A STUDY OF A CATENA IN THE TAI FOREST, IVORY COAST

Master of Science Thesis
Agricultural University Wageningen
Department of Soil Science and Geology
The Netherlands

DICO FRATERS
NOVEMBER 1986
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CONTENTS

I INTRODUCTION

In this M.Sc. thesis attention will be paid to the soil catena. The catena is a particularly valuable mapping unit in the reconnaissance soil surveys (WATSON, 1965). GREENE (1945; 1947) stresses the value of the catena in the study of soil formation. YOUNG (1976) emphasises that the usefulness of the concept is not confined to reconnaissance work, but has its value in detailed soil surveys too.

The catena has been differently defined by various authors. Some different point of view will be shown below.

As an example a catena in the southwestern region of Ivory Coast will be given. In the description of the area attention will be paid to climate, geology, geomorphology, soils, vegetation and fauna. Some remarks will be made on human activity.

Thereupon the different aspects of the soils of the catena will be discussed.

The catena studied in this thesis is situated in the northwestern part of the National Park near Taï, in the area which was studied and surveyed by FRITSCH (1980). In addition to this study, use was made of material collected by VAN KEKEM for the International Soil Reference and Information Centre (ISRIC). He made five monoliths, sampled the different layers of the five profiles and made field descriptions of them (VAN KEKEM, not published). The samples were analysed at the ISRIC laboratory.

This thesis is meant to give the basis information for the preparation of a poster at ISRIC.

II THE CATENA CONCEPT

The oldest, still quoted definition of a soil catena is the one formulated by MILNE in 1935 (1935a, 1935b) as a solution for the problems he envisaged by smaller scale mapping in e.g. undeveloped countries: a regular repetition of a certain sequence of soil profiles in association with a certain topography.

BUSHNELL (1942) stresses the importance of the drainage conditions as the cause of different soil development within the catena. In the same paper he published a letter of MILNE, who at that time (1938) defined the catena as a topographic-denudational-hydrologic sequence in which parent material (here is meant parent rock, see discussion below) is identical throughout. In this concept all the important differentiation factors are mentioned. YOUNG (1976) agrees with him when he argues that the soil catena is primarily a function of relief, together with the indirect effects of relief upon hydrology. The essential feature which gives the genetic unity to a catena is that water and soil material can move laterally downslope. But YOUNG wants slopes developed on two or more rock types to be included.

DUCHAUFOUR (1983) defines a catena as a scalariform disposition of genetically associated soils formed by the movement of water, which acts along the slope - even when it is very weak and little conspicious - and which affects the pedogenesis differently at different sites. This concept is very much like YOUNG´s. DUCHAUFOUR includes different rock types within the catena. A "chaîne de sols" for him is equal with catena, toposequence and topolithosequence in the case of more than one parent rock.

This latter point, whether or not to include different rock types, is one of the most controversial in the catena concept discussion. In literature confusion is sometimes raised when the term parent material is used, because some authors - e.g. BUSHNELL - use this, incorrectly for rock type.

Although MILNE and YOUNG have, apparently, completely different points of view, the differences are rather small if one gives their concepts a closer look. YOUNG (1976) finds that where required, a distinction may be made between simple catenas and compound catenas, the latter consisting of slopes formed in two or more rock types. MILNE (quoted by BUSHNELL 1942) argues that it would be better not to employ the word catena unmodified for sequences on more than one rock type. BUSHNELL (1942) elaborates on this and suggests to differentiate between the simple catenas, which are made up of soil series homologous in all features except those due to drainage*1 variations, and multiple catenas, which are groupings of catenas homologous in all features except those due to some one formation factor*1 of which there is a gradation of characteristics. For catenas where there is a change in parent material (= rock type) along the slope, he suggested the name Byndel. Other names suggested are Collig (time), Flor-catena (vegetation) and Climo-catena (climate).

