March are late dry season months when insolation is increasing with the apparent northward migration of the sun, the Harmattan haze has already disappeared, and clearer skies permit uninterrupted sunshine. August is in the midst of the rainy season and the heavy rains of the preceding months have led to a lowering of atmospheric temperatures. Despite the little dry season--"August break," a high degree of cloudiness persists which deflects incoming solar radiation.

Temperatures across the area are high enough to permit year round growth of domesticated plants and agricultural activities. A seasonal pattern to cropping is necessary due to lack of moisture, not a temperature-induced dormant season. Year round farming is feasible where water can be supplied by irrigation and the terrain and soils are favorable.

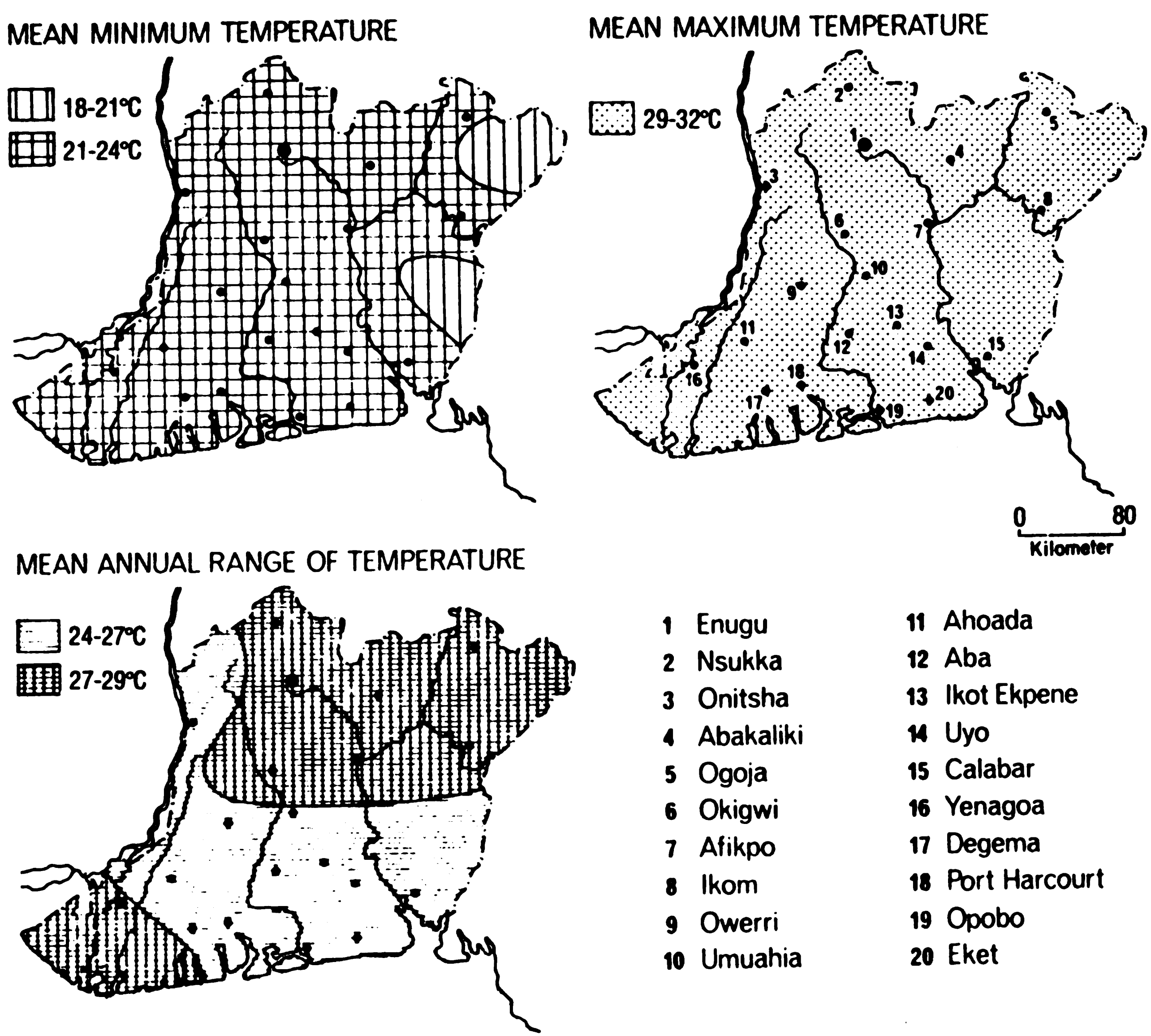


Fig. 3.--Mean minimum and maximum temperatures (1951-1960).(Floyd, 1969).

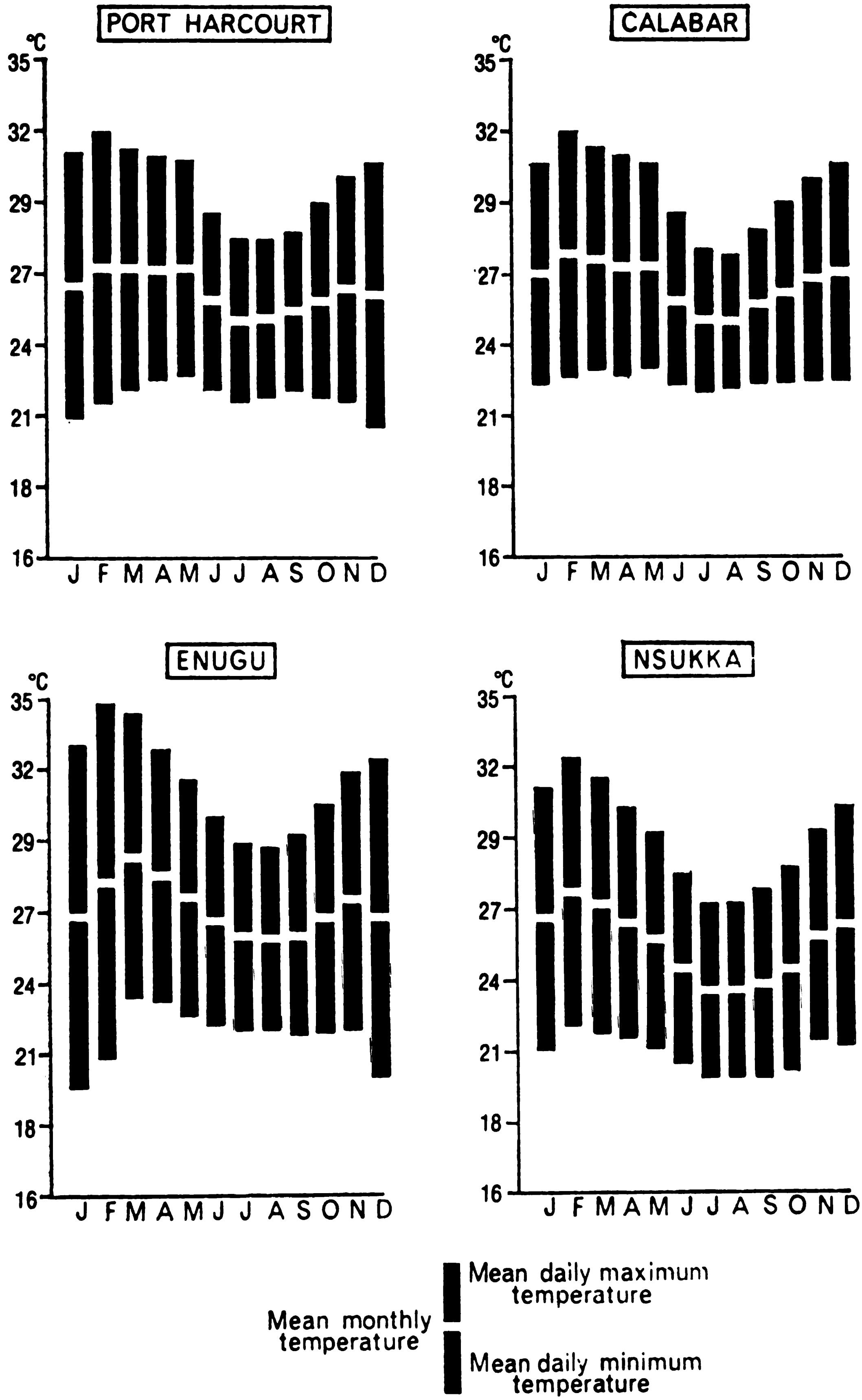


Fig. 4.--Seasonal march of temperatures at selected stations.

The rainfall pattern of the region indicates a continuous decrease from the coast inland. There is a strong influence of a maritime location and altitude and the configuration of the Eastern Nigerian shore is such that the region faces almost squarely the onshore moisture-bearing winds of the Atlantic. The monsoon winds of the wet season give rise to an annual rainfall in excess of 4064 mm (160") in the Delta while Bonny peninsula receives over 4250 mm a year. This convectionally-induced rainfall diminishes rapidly inland. The central areas of the region have an annual rainfall of 2032-2286 mm (80-90"). However local variations in annual rainfall due to terrain, vegetational cover, etc., do exist.

In the light of the mean annual figures, all of Eastern Nigeria may be said to experience a tropical wet climate (Koppen's Af climate), which implies a rainfall surplus. However, it is the seasonal distribution of rain which is critical, rather than the overall receipts, for an excess of rain at one season may be followed by a deficit at another. This is the pattern which obtains in Eastern Nigeria. The relationship between incoming rainfall and evapotranspiration is the true measure of humidity or aridity of a place. If rainfall is greater than potential evapotranspiration the place is humid. If the reverse is true, the place is arid. In these terms, many parts of Eastern Nigeria are "arid" for some part of the year, humid for the remaining months (Figure 5). Unfortunately, measurements of evapotranspiration are not yet available over a wide enough area to permit precise calculation of the water balance on a regional basis.

Basically there are two seasons, namely, the dry season--taken as months with rainfall lower than 62.5 mm (2.5") and this is less than one month at the coast, e.g., Bonny and Brass. This increases gradually inland. In southern inland locations it is two to three months, e.g., Ahoada and Ikot Ekpene; in central inland locations it is three to four months, e.g., Umuahia, Owerri, and Afikpo; in northern inland areas it is four to five months or over, e.g., Nsukka and Ogoja.

The number of rainy days--days with more than 0.25 mm of rain, shows a distribution similar to the quantity of rainfall and the length of the dry season.

Water Resources.--Of the rain which falls over Eastern Nigeria, only a relatively small percentage reaches the water table (Floyd, 1969). This is as a result of a combination of factors, namely, runoff, evaporation and transpiration, geological formations, soil structure and vegetative cover.

From an estimated total of 159.6 billion liters of rain falling on Eastern Nigeria every year, only some 9.9 billion liters remain after deductions accruing from losses via run-off, evapotranspiration, etc. (Mitchell-Thome,

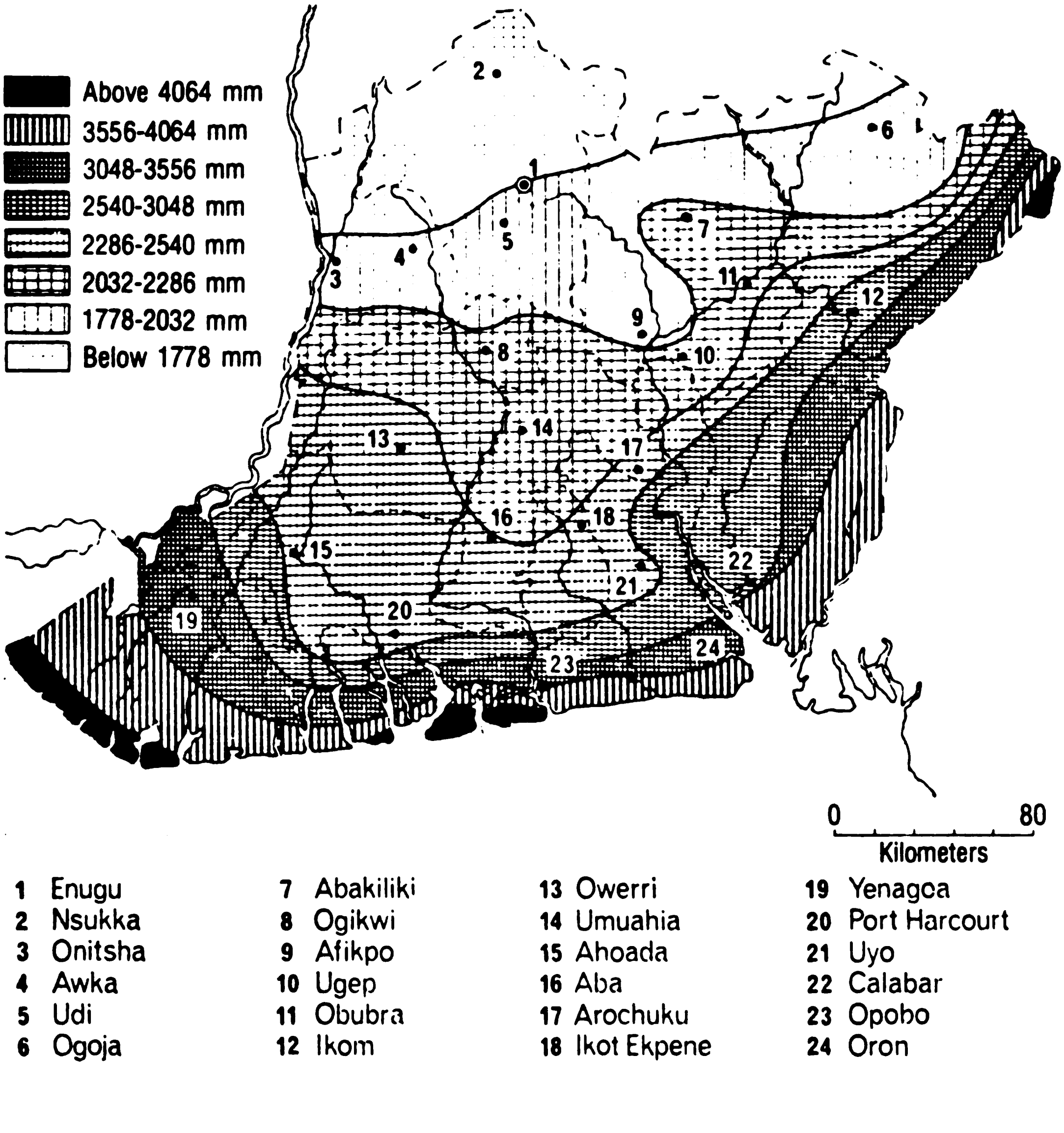


Fig. 5.--Mean annual rainfall, Eastern Nigeria.

1963). Of these 9.9 billion liters, only gravity water attains the zone of saturation, perhaps 5.9 billion liters.

The high rate of natural withdrawal understandably fluctuates from place to place within the region. Figure 6 shows the areal distribution of hydrological provinces in rank order. The area of highest potential as regards recharge (and the lowest rate of natural withdrawal) extends south-eastwards from Onitsha to Oron and includes Awka, Orlu, Owerri, Umuahia, Aba, Ikot Ekpene, Uyo and Eket (Floyd, 1969). It also includes the eastern side of the Nsukka-Okigwi Plateau.

Vegetation.--The human factor which entails settlement and agricultural activities has done a lot to transform the vegetational cover of Eastern Nigeria (Floyd, 1969). Farming invariably involves marked modification, even destruction, of the natural vegetation over wide areas. In the Coastal Plain area, e.g., Owerri, Annang, the widespread cultivation of oil palms (Elaeis guineensis) has produced a distinctive type of vegetation referred to as "oil palm bush" which is quite different from the original rainforest.

The main vegetational zones of Eastern Nigeria are illustrated in Figure 7 though there are variations in the actual vegetation types within each zone. The study area comes under Lowland Rain Forest (tropical rainforest) greatly modified (oil palm 'bush') and hence mature 'climax'

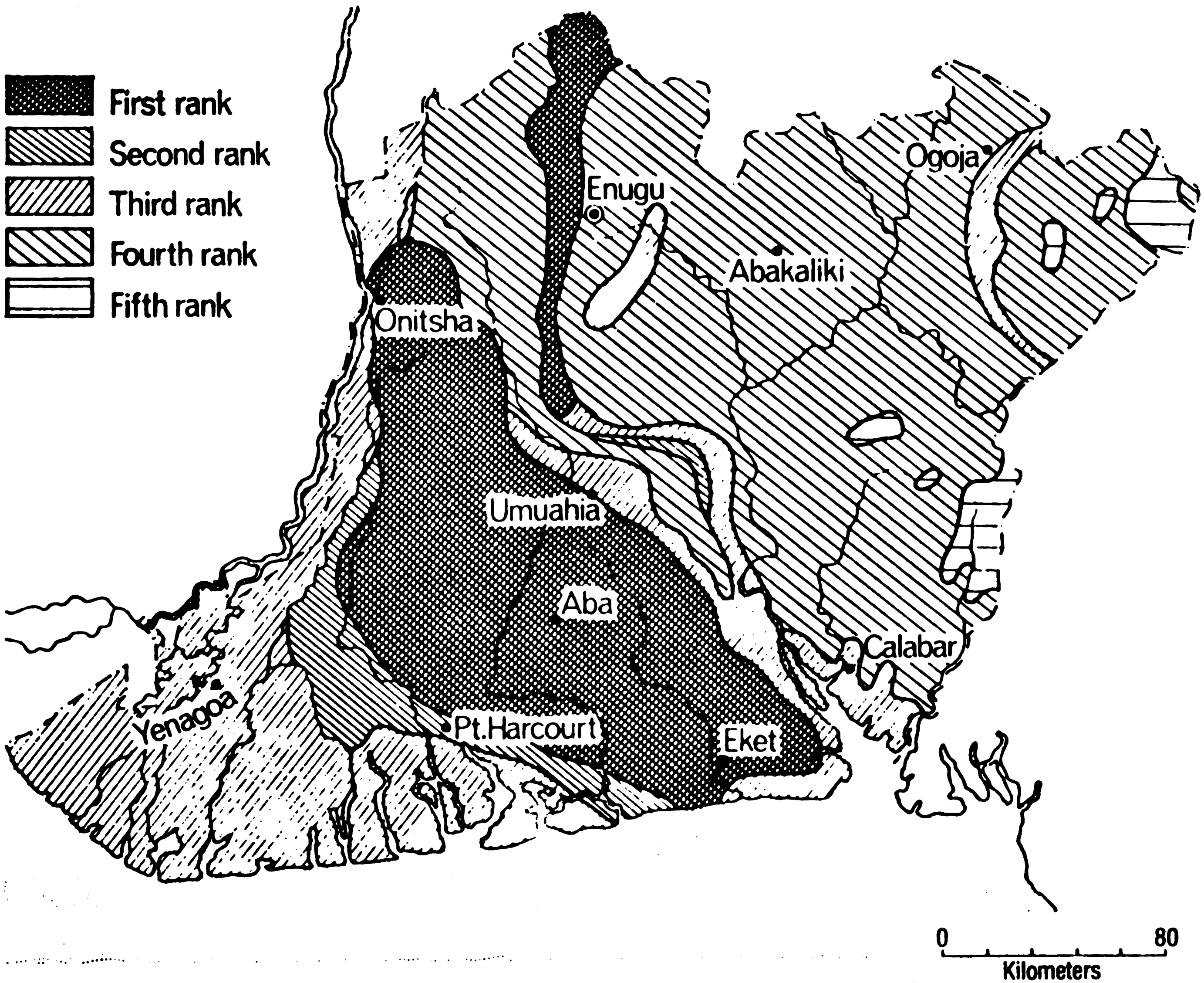


Fig. 6.--Hydrological provinces in rank order (after Mitchell-Thome).

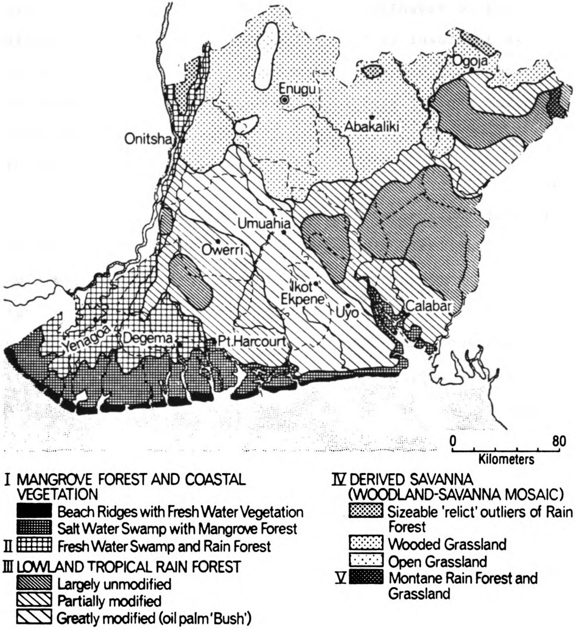


Fig. 7.--Vegetation--Eastern Nigeria (Floyd, 1969).

forests are rare. Over much of the rainforest zone west of the Cross River few areas of undisturbed timber remain. Virgin rainforest in other than small, remote and isolated stretches has virtually disappeared. High secondary growth forest is more abundant, particularly northwest of Port Harcourt, but it is neither as lush nor as luxuriant as the original plant cover. The main trees are the palms and other trees include mangoes (Magnifera indica), avocado pears, bananas (Mush sapientum), oranges (Citrus spp), paw paws (Carica papaya) and plantains.

Geology.--Basement Complex Formation consisting of outcrops of metamorphic and igneous rocks (schists, gneisses, and granites) cover about 15 percent of Eastern Nigeria, Figure 8. It has been described as Pre-Cambrian in age while certain of the schists have been considered Archean in age (among the oldest in the world), dating back nearly three billion years. Reyment (1965) has suggested that two of the major series of rocks, older and younger granites may be much younger, dating from the Lower Palaeozoic and Mid Jurassic ages, respectively.

The Basement Complex is overlain by a series of much younger Upper Cretaceous and Tertiary sedimentary strata, both marine and continental in origin. The sedimentary rocks were laid down either in a great embayment of the sea which reached north and east along the approximate lines of the present Niger and Benue Valleys, or in

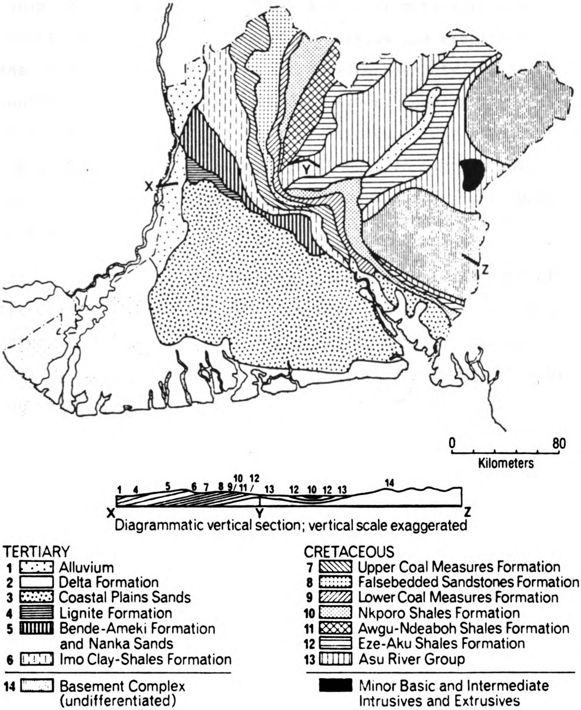


Fig. 8.--Geology of Eastern Nigeria (after R. Monkhouse).

the lacustrine or terrestrial environments left by the retreat of the seas southwards into the present Bight of Benin (Monkhouse, 1966). The sedimentary materials are largely derived from subaerial denudation and erosion of the rocks of the Basement Complex, with possibly smaller contributions from the sedimentary areas bounding the banks of the Niger beyond the territory of present-day Nigeria. Figure 8 illustrates the geology of Eastern Nigeria while Table 2 outlines geological formations and groups of rocks in Eastern Nigeria.

The Coastal Plain Sands.--The sedimentary rocks of the Coastal Plain Sands are the youngest Tertiary beds that occur in Eastern Nigeria. They outcrop over a very wide area, almost 25 percent of the region, and they are probably the most extensive also. They constitute a broad plain sloping gradually towards the sea but northwards they rise to form low hills with elevations of 1800 meters or more above sea level. They occupy the area between a line through Umuduru, Orlu and Ihiala and the coast and form the extensive featureless plains of former Owerri Province which slope gradually seawards. Their extension to both the east and west of this area is also known. Further north they occupy a considerable area around Orlu, Oba, and Nnobi. Evidence of uplift of these younger beds can be gleaned at Itu where there is an obvious juvenile river system actively cutting into the beds. The Imo River cuts

Table 2.--Geological formations and groups of rocks in Eastern Nigeria (Floyd, 1969).

Formation	Group	Age
A. Niger and Cross River Alluvium B. Delta Formation	Delta and Alluvium	Quaternary
C. Coastal Plains Sands	Coastal Plains Sands	Tertiary
D. Lignite Formation E. Bende-Ameki Formation	Bende-Ameki	
F. Imo Clay-shales Formation	Imo Clay-shales	
G. Upper Coal Measures H. Falsebedded Sandstones I. Lower Coal Measures J. Nkporo Shales	Plateau and Escarpment	Cretaceous
K. Awgu-Ndeaboh Shales L. Eze-Aku Shales M. Asu River Group	Cross River Plain Group	
N. Basement Complex	Basement	Largely Pre-Cambrian

through the western part of the Coastal Plain Sands and exposures at certain points along its bank (e.g., near Ife in Mbaise) give a fair picture of the formation which consists of a soft friable yellowish/white falsebedded pebbly sands overlying grey gritty clays not unlike those of the lignite group.

The Coastal Plain group consists of a series of white and honey-colored clayey sands with bands and beds of clay, usually of very fine texture. The sands, which make up by far the greater part of the deposit, possess several characteristics which are always present where good exposures are found, and without which it is unsafe to identify beds as belonging to this group. They are always falsebedded and this is usually a very prominent feature, and they always contain rounded grits and pebbles, sometimes in patches and bands, but more often distributed heterogenously through them. Their lack of consolidation is another striking feature, for they are soft enough to be easily broken out with the hands and lack any cementing material whatever. Good exposures occur also in Itu Division of the Cross River State but current-bedding is nowhere evident.

Their color too is a persistent characteristic where fresh sections are obtained. In the more northern areas of the Coastal Plain Sands the beds may be stained deep red by iron oxides, the direction of staining being top to bottom. The white and honey-colored varieties are abundant but there are variations to purple and red depending on the amount of iron staining present. Their mode of weathering is striking for where the streams are of high grade they carve enormous gulches in these soft deposits and they provide many excellent examples of gully erosion. On top the sands are usually ironstained and become deep chocolate-red in color. Vertically downward this often appears to go to a considerable depth. Instances have frequently been seen, particularly on vertical faces, where the red stain is a mere skin on the unstained sands and has not penetrated horizontally more than about 3 cm. In the Oba neighbourhood there is a very marked similarity between the soft clayey sandstones of the Lignite group and those of the Coastal Plain Sands, but the presence of the persistent characteristics just enumerated will allow the Coastal Plain Sands to be identified with certainty, for the loosely compacted sandstones of the Lignite group are never current-bedded nor do they contain rounded pebbles.

Many exposures of Coastal Plain Sands can be seen in the various tributaries of River Ideh in Agulu. The River Ideh rises on a low watershed on the Bende-Ameki group, drains through Agulu Lake and flows westward to the Niger River. The Coastal Plain Sands are exposed in a series of deep canyon-like gullies which have scarred the hillsides in a remarkable way. They have been cut by the numerous small tributaries which join the main stream from the north and south and their heads are now approaching, in some places, the summits of the ridges.

The Coastal Plain Sands are fluvio-lacustrine in origin and must have been laid down under conditions which were subject to frequent and rapid changes. They are widely distributed over the southern portions of Eastern Nigeria and the Bendel State after a marked subsidence and more transgression in the late Tertiary times under conditions of rapidly changing currents. Much of what some geologists describe as "recent accumulations" are merely surficial materials derived from the Coastal Plain Sands over which they form a thick mantle. They are red sands or sandy earths with a striking monotony of features and lacking any form of stratification and/or sorting. Color range is from light to reddish brown to red.

The relation between the Coastal Plain Sands and the older groups is one of unconformable overlap. South-east of Orlu they overlap the Lignites completely and rest on beds of the Bende-Ameki group. Similarly beyond Oba the Lignites are again obscured by the younger group which at Abagana overlies shales of the Bende-Ameki group, while in the Enugu area they overlie fresh water beds of Cretaceous age, so that there is no doubt that the sands in these areas completely buried the old land surface, from which they are now being actively removed.

Land Use

Some authors have recognized five different systems of farming within Eastern Nigeria, viz., shifting cultivation; bush fallowing; rudimentary sedentary cultivation; intensive sedentary cultivation ("compound farming") and intensive sedentary cultivation (terrace farming). There are no clear-cut distinctions among some of these systems and a few, e.g., terrace farming are restricted to specific areas especially in high elevations like Maku near Awgu, forty-eight kilometers south of Enugu.

Food crops are grown mainly for local consumption and the major crop is yam (Discorea spp.). Shifting cultivation is sometimes called "slash and burn" agriculture. This refers to a system in which the land is cleared manually, most of the vegetation is burned and the land cropped by hand operations for one to two years. The fertility of the land is maintained by leaving it fallow, say for three to seven years, the period being dictated largely by the degree of agricultural population pressure. The system has also been called migratory agriculture which entails periodic movement of fields or plots of crop land (land rotation), also the relocation of villages after the area in the immediate vicinity of the settlement has been worked over for agricultural purposes (Allan, 1967;

Schlippe, 1956). In Nigeria, the homes of the cultivators are usually not moved when the cultivators shift cultivation sites except the few nomadic cattle-rearers of Northern Nigeria.

In the Coastal Plain Sands area the farming system is based on rotation of crops, the use of household refuse on land within the compound, and the application of fertilizers (in very few areas). Mound cultivation, which is common, is probably a satisfactory erosion control, but in many places the farm is still left at the mercy of the heavy rains. Staple grains are rare. Yams (*Discorea* spp.), cocoyam (*Colocasia antiquorum*), cassava (*Manihot utilissima*), maize (*Zea mays*), and plantains are cultivated for food. Palm produce (*Eleais guineensis*) and kola nuts (*Cola nitida*) constitute the major export crops. Cultivation of cash crops is increasingly popular. In many places this has necessitated the abandonment or mitigation of fallow and shifting cultivations, a situation which tampers with the old system of community ownership of farm land.

MATERIALS AND METHODS

Field Procedures

Field studies are an extremely important part of research of this type. The existence of a paucity of soil data was fully recognized during field trips of the Soil Correlation Committee in the Eastern States of Nigeria in 1973 and 1974 (Lekwa, 1974).

The area along a line from Umuahia to Ka (traversing about 140 km), being representative of the Coastal Plain Sands of Nigeria, was selected for preliminary field studies (Figure 1) with the aid of topographic maps (scales 1:50,000; 1:100,000; 1:250,000; and 1:500,000, owing to inadequate coverage of one scale map), the soil map of Eastern Nigeria (scale 1:100,000) and a geological map (1:100,000) of Eastern Nigeria.

This general area was investigated in the field using soils and geomorphological criteria for selection of topo- and lithosequences of soils. Several locations were explored using roadcuts and random soil auger borings in selecting the pedon sites. The transition from "red" soils in the north to "brown" soils in the south of the area (a climosequence), was also considered. Field trips were also made to Benin Division in Bendel State where the Coastal Plain Sands formation is also located.

Each pedon was described as to its position in the landscape and the characteristics of the landform, such as slope, elevation and natural drainage. Observations were also made regarding evidence of active erosion and current land use or vegetative cover. These are recorded in Appendix A.

Fresh pits were dug to a depth of 1.8-2.0 m for examination, description and sampling of soils. An auger was used for deeper sampling where necessary, most commonly to a depth of about 2.5 meters. The deeper samples were taken at arbitrary depth intervals or upon changes in color or texture. Fourteen pedons were examined and described. Particle size distributions were analyzed routinely in the laboratory. Of these, nine were investigated and studied more extensively in the laboratory and are numbered one through nine.

Each pedon was described as to its morphology by horizons according to criteria and terminology discussed in the Soil Survey Manual (Soil Survey Staff, 1951) and were subsequently sampled according to procedures outlined by the Soil Survey Staff (1971).

The samples were taken from the vertical face at the end of the profile pit. Two full bags (1 kg each) of soil were collected from each horizon for laboratory work.

Oriented clods for thin sections were collected from selected horizons. Profile descriptions appear in Appendix A. Location of the profile pits are shown in Figure 1.

Physical Methods

The soil samples were numbered, air-dried, and weighed prior to crushing with a wooden roller. They were then sieved through a 2 mm sieve to separate the fine-earth fraction from the coarse fraction. The material greater than 2 mm was washed, air dried and weighed to determine the coarse fraction content.

Particle-size distribution analyses.--Soil samples corresponding to 50 g of oven-dried samples were shaken overnight using sodium hexametaphosphate as the dispersing agent. Silt and clay fractions were determined by the pipette method (Kilmer and Alexander, 1949). The total sand fraction was separated by wet sieving through a 300-mesh sieve. The sand was further fractionated by dry sieving with the appropriate sieves. All determinations were made in duplicate for each soil sample.

Water retention at 0.3 and 15 bars.--Water saturated samples were equilibrated at 0.3 and 15 bar pressures. Water retention of 0.3 bar was determined in pressure-plate pressure cookers. Water retention at 15 bar was determined in a pressure-membrane apparatus.

The percent of water retained was calculated on an oven-dry basis (Richards, 1949). Water holding capacity of the soil material was calculated as the difference between the 0.3 bar and the 15 bar retentions. The 15 bar water retention multiplied by 2.5 was used to estimate the clay content in each horizon as recommended by the Soil Survey Staff (1975).

Bulk density.--Natural clods of about 25 to 100 cc were covered with a saran-methyl-ethyl ketone (1:4 to 1:8 ratio) solution. After being coated each clod was weighed in air and in water to obtain its volume by Archimedes' principle. The bulk density was corrected for weight and volume of the plastic coating assuming a density of 1:3 g/cc for the coating (Brasher *et al.*, 1966).

Chemical Methods

Soil reaction (pH).--Soil pH was determined in water (1:1 ratio), 1N-KCl (1:1) and in 0.01M·$CaCl_2$ (1:2) (Jackson, 1958; Schofield and Taylor, 1955).

ΔpH.--The value of delta pH was determined by subtracting the soil water suspension pH from the soil 1N-KCl suspension pH (Mekaru and Uehara, 1972).

Cation exchange capacity.--The CEC of the soils was determined by the 1N-NH_4OAC, pH 7.0, method (Soil Survey Investigations Staff, 1967).

Exchangeable bases.--Exchangeable Ca, Mg, K and Na were extracted with 1N-NH_4OAC, pH 7.0. The leachate was evaporated to dryness and the residue dissolved in 6 N-HCl. Calcium and magnesium were determined by titrating with EDTA (Jackson, 1958). Potassium and Na were determined by flame photometry.

Citrate-dithionite-bicarbonate extractable Fe and Al.--Fe and Al were determined by the method described by Mehra and Jackson (1960). Fe in the extracting solution was determined colorimetrically using the potassium thiocyanate method of Jackson (1958). Al was determined colorimetrically using the aluminon method of Hsu (1963).

Ammonium oxalate Al and Fe.-- These were determined by the method outlined by McKeague and Day (1966). The Al in the extracting solution was determined colorimetrically using the aluminon method (Hsu, 1963). The Fe in the extracting solution was determined colorimetrically by the Jackson method (1958).

Extractable Al and exchangeable acidity.--Al was extracted with 1N-KCl. Al was determined by the titration method and colorimetrically as outlined by the Soil Survey Investigations Staff (1967).

Organic carbon and total nitrogen.--The organic carbon content was determined by the Walkley-Black method as described by the Soil Survey Investigations Staff (1967).

Total nitrogen was determined by the Kjeldahl method (Soil Survey Investigations Staff, 1967).

Available phosphorus.--This was determined by two methods:

a. Bray's No. 1 method (1945) with 0.03 N NH_4F + 0.025 N HCl as extractant.

b. North Carolina Method (Nelson *et al*., 1953) with 0.05 N HCl + 0.025 N H_2SO_4 as extractant.

Phosphorus in all the extracting solutions was determined colorimetrically by the ascorbic acid-molybdate blue method of Murphy and Riley (1962).

Inorganic forms of phosphorus.--The fractionation of inorganic P forms was carried out according to the procedure of Chang and Jackson (1957) using Peterson and Corey (1966), and Chang (1962) modifications. Phosphorus in the extracts was determined colorimetrically by the blue color method of Murphy and Riley (1962). Appendix C gives the reagents and procedures in detail.

Phosphorus fixation capacity.--The method of Kurtz *et al*. (1946) was used to measure "phosphorus fixation capacity." A 2 gm sample of soil was shaken for 24 hours with 50 ml of KH_2PO_4 solution containing 6 ppm P and adjusted to pH 7.0. After centrifugation the phosphorus in the supernatant was determined and the amount sorbed obtained by difference.

Mineralogical Methods

Preparation of clay fractions (<2 μm) for x-ray diffraction.--A known weight of soil sample was treated with 1N-sodium acetate solution (buffered to pH 5 with acetic acid), digested and centrifuged, to remove the carbonates (if any) and soluble salts. Organic matter was removed with 30% H_2O_2.

