FERRALLITIC AND FERRUGINOUS TROPICAL SOILS OF WEST AFRICA

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This review of the literature on Ferrallitic and Ferruginous Tropical soils was completed in 1973, but reproduction was delayed until the content could be appraised by C. Charreau of IRAT during his service as Visiting Professor at Cornell in early 1974. Professor Charreau has found that the paper reflects the French literature cited accurately. He has noted that much work is under way currently on Ferrallitic and Ferruginous soils and that concepts are changing, especially for Ferruginous soils. Readers are advised to follow the French literature as it appears. For example ORSTOM Memoire No. 61, Les Sols Rouges sur Sables et sur Grès d'Afrique Occidentale, by R. Fauck, which was issued in late 1972, adds to the information reported here but was not available to the author.

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Ferrallitic and Ferruginous Tropical
Soils of West Africa[1]
by

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I. Introduction

The purpose of this paper is to review the literature on West African soils, in particular that literature compiled by the French research organization ORSTOM, Office de la Recherche Scientifique et Technique Outre-Mer. Particular emphasis is given to the views of ORSTOM pedologists in the areas of soil genesis, morphology and classification with respect to two major soil groups, Ferrallitic and Ferruginous Tropical soils, sols ferrallitiques et sols ferrugineux tropicaux. A tentative correlation is given for these soils in terms of the "New Soil Taxonomy" of the U. S. National Cooperative Soil Survey (popularly called the 7th Approximation). Important factors in the genesis of these soils are discussed.

II. Geographic Distribution

The Soils Map of Africa by J. L. D'Hoore (1964) shows a rough distribution of the major soils throughout Africa. The predominant soils shown on the map fall within three major soil classes, these being: Ferruginous Tropical soils (sometimes called Fersiallitic soils), Ferrisols and Ferrallitic soils. The definitions for these classes fall within the limits dictated by Aubert (1965) and Aubert and Ségalen (1966) with the exception that D'Hoore's Ferrisols, due to their narrow definition, are not distinguished from the Ferrallitic class by the French. Geographically most of Senegal, Niger, and Upper Volta are dominanted by Ferruginous

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Tropical soils. Similarly soils in western Guinea, northern Ivory Coast, Ghana, Togo and Dahomey along with northern and western Nigeria are predominantly Ferruginous Tropical soils. The coastal areas of Nigeria, Dahomey, Togo and Ghana along with central and southern Ivory Coast are within the Ferrallitic class. Liberia, Sierra Leone, Portuguese Guinea and most of Guinea are dominated by Ferrallitic soils.

III. A Model of Ferrallitic and Ferruginous Tropical Soils

Over the past decade a good deal of research has been done by the ORSTOM pedologists on Ferruginous Tropical and Ferrallitic soils. This work has been somewhat influenced by the work of American pedologists. The 7th Approximation in particular has had a great effect on the recent revision of the classification of Ferrallitic soils and in the formulation of a Ferrallitic model.

Chatelin (1972) proposed three key concepts influencing the study and classification of Ferrallitic and Ferruginous Tropical soils. The first is that Ferrallitization, a geochemical process, is the basis of definition of these soils. Aubert and Ségalen outline this process as an attack on primary minerals by abundant warm water with dissolved oxygen and CO_2 percolating through the soil profile over a long period of time. The mechanisms of attack are essentially oxidation, hydrolysis and dissolution resulting in the almost complete removal of bases, the destruction of the primary mineral lattice structures and the dissolution of silica accompanied by the liberation of iron and alumina. The primary minerals resist this alteration in relation to their structural organization, their richness in bases, and the presence or absence of ferrous iron. Only a small number of minerals resist these attacks with the rest forming a ferruginous or aluminous residue depending on the original composition.

The silica can be completely eliminated or can combine with alumina to form kaolinite. The uncombined alumina may remain in the form of hydroxides such as gibbsite and, rarely, boehmite. The predominance of gibbsite or kaolinite depends on the drainage conditions, more kaolinite being formed under poor drainage conditions. Iron (reducible, complexable, and susceptible to translocation) accumulates in the form of hematite or goethite. Chatelin (1972) states that a simple geochemical index, SiO_2/Al_2O_3, permits a comparison of original rock and soil and shows the degree of weathering of the original material. Thus a continuum can be set up in which certain empirically chosen limits, stages, or degrees of intensity of weathering can be determined.

The second key concept concerns the manner of deposition of the soil material. Distinctions are made as to whether the soil is residual, covered by transported materials, disturbed, formed from colluvium or contains a stone-line or layer of gravel. These characteristics reflect the way a particular soil material was deposited or formed in place and have a direct influence on the interpretation of the geochemical ratio, SiC_2/Al_2O_3.

The action of the ecological milieu is the basis of the third key concept. It was thought at first that the geochemical ratio alone would be sufficient to represent the effect of climatic conditions on the evolution of a particular soil. But it soon became apparent that this distinction was only valid on a very small scale in a general comparison of world-wide soils and that in a smaller domain, such as that defined by Ferrallitic and Ferruginous Tropical soils, a characteristic more influenced by local climatic conditions would be necessary--hence, the importance of the degree of base saturation and quantity of organic matter in the soils.

Lately introduced to French pedologists is the idea of "polygenesis". This refers to the notion that many Ferrallitic soils have been influenced by different climatic and geomorphological conditions in the past, these conditions having left their marks on present-day soils (for instance, the case of Ferrallitic soils with a high base saturation but low CEC). As of yet, however, more research has to be completed before these concepts can be more precisely formulated.

Chatelin and Martin (1972) tackled the difficulties involved in applying the concepts of the genesis of temperate soil profiles to Ferrallitic soils. In temperate regions a soil solum may not encompass all the material down to the parent rock. In the case of Ferrallitic soils, the weathering may be very deep to the unaltered rock, several dozens of meters in some cases. However, French pedologists have used the notion of the solum in its totality, down to the rock, to confirm their interest in genetic and evolutionary studies of the "whole soil."

In describing a soil, Chatelin and Martin (1972) have devised a typology of seven diagnostic horizons. Any Ferruginous Tropical or Ferrallitic soil can be described on the basis of these horizons. It is stated, however, that this list is not complete and that new studies may produce other additions. These horizon designations may not be completely accepted by all French pedologists. However, the author found their descriptions valuable for the presentation of the Ferrallitic and Ferruginous Tropical Soils model. The following is a description of these seven diagnostic horizons.

A. The appumique horizon refers to the upper part of the soil. It contains an accumulation of organic matter and/or is impoverished or depleted (appauvri) in clay and sesquioxides. Impoverishment is used in the widest sense of the term, covering translocation of substances to another horizon or perhaps clay destruction. The characteristic of impoverishment assumes the presence of a structichrome horizon (see following) such that the ratio of clay in the two horizons is greater than 1/1.4 (Muller, 1972). Impoverishment or depletion in clay and iron is not diagnostic, as both states cannot be distinguished for all Ferrallitic soils known at present. An appumique horizon can have a small amount of organic matter on the surface. Roots may form a dense matting. The texture of the horizon is generally fine, but the horizon may contain a small amount of gravel, pebbles, etc. The horizon is usually represented by A and subdivided into A_{00}, A_1, and A_3 (when referring to most Ferrallitic soils an A_2 is not present since translocation has not occurred).

B. The structichrome horizon is a friable horizon which has a purely pedological structural organization i.e. showing no relation to the structure of the constituents of the original material. Essentially a mineral horizon, the upper portion can contain a small amount of organic matter but can be distinguished from the appumique horizon by its color, structure and sometimes texture. The color is homogenous and is usually maximally differentiated from the rest of the profile. Characteristic components are kaolinite and sesquioxides. It may contain lesser amounts of illite and traces of montmorillonite (these later two being more representative of Ferruginous Tropical than Ferrallitic soils) (Beaudou, 1971). It also may contain gravel or coarse particles, but these may not exceed 60 percent of the total weight of the horizon. This is the major diagnostic horizon of Ferrallitic soils and is usually represented by B.