In the U.S.A. (Soil Survey Staff, 1962; Watson, 1965) a catena is restricted to similar parent materials (the word similar is used because catena is a mapping unit here, and between equal map units slight differences may occur). According to WINTERS (1947) this means that soils on colluvial deposits have to be placed in a catena seperate from that of soils on the upland. So one rock type could, due to catenary processes led to two parent materials and according to WINTERS, two catenas should be distingiushed in that case. This violates the catena concept as proposed by

*1 BUSHNELL regards drainage as one of the soil forming factors and not relief. The other 4 factors are: time, (parent)material, vegetation and climate.

MILNE and would make the catena concept less useful as a.o. mapping unit. BUSHNELL (1942) included colluvial deposits in the catena. Similarly BUNTING (quoted by WATSON, 1965) considered it incorrect to apply the term catena where soil differences result from pedogenesis 'in situ' over various parent rocks, but he regarded different kinds of parent materials formed by denudation processes as a part of the catena concept. GRIFFITH (1952) opposed to the restriction of the term catena to a sequence of soils on similar parent material and stated if it were adhered to, there would be no catenas in Uganda. In his opinion parent material should not be allowed to enter into discussion, nor parent rock.

DUCHAUFOUR (1983) comes up with an other view on the catena concept. He states that there is a great variety of catenas consequent on the nature and the variety of the processes that are active due to the topography. The processes can de classified according to decreasing intensity as follows: (1) erosion, (2) lateral and oblique eluviation of clays, (3) transport in (pseudo)solution and (4) local modification by the hydrological regime and oxidation-reduction potential. He suggests to distinguish 3 catenary types in which the processes of mecanical movement (1 and 2) give way progressively to processes associated with hydromorphy. The names he gave are:

(1) chaîne de sols faisant intervenir l'érosion,
(2) chaîne de sols faisant intervenir les transport de matière en solution ou suspension fine, and
(3) chaiñe de sols à variations de Eh en milieu hydromorphe.

The example discussed in this thesis is a simple catena as defined by BUSHNELL and YOUNG, and belongs to the " chaînede sols faisant intervenir les transport de matière en solution ou suspension fine" of DUCHAUFOUR's classification as will be shown in paragraph III.2.

III AN EXAMPLE; TAI FOREST, IVORY COAST

The catena studied in this thesis is situated in the Taï Biosphere Reserve, see figure III.1a and 1b, in the south-west of Ivory Coast. This national park has a surface area of about 3500 km^2, and is the last remaining portion in Ivory Coast of the once vast primairy forest of West Africa.

III.1 The Physical Environment

In the next paragraphs the following subjects will be elaborated upon: climate, geology, geomorphology, soils, vegetation, fauna and human activity.

III.1.1 Climate

The climate is of a tropical rainy type; Aw in Köppen's classification (Tropical climates, allmonthly mean temp. over 18°C, dry season in winter), with two rainy seasons. Four seasons are distinguished, but there is no agreement on how to define these (DRC-report 1967, FRITSCH 1980, COLLINET et al. 1984). In this paper the differentiation by FRITSCH (1980), that was devised for the Taï biosphere Reserve, will be followed:

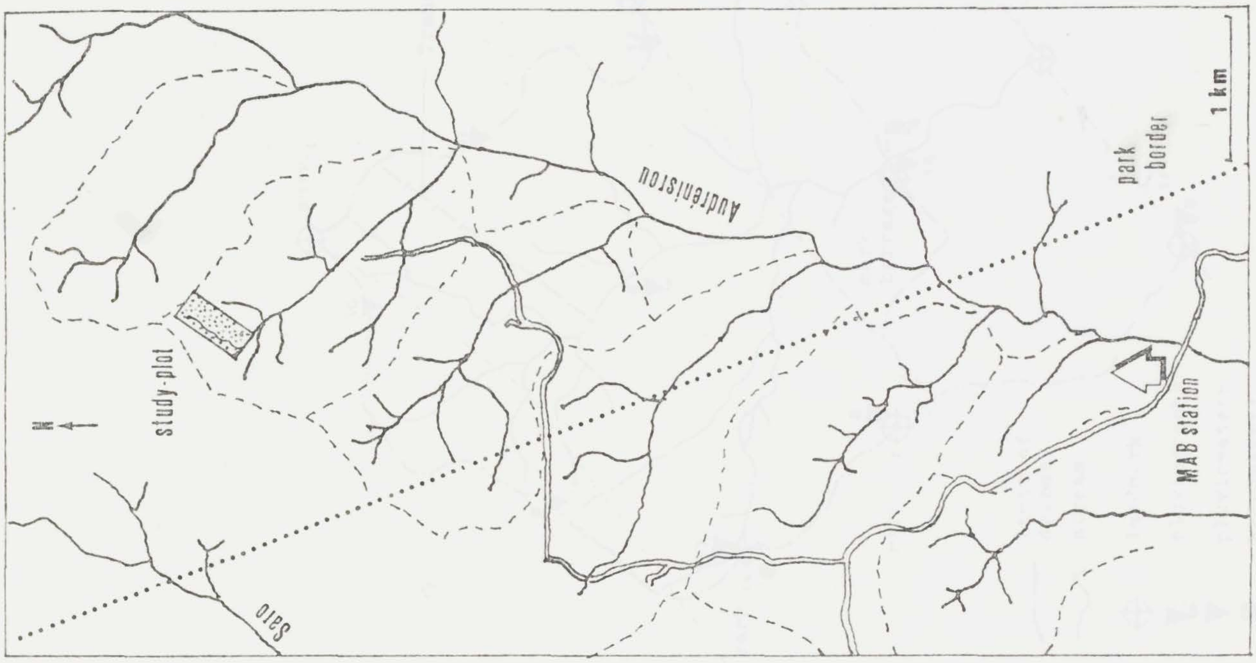
- long rainy season from March to July, which accounts for almost 45 % of the rain;
- a short dry season from July to September;
- a short rainy season from September to November, which accounts for almost 30 % of the rain;
- a long dry season from November to March.

The data are given in table III.1.

The mean annual precipitation for Taï is according to CASENAVE et al. (1980) 1833 mm with a standard deviation of 338 mm. Although the Taï weather station has recordings since 1924, only those for the periods 1944-1959 and 1966-1979 are considered reliable. The DRC (1967) reports an annual precipitation of 1948 mm for Taï using the data of

Figure III.1a and 1b.
Below: 1b. South-West Ivory Coast, the map shows the the location of the MAB research station.
Above: 1a. A detailed view of the MAB site. The catena studied, is situated in the study-plot indicated. (After VOOREN 1985)