The treated sample was subjected to dithionite-citrate-bicarbonate treatment (Mehra and Jackson, 1960) to remove the free iron oxides. The residue was washed thrice with 1 N-NaCl and once with methanol to remove the citrate-dithionite reagent.

The clay fraction was separated from the soil by dispersion and sedimentation according to procedures described by Kittrick and Hope (1963). The clay suspension, collected in large bottles was flocculated by the additions of solid sodium chloride to give a solution of approximately 0.3 N salt concentration.

The clay samples obtained were washed to remove excess salt. For x-ray diffraction analysis, oriented clay specimens were made by depositing clay suspensions onto glass slides and evaporation. For preliminary tests (pedons 1, 5, 8, 9) two clay suspensions were made and subjected to the following standard treatments suggested by Jackson (1956):

i. Mg-saturation and ethylene-glycol solvation;

ii. K-saturation at room temperature, heating at 350°C and 550°C.

X-ray diffractograms were obtained on the plate specimens using CuKα radiation over the range 2° 2 theta to 30° 2 theta.

From results of the preliminary tests, selected clay samples were subjected to only K-saturation.

Samples from which the iron oxides had not been removed were also analyzed by the x-ray diffraction method.

<u>Mineralogy of the sand and coarse-silt fractions</u>.--After the removal of free iron oxides, organic matter, sand and clay, a particle size separation by sedimentation was made at 20 μm, the lower limit of the coarse silt fraction.

For preliminary tests two sand fractions (0.05-0.2; 0.2 mm-2.0) and a coarse silt fraction were taken of a sample from each profile (upper part of B, as shown by * beside Table 4) was examined by means of optical microscopy. There were only small mineralogical differences percentwise among the subfractions of a given sample, and subsequently only the predominant sand size subfraction (0.05-2 mm) was examined.

Approximately 50 mg of the size fraction (sand or coarse-silt) to be examined was placed on a microscope slide, and mixed thoroughly with five drops of immersion oil of index of refraction, n = 1.54. Line counts were made on all samples with a petrographic microscope. Between 300 and 500 grains were counted for each sample.

Four pedons 1, 4, 8 and 9 were further examined for heavy minerals (>2.85 sp. gravity). The optical and physical mineralogic constants reported by Krumbein and Pettijohn (1938) and Kerr (1959) were used as references to identify opaque and non-opaque minerals.

Micromorphology-Thin Sections

Undisturbed soil samples of selected profiles were collected from the vertical face of the horizons. These vertically and horizontally oriented sections were prepared for each selected horizon by Gary Section Service, Tulsa, Oklahoma.

RESULTS AND DISCUSSIONS

Soil Formation Factors

Climate-temperature.--Climatic data for selected stations within the study area have been used to estimate the soil temperatures. The mean annual air temperatures range between 24°C (75°F) and 27°C (80°F) (Figure 4). There are also pronounced dry and wet seasons. Seasonal temperatures vary primarily with clouds and rain.

As the mean annual air temperature is greater than 8°C (47°F) with adequate rainfall, the soils have a mean soil temperature of about 1.1°C (2°F) higher than the air temperature (Smith *et al.*, 1964). Therefore, it can be concluded that in all the fourteen pedons the mean annual soil temperature at 50 cm depth is higher than 22°C (71.6°F).

In the Tropics, differences between summer and winter soil temperatures are small. The differences between the mean monthly summer and mean monthly winter temperatures at 50 cm depth are less than 5°C (Soil Survey Staff, 1975). Consequently, all the soils in this study are classified in the isohyperthermic temperature class.

Climate-moisture.--For pedons 1-4, 7, 13 and 14, the mean annual rainfall ranges from 2032-2286 mm (80-90 in.) in those areas (Figure 5). The precipitation exceeds the potential evapotranspiration on an annual basis. However, the soils remain depleted of stored water during more than 60 consecutive days (January-March) during the dry season which starts in December. The rainy season starts in late May, with the most intense period being July-August. During this period a considerable surplus of water is in the soil during more than 180 cumulative days, enough to maintain all of the control section constantly moist during more than 90 consecutive days. Based on these data, the soil moisture regime would be ustic for pedons 1-3, 7, 13 and 14. Pedon 4 has an aquic moisture regime.

Pedons 5, 6, 8, 9, 10, 11 and 12 are in an area of greater rainfall, 2286-2540 mm (90-100 in.) (Figure 5). The monthly rainfall: evapotranspiration ratio exceeds one in at least nine months. The dry season is not as pronounced as in the other section of the Coastal Plain Sands areas, suggesting the predominance of an udic soil moisture regime. Pedons 8 and 9 have aquic moisture regimes.

Organisms.--Over the entire area, rainfall is high enough to permit luxuriant native tree growth. Man's agricultural activities modify effectively organisms as a soil formation factor in this area.

On the higher elevations of the northern sites, high population density prevails, with more people involved in farming. The population density thins as one goes south in the study area and there more people are involved in fish farming than in land cultivation. Therefore savanna and derived savanna with few forests prevail on the higher topographic positions while on the lower sites there are more forested areas. However, 'oil palm bush' are found throughout the area. The establishment of a stable plant community is hampered by man's agricultural activities.

The length of fallow in the brush fallow-cropping system, which involves natural biocycling of nutrients, is affected by population density and increased pressure on land. Consequently, the fallow portion is relatively shorter in the northern part of the study area.

<u>Topography</u>.--Eleven of the fourteen pedons (1-3, 5-7, and 10-14) are situated on gently sloping upland surfaces with deep water tables and reflect their regional moisture regimes. These higher topographic sites represent well-drained soils.

On the lower gently sloping surfaces locally, the effect of groundwater is indicated by the somewhat poor and poor natural drainage of the soils (pedons 4, 9 and 8).

Other subfactors in topography such as direction of exposure, slope percent, and shape of land, are not included in the study.

Time.--All the pedons are developed in the same geological formation--Coastal Plain Sands. This formation is of Pliocene age (Floyd, 1969). Soils located on higher surfaces are presumed to be comparatively older than those on lower surfaces that may have been cut into the Coastal Plain Sands later. However, studies of the ages of surfaces are not available in this area to date. All the pedons sampled are deep weathered profiles indicating relatively old soils.

Parent material and lithosequences.--The fourteen pedons are formed from unconsolidated sediments. The deepest soil horizons most similar to the initial materials are the B_3.

Light-colored minerals predominate in the parent materials. The clay mineralogy of the soils tend to be highly kaolinitic as shown later. The textures of the B_3 horizons vary with their clay contents. The textures of the B_3 horizons range from finer fine-loamy to coarse-loamy and sandy.

Lithosequences of well-drained soils with ustic moisture regimes developed in coarse-loamy to finest fine-loamy materials are pedons 13; 14 or 2 or 3; and 1 or 7.

Lithosequences of well-drained soils with udic moisture regimes developed in coarse-loamy to finest fine-loamy materials are pedons 6 or 11 or 12; 5; and 10.

Pedons 4, 9 and 8 have aquic moisture regimes. They formed in sandy, coarse-loamy and fine-loamy materials, respectively. They constitute a chrono-lithosequence as pedon 4 is located on a higher, probably, older surface as well as being formed in sandy material. Pedons 9 and 8 form a lithosequence developed in coarse-loamy and fine-loamy materials, respectively, but as pedon 9 is somewhat poorly drained and pedon 8 is poorly drained, they may actually represent a topo-lithosequence.

Other genetic sequences.--The following genetic sequences are also observable:

i. Toposequences in udic moisture areas are: pedons 8 (poorly drained) and 5 (well-drained) in coarser fine-loamy materials; pedons 9 (somewhat poorly drained) and 6 or 11 or 12 (all well-drained) are in coarse-loamy materials.

ii. Chrono-climosequences: Pedons 11 or 12 or 6 and 13 are all well-drained, in coarse-loamy materials and occur on increasingly higher surfaces (4 to 60 m). Of these pedons only 13 is in an ustic instead of in udic moisture regime. These apparently represent a chrono-climosequence of soils.

Pedons 5 and 2 or 3 or 14 are well-drained and in coarser fine-loamy materials. Pedon 5 is in an udic moisture regime on a lower elevation and a presumably younger surface. Pedon 2 or 3 or 14 is in an ustic moisture regime on a higher elevation and a presumably older surface.

Pedons 10 and 7 or 1 are formed in finer fine-loamy materials and situated in udic and ustic moisture regimes, respectively. They constitute another chrono-climosequence. Biosequences of soils are not visualized in sites studied.

Macromorphology

The detailed morphological descriptions of the studied pedons are presented in Appendix A. Table 3 gives a summary of the field morphological descriptions of the soils.

Within the well-drained profiles a wide range for the color component hue is observed. Soils located on the highest physiographic surfaces (perhaps oldest) in the ustic moisture area (pedons 1-3, 7, 13 and 14) have more reddish subsoils (7.5YR-5YR-2.5YR) than those located in the udic moisture regime (10YR-7.5YR) on the lower physiographic surfaces (pedons 5, 6, 10-12). These represent chrono-climosequences of soils. Each of these groups of soils are formed from coarse-loamy to fine-loamy materials.

Table 3.--Field morphological descriptions of the soils.

Horizon	Depth cm	Color (moist)	Boundary*[a]	Structure*[b] (and consistence)*[c]	Texture
			Pedon 1--150 m. a.s.l.		
Ap	0-10	7.5YR 3/2	ai	cr, (mfr)	sandy loam
B1	10-22	5YR 5/4	g	cr, (mfr)	sandy loam
B21t	22-45	5YR 4/6	i	cr, (mfr)	sandy clay loam
B22t	45-75	5YR 4/8	i	cr, (mfr)	sandy clay loam
B3	75-180	2.5YR 5/8	-	cr, (mfr)	sandy clay loam
			Pedon 2--150 m. a.s.l.		
Ap	0-13	10YR 4/2	g	cr, (mvfr)	sandy loam
B1	13-30	10YR 5/4	g	cr, (mvfr)	sandy loam
B21t	30-55	7.5YR 5/6	g	cr, (wps)	sandy loam
B22t	55-108	5YR 6/6	-	2cr, (ws-wps)	sandy clay loam
B3	108-180	5YR 6/8	-	2cr	sandy clay loam
			Pedon 3--150 m. a.s.l.		
Ap	0-12	5YR 3/2	c,s	1,cr, (mfr)	sandy loam
B1	12-22	2.5YR 3/6	s	2,cr, (mfr)	sandy loam
B21t	22-45	2.5YR 4/6	-	2,cr, (mfr)	sandy clay loam
B22t	45-137	2.5YR 4/6	-	3,abk (dsh)	sandy clay loam
B3	137-180	2.5YR 4/8	-	3,abk (wps)	sandy clay loam

Table 3.--Continued.

Horizon	Depth cm	Color (moist)	Boundary*a	Structure*b (and consistence)*c	Texture
			Pedon 4--145 m. a.s.l.		
Ap	0-12	10YR 4/1	c,s	o,sg (ml)	sand
A21g	12-30	10YR 5/1	c,s	o,sg (ml)	sand
A22g	30-140	10YR 7/1	a,i	o,sg (ml)	sand
Bhirm	140-200	5YR 2/1	-	m (mvfi)	sand
			Pedon 5--60 m. a.s.l.		
Ap	0-13	10YR 3/3	c,s	cr, (mfr)	loamy sand
B1	13-38	10YR 4/4	g	(mfr)	sandy loam
B21t	38-88	10YR 5/6	c,s	2,cr (wps)	sandy clay loam
B22t	88-150	5YR 4/6	c,s	cr, (wps)	sandy clay loam
B3	150-180	7.5YR 5/6	-	sbk	sandy clay loam
			Pedon 6--50 m. a.s.l.		
Ap	0-18	10YR 3/3	-	cr	sandy loam
B1	18-53	10YR 4/4	-	cr	sandy loam
B21	53-110	10YR 5/4	-	cr	sandy loam
B22	110-143	7.5YR 5/6	-	cr	sandy loam
B3	143-180	7.5YR 5/8	-	cr	sandy loam

Table 3.--Continued.

Horizon	Depth cm	Color (moist)	Boundary*a	Structure*b (and consistence)*c	Texture
			Pedon 7--106 m. a.s.l.		
Ap	0-20	7.5YR 4/4	ai	cr, (mfr)	sandy loam
B21t	20-55	5YR 4/3	-	cr, (mfr)	sandy clay loam
B22t	55-100	5YR 5/6	i	cr, (mfr)	sandy clay loam
B31	100-150	2.5YR 5/6	-	cr, (mfr)	sandy clay loam
B32	150-210	2.5YR 5/8	-	sbk	sandy clay loam
			Pedon 8--20 m. a.s.l.		
Ap	0-10	5YR 2/1+10YR 5/1	a,s	cr, (mfr)	sandy loam
A2g	10-23	10YR 6/1	c	m, (mfr)	sandy loam
B21tg	23-40	10YR 7/1+10YR 6/6	i	1,sbk (mfr)	sandy loam
B22tg	40-72	10YR 6/1+5YR 5/6	c,w	sbk (dsh)	loam
IIB23tg	72-120	10YR 6/1+7.5YR 5/8	c,w	1-2,sbk (mfi)	sandy clay loam
IIB3	120-180	2.5Y 6/2	-	sbk, (mfvi)	sandy clay loam-sandy loam
			Pedon 9--30 m. a.s.l.		
A1	0-2	10YR 2/2	a,s	o,sg (ml)	sandy loam
A2	2-10	10YR 4/2	c,s	1,vf sbk (mvfr)	sandy loam
IIB21tg	10-28	10YR 5/2, mottled	c,s	2,m,sbk (mvfr)	sandy loam
IIB22tg	28-87	2,5Y 6/2, mottled	c,s	1,m,sbk (mfr)	sandy loam
IIB3	87-180	2.5Y 7/2, mottled	-	2,m,sbk (mfr)	sandy loam

Table 3.--Continued.

Horizon	Depth cm	Color (moist)	Boundary*a	Structure*b (and consistence)*c	Texture
		Pedon 10--30 m. a.s.l.			
Ap	0-15	10YR 2/2	-	1,f,cr (mvfr)	sand-loamy sand
AB	15-40	10YR 3/3	-	1,f,cr (mvfr)	sand
B21t	40-80	7.5YR 4/3	d	1,f,cr (mvfr)	sandy clay loam
B22t	80-130	7.5YR 5/6	d	1,sbk (wps)	sandy clay loam
B3	130-180	7.5YR 5/4, mottled	-	1,f,sbk	sandy clay loam
		Pedon 11--4 m. a.s.l.			
Ap	0-20	10YR 2/2	-	1,f	sand
AB1	20-40	10YR 3/3	g	1,cr	sand
AB2	40-60	10YR 3/2	-	1,f,cr	loamy sand
B1	60-85	10YR 3/3	-	(mvfr)	sandy loam
B2t	85-185	10YR 5/4-5/6	-	(mfr)	sandy loam
		Pedon 12--8 m. a.s.l.			
A1	0-2	10YR 3/2	a,w	2,f,cr (mvfr)	loamy sand
AB	2-18	10YR 3/3	-	1,c,sbk	loamy sand
B21t	18-50	7.5YR 4/3	cw	1,m,sbk	sandy loam
B22t	50-80	7.5YR 4/4	g,s	1,c,sbk	sandy clay loam
B3	80-180	7.5YR 5/6	-	2,c,sbk	sandy clay loam

Table 3.--Continued.

Horizon	Depth cm	Color (moist)	Boundary*[a]	Structure*[b] (and consistence)*[c]	Texture
Pedon 13--60 m. a.s.l.					
Ap	0-15	10YR 4/2	c,w	o,sg (dl)	sand
AB	15-51	10YR 3/3	g	2,c,sbk (ds)	loamy sand
B21t	51-111	7.5YR 5/4	g,s	2,c,sbk (dsh)	sandy loam
B3	111-190	7.5YR 5/6	-	2,c,sbk (dh)	sandy loam-sandy clay loam
Pedon 14--105 m. a.s.l.					
Ap	0-10	10YR 4/2	a,s	o,sg (dl)	sand
AB	10-40	10YR 3/3	c,s	1,f,cr-2c sbk (ds)	loamy sand
B21t	40-100	7.5YR 4/4	g,s	2,c-m,sbk (dsh)	sandy loam-sandy clay loam
B3	100-190	7.5YR 5/6	-	2,c,sbk (dh)	sandy clay loam

[a] a=abrupt, c=clear, d=diffuse, g=gradual, i=irregular, s=smooth, w=wavy.

[b] o=structureless, 1=weak, 2=moderate, 3=strong, c=coarse, cr=crumb, f=fine, m=massive, sbk=subangular blocky, sg=single grain, vf=very fine,

[c] dh=hard (dry soil), dl=dry loose, ds=dry soft, dsh=dry slightly hard, mfi=moist firm, mfr=moist friable, ml=moist loose, mvfi=moist very firm, mvfr=moist very friable, wps=wet slightly plastic, ws=wet sticky.

Soils developed in finer fine-loamy materials located on high surfaces show more reddish subsoils than those developed in coarser fine-loamy or coarse-loamy materials with the same moisture regime (pedon 1 or 7; pedon 2 or 3 or 14; and pedon 13, respectively). These are a lithosequence of well-drained soils with ustic moisture regime.

Pedons 5 and 10 have comparatively more reddish subsoils (10YR-5YR-7.5YR) than pedon 11, 12 or 6 (10YR; 7.5YR or 7.5YR). All are well-drained soils with an udic moisture regime and are a lithosequence. Pedons 5 and 10 developed in fine-loamy materials and pedons 11, 12 and 6 are coarse-loamy.

There are redder subsoils in well-drained soils with ustic moisture regimes while the udic soils on comparable textured materials (except pedon 12) have more yellowish subsoils. These are climosequences of soils. The udic soils are also on lower surfaces (4-60 m) than the ustic soils (60-150 m) and are probably younger. So these may actually be chrono-climosequences of soils.

The more poorly drained soils (pedons 8 and 9) are paler, more mottled and more yellowish-brown in subsoil colors (10YR-2.5Y) (Table 3). They are found mostly in the southern zone of the study area at lower elevations. Pedon 4, though poorly drained, has a more reddish and darker (5YR 2/1) subsoil than pedons 8 and 9. It is situated on an area with an ustic moisture regime, at a higher elevation, and it has a spodic instead of an argillic subsoil horizon.

Pedons 8 and 5 are located in an udic moisture regime area with higher annual rainfall and both developed from coarser fine-loamy materials. Pedon 5 has a brighter less gray and more reddish subsoil (10YR-5YR-7.5YR) than pedon 8 (10YR-2.5Y). These differences represent a toposequence of soils.

However, within the entire study area, well-drained soils with reddish subsoils can be found where soils with yellowish brown subsoils predominate and vice-versa. This is shown by pedon 5 with yellowish red (5YR 4/6) subsoil from 88-150 cm in the udic area, and by pedons 13 and 14 with brown to strong brown (7.5YR 4/4-5/6) subsoils in the ustic area. Since the increase in the annual rainfall and its intensity towards the south is gradual (that is from Umuahia to Port Harcourt, Figure 5), the boundary between the two groups of 'colored' soils is not sharp.

The degree of structure development shows little change with depth in well-drained pedons 1, 2 and 6. There is some difference in the consistence and this is due to more clay in the subsoil and more plasticity and stickiness, particularly in pedon 2. Pedon 6 is developed in coarser parent material (coarse-loamy) on lower physiographic positions.

In most of the other well-drained pedons (3, 5, 7, 10, 12, 13 and 14) one can observe structure development increase from A to the lower B horizons in the form of crumb to subangular blocky structures. The development of fairly well expressed crumb structure in the upper horizons is attributed to the presence of grass and forest regrowth and higher contents of organic matter. There are no obvious genetic sequence relationships between the well drained soils with these observed differences in structure development.

Among the more poorly drained soils, the structure development in pedon 8 increases from A to B horizons, going from massive to medium subangular blocky. Compared to the other pedons studied, this one exhibits more stickiness when moist and more hardness when dry. As in pedon 8, pedon 9 has increased structure development from A_1 to B, structureless to subangular blocky, respectively. Worm holes and humus coated sand grains are observable within the horizons.

Pedons 4, 8, and 9 are the poorly drained (pedons 4 and 8) and somewhat poorly drained (pedon 9) members of the soils under study. All of them have eluvial and illuvial horizons clearly visible as do the associated well drained soils, except pedon 6.

Pedon 4 has homogenous textural classes of sand from the Ap to the Bhirm horizon. It shows a weak expression of structure and consistence which is a reflection of the low amount of clay and high sand content. An iron-humus pan is encountered below 140 cm in the massive Bhirm horizon. The consistence at this horizon is very firm and compact. The base of this iron-humus pan was not reached. This kind of soil is associated with very sandy parent materials in poorly drained situations in the study area.

Physical Properties

Particle size distribution.--The particle size distribution data for the fourteen pedons are shown in Table 4.

The upper horizons of these soils have a lower content of clay (except pedons 4 and 6) and are higher in sand (except pedons 4, 6 and 9) than the subsoil horizons. Several processes help to explain these properties.

a. Eluviation and illuviation.--Eluviation is the process whereby clay is mobilized in the upper horizons and is transported in suspension down to the lower horizons. This process is reflected in the development of eluvial upper horizons (A_1, A_2). Illuviation is the process of formation of a zone of accumulation of the clay or other eluviated material in the lower part of the solum. The presence of an A_2 horizon does not automatically result

Table 4.--Particle size distributions in percent, clay fraction ratios, and textural classes.

Horizon	Depth cm	Sand, mm		Silt, mm		Clay, µ			Ratios		Textural** Class
		Coarse 2-.25	Fine .25-.05	Coarse .05-.02	Fine .02-.002	Coarse 2-.2	Fine < .2	Total < 2.	Fine clay/ Coarse clay	Fine clay/ Total clay	
		%									
						Pedon 1--AMS1					
Ap	0-10	51	30	1	3	6.9	8.1	15	1.3	.54	SL
B1	10-22	45	33	1	4	7.1	9.9	17	1.4	.58	SL
*B21t	22-45	42	25	0	5	10.8	17.2	28	1.6	.61	SCL
B22t	45-75	42.5	19	0.5	4	13.1	20.9	34	1.6	.61	SCL
B3	75-180	40	21	2.0	3	13.0	21.0	34	1.6	.62	SCL
						Pedon 2--AMM2					
Ap	0-13	59	15	1	10	6	9	15	1.5	.60	SL
B1	13-30	56	14	1	13	7.4	9.6	16	1.5	.60	SL
*B21t	30-55	57	13	1	10	7.1	11.9	19	1.7	.63	SL
B22t	55-108	55	10	1	13	7.5	13.5	21	1.8	.64	SCL
B3	108-180	53	11	2	13	7.8	13.2	21	1.7	.63	SCL
						Pedon 3--AMF3					
Ap	0-12	62	18	2	4	6.4	7.6	14	1.2	.54	SL
B1	12-22	56	19	3	5	7.4	9.6	17	1.3	.56	SL
*B21t	22-45	52	12	7	8	7.5	13.5	21	1.8	.64	SCL
B22t	45-137	58	12	3	5	7.4	14.6	22	2.0	.67	SCL
B3	137-180	60	8	4	7	8.0	13.0	21	1.6	.62	SCL
						Pedon 4--AMM4					
Ap	0-12	74	23	1	0	.9	1.1	2			S
A2g	12-30	64	33	1	0	.8	1.2	2			S
*A22g	30-140	60	38	1	0	0.0	1.0	1.0			S
Bhirm	140-200	59	37	2	0	1.0	1.0	2.0			S

Table 4.--Continued.

Horizon	Depth cm	Sand, mm Coarse 2-.25	Sand, mm Fine .25-.05	Silt, mm Coarse .05-.02	Silt, mm Fine .02-.002	Clay, μ Coarse 2-.2	Clay, μ Fine < .2	Clay, μ Total < 2.	Ratios Fine clay/ Coarse clay	Ratios Fine clay/ Total clay	Textural** Class
		%									
					Pedon 5--ASU5						
Ap	0-13	56	26	2	5	5	6	11	1.2	.55	LS
B1	13-39	59	23	1	2	6.5	8.5	15	1.3	.57	SL
*B21t	38-88	51	19	0	9	8	13	21	1.6	.62	SCL
B22t	88-150	50	22	2	2	9	15	24	1.7	.62	SCL
B3	150-180	46	27	1	3	8.5	14.5	23	1.7	.63	SCL
					Pedon 6--AK6						
Ap	0-18	69	14	0	2	6	9	15	1.5	.60	SL
B1	18-53	69	13	1	3	6	8	14	1.3	.57	SL
B21	53-110	65	18	1	1	6.5	8.5	15	1.3	.56	SL
*B22	110-143	49	33	0	3	6	9	15	1.5	.60	SL
B3	143-180	63	15	1	3	8	10	18	1.3	.56	SL
					Pedon 7--UM7						
Ap	0-20	61	19	0	4	7	9	16	1.3	.56	SL
*B21t	20-55	54	21	0	3	9.5	13.5	22	1.6	.61	SCL
B22t	55-100	55	14	0	2	10	19.0	29	1.9	.66	SCL
B31	100-150	54	14	0	3	10.5	18.5	29	1.8	.64	SCL
B32	150-210	55	12	0	3	11.1	18.9	30	1.7	.63	SCL
					Pedon 8--PH8						
Ap	0-10	31	32	11	18	4	4	8	1.0	.50	SL
A2g	10-23	29	27	11	17	7.3	8.7	16	1.2	.54	SL
*B21tg	23-40	30	23	10	18	1.9	17.1	19	9.0	.90	SL
B22tg	40-72	27	20	10	19	8.3	15.7	24	1.9	.65	L
IIB23tg	72-120	34	20	7	13	8.4	17.6	26	2.1	.68	SCL
IIB3	120-180	30	33	9	8	6.2	13.8	20	2.2	.69	SCL-SL

Table 4.--Continued.

Horizon	Depth cm	Sand, mm Coarse 2-.25	Sand, mm Fine .25-.05	Silt, mm Coarse .05-.02	Silt, mm Fine .02-.002	Clay, μ Coarse 2-.2	Clay, μ Fine < .2	Clay, μ Total < 2.	Ratios Fine clay/ Coarse clay	Ratios Fine clay/ Total clay	Textural** Class
		%									
Pedon 9--ET9											
A1	0-2	55	20	12	5	3.8	4.2	8	1.1	.53	SL
A2	2-10	49	25	10	7	3.9	5.1	9	1.3	.57	SL
*IIB21tg	10-28	50	25	6	4	1.5	13.5	15	9.0	.90	SL
IIB22tg	28-87	60	15	2	5	4.5	13.5	18	3.0	.75	SL
IIB3	87-180	59	16	1	6	5.1	12.9	18	2.5	.72	SL
Pedon 10--BO10											
Ap	0-15	30	59	1	2			8			S-LS
AB	15-40	44	46	0	3			7			S
B21t	40-80	28	44	1	2			25			SCL
B22t	80-130	26	42	1	4			27			SCL
B3	130-190	25	41	0	3			31			SCL
Pedon 11--IK11											
Ap	0-20	60	29	4	2			6			S
AB1	20-40	66	24	1	2			7			S
AB2	40-60	69	20	0	2			9			LS
B1	60-85	58	24	2	3			13			SL
B2t	85-185	57	23	2	4			14			SL
Pedon 12--KaL12											
A1	0-2	61	19	4	9			7			LS
AB	2-18	63	20	3	6			8			LS
B21t	18-50	59	11	7	10			13			SL
B22t	50-80	58	8	5	7			22			SCL
B3	80-180	60	7	4	6			23			SCL

Table 4.--Continued.

Horizon	Depth cm	Sand, mm Coarse 2-.25	Sand, mm Fine .25-.05	Silt, mm Coarse .05-.02	Silt, mm Fine .02-.002	Clay, μ Coarse 2-.2	Clay, μ Fine < .2	Clay, μ Total < 2.	Ratios Fine clay/ Coarse clay	Ratios Fine clay/ Total clay	Textural** Class
		%									
					Pedon 13--OKN13						
Ap	0-15	70	19	0	5			6			S
AB	15-51	79	7	0	1			13			LS
B21t	51-111	67	10	2	5			16			SL
B3	111-190	60	15	2	3			20			SL-SCL
					Pedon 14--EZ14						
Ap	0-10	80	10	2	3			5			S
AB	10-40	70	15	3	4			8			LS
B21t	40-100	61	14	1	4			20			SL-SCL
B3	100-190	60	11	1	1			27			SCL

**SL=sandy loam; SCL=sandy clay loam; S=sand; LS=loamy sand; L=loam.

*Sample examined for mineralogy of coarse silt and fine sand (.25-.02 mm) fractions.

in the development of an argillic horizon. This can be seen in pedon 4 which, though it has an A_2g horizon, has no argillic horizon. Removal of other materials like hydrous oxides of Fe, Al, or humus can lead to an ochric epipedon especially in a sandy material like pedon 4. This is further shown by the development of a spodic horizon (a humus-iron pan at below 140 cm) in that pedon instead of a clay accumulation.

Eluviation processes cannot explain the lack of differences in the sand contents between the A and B horizons of pedon 9. However, in pedon 9 differences in clay content of the A and B horizons are evident. In pedon 6 there is little or no field evidence of argillans in the B horizon, and no laboratory evidence of more sand in the surface or more clay in the subsoil. However, it is possible that the mobilized clay once in suspension has not been deposited in the solum; or that subsequent weathering and solution, or pedoturbation has destroyed any evidence of clay eluviation and clay accumulation.

These seem to be deeply weathered soils and the clay contents of B_3 horizons seem to be higher than those of the upper part of the profiles. This may be associated with more clay decomposition deeper in the profile after the soils had attained a reasonable degree of weathering.

In pedons 8 and 9 with aquic moisture regimes the eluvial and illuvial processes could be expected to be more important while on slightly higher better drained soils on convex slopes (including all pedons except 4, 8 and 9), erosion could also be active.

b. Erosion.--The particle size fraction distributions can be altered due to differential removal through erosion. The clay fraction once suspended in surface run-off would remain in suspension for a longer period than would the coarser fractions. This could result in its differential removal. Moss (1965) and Vine (1949) have attributed the occurrence of more sandy surface soils in some parts of Africa, to this process.

c. Faunal activity.--Working in Africa, Nye (1955a) observed that material moved to the surface by ants was more sandy than the soil below the surface. Ant-hills and thin depositions of sandy materials on leaves of the forest floor have been noticed during field study. In some areas of the Coastal Plain Sands activities of termites, earthworms and other burrowing animals have also been observed. No extensive studies were done on these materials to determine their physical and chemical compositions.

It is possible that burrowing creatures may help move clay, instead of sand, to the surface and termite activity, for example, may affect more than the plow layer. Worm-holes and casts were observed down to 125 cm in some pedons during the field study. However, while no examples can be cited now, it is likely that other faunal activity may also contribute to these profile differences.

d. Lithosequences.--In pedons 2 or 3, 13, 14, 1 or 7 (all well drained and in the ustic moisture regime), there are greater clay contents in the B horizons and less sand content in their A horizons as their B_3 horizons are lower in sand and higher in clay. These pedons are lithosequences developed in coarse-loamy to fine-loamy materials.

Among the lithosequences of well drained soils with udic moisture regimes (pedons 11, 12 or 6, 5 and 10), there are similar profile texture differences with differences in the textures of the B_3 except that there is little difference in textural differentiation in pedon 6. The reason for this lack of texture profile development in pedon 6 is not known. Pedons 11 or 12; 5; and 10 developed in coarse-loamy to finer fine-loamy materials, respectively.

Considering the soils with aquic moisture regimes and without spodic horizons, pedons 8 (poorly drained) and 9 (somewhat poorly drained) may represent a lithosequence or topo-lithosequence of soils. Both pedons show evidence of vertical variations in parent materials in their lower silt contents of the deeper horizons, those with II's preceding their horizon designations. This is also evident in no change of sand content with depth in pedon 9. Pedon 8 is lower in sand throughout and higher in silt.

It is also higher in clay content beneath the Ap horizon. Both pedons show markedly higher fine clay:total clay ratios particularly in their B21tg horizons and these ratios are higher in the deeper horizons than in their upper horizons, indicating eluvial surfaces and illuvial subsoils.

e. Toposequences.--Considering the toposequences pedons 9 and 11 or 12 in coarse-loamy materials or 8 and 5 in fine-loamy materials, there is a more gradual increase in clay content beginning deeper from the surface in the better drained soils. The ratio of fine clay:total clay is greater in the upper subsoil of pedon 8 compared to pedon 5 indicating more fine clay movement into the upper subsoil. However, pedon 8 is higher in silt content than 5 and so this should be considered a litho-toposequence of soils. Evidences of climo-sequences of soils are not shown by differences in particle size distributions.

f. Ratios, fine clay/coarse clay and fine clay/total clay.--In Table 4 the fine clay and coarse clay percentages in eight of the pedons show that the downward increase in clay is accounted for largely by the fine-clays. Illuviation of fine clays is shown more distinctly by the fine clay:coarse clay ratios. The magnitude of this ratio increases with depth, in all but pedon 6, as would be expected if most illuviation is in the fine clay fraction. In five of the seven profiles this ratio reaches a maximum and decreases with further depth. This maximum is nearest the surface in the more poorly drained pedons 8 and 9.

Of all the pedons, the fine clay:total clay ratio for identification of argillic horizon (Soil Survey Staff, 1975) is well shown by pedons 8 and 9 which have poor and somewhat poor natural drainage, respectively. They meet the one-third greater fine clay to total clay ratios that has been used as an index of pedological development for argillic horizons. Their maxima fine:total clay ratios are in their upper Bt horizons.

g. Ratio, % 15-bar water/% clay.--The ratio, percent 15-bar water to percent clay determined with the Calgon-pipette method has been used as a substitute way to judge the degree of dispersion attained in particle size distribution analysis (Soil Survey Staff, 1975). This ratio does not exceed 0.6 if the clay readily disperses. The effect of removal of Fe and Al oxides and hydrous oxides on dispersion was not determined here. Values between 0.36 and 0.41, a mean of 0.38, are found in the nine soils studied (Table 5). In many cases the values increased slightly with depth.

Comerma (1968) and later Benavides (1973) used this ratio as a criterion to judge the degree of weathering of some soils of Venezuela and Colombia. Comerma (1968)

Table 5.--Fifteen bar water percent, total clay by pipette method or calculated clay from 15 bar water content x 2.5 and ratio 15 bar water:clay.

Horizon	Depth cm	15-bar water %	Clay		15-bar H_2O %
			Pipette	15-bar water x 2.5	Clay %
			Pedon 1--AMS1		
Ap	0-10	5.5	15	13.8	0.36
B1	10-22	6.4	17	16.0	0.37
B21t	22-45	11.0	28	27.5	0.39
B22t	45-75	14.5	37	36.3	0.39
B3	75-180	13.4	34	33.5	0.39
			Pedon 2--AMM2		
Ap	0-13	5.4	15	13.5	0.36
B1	13-30	6.3	16	15.8	0.39
B21t	30-55	7.5	19	18.8	0.39
B22t	55-108	8.3	21	20.8	0.39
B3	108-180	8.5	21	21.3	0.40
			Pedon 3--AMF3		
Ap	0-12	5.4	14	13.5	0.38
B1	12-22	6.8	17	17.0	0.40
B21t	22-45	8.2	21	20.5	0.39
B22t	45-137	8.6	22	21.5	0.39
B3	137-180	8.4	21	21.0	0.40

Table 5.--Continued.

Horizon	Depth cm	15-bar water %	Clay		15-bar H_2O %
			Pipette	15-bar water x 2.5	Clay %
			Pedon 4--AMM4		
Ap	0-12	0.6	2	1.5	0.30
A21g	12-30	0.8	2	2.0	0.40
A22g	30-140	0.19	0.5	0.48	0.38
Bhirm	140-200	0.8	2	2.0	0.40
			Pedon 5--ASU5		
Ap	0-13	4.2	11	10.5	0.38
B1	13-38	5.8	15	14.5	0.38
B21t	38-88	8.5	21	21.3	0.40
B22t	88-150	9.7	24	24.3	0.40
B3	150-180	9.2	23	23.0	0.40
			Pedon 6--AK6		
Ap	0-18	5.6	15	14	0.37
B1	18-53	5.4	14	13.5	0.38
B21	53-110	5.5	15	13.8	0.36
B22	110-143	5.6	15	14.0	0.36
B3	143-180	7.1	18	17.8	0.39

Table 5.--Continued.

Horizon	Depth cm	15-bar water %	Clay		15-bar H_2O %
			Pipette	15-bar water x 2.5	Clay %
			Pedon 7--UM7		
Ap	0-20	6.0	16	15	0.37
B21t	20-55	8.6	22	21.5	0.39
B22t	55-100	11.8	29	29.5	0.41
B31	100-150	11.9	29	29.8	0.41
B32	150-210	12.0	30	30.0	0.40
			Pedon 8--PH8		
Ap	0-10	3.4	8.4	8.5	0.40
A2	10-23	6.4	16.3	16.0	0.39
B21tg	23-40	7.3	18.2	18.3	0.40
B22tg	40-72	9.2	23.5	23.0	0.39
IIB23tg	72-120	10.3	26.2	25.8	0.39
IIB3	120-180	4.0	10.3	10.0	0.38
			Pedon 9--ET9		
A	0-2	3.0	8	7.5	0.37
A2	2-10	3.2	9	8.0	0.35
IIB21tg	10-28	5.0	15	12.5	0.30
IIB22tg	28-87	7.0	18	17.5	0.38
IIB3	87-180	6.8	18	17.0	0.38

proposed values below 0.3 for highly weathered soils; values values between 0.3 and 0.4 characterize soils having an intermediate degree of weathering, and values above 0.4 are typical of recent alluvial soils. Most of the soils of the study area can be characterized as having an intermediate degree of weathering using this ratio.

h. Available water.--Available water is estimated as the difference between the water available at field capacity (0.3 bar tension) and the water content at the permanent wilting point (15 bar tension) (Peters, 1965).