C. Sterimorphe represents all indurated horizons present in Ferruginous Tropical and Ferrallitic soils regardless of composition or position in the profile. Rarely homogeneous, the sterimorphe horizon shows variation in color (contrast and deposition of mottles) and form. The definition is mostly morphological but has mineralogical implications also, as only metallic sesquioxides accumulate and harden in Ferrallitic and Ferruginous Tropical soils (Maignien, 1966). Hardening occurs under a wide range of iron, aluminum, manganese and titanium contents. This horizon is usually represented as B_v, B_{cr}, Cm or B_{2m}[1]

D. The gravillonnaire or fine gravel horizon is a horizon containing more than 50 or 60 percent fine gravel by weight, thus making the structure of the fine earth fraction undistinguishable. These fine gravel are considered to have been formed by hardening of sesquioxides in ancient landscapes which have since been disturbed or covered by transported materials. The fine gravel may show the same sesquioxide composition as the sterimorphe horizon. Larger blocks or pebbles may be mixed in. The concept of this horizon is purely morphological and does not always require genetic interpretations. Small or fine gravel are distinguished from concretions where hardening and its limits are indecisive. From a genetic point of view the fine gravel are ancient forms while concretions are found in their genetic milieu and can represent different stages of weathering. Concretions are found in gravillonnaire, structichrome and sterimorphe horizons. Fine gravel, as used by the French, always have a pedological origin.

E. The horizon graveleux or gravel horizon is composed of elements of the geological substructure. Quartz is especially well represented but other highly unalterable minerals or rock fragments are present, such as jaspar or quartzites. As in the gravillonnaire horizon above, the percentage of coarse particles in such a horizon is greater than 50 or 60 percent by weight. The current terms commonly used to describe these last two horizons (fine gravel and gravel) are: Stone-lines, beds of pebbles, gravel, etc. They are represented as B_{gr}.

F. The <u>retichrome</u> horizon is characterized by mottling. A typical retichrome horizon consists of contrasting mottles making an alveolar or honeycomb pattern, the mesh of which has open spaces the width of several centimeters. This is a mineral horizon with a structure unlike that of the parent rock. Several authors have said that such a horizon is formed under waterlogging conditions at lower levels accompanied by segregation of iron (Martin, 1966). Various intergrades exist depending on the structure and degree of hardening of the material and the appearance of primary mineral particles. The horizon is represented as B_v, or B_V as the indurated variant. It has characteristics comparable to "ground-water laterite and plinthite" as defined by American pedologists.

G. The <u>altérique</u> horizon or horizon of alteration is the lowest horizon in the process of developing a pedological structure. Usually found in close proximity to the parent rock, the original rock structure is preserved in some fashion. The mineralogical composition is highly variable but in some cases a layer of gibbsite can be seen in direct contact with the rock. This horizon is represented by C. (Chatelin and Martin, 1972).

IV. Fundamental Tenets of the French Classification System Applicable to Ferruginous Tropical and Ferrallitic Soils.

Maignien (1965) states that the French soil classification system is fundamentally a genetic system and at the same time a universal system which seeks to integrate and correlate all soils. The soil is defined by morphological, physical and chemical characteristics of the entire profile. These characteristics are recognizable and measurable in the field.

Probably the most original part of the classification system has been built around Ferruginous Tropical and Ferrallitic soils. Chatelin (1972) calls the classification of these soils "selective", because the classification does not contain stable elements. To define a given soil it is necessary to select successively all criteria applicable by comparison to the "classification grid", making a suitable choice of "sign" from each taxonomic level. These "signs" are often conceived to represent a process, the evolutionary processes being the major directive principles.

The system previous to 1966 had grouped Ferruginous Tropical and Ferrallitic soils in the same class. In 1966 Aubert and Ségalen revised the classification of Ferrallitic soils. Under this revision Ferrallitic soils constitute a class of their own. This was done for two reasons: 1) It was found that some soils which met all the criteria for classification as Ferrallitic soils did not contain appreciable quantities of gibbsite. It was therefore postulated that the presence or absence of significant quantities of gibbsite depended to a large degree on local drainage conditions. If drainage is good, silica is easily eliminated in the drainage water and gibbsite would be abundant. If drainage were not good, silica would not be easily eliminated and kaolinite would predominate (Ségalen, 1966). 2) It was necessary to define more completely the milieu in which these soils are actually evolving along with certain pecularities of the profile which may be "accidental" such as truncation, or the deposition of different materials, "stone-lines" etc. Thus more consideration was given to the present climate and the immediate geomorphological past.

V. The Revised Classification of Ferrallitic Soils.

This classification was formulated by Aubert and Ségalen in 1966. The central concept of the Ferrallitic soil class is:

A. Soils showing a complete alteration of primary minerals with some inherited species, such as ilmenite, leucoxene, magnetite, zircon, illite, residual quartz, and an elimination of the major part of the alkaline earths and bases and a large portion of the silica.

B. Soils with an abundance of the following synthesis products: 1:1 silicate clays in the kaolinite family, with or without hydroxides of aluminum, iron, and other minerals such as manganese dioxide, etc.

C. An ABC profile including: 1) An appumique, A, horizon where organic matter has accumulated, 2) a thick B horizon where primary minerals other than quartz are rare or absent and having the secondary minerals cited above, 3) a C horizon of variable thickness depending on the nature of the parent rock. It may be 20 cm or 20 m.

D. Soils forming in a climate having abundant warm rainfall determining the following physico-chemical characteristics: 1) A low CEC, 2) a low quantity of exchangeable bases, 3) a variable degree of base saturation (usually low), 4) an acid pH.

E. Soils showing effects of a number of non-specific processes such as: 1) accumulation of organic matter at high altitudes or high rainfall, 2) waterlogging of profiles especially on flat level plains, 3) impoverishment or depletion of clay or iron, 4) translocation of iron and/or clay, 5) mechanical processes such as "disturbance" (remaniement) and "rejuvenation" (rajeunissement). "Rejuvenation" refers to the deposition of less weathered materials containing primary minerals over an old highly weathered horizon.

The subclasses are differentiated on the basis of the effect which the present climate has had on the evolution of the soil. The most important aspects of climate in this case are the rainfall and water regime in the soil. According to Aubert and Ségalen (1966) the observation of a number of profiles has shown that certain properties such as the quantity of exchangeable bases and pH are in direct relation to local climatic conditions, especially the rainfall. In other words the intensity of percolation through the soil is the determining factor. Three subclasses are distinguished (Boyer, 1970) and (Aubert and Ségalen, 1966):

A. Strongly desaturated (desaturé) Ferrallitic soils where 1) exchangeable bases are very low, less than 1 meq/100 g of soil, 2) the degree of base saturation is low, less than 20 percent and 3) the pH is very acid, less than 5.5.

These soils correspond to an equatorial climate of one to four seasons with a very short dry period. Rainfall is greater than 1.8 m.

B. Moderately desaturated Ferrallitic soils with 1) 1 to 3 meq of exchangeable bases per 100 g of soil, 2) 20 to 40 percent base saturation and 3) a pH of 4.3 to 6.

These soils correspond to an equatorial climate of four seasons where the dry season lasts two or three months or a tropical climate with a dry season of three to five months. Rainfall is at least 1.3 m.

C. Weakly desaturated Ferrallitic soils have: 1) 2 to 8 meq exchangeable bases per 100 g of soil, 2) 40 to 80 percent base saturation, 3) a pH of 5.0 to 6.5.