III.1a



III.1b

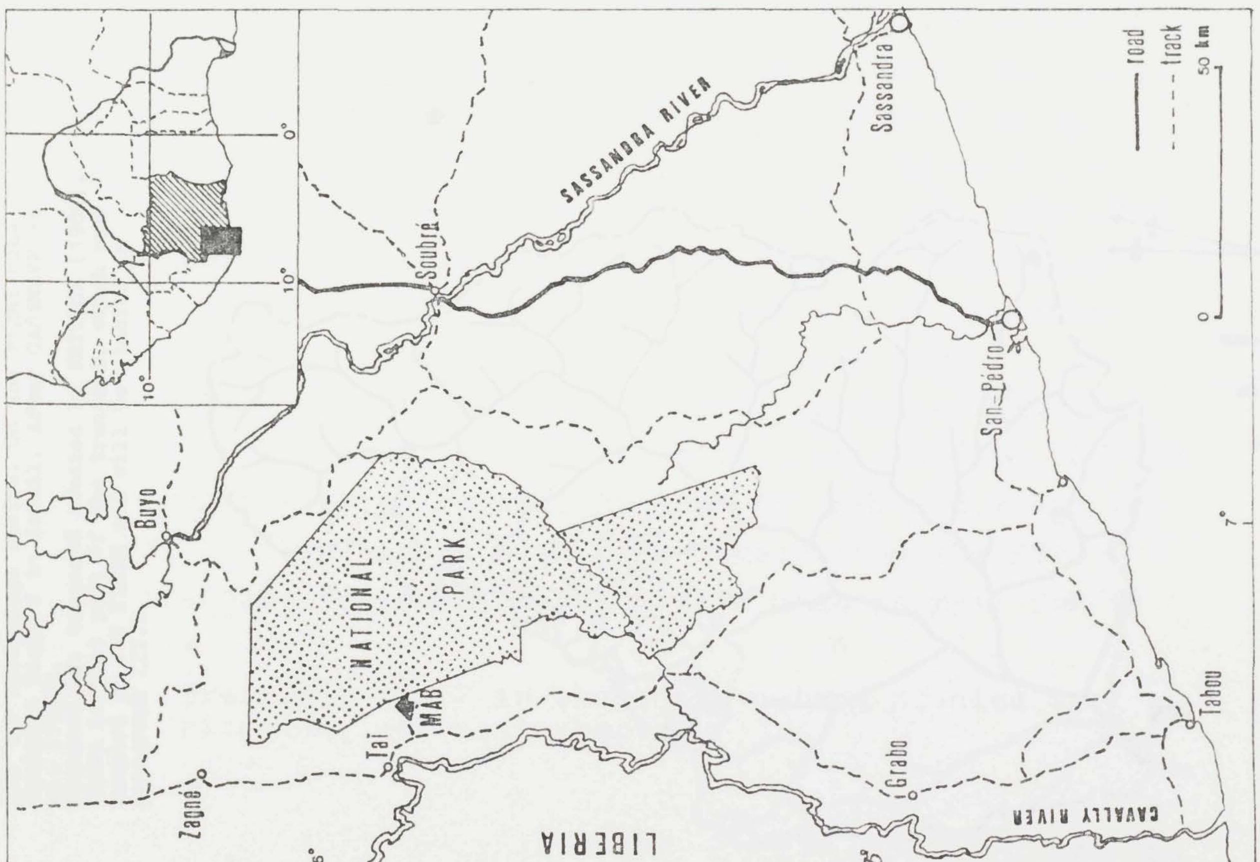