Studies conducted on Hawaiian oxisols have shown that water retention in the tension range between 0 and 0.3 bar is primarily influenced by the size, shape and arrangement of the soil aggregates, whereas the size, shape and arrangement of the soil particles play the dominant role at higher tensions (Sharma and Uehara, 1968a; El Swaify *et al*., 1970).

Table 6 presents data on the moisture retention properties of the nine pedons. According to the data the moisture retention capacity at both 0.3 and 15 bars is closely related to the properties of the clay fraction. They commonly increase with depth. The moisture retained at 0.3 bar tension if measured in undisturbed soil samples is considered to be somewhat indicative of the field moisture holding capacity. However, in some soils, especially sandy soils, this measurement may underestimate this

Table 6.--Bulk density, percent water retention at 0.3 and 15-bar tensions, percent available water, and total available water.

Horizon	Depth cm	Bulk Density g/cc	0.3 bar H_2O %	15-bar H_2O %	Available water* 0.3 - 15-bar %	Total available water g/cm^2 to 180 cm
			Pedon 1--AMS1			
Ap	0-10	1.60	12.6	5.5	7.1	
B1	10-22	1.58	12.2	6.4	5.8	
B21t	22-45	1.63	19.8	11.0	8.8	
B22t	45-75	1.62	24.7	14.5	10.2	
B3	75-180	1.60	22.7	13.4	9.3	26.1
			Pedon 2--AMM2			
Ap	0-13	1.55	9.8	5.4	4.4	
B1	13-30	1.56	11.2	6.3	4.9	
B21t	30-55	1.59	11.3	7.5	3.8	
B22t	55-108	1.61	15.6	8.3	7.3	
B3	108-180	1.64	16.2	8.5	7.7	19.0
			Pedon 3--AMF3			
Ap	0-12	1.50	10.1	5.4	4.7	
B1	12-22	1.53	13.4	6.8	6.6	
B21t	22-45	1.56	15.6	8.2	7.4	
B22t	45-137	1.62	16.3	8.6	7.7	
B3	137-180	1.59	16.2	8.4	7.8	21.3

Table 6.--Continued.

Horizon	Depth cm	Bulk Density	0.3 bar H_2O	15-bar H_2O	Available water* 0.3 - 15-bar	Total available water g/cm^2 to 180 cm
		g/cc		%		
			Pedon 4--AMM4			
Ap	0-12	1.65	0.72	0.6	0.12	
A21g	12-30	1.51	1.20	0.8	0.40	
A22g	30-140	1.45	0.30	0.19	0.11	
Bhirm	140-200	1.68	1.50	0.80	0.70	1.01
			Pedon 5--ASU5			
Ap	0-13	1.53	7.6	4.2	3.6	
B1	13-38	1.60	11.7	5.8	5.9	
B21t	38-88	1.59	15.2	8.5	6.7	
B22t	88-150	1.63	17.7	9.7	8.0	
B3	150-180	1.62	17.3	9.2	8.1	20.4
			Pedon 6--AK6			
Ap	0-18	1.59	10.2	5.6	4.6	
B1	18-53	1.63	12.3	5.4	6.9	
B21	53-110	1.62	12.3	5.5	6.8	
B22	110-143	1.64	11.0	5.6	5.4	
B3	143-180	1.61	13.2	7.1	6.1	18.0

Table 6.--Continued.

Horizon	Depth cm	Bulk Density	0.3 bar H_2O	15-bar H_2O	Available water* 0.3 - 15-bar	Total available water g/cm^2 to 180 cm
		g/cc	%			
			Pedon 7--UM7			
Ap	0-20	1.60	11.2	6.0	5.2	
B21t	20-55	1.59	17.3	8.6	8.7	
B22t	55-100	1.65	21.5	11.8	9.7	
B31	100-150	1.64	21.8	11.9	9.9	
B32	150-210	1.63	22.8	12.0	10.8	27.1
			Pedon 8--PH8			
Ap	0-10	1.59	15.4	3.4	12.0	
A2	10-23	1.55	20.2	6.4	13.8	
B21tg	23-40	1.64	19.9	7.3	12.6	
B22tg	40-72	1.65	20.0	9.2	10.8	
IIB23tg	72-120	1.66	19.9	10.3	9.6	
IIB3	120-180	1.67	12.6	4.0	8.6	30.1
			Pedon 9--ET9			
A1	0-2	1.60	11.4	5.1	6.3	
A2	2-10	1.58	10.2	4.3	5.9	
IIB21tg	10-28	1.61	16.5	8.0	8.5	
IIB22tg	28-87	1.65	16.2	7.0	9.2	
IIB3	87-180	1.66	15.6	6.8	8.8	26.1

*Available water percent = 0.3 bar minus 15 bar tension.

capacity. The 0.3 bar may or may not be representative of field capacity in the various soil textures. Fine textured soils will drain to much higher tensions and coarse-textured soils usually reach equilibrium at much lower tensions under field conditions. Franzmeier et al. (1960) stated that water contents at field capacity are better related to those of 0.06 atmospheres than to those at 0.3 atmosphere. Thus, since the 15 bar moisture retention capacity is considered to be comparable to permanent wilting percentage the 0.3 bar values shown may lead to an underestimation of the plant available water holding capacity of the soils.

Sharma and Uehara (1968a) demonstrated that heavy-textured kaolin-oxide soils have moisture release curves, which in some respects resemble those of sandy soils. Water in large soil pores moves rapidly under gravitational forces, and field capacity is attained at low tensions (0.1 to 0.15 bars) because at these low values the hydraulic conductivity is also very low, much like that of sandy soils. The water in the fine intra-aggregate pores is for the most part, immobile and can be extracted only by applying tensions higher than 100 bars (Sharma and Uehara, 1968b; Uehara and Keng, 1973).

From the data (Table 6) the soils with more clay seem to have more available water than the sandy soils when the 0.3 bar and 15-bars are used in the computation.

Under certain conditions these moisture constants may be in considerable error. For example, in sandy soils the field capacity may be represented by tensions as low as 50 cm of water. Also the field capacity is strongly influenced by stratification (Bartelli and Peters, 1959). It has been stated that in many instances the 15-bar percentage does not give a true representation of the wilting point of soils in place (Richards and Weaver, 1944). The wilting point is controlled by such factors as root ramification, evaporative demand and soil texture.

Clay content is the principle factor affecting the relative magnitudes of water retained at 0.3 and at 15-bar, Figure 9. The water at 0.3-bar minus the water at 15-bar tensions plotted against percent clay (Figure 10) show an almost linear relationship, as does the 15-atmosphere moisture percent which increases gradually with clay content, with some obvious deviations of the values for some samples--upper horizons of pedons 5 and 8. A high degree of correlation, $r = 0.70$ is found between available moisture and clay content of the nine soils. This is not in agreement with results found by some workers in the temperate areas.

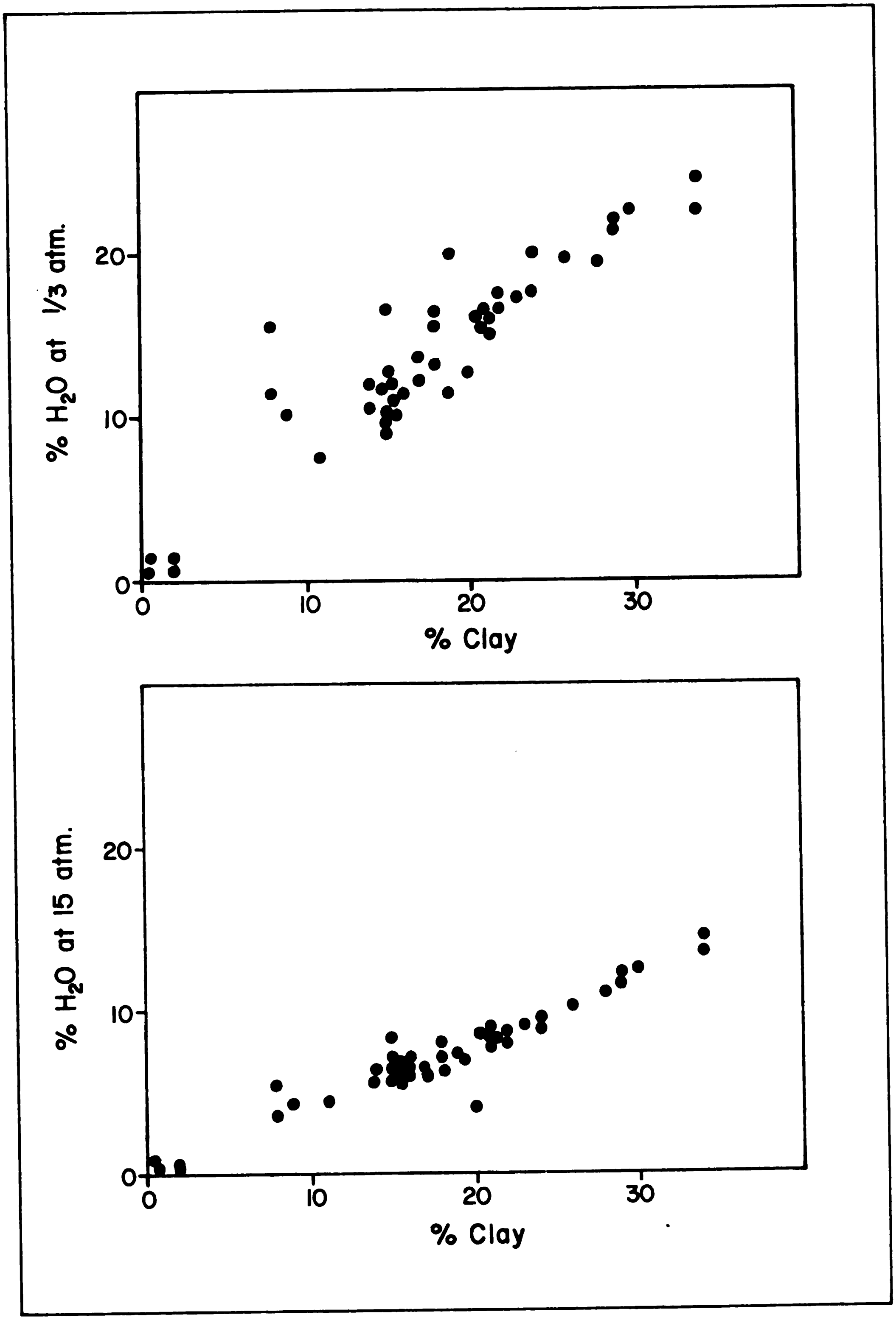


Fig. 9.--Moisture retention percent (1/3 atm.-15 bars) versus percent clay.

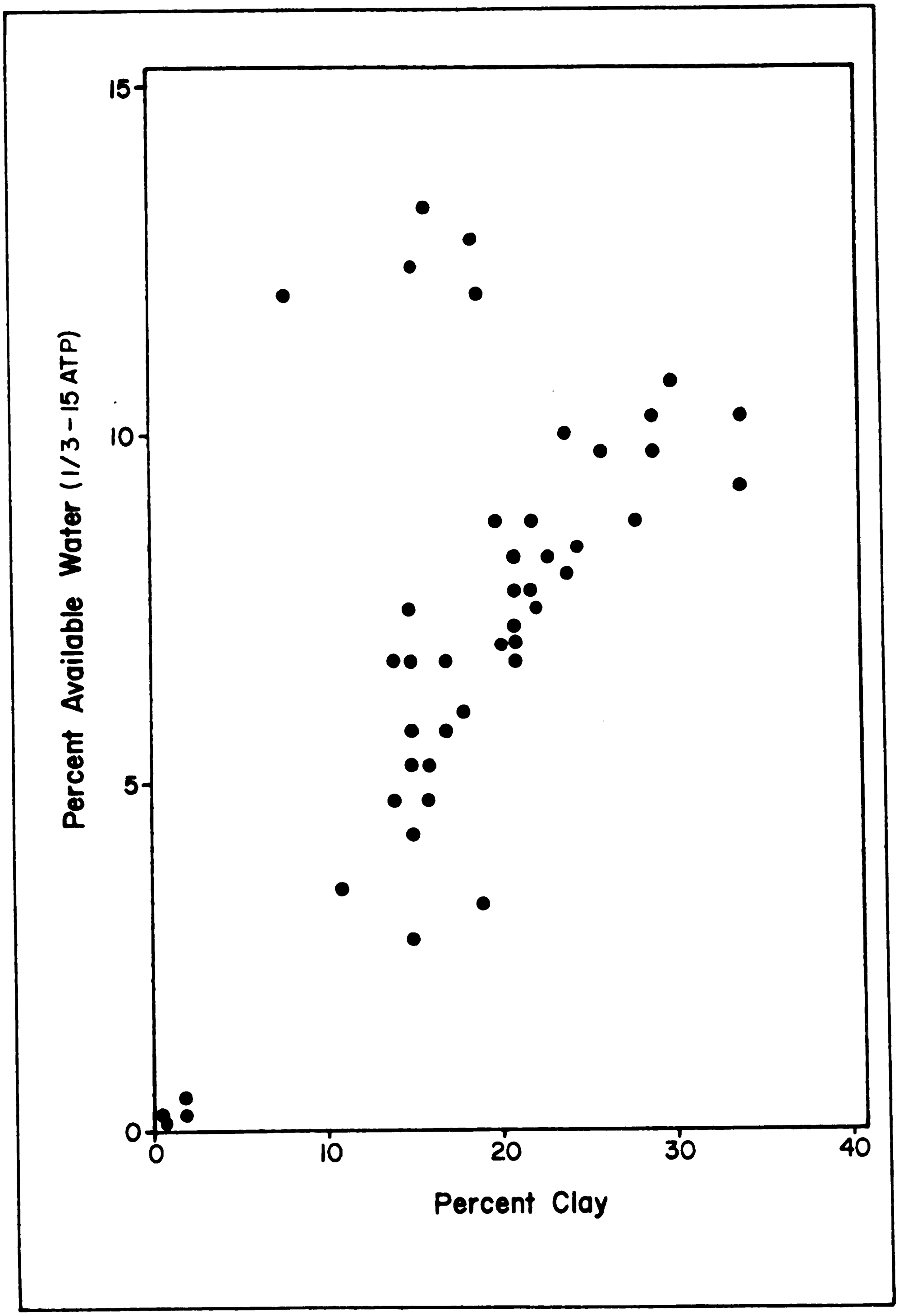


Fig. 10.--Available water percent (1/3 atm.-15 bars) versus percent clay.

Regression coefficients and partial regressions of available water percent on percent clay and organic carbon

	Regression coefficients of		'r'		't'	
	% clay	organic carbon	% clay	O.C.	% clay	O.C.
Available water percent	1.76	-0.071	.70	-0.28	22**	-35.5°

**Highly significant, at 1% level

°Nonsignificant at 20% level

The prediction equation for the above significant relationship, where X is available water and Y % clay, is:

$$Y = 1.76X + 5.3$$

In the temperate region silty soils have the most readily available moisture and the available moisture capacity decreases with clay content (Franzmeier *et al.*, 1960; Jamison and Kroth, 1958). Franzmeier *et al.* (1960) have stated that readily available water capacity (R.A.W.C.) of a soil is a better estimate of the water available for plant growth than the usual measures of available water. R.A.W.C. is defined as the difference between the water content of the soil at field capacity and the lower turgor pressure percentage (Franzmeier *et al.*, 1960). Franzmeier *et al.* (1960) found an insignificant negative correlation coefficient when they compared readily available water capacity with percent clay in some soils of the temperate region.

Clay particles by themselves form pores so small, suctions holding much of the water are greater than a plant can overcome in obtaining moisture. Sand particles form pores too large for the surface tension to overcome gravitational forces and, therefore, available water-holding capacity is low unless smaller clay or silt particles fill the large pores. Pores between silt particles are in size ranges that hold water in the tension range available to plants.

Regression analysis as presented indicated an insignificant negative correlation coefficient ($r = -0.28$) when available water percent is compared with organic matter content. It is still uncertain as to what extent and under what conditions organic matter and other aggregating agents will improve water storage. Jamison and Kroth (1958) found for soils of the South-Eastern United States, that except for sandy soils, organic matter increases did not increase the capacity of a soil to store available moisture. Feustal and Byers (1936) found that there is little to be gained by adding peat or muck to a clay soil in equal proportions by volume. They found that retention of water by organic soils at the wilting point is high.

The bulk density values (Table 6) range from 1.50-1.67 g/cc. It has been pointed out that the clod method used here usually gives higher bulk density values than other methods (Tisdale, 1951; Blake, 1965). Most of the values obtained seem to be close to those expected from soils with the textures--sandy loam to sandy clay loam.

The total available stored water for the nine soils, except pedon 4, range from 18.0 g/cm^2 to 180 cm to 30.1 g/cm^2 to 180 cm (Table 6). Pedons 1 or 7 have more total available water than pedon 2 or 3 to 180 cm. This lithosequence of soils (pedons 2 or 3 and 1 or 7) are developed in coarser fine-loamy and finer fine-loamy materials, respectively, in an ustic moisture regime.

Pedon 5 developed in fine-loamy materials has more total available water than pedon 6 developed in coarse-loamy materials. They are a lithosequence of soils with udic moisture regimes.

In the more poorly drained soils, pedon 8 can hold more available water than pedon 9 and much more than pedon 4. Pedon 8 has the highest silt content and is developed in fine-loamy materials while pedon 9 is coarse-loamy. These represent a lithosequence of soils with aquic moisture regimes. The poorly drained members of a topo-lithosequence have shallower water-tables at least seasonally and consequently more available water (if all other factors are constant and roots can penetrate the saturated layers) when the water-table is present. Pedon 4 is sandy throughout with much less clay content. The low total available water of pedon 4 is associated also with the iron-pan development at 140 cm. While that horizon has the highest available water in the profile, it may not actually be available to plants, if their roots cannot penetrate it.

Pedons 5 and 8 developed in coarser fine-loamy materials. Pedon 8 with aquic moisture regime and located on lower physiographic surfaces has more total available water to 180 cm than pedons 5 (well-drained) with udic moisture regime on higher physiographic surfaces. The higher available water can be associated with organic matter and high silt contents. These represent a topo-sequence or litho-toposequence of soils.

Pedons 6 (well-drained) and 9 (somewhat poorly drained) developed in coarse-loamy materials. Pedon 9 with aquic moisture regime has more available water to 180 cm than pedon 6 and this is associated with higher organic matter content. These represent a toposequence of soils.

Pedons 2 or 3 developed in coarser fine-loamy materials in an ustic moisture regime show no difference in total available water to 180 cm from pedon 5 developed in similar materials in an udic moisture regime. They are a well-drained climosequence or chrono-climosequence of soils.

Chemical Properties

Soil reaction (pH and ΔpH).--The results of pH values determined in water (1:1 ratio), KCl (1:1), and $CaCl_2$ (1:2 ratio) are given in Table 7.

The data obtained in a 1:1 soil-water suspension show that nearly all of the soils, except Pedons 2 and 6, are very strongly acid (pH 4.5-5.0) and they are strongly acid (pH 5.1-5.5). Pedon 4 which is the sandiest of all the pedons is extremely acid (pH 2.6-4.4). It shows a decrease in pH value with depth, except for the Bhirm horizon (pH 3.0) which has high organic matter content. In the other pedons there is little change with depth, the pH values vary only by a few tenths (0.2 to 0.6) pH throughout the entire depth of the pedons.

The pH measurements made in KCl and $CaCl_2$ suspensions show depth distribution patterns similar to those obtained in water suspensions although they are lower in absolute values (-0.3 to -1.4, ΔpH). The range in pH differences with depth are similar in KCl and $CaCl_2$ to those in H_2O, except for pedon 4, which show a smaller difference in water (1.8 versus 2.4-2.6 pH units). All the soils show a negative charge according to the negative values of ΔpH (pH in KCl minus pH in H_2O) (Mekaru and

Table 7.--Soil reaction in various suspending media, ΔpH, organic carbon, total nitrogen, and C/N ratios.

Horizon	Depth cm	pH			ΔpH	Organic Carbon %	Total N %	C/N Ratio
		H_2O	KCl	$CaCl_2$				
				Pedon 1--AMS1				
Ap	0-10	4.8	4.2	4.2	-0.6	1.76	0.17	10.4
B1	10-22	4.8	4.2	4.3	-0.6	1.60	0.11	14.5
B21t	22-45	4.6	4.0	4.4	-0.6	0.80	0.09	9.6
B22t	45-75	4.5	4.2	4.2	-0.3	0.71	0.08	8.9
B3	75-180	4.5	4.0	4.0	-0.5	0.53	0.04	13.3
				Pedon 2--AMM2				
Ap	0-13	5.1	4.3	4.5	-0.8	1.03	0.13	7.9
B1	13-30	4.9	4.0	4.0	-0.9	0.72	0.10	7.2
B21t	30-55	5.2	4.2	4.4	-1.0	0.54	0.09	6.0
B22t	55-108	5.1	4.3	4.6	-0.8	0.25	0.05	5.0
B3	108-180	5.0	4.4	4.3	-0.6	0.12	0.03	4.0
				Pedon 3--AMF3				
Ap	0-12	4.8	4.0	3.9	-0.8	1.10	0.13	8.5
B1	12-22	4.9	4.0	4.0	-0.9	1.02	0.11	9.3
B21t	22-45	4.7	4.2	4.2	-0.5	0.53	0.10	5.3
B22t	45-137	4.9	4.2	4.1	-0.7	0.33	0.07	4.7
B3	137-180	4.9	4.2	4.2	-0.7	0.28	0.04	7.0

Table 7.--Continued.

Horizon	Depth cm	pH			ΔpH	Organic Carbon %	Total N %	C/N Ratio
		H_2O	KCl	$CaCl_2$				
				Pedon 4--AMM4				
Ap	0-12	4.4	4.0	4.1	-0.4	2.89	0.19	15.2
A2g	12-30	3.8	3.0	3.0	-0.8	0.31	0.05	6.2
A22g	30-140	2.6	1.9	1.8	-0.7	0.39	0.04	9.8
Bhirm	140-200	3.0	1.6	1.5	-1.4	1.97	0.17	11.6
				Pedon 5--ASU5				
Ap	0-13	5.3	4.5	4.4	-0.8	2.60	0.18	14.4
B1	13-38	5.0	4.4	4.3	-0.6	0.55	0.10	5.5
B21t	38-88	4.8	4.2	4.1	-0.6	0.36	0.08	4.5
B22t	88-150	4.7	4.1	4.1	-0.6	0.20	0.06	3.3
B3	150-180	5.0	4.4	4.3	-0.6	0.18	0.03	6.0
				Pedon 6--AK6				
Ap	0-18	5.2	4.2	4.4	-1.0	0.34	0.15	2.3
B1	18-53	5.0	4.4	4.13	-0.6	0.22	0.09	2.4
B21	53-110	5.1	4.3	4.6	-0.8	0.21	0.06	3.5
B22	110-143	5.5	4.5	4.5	-1.0	0.13	0.04	3.3
B3	143-180	5.2	4.2	4.1	-1.0	0.11	0.03	3.7

Table 7.--Continued.

Horizon	Depth cm	pH			ΔpH	Organic Carbon %	Total N %	C/N Ratio
		H_2O	KCl	$CaCl_2$				
				Pedon 7--UM7				
Ap	0-20	5.0	4.4	4.3	-0.6	1.26	0.12	10.5
B21t	20-55	4.8	4.2	4.1	-0.6	0.45	0.08	5.6
B22t	55-100	4.9	4.1	4.1	-0.8	0.39	0.06	6.5
B31	100-150	5.1	4.3	4.6	-0.8	0.28	0.04	7.0
B32	150-210	5.0	4.4	4.3	-0.6	0.17	0.03	5.7
				Pedon 8--PH8				
Ap	0-10	5.3	4.5	4.7	-0.8	1.98	0.17	11.6
A2g	10-23	4.8	4.2	4.1	-0.6	0.42	0.13	3.2
B21tg	23-40	5.0	4.4	4.3	-0.6	0.35	0.10	3.5
B22tg	40-72	5.1	4.3	4.3	-0.8	0.28	0.09	3.1
IIB23tg	72-120	4.8	4.2	4.1	-0.6	0.14	0.05	2.8
IIB3	120-180	4.7	4.1	4.0	-0.6	0.12	0.04	3.0
				Pedon 9--ET9				
A1	0-2	4.5	3.8	4.2	-0.7	1.80	0.16	11.3
A2	2-10	4.8	4.1	4.0	-0.7	0.70	0.15	4.7
IIB21tg	10-28	5.0	4.2	4.3	-0.8	0.30	0.10	3.0
IIB22tg	28-87	4.9	4.0	4.1	-0.9	0.20	0.08	2.5
IIB3	87-180	4.5	3.9	4.2	-0.6	0.11	0.05	2.2

Uehara, 1972; Van Raij and Peech, 1972). Negative ΔpH values are indicative of a net negative charge of the soil colloids, meaning the soils are therefore cation exchangers (Uehara and Keng, 1973). This negative charge in turn is a result of the predominance of layer silicates with a permanent charge, over oxides and hydrous oxide systems, or it could be partially due to organic matter specifically absorbed on colloids or minerals of constant surficial potential (Mekaru and Uehara, 1972).

ΔpH like the pH in H_2O shows little difference with depth, except in pedon 4 which is sandy and has a spodic subsoil horizon. It shows a marked increase in ΔpH from the surface to the subsoil horizon. This increase is associated with increased carbon content of the Bhirm horizon.

Differences in pH do not show significant relationships among the pedons in the genetic sequences.

Organic carbon content and nitrogen.--Table 7 shows the organic carbon and nitrogen contents. All the pedons show a decrease in organic carbon and nitrogen contents with depth except pedon 4 which has a spodic horizon.

Pedons 2 and 3 have organic carbon content values that range between 1.03-1.10% for A horizons. Pedon 1 or 7 have higher values (1.76-1.26%) than pedon 2 or 3. Among other things, this is associated with finer parent materials as pedons 1 or 7 and 2 or 3 are lithosequences of well drained soils developed in finer fine-loamy and coarser fine-loamy materials, respectively. Pedon 5 (coarser fine-loamy) has the highest surface organic carbon content (2.60%) and is located on a lower physiographic surface with an udic moisture regime. Pedon 6 (coarse-loamy) has lowest organic carbon (.34%) and nitrogen contents even though it has an udic moisture regime.

Pedons 4, 8 and 9 have aquic moisture regimes and are located on lower physiographic surfaces (except pedon 4). They constitute a chrono-lithosequence with pedon 8 (coarser fine-loamy) having slightly higher organic carbon (1.98%) and nitrogen content than pedon 9 (coarse-loamy 1.80%). Pedon 4 has the highest organic carbon content, 2.89%. Though it has the highest total sand content, this high organic carbon content can be explained by the cultivational history of the soil and its poor natural drainage. The pedon is located at a vegetable plot nursery.

It is evident that soils located on lower physiographic surfaces with udic or aquic moisture regimes and developed in fine-loamy materials have more organic carbon and nitrogen contents than their counterpart on higher physiographic surfaces developed in similar parent materials. Thus some of the differences in relative levels of organic matter content can be related to differences in parent materials and clay content.

Allison (1973) stresses the importance of soil texture as a factor in determining the level of organic matter content. He states that under similar climatic conditions the quantity of organic matter present may be 2-4 times as great in a fine textured clay soil as in one that is very sandy. He attributes this in part to greater aeration and increased oxidation in the very sandy soils but more importantly to:

a. the formation of organic inorganic complexes.
b. sorption of organic matter on clay particles.
c. the formation of metal-organic compounds such as Ca, Fe and Al humates.

There is no great variation in texture of the soils studied except pedon 4. It seems that clay content and the formation of Fe, Al humates and organic-inorganic complexes will probably play greater roles in the reasons presented.

Difference in altitude could be another factor that can account for the different levels in organic carbon content among well-drained soils. The relief of the area under study is gently sloping to almost flat with the highest site slope being about 2%. The difference in elevation, however, would be reflected in the relative air temperature levels. Trewartha (1954) states that there may be an increase of 6°C per 100 m decrease in altitude. Ignatieff and Lemos (1963) showed that at high temperatures above

25°C organic matter is destroyed more rapidly especially in coarse textured soils.

Much of the differences in organic carbon content may also be related to land use. Cultivation of crops in most of the area involves burning the vegetation before tillage of the land. Since much of the area under study is used for cultivated crops with the subsistence fallowing system, the lower organic matter content would be attributed to this factor as well. However in all the pedons which have low organic matter content the decrease in organic carbon with depth is gradual. Despite this decrease with depth all the pedons contain some organic carbon even in the lowest horizons examined.

The carbon contents of the well-drained soils can be considered in relation to nitrogen contents, rainfall and elevations. The regression coefficients show a significant positive relationship between these factors and the carbon contents of the soils. In other words, the data presented show that soils with high nitrogen contents have higher carbon contents than those with low nitrogen contents; soils from areas of high rainfall have higher carbon contents than those from areas of low rainfall.

Regression coefficients, their standard errors and t values of partial regressions of carbon on nitrogen and elevation

	Regression coefficients		Standard Errors		"t" value	
	Nitrogen	Elevation	N_2	Elev.	N_2	Elev.
Carbon on	0.056	0.012	0.0059	.0017	9.49**	2.65

Prediction equation of % carbon on nitrogen is $\hat{y} = 0.052 + 0.056X$ where X = % carbon
y = % nitrogen

**Highly significant at 5% level.

However, the partial regression coefficient of carbon on elevation is barely significant. The nitrogen contents of all the soils are low (Table 7). At high annual temperatures the nitrogen and organic matter contents seem to increase as precipitation becomes higher. As one climbs from sea level to high altitudes a slight increase in soil nitrogen and organic matter becomes noticeable. The soils of the area are located on gently sloping to almost flat topography but there is no marked increase in elevation between them (approximately 150 m).

The nitrogen content of the soils range from 0.03-0.19% with a mean of 0.09%. The carbon-nitrogen ratio ranges from 2.2 to 15.2 (mean of 6.6). The results of the data (Table 7) show that there is a slight increase in C/N ratio with increasing rainfall. There is no significant relationship between C/N ratio and elevation. With limited data on ranges of mean annual temperatures of the area, no relationship is found between the C/N ratio and temperature.

Cultivational history and rainfall appear to be some of the major factors governing the organic matter and nitrogen contents of the soils studied.

Temperature may play a minor role. Prescott (1931) found no direct effect of temperature on the nitrogen content of Australian soils over a range of 13°-25°C (56°-77°F). Presumably the relationship between rainfall and organic matter or nitrogen content of the soils is a relatively simple one in which increasing rainfall favors increasing vegetative growth and therefore production of organic matter without having much effect on its rate of decomposition. The role of the cultivation method involving "slash and burning" of vegetation can be seen in the area especially with soils on the higher surfaces (pedons 1, 2, 3, and 7) where there are fewer thickets and thus greater ease of burning the vegetation. Except in pedon sites of uncultivated areas the increasing total nitrogen content of the surface soil can be clearly associated with rise in elevation.

The influence of temperature on the other hand is more complicated in that increasing temperature, within limits, favors both the rate of production and decomposition of organic matter. In the studied area with its alternating dry and wet seasons the effect of high temperatures on microbiological activity seems to be nullified during part of the year by the adverse effect of dry conditions. This would slow down organic matter decomposition in the surface soil without necessarily slowing down vegetative growth and organic matter production provided moisture is available in the subsoil. Moreover, a rapid breakdown of plant residues does not preclude a build up in the soil of stable humus more resistant to microbial activity. In view of such modifying influences it appears that too much emphasis has been placed, in the past, on temperature as a major factor in organic matter decomposition in the tropics.

It becomes more evident that within the study area the problem is not so much one of building up the available nitrogen in the soil as of conserving that already present. This could be done by determining the best cropping systems and management practices to maintain a desirable available nitrogen balance. Such practices should include adequate protection against erosion, a proper selection of crop rotations (including legumes), conservation of crop residues and doing away with bush burning which is prevalent in the area.

Exchangeable bases.--In all nine soils exchangeable bases extracted with neutral 1N-NH_4OAC are very low (Table 8). Most pedons have 1.2 to 0.12 m.e. exchangeable bases/100 g soil throughout their profiles. However, pedon 4, a sandy spodosol, has less than 0.06 m.e./100 g

Table 8.--Exchangeable bases, extractable Al, cation exchange capacity and percent base saturation.

Horizon	Depth cm	Exchangeable Bases Ca^{++}	Mg^{++}	K^{+}	Na^{+}	Extr Al^{+3}	Sum of bases	Sum of bases + Al	CEC	CEC/% Clay X10^2	Base Sat. %	Al* Sat. %
		me/100 g soil										
						Pedon 1--AMS1						
Ap	0-10	0.10	0.05	.10	.04	.25	.29	.54	5.0	33.3	5.8	46.3
B1	10-22	0.09	0.06	.11	.04	.20	.30	.50	4.5		6.7	40.0
B21t	22-45	0.09	0.05	.07	.04	.10	.25	.35	4.0	14.0	6.3	28.6
B22t	45-75	0.09	0.05	.05	.03	.10	.22	.32	3.6	11.0	6.1	31.3
B3	75-180	0.01	0.03	.08	.02	.05	.14	.19	3.0	8.8	4.7	26.3
						Pedon 2--AMM2						
Ap	0-13	0.09	0.05	.09	.04	.34	.27	.61	5.3	35.3	5.1	55.7
B1	13-30	0.10	0.07	.09	.03	.30	.29	.59	4.6		7.3	50.8
B21t	30-55	0.09	0.05	.09	.02	.15	.25	.40	4.3	23.0	6.1	37.5
B22t	55-108	0.04	0.01	.06	.02	.14	.13	.27	2.6	12.0	5.0	37.0
B3	108-180	0.04	0.01	.05	.02	.13	.12	.25	1.7	8.1	7.1	52.0
						Pedon 3--AMF3						
Ap	0-12	0.1	0.06	.09	.02	.30	.27	.57	5.6	40.0	4.8	52.6
B1	12-22	0.1	0.08	.05	.02	.20	.25	.45	5.0		5.0	44.4
B21t	22-45	1.0	0.09	.09	.03	.20	1.21	1.41	5.3	25.0	14.2	14.2
B22t	45-137	0.1	0.05	.07	.02	.18	.24	.42	3.2	14.0	7.5	42.9
B3	137-180	0.1	0.05	.08	.03	.25	.26	.51	2.9	14.0	9.0	49.0
						Pedon 4--AMM4						
Ap	0-12	0.01	0.01	.02	.01	.35	.05	.40	3.8	190.0	1.3	87.5
A21g	12-30	trace	0.01	.01	trace	.41	.02	.43	1.1		1.8	95.3
A22g	30-140	trace	trace	.01	trace	.44	.01	.45	0.9		1.1	97.8
Bhirm	140-200	trace	trace	.01	trace	.12	.01	.13	3.3	165.0	0.3	92.3

Table 8.--Continued.

Horizon	Depth cm	Exchangeable Bases Ca^{++}	Mg^{++}	K^{+}	Na^{+}	Extr Al^{+3}	Sum of Bases	Sum of bases + Al	CEC	CEC/% Clay X10^{2}	Base Sat. %	Al* Sat. %
		me/100 g soil										
						Pedon 5--ASU5						
Ap	0-13	1.01	.28	.11	.04	.37	1.44	1.81	7.5	159.0	19.2	25.0
B1	13-38	0.90	.10	.08	.04	.42	1.12	1.54	6.0		28.0	27.3
B21t	38-88	0.07	.10	.10	.06	.30	.33	.63	5.1	24.0	6.5	47.6
B22t	88-150	0.08	.10	.09	.04	.33	.31	.64	4.5	19.0	6.9	51.6
B3	150-180	0.07	.10	.07	.02	.35	.26	.61	4.5	20.0	5.8	57.4
						Pedon 6--AK6						
Ap	0-18	0.10	.06	.09	.03	.30	.28	.58	5.8	38.7	4.8	51.7
B1	18-53	0.09	.07	.07	.03	.34	.26	.60	5.2		5.0	56.7
B21	53-110	0.10	.10	.07	.03	.37	.30	.67	4.8	32.0	6.3	55.2
B22	110-143	0.08	.10	.04	.02	.30	.24	.54	3.8	25.0	6.3	55.6
B3	143-180	0.09	.10	.07	.03	.33	.29	.62	2.9	16.0	10.0	53.2
						Pedon 7--UM7						
Ap	0-20	0.16	.12	.11	.04	.30	.43	.73	5.3	33.1	8.1	41.1
B21t	20-55	0.12	.10	.08	.03	.25	.33	.58	4.8	22.0	6.9	39.4
B22t	55-100	0.10	.09	.10	.03	.30	.32	.62	4.6	16.0	7.0	48.4
B31	100-150	0.11	.10	.15	.04	.10	.40	.50	3.5	12.0	11.4	20.0
B32	150-210	0.10	.07	.14	.04	.15	.35	.50	3.1	10.0	11.3	30.0
						Pedon 8--PH8						
Ap	0-10	0.10	.60	.04	.02	.14	.76	.90	5.0	62.5	15.2	15.6
A2g	10-23	0.08	.12	.06	.01	.27	.27	.54	4.0		6.8	50.0
B21tg	23-40	0.10	.06	.04	.01	.90	.21	1.11	5.1	27.0	4.1	81.1
B22tg	40-72	0.15	.17	.05	.02	.70	.39	1.09	4.2	17.0	9.3	64.2
IIB23tg	72-120	0.10	.14	.04	.03	1.60	.32	1.92	5.0	19.0	6.4	83.3
IIB3	120-180	0.16	.12	.02	.01	1.40	.31	1.71	5.4	27.0	5.7	81.9

Table 8.--Continued.