These occur in a tropical climate with a long dry season of three to six months with 1.2 to 1.6 m of rainfall.

Six groups have been proposed for the above three subclasses (Aubert and Ségalen, 1966).

A. The "typical" group exists for all three subclasses. In each case the group corresponds to the central concept of the subclass. These soils are not as extensive as one might think due to the extremely long and numerous erosion cycles which exist and have existed in West Africa. Typical groups are usually found in volcanic or "newer" regions. The C horizon is usually the thickest and the B horizon a bright red or yellow.

B. The humic group has an accumulation of organic matter that must be at least 7 percent in the first 20 cm or more than 1 percent at 1 m.

C. The "translocated" group (lessivé). (Lessivé as used by French pedologists refers to migration of iron or clay as distinguished from leaching of bases or silica.) In this sense the loss of clay from A is compensated by a gain in B (Leneuf, 1966). This group does not seem to be applicable to the first sub-class of the strongly desaturated Ferrallitic soils.

D. The "impoverished or depleted" group (appauvri) refers to those soils in which clay appears to have been lost from the A horizon, assuming that the amount of clay throughout was homogeneous at an earlier time. As such the loss of clay from A does not always mean that it will accumulate in B. The clay in A may have decomposed or, more likely, migrated obliquely, especially on lower slopes (Roose, 1968). Impoverished groups have been found for all three subclasses.

E. The "disturbed" group (remanié) refers to the disturbance of the upper part of a profile by the action of fauna (for example termites) or geomorphic processes. These processes usually lead to a distribution of fine materials over a bed of coarse fragments slightly rounded (quartz pebbles, fine gravel, lateritic debris, etc.), which in turn is over a portion of the profile which has not moved but evolved in place. However, the fundamental process of Ferrallitization has not been modified by the foreign materials to any great extent. Throughout vast zones of Africa, new erosion surfaces are formed at the expense of former surfaces, thus inducing the truncation of profiles and the distribution of foreign elements coming from similar profiles, but at some distance away, over this truncated surface.

F. The "penevolved" group (pénévolué) designates those soils whose normal evolution has been disturbed by an outside influence: 1) Erosion truncates a profile and covers the remaining part with relatively less-weathered material, or truncates the profile to such an extent that "fresher" minerals are exposed at the surface, 2) recent materials such as alluvium or volcanic ash are deposited on a Ferrallitic soil modifying the morphology to a depth of at least 50 cm, 3) not enough time has passed for the complete elimination of residual minerals such as illite.

The same characteristics of the various groups above, expressed to a lesser extent, may define subgroups. A particularly important subgroup is defined by "indurated" soils or soils having an indurated horizon (Aubert and Ségalen, 1966).

VI. Examples of Ferrallitic Soils.

During the mid 1960's, the Development and Resources Corporation of New York prepared a soil survey of the southwest region of Ivory Coast (Development and Resources Corporation, 1968). The survey was prepared using the criteria of the U.S. Soil Taxonomy (7th Approximation). The following soil series is classified as an Arenic Oxic Dystropept or in the French system a "moderately desaturated impoverished (modal) Ferrallitic soil." The example was chosen to help familiarize those knowledgeable of the Soil Taxonomy of the U.S. with some of the terms used in the French classification system. The descriptions and analytical data which follow were taken from the survey of the southwest region (Development and Resources Corporation, 1968).

<u>BASA SERIES</u>

The Basa series, according to the New Classification System of the USDA, comprises soils of the Arenic Oxic Dystropepts, members of a well drained sandy over fine loamy, siliceous over mixed isohyperthermic family. Arenic Oxic Dystropepts have been called Latosols and the Basa series is identified with the Red Latosol great group because of the characteristic reddish color of the subsurface horizons. In the system of Aubert and Segalen, this series is "sol ferrallitique moyennement desature appauvri modal." Basa soils typically have moderately dark, thin to moderately thick A-horizons that grade with depth through brownish-colored, moderately thick, sandy upper sola into underlying clayey and plinthic lower sola.

<u>Typifying Profile</u>: Basa loamy sand - Oil palm plantation
(Colors for moist conditions unless otherwise noted.)

A11 0 - 5 cm. Very dark grayish-brown (10YR3/2) loamy sand, brown (10YR5/3, dry); weak fine crumb structure; soft, very friable, sticky, non-plastic; plentiful fine random inped and exped roots: many micro, very fine and fine inped and exped dendritic pores; strongly acid, pH 5.2; abrupt smooth boundary. 4 to 7 cm. thick.

A12 5-17 cm. Dark brown (10YR3/3 loamy sand, brown (10YR5/3, dry); very weak sub-angular blocky structure; soft, very friable, non-sticky, non-plastic; plentiful fine random inped and exped roots; many micro and very fine and common fine inped and exped dendritic pores; medium acid, pH 5.6; gradual smooth boundary. 10 to 15 cm. thick.

C1 17-35 cm. Dark brown (7.5YR4/4) sand, brown (10YR5/3, dry); very weak fine sub angular blocky structure; soft, very friable, non-sticky, non-plastic; plentiful fine random inped and exped roots; many micro and very fine inped and exped dendritic pores: medium acid, pH 5.6; gradual smooth boundary 15 to 25 cm. thick.

C2 35-70 cm. Dark brown (7.5YR4/4) sand, brown (7.5YR5/2, dry); very weak fine sub-angular blocky structure to single grain; loose, very friable, non-sticky, non-plastic, plentiful fine random inped roots; many micro and very fine inped and exped dendritic pores; strongly acid, pH 5.5; gradual smooth boundary. 25 to 45 cm. thick.

C3 70-85 cm. Dark brown (7.5YR4/4) loamy sand, pale brown (10YR6/3, dry); very weak fine and medium subangular blocky structure; soft, very friable, slightly sticky, non-plastic; plentiful fine random mostly inped roots; many very fine continuous mostly inped dendritic pores; strongly acid, pH 5.3; abrupt wavy boundary. 10 to 20 cm. thick.

I-IIB1 85-110 cm. Dark brown (7.5YR4/4) sandy loam, brown (7.5YR5/4, dry): weak medium and fine subangular blocky structure; slightly hard, slightly firm, slightly sticky, slightly plastic; few fine random inped and exped roots; many fine and medium continuous, vertical mostly inped pores; very few, thin clay films on ped faces and in pores: very strongly acid, pH 5.0; gradual smooth boundary. 20 to 30 cm. thick.

IIB21 110-142 cm. Strong brown (7.5YR5/6) sandy clay loam with common medium distinct yellowish-red (5YR4/6) mottles reddish-yellow (7.5YR6/6, dry); weak medium subangular blocky structure; slightly hard, slightly firm, slightly sticky, slightly plastic; few fine random mostly inped roots; many micro and very fine mostly inped dendritic pores; common thin clay films on ped faces and in pores; very strongly acid, pH 5.0; gradual smooth boundary. 25 to 40 cm. thick.

IIB22 142-175 cm. Reddish brown (5YR4/4) to yellowish-red (5YR4/6) sandy clay with many medium distinct dark brown (10YR3/3) and light yellowish brown (10YR6/4) mottles yellowish red (5YR5/6, dry); weak medium and fine subangular blocky structure; slightly hard, slightly firm, sticky, plastic; few roots; many very fine continuous mostly inped pores; common thin clay films on ped faces and in pores; many krotovinas; strongly acid, pH 5.1; gradual smooth boundary. 25 to 40 cm. thick.

IIB23cn 175-240 cm. Reddish-brown (5YR4/4) to yellowish red (5YR4/6)clay with common medium distinct dark brown (10YR3/3) and red (2.5YR4/8) mottles; yellowish red to reddish yellow (5YR5/5-6/6, dry), weak medium and fine subangular blocky structure; slightly hard, slightly firm, sticky, plastic; few roots; many fine continuous inped pores; common thin clay films on ped faces and in pores; strongly acid, pH 5.2.