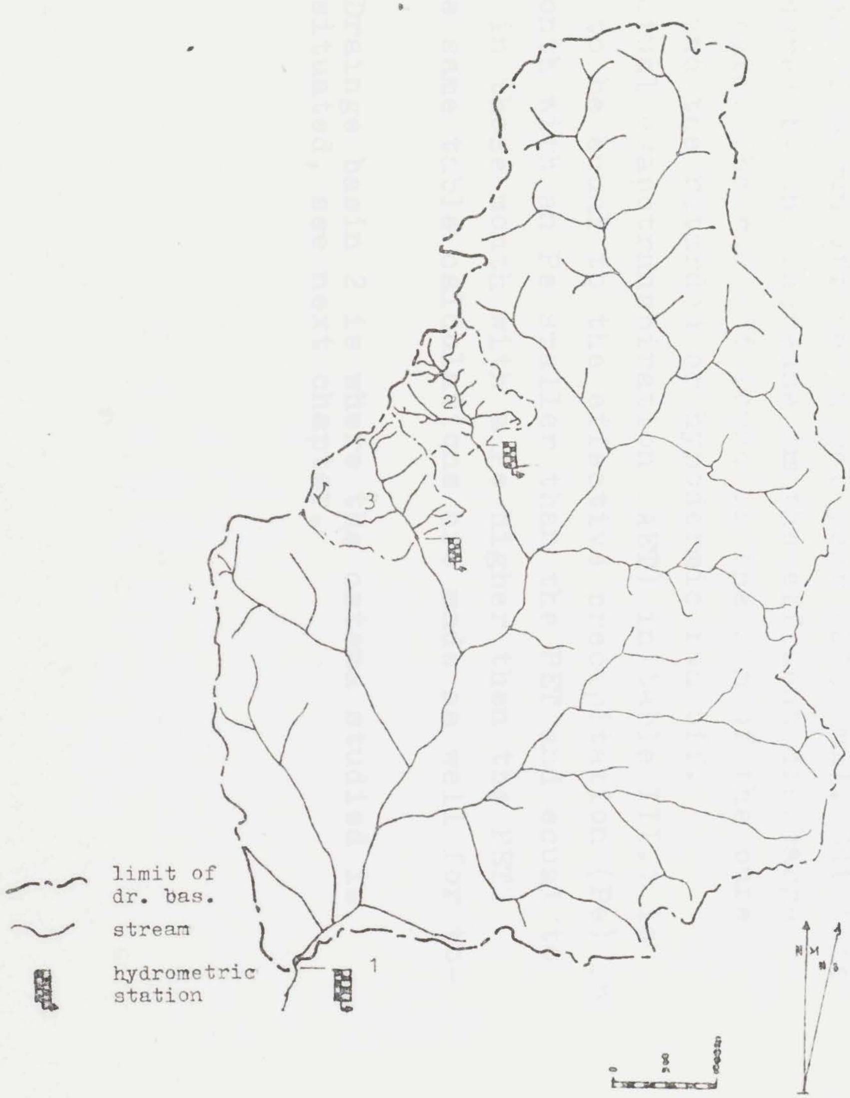
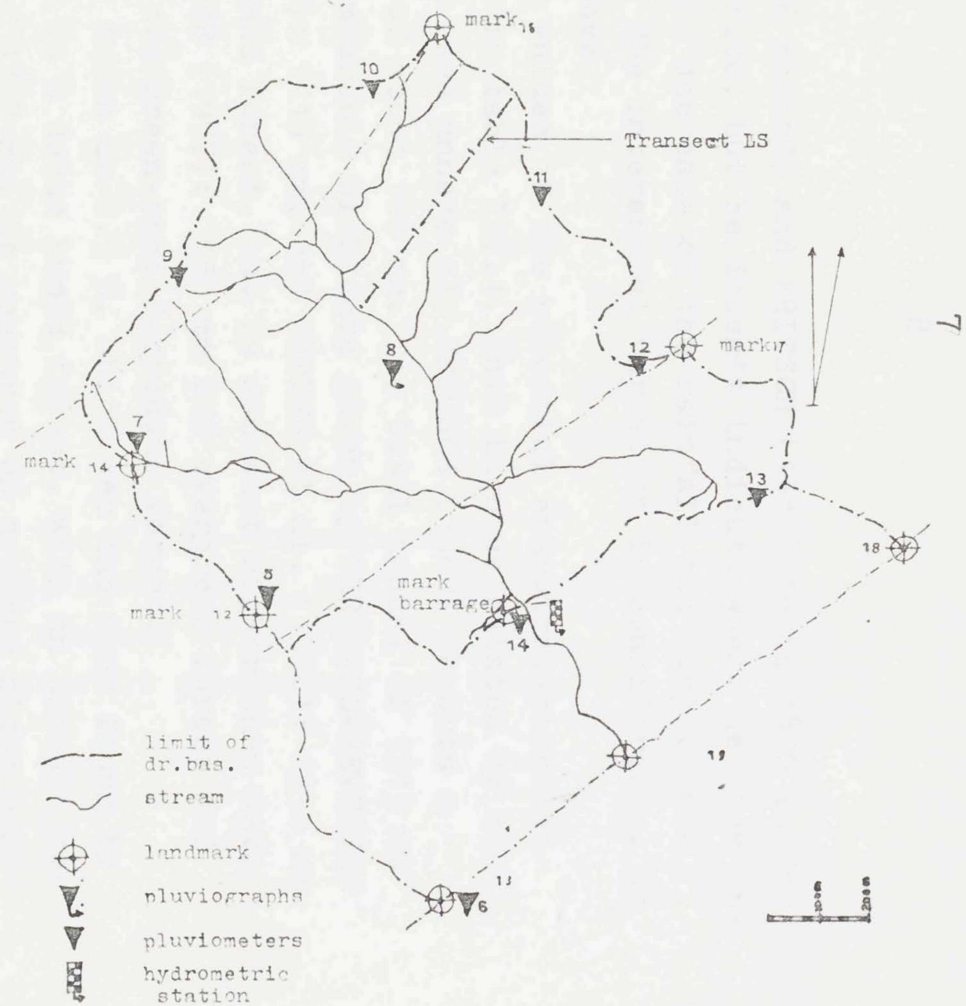