Horizon	Depth cm	Exchangeable Bases Ca^{++}	Mg^{++}	K^{+}	Na^{+}	Extr Al^{+3}	Sum of bases	Sum of bases + Al	CEC	CEC/% Clay X10[2]	Base Sat. %	Al* Sat. %
		me/100 g soil										
						Pedon 9--ET9						
A1	0-2	0.33	.36	.10	.03	.60	.82	1.42	4.2	52.5	19.5	42.3
A2	2-10	0.08	.09	.10	.03	.56	.30	0.86	3.7		8.0	65.1
IIB21tg	10-28	0.10	.14	.20	.06	.41	.50	0.92	3.6	24.0	13.9	44.6
IIB22tg	28-87	0.09	.09	.10	.07	.39	.35	0.74	3.5	20.0	10.4	52.7
IIB3	87-180	0.04	.08	.10	.08	.30	.30	0.60	3.0	17.0	10.0	50.0

$$*\%\ \text{Al saturation} = \frac{\text{Extractable Al}}{\text{Sum of Bases + Extr. Al}} \times 100$$

throughout. Differences associated with genetic sequences are not very evident.

Among the more poorly drained soils (pedons 4, 8 and 9) pedons 8 and 9 have more exchangeable bases than pedon 4. Pedons 8 and 9 developed in fine-loamy and coarse-loamy materials, respectively. It is probable that, among other things, a more suitable environment for microbial activities is provided by pedon sites 8 and 9 than pedon site 4.

Base saturation.--All the soils have low base saturations, ranging from 0.3 to 28%. The percent base saturation is highly dependent on the method used for its determination due to the considerable portion of the pH-dependent charges (pH-dependent CEC) present on soil colloids (Kamprath, 1970; Kamprath and Foy, 1971). As mentioned earlier the magnitudes of these percent base saturations may be associated with microbial activities and the forest ecosystem of the individual pedon sites.

The very low contents of the exchangeable bases in these soils indicate a deficiency in weatherable minerals. Continuing leaching losses may also account for their low content. Some conclusions can be made from the exchangeable bases as follows:

1. Associated with high sand contents (47 to 98%) and sandy to fine-loamy materials in these soils, especially pedon 4, all the pedons have low K, Mg

and Ca contents. Thus they have low content, if any, of weatherable minerals. These data appear to represent the minimal values that are reached by advanced weathering in such soils.

2. In a few cases the upper horizons (pedons 5, 8 and 9) have a slightly higher content of exchangeable bases. This is attributed to recycling of nutrients by vegetation and manuring.

3. A comparison of the average values ($\bar{X}$) and ranges in Figure 11 with a few soils in other parts of the country (Ford, 1968) shows similar values as indicated below.

Site	pH	Exch. K me/100 g	Exch. Ca me/100 g	Exch. Mg me/100 g	Tentative Classif.
Abak	4.5	0.09	0.25	0.18	Typic Paleustult
Calabar	4.6	0.04	0.12	0.12	Typic Paleudult
Benin	5.2	0.05	0.44	0.25	Oxic Paleudult
NIFOR	5.4	0.08	1.88	0.52	Oxic Paleudult
Umudike	5.0	0.06	0.90	0.15	Ustoxic Paleustult
$\bar{X}$ (ranges)		.07(0.-0.2)	0.17(0.-1.01)	0.09(0.-0.6)	

The Calabar, Benin and NIFOR sites are within the Coastal Plain Sands, but located outside the study area. All these soils are used for oil palm production.

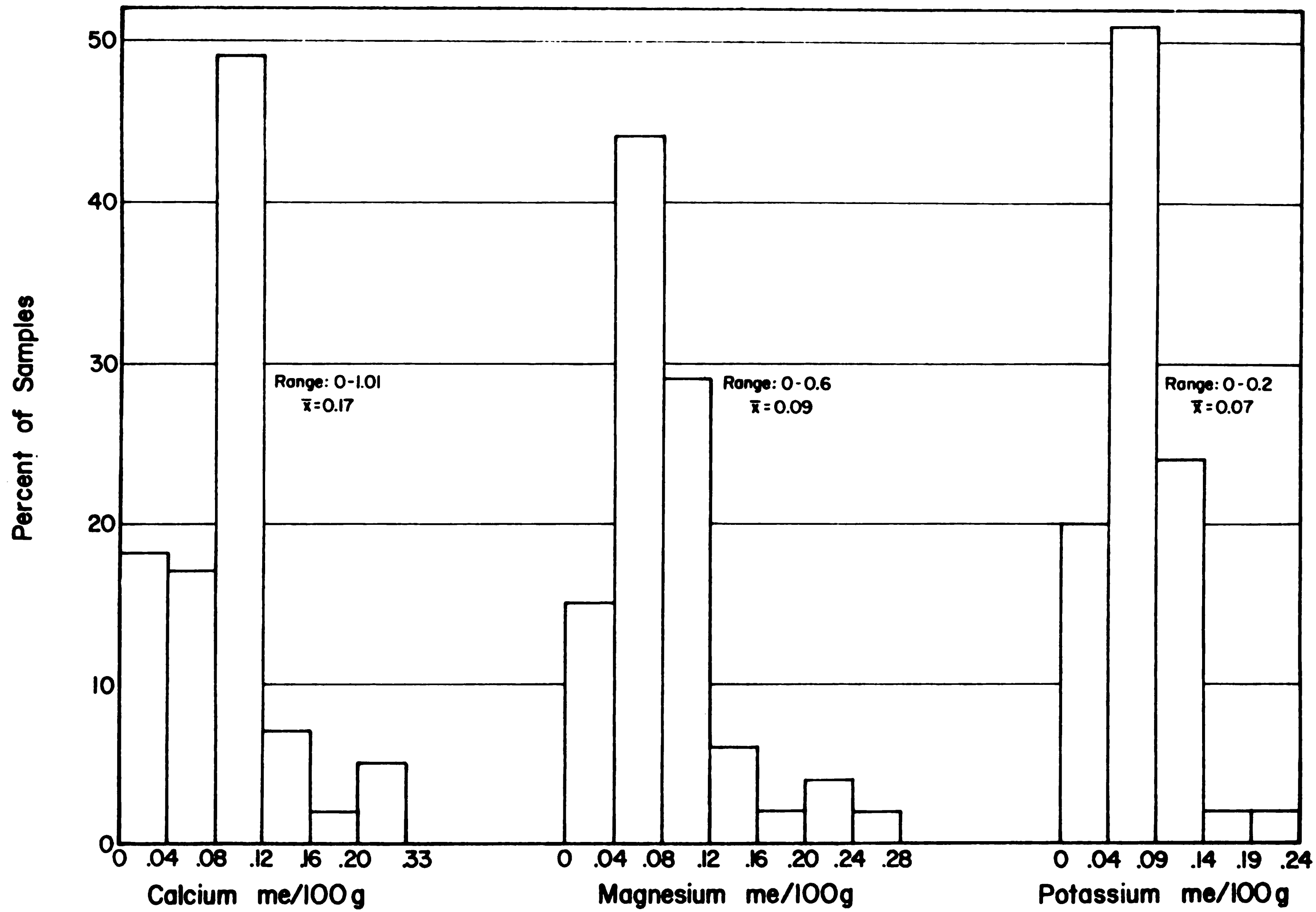


Fig. 11.--Frequency distribution of exchangeable Ca, Mg and K.

Significance to land use and management.--It has been suggested that the absolute value of exchangeable Mg may not be an effective way to evaluate the availability of this nutrient for crop growth. A level of 4% of Mg saturation has been used for Mg soil test interpretation on Ultisols (Adams, 1962; Henderson, 1970). Only the surface horizons of pedons 5, 8 and 9 exceed this value.

According to Juo and Ballaux (1977) leaching losses of applied Ca in highly weathered soils in the lowland tropics may not be as great as generally believed. A substantial portion of applied Ca would be adsorbed by Fe and Al oxides and hydrous oxides. Any Ca ions leached downward may be retained in the lower horizons which are also normally depleted in calcium.

Low levels of available Ca and Mg and the high level of exchangeable Al saturation are important limiting factors in food production on Ultisols and Oxisols in the humid tropics (Juo and Ballaux, 1977). The low levels of Ca and Mg under the high rainfall prevalent on the lower Coastal Plain Sands area must have been affected to some extent by the prolonged cropping of the area.

Excellent yields may be given by oil palms (*Elaeis guinnensis*) on some of the very acid soils of extremely low exchangeable Ca content, especially if K and Mg supplies are maintained by manuring. However, with other crops, these soils may cause special problems, and it may then be more necessary to recognize distinctions between these soil conditions and those of forested regions of less intense leaching. In the study area, 'liming' has long been practiced by local farmers in the form of "slash and burn" of vegetation. With increasing population density this practice has approached a level of diminishing return as a result of shortened fallow periods. To establish more permanent and productive cropping system on these Coastal Plain Sands, the use of commercial fertilizers and liming materials are highly encouraged. If a major portion of applied calcium is leached below the rooting zone of shallow-rooted crops, planting short-term fallow species with deep-rooting systems could effectively recycle calcium back to the surface layer of the soil providing that the plant residue is returned either as mulch or by burning. However, if economic lime amendments are not available this may prove impractical with current land use pressures.

The low values of exchangeable K still support crop production. This may be due to the fact that even in soils containing large amounts of total K, only a small part, usually less than 1% of the K is in exchangeable form, and much smaller amounts are in soil solution (Doll and Lucas, 1973). Most of the nonexchangeable K tends to be released very slowly as the exchangeable K is depleted from the soil. Consequently, taxonomically speaking, these data are not very helpful as they give only an indication of a minimum amount of the available K present in these soils. They are, however, very important from the fertility viewpoint as good and very conclusive correlations have been obtained between the exchangeable K and crop responses to fertilizers (Conyers and McLean, 1969; Doll and Lucas, 1973). Content of weatherable K minerals is also needed in addition.

With the prevalent high rainfall of the area (2000-2500 mm annually) accumulation of nutrients such as K is not likely to be appreciable. Lutrick (1958) confirmed the downward movement of added KCl in profiles of two Ultisols. Despite the effect of leaching, his data showed a considerable accumulation of K in the surface soil with or without K fertilization. It has been a common experience for some previously uncultivated soils of the Coastal Plain Sands to show little or no crop response to K fertilization especially after a long fallow period. In oil palm growing areas, this lack of response could continue for several years before yields decline.

These observations suggest that the soils either contain an adequate supply of K (the determined low exchangeable values notwithstanding) to satisfy crop needs for a considerable period of time or possess properties through which the soils retain K against leaching losses. This might seem an anomaly considering the low values shown by data in Table 8. Another explanation may be the fact that the root system of the crops extend to various depths of soil profile for nutrients and this may account for the lack of crop response to K fertilization in these soils during the first few years of cultivation. This would be particularly true for annual crops such as corn (*Zea mays*) and soybean (*Glycine max L*) which have a relatively low K requirement.

Exchangeable Al and Al saturation.--Exchangeable Al represents aluminium extracted with unbuffered 1N-KCl. In calculating Al saturation the sum of exchangeable bases and Al is used as an approximation of the cation exchange capacity (ECEC) at field pH. According to Kamprath and Foy (1971), the Al saturation of the ECEC of the soil greatly affects the Al concentration of the soil solution. Aluminium is so tightly held by soil colloids that only when the Al saturation is about 60 percent of the ECEC does a substantial amount of Al become present in the soil solution (Nye *et al*., 1961; Evans and Kamprath, 1970).

Table 8 shows data which indicate that exchangeable Al and Al saturation increases with depth in pedons 5 and 8, attaining Al saturation values of 57 and 83% in a lower horizon. In these pedons Al saturation and % base saturation show an inverse relationship. Pedon 4 has the highest Al saturation ranging from 87.5% in the Ap horizon to 97.8% in A22g and 92.3% in the Bhirm horizon. The sandy nature of this pedon and its extreme acidity in addition to its low content of exchangeable bases account for the high Al saturation values.

For soils on the higher surfaces pedons (1, 2, 3 and 7) considering their relatively higher clay contents and their low base saturation percentages, the exchangeable Al values are low. These values are 0.25 to 0.34 m.e./ 100 g in the surface horizons and they decrease with depth to as little as 0.05 in the lower parts of the sola. Al saturation values are high, however, up to 55.7% due to the low CEC of these soils.

In acid soils exchangeable Al is generally recognized as the predominant cation as determined by the exchange process with a neutral salt solution, like KCl. This determination is based on the assumption that aluminium ions are counter ions balancing excess permanent negative charge on the surface of the solid phase. According to Amedee and Peech (1975) this method of determining exchangeable Al by extraction is not satisfactory.

In view of these results it is interpreted that in the poorly to somewhat poorly drained soils (pedons 8 and 9 respectively) on the lower surfaces, most of the Al is in exchangeable form. On the other hand, for soils located on higher surfaces, where ΔpH values are low and negative, most of the Al is in nonexchangeable form. However, the level of Al saturation in most of the soil samples is not high enough (less than 60% Al saturation), at plow layer at least, to prevent or seriously affect the growth of most crops in the study area. A possible potential limitation, if the Al saturation is too high, may arise from the effect of the fertilizer salt concentration on the concentration of aluminium in the soil solution. It can be expected, for example, that heavy K fertilization will increase the Al concentration in the soil solution of these soils with low exchangeable K (MacLeod and Jackson, 1967).

Present theories concerning acidic Al in soil suggest that concentrations of the specific forms of Al depend on soil pH and the types and amounts of clay and organic matter present (Pionke and Corey, 1967). Using simple correlation it is found that pH is most highly correlated with exchangeable Al (Table 9). The negative correlation coefficient is affected by the salt concentration used in the pH measurement, being greater for pH (KCl) than for pH (H_2O). This phenomenon is probably due to the effect of the hydrogen ions released during the hydrolysis reaction associated with the aluminium displaced by 1N-KCl, the extractant for Al.

At constant pH and a given concentration of Al^{+3} in solution, an increase in organic matter would increase the nonexchangeable acidic Al (that is Al extracted at pH 4.8 1N-NH_4OAC minus KCl-exchangeable Al) most likely

Table 9.--Correlation coefficients for the relationships between some soil properties.

Soil Properties	All soils, n = 45
pH (H_2O) vs. Exch. Al	-0.591**
pH (KCl) vs. Exch. Al	-0.725**
pH (H_2O) vs. % Organic matter	-0.154*
pH (H_2O) vs. % Clay	n.s.
ΔpH vs. Exch. Al	-0.332*

*Significant at 5% level.

**Significant at 1% level.

n.s. Not significant (significant at 20% level).

at the expense of the exchangeable Al (Pionke and Corey, 1967).

Cation exchange capacity (CEC).--The cation exchange capacity determined by 1N-NH_4OAC (pH 7) is shown in Table 8. The summation of exchangeable bases plus aluminium is also shown. It is realized that the NH_4OAC (pH 7) method includes both the permanent and pH-dependent components. In all the soils the CEC by 1N-NH_4OAC (pH 7) is much greater than the CEC by sum of bases plus aluminium.

In comparison with soils of the temperate regions, the CEC of these soils, including pedon 4, a Spodosol developed in sand, is very low. In the well-drained pedons differences associated with genetic sequences are not evident.

Within the soils with aquic moisture regimes, pedon 8 (fine-loamy) has more CEC than pedons 4 and 9, sandy and coarse-loamy, respectively. These soils constitute a lithosequence of soils.

In all the soils, except pedons 4 and 8, the CEC values decrease with depth and this seems to be correlated with a decrease in organic matter content. Pedon 8 shows only small variations of CEC with depth. The small organic carbon content in the Ap, decreasing with depth, is apparently offset by the increasing clay contents with depth in this Tropaquult. It is apparent from the usual depth distribution of CEC values that the organic matter fraction would be one of the major sources of CEC especially in the upper horizons and in the Bhirm of pedon 4. A regression analysis was made of the data relating CEC to organic carbon and clay content on all of the nine profiles as a group, on the surface horizons (A_1, A_2) plus Bhirm, and subsequently on the other subsoils and on the subsoils on the lower and higher surfaces.

The regression coefficients show a significant positive relationship between CEC of the surface horizons plus Bhirm and organic carbon or percent clay. It is also shown that the clay of the subsoils on lower surfaces and CEC are significantly correlated. All subsoils (B_2 or B_3

horizons), except Bhirm, have low CEC/percent clay values (Table 8). This is to be expected since kaolinite, as will be shown later, is the dominant mineral in the clay fraction. These subsoil values are higher for soils on lower physiographic surfaces than for those on higher physiographic surfaces.

Regression coefficients, "F" and "r" of CEC on percent clay and percent organic carbon

	Regression coefficients		"F"		"r"	
	% clay	O.C.	% clay	O.C.	% clay	O.C.
CEC (all horizons of 9 soils) n = 45	.46	.17	.44°	3.45°	.09	.27
CEC (A_1, A_2, Bhirm horizons) n = 14	.38	.26	126**	12.41**	.95	.71
CEC (all other subsoils except Bhirm) n = 31	-.04	.39	1.94°	-98.9°	.25	.57
CEC (all other subsoils on higher surfaces) n = 16	-.05	-.13	1.28°	1.93°	-0.29	-0.36
CEC (all other subsoils on lower surfaces) n = 15	-0.22	.29	80.69**	.23°	.52	.41

°Not significant, even at 20% level.

**Significant at 5%.

O.C. = organic carbon

r = correlation coefficient. F = variance ratio

The prediction equations for the above significant relationships are as follows: ($\hat{Y}$ is the % organic carbon, X is the CEC, Y = CEC and Xc = % clay)

a. $\hat{Y} = .26X + .35$ for all horizons A_1, A_2, Bhirm.

b. $Y = .15 + .38Xc$ for all horizons A_1, A_2, Bhirm.

c. $Y = 8.62 = .22Xc$ for all other subsoils on lower surfaces.

The CEC values given by the sum of exchangeable bases and exchangeable Al are appreciably lower than those represented by 1N-NH_4OAC pH7. As mentioned previously the CEC obtained by the NH_4OACpH7 method includes both the permanent and the pH-dependent components, hence would not be indicative of the magnitude of this property at field reaction (pH) level of the soils.

According to the data obtained the CEC values of the subsoils on the higher surfaces are very low considering that they are higher in clay content (pedon 1 has a maximum of 34% clay) and contain more organic matter than most other soils. According to Sumner (1963) this marked reduction in CEC of the soils on the higher surfaces can be attributed to one or both of the following:

1. Reduction in negative charge or even generating a positive charge by the mutual neutralization of the negative charge on the clay by the positive charge in the iron oxides. This effect is

reflected in the low CEC/100 gms of clay found in the lower part of the sola of the soils on the higher surfaces (8.-25. m.e. versus 16.-32 m.e.).

2. The negative charge sites on the clay may be blocked by iron oxide covering. According to Sumner (1963) this blocking effect increases with increasing degree of crystallinity of the iron oxides. The appreciably higher Fe_2O_3-d minus Fe_2O_3-0 in the higher well-drained soils (.90-3.0%) indicate more crystalline iron oxides than are found in the well-drained soils on the lower surfaces (.45-.90%).

Extractable iron and aluminium oxides.--Iron and aluminium oxides and hydrous oxides are among the major components of soils in the tropics. It has been shown that these oxides exist in the soil in the forms of amorphous and crystalline inorganic oxides. Selective extractive methods have been used to differentiate these forms of Fe and Al. The acid ammonium-oxalate method (Schwertmann, 1964) extracts mainly the amorphous forms of inorganic Fe and Al while the free oxides as well as the major portion of organic complexes can be determined by the method of Mehra and Jackson (1960) using a dithionite-citrate-bicarbonate system. These procedures have been successful in differentiating forms of Fe and Al in some temperate soils (McKeague *et al*., 1971).

Table 10 shows the contents of these two forms of extractable Fe and Al in the nine pedons studied intensively. The dithionite-citrate-bicarbonate Fe is referred to as the free iron. However, it cannot be assumed that all of the Fe not retained in silicate mineral lattices is extractable by this procedure (Moore, 1973). The dithionite-extractable Fe content generally increases with depth in eight of the nine soils studied (all but pedon 9), but shows a maximum in the upper B horizon of the more poorly drained soils (pedons 4, 8 and 9). The well drained soils on the higher physiographic surfaces (pedons 1, 2, 3 and 7) have Fe contents ranging from 0.76 to 3.22% in their horizons. In all these well-drained pedons the Al_2O_3-d is less than the Fe_2O_3-d, and the amount of free Fe oxides seem to follow the same distribution pattern as the clay content within the same profiles as shown in Figure 12A, B and C. This clearly indicates the combined movement of Fe and clay into the subsoil.

The values of the Fe_2O_3-d contents for the soils on lower physiographic surfaces (pedons 5, 6, 8 and 9) are considerably lower, within the range of 0.09 to 1.12 in the 0-30 cm and 1.12 to 0.10 in the subsurface horizons. In all of these the Al_2O_3-d exceeds the Fe_2O_3-d.

In the more poorly drained soils (pedons 4, 8 and 9), the extractable Al parallels the clay contents as shown in Figures 12 D and E. Apparently Fe may be lost

Table 10.--Percentages of dithionite or oxalate extractable Fe_2O_3, Al_2O_3, and active iron, active aluminium, clay:dithionite Fe and dithionite Fe:coarse silt plus sand ratios.

Horizon	Depth cm	Citrate-dithionite Fe_2O_3-d	Citrate-dithionite Al_2O_3-d	Ammonium Oxalate Fe_2O_3-O	Ammonium Oxalate Al_2O_3-O	Active Fe_2 ($x10^2$)	Active Al_2 ($x10^2$)	Clay: Fe_2O_3-d	Fe_2O_3-d: .02-2 mm ($x10^2$)
		%				Ratios			
				Pedon 1--AMS1					
Ap	0-10	1.86	0.59	0.11	0.05	5.9	8.5	8.1	2.3
B1	10-22	2.36	0.71	0.07	0.09	3.0	12.7	7.2	3.0
B21t	22-45	2.69	0.65	0.09	0.07	3.3	10.8	10.4	4.0
B22t	45-75	2.86	0.92	0.07	0.10	2.4	10.9	11.9	4.6
B3	75-180	3.22	0.47	0.19	0.21	5.9	44.7	10.6	5.1
				Pedon 2--AMM2					
Ap	0-13	0.76	0.45	0.23	0.04	30.3	8.9	19.7	1.0
B1	13-30	1.07	0.74	0.11	0.05	10.3	6.8	15.0	1.5
B21t	30-55	1.97	0.51	0.10	0.13	5.1	25.5	9.6	2.8
B22t	55-108	1.98	0.67	0.09	0.11	4.5	16.4	10.6	3.0
B3	108-180	1.66	0.13	0.03	0.06	1.8	46.2	12.7	2.5
				Pedon 3--AMF3					
Ap	0-12	1.86	0.38	0.19	0.03	10.2	7.9	7.5	2.3
B1	12-22	1.93	0.51	0.16	0.05	8.3	9.8	8.8	2.5
B21t	22-45	2.00	0.56	0.26	0.09	13.0	16.2	10.5	2.8
B22t	45-137	2.36	0.58	0.40	0.10	16.9	17.2	9.3	3.2
B3	137-180	2.38	0.57	0.42	0.11	17.6	19.3	8.8	3.3

Table 10.--Continued.

Horizon	Depth cm	Citrate-dithionite		Ammonium Oxalate		Active Fe_2 ($x10^2$)	Active Al_2 ($x10^2$)	Clay: Fe_2O_3-d	Fe_2O_3-d: .02-2 mm ($x10^2$)
		Fe_2O_3-d	Al_2O_3-d	Fe_2O_3-0	Al_2O_3-0				
		%				Ratios			
				Pedon 4--AMM4					
Ap	0-12	0.06	0.01	0.015	0.003	25.0	30	33.3	0.06
A21g	12-30	0.08	0.02	0.012	0.002	15.0	10	25.0	0.08
A22g	30-140	0.12	0.01	0.001	0.005	0.8	50	8.3	0.12
Bhirm	140-200	2.24	0.03	0.42	0.008	18.7	27	0.9	2.3
				Pedon 5--ASU5					
Ap	0-13	0.52	1.23	0.014	0.23	2.7	18.7	21	.62
B1	13-38	0.85	1.29	0.023	0.25	2.7	19.4	18	1.0
B21t	38-88	0.89	1.34	0.026	0.19	2.9	14.2	23	1.3
B22t	88-150	0.90	1.18	0.014	0.18	1.6	15.3	27	1.2
B3	150-180	0.92	1.17	0.012	0.20	1.3	17.1	25	1.2
				Pedon 6--AK6					
Ap	0-18	0.35	0.98	0.006	0.09	1.7	9.2	42	.42
B1	18-53	0.35	1.01	0.001	0.10	0.3	9.9	40	.42
B21	53-110	0.45	1.21	0.006	0.17	1.3	14.0	33	.54
B22	110-143	0.77	1.27	0.009	0.19	1.2	15.0	19	.94
B3	143-180	0.79	1.09	0.006	0.22	0.8	20.2	22	1.0

Table 10.--Continued.

Horizon	Depth cm	Citrate-dithionite Fe_2O_3-d	Citrate-dithionite Al_2O_3-d	Ammonium Oxalate Fe_2O_3-O	Ammonium Oxalate Al_2O_3-O	Active Fe_2 ($x10^2$)	Active Al_2 ($x10^2$)	Clay: Fe_2O_3-d	Fe_2O_3-d: .02-2 mm ($x10^2$)
		%				Ratios			
				Pedon 7--UM7					
Ap	0-20	0.77	0.45	0.07	0.02	9.1	4.4	21	.96
B21t	20-55	0.98	0.53	0.08	0.05	8.2	9.4	22	1.3
B22t	55-100	1.01	0.62	0.08	0.08	7.9	12.9	28.7	1.5
B31	100-150	0.99	0.58	0.09	0.10	9.1	17.2	29.3	1.5
B32	150-210	0.94	0.49	0.03	0.12	3.2	24.5	31.9	1.4
				Pedon 8--PH8					
Ap	0-10	0.12	1.80	0.012	0.19	10.0	10.6	66.7	0.16
A2g	10-23	0.09	1.55	0.001	0.22	1.1	14.2	177.8	0.13
B21tg	23-40	1.12	2.10	0.002	0.27	0.2	12.9	17.0	1.8
B22tg	40-72	0.65	1.70	0.001	0.30	0.1	17.6	36.9	1.1
IIB23tg	72-120	0.45	2.31	0.003	0.32	0.7	13.9	57.8	0.74
IIB3	120-180	0.73	2.50	0.001	0.31	0.1	12.4	27.4	1.0
				Pedon 9--ET9					
A1	0-2	0.10	1.2	0.001	0.16	1.0	13	80	.11
A2	2-10	0.12	1.6	0.001	0.26	0.8	16	75	.14
IIB21tg	10-28	0.13	1.9	0.003	0.26	2.3	14	115	.16
IIB22tg	28-87	0.11	2.2	0.002	0.29	1.8	13	160	.14
IIB3	87-180	0.10	1.6	0.001	0.28	1.0	18	180	.13

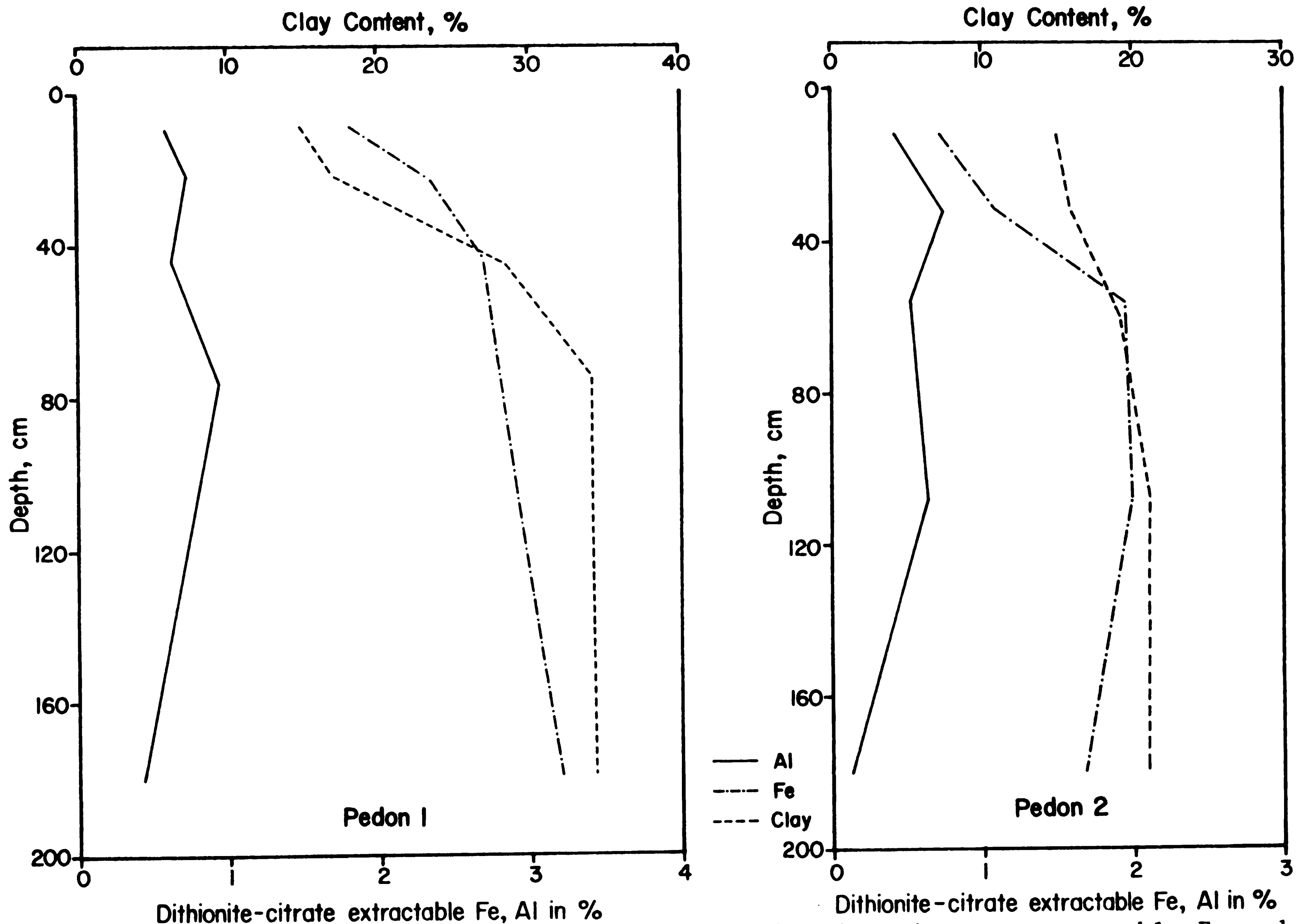


Fig. 12A.--Distribution with depth of clay and dithionite-citrate extractable Fe and Al.

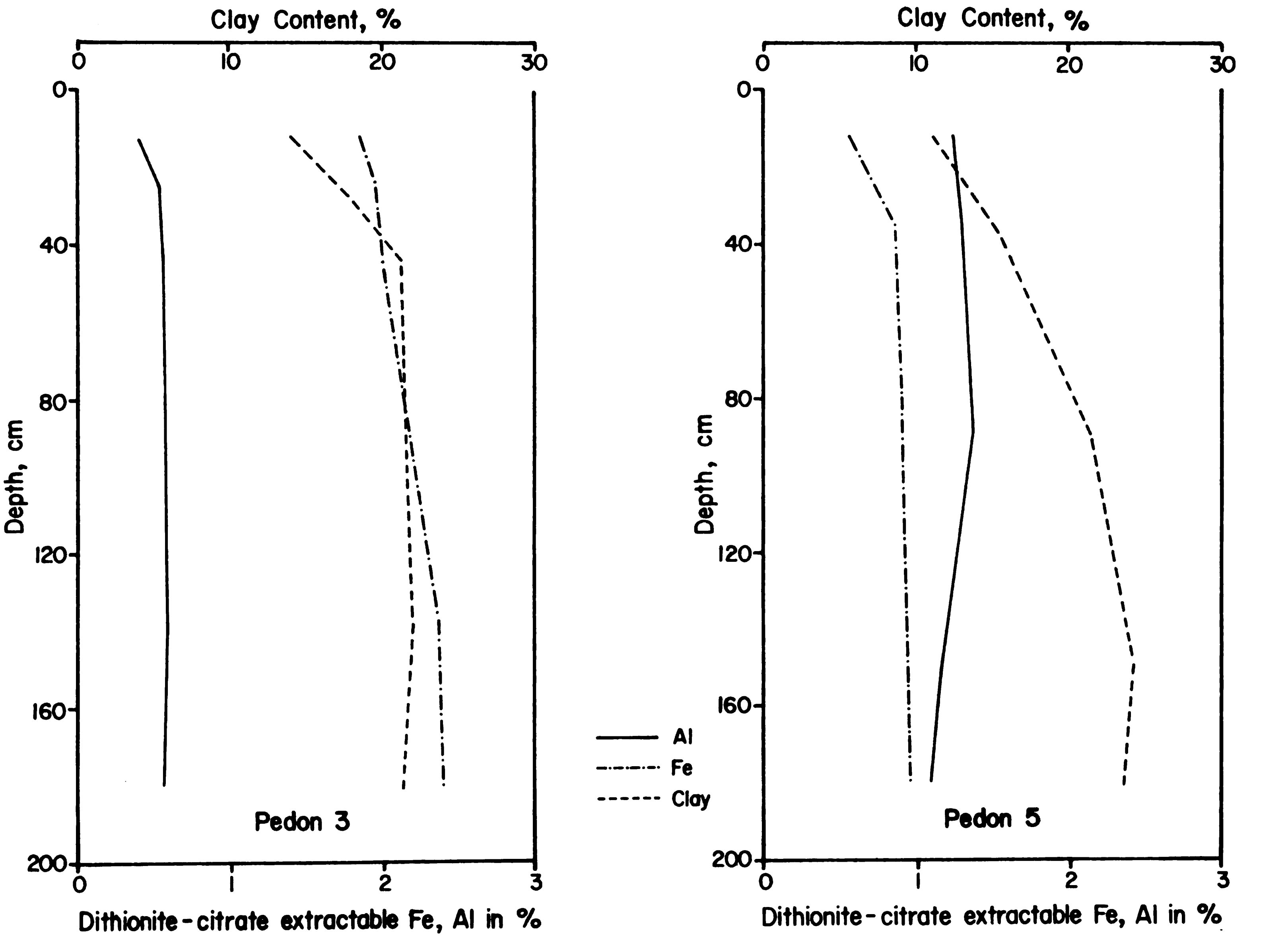


Fig. 12B.--Continued.