Type Location: Southwest Ivory Coast; 3.8 kilometers west of the Catholic Church in Sassandra; sample strip 7, line 2, stake 4b.

Range in Characteristic: The A-horizon generally is of a moderately coarse or coarse texture (i.e. fine sandy loam, sandy loam, loamy sand or sand) and ranges in color from very dark grayish-brown (10YR3/2) to dark brown (10YR3/3-4/3). Thickness of the A-horizon ranges from 10 to about 20 cm. The sandy-textured, weakly-structured upper profile of these soils has a thickness range of 50 to more than 100 cm. and a texture that infrequently is finer than loamy very fine sand. However, the upper story is permitted to include sandy loams, especially in the lower part. The sandy upper story has colors on 7.5YR and 10YR hues with values and chromas of 4 and 5. The lower profile ranges in texture from sandy clay loam to clay but, most often, is sandy clay. Color usually is on 5YR hues with higher-chroma plinthic mottles. The plinthic mottles occur in the lower clayey solum and occupy from 10 to 60 percent or more of the soil body. Structure generally is weak. Solum thicknesses usually exceed the depth of the 240 cm. test pits. pH in the A1-horizon at 10 cm. depth is centered in 4.7 but may range from 4.1 to 5.2. pH at 75 cm. pH values are found on depressional sites; whereas the higher values are found on convex slopes and ridges.

Competing Series and Their Differentiae: The Ombloke series is coarser textured in the lower sola. The Govia series has a similarly sandy-textured upper story but is underlain at 20 to 40 cm. by hardened plinthite nodules and fragments of ferruginous crust rather than fine-textured, gravel-free sediments.

Setting: These soils occur in the undulating to rolling uplands of the Continental Terminal's Tertiary sediments, with dominant slope gradients ranging from 0 to 12 percent. The regolith is a moderately thick to thick deposit of coarse and moderately coarse textured Tertiary sediments overlying remnants of an old peneplain ferruginous crust that, in turn, rest on granitoid rocks. The sediments, thought to be aeolian in origin, are marginal to the coastline near Sassandra, within the 1600 to 1700 mm. rainfall belt. Mean annual temperature is about 26°C.

Principal Associated Soils: These include the well drained Govia and Lableko series. Both are geographically associated with Basa soils. The Govia series has a similarly coarse-textured upper profile but is underlain at a relatively shallow depth by ironstone nodules and fragments of peneplain ferruginous crust. The Lableko series has a finer-textured upper profile.

Drainage and Permeability: Well to excessively drained with slow run-off and rapid internal drainage. Rapidly permeable in the upper profile but moderately permeable in the lower profile.

Use and Vegetation: Most of this area has been under oil palm for the past 50 to 60 years.

Distribution and Extent: Basa soils are limited in extent, being confined to the relatively small Association V.

Basa Series - Analytical Data

PROFILE PROFIL NO.	HORIZON	DEPTH PROFONDEUR CM.	GRAVEL GRAVIER (2 MM) %	SAND / SABLE (MM) VERY COARSE TRES GROSSIER (2-1) %	COARSE GROSSIER (1-.5) %	MEDIUM MOYEN (.5-.25) %	FINE FIN (.25-.1) %	VERY FINE TRES FIN (.1-.05) %	TOTAL (2-.05) %	SILT / LIMON (μ) COARSE GROSSIER (50-20) %	FINE FIN (20-2) %	TOTAL (50-2) %	CLAY / ARGILE (μ) COARSE GROSSIER (2-.2) %	FINE FIN (<.2) %	TOTAL (<2) %	TEXTURAL CLASS CATEGORIE DE TEXTURE	BULK DENSITY DENSITÉ APPARENTE G/CC
								BASA SERIES 7-2-46 (modal)									
1	A11	0-5	-		60.4		22.9		83.3	1.8	4.5	6.3			10.3	ls	2.01
2	A12	5-17	-		61.2		23.2		84.4	2.0	3.0	5.0			10.0	ls	1.89
3	C1	17-35	-		58.9		27.8		86.7	2.5	4.0	6.5			7.0	s	1.90
4	C2	35-70	-		63.4		25.8		89.2	2.3	5.8	8.1			4.8	s	2.08
5	C3	70-85	-		60.4		24.3		84.7	2.5	4.3	6.8			9.3	ls	1.66
6	I-II B1 b	85-11	-		57.2		13.8		71.0	1.9	5.5	7.4			19.0	sl	1.86
7	II B21b	10-14	-		47.9		13.5		61.4	1.5	4.0	5.5			34.0	scl	1.54
8	II B22b	42-17	-		41.4		9.2		50.6	1.6	6.3	7.9			42.3	sc	1.67
9	II B23b	75-24	-		35.2		7.1		42.3	1.4	7.0	8.4			48.8	c	1.67

PROFILE PROFIL NO.	TOTAL PORE SPACE ESPACE VIDE %	PH 1:1 (H2O)	PH 1:1 (KCL)	C %	N %	O.M. MATIERE ORGANIQUE %	C/N	P PPM	MN ++ MEQ./100 G	C.E.C. (NH4+) MEQ./100 G	EXCH. CATIONS. CATIONS ECHANGEABLES MEQ./100 G H	NA.	CA.	MG.	K.	TOTAL CATIONS MEQ./100G	TOTAL BASES MEQ./100G	SATURATION %
							BASA SERIES 7-2-46 (modal)											
1	25	5.4	--	0.1	.01	0.3	17	452	--	6.0	--	.06	2.0	0.5	.11	--	2.7	44
2	28	5.9	--	0.1	.01	0.2	20	380	--	4.5	--	.07	1.4	0.4	.06	--	2.0	44
3	28	6.3	--	--	--	--	--	--	--	3.3	--	.04	1.2	--	.05	--	1.3	38
4	22	6.6	--	--	--	--	--	--	--	2.5	--	.05	0.7	--	.04	--	0.8	32
5	38	6.2	--	--	--	--	--	--	--	2.6	--	.06	1.0	--	.04	--	1.1	41
6	30	6.2	--	--	--	--	--	--	--	4.0	--	.08	1.0	--	.05	--	1.2	30
7	42	5.4	--	--	--	--	--	--	--	5.6	--	.12	1.1	0.1	.05	--	1.4	24
8	35	5.4	--	--	--	--	--	--	--	5.9	--	.11	0.9	<0.1	.07	--	1.1	19
9	35	5.4	--	--	--	--	--	--	--	5.2	--	.16	0.8	<0.1	.04	--	1.1	21

The second example of a Ferrallitic soil (Chatelin, 1969) comes from the same area in Central African Republic as the Ferruginous Tropical soil to be described in Section VIII. This Ferrallitic soil, as is characteristic of most Ferrallitic soils, was formed on a land surface older than that of the Ferruginous Tropical soil. Due to its topographically elevated position it is also better drained. The parent rock, gneiss, is the same as that of the Ferruginous Tropical soil to be described in Section VIII.

The clay fraction of the whole soil contains approximately 85 percent kaolinite and 15 percent illite, with the quantity of illite decreasing slightly with depth. The principal form of iron is hematite. There was no gibbsite in this particular profile, and a sample taken from the surface horizon showed the clay fraction to be 4.8 percent quartz.