Figure III.2 Upper drainage basin of the Audrénisrou with the two subdrainge basins. On the right subdrainage basin 2 in detail. After CASENAVE et al. (1980).
Transect LS: transect studied by FRITSCH (1980), shown is that part of the transect, which was sampled by VAN KEKEM and will be studied in paragraph III.2.





the 1956-1966 period, and FRITSCH (1980) found 1800 mm for a 20 year period, but he doesn't indicate when. He does observe a slight decrease of the rainfall the last decade (1969-1978). The interannual variation is considerable, as was shown above.

The montly values of the potential evapotranspiration (PET), shown in table III.1, have been calculated by the TURC formula (see annexe c). FRITSCH (1980) reports a monthly PET of about 100 mm. The total annual of 1313 mm (TURC) is comparable with data given by BERNHARD-REVERSAT et al. (1978): 1219 mm, and HUTTEL et al. (1978): 1314 mm for dense humid forest, but is somewhat higher then data given by ROOSE (1977): 1150 mm for evergreen forest and 1168 mm for evergreen-semi deciduous forest.

Run off is taken as 2.3 %, which was the mean found by ROOSE (1977) in a dense humid forest, with an annual precipitation of 1767 mm. He measured on a upper slope position (comparable with those of profile 1 and 2, described in the next chapter) with a decline of 14 %, in a pit. For dry years (1468 mm) he found 1.3 % run off and for a wet year (2052 mm) he found 5.3 % run off. CASENAVE et al. (1980) reports for drainage basin 2* (see figure III.2) more than 10 % run off for a wet year (2135 mm). But this was measured by the increase in the effluent discharge after a rain. The run off found is the sum of the pure run off and the retarded or hypodermic run off.

The actual evapotranspiration (AET) in table III.1 is assumed to be equal to the effective precipitation (Pe) in those month with an Pe smaller than the PET and equal to the PET in those month with a Pe higher then the PET.

In the same table calculations are made as well for to-

* Drainge basin 2 is where the catena studied is situated, see next chapter.

Table III.1 Climatic data for Taï Station (1944-1954; 1966-1979)
(CASENAVE et al.,1980; VAN KEKEM, not published)

	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total/Mean
T av (°C)	26.1	27.1	27.3	27.4	26.8	25.7	24.7	25.3	25.9	26.5	26.2	25.3	26.2
T min (°C)	20.2	21.4	21.5	21.8	22.0	21.6	20.8	20.9	21.4	21.8	21.1	20.3	21.2
T max (°C)	31.9	32.8	33.0	32.9	31.6	29.7	28.5	29.6	30.3	31.1	31.2	30.3	31.1
P (mm)	21	65	148	170	216	269	124	132	293	240	108	47	1833
PET (mm)	120	125	136	132	113	91	81	84	105	111	111	104	1313
AET (mm)	21	65	136	132	113	91	81	84	105	111	105	47	1091 + 200
Run off (mm)	0	0	3	4	5	7	4	3	9	6	3	0	44
Deficit (mm)	99	60	0	0	0	0	0	0	0	0	6	57	222 - 200
Recharge (mm)	0	0	9	34	98	59	0	0	0	0	0	0	200
Drainage (mm)	0	0	0	0	0	112	39	45	179	123	0	0	498

T av= average daily temperature; T min= av minimum T ; T max= av maximum T;
P= precipitation; PET= potential evapotranspiration; AET= actual evapotranspiration;
Recharge= recharge of soil water reserve, which is assumed to be 200 mm.
For futher explanations and calculations of the different parameters see text.