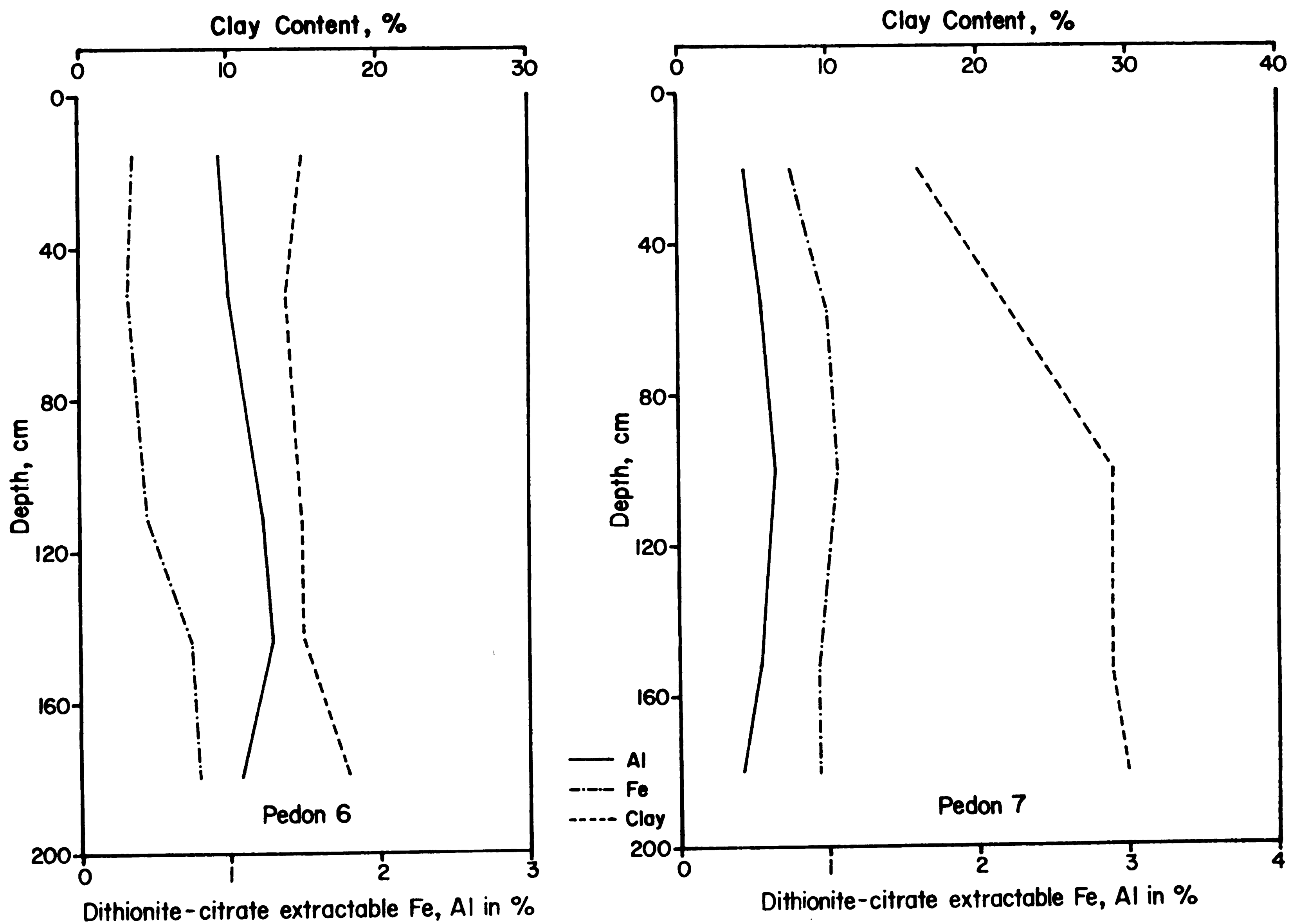


Fig. 12C.--Continued.

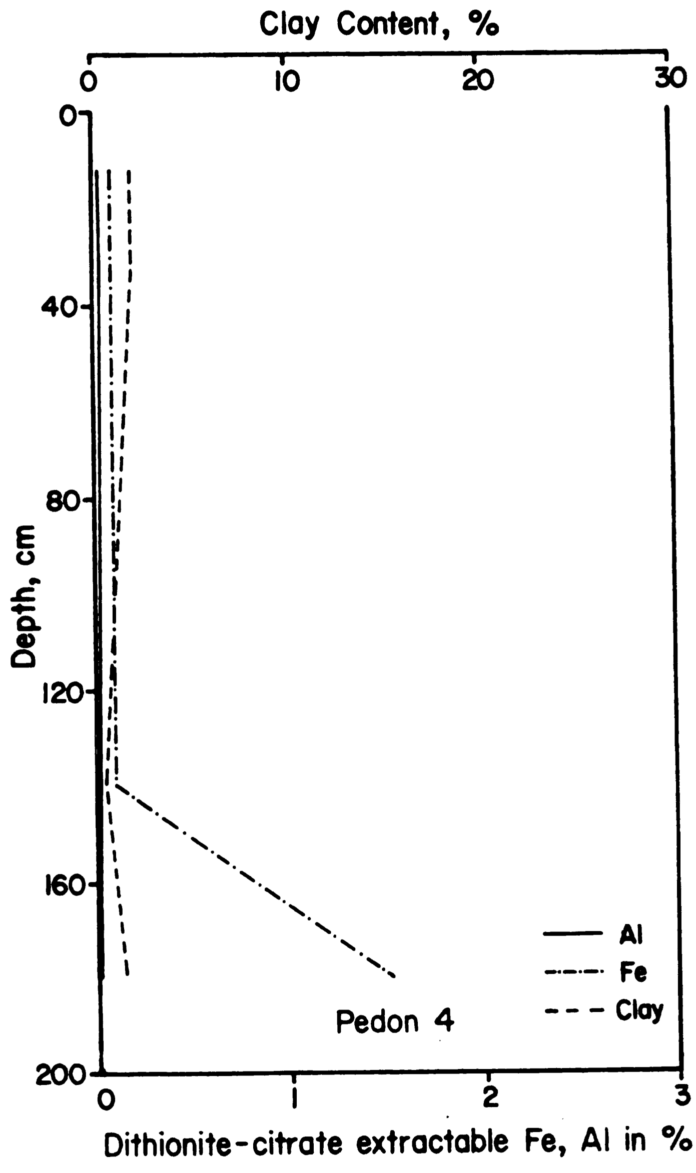


Fig. 12D.--Continued.

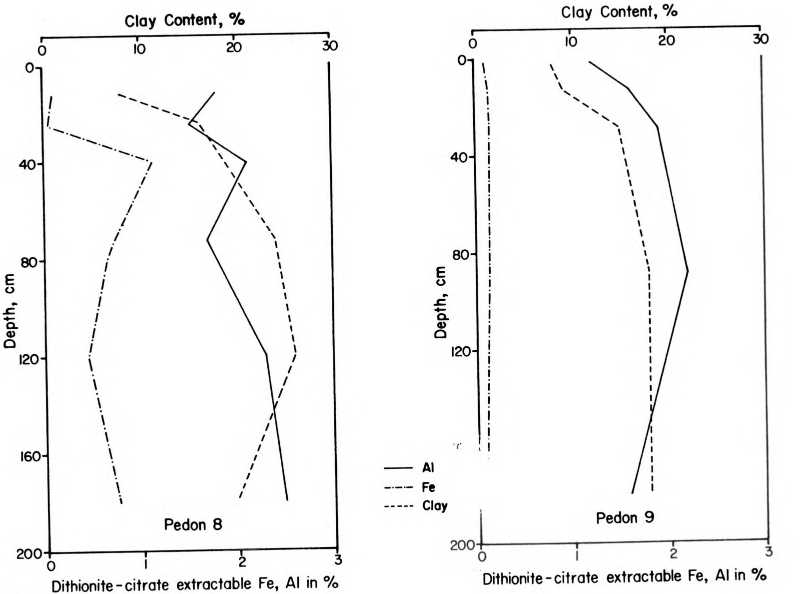


Fig. 12E.--Continued.

during profile development under these moisture or drainage conditions. The differences may be related to their aquic moisture regimes.

As shown in Figure 13, the clay-dithionite Fe ratios in the well drained pedons 1, 2 or 3 and 5 or 7 usually increase as a function of depth, but is higher in the last two on the lower surfaces. By contrast, these ratios are much more variable with depth in the more poorly drained pedons (4, 8 and 9). Also, the clay: dithionite-Fe ratios (Table 10), may decrease or increase with depth instead of following the clay content distribution as in the aforementioned pedons. A marked accumulation of Fe_2O_3-d is evident deep in pedon 4, Figure 12D. This is paralleled by a high organic content as mentioned earlier. In pedon 6, there is no particular trend in the clay:dithionite-Fe ratio with depth. This soil is an Oxic Dystropept, as discussed later, with no argillic horizon. This increase and decrease pattern in this pedon suggest that either the small Fe content difference is partially independent of any clay illuviation or it is due to differences in parent material.

Examination of the Fe_2O_3-dithionite/coarse silt + sand values in Table 10 shows almost constant pattern and high values with depth in all the first three soils on higher land surfaces. These values are lower and more variable with depth in the more poorly drained soils

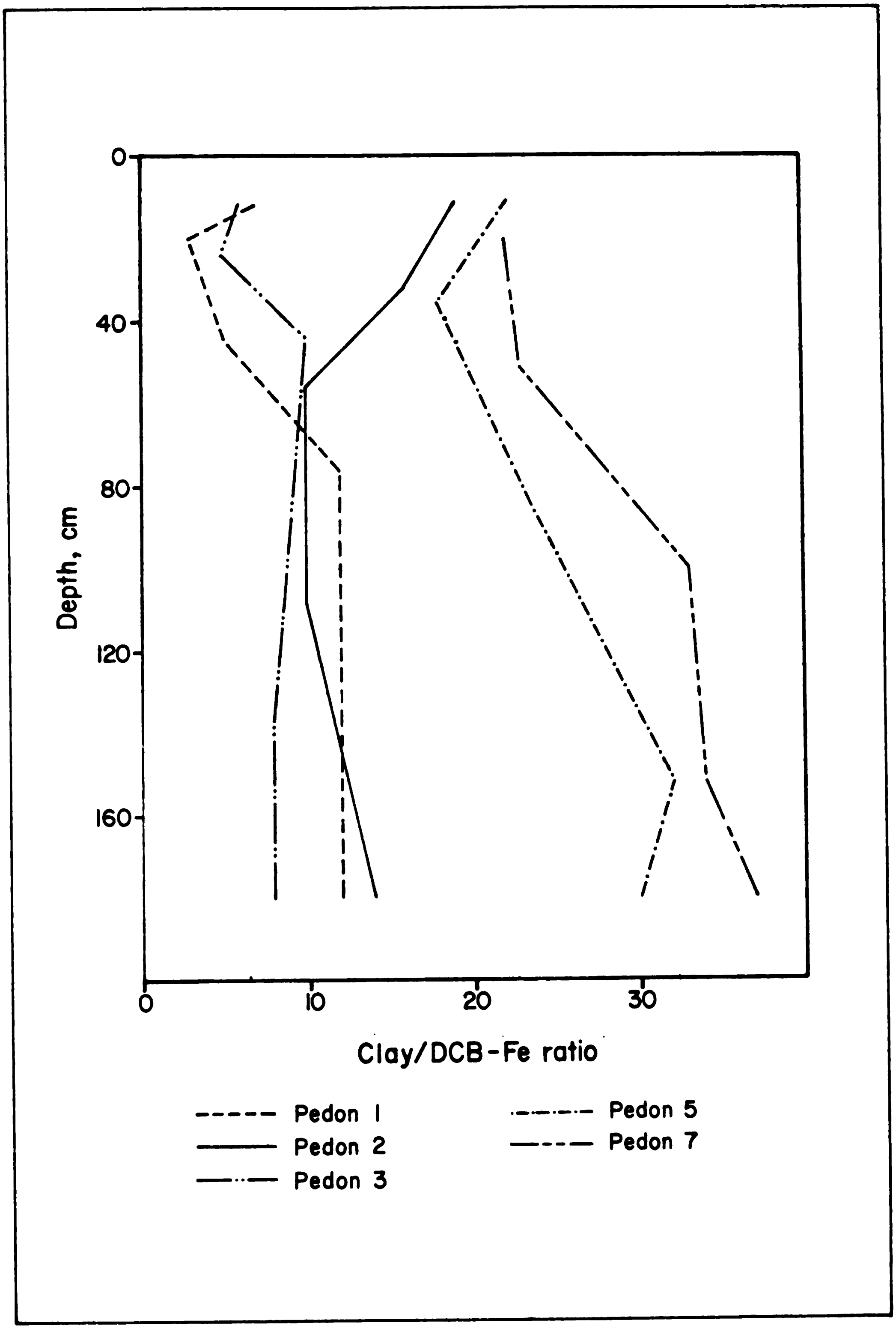


Fig. 13.--Relationship between clay/dithionite-Fe ratio and profile depth.

(pedons 4, 8 and 9). This also confirms the movement of iron oxides in the more poorly drained soils since the coarse-silt and sand are weathered to a fairly uniform suite of resistant minerals in all the horizons. This fact is indicated in the mineralogy of the coarse-silt and sand fractions studied with a petrographic microscope as discussed later. The Fe_2O_3-dithionite/coarse-silt + sand ratios are also lower on the well drained soils on the lower land surfaces (pedons 5, 6 and 7) but not so variable with depth as in the more poorly drained soils.

In the comparison between iron oxide and clay movements one or two means of movement can be implied. The iron oxides may have moved by physical translocation. Reduction, solution, migration with organic matter and reprecipitation may also occur as shown by pedon 4. The different amounts of iron oxides in the different horizons in pedons 1, 2, and 3 seem to show a trend typical of illuviation by suspension with finer particles increasing into the lower horizons. Another pathway by which iron could have been transported down the soils is by absorption on, and subsequent movement with, clay particles. According to Parks (1965) when hydrous iron oxides are freshly precipitated they have iso-electric points above pH7 and will be positively charged in soils with lower pH values. At an early stage of weathering, they may have been absorbed on to negatively charged clay surfaces and moved downwards with the clays. Although this mechanism seems highly speculative and there is no present evidence either for or against it, it does in part explain the similarity between the clay and iron oxides distributions with depth and the close range of the clay-dithionite Fe values in the old well drained soils. However, even if it prevailed at an early stage of soil formation, it is no longer operative as the iron oxides are presently highly crystalline with very low iso-electric points.

The amounts of dithionite or oxalate extracted Al are lower in comparison with those of iron for pedons 1, 2, 3, 4 and 7, but the distribution of these forms of Al according to depth is similar to that of Fe except in pedon 4 which shows no strong accumulation of Al deep in the profile. For the soils on the higher surfaces (pedons 1, 2, 3 and 4) the amounts of Al extracted by the two methods are less than on the lower surface soils while for Fe the reverse is true. This increase in extractable Al contents as one goes from high elevations to sea level is in agreement with increasing rainfall in the area studied. However, the more poorly drained pedons 8 and 9 show much larger amounts of extractable Al and these parallel the profile clay contents, Figure 12E.

The relative abundance of Fe and Al in the amorphous forms is much less when compared with the results obtained by McKeague and Day (1966) and McKeague *et al*. (1971) on soils of the temperate region. McKeague and Day (1966) found amorphous Fe_2O_3 values between 0.47-5.56% in their study. The low content of amorphous Fe and Al (ammonium-oxalate extractable) fractions in the present study may be due to the high temperature condition and the alternating wet and dry season prevalent in the Coastal Plain Sands area. Sherman _et al_. (1964) stated that drying at elevated temperature causes the amorphous Fe and Al oxides to dehydrate and subsequently shift to a system of greater crystallinity.

The distribution of oxalate extractable Fe or Al to total free Fe or Al within each pedon can be conveniently expressed as "active Fe or Al ratio" (Blume and Schwertmann, 1969). These ratios are obtained as follows:

$$\text{Active Fe or Al ratio} = \frac{\text{Oxalate Fe or Al}}{\text{Dithionite Fe or Al}} \times 100$$

Table 10 gives the active Fe and Al ratios for the nine pedons, as percents of the dithionite forms of each. Ratios of active Fe in most of the six well-drained pedons (except pedon 3) decrease with depth while active Al ratios increase (except pedon 5). The comparatively low values of oxalate-Fe and Al in pedon 4 may account for the erratic pattern of the active ratios in this profile. The high oxalate and dithionite extractable Fe in the deepest horizon of this profile, a spodic horizon, are most striking.

The decreases in active Fe with depth indicate that higher proportions of Fe are present in more crystalline forms in the lower horizons of the well-drained profiles. The higher ratios observed in the surface horizons reflect the large amount of amorphous Fe released by weathering near the surface (Follet _et al_., 1965) and the retarded rate of crystallization of Fe oxides and hydroxides in the presence of organic matter (Schwertmann _et al_., 1968).

Nevertheless, the same relationship does not hold true in the case of Al where the active Al ratios are calculated in the same way as for Fe. The actual chemical and physical forms of Al in soil extracted by the dithionite and oxalate reagents are poorly understood. In view of this no further interpretative comments can be made at this point.

The low amounts of extractable and active Fe in the more poorly drained soils, pedons 8 and 9, can be explained by the oxidation-reduction regime and related soil-ground water movement at each site. Soils located on the higher surfaces have deeper water-tables than those on the lower surfaces. The former soils have undergone longer periods of alternating oxidation and reduction than soils near sea level. This fact can be reflected by the larger amounts of extractable Fe shown by the results (Table 10). Soils at the higher elevation and older in age probably have lost the smallest amount of iron from the solum and may have had the opportunity to accumulate iron through biocycling. Since these soils are well drained and the sola have less reducing conditions, little or no iron is lost. As stated earlier, there have been translocation of iron along with clay within the sola of some pedons (1, 2 and 3). The pedons with the more pronounced increase in clay and iron within the solum may have been changed much less by soil development, in terms of total iron and clay than soils at the lowest surfaces with little or no increase in iron content in the B horizon. Also in the poorly drained sites with permanently gleyed horizons, precipitation of iron oxides can be envisaged as being caused by occasional flushes of oxygenated water, which oxidize ferrous compounds and decrease their solubility. There is also the possibility of microbial oxidation, for example, by Ferrobacillus ferro-oxidans. Silica and aluminium are unaffected by change in redox potential and will tend to stay in solution, leaving comparatively unadulterated amorphous ferric compounds to precipitate, as in pedon 4 herein (Deshpande _et al_., 1968). Alternating wetting and drying seem to be essential for clay movement in well-drained soils (Thorp _et al_., 1959), and this cyclic moisture regime would reach its maximum intensity in the areas with shallow water-tables, such as in pedons 8 and 9. Juo _et al_. (1974), working on selected soils of Nigeria, found similar amounts, distribution and co-migration of clay and dithionite-extractable Fe (Lessivage).

Distribution of phosphorus forms.--The amounts of the various forms of phosphorus are given by horizons in Table 11.

All the forms of phosphorus usually decrease with depth in these soils. Pedon 4, a poorly drained, very acid sandy soil with a spodic subsoil horizon, has an increase of organic-P and Fe-P in the subsoil. Al-P and Ca-P are very low in this pedon. Ca-P while very low in pedon 3, increases somewhat with depth.

Similar amounts of available phosphorus are extracted by the Bray P_1 and North Carolina methods. There is a close correlation between the available phosphorus determined by these methods (r = .79, significant at 5% level). The relative merits and demerits of these methods are not determined in the present study as this would involve correlation of the chemically determined available P and applied phosphorus with crop response. The two extractants are similar in selectivity of solution of available P in acid soils hence the high degree of correlation. The selection of a suitable routine soil chemical test for soil available P must be based on the distribution pattern of the active inorganic P forms present in the soils according to Uzu et al. (1974) and Chang and Juo (1962).

Table 11.--Amounts of various forms of phosphorus, organic C/P ratios, and P-fixation capacities.

Horizon	Depth	Available P		Organic	Active P			Total	Org. C/P	P-fix.
	cm	Bray P_1	N. Car.	P	Fe-P	Al-P	Ca-P	active P	ratio	cap.
		ppm								%
				Pedon 1--AMS1						
Ap	0-10	10.0	11.0	100	14	3.5	.79	18.3	176	75
B1	10-22	8.0	8.1	80	13	2.5	.95	16.5	200	83
B21t	22-45	6.0	5.8	47	8	1.1	.10	9.2	183	89
B22t	45-75	3.5	4.5	40	6	0.9	.10	7.0	178	90
B3	75-180	3.0	3.5	21	9	0.8	.10	9.9	250	95
				Pedon 2--AMM2						
Ap	0-13	10.0	10.0	61	12.0	5.0	2.0	19.0	169	70
B1	13-30	7.5	8.0	45	10.1	3.0	1.9	15.0	160	85
B21t	30-55	5.0	7.0	30	7.9	1.5	0.9	10.3	180	90
B22t	55-108	4.0	5.0	19	6.5	0.9	0.7	8.1	132	95
B3	108-180	3.5	5.0	6	6.0	0.8	0.1	6.9	200	95
				Pedon 3--AMF3						
Ap	0-12	7	7.5	65	11.0	2.0	.12	13.12	169	76
B1	12-22	5	4.0	53	8.0	2.0	.10	10.1	192	80
B21t	22-45	4	4.0	27	6.0	1.5	.10	7.6	196	92
B22t	45-137	4	3.0	16	5.4	0.4	.60	6.4	206	95
B3	137-180	3	3.0	7	3.0	0.8	.90	4.7	400	100

Table 11.--Continued.

Horizon	Depth cm	Available P Bray P_1	Available P N. Car.	Organic P	Active P Fe-P	Active P Al-P	Active P Ca-P	Total active P	Org. C/P ratio	P-fix. cap.
		ppm								%
				Pedon 4--AMM4						
Ap	0-12	4	5	72	2.0	0.2	trace	2.2	314	30
A21g	12-30	2.1	1.3	11	1.8	0.1	trace	1.9	280	37
A22g	30-140	0.9	1.1	20	1.8	0.1	trace	1.9	195	40
Bhirm	140-200	0.5	0.4	25	4.0	0.1	trace	4.1	230	40
				Pedon 5--ASU5						
Ap	0-13	12	10.0	130	11.6	7.0	3.0	21.6	200	65
B1	13-38	9	9.0	70	11.4	6.0	2.0	19.4	80	70
B21t	38-88	6	6.5	43	6.2	5.0	3.0	14.2	84	73
B22t	88-150	5	4.0	23	5.0	4.7	2.0	11.7	154	79
B3	150-180	3	3.0	21	4.0	4.0	1.5	9.5	164	80
				Pedon 6--AK6						
Ap	0-18	10	11.2	57	10.0	3.0	1.8	14.8	60	65
B1	18-53	7	9.5	25	9.8	3.0	0.9	13.7	88	70
B21	53-110	6	8.5	17	8.2	2.0	0.6	8.9	124	75
B22	110-143	5	5.0	6	6.1	1.5	0.1	7.7	216	80.5
B3	143-180	5	5.0	3	5.4	0.9	0.1	6.4	360	80

Table 11.--Continued.

Horizon	Depth cm	Available P Bray P_1 (ppm)	Available P N. Car. (ppm)	Organic P (ppm)	Active P Fe-P (ppm)	Active P Al-P (ppm)	Active P Ca-P (ppm)	Total active P (ppm)	Org. C/P ratio	P-fix. cap. %
				Pedon 7--UM7						
Ap	0-20	8	9	73	10	1.5	0.9	12.4	173	70
B21t	20-55	5	5	45	8	0.9	0.1	9.0	100	80
B22t	55-100	5	4	27	8	0.9	0.1	9.0	144	90
B31	100-150	3	3.5	16	6.9	0.8	0.1	7.8	175	95
B32	150-210	3	3.5	9	4.5	0.8	0.1	5.4	190	90
				Pedon 8--PH8						
Ap	0-10	13	12.0	140	4.0	6.1	5.9	16.0	140	50
A2g	10-23	10	10.5	105	3.0	5.7	4.3	13.0	40	65
B21tg	23-40	6	7.0	85	3.0	4.5	3.9	11.4	54	69
B22tg	40-72	5.5	5.5	70	2.1	3.2	2.6	7.9	90	70
IIB23tg	72-120	5.0	5.0	60	2.0	2.0	1.5	5.5	70	75
IIB3	120-180	5.0	5.0	40	2.1	2.0	0.9	5.0	133	70
				Pedon 9--ET9						
A1	0-2	11	12	130	6.0	6.9	8.2	21.2	138	55
A2	2-10	8	8	120	4.0	5.2	5.9	15.1	58	70
IIB21tg	10-28	5	5	70	3.0	4.0	5.0	12.0	75	75
IIB22tg	28-87	4	5	65	2.1	2.4	4.0	8.5	105	80
IIB3	87-180	3.5	4	55	1.9	2.2	3.5	7.6	73	75

Bray P_1: 0.03 N•NH_4F + 0.025 N•HCl extractant.

North Carolina Method: 0.05 N•HCl + 0.025 N•H_2SO_4 extractant.

The active fractions of P can be grouped into Ca-bonded phosphates (Ca-P), aluminum-bonded phosphates (Al-P) and iron-bonded phosphates (Fe-P). The relative amounts of these forms in the active fraction are shown in Figure 14, for all but pedon 4, where Fe-P is the predominant active form. The relatively inactive fractions, occluded and reductant-soluble forms, were not determined in this study. The Fe-P accounts for over half the total extractable inorganic phosphate forms (70-80%) in most of the well-drained pedons (pedons 1-3, 6 and 7). Even in pedon 5, also well-drained, Fe-P is the most abundant active P form, but Al-P and Ca-P are relatively more abundant in this pedon. There is very little P present as Ca-P in the well-drained soils. This is associated with the low pH values of these soils.

Pedon 1 has slightly higher Fe-P contents than pedon 2 or 3. These are a lithosequence of well-drained soils with ustic moisture regimes. Pedon 1 developed in finer fine-loamy materials and pedon 2 or 3 in coarser fine-loamy materials. However, pedon 7 also developed in finer fine-loamy materials in the ustic area but it has the lowest Fe-P content of these four pedons. Pedon 5 has slightly more Fe-P content in the upper part and less below than pedon 6. They are a lithosequence of well-drained soils developed in coarser fine-loamy and coarse-loamy materials, respectively, with udic moisture regimes.

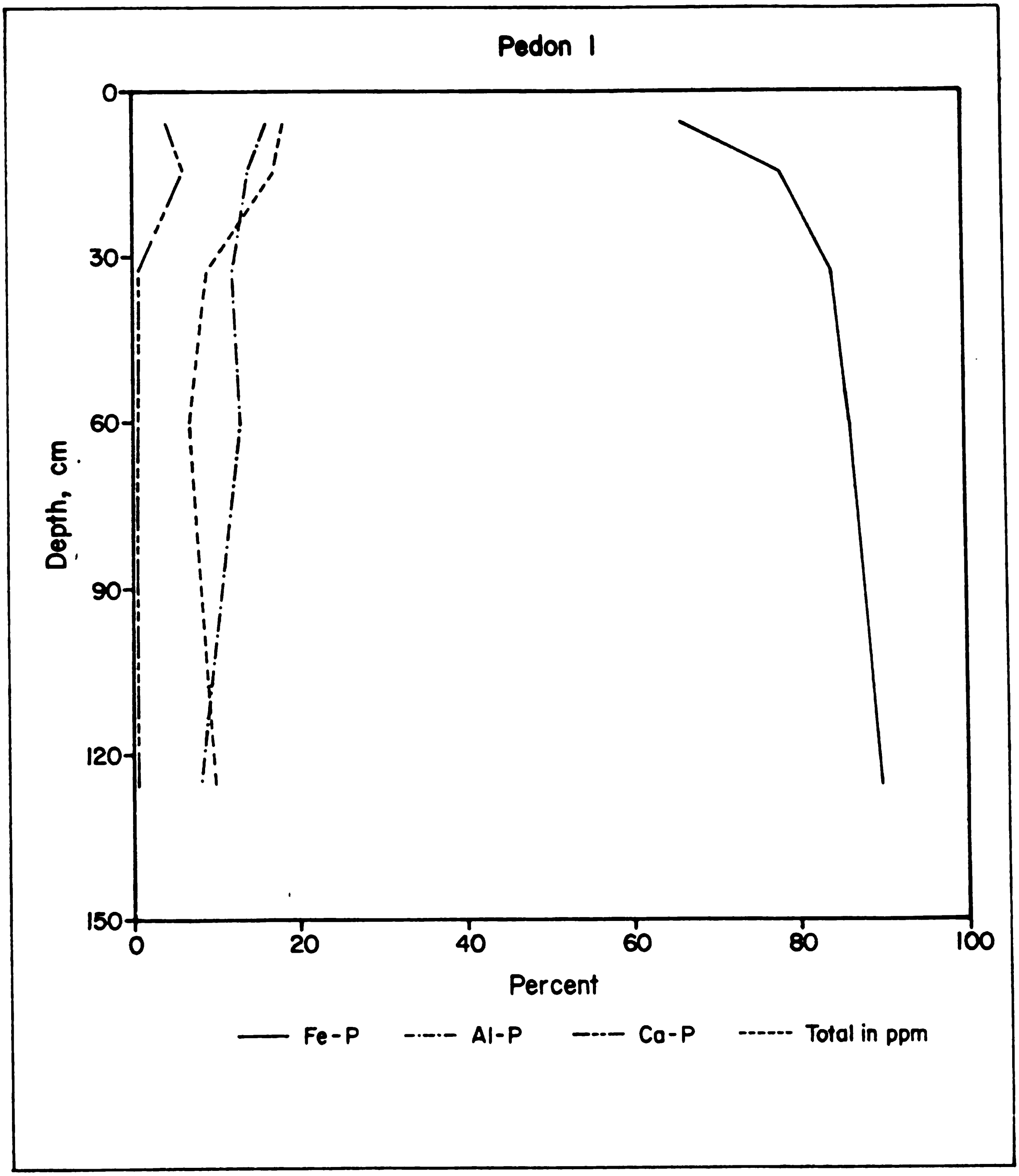


Fig. 14.--Relative distribution of the various active P forms as percentage of total active P.

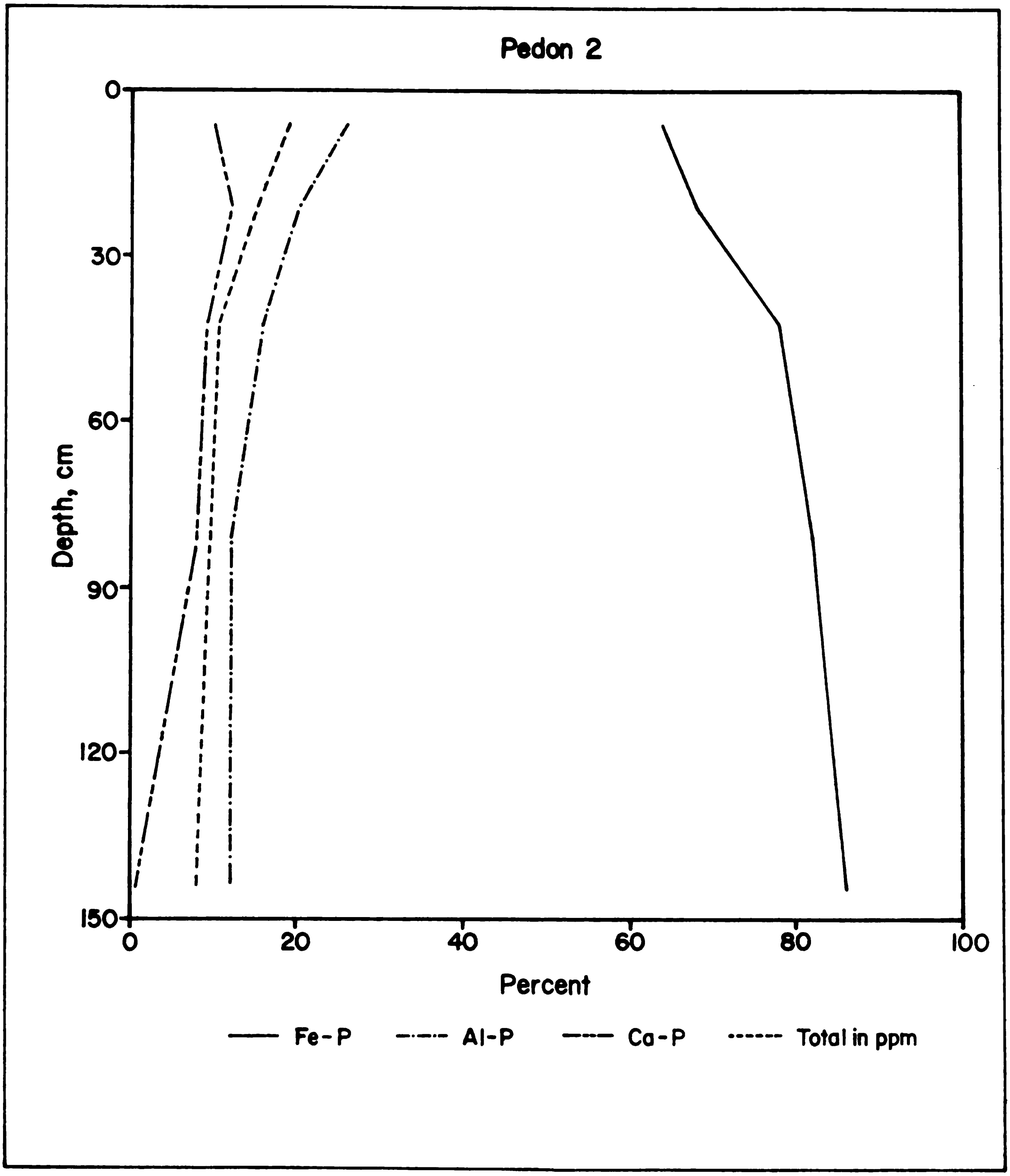


Fig. 14.--Continued.

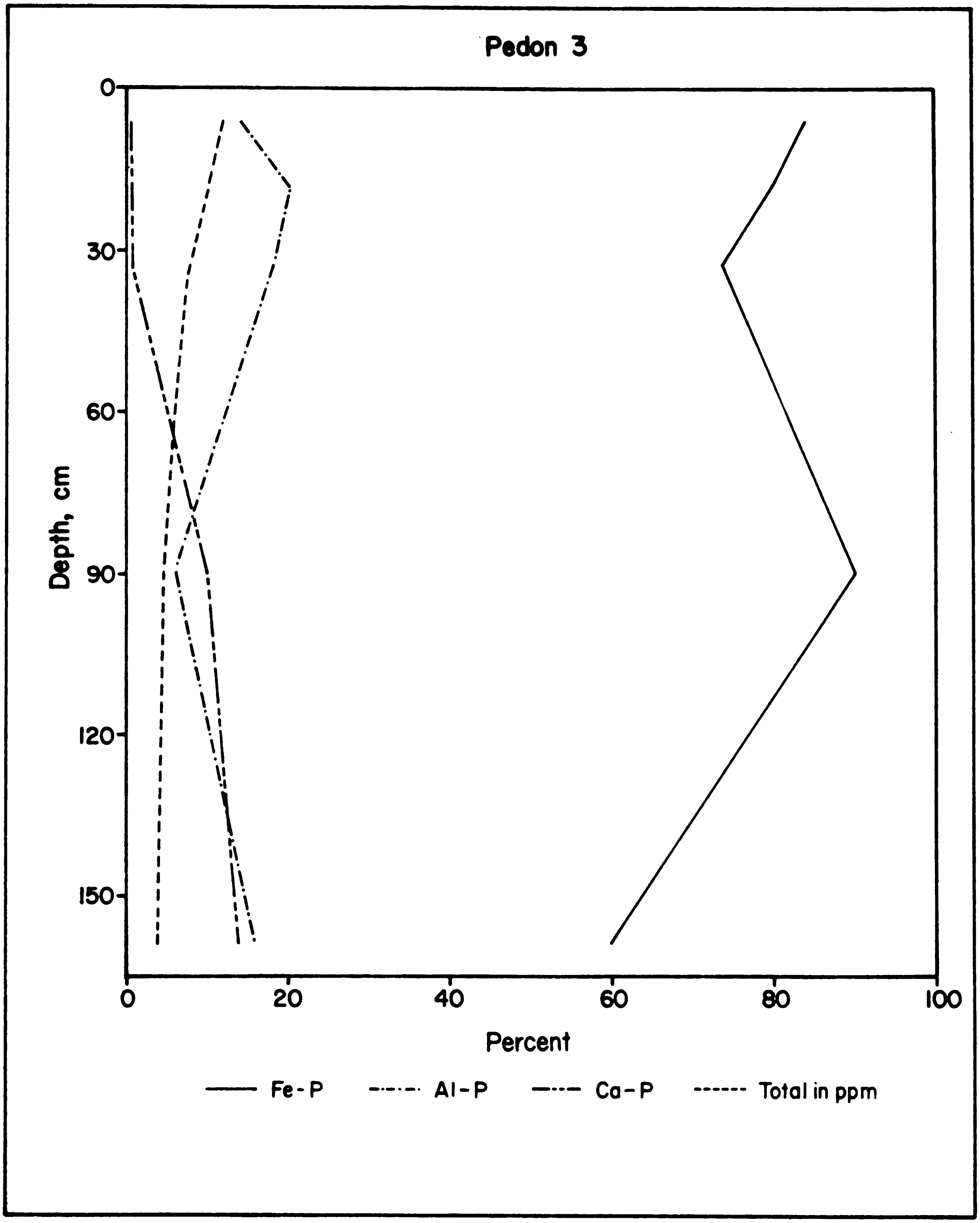


Fig. 14.--Continued.