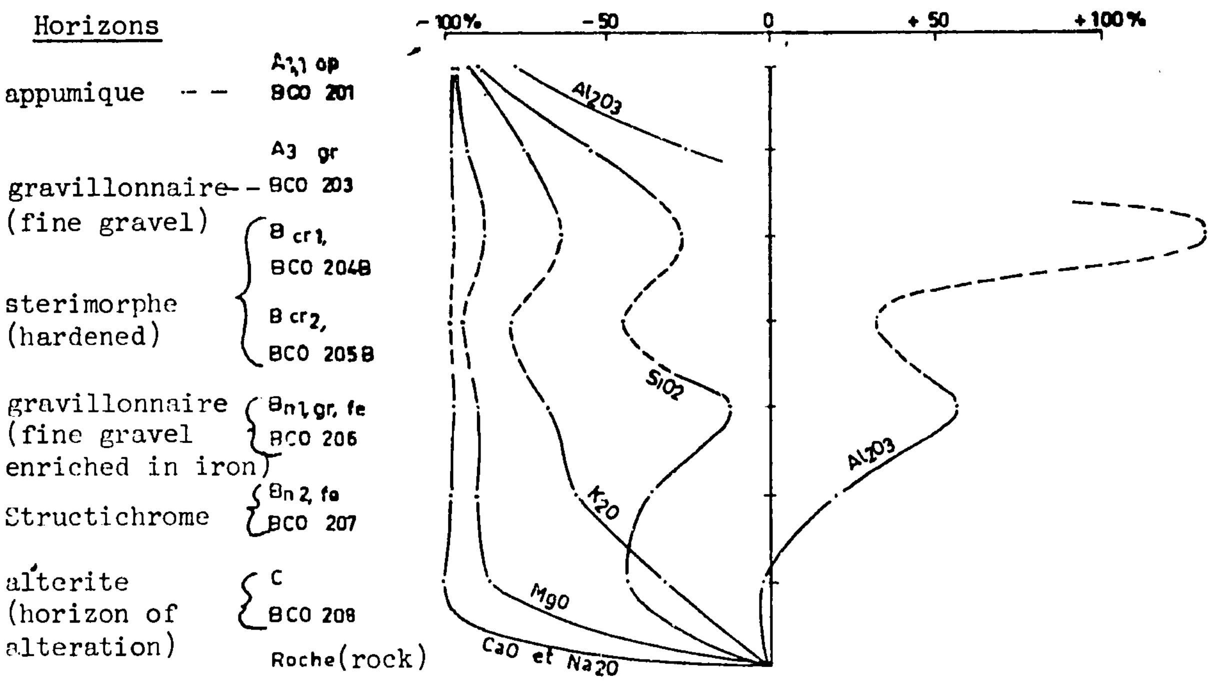
The CEC is generally low, perhaps due in part to the blockage of exchange sites on the silicate clays by iron oxides. The percent base saturation is in the 20 to 40 percent range for the B horizon putting this particular soil in the subclass of "moderately desaturated Ferrallitic soil."

Iron in excess of 12 percent in all horizons is sufficiently high to saturate all the silicate clays (D'Hoore, 1954). Iron is also important in the aggregation of silicate clays and quartz, for the formation of "pseudo sand and silt" particles. Iron is always more abundant in the sand and silt fraction than in the clay fraction. Analysis also showed that small gravel concretions in horizons A and B are much more rich percentage-wise in iron than the hardened horizons.

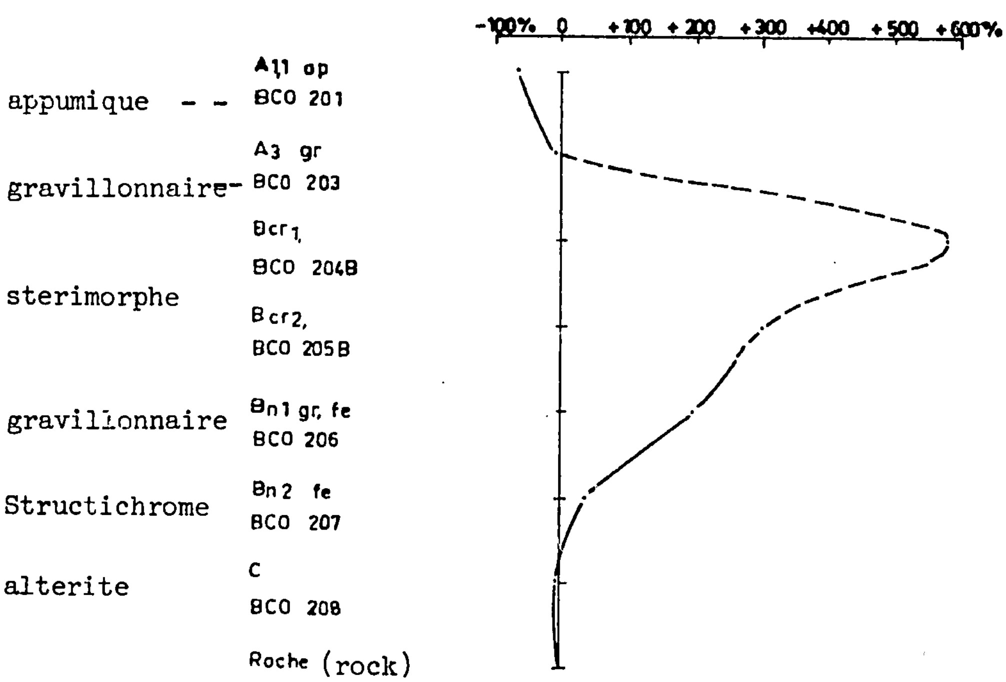
The following graph adapted from Chatelin (1969) represents in summary a picture of the genesis of these Ferrallitic soils by presenting the gains and losses of certain elements in comparison to the parent rock.

The values for the C horizon were calculated on the basis of the total composition including fine earth and coherent rock debris, for the fine earth fraction only for horizons B and A, and for crushed samples of the indurated horizon.

Curves of Gains and Losses of Silica Alumina and Bases
In a Ferrallitic Soil (Chatelin, 1969)



Gains and Losses of Iron (Chatelin, 1969)



- - - Dashed curves correspond to indurated elements.

These results show that leaching has removed nearly all of the bases except in the horizon of alteration where they have not decreased. Major compounds of silica, alumina, and iron weather, and the elements are lost or retained in disproportionate amounts, contrary to the case for Ferruginous Tropical soils. Up from the horizon of alteration (C), alumina is concentrated relative to silica, but their curves still show corresponding forms. This implies that the geochemical ratio, SiO_2/Al_2O_3, remains constant, with the exception of the accumulation of some alumina in the indurated horizon. Iron accumulates in great amounts, especially in the indurated horizon (sterimorphe), but is impoverished or translocated out of the surface horizon (Chatelin, 1969).

VII. Classification of Ferruginous Tropical Soils.

According to Aubert (1965) Ferruginous Tropical soils belong to the class of soils "rich in sesquioxides and metallic hydrates." The metallic hydrates include those of iron, manganese, titanium and often aluminum. These sesquioxides and hydrates are often concentrated in the presence of "well-evolved" humus under the conditions of a warm climate which is humid at least part of the year. Concentration is measured in terms of the ratio, free iron content/total iron content (Maignien, 1961). The accumulation of these sesquioxides and metallic hydrates produces a characteristic color of red or dark beige in the horizon of concentration of these materials. Ferruginous Tropical soils have no free alumina. The mineral colloids are composed mostly of kaolinite mixed with some illite and other metallic oxides. The proportion of silt to clay may be fairly high and the base saturation of the exchange complex is usually more than 40 percent. Free iron is concentrated and appears free and unattached with respect to the surfaces of colloidal minerals (Aubert, 1965).

Maignien (1965) describes the Ferruginous Tropical soils as having an ABC profile and a B horizon distinguished by its color, structure or texture. The limits between horizons are distinct and sharp. The surface horizon is usually a dark color, grey to greyish black, and becomes darker when moist. The colors of the lower horizons are clearer and in the yellow range. One major characteristic is the striking variation between the color of the dry soil and the wet soil. Ferruginous Tropical soils are usually 200 to 250 cm deep. The horizons of alteration, C, are not very thick (less than 100 cm), are weakly colored (light pale grey with streaks and diffuse spots of rust color). With depth one may find concretions or indurated horizons composed principally of iron oxides. The following are typical analytical characteristics: 1) a sandy surface texture, with a tendency toward clay movement. The clay accumulates in a lower horizon thus clogging further movement (this also orients the distribution of iron oxides), 2) a weakly developed surface soil structure, with a "nut-like" structure in the B horizon, 3) the organic content is low (1 to 2.5 percent) under natural vegetation with a C/N ratio of 14-17, 4) the surface pH is 6.0 to 6.5 varying slightly with dpeth, 5) base saturation is approximately 70 to 90 percent in the horizons of accumulation, 6) CEC is low due to the predominance of kaolinite in association with illite and sometimes a trace of montmorillonite, 7) the ratio of free iron to total iron is always greater than 50 to 60 percent. The subclasses of Ferruginous Tropical soils represent two groups:

A) Those showing little or no mobile iron oxides. These may be further divided into three subgroups: 1) Those where iron migration is only beginning, 2) those whose iron oxide has migrated and is now stable and 3) those whose "fersiallitization" (migration of iron oxides) processes are slight but identifiable.

B) The second subclass consists of Ferruginous Tropical soils having mobile iron and/or clay. This subclass includes the following subgroups: 1) Those without concretions, 2) those with ferro-manganese concretions, generally found in the median part of the profile or at the lower parts of the horizon of accumulation, 3) those with indurated horizons and concretions, usually found on poorly drained plateaus with moderate or slight slopes or having surface soils which have been eroded by cultivation, and 4) those influenced by water accumulation and having illuvial and deeper horizons that are enriched with spots or mottles often accompanied by concretions.

In Senegal (Maignien, 1965) one finds both subclasses of Ferruginous Tropical soils, those having little or no mobile iron oxides and those showing mobile iron. Those having no mobile iron oxides have neither a B horizon of clay accumulation nor an A_2 eluvial horizon. In Senegal one sees predominantly the second subgroup of the subclass of soils showing little or no mobile iron oxides. These are soils whose iron oxides have migrated and are now stable. The B horizon is differentiated by color and structure conditioned by an accumulation of iron eluviated previously from the surface horizons. In general these soils are very sandy, presenting a thin surface horizon (20 to 30 cm) weakly enriched in organic material (less than 0.4 to 0.5 percent) with a noticeable structure, a slight A_2 horizon lightly discolored, a B horizon 50 to 100 cm thick, red in color, and hard during the dry season.

Those in the subclass showing mobile iron also have a B horizon of clay illuviation. The four subgroups mentioned previously for these soils are all represented in Senegal. The criterion of intensity of accumulation of iron, which is the basis of division of these subgroups, is dependent on the temporary rising of the water level in the wet season due to the "clogging" effect of the clay horizon, thus impairing iron movement. Soils of the first subgroup, those without concretions, have a sandy texture and are considered transitional to soils with concretions. The illuviation of clay is quite noticeable and is linked to the horizon of accumulation of well-evolved organic matter. The second subgroup, those with ferro-manganese concretions, represents a stage of evolution more advanced than the previous subgroup. An accumulation of iron in the form of spots and hardened concretions is found just below the horizon of clay accumulation. There exists a clear relation between the intensity of concretion development and clay accumulation. Marks of temporary waterlogging are shown by the development of a greyish black humus horizon approximately 30 cm thick and a C/N ratio close to 14. The A_2 horizon, a yellowish orange color, is porous, showing the eluviation of clay.

The third subgroup of soils having mobile iron and/or clay, or those with concretions and an indurated horizon (sometimes showing in outcrops), represents the ultimate in translocation of iron. Again the clay horizon induces a clogging effect during the wet season, which produces concretions and finally induration. This hardening process is pronounced on the sides of hills where iron has accumulated by oblique or lateral migration. Generally, when the hardening is complete, surface erosion accelerates, proceeding with erosion of the more loose surface horizons first and, frequently, erosion of the horizon of clay accumulation later. This results in outcropping of indurated or concretionary horizons.

The fourth subgroup of Ferruginous Tropical soils having mobile iron and/or clay is influenced by water accumulation and the formation of concretions. It represents a transition to the "constantly wet soil" (hydromorphe), a separate soil class. This subgroup also has a distinct illuvial clay horizon. But one sees spots of a rusty color and sometimes also concretions at the top of the B horizon and sometimes at the base of the A_2. These soils are very wet in the rainy season (Maignien, 1965).

VIII. Examples of Ferruginous Tropical Soils.

The following is a description of a Ferruginous Tropical soil representative of northern Ivory Coast and the adjacent area of Upper Volta (Perraud, 1971). Unfortunately, examples described in terms of the Soil Taxonomy of the USDA were not found. A Sudanese type of savannah vegetation is found in this region. This particular soil has been classified as "disturbed" (remanié) by Perraud. This particular soil profile developed from ferrallitic material previously weathered from granite. The topography is rolling and the upper horizons were truncated by erosion. A covering, sandy or sandy clay in texture, was deposited over the deep ferrallitic horizons. The following is a description of a soil examined in this disturbed region.

Classification: "Disturbed Ferruginous Tropical Soil with Concretions"

Parent Material: Disturbed ferrallitic material originally weathered from granite.

Locality: Kongolo

Climate: Tropical with one rainy season 1,100 - 1,200 mm.

Site: From the upper slope of undulating topography

Profile Description (Perraud, 1971):

A_1, 0-15 cm.	Grey, sandy to coarse sands, crumbly structure interwoven with fine roots, porous, friable
A_3, 15-40 cm.	Beige, sandy clay, slightly developed polyhedric structure with weak cohesion, humid, friable, good rooting zone, (massive structure and hard when dry).
B, 40-70 cm.	Small ferruginous gravels and quartz pebbles, when dry concretions have a tendency to weld themselves together to begin formation of an indurated horizon.

B_2, 70-110 cm.	Dark yellowish-orange, sandy clay with coarse sands, numerous quartz grains and fine gravels, ferruginous and manganese concretions, finely developed polyhedric structure, firm.
B_2, 110-130 cm.	Yellow and orange streaks, sandy clay to clay numerous grains of quartz, fine polyhedric structure, friable.

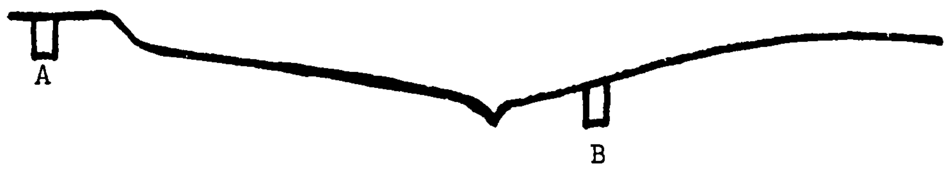
Analytical Data

	Depth			
	0-5 cm.	5-15 cm.	20-35 cm.	70-90 cm.
sand - %	86.7	86.6	81.8	60.3
silt - %	6.9	6.1	13.8	12.0
clay - %	6.0	7.1	4.1	27.6
OM - %	0.96	0.87	-	-
CEC - meq/100 g	3.66	3.36	3.28	4.72
base saturation - %	75	65	36	67

The CEC seems to be rather low considering the high amount of organic matter. Unfortunately, information on the analytical methods was not given, as was the case with most of the ORSTOM data reviewed by this author. However, Maignien (1969) cited an error of approximately 10 to 20 percent in the determination of CEC for most soils. Maignien (1961) also states that CEC was usually determined by ammonium acetate at pH 7.