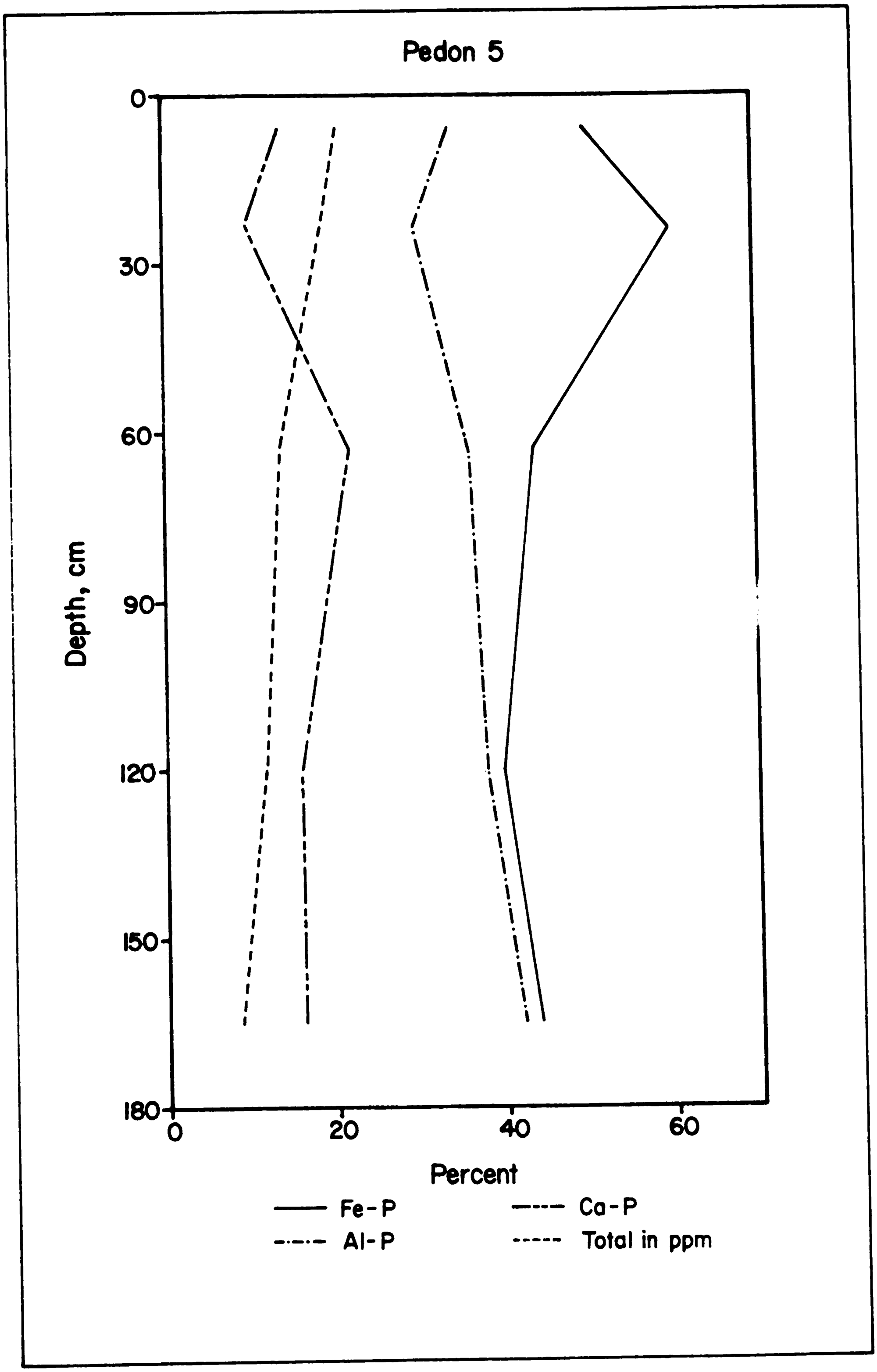
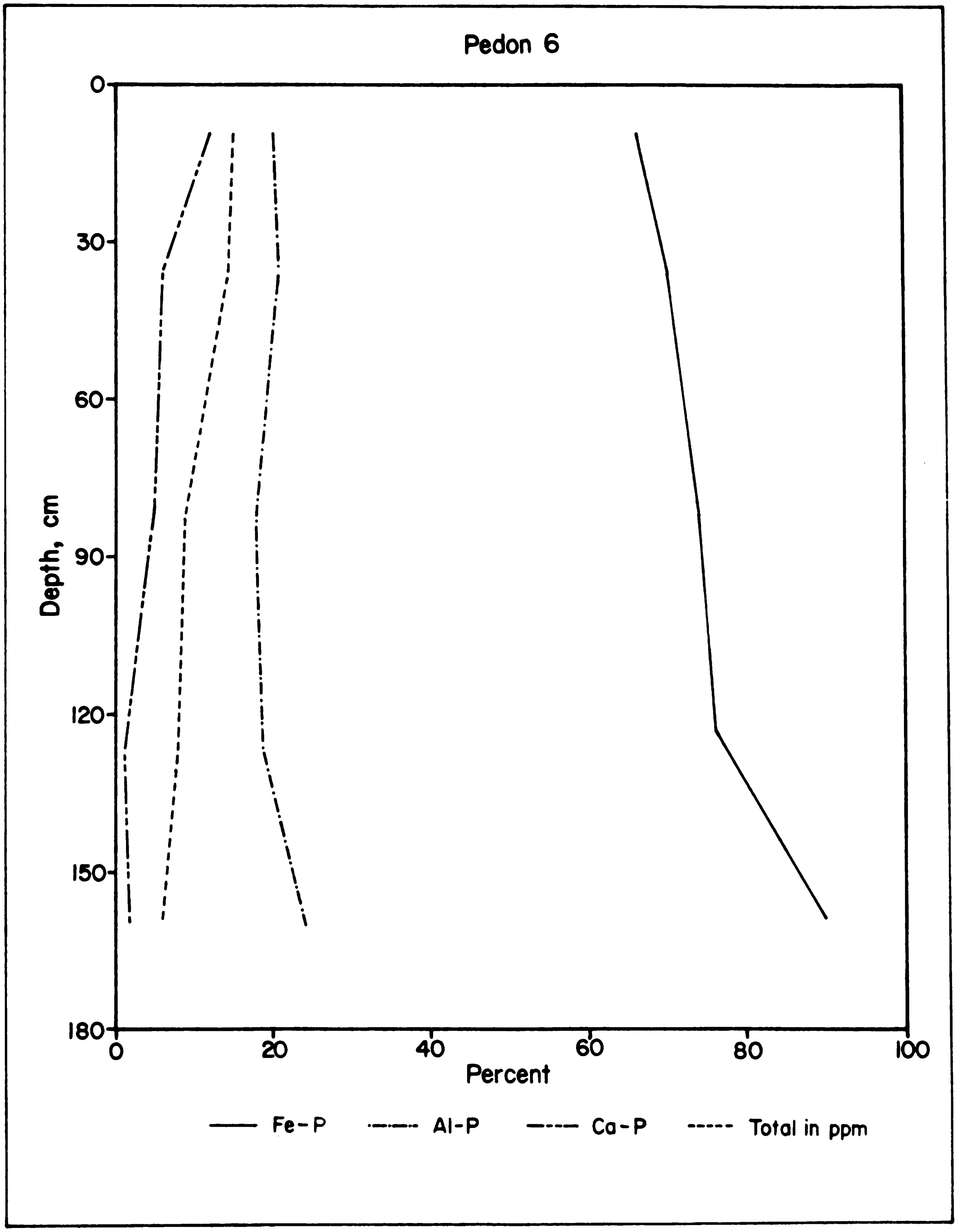


Fig. 14.--Continued.



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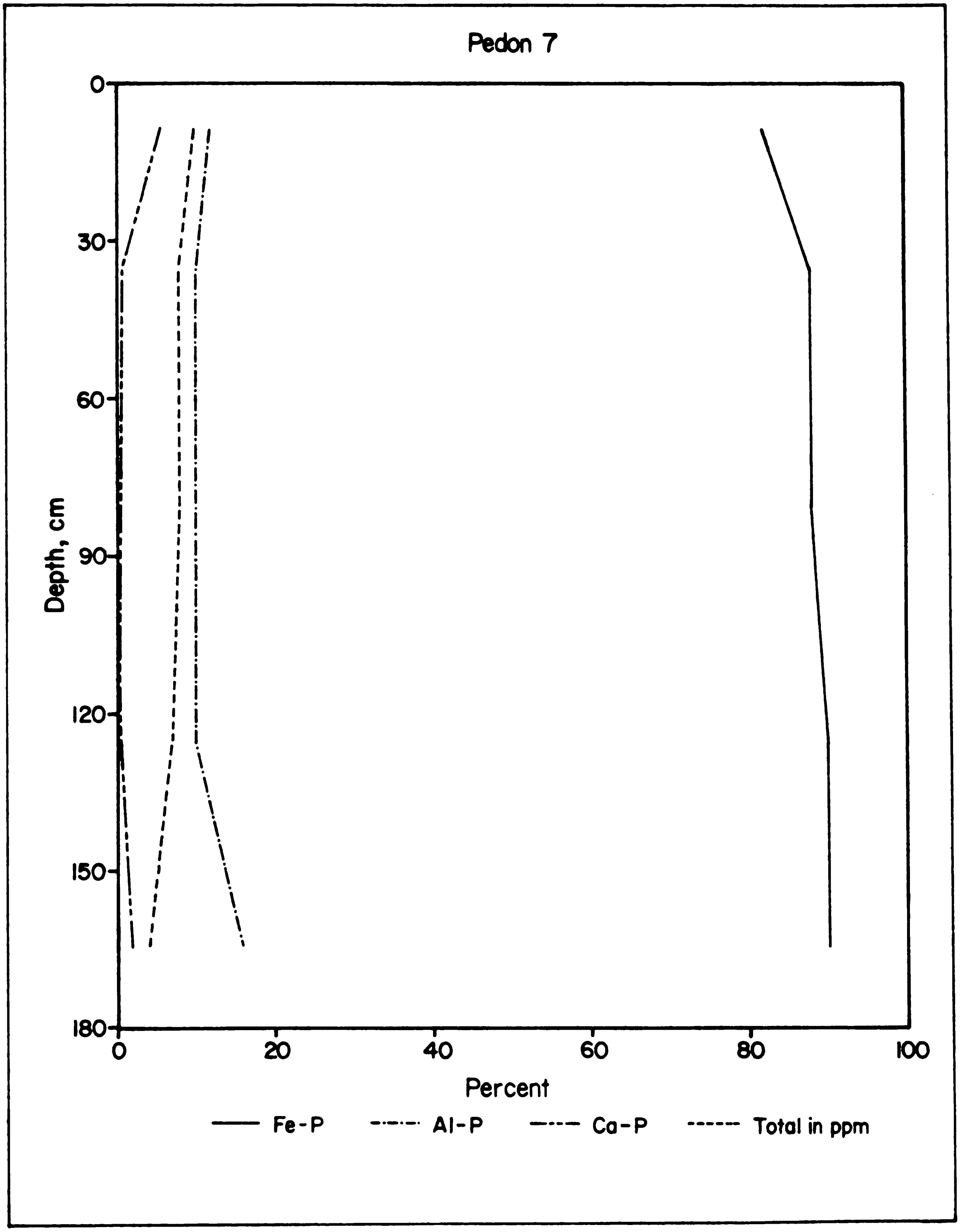


Fig. 14.--Continued.

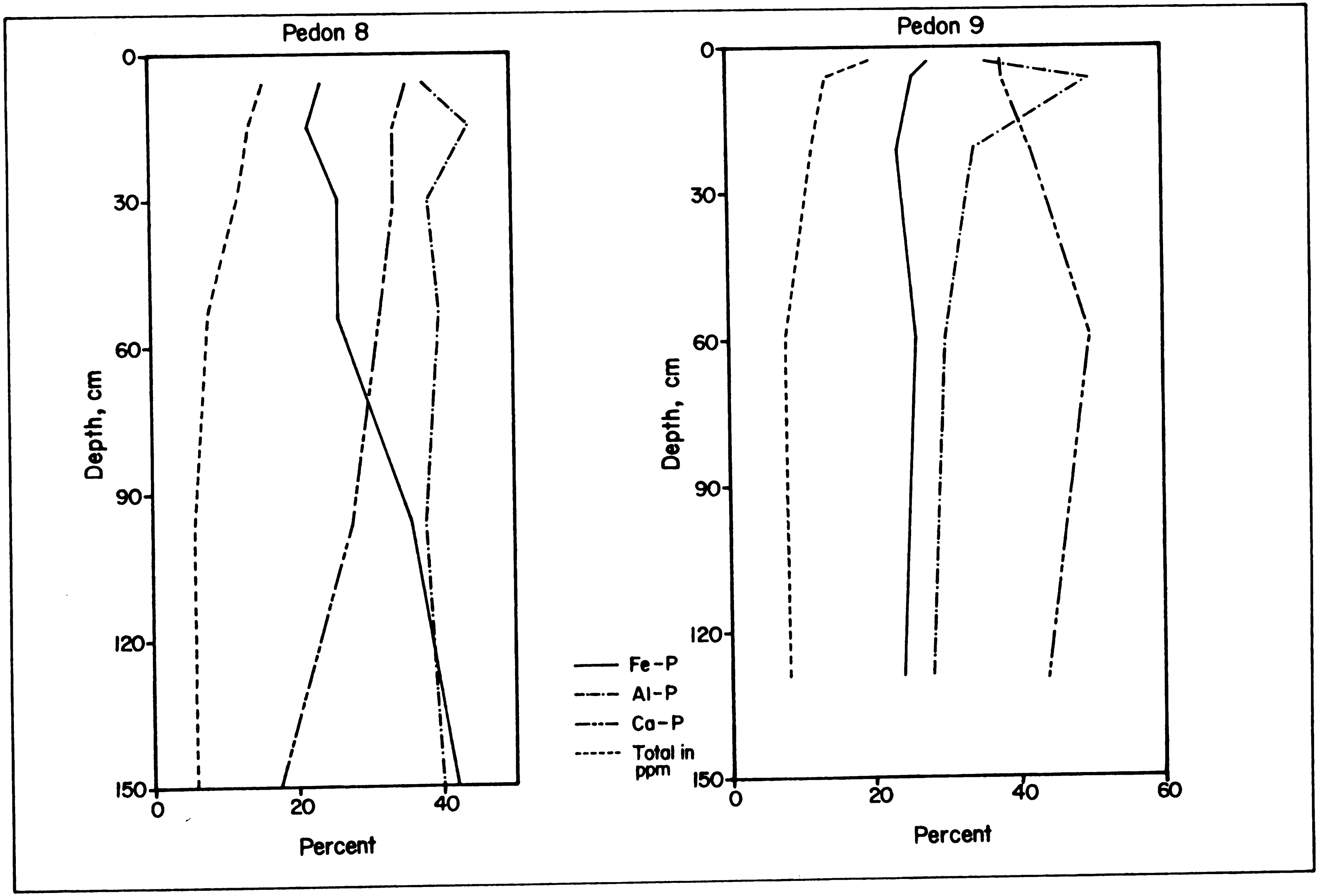


Fig. 14.--Continued.

There are apparently no clear cut litho- or climosequence relationships to amounts of active P forms in these well-drained soils. However, the relative amount of Fe-P in the active P is greater in the well-drained soils of ustic areas (pedons 1-3 and 7).

For pedons 8 and 9 with aquic moisture regimes and Bt subsoil horizons the three forms of active P are more evenly divided. But, as in the well drained soils, there are little textural (lithosequence) associated differences in the active P forms. However, Fe-P is the least abundant of the three mineral forms, Al-P being the most abundant form in the poorly drained soil (pedon 8) and Ca-P the most abundant form in the somewhat poorly drained soil (pedon 9).

When these soils are compared to the well drained soils in the udic moisture regimes at similar elevations, the difference in distributions of active P forms are apparently toposequence relationships. It will be interesting to see if these toposequence relationships also hold in the ustic moisture regimes at higher elevations.

The low level of Al-P and Ca-P in the well-drained soils is attributed to the strong weathering of the soils under well-drained conditions. The low Al-P content suggests that the capacity of these soils to supply plant available P from this inorganic pool is, therefore, limited (Chang and Juo, 1962; Juo and Ellis, 1968). In acid soils, such as these under study, Al-P has been found to be more available than Fe-P for upland crops (Hanley, 1962; Payne and Hanna, 1965). However, Juo and Ellis (1968) using synthetic materials found the colloidal forms of Al-P and Fe-P to have almost the same degree of availability and they were much more available than the more crystalline forms of strengite, $FePO_4$-H_2O and variscite, $AlPO_4$-$2H_2O$.

Since most of these soils under study are highly weathered, the relatively high content of Al-P and Ca-P in the more poorly drained, non-spodic soils (pedons 8 and 9), may be due to poor drainage conditions rather than degree of weathering (Juo and Ellis, 1968; Westin and deBrito, 1969; Uzu *et al*., 1974). These soils are found in the more forested udic areas of the study area.

The organic phosphorus form (like the inorganic phosphorus) in all the pedons is relatively high in the surface horizons and decreases with depth, to a very low level in the well drained pedons 1, 2, 3, 5, 6 and 7, while the soils with aquic moisture regimes and finer subsoils (pedons 8 and 9) have relatively higher organic P contents in their subsoils. The high organic P values are related to the organic matter content of the various sites. The relationship between organic matter content (Y) and organic P (X_1) is statistically significant ($r = 0.69$**, significant at the 5% level). Regression analysis shows no significant relationship (even at 20% level) between organic

P (Y), and soil pH (X_2). The prediction equations are as follows:

a. $Y = 0.023 + 0.033 X_1$ $r = 0.69^{**}$ (Organic P)

b. $Y = 4.79 - 0.317 X_2$ $r = -0.23$ not significant

The presence of organic P at considerable depths, particularly in pedon 4, may indicate possible mobilization of organic P and downward movement through leaching. The high organic P in the poorly drained profiles with B_2t horizons (pedons 8 and 9) compared to better drained soils (pedons 1-3 and 5-7), a toposequence relationship, may also be attributed to low level of biological activities under these conditions or biocycling of nutrients. Organic P may supply a substantial portion of available P during the process of mineralization (Enwezor and Moore, 1965).

The organic C:P ratios (Table 11) are relatively low in the upper parts of all but the Spodosol, pedon 4, in most cases they are below 200 in the Ap horizons. These values represent a much lower relative phosphorus content in these soils than in the United States where the average organic C:P ratio is in the order of 110. Since the C:P ratios for most of the soils are below 200, mineralization of organic P is expected to readily occur (Tisdale and Nelson, 1956), leading to an increase in the level of available P, provided the P thus released is not fixed in unavailable form by other soil components.

As most of the phosphorus in these soils is in the organic form, the importance of maintaining organic matter is evident in order to maintain organic P. Fertilization and liming can provide a more favorable environment for the microorganisms responsible for mineralization.

The ability of these soils to fix added orthophosphate increases with depth (Table 11). The fixation is considerably lower in the poorly drained, sandy, pedon 4. Considering the climosequences of well drained soils, pedons 2 or 3 and 1 or 7 with ustic moisture regimes and pedons 5 and 6 with udic moisture regimes, slightly higher fixation capacities are associated with the soils developed on higher physiographic surfaces in ustic regimes than soils located on lower physiographic surfaces in udic regimes.

In the lithosequence of soils, pedons 9 and 8, there are no significant differences in their P-fixation capacities. There is somewhat less P-fixation capacity in these soils with an aquic moisture regime when compared with the well-drained soils, a toposequence relationship.

As all the soils are acid (pH values range 2.6-5.2) and contain considerable amounts of hydrated iron oxides an ideal condition for phosphorus fixation is provided. There is a close correlation between phosphorus fixation and free iron oxides ($r = 0.65^{**}$, significant at the 5% level). The prediction equation is $Y = 70.9 + 7.8X$ where Y is

P-fixation and X is free iron oxides. Al-oxides seem to be of less importance because they are present in less amounts except in the finer poorly drained soils, which show less P-fixation.

Generally phosphorus fixation in the soils studied seems to also have a close relationship with clay content. Regression analysis of P-fixation capacity versus clay content shows a significant relationship between them ($r = 0.84^{**}$, significant at the 5% level). This may be associated with an indirect effect of the iron and aluminium oxide contents found in the clay fraction and the finer materials associated with clay contents. Thus, pedon 4 which is sandy, and has a spodic instead of an argillic B horizon, retains much less phosphorus than the other finer soils of similar drainage (pedons 8 and 9).

Practical applications.--Though the traditional farming practices involve "slash and burn," organic P can contribute an important source of P for crops grown in the study area. However, excessive land preparation and intensive bush burning may result in great loss of organic P from the soils of the Coastal Plain Sands. In the savanna/derived savanna areas, phosphorus deficiencies are likely to be high as high population density tends to result in shorter fallow periods and probable loss of topsoil through erosion.

Much work has not been done on fractionation of phosphorus forms in Nigerian soils. The present study coupled with results of other workers necessitates a reassessment of phosphorus supplying power of these soils. The soil test values or patterns commonly observed in the temperate soils may be quite different in tropical conditions.

Mineralogy of the Sand and Coarse Silt Fractions

Mineralogy of soils is used directly at the family level, and at some higher levels, as a classification criterion in Soil Taxonomy (Soil Survey Staff, 1975). Percentages of minerals present in the coarse silt and sand fractions are used in classifying those soils that belong to fragmental, sandy, sandy skeletal, loamy or loamy skeletal families.

The mineralogical compositions of the sand and coarse-silt fractions of the soils are shown in Table 12 and are expressed in percentage of grains counted. Quartz is the predominant mineral in all of these soils ranging from 96.8-99.8% in the family control section. Many of the quartz grains are irregularly shaped, clean and without inclusions. They are of different sizes and are of low order interference color but bright. They exhibit sharp extinction within a small angle of rotation. In some grains the extinctions are sometimes wavy. In all the

Table 12.--Mineralogical composition of the fine sand and coarse-silt fractions determined with a petrographic microscope.

Horizon	Depth cm	Light fractions Quartz %	Heavy fractions > 2.85 sp. gr. %	% Quartz in family control section
		Pedon 1--AMS1		
Ap	0-10	98.2	0.9	
B1	10-22	98.5	0.7	
B21t	22-45	97.0	0.8	97.0
B22t	45-75	98.1	1.2	
B3	75-180	98.0	0.9	
		Pedon 2--AMM2		
Ap	0-13	96.4	nd	
B1	13-30	98.9	nd	
B21t	30-55	99.6	nd	99.6
B22t	55-108	97.2	nd	
B3	108-180	99.5	nd	
		Pedon 3--AMF3		
Ap	0-12	98.9	nd	
B1	12-22	98.8	nd	
B21t	22-45	98.3	nd	98.3
B22t	45-137	97.5	nd	
B3	137-180	97.7	nd	
		Pedon 4--AMM4		
Ap	0-12	98.6	0.8	
A21g	12-30	97.7	0.9	98.5
A22g	30-140	98.9	0.7	
Bhirm	140-200	98.5	0.9	
		Pedon 5--ASU5		
Ap	0-13	93.7	nd	
B1	13-38	96.9	nd	
B21t	38-88	97.8	nd	
B22t	88-150	98.6	nd	
B3	150-180	95.4	nd	

Table 12.--Continued.

Horizon	Depth cm	Light fractions Quartz %	Heavy fractions > 2.85 sp. gr. %	% Quartz in family control section
		Pedon 6--AK6		
Ap	0-18	95.7	nd	
B1	18-53	97.6	nd	
B21	53-110	99.8	nd	99.8
B22	110-143	97.5	nd	
B3	143-180	96.7	nd	
		Pedon 7--UM7		
Ap	0-20	92.9	nd	
B21t	20-55	96.8	nd	
B22t	55-100	99.5	nd	96.8
B31	100-150	98.9	nd	
B32	150-210	97.2	nd	
		Pedon 8--PH8		
Ap	0-10	98.5	0.9	
A2g	10-23	95.6	0.8	
B21tg	23-40	96.9	0.7	
B22tg	40-72	97.3	0.9	96.9
IIB23tg	72-120	98.1	0.9	
IIB3	120-180	96.0	1.2	
		Pedon 9--ET9		
A1	0-2	97.7	0.9	
A2	2-10	96.4	0.8	
IIB21tg	10-28	98.1	1.1	98.1
IIB22tg	28-87	99.0	0.9	
IIB3	87-180	98.2	0.9	

nd = not determined

soils the percent of weatherable minerals is less than 10%. Feldspars and ferro-magnesian minerals are almost absent in all the horizons studied.

Results of heavy mineral counts on pedons 1, 4, 8 and 9 indicate the presence of zircon, tourmaline, rutile and staurolite in the non-magnetic suite. Some magnetite was recognized as black, opaque particles. The heavy mineral fractions are low (Table 12) and change little in composition or amount from the A to the B3 horizons in most of the pedons. It is difficult to establish any real difference in heavy mineral composition throughout the four pedons studied. The grain counts of these heavy minerals do not necessarily prove a uniform parent material for all the four soils since pedons 4 and 8 are extremes in sand and silt contents, respectively, of all the nine pedons. It is also difficult to use these grain counts as evidence of any systematic variation in parent material that can be related to the soils as they now occur on the landscape. Soil drainage class appears to have no influence on the sand and coarse silt mineralogy for these soils.

All the soils studied have siliceous mineralogy. The soils occur along the same gently undulating to flat landscape. Therefore, this general relationship between soil mineralogy and occurrence on Coastal Plain Sand landscapes should aid soil survey in classification at the family level of sandy and loamy soils for it will permit delimiting soils that are members of siliceous mineralogy family on a geographic basis on the Coastal Plain Sands of Nigeria; irrespective of drainage class. Pedons on elevations below 20. m were not studied mineralogically.

Geologists consider a sediment mature when it contains only the most stable mineral species, such as quartz. The percentage of quartz in all the profiles is high. The absence of feldspar from the soils especially those on higher older surfaces is expected. Judging from the percentage of quartz and the low heavy minerals contents (less than 1% in most cases) for the four pedons, it can be concluded that most of these sediments had little in the way of feldspars or other weatherable minerals in the sand and coarse silt fractions when deposited or they are strongly weathered _in situ_. Moreover the lack of weatherable minerals is further substantiated by the predominance of kaolinite in the clay fraction. Since the parent materials of these soils are of sedimentary origin it would appear probable that much of the sediment was highly weathered material prior to its transport from the source area. However, it is also possible that the very young soils not fully investigated (pedons 11 and 12 at elevations 4 and 8 m respectively) may still not have attained their maximum degree of weathering.

Clay Mineralogy

X-ray diffraction was used to study the clay fraction of the soils. Preliminary studies of selected horizons of all the soils show the predominance of 1:1 type clays. Magnesium saturation and glycerol solvation gave no 2:1 clays. Subsequently clays from selected samples of pedons were only K-saturated and heated to 550°C.

Figure 15 shows the x-ray diffraction data of selected pedons (1, 4, 5, 8 and 9). Kaolinite is identified by its diffraction peaks in the range 7.13-7.14 A° and 3.54-3.64 A° which dissappeared upon heating the specimens to 550°C. In general kaolinite is by far the most abundant and predominant clay mineral in all the pedons.

The relative contents of kaolinite in clay by pedons, expressed in average percentage values are as follows: pedon 1 > pedon 4 > pedon 5 > pedon 9 > pedon 8. In most of the pedons the content of kaolinite is highest in the upper two or three B horizons and then decrease slightly with depth. More kaolinite is found in soils located on the higher and relatively older surfaces though these soils may have different parent materials. Some quartz was found only in the clay fraction of pedons 1 and 5 as shown by the x-ray diffractograms. None of the other common minerals, like geothite, which might be present, are shown by the x-ray diffraction. However, the

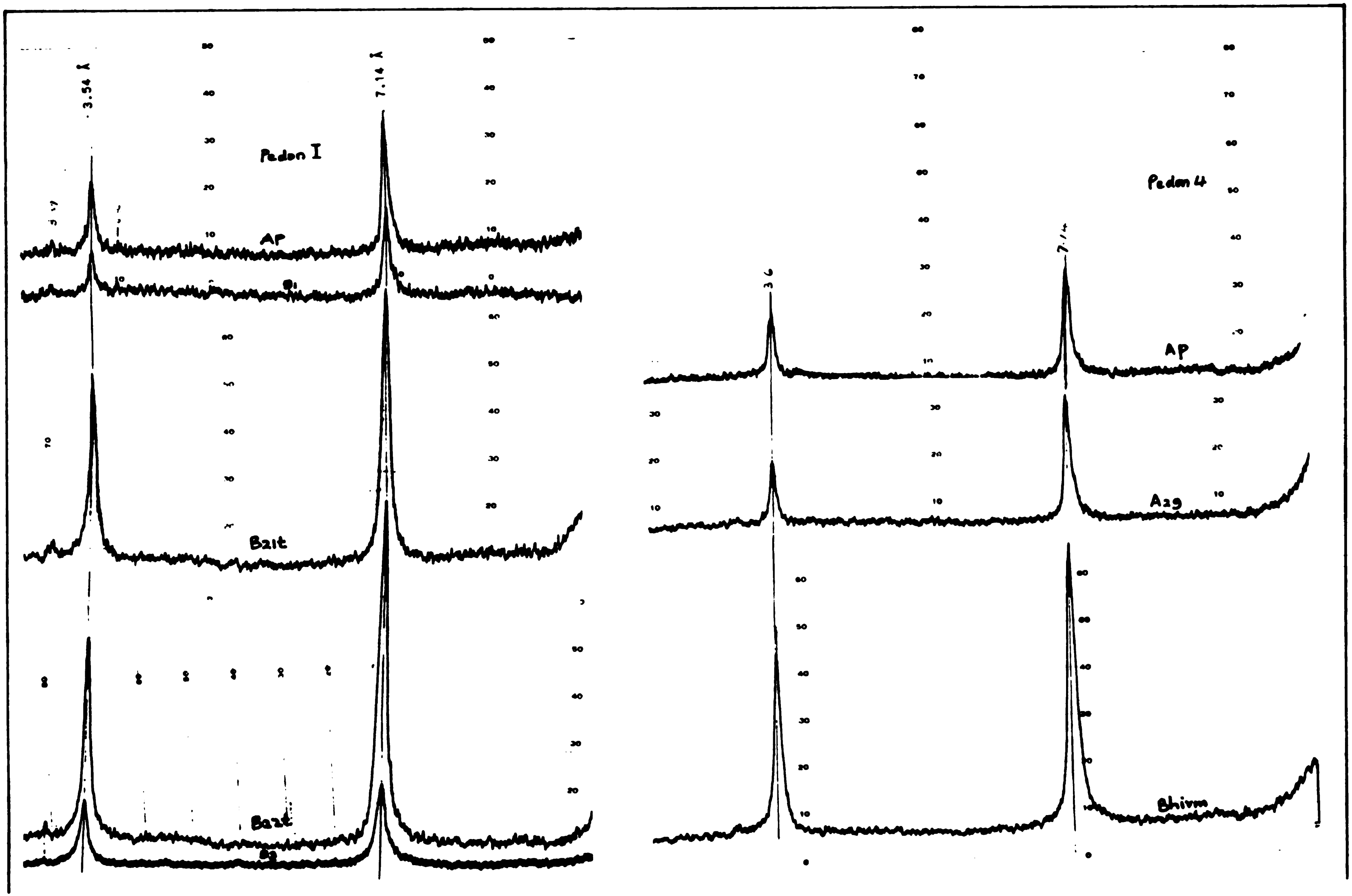


Fig. 15.--X-ray diffraction patterns of clay fraction (<2μ) of selected pedons.

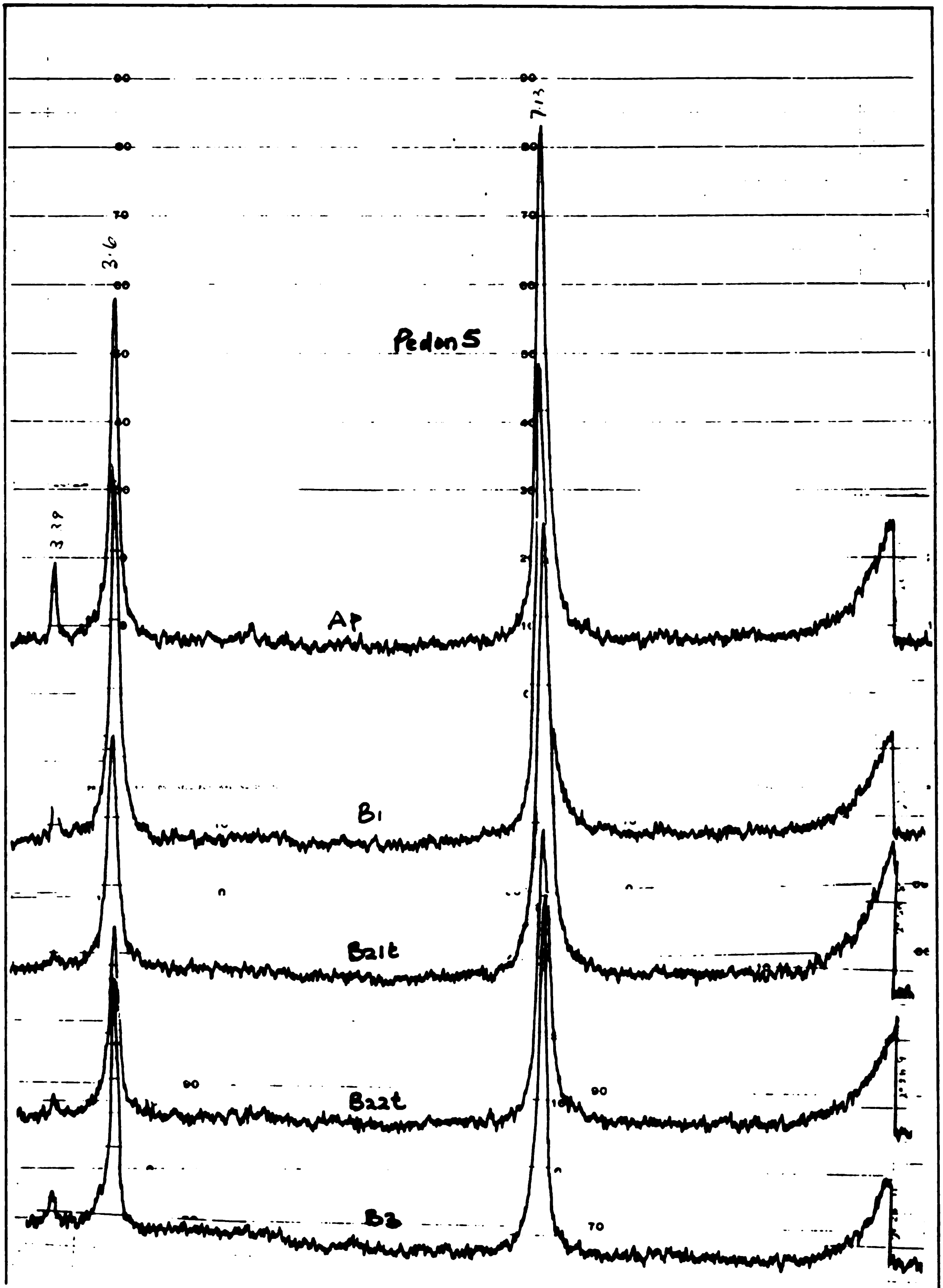


Fig. 15.--Continued.

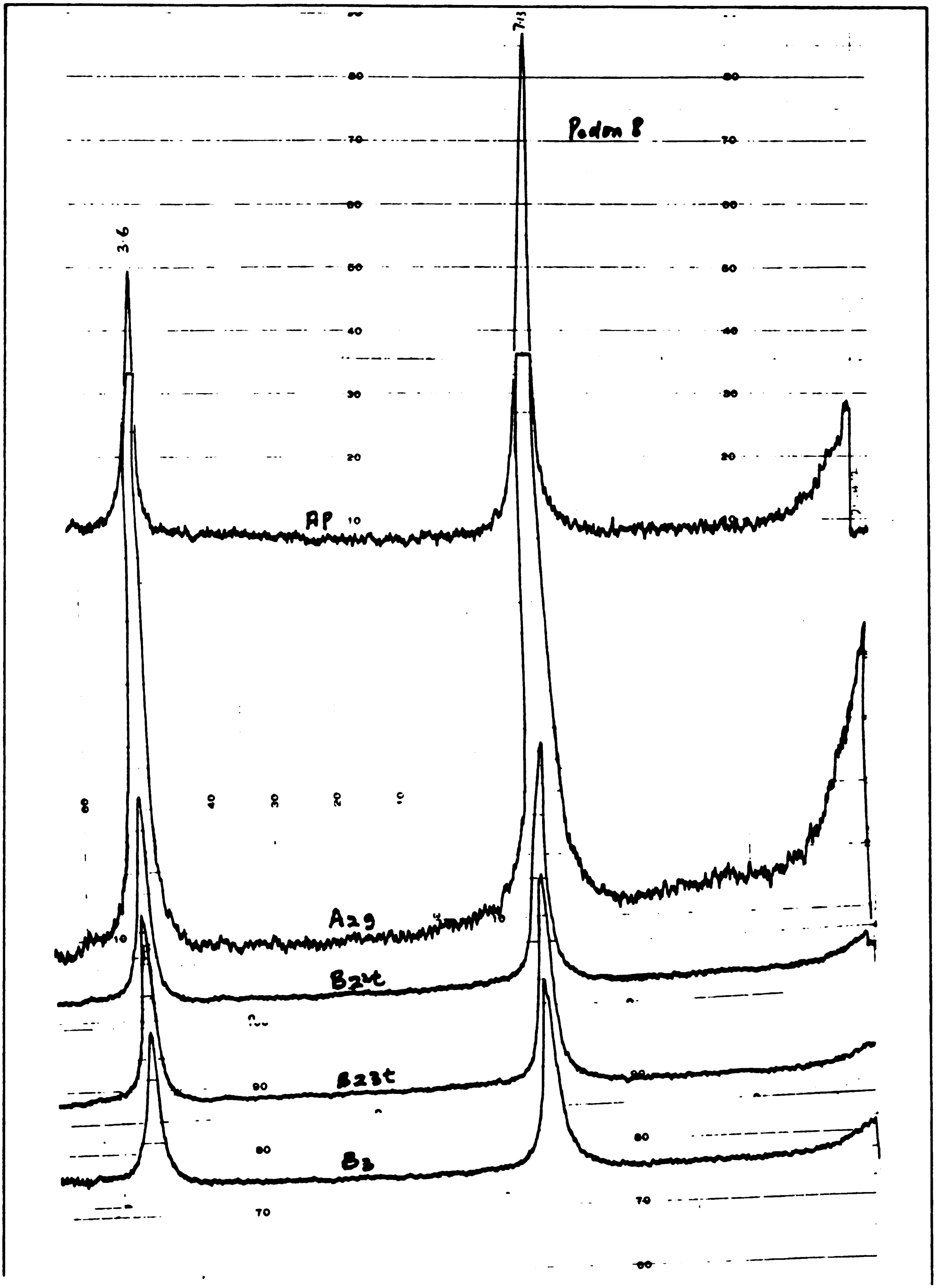


Fig. 15.--Continued.

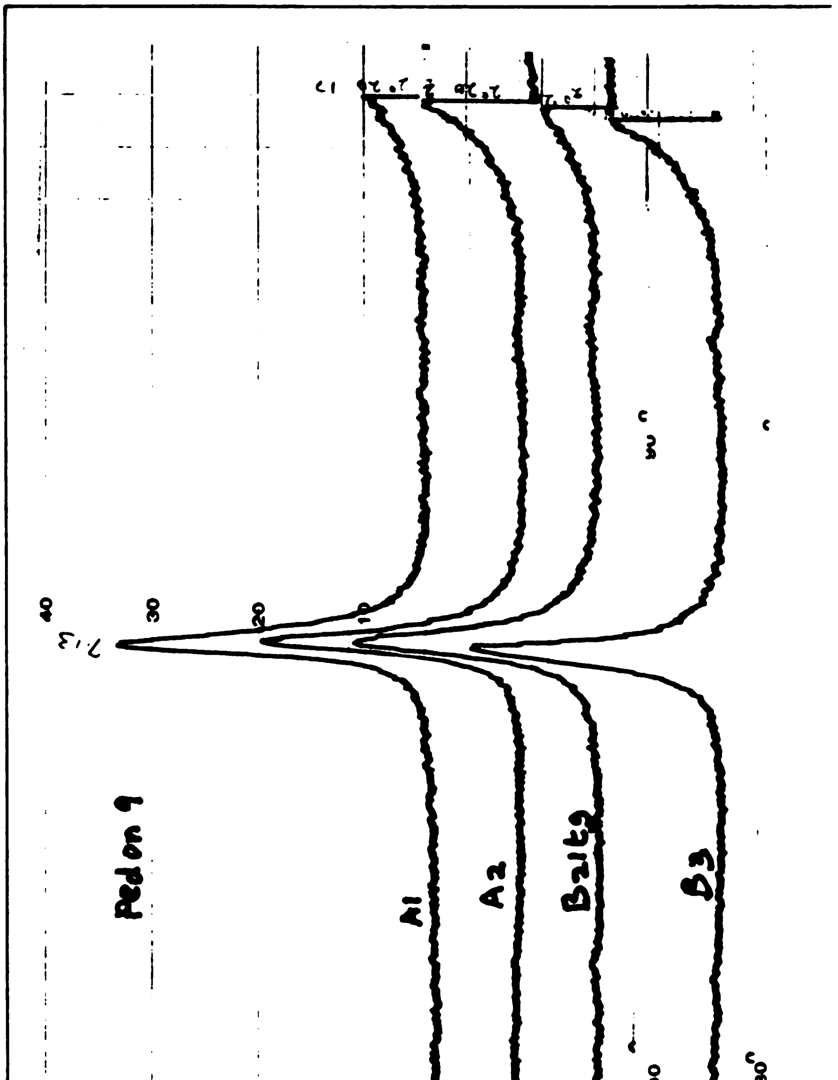


Fig. 15.--Continued.

peak identifying quartz, 3.39 A°, may also be due to gibbsite. Formation and accumulation of gibbsite might be expected under the climatic conditions of the study area.

All the soils of the study area have been shown to possess characteristics that are conducive to good permeability. They are strongly to very strongly acid and have low base saturation. These properties reflect conditions that would not have been favorable for montmorillonite. The absence of montmorillonite in the relatively younger pedons may indicate high content of 1:1 type clays in the parent material. This suggests that kaolinite was inherited from the parent material and may not be of pedogenic origin even though prevailing conditions of low pH and low base saturation are also conducive to the formation of kaolinite from 2:1 layer silicates or primary minerals such as feldspars through processes involving dealumination and desilication.

Micromorphology--Thin Sections

Thin sections, both horizontal and vertical, made from clods taken from selected profiles 1, 3, 5 and 7 were examined petrographically. Features are described and classified according to Brewer (1964).

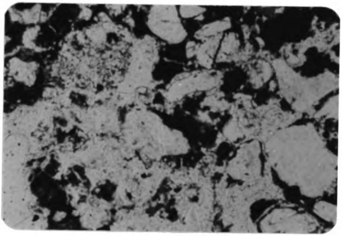
Skeletal grains have the same morphological variability in all the pedons. In general, they are randomly distributed, large grains are rounded, and many small ones are angular. All the grains are mainly quartz. Some iron oxide coatings are present on weathered quartz grains. Weatherable minerals are almost absent. Higher in the profiles, the number of red-coated grains decreases compensated by a yellowish-red staining of the plasma. The density of skeletal grains is higher in the B3 horizon than in the upper horizons. The predominance of rounded sand grains are due to transportation by water of the parent rock material.

Voids in all the soils are of mainly two different types: simple packing voids and vughs or channels. Vughs constitute the characteristic voids in the subsurface horizons, especially irregular orthovughs. Almost all the vughs and some channels are lined by ferri-argillans and organo-argillans. Vughs, and channels may owe their occurrence to packing, adhesion and attraction between particles and also to differential weathering and leaching. Channels may be caused by faunal activities, plant root systems or other biological processes. Worm holes and termite activities are also observable in the study area.

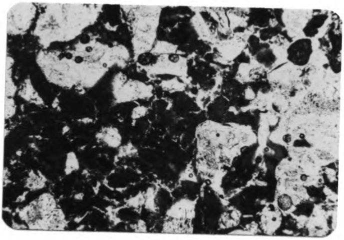
The influence of organic matter is seen especially in the A horizons. Plant roots occur in the voids and cross-sections show the internal structure of the roots. Presence of organic matter decreases with depth in all the pedons. Some voids and vughs are filled with organic matter. In comparison with the temperate region, the small amounts of humified materials observed may be due to rapid destruction under tropical conditions. Fragments of charcoal observed in the S-matrix of the top horizons may be due to the persistent bush burning during land cultivation.

Plasmic fabric in most of the pedons are almost completely isotropic which are described as isotic, isotic-undulic or isotic-inundulic. The plasma is generally reddish-yellow in color. The isotropic character of the S-matrix is related to strong weathering of the soils (Stoops, 1968). Isotic plasmic fabric is found in the A horizon of most of the soils. Presence of humic compounds in the plasma may also contribute to the isotropic character of the plasma. Low development of plasmic structure in the surficial horizons may also be due to the low amount of clay in the upper horizons. The isotic nature of the plasmic fabric is apparently associated with the type and amount of clay and iron. The soil matrix in all the soils range from granular to intertextic. This explains the great porosity and friability of these soils.

The most significant micromorphological features in the studied soils are the illuviation ferri-argillans (Figures 16-19). The maximum amount of these cutans are shown in some areas of the thin section of the argillic horizons. In most of the profiles these ferri-argillans are very slight and constitute one of the major components of the plasma and they appear clear, red or yellowish-red with weak continuous orientation. They also cover the



a.

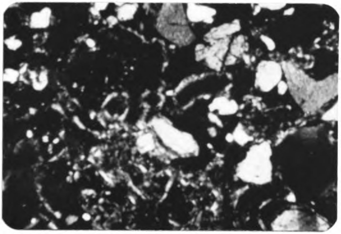


b.

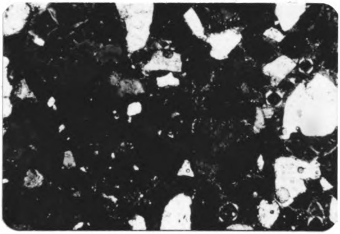
Fig. 16A.--Micromorphology of pedon 1 (plain light).

a. B21t (70X)

b. B22t (70X)



a.

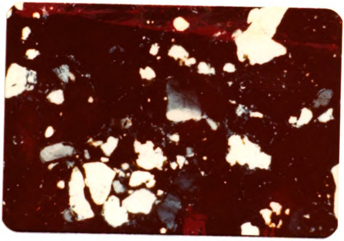


b.

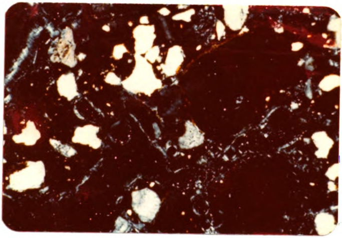
Fig. 16B.--Micromorphology of pedon 1 (crossed nicols).

a. B21t horizon with ferri-argillans showing strong continuous orientation (70X)

b. B22t horizon (70X)



a.

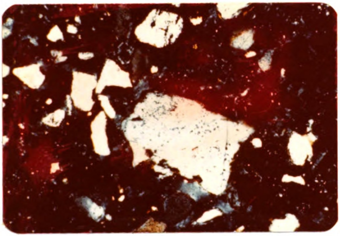


b.

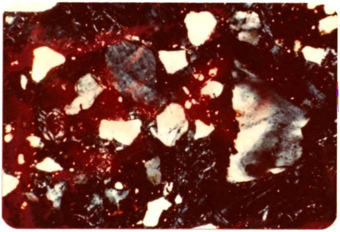
Fig. 17.--Micromorphology of pedon 3 (crossed nicols).

a. B21t horizon (70X)

b. B22t horizon (70X)



a.



b.

Fig. 18.--Micromorphology of pedon 5 (crossed nicols).

a. B21t horizon (70X)

b. B3 horizon (70X)

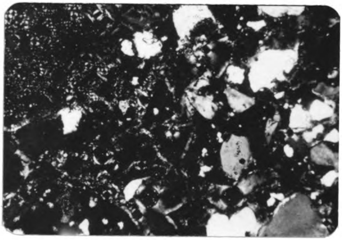


Fig. 19.--Micromorphology of pedon 7 (crossed nicols).
B22t horizon (70X)

walls of vughs, channels and weathered surfaces of quartz grains.

The presence of ferri-argillans is considered to be evidence of clay illuviation. These ferri-argillans are slightly more expressed in soils located at higher physiographic surfaces in the ustic moisture regime area of the study area. The intensity of illuviation can be assessed by the surface area occupied by these illuvial features in the cross-section and by the thickness of the material. The ferri-argillans are slightly more abundant in the deepest layers in accord with the clay and iron distribution in the soils.

In general, the co-migration of clay and iron is the major property associated with the micromorphological characteristics of the soils studied. Iron, probably in the form of hematite, covers all the components of the soil matrix. Other pedological features observed include cross sections of roots, generally most common in the surface horizons. The dynamic nature of the plasma is primarily due to its susceptibility to mobilization being the colloidal fraction of the soil. Consequently soil forming processes affect the plasma. Free iron oxides play a significant part in the evolution of the plasmic fabric (Stoops, 1968). As the free iron oxide content increases, the plasmic fabric is less well developed. This is shown by the nature of plasmic fabric obtained in these studied soils. However, the plasmic fabric for all the soils range from isotic to undulic or inundulic. Detailed micromorphological descriptions of the selected pedons are given as follows:

Pedon 1--AMS1

Ap 0-10 cm. Randomly distributed skeleton grains with sharp extinction. Simple packing voids present. Plasmic fabric: at 35X magnification it is undulic, but at 100X magnification it is isotic. Soil matrix: porphyroskelic to intertextic. Plasma consists of organic matter.

B21t and B22t: 22-75 cm. There are skeletal grains randomly distributed. The plasma consists of clay and organic matter. There are diffuse reddish brown ferri-argillans on some skeleton grains. The vughs and some channels are also lined by ferri-argillans. Voids: many irregular orthovughs, few simple channels and metavughs. Plasmic fabric: inundulic to insepic. Matrix: granular.

B3: 75-180 cm. Few skeleton grains and the groundmass is porous. The plasma is reddish brown in color and has a high content of highly dispersed iron oxide. Low organic matter content. Plasmic fabric: isotic-inundulic. Matrix: granular-intertextic.

Pedon 3--AMF3

Ap 0-12 cm. Skeleton grains of varying sizes and shapes. Simple packing voids. Plasma filled with organic matter. Plasmic fabric: isotic-undulic. Matrix: granular-porphyroskelic. Few vesicles filled with organic matter and some opaque materials.

B1: 12-22 cm. Fewer skeletal grains than the overlying horizon, Ap. Groundmass is also porous. Plasma has less organic matter and it is reddish-brown in color. More ferri-argillans and clay than in Ap horizon. Vughs are irregular orthovughs. Simple packing voids are present. Plasmic fabric: isotic-inundulic. Matrix: granular to intertextic.

B21t to B22t: 22-137 cm. Skeleton grains, some rounded and varying sizes. Less organic matter in the plasma. More reddish-brown ferri-argillans and clay fill the plasma. Simple packing voids and irregular orthovughs. Plasmic fabric: insepic-undulic. Matrix: granular to intertextic.

B3: 137-180 cm. More ferri-argillans than in overlying horizon. Low organic matter. Same as overlying horizon in other respects.

Pedon 5--ASU5

Ap 0-13 cm. Few skeleton grains and the groundmass is very porous. The plasma consists of organic matter and clay. Simple packing voids. Few large irregular orthovughs. Few simple embedded grain ferri-argillans with weak orientation. Plasmic fabric: inundulic-isotic. Matrix: granular.

B1: 13-38 cm. Skeleton grains predominantly quartz are distributed randomly. Simple packing voids. Ortho- and metavughs are present. Less organic matter than in Ap. Ferri-argillans not as concentrated as in pedons 1 and 3. Some skeleton grains are coated with ferri-argillans and organic matter. Plasmic fabric: isotic/insepic. Matrix: granular.

B21t and B22t: 38-150 cm. Randomly distributed skeleton grains. Numerous irregular interconnected orthovughs, very few channels and vesicles. Simple packing voids. Few large irregular orthovughs. Plasma filled with ferri-argillans with stronger orientation than in B1 horizon. Plasmic fabric: insepic. Matrix: granular.

B3: 150-180 cm. Description similar to B2t, but with slightly more ferri-argillans and less organic matter.

Pedon 7--UM7

Ap 0-20 cm. Skeleton grains are randomly distributed. Simple packing voids filled with organic matter. Plasma filled with dark opaque materials and few reddish-brown ferri-argillans.

B21t and B22t: 20-100 cm. Few large-sized skeleton grains with many small and medium sized grains distributed throughout the plasma. Simple packing voids, irregular orthovughs and metavughs are present. Some part of the plasma consists of yellowish (clay) color around reddish brown iron oxides. The groundmass is porous. Black opaque materials are evident. More ferri-argillans than in Ap horizon. Plasmic fabric: isotic-undulic. Matrix: granular-intertextic.

B31 and B32: 100-210 cm. Same as B22t except that more ferri-argillans are present than in the overlying horizon. Less organic matter present.

It is probable that deeper sampling depths, 2m - 3m, would be preferred for more evidence of oriented clay skins in these soils and possible decreases in clay contents with depth. In ancient soils it is common that the most abundant and thickest clay skins are between depths of 2m and 3m. At that depth there is only a little biologic activity, and peds and pores should be stable (Soil Survey Staff, 1975). This may in part explain the scarcity of oriented clays in these soils under study.

Soil Classification and Correlation

A summary of the characteristics of the fourteen pedons is used to classify the soils in the U.S. Soil Taxonomy (Soil Survey Staff, 1975) and with the FAO/ UNESCO Soil Map of the World Legend (1973).

In these relatively old soils, judged by their low base saturations and thick sola, identification of an argillic horizon in the field is not easy. Hill and Bennet (1974) working in the Central Nigeria Project area emphasizes the field observation of cutans which is often difficult for young soil surveyors. Van Wambeke (1967) states that the identification of argillic horizons in tropical areas is often only a matter of appreciating the amount, the thickness and the location of cutans.

With USDA Soil Taxonomy.--In terms of the USDA Soil Taxonomy, all the pedons except 4 and 6 have subsurface horizons that may qualify as argillic on the basis of increases of clay content with depth; an increase of the fine clay:coarse clay ratios with depth, although only pedon 8 and 9 have one-third more fine clay in the Bt horizon; and the presence of some weak void ferri-argillans in the B horizons. In most of the soils the diagnosis of the argillic horizon is based on the ratio of the clay content of the illuvial horizon to the eluvial horizon being greater than 1.2 (Soil Survey Staff, 1975). Oxic horizons were not observed in these soils in the field or by laboratory data. Therefore, these soils are excluded from the order of Oxisols.

According to the base saturation and other diagnostic properties; all the pedons except pedons 4 and 6 are classified as Ultisols. The clay distribution is such that the percentage clay does not decrease by as much as 20% of the maximum within a depth of 1.5 m of the soil surface. Therefore, the well drained Ultisols are classified as Paleustults and Paleudults at the Great Group level. Pedons 1, 2, 3, 7, 13 and 14 are classified as Paleustults.

The soils classified as Paleudults (pedons 5, 10, 11 and 12) meet the proposed classification of Kandiudults (Moorman et al., 1977) with the following diagnostic criteria:

1. CEC (1N-NH_4OAC) of less than 24 m.e./100 g in the upper 50 cm of the argillic horizon.
2. Less than 10% weatherable minerals in the 20-200 micron fraction of the upper 50 cm of the argillic horizon. No saprolitic material present.
3. No fragipan or "continuous phase" plinthite.

In the study area the soil profiles are usually well aerated and structures are favorable to root penetration. It is possible that argillic horizons in these dominantly kaolinitic materials have less agronomic importance than in soils dominated by 2:1 clays. For practical reasons, it may be more convenient to lower the taxonomic weight of the argillic horizon as soon as the material in which it has formed reaches a certain degree of weathering (Van Wambeke, 1967).

All the well drained Ultisol profiles except pedons 11 and 13 meet requirements for the typic subgroup. Pedons 11 and 13 qualify as an Arenic Paleudult and an Arenic Paleustult, respectively. The others are classified as Typic Paleustults (pedons 1, 2, 3, 7 and 14) and Typic Paleudults (pedons 5, 10 and 12). Differences in particle-size classes lead to different family classes, namely fine-loamy and coarse-loamy for these soils. All the Typic Paleustults are fine-loamy. Pedon 13 an Arenic Paleustult is coarse-loamy. In the Typic Paleudults pedons 5 and 10 are fine-loamy and pedon 12 is coarse-loamy. Pedon 11 an Arenic Paleudult is also coarse loamy. Next to pedon 4 this is the sandiest pedon studied.

Considering the relative elevation of the more poorly drained profiles and other properties, these soils may not have attained the same degree of weathering as rapidly as the geographically associated well drained profiles. Their low base saturation may indicate that these soils might have undergone previously well-drained cycles, or their parent materials are derived directly from kaolinitic sources, or that their physiographic positions (receiving run-on in addition to rainfall) are associated with more leaching.

Pedon 4 is sandy throughout the profile, has a spodic subsoil horizon, and is naturally poorly drained. It is classified as an Aeric Grossarenic Tropaquod. Its distribution is not extensive in the study area. Pedons 8 and 9 are poorly drained and somewhat poorly drained, respectively. Pedon 8 has been shown to have more silt than pedon 9 and is a Typic Tropaquult while pedon 9 is Typic Paleaquult. Pedon 8 is fine-loamy while pedon 9 is coarse-loamy.

The family texture classes range from sandy to coarse-loamy to fine-loamy. Weatherable minerals in the coarse-silt to fine sand fractions in all the soil samples constitute less than 10%. This places all the soils in the siliceous mineralogy class. All soils are in the isohyperthermic temperature class as previously stated.

On the basis of the data obtained in this study, the fourteen pedons are classified as follows at the family (and series) level of Soil Taxonomy:

Pedons 1, 2, 3, 7 and 14: Typic Paleustults, fine-loamy, siliceous, isohyperthermic (1 and 7--Amakama; 2, 3 and 14--Itaja).

Pedons 5 and 10: Typic Paleudults, fine-loamy, siliceous, isohyperthermic (5--Asa; 10--Bori).

Pedon 12: Typic Paleudult, coarse-loamy, siliceous, isohyperthermic (Ogoni).

Pedon 4: Aeric Grossarenic Tropaquod, sandy, siliceous, isohyperthermic (Ihie).

Pedon 6: Oxic Dystropept, coarse-loamy, siliceous, isohyperthermic (Akwete).

Pedon 8: Typic Tropaquult, fine-loamy, siliceous, isohyperthermic (Port Harcourt).

Pedon 9: Typic Paleaquult, coarse-loamy, siliceous, isohyperthermic (Eteo).

Pedon 11: Arenic Paleudult, coarse-loamy, siliceous, isohyperthermic (Ka).

Pedon 13: Arenic Paleustult, coarse-loamy, siliceous, isohyperthermic (Ngwa).

Table 13 gives the proposed tentative series names of these soils.

Pedons 4, 8 and 9 have aquic moisture regimes. These form a chrono-lithosequence. Pedon 4 is located on a higher site and is very sandy. The parent material texture of pedon 8 (fine-loamy) is finer than 9 (coarse-loamy) and the difference in elevation between them is slight, about 10 m. Pedon 4 is an Aeric Grossarenic Tropaquod. Pedons 8 and 9, from sandy clay loam and sandy loam materials, respectively, are a fine-loamy Typic Tropaquult and a coarse-loamy Typic Paleaquult, respectively.

Pedons 5, 6, 10, 11 and 12 have udic moisture regimes. Pedons 5 and 10 on sandy clay loam materials, and pedons 12 and 11 on sandy loam materials may represent a chrono-lithosequence as they also occur on successively lower elevations of 60 m, 30 m, 8 m, and 4 m, respectively. Actually all four pedons are Paleudults but pedons 5, 10 and 12 are Typic Paleudults while pedon 11 at the lowest elevation is an Arenic Paleudult, coarse-loamy. Pedons 5 and 10 are fine-loamy and pedon 12 is coarse-loamy. Pedon 6 is at 50 m elevation and is a coarse-loamy Oxic Dystropept without a texture profile differentiation. That the differences in elevation (age) are not evident in the classification of these soils may be because

Table 13.--Proposed tentative series and their tentative correlations.

Pedon	Tentative Series	Tentatively Correlated Series Moss (1957)
1	Amakama	Alagba (normal subseries - b)
2	Itaja	Alagba (sandy subseries)
3	Itaja	Alagba (sandy subseries)
4	Ihie	None
5	Asa	Uyo
6	Akwete	None
7	Amakama	Alagba (normal subseries - b)
8	Port-Harcourt	Idesan (silty variation)
9	Eteo	None
10	Bori	Uyo
11	Ka	Ahiara
12	Ogoni	Uyo
13	Ngwa	Kulfo
14	Itaja	Alagba (sandy subseries)

they are all weathered beyond stages where such differences may have been important.

Pedons 1-3, 7, 13 and 14, all have ustic moisture regimes and form lithosequences. Of these pedons 2, 3 or 14 are from coarser sandy clay loam materials and pedon 1 or 7 are from finer sandy clay loam materials and on similar elevations (150-106 m above sea level). Pedon 13 is from sandy loam and on a lower elevation (60 m above sea level). All but pedon 13 are fine loamy Typic Paleustults. Pedon 13 is a coarse-loamy Arenic Paleustult. The difference in its parent material is reflected in a difference in its subgroup and family classification from the soils on the same elevation or higher elevation in finer parent materials. Some textural differences in the finer parent materials are recognized at the series or subseries level.

The general topography of the study area is nearly flat for most pedons. Variation in aspect and elevation influence vegetation by varying conditions for organic activity--savanna/derived savanna, versus forests on the higher and lower surfaces, respectively. Soils on the higher surfaces have deep water table while those on lower surfaces have more shallow water-tables. More conspicuously, locally the soils with higher water tables have aquic moisture regimes. Their topo-relationships to better drained soils with textural B horizons appear as aqui suborder Aquults (pedons 8 and 9). In the case of pedon 4, in very sandy materials and with a spodic B horizon, the toporelationship appears as an aquic suborder of another order, Aquod. This is apparently a topo-lithosequence relationship.

Among the well-drained soils, differences between the Udults and Ustults, as pointed out elsewhere, are a reflection of differences in their climatic moisture regimes (a climosequence) but these are also correlated with increasing elevations inland from the seashore. The Ustults also reflect the redder subsoil colors particularly in the finer materials, while coarser materials are more yellowish in both Ustults and Udults.

The establishment of a stable forest ecosystem has been tampered with by the slash and burn system of agriculture in the study area. Within the dominant "oil-palm bush" vegetation can be found savanna and derived savanna giving rise to almost similar biotic communities. Biocycling of nutrients has been shown to take place. Consequently the extensive leaching of nutrients is counter-acted by the biocycling process, leading to a decrease of bases with depth. Clear-cut biosequences of soils may not be easily proposed as this is dependent on the litho and toposequences and land utilization as mentioned earlier.

The prevalent slash and burn system of agriculture affects the establishment of a climax forest or unmodified rain forest. A heterogenous collection of trees and shrubs of all shape and sizes in various stages of growth or decay is found. Most of the pedons on the higher physiographic surfaces and within the ustic moisture regime have either scant forest/oil-palm bush or derived savanna. The impact of organisms such as fauna on soil development is dependent on other factors like soil reaction and climatic conditions for biological activities.

With FAO/UNESCO Soil Map of the World Legend.--Using the FAO/UNESCO soil map legend most of the soils have an argillic B horizon with a clay distribution such that the percentage of clay does not decrease from its maximum by as much as 20% within 150 cm of the surface. Consequently all the pedons except 4 and 6 can be classified as Nitosols (FAO/UNESCO, 1973). According to the base saturation of these soils, all the pedons (including pedons 8 and 9) are Dystric Nitosols.

Pedons 8 and 9 have impeded drainage but they satisfy the requirements for Nitosols. However, within the FAO/UNESCO legend, there is no provision for more poorly drained Nitosols. Therefore, for pedons 8 and 9, Gleyic Nitosols are proposed. It is realized that pedon 9 is somewhat poorly drained. Further separation should be made at lower categories, if the legend provides for that, but the lack of this provision presents a setback towards total applicability of the FAO/UNESCO system down to the series level.

Pedon 4, on the other hand, though poorly drained is not a Nitosols. It is classified as a Gleyic Podzol due to the presence of a spodic horizon and hydromorphic properties within the profile. Pedon 6 because of lack of a texture B is classified as a Dystric Cambisol.

The topography of the study area is generally flat to gently undulating. Therefore, the effect of relief on these soils is limited and the morphology of the soil profiles is remarkably uniform in most parts of the study area. The geologic age of the soils is generally about the same, namely Pliocene/Pleistocene though the soils located on higher surfaces further inland show characteristics of relatively older age and a dryer climate than soils on lower surfaces near the coast. All the soils belong to a geological formation of similar age--the Coastal Plain Sands formation.

The existing distribution of forest and savanna or derived savanna vegetation cannot be said to be stable due to the subsistence farming system, which among other things, involves cutting and burning of vegetation in the course of land preparation. Therefore the effect of vegetation on soil formation and soil properties cannot be attributed exclusively to its present composition, but to successional sequences.

Comparison and Correlation of Classification Systems

The Soil Taxonomy is a multi-categoric system that applies concepts of pedogenic processes and soil characteristics. On the basis of this, categories starting from orders to series have been established based on the presence or absence of a variety of combinations of diagnostic horizons and quantitative values of soil properties. The FAO/UNESCO legend is a bicategorical scheme which recognizes 26 higher classes subdivided into 104 soil units. The soil units are differentiated on the basis of quantitative criteria similar to those of U.S. Soil Taxonomy.

In the present study, the U.S. Soil Taxonomy appears to be by far the most elaborate and most quantitative especially in definitions of taxa in terms of soil properties subject to measurement by defined methods. However, certain requirements involve costly outlays. For example, preparation of thin sections for identification of clay skins, where these are not observed in the field, in an argillic horizon. Moreover a considerable amount of morphological, analytical and climatological data are needed for positive placement of soils in the lowest category of the system.

Definitions in the FAO system are less precise. In many cases it is difficult to place soils down to the lowest category or accurately within a soil unit. To correlate the two systems one faces the problem of different criteria employed in their definitions. At the suborder or Great group level of the U.S. Soil Taxonomy, most of the soils were broadly classified under ustic and udic soil moisture regimes. Using the FAO system, this criterion is not considered. Ultisols can be Acrisols or Nitosols in the FAO system due to overlap of chosen differentiating characteristics.

In correlation of series throughout Nigeria it may be necessary to classify the soils according to either the FAO or U.S. Soil Taxonomy system. Using the U.S. Soil Taxonomy it is possible to classify the soil at all levels down to the series, provided analytical data are present. However, the use of the FAO system poses some problems. A number of soils occurring commonly in Nigeria may not appropriately fit one of the existing soil units. There are no criteria for grouping soils into any classes below the sub-unit level of the FAO system. It is proposed that new sub-units be defined as necessary to take care of certain characteristics, e.g., Ferralic Nitosols for Nitosols having ferralic or ferric properties (e.g., pedons 2 and 3). It would appear as if soils with impeded drainage should not be classified as Nitosols. It is proposed that Gleyic Nitosols be introduced for more poorly drained Nitosols. Characteristics transitional between the higher level units should be established, e.g., drainage differences, presence of petroferric or lithic phases, etc., should be used to differentiate soils from those typic or modal within the units. Phases may be used in any category in the U.S. Taxonomy for practical purposes.

At the family level it is recommended that the family differentia for particle size and mineralogy as defined by the USDA (Soil Survey Staff, 1975) criteria be used. Mineralogical classes may, in some cases, be deduced from the nature of the parent material or age of the land surfaces, with the aid of limited benchmark data, such as those on the nine pedons in this study.

It is obvious that the two classification systems are not compatible in many respects even though they have similar diagnostic horizon definitions. Their correlation cannot be achieved with great accuracy. For soil and land management problems and classification it is recommended that the U.S. Soil Taxonomy be adopted while exploring the adaptability of the FAO system. For instance, soils classified into the same soil families using the Soil Taxonomy, should have almost the same management requirements and similar potentials for crop production. This would afford a better basis for correlation and establishment of benchmark sites within an ecological zone.

However, as a means of international communication, the FAO system can be adopted as a basis for higher-category groupings. The French Classification system used in some northern parts of Nigeria is based on the evolution of the entire profile and the type of humus; the amount of "lessivage" is considered for the lower categories. Much emphasis is placed on climatic zonation as compared with lithogenic influences. The class boundaries are imprecise and allow for too much subjective interpretation. For soil correlation work in Nigeria, an English-speaking country, the adoption of the French system poses great difficulties.

Series correlation.--The purposes of the Series category, like the Family, is mainly pragmatic. The Family and Series differentiae as outlined in U.S. Soil Taxonomy (Soil Survey Staff, 1975) are therefore recommended. For the present study and future series correlation in Nigeria, the following modifications are proposed, taking into account the difficulty in acquiring the extensive laboratory data required by the U.S. Soil Taxonomy:

(1) Depth to bedrock (if any)

a. 0 - 30 cm : very shallow
b. 30 - 90 cm : shallow
c. 90 -150 cm : deep
d. > 150 cm : very deep

The 30 cm limit corresponds with the limit for Lithosols of D'Hoore (1964).

(2) Texture of diagnostic horizons present affect water holding capacity of the soils. Structure, mineralogy and amount of organic matter should also be considered in series differentiae and correlation. Attention is centered on the genetic horizons of major biologic activity below the depth of normal ploughing.

Nature and degree of expression of one or more horizons should be considered.

Fine sand:coarse sand ratio may also be used for separating soil series. In general the clay content of the B horizon (if present) can be used.

(3) Drainage

These classes are recognized:

USDA	FAO
Poorly drained	Very poorly drained
Somewhat poorly drained	Poorly drained
Moderately well drained	Imperfectly drained
Well drained	Well drained

The degree and depth of mottling are considered in poorly- and somewhat-poorly drained soils. For gleyed conditions a value of 4 or more and chroma of 2 or less (Munsell Color Notation) for moist soils are used for separation.

(4) Large differences in color: Color of the B horizon (if present) is used. Three classes can be used as very approximate guides only:

"Red"--Hues of 5YR or redder

"Brown"--Hues of 7.5YR or 10YR (no mottles)

"Gray"--Hues of 10YR (with mottles) or more yellow

Table 13 shows the proposed tentative series and their proposed correlation for the study area. These series are proposed using the above guidelines and field study. It is strongly emphasized that these proposals are tentative based solely on data obtained from the study area. The correlated series are based on soils derived from sedimentary rocks in Western Nigeria (Moss, 1957) that are mostly Alfisols. Consequently, approximate correlations have been made in this study pending further studies.

Vine (1956) provisionally defined four "Fascs" roughly equivalent to Families to cover the "Latosols" of Nigeria. Using this grouping, the soils of the study area can be classified as follows:

(1) Benin Fasc. These are deep red porous soils derived from sandy loam to sandy clay loam deposits. Pedons 1, 2, 3, 7, 13 and 14 are included under the Benin Fasc.

(2) Calabar Fasc. These are derived from similar sandy deposits but are brown as opposed to red. Pedons 5, 6, 10, 11 and 12 are classified under the Calabar Fasc.

The above classification is not recommended for soil mapping due to variability within them plus the distinction based mainly on color. Within the Fascs there may be some series that are separated solely on basis of color. On a broad basis the soils of the study area can be placed in the Benin and Calabar Fascs but the detailed subdivision of each into series according to the texture of the suboils and other characteristics is recommended. In soil surveys in Western Nigeria the more clayey soils of the Benin Fasc were placed in Alagba Series and the more sandy ones in Kulfo Series.

Erosion features were not observed in the study area. Stones constitute less than 1% of the particle size distribution of the soils. Consequently the important phases locally should be soil types within the area. The texture of the plow layer should be used in this instance.

SUMMARY AND CONCLUSIONS

Fourteen pedons representing soils found along a 126 km transect (Umuahia to Port-Harcourt) traversing Imo and River States of Nigeria and within the Coastal Plain Sands geologic formation were investigated in the field with some supplemental laboratory measurements of particle size distributions. On the basis of the data obtained nine of the fourteen pedons were selected for more intensive studies that included their clay mineralogy, micromorphology, physical and chemical properties. Their characteristics were established and the classification of all the fourteen pedons at the family level was made using the U.S. Soil Taxonomy. Approximate classification of the soils was also done with the FAO/UNESCO Soil Map of the World Legend. Tentative series were proposed and these are tentatively correlated with series used in the Western Region of the country.

Mineralogy.--Mineralogy of the coarse-silt and fine sand fractions of all the soils indicate the dominance of quartz. Weatherable minerals constitute less than 10% in these fractions. The heavy minerals in selected pedons show the predominance of zircon, staurolite, tourmaline and rutile.

The x-ray diffraction analyses of clay show the predominance of kaolinite. Thus, the lack of appreciable weatherable minerals in the coarse silt and sand fractions is not surprising since kaolinite is the dominant mineral in the clay fraction. Quantitatively, soils located on higher land surfaces, and thus relatively older, have more kaolinite than the presumably younger soils on the lower surfaces. Clay minerals of the 2:1 type were not found even in the younger more poorly drained soils. Small amounts of quartz were found in the clay fraction of pedon 1 an ustic and pedon 5 an udic soil. Since kaolinite is the predominant clay mineral in these soils, the prevailing dry and wet moisture conditions, low base saturation and low pH, preclude the condition conduvice to formation of montmorillonite. Kaolinite may have been largely inherited from the parent material instead of as a result of pedogenesis.

Micromorphology.--Intense weathering conditions, resistant minerals and the alternately dry and wet seasons prevalent in the area are reflected in the micromorphological characteristics of the soils. In most of the soils isotic and undulic plasmic fabrics characterize the micromorphology, indicating relatively advanced weathering stages. Insepic fabric is also shown. These types of plasmic fabric can be due to the masking of the birefringent plasma by the sesquioxides. Ferri-argillans are only slightly evident especially in soils on the higher surfaces with higher amounts of free iron oxides (pedons 1, 2 and 3). Skeletal grains are composed mainly of quartz that vary in shape and size. Some voids are filled with organic matter. Pedological features include cross-sections of roots, generally most common in the surface horizons. Voids are predominantly simple packing voids.

Genetic sequences.--Considering the soil formation factors (the textures of the B3 horizons, the natural drainage classes, elevations and other data), genetic sequences of soils have been recognized. Soils with aquic moisture regimes (poorly or somewhat poorly drained) constitute a lithosequence of soils formed in sandy (pedon 4), coarse-loamy (pedon 9) and coarser fine-loamy (pedon 8) materials, respectively. Lithosequences of well-drained soils with ustic moisture regimes (at higher elevations further inland) developed in coarse-loamy, coarser fine-loamy and finer fine-loamy materials are pedons 13; 2 or 3 or 14; and 1 or 7; respectively. Pedons 6 or 11 or 12; 5; and 10 represent lithosequences of well-drained soils with udic moisture regimes developed in coarse-loamy, coarser fine-loamy and finer fine-loamy materials, respectively. Pedons 9 (somewhat poorly drained) and 11 or 12 or 6 (all well drained); with pedons 8 (poorly drained) and 5 (well drained) represent toposequences of soils formed in coarse-loamy and coarser fine-loamy materials, respectively.