A second description given by Chatelin (1969) is of a Ferruginous Tropical soil formed over gneiss in the Central African Republic (in the immediate region of Bassangoa). High topographical positions are occupied by Ferrallitic soils with Ferruginous Tropical soils or Vertisols on the lower slopes due to the effects of reduced drainage. The area is a bush savannah with a tropical climate of two seasons, wet and dry. The rainy season lasts seven to eight months, a dry season during the rest of the year.

The following sketch is a rough approximation of the topographic location of the Ferrallitic and Ferruginous Tropical soils (Chatelin, 1969).



A. Ferrallitic Profile

B. Ferruginous Profile

The color is considered an important criterion in the identification of Ferruginous Tropical soils, this profile showing the typical color succession: Grey, beige and ocre (yellowish orange) (Maignien, 1961). The comparatively shallow depth of the profile, 4.5 m, is another typical characteristic. Texturally one sees that horizons A_1 and A_3 are impoverished in clay with maximum amounts of clay-size particles occuring in the presently forming indurated horizon. There are no evidences of clay coatings or skins.

X-ray diffraction shows that all horizons consist of approximately 75 to 78 percent kaolinite with approximately 22 to 25 percent illite in the clay fraction, the illite content increasing with depth. Hematite and goethite exist only in traces.

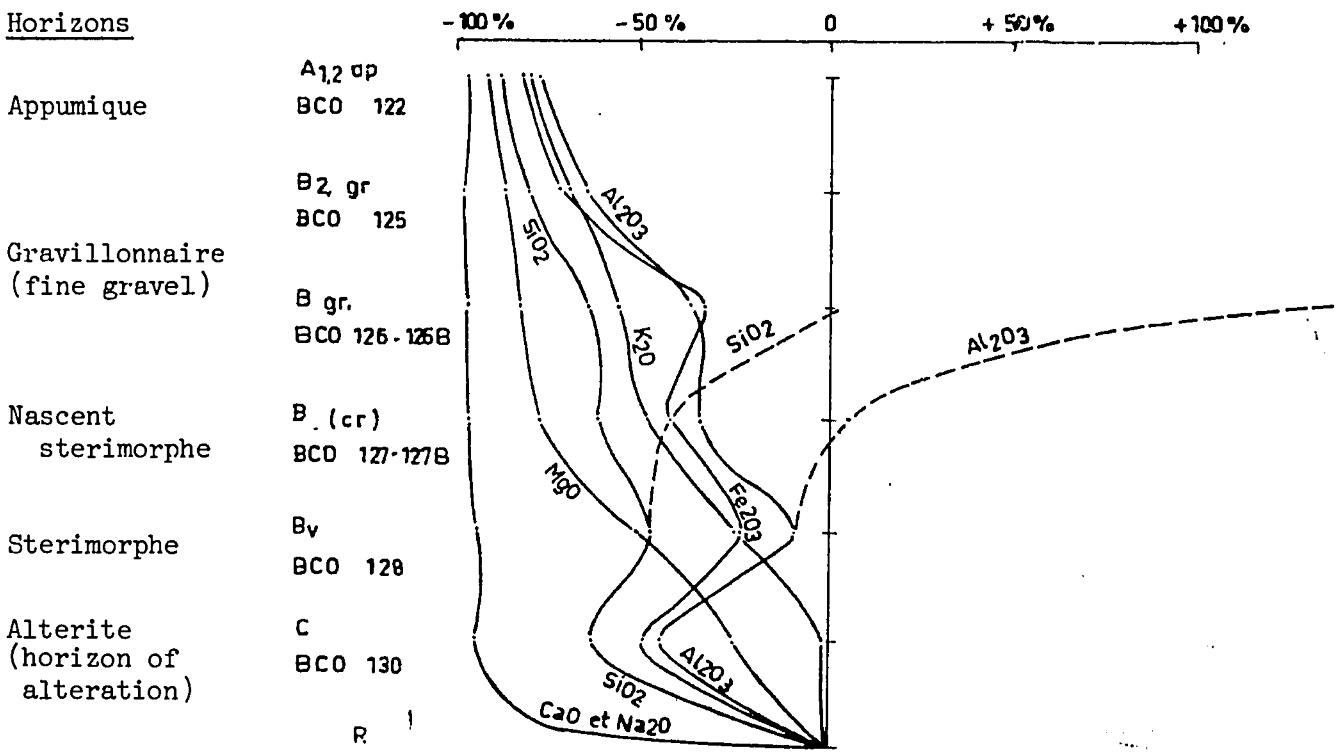
The CEC is highest in the nascent indurated horizon. Exchangeable bases, dominated by calcium, decrease with depth. Base saturation is approximately 60 to 70 percent for horizons containing humus and 30 to 40 percent for pure mineral horizons.

The quantity of iron in the clay fraction is generally much lower than in Ferrallitic soils. In this soil much of the iron is crystallized as goethite and little is fixed on the surfaces of silicate clay particles (unlike Ferrallitic soils). Iron also plays an important role in the aggregation of non-quartz coarse particles, especially in the upper horizons for which the ratio of iron to silicates is considerably higher in the silt and sand-size fractions than in the clay fraction.

The soil also has considerable quantities of alterable minerals, unlike Ferrallitic soils, especially in the silt and sand-size fractions which are rich in K, Mg, Ca and Na.

In summary, important geochemical processes for the genesis and classification of Ferruginous Tropical soils can be seen by an examination of the following graph. Here gains and losses of important elements in comparison to the composition of the parent rock can be seen. These figures have been calculated for the fine earth fraction and coherent debris fractions of the C horizon, and for the fine earth fraction and small gravel for horizons A and B (Chatelin, 1969).

Gains and Losses of Silica, Alumina, and Bases
for a Ferruginous Tropical Soil (Chatelin, 1969)



- - - Dashed curves correspond to indurated elements.

Major elements such as silica, alumina and iron are not dissociated as in the genesis of Ferrallitic soils. Beginning with the horizon of alteration, silicate materials have been subjected to losses, with alumina also falling below its original percentage as found in the parent rock. The same is true for iron; this is a fundamental difference in genesis between Ferruginous Tropical and Ferrallitic soils. Iron is partially leached from the bottom of the profile.

It is thought that the genesis of Ferruginous Tropical soils involves the synthesis of kaolinite and that gibbsite is not formed since it is used up in resilication. This occurs only on lower slopes or, in the case of soils in more arid regions, on vast flat landscapes where drainage is hindered during the rainy season, a situation characteristic of Ferruginous Tropical soils. Iron is trapped along with silica in such regions (Beaudou 1971).

IX. Correlation of Ferruginous Tropical and Ferrallitic Soils with the American System of Soil Taxonomy.*

Sys (1969) has compiled a list correlating French with American taxa. Most Ferruginous Tropical soils would be classified as Ustalfs if they had an argillic horizon, and those without such a horizon would probably be classified as Tropepts. Most Ferrallitic soils would fall into one of three soil orders: Inceptisol, Oxisol, and Ultisol, with the more common suborders being Tropept, Orthox, Ustox, Udox, Udult, Ustult, and Humox.

There are several problems in the correlation of these soils. One of the greater problems involves the general lack of quantitative limits in the French system. Strict limits, as one percent weatherable minerals for an oxic horizon or 35 percent base saturation of the exchange complex of argillic horizons in distinguishing Alfisols from Ultisols, do not exist in the French system. Criteria seem at times to be a bit arbitrary or poorly defined

*This section draws heavily on publications by Sys, who represents the Belgian school of soil science.

for soils in West Africa. The only criterion that may even resemble the American system is the SiO_2/Al_2O_3 ratio of 2, which separates Ferrallitic from Ferruginous Tropical soils. Even this limit is ignored if gross morphological features contradict the classification imposed by this limit (Maignien, 1961).

Americans have made the three divisions of ust-, ud- and orthox based on soil moisture regimes whereas the French have insisted that soil moisture in a broader ecological context can be best approximated by the determinations of CEC and the degree of base saturation, hence the reasoning behind the division of subclasses for Ferrallitic soils (Chatelin, 1967).

The central concept of Ferrallitic soils as being highly weathered to great depths has also occasioned French pedologists to study C material down to the lithologic contact.

The necessity of recognizing clay skins to demonstrate clay mobility has imposed great limitations in correlation. French pedologists hypothesize that clay movement is only important in intermediate stages of chemical weathering and is nonexistant or so slight as to be unimportant in highly weathered soils (Sys, 1969). The French also give greater importance to lateral or oblique movement of clays over hardened horizons which "impoverish" a surface horizon of clay without evidence of vertical accumulation below.

Study of highly weathered soils on a series of very ancient erosion surfaces in close proximity to younger ones has also prompted French pedologists to look more closely at mechanical influences that changed residual soil development. Downslope slipping of soil materials to form stone-lines and partially bury a previously weathered profile has been one factor leading to the formulation "disturbed, penevolved" (remanié, penevolué) in the classification of Ferrallitic soils. Other mechanical effects such as truncature by erosion, burying under colluvium or aeolian deposits or mixing by termites are all given special status in the French system.

At present one of the most striking inconsistencies in the application of "Soil Taxonomy" to the soils of West Africa has been the classification of most soils of the region as Alfisols on the basis of the 35 percent base saturation in the argillic horizon even though most of these soils have a very low CEC. Sys (1967) has concluded that these soils would better be classified as Ultisols since the more weathered concept fits them better.

X. Genesis of Ferruginous Tropical and Ferrallitic Soils.

A. Ferruginous Tropical Soils.

According to Sys (1967), Ferruginous Tropical soils are natural soil individuals in a dry tropical climate with less than 1,000 - 1,200 mm of annual rainfall. However, in this region the most important factor seems to be the age of the erosion surface. Ferruginous soils with greater than 40 percent base saturation develop on recent erosion surfaces. The possible effect of changes in past climates, especially during Pleistocene, has not been adequately defined in this case.

An examination of several Ferruginous Tropical soils in Senegal by Maignien (1961) has pinpointed certain important aspects of Ferruginous Tropical soil genesis. It seems that parent material is not a determining factor. In Senegal the predominant parent materials for both Ferruginous Tropical and Ferrallitic soils were Continental Terminal deposits. These deposits are sandy clay materials reworked from a clay sandstone of the Mio-Pliocene period. Apparently this material had already passed through a process of Ferrallitization and was already highly weathered before the formation of the new soils began.

Unique drainage conditions are important determinants of Ferruginous Tropical soil development. Not only is drainage limited in the depressions of the Senegalese landscape but also much of the external drainage of the dominant subhorizontal low plateaus is slow. As a result soils are waterlogged for a long time after torrential rainfalls, which are concentrated in 40 to 50 days. In many of these soils translocation of clay and iron produces a deep horizon of clay accumulation. As a result of this horizon, waterlogging is increased even more and translocation of clay and iron is virtually stopped, at least vertically. This creates a situation of oblique or lateral translocation of these materials (clay and iron), which is accentuated on the lower slopes of these large plateaus forming concretions above the clay horizon. Buringh (1970) states that when the soil dries hematite is formed. Indurated horizons form where ferruginous zones of accumulation are exposed on slopes. Also surfaces tend to be glazed and are easily crusted due to the poor drainage conditions.

The vegetation usually found in Ferruginous regions includes savannahs of herbaceous vegetation and other sorts of stemmy growth, shrubs, small trees, etc. As a result, the surface horizons of virgin soils have significant accumulations of organic matter (perhaps also attributable to the waterlogging phenomena). Soil structure is "nut-like" or even massive, perhaps determined in part by the rooting patterns of the natural vegetation.

Centuries-old management practices of burning savannah vegetation and other exploitive measures have undoubtedly left their mark on the morphologic characteristics of these soils. Maignien (1965) has suggested that excessive exploitation has reduced organic matter levels and, in part, caused the formation of sandy surface horizons. He also stated (1961) that the inhibition of the return of the natural climax vegetation has stopped the natural process of bases being brought up from less weathered depths, thus causing the soil to become more acid.

B. Ferrallitic Soils.

Sys (1967) defines Ferrallitic soils as natural climatic soil individuals in the humid tropics where annual rainfall is more than 1,000 - 1,200 mm. Buringh (1970) emphasizes the diverse nature of Ferrallitic parent materials and the fact that such soils can develop from any parent material given the right length of time and suitable climatic and geomorphologic conditions. The most important influence of the parent material is its effect on the sesquioxide content, basic rock producing high concentrations of iron oxides in the form of concretions while acidic rocks or materials produce more kaolinite.

Maignien (1971) points out that Ferrallitic soils usually evolve on plateau summits of old erosion surfaces. In Senegal, however, an intermediate situation was found, as the area is transitory to a drier climate. Here Ferrallitic soils are located in areas of accentuated hilly relief, where drainage is better, allowing the limited rainfall to percolate efficiently through the profiles. Lack of waterlogging and the related clogging and warping effects characteristic of Ferruginous Tropical soils are considered necessary for the formation of Ferrallitic soils. The good drainage of Ferrallitic soils is furthered by the pseudosands cemented by iron and the generally well-developed structure of these soils. Forest vegetation characterized by its extensive mat of roots and interlacing canopy is perhaps important in the formation of this structure. Under normal ferrallitic drainage conditions, iron mobility is greatly reduced from the ferruginous situation, since there is a tendency for the more or less even distribution of iron over the surface of kaolinitic minerals. Support for this hypothesis was given by Follett (1965). Maignien (1961) suggests that variations in texture between the surface and lower horizons (impoverishment) are the result of disturbance and related erosional processes which plane down the surface and sweep away the fine materials. Buringh (1970) refers to similar processes being responsible for the formation of stone-lines buried beneath finer materials. Impoverishment in surface horizons could also be attributed to the loss of silica when savannah vegetation is burned and residues are transported out of the area by wind and water erosion (D'Hoore, 1954).

Human factors which convert forests to savannahs by annual burning result in the degradation of clay horizons of accumulation and the loss of bases and organic matter (Maignien, 1971).

C. Termite Activity and Ferruginous Tropical and Ferrallitic Soils.

Nye (1954) cited termite and earthworm activity as being responsible for the transport of fine earth to the surface horizons leaving a layer of coarse gravels and pebbles below. Lee and Wood (1971) point out that termites can alter the physical and chemical properties of tropical soils in significant ways. Instances of the formation or decomposition of laterite in abandoned channels have been seen. In some places, these channels become filled with fine materials originating at the surface. Cemented surface horizons are found in some areas of high termite activity. The microrelief imposed by termite construction influences pedogenetic processes. Even formation of small amounts of montmorillonite has been attributed to the concentration of bases in termite landscapes. Termites in some instances play a useful role in the regeneration of areas burned by man. Organic matter and its nutrients are concentrated from the surrounding areas thus allowing resumption of forest growth.

D. Speculative Genetic Effects.

One cannot help wondering, when examining the data on a number of West African soils, why some highly weathered Ferrallitic soils have such a high base saturation and an extremely low CEC. There are several instances of 3 to 4 meq of CEC and 60 to 70 percent base saturation. These soils are usually found in regions of prolonged dry season, but to be so highly weathered, the past climate must have been more humid. The bases necessary to resaturate the complexes might have originated from the dust (Harmattan Haze) which blows down from the desert every dry season (Cline, personal communication). Or perhaps it could be due to base recycling by plants. Much further research needs to be done on Ferruginous Tropical and Ferrallitic soils before this and other questions can be answered.

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