Chrono-climosequences of udic and ustic well-drained soils are: pedons 11 or 12 or 6 and 13 (developed in coarse loamy materials); pedons 5 and 14 or 3 or 2 (developed in coarser fine-loamy materials); and pedons 10 and 7 or 1 (developed in finer fine-loamy materials). The pedons are listed in order of their increasing elevations within each parent material group and the ustic pedons are at the highest elevations (60 m+). Clear-cut biosequences of soils were not evident.

a. Lithosequences.--Pedons 4, 9 and 8 are a lithosequence of soils with aquic moisture regimes developed in sandy, coarse-loamy and coarser fine-loamy materials, respectively. No textural B horizon is observed in pedon 4, a sandy soil with a spodic B horizon (Bhirm). Pedon 4 is the most acid soil studied, has the lowest P-fixation capacity and very low available water holding capacity. There is less clay and silt contents throughout pedon 9 (coarse-loamy) and it has less water holding capacity (26 cm) than in pedon 8 (coarser fine-loamy, 30 cm), and both have argillic horizons.

In pedons 13 (coarse-loamy); 14 or 2 or 3 (coarser fine-loamy); and 1 or 7 (finer fine-loamy); all well-drained and with ustic moisture regimes (lithosequences developed in coarse-loamy to finer fine-loamy materials), there are greater clay contents in the B horizons and less sand content in their A horizons as their B3 horizons are lower in sand and higher in clay. The finer textured pedons also have higher available water holding capacities. Similar profile texture differences and available water holding capacities with differences in the textures of the B3 (except that pedon 6 has no finer subsoil) are observed among the lithosequences of well-drained soils with udic moisture regimes (pedons 11 or 12 or 6; 5; and 10 developed in coarse-loamy to finer fine-loamy materials, respectively). Some of the reasons for the clay distribution patterns in these well-drained soils include eluviation with illuviation, differential removal of the fine particle size fractions by erosion plus faunal activity. Faunal activity and pedoturbation may explain the lack of argillic horizon in pedon 6.

The lithosequences of well-drained soils have more reddish subsoil colors on the finer materials at higher elevations, in both ustic and udic moisture regimes (chrono-lithosequences).

The general pattern of soil structures with depth for these well-drained soils is mostly fine, porous crumb to subangular blocky. The subangular blocky B horizons of most of the soils are weakly developed. The lithosequences of soils with ustic moisture regime soils developed in coarse-loamy materials (pedon 13), coarser fine-loamy materials (pedon 2 or 3 or 14) and finer fine-loamy materials (pedon 1 or 7) show an increasingly more homogenous structure development with depth in the finer materials. For udic moisture regime soils, pedon 11 or 12 (coarse-loamy), 5 (coarser fine-loamy) and pedon 10 (finer fine-loamy) show increased structural development from fine crumb throughout to crumb structure in the surface over subangular blocky lower horizons in the finer materials.

The development of fairly well expressed crumb structure in the upper horizons is attributed to the presence of grass and forest regrowth and higher organic matter contents.

b. Toposequences.--There is a higher proportion of fine-clay in relation to coarse-clay in most of the subsoils of pedons with argillic horizon (all but pedons 4 and 6). The ratio of fine-clay:total clay is greater in the upper subsoil of pedon 8 compared to pedon 5 (toposequence of soils in coarser fine-loamy materials) indicating more fine-clay movement into the upper subsoil. However, pedon 8 is higher in silt content than pedon 5 and this may be a litho-toposequence of soils. Pedons 8 and 9 show markedly higher fine-clay:total clay ratios particularly in their B21tg horizons and these ratios are higher in the lower B horizons than in their Ap or A2 horizons, indicating eluvial surfaces and illuvial subsoils. This is in spite of the evidently coarser deeper subsoil materials in the II layers of these profiles. Illuvial clay skins were observed in the field in pedons 8 and 9.

The more poorly drained soils are also paler, more mottled and more yellowish in subsoil colors than the well-drained soils. These are found mostly in the southern zone of the study area at lower elevations. All of these differences when compared to better drained soils from similar parent materials locally, represent toposequences of soils.

Increased structural development in the subsoils is also observed in the more poorly drained members of these toposequences of soils (pedons 9 versus 11 or 12 or 6; and 8 versus 5) developed in coarse-loamy and coarser fine-loamy materials, respectively.

The more poorly drained members of the toposequences (pedon 9 and 8) have shallower water-tables, at least seasonally, and consequently may have more available water within 180 cm than the available water measurements indicate if it is available to the plants. The more poorly drained soils of the toposequences (pedons 8 and 5; or 9 and 6) have more calculated available water than the well-drained soils and this can be associated with their greater organic matter and higher silt contents (a lithologic difference).

Pedons 8 and 5 (coarser fine-loamy) and 9 or 6 (coarse-loamy) are toposequences of soils with associated differences in the forms or amounts of active P present. In the more poorly drained soils Al-P and Ca-P are more abundant than Fe-P and are almost equally distributed within the profiles. On the other hand, Fe-P is the most abundant among the well-drained soils, with Ca-P being the least abundant.

The more poorly drained soils in these toposequences also fix less phosphorus. Organic C:P ratios generally indicate that more mineralization of P may occur with greater organic matter contents and may provide more suitable environments for microbial activities.

c. Chrono-climosequences.--The lithosequence of ustic well-drained soils developed in coarse-loamy to finer fine-loamy materials (pedons 13 coarse-loamy; 2 or 3 or 14 coarser fine-loamy; and 1 or 7 finer fine-loamy) have more reddish subsurface colors with similar textures of materials than udic well-drained soils (pedons 11 or 12 or 6 in coarse-loamy; 5 in coarser fine-loamy; and 10 in finer fine-loamy materials). These are climosequences of soils. But they may be chrono-climosequences as they occur on higher elevations with the more ustic moisture regimes in each case. The ustic pedons studied more intensively also contain higher Fe_2O_3-d and less Al_2O_3-d than the udic pedons in this study.

The well-drained ustic pedons (1, 2, 3 and 7) contain larger amounts of dithionite extractable Fe_2O_3 in most cases (pedons 1, 2 and 3) and larger amounts of Fe_2O_3 than Al_2O_3-d in all cases than do the well-drained udic pedons (5 and 6). The well-drained udic pedons both contain larger amounts of dithionite extractable Al_2O_3 than Fe_2O_3 (Table 10). Likewise the active P in the ustic pedons (Figure 14) is predominantly (> 70%) Fe-P. Pedon 6 in the udic group, which does not have an argillic horizon, approaches this proportion of active P as Fe-P, but Al-P is more than one-third of the active P in pedon 5.

In the climosequence of well drained ustic soils (developed in coarser and finer fine-loamy materials; pedons 2 or 3 and 1 or 7) and the udic well-drained soils (developed in coarse-loamy to coarser fine-loamy materials; pedons 6 and 5), the udic soils also have slightly lower phosphorus fixation capacity than the ustic soils and higher CEC/100 gms of clay in the subsoil.

Soils with udic moisture regimes also have somewhat higher base saturation than those with ustic moisture regimes. This can be associated with increased rainfall, more forests or their somewhat poorer natural drainages. This may represent a bio-climosequence of soils.

Soil classification.--On the basis of data obtained in this study, the fourteen pedons are classified as follows (using the U.S. Soil Taxonomy):

Pedons 1, 2, 3, 7 and 14: Typic Paleustults, fine-loamy, siliceous, isohyperthermic.

Pedons 5 and 10: Typic Paleudults (or Typic Kandiudults), fine-loamy, siliceous, isohyperthermic.

Pedon 12: Typic Paleudult (or Typic Kandiudult), coarse-loamy, siliceous, isohyperthermic.

Pedon 4: Aeric Grossarenic Tropaquod, sandy, siliceous, isohyperthermic.

Pedon 6: Oxic Dystropept, coarse-loamy, siliceous, isohyperthermic.

Pedon 8: Typic Tropaquult, fine-loamy, siliceous, isohyperthermic.

Pedon 9: Typic Paleaquult, coarse-loamy, siliceous, isohyperthermic.

Pedon 11: Arenic Paleudult (or Arenic Kandiudult), coarse-loamy, siliceous, isohyperthermic.

Pedon 13: Arenic Paleustult, coarse-loamy, siliceous, isohyperthermic.

Using the FAO/UNESCO soil classification system, all the soils except pedons 4, 6, 8 and 9 are further classified as Dystric Nitosols. Gleyic Nitosols have been proposed for pedons 8 and 9. Pedon 4 is classified as a Gleyic Podzol and pedon 6 as a Dystric Cambisol.

For soil correlation and classification the U.S. Soil Taxonomy system is proposed. The FAO/UNESCO system is to be correlated at the higher categories for international communication. Series differentiae of the USDA system are recommended with slight modifications, where necessary, to suit local conditions.

Tentative series have been proposed and tentatively correlated, as near as possible, with series used in the western part of Nigeria.

RECOMMENDATIONS

The genetic sequences of soils and soil characteristics based on these pedons need careful testing in the field and laboratory. Mineralogical studies have not been made to date of pedons at sites below 20 m elevation.

Most of the sites (11 of the 14) studied are well-drained. It is thus proposed that more study be given to the classification of the more poorly drained soils in the study area, particularly in the northern part of the area. This will also facilitate classification of the more poorly drained soils using the FAO/UNESCO Legend.

Considering the relatively high content of iron oxides in these soils, it is proposed that clay contents (2μ and 0.2μ) and presence of argillic horizons be tested after removal of the sesquioxides. As already mentioned there is need to examine similar pedons deeper, 2-3 m, to check the relative abundance of argillans in these soils and their possible decreases in clay content and clay mineralogy with depth.

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APPENDICES

APPENDIX A

PEDON DESCRIPTIONS

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PEDON DESCRIPTIONS

Pedon 1--AMS1

Location:	About 16 km south of Umuahia on Umuahia to Aba new road. Site of National Cereal Research Institute, Nigeria.
Setting:	About 150 m above sea level.
Vegetation:	Forest regrowth; scattered oil palms, *Elaeis guinnensis*.
Drainage:	Well drained.
Relief:	0.5 - 1 percent slope
Erosion:	None

Ap 0-10 cm. Dark brown (7.5 YR 3/2); sandy loam; crumb structure; friable when moist, nonsticky and non-plastic; many pores; many fibrous and woody roots; high organic matter content; intimate humus admixture. Sharp, irregular boundary.

B1 10-22 cm. Reddish brown (5 YR 5/4); sandy loam; crumb structure; soft when dry, friable when moist, slightly sticky and slightly plastic; medium organic matter content; gradual boundary.

B21t 22-45 cm. Yellowish red (5 YR 4/6); sandy clay loam; crumb structure; friable, sticky and plastic; moderately porous; few fibrous roots; irregular boundary.

B22t 45-75 cm. Yellowish red (5 YR 4/8); sandy clay loam; crumb structure; many pores; faunal activity; low organic matter content; irregular boundary.

B3 75-180 cm. Red (2.5 YR 5/6); sandy clay loam; crumb structure; friable when moist, nonsticky, nonplastic; few fibrous roots; low organic matter content.

All colors are moist except where stated otherwise.

Pedon 2--AMM2

Location:	About 15 km south of Umuahia on Umuahia-Aba new road. Site of National Cereals Research Institute Amakama, Nigeria.
Setting:	About 150 m above sea level.
Vegetation:	Forest regrowth and scattered oil palms.
Drainage:	Well drained.
Relief:	1% slope.
Erosion:	None

Ap 0-13 cm. Dark grayish brown (10 YR 4/2); sandy loam; crumb structure; loose to very friable, nonsticky, nonplastic; moderate pores; common fibrous roots;

medium organic matter; gradual boundary; strongly acidic.

B1 13-30 cm. Yellowish brown (10 YR 5/4); sandy loam; crumb structure; loose when dry, very friable to slightly plastic and sticky when wet; low organic matter; gradual boundary.

B21t 30-55 cm. Strong brown (7.5 YR 5/6); sandy loam; crumb structure; slightly plastic; few fibrous roots; gradual boundary.

B22t 55-108 cm. Reddish yellow (5 YR 6/6); sandy clay loam; moderately developed crumb structure; slightly plastic and sticky; few roots.

B3 108-180 cm. Reddish yellow (5 YR 6/8); sandy clay loam; moderately developed crumb structure; very low organic matter; very few roots.

Pedon 3--AMF3

Location: About 16 km south of Umuahia on Umuahia to Aba new road. Site of National Cereals Research Institute, Amakama, Nigeria.

Setting: About 150 m above sea level.

Vegetation: Shrubs regrowth, *Acacia barteri*.

Drainage: Well drained.

Relief: 1% slope.

Erosion: None apparent.

Ap 0-12 cm. Dark reddish brown (5 YR 3/2); sandy loam; crumb structure; loose when dry, friable when moist; nonsticky, nonplastic; medium organic matter content; abundant pores; very strongly acid; clear, smooth boundary.

B1 12-22 cm. Dark red (2.5 YR 3/6); sandy loam; weakly developed crumb structure; friable when moist; nonsticky, nonplastic; common roots; smooth boundary.

B21t 22-45 cm. Red (2.5 YR 4/6); sandy clay loam; moderately developed crumb structure; friable, nonsticky, nonplastic; low organic matter content; common fibrous roots.

B22t 45-137 cm. Red (2.5 YR 4/6); sandy clay loam; well developed angular blocky structure; slightly hard.

B3 137-180 cm. Red (2.5 YR 4/8); sandy clay loam; well developed angular blocky structure; slightly hard; moderately sticky and slightly plastic; low organic matter; very few roots.

<u>Pedon 4--AMM4</u>

Location: About 16 km south of Umuahia on Umuahia to Aba new road. Site of National Cereals Research Institute, Amakama, Nigeria.

Setting: About 145 m above sea level. About 3 m from a flowing stream used as a source for dry season irrigation for vegetable garden nursery.

Vegetation: Mainly shrubs and grasses; bush regrowth.

Drainage: Poorly drained.

Relief: About 1% slope.

Erosion: No evidence of accelerated erosion.

Ap 0-12 cm. Dark gray (10 YR 4/1); coarse sand; single grain structure; loose; very porous; some fibrous roots; strongly acid; clear smooth boundary.

A21g 12-30 cm. Gray (10 YR 5/1); coarse sand; single grain structure; loose; few fibrous roots with some thicker roots; clear smooth boundary.

A22g 30-140 cm. Gray (10 YR 7/1); coarse sand; single grain; loose; a few roots; abrupt, irregular boundary, varying from 100 to 180 cm below the surface.

Bhirm 140-200 cm. Black (5 YR 2/1) to dusky red (2.5 YR 2/1); sand; iron-humus pan; very firm, massive and compact; no roots. Base of iron pan not reached.

Pedon 5--ASU5

Location: Asa-Umunka, about 9 km from Aba on Aba-Port Harcourt road.

Setting: About 60 m above sea level. Almost flat terrain.

Vegetation: Oil palm, Elaeis guinnensis; cassava, Manihot utilissima; and forest regrowth.

Drainage: Well drained.

Relief: 1-2% slope.

Erosion: None.

Ap 0-13 cm. Dark brown (10 YR 3/3); loamy sand; crumb structure; friable when moist, nonsticky, nonplastic; high organic matter; many fibrous roots; clear smooth boundary.

B1 13-38 cm. Dark yellowish brown (10 YR 4/4); sandy loam; friable, nonsticky and nonplastic; medium organic matter; gradual boundary.

B21t 38-88 cm. Yellowish brown (10 YR 5/6); sandy clay loam; crumb structure, moderately developed; slightly plastic and slightly sticky; thick fibrous roots; clear smooth boundary.

B22t 88-150 cm. Yellowish red (5 YR 4/6); sandy clay loam; crumb structure; slightly plastic and slightly sticky; low organic matter; few roots; clear smooth boundary.

B3 150-180 cm. Strong brown (7.5 YR 5/6); sandy clay loam; subangular blocky structure; low organic matter; few roots.

Pedon 6--AK6

Location:	About 37 km south of Aba. Two km south of Rubber Research Institute of Nigeria, Akwete, Nigeria.
Setting:	Almost flat land. About 50 m above sea level. Groundwater below 1.50 m.
Vegetation:	Oil palm, *Elaeis guinnensis*; cassava *Manihot esculenta*; shrubs and local vegetables.
Drainage:	Well drained.
Relief:	1-1.5% slope.
Erosion:	None

Ap 0-18 cm. Dark brown (10 YR 3/3); sandy loam; crumb structure; fibrous and woody roots; low organic matter; strongly acid.

B1 18-53 cm. Dark yellowish brown (10 YR 4/4); sandy loam; crumb structure; many woody and common fibrous roots.

B21 53-110 cm. Yellowish brown (10 YR 5/4); sandy loam; crumb structure; few roots.

B22 110-143 cm. Strong brown (7.5 YR 5/6); sandy loam; crumb structure; few roots.

B3 143-180 cm. Strong brown (7.5 YR 5/8); sandy loam; crumb structure; no roots.

Pedon 7--UM7

Location: Umuojima-Owerrinta, about 33 km from Umuahia on Umuahia-Aba old road. South 8 km to Ugba junction.

Setting: About 106 m above sea level. Almost flat topography.

Vegetation: Oil palms, Elaeis guinnensis, Acacio barteri, shrubs.

Drainage: Well drained.

Relief: 1.5% slope.

Erosion: None

Ap 0-20 cm. Dark brown (7.5 YR 4/4); sandy loam; crumb structure; friable when moist, nonsticky and nonplastic; high organic matter; many fibrous roots; sharp irregular boundary.

B21t 20-55 cm. Reddish brown (5 YR 4/3); sandy clay loam; crumb structure; friable when moist, slightly sticky and slightly plastic; few roots.

B22t 55-100 cm. Yellowish red (5 YR 5/6); sandy clay loam; crumb structure; friable when moist; moderately porous; low organic matter; irregular boundary.

B31 100-150 cm. Red (2.5 YR 5/6); sandy clay loam; crumb structure; friable; low organic matter; few roots.

B32 150-210 cm. Red (2.5 YR 5/8); sandy clay loam; subangular blocky structure; low organic matter; no roots.

Pedon 8--PH8

Location: About 3 km from the Agricultural Farm Center at Port Harcourt, along Aba-Port Harcourt Road.

Setting: About 20 m above sea level. Almost flat topography. Liable to high water table during the rains.

Vegetation: Mainly shrubs.

Drainage: Poorly drained.

Relief: 0.5-1% slope.

Erosion: None.

Ap 0-10 cm. Black (5 YR 2/1); sandy loam; few medium gray (10 YR 5/1) mottles; friable; abrupt smooth boundary.

A2g 10-23 cm. Gray (10 YR 6/1); sandy loam; massive; friable; many pores and roots; clear faint boundary.

B21tg 23-40 cm. Light gray (10 YR 7/1); sandy loam; with few brownish yellow mottles (10 YR 6/6); weak, fine and medium subangular blocky structure; peds have irregular faces with no coatings; friable; irregular boundary.

B22tg 40-72 cm. Gray (10 YR 6/1); loam; with many medium yellowish red (5 YR 5/6) to yellowish brown (10 YR 5/6) mottles; few thin discontinuous clay skins on some cleavage faces; firm to slightly firm; many pores and roots; clear wavy boundary.

IIB23tg 72-120 cm. Gray (10 YR 6/1); sandy clay loam; many fine to coarse strong brown (7.5 YR 5/8) mottles; weak, medium, irregular angular to sub-angular blocky structure; firm; clear, wavy boundary.

IIB3 120-180 cm. Light brownish gray (2.5 Y 6/2); sandy clay loam-sandy loam; with common pale yellow mottles; massive.

<u>Pedon 9--ET9</u>

Location:	Extends directly west of the Port Harcourt-Bori road, between the villages of Oyu and Eteo. Approximate geographical position is 4° 44' N latitude and 7° 11' E longitude.
Setting:	Almost flat. About 30 m above sea level Depth to groundwater is greater than 1.30 m.
Vegetation:	Secondary shrubs and raffia palms.
Drainage:	Somewhat poorly drained.
Relief:	0-0.5% slope.
Erosion:	None.

A1 0-2 cm. Very dark brown (10 YR 2/2); sandy loam; loose; structureless; sand grains humus coated; worm excrements; many roots and worm holes; abrupt smooth boundary.

A2 2-10 cm. Dark grayish brown (10 YR 4/2); sandy loamy; weak, very fine, subangular blocky structure; very friable; sand grains humus coated; many fine lumps of humus; common roots, and many worm holes; clear smooth boundary.

IIB21tg 10-28 cm. Grayish brown (10 YR 5/2); sandy loam; with gray distinct, fine and common mottles; moderate, medium subangular blocky; very friable; little organic matter; few roots; clear smooth boundary.

IIB22tg 28-87 cm. Light brownish gray (2.5 Y 6/2); sandy loam; with rust spots and mottles, prominent, medium to coarse; weak, medium subangular blocky; moist, friable; little organic matter; few roots; common worm holes; clear smooth boundary.

IIB3 87-180 cm. Light gray (2.5 Y 7/2); sandy loam; with mottles, prominent, coarse and many; moderate, medium subangular blocky; friable; little organic matter; few roots; common pores and worm holes.

Pedon 10--BO10

Location: Experimental Farm Bori Rivers State, Nigeria. About 13 km north of Bien Gwara.

Setting: Level to gently sloping topography. About 30 m above sea level.

Vegetation: Under cultivation. Mainly maize, *Zea mays*; cassava, *Manihot esculenta*. Some wild palms, *Elaeis guinnensis* are also present.

Drainage: Well drained.

Erosion: None.

Ap 0-15 cm. Very dark brown (10 YR 2/2); sand-loamy sand; weak, fine crumb structure; very friable and porous.

AB1 15-40 cm. Dark brown (10 YR 3/3); sand; weak, fine crumb structure; very friable and porous; strongly acid.

B21t 40-80 cm. Dark brown (7.5 YR 4/3); sandy clay loam; weak, fine crumb structure; very friable and porous; diffuse boundary.

B22t 80-130 cm. Strong brown (7.5 YR 5/6); sandy clay loam; weak, subangular blocky structure; slightly plastic; porous; diffuse boundary.

B3 130-180 cm. Brown (7.5 YR 5/4); sandy clay loam; with common strong brown mottles; weak, fine blocky structure.

Pedon 11--IK11

Location: About 36 km north of Ka-Ogoni in Rivers State Nigeria. Approximately 4° 35' N latitude and 7° 22' E longitude.

Setting: Almost flat. About 4 m above sea level.

Vegetation: Regeneration after cultivation. Oil palms, *Elaeis guinnensis* and bamboo.

Drainage: Well drained.

Erosion: None.

Ap 0-20 cm. Very dark brown (10 YR 2/2); sand; weak, fine crumb structure; very porous; some fibrous roots.

AB1 20-40 cm. Dark brown (10 YR 3/3); sand; weak, crumb; few fibrous roots; gradual boundary.

AB2 40-60 cm. Very dark gray-brown (10 YR 3/2); loamy sand; weak, fine crumb; fairly porous.

B1 60-85 cm. Dark brown (10 YR 3/3); sandy loam; very friable; fairly porous.

B2t 85-185 cm. Yellowish brown (10 YR 5/4-5/6); sandy loam; friable; fairly porous; roots down to 130 cm.

Pedon 12--KaL12

Location: East of the village of Ka-Lori and north of the village of Sime Luekon,Rivers State,

	Nigeria. Approximate geographical position is 4° 48' N latitude and 7° 27' E longitude.
Setting:	Slightly undulating. About 8 m above sea level. Depth to groundwater is about 1.8 m.
Vegetation:	Dense overgrowth of secondary shrubs of which Musanga cecroides is one of the most characteristic.
Drainage:	Well drained.

A1 0-2 cm. Very dark grayish brown (10 YR 3/2); loamy sand; very friable; moderate, fine crumb structure; sand grains are humus coated; many roots and few pores; abrupt wavy boundary.

AB 2-18 cm. Dark brown (10 YR 3/3); loamy sand; weak, coarse subangular blocky structure; sand grains humus coated; many roots and few pores, few worm holes.

B21t 18-50 cm. Dark brown (7.5 R 4/3); sandy loam; weak, medium, subangular blocky structure; little organic matter; common roots; few pores; clear wavy boundary.

B22t 50-80 cm. Dark brown (7.5 YR 4/4); sandy clay loam; weak, coarse subangular blocky structure; little organic matter; common roots; very few worm holes; gradual smooth boundary.

B3 80-180 cm. Strong brown (7.5 YR 5/6); sandy clay loam; moderate, coarse subangular blocky structure; medium organic matter; few roots and very few worm holes.

Pedon 13--OKN13

Location:	Okpala-Ngwa on Umuahia-Aba old road. Approximate geographical position is 5° 8' N latitude and 7° 19' E longitude.
Setting:	About 60-65 m above sea level. Almost flat.
Vegetation:	Bush regrowth, cassava, and oil palms.
Drainage:	Well drained.
Relief:	About 1% slope. Depth to groundwater greater than 1.90 m.
Erosion:	None.

Ap 0-15 cm. Dark grayish brown (10 YR 4/2); sand; structureless, single grains; dry loose; sand grains humus coated; many roots; strongly acid; clear wavy boundary.

AB 15-51 cm. Dark brown (10 YR 3/3); loamy sand; moderate, coarse, subangular blocky; dry, soft; sand grains humus coated; common roots; few worm holes; gradual boundary.

B21t 51-111 cm. Brown (7.5 YR 5/4); sandy loam; moderate, coarse subangular blocky; dry, slightly hard; few worm holes; few roots; gradual, smooth boundary.

B3 111-190 cm. Strong brown (7.5 YR 5/6); sandy loam-sandy clay loam; moderate, coarse subangular blocky; dry, hard; few pieces of charcoal; few roots; common pores; no worm holes.

Pedon 14--EZ14

Location: Situated about 24 km from Umuahia at Eziama. Approximate geographical position is 5° 24' N latitude and 7° 21' E longitude.

Setting: About 105 m above sea level. Gently undulating.

Vegetation: Bush regrowth and oil palms.

Drainage: Well drained.

Relief: 1-1.5% slope. Depth to groundwater is greater than 1.50 m.

Erosion: None.

Ap 0-10 cm. Dark grayish brown (10 YR 4/2); sand; structureless, single grains; dry, loose; sand grains humus coated; many fine lumps of humus (worm excrements); many roots; few worm holes; abrupt smooth boundary.

AB 10-40 cm. Dark brown (10 YR 3/3); loamy sand; moderate, coarse, subangular blocky-moderate to weak, fine crumb structure; dry, soft; common roots and pores; few worm holes, clear smooth boundary.

B21t 40-100 cm. Brown (7.5 YR 4/4); sandy loam-sandy clay loam; moderate, coarse subangular blocky to medium subangular blocky; dry, slightly hard; little organic matter; few roots and common pores; gradual smooth boundary.

B3 100-190 cm. Strong brown (7.5 YR 5/6); sandy clay loam; moderate, coarse subangular blocky; dry, hard; little organic matter; few roots and many pores.

APPENDIX B

SOME ANALYTICAL REAGENTS AND PROCEDURES

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Fractionation of inorganic phosphorus forms using Petersen and Corey (1966) method

Reagents

Ammonium chloride, 1N - Dissolve 53.3 g NH_4Cl in water and dilute to 1 liter.

Ammonium fluoride - 0.5 N, pH 8.2. Add 17.3 ml of concentrated HF and 33.3 ml of 15 N NH_4OH to about 900 ml of water. Adjust to pH 8.2 by the addition of 4 N NH_4OH using the pH meter and dilute to 1 liter.

Sodium hydroxide, 0.1 N - Dissolve 4.1 g of NaOH in water and dilute to 1 liter.

Sulfuric acid, 0.5 N - Dilute 14 ml of concentrated H_2SO_4 to 1 liter.

Sodium citrate, 0.3 N - Dissolve 88.2 g of tribasic sodium citrate ($Na_3C_6H_5O_7 \cdot 2H_2O$) in 900 ml of water and dilute to 1 liter.

Sodium dithionite - Reagent grade $Na_2S_2O_4$.

Saturated sodium chloride solution - Suspend 400 g of NaCl in 1 liter of water. (The solubility of NaCl in water is 36 g/100 ml of water at 20°C.)

Activated charcoal (phosphorus free)

Primary phosphorus standard (50 ppm) - Dissolve 0.2195 g dried reagent grade KH_2PO_4 in about 400 ml of water in a 1,000 ml volumetric flask, add 25 ml of 7N-H_2SO_4 and dilute to volume.

Secondary phosphorus standards (2 and 20 ppm) - Dilute 20 ml of the 50 ppm stock solution to 500 ml for the 2 ppm standard. For the 20 ppm standard, dilute 200 ml to 500 ml. These dilute solutions do not keep well and should be made fresh each time a standard curve is run. A separate standard curve should be prepared for each phosphorus fraction. In preparing standard curves for the individual fractions, the standards should be made up in the extracting solutions and treated exactly like the samples in the analytical procedure so that the standards contain the same concentrations of extractants or added reagents as the sample solutions. For the present study it is found more convenient and accurate to prepare standards ranging from 0, .1, .2 to 1.0. The concentration of the phosphorus in extracts (in ppm) is found by multiplying readings from standard curve with appropriate dilution factors.

Chloromolybdic boric acid solution - Dissolve 3.5 g of $(NH_4)_6MO_7O_{24}\cdot 4H_2O$ in about 150 ml of water by warming to about 60°C. Filter the solution if cloudy. When the solution has cooled, slowly add 75 ml of concentrated HCl with stirring and again let the solution cool. Dissolve

30 g of boric acid in 200 ml of water by warming to about 80°C. Allow this solution to cool, add it to the molybdate solution, dilute the final solution to 1 liter and mix thoroughly.

Chlorostannous reductant - Dissolve 12 g of stannous chloride, $SnCl_2 \cdot 2H_2O$ in 50 ml of 6N HCl. Place the solution on a steam hot plate until clear and then dilute to 1 liter with water. When the solution has cooled, it should be stored under a 10 mm layer of white mineral oil in a brown bottle with a syphon.

Bray reductant (amino-naphthol-sulfonic acid reductant) - Grind the following dry materials and mix them thoroughly: 2.5 g 1-amino-2-naphthol-4-sulfonic acid (Eastman 360); 5.0 g sodium sulfite (Na_2SO_4); 146 g sodium bisulfite (Meta, $Na_2S_2O_5$). Dissolve 8 g of the resulting powder mixture in 50 ml of warm water. If possible, allow the solution to stand overnight before using. A fresh portion of this solution should be made up from the dry powder every 3 weeks.

Potassium permanganate, 0.25 M - Dissolve 39.5 g of $KMnO_4$ in water and dilute to 1 liter.

Isobutyl alcohol

Ethyl alcohol, 95%

Ethyl alcohol, absolute

Molybdate-sulfuric acid reagent - Dissolve 60 g of ammonium molybdate in 800 ml of water by bringing the water to a boil. Cool the solution, and add 84 ml of concentrated H_2SO_4. Cool and dilute to 1 liter.

Stannous chloride reductant - Add 3.0 g of stannous chloride to 200 ml of water and follow with an addition of 56 ml of concentrated HCl. Swirl until the solution is clear (the heat of dilution of HCl should dissolve the $SnCl_2 \cdot 2H_2O$ if it is good reagent). Add 400 ml of water and 130 ml of concentrated H_2SO_4. Cool and dilute to 1 liter. This solution should be prepared daily.

Procedure

Extraction and determination of aluminium phosphate.

To 1 gm soil is added 50 ml 1N-NH_4Cl and shaken for 30 min. to remove the easily soluble and loosely bound phosphorus and exchangeable calcium. After centrifugation, 50 ml 0.5N NH_4F, pH 8.2 is added to the soil after discarding the supernatant solution. This is shaken for 1 hour and centrifuged. The supernatant is treated with about 0.5 g phosphorus-free activated charcoal and placed on the filter paper. Organic matter is thus removed giving a clear solution. The soil is saved for extraction of iron phosphate.

To about 3 ml aliquot of the extract is added 3 ml chloromolybdic boric acid solution and mixed thoroughly. One drop of chlorostannous reductant is added, mixed and absorbance of the blue color is measured at 660 mμ within

15 to 30 minutes. A filter of 650 mμ can also be used if 660 mμ is unavailable.

Extraction and determination of iron phosphate.

Wash the soil sample used for extraction of aluminium phosphate twice with 25 ml portions of saturated NaCl by centrifugation and decantation. Add 50 ml of 0.1N NaOH and shake for 17 hours. Centrifuge the suspension and decant the supernatant solution for P analysis. Add 5 drops of concentrated H_2SO_4 and swirl the flask so that the organic matter will flocculate. Addition of concentrated H_2SO_4 is continued until the dispersed organic matter flocculates. Using 3 ml aliquot of the extract the color is developed and measured in the same manner as for the aluminium phosphate.

Extraction and determination of calcium phosphate.

The remaining soil residue is washed with two successive centrifuge washings with saturated NaCl (25 ml). Add 50 ml of 0.5 N H_2SO_4, shake for 1 hour and centrifuge.

Take a 3 ml-aliquot of the extract and develop and measure color in the same manner as for aluminium and iron phosphate.

Organic phosphorus determination (Legg and Black, 1955).

Ignition and extraction.

One gm sample of soil was placed in a beaker on a raised asbestos sheet in a muffle furnace at 240°C for 1 hour. The ignited sample was transferred to a 100 ml centrifuge tube, using a brush to remove any particles adhering to the beaker.

To the ignited soil in the centrifuge tube, and to a comparable 1 gm sample of non-ignited soil in a similar tube, was added 10 ml of concentrated HCl, and heated on a steam plate for 10 minutes (final solution temperature about 70°C). The tubes were removed from the steam plate, and an additional 10 ml of concentrated HCl added and allowed to stand at room temperature for 1 hour.

About 50 ml of water was added, mixed with the acid and suspension centrifuged. The extracts were poured into 250 ml volumetric flasks and made to volume with distilled water.

Determination of inorganic P in extracts.

Inorganic phosphorus was determined by Bray's No 1 method (1945) with 0.03 N NH_4F + 0.025 N HCl as extractant. Phosphorus in the extract was determined colorimetrically by the blue color method of Murphy and Riley (1962).

Calculation of organic phosphorus content.

The difference in content of inorganic phosphorus found in the extracts of the ignited and non-ignited samples may be taken directly as an estimate of the content of organic phosphorus in the soil.

Remarks.

This method of determination comes very handy in cases where perchloric acid hood chamber is unavailable.

Particle size analysis--pipette method (Steele and Bradfield, 1934)

Summary. A uniform suspension of soil in water is prepared and allowed to stand. Samples are removed at different times from a measured depth (rising gravity on a tube centrifuge) evaporated to dryness and weighed. The largest particles in any sample are those with a settling velocity just equal to the specific value for depth/time. With all smaller particles, the concentration of the sample is the same as that of the original suspension. The relation of particle size and settling velocity is given by Stokes' Law. By taking samples at different values of depth/time, a series of summation percentages is obtained. The difference between two successive summation percentages gives the measurement of the fraction between those two limits of size.

Equipment.

1. 2-way stopcock sealed to the upper stem of a 5 cc pipette calibrated for total volume.
2. Sieves--Nos. 300 mesh, and 140 mesh.
3. Centrifuge (International with head carrying 8-100 cc tubes.
4. Evaporating dishes.
5. Large aspirator bottles and weighing dishes.

<u>Procedure</u>. Five gm soil from which organic matter has been removed is dispersed with Calgon. After dispersion the suspensions are washed through a 300 mesh sieve keeping the amount of water as small as possible. The sands remaining on the sieve are washed into an evaporating dish, dried at 105°C, and weighed. The sands are further fractionated using appropriate sieves.

The suspension of clay and silt is caught in a weighed 250 cc bottle and made up to volume. The suspensions thus prepared are stirred for 2 min., shaken, time noted and allowed to stand. Ordinarily in a set of 8 suspensions stirring is done at 5 minute intervals, to allow time for sampling. Samples of 5 cc are removed at the time shown below, placed in weighed dishes, evaporated to dryness at 105°C.

The pipette is slowly filled, stopcock closed and the suction tube removed. Reversing the stopcock, the sample is allowed to drain into the weighing dish and the excess suspension is washed out with distilled water.

Four successive gravity samples are taken without again stirring the suspension. After the last gravity sample is removed, the suspensions are stirred for a few minutes. Portions of 25 cc are placed in centrifuge tubes and centrifuged as soon as possible for the required time. Ordinarily four samples are run at one time, each in duplicate. The time is taken from the moment the motor

Depth and Time of Sampling Soil Suspensions. Temperature 25°C

Depth of Sampling cm	By Gravity hrs	mins	secs	By Centrifuge hrs	mins	secs	Equiv. radius mμ	Equiv. diameter mm
5	0	33	11				2500	.005
5	3	27	40				1000	.002
2	5	31	44				500	.001
2	22	6	56				250	.0005
2				0	4	16	125	.00025
2				0	17	3	63	.000125
2				1	8	1	31	.0000625

is turned on until it is turned off. The speed of the centrifuge is maintained as nearly as possible at 2200 rpm using a vibration tachometer.

The temperature is maintained fairly constant by working in a cool room of constant temperature.

$$t \text{ (time of centrifuging)} = \frac{n \log \frac{R^2}{R^1}}{3.81\ N^2\ r^2 (d_1 - d_2)}$$

where n = viscosity of the medium.

R_1, R_2 are distances from the axis of rotation to the surface of the suspension and to the sampling depth, respectively. In this case, they are R_1 = 22 cm and R_2 = 24 cm.

N = Revolutions per second

r = Radius of the particle

d_1 and d_2 = densities of the particle and of the medium, respectively.