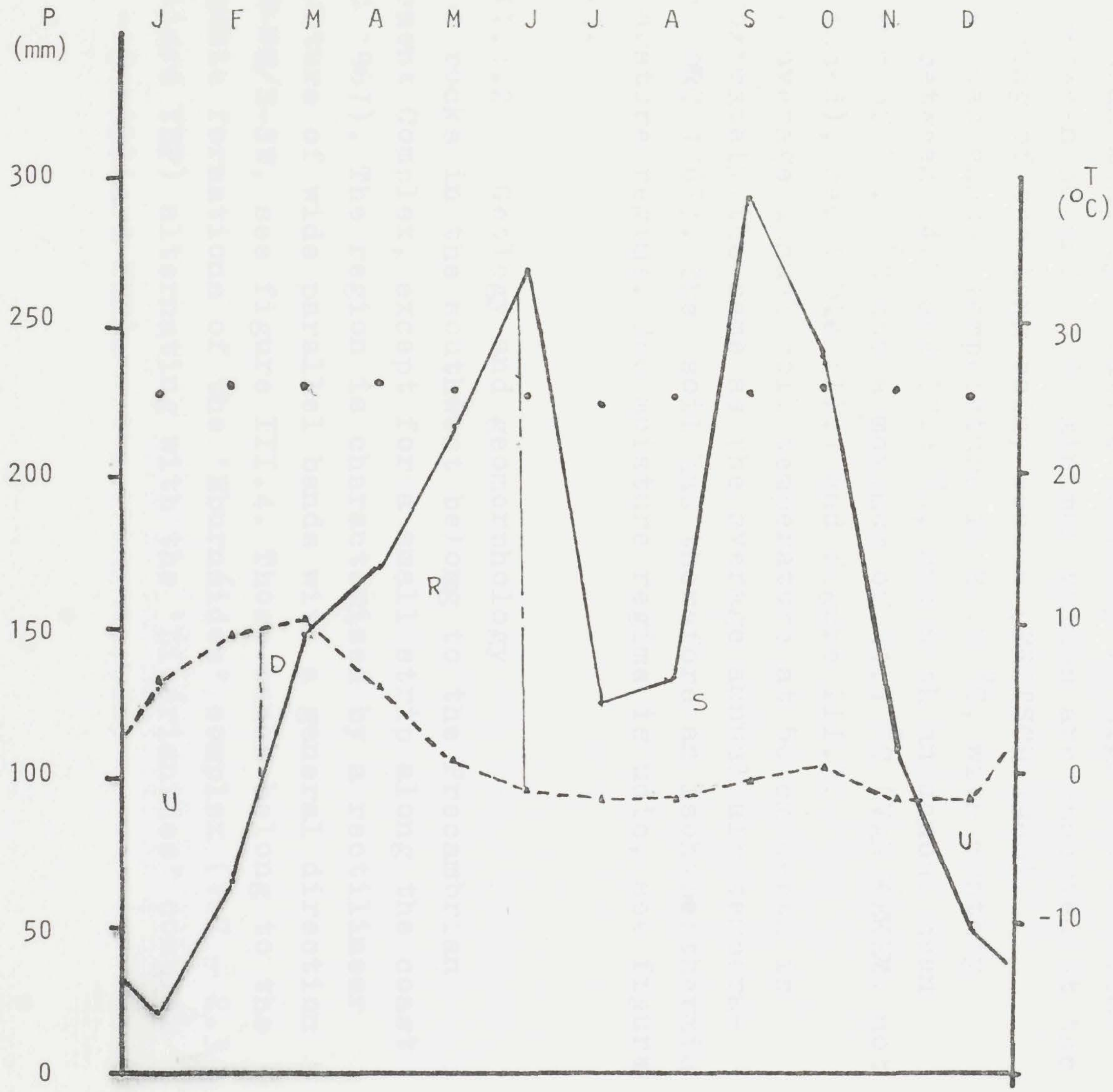


Figure III.3

Climatic data and soil water balance

tal deficite as for drainage. To be able to calculate the latter an estimation is needed of the soil water reserve. For similar soils under dense humid forest ROOSE (1977) reports 200 mm, which is good enough for this purpose. The drainage equals than the Pe - AET - Rsw, in which Rsw is the amount used to recharge the soil water reserve to its maximum of 200 mm. The annual drainage found is 498 mm comparable with data reported by ROOSE (1977): 427 mm (P= 1767) and BERNHARD-REVERSAT et al. (1978): 525 mm (P= 1950).

The deficit is calculated by substracting the AET from the PET, this gives 222 mm/year, occurring in the long dry season. FRITSCH (1980) found a total hydrological deficit of 247 mm, varying from 8 to 107 mm/month in the period November - February, see figure III.2.

The mean monthly relative humidity is high and oscillates between 50 and 70 %, minimum values are observed at the beginning of the long rainy season (FRITSCH 1980).

The mean annual temperature is 26.2 °C, with monthly means between 24.7 and 27.4 °C, and with an annual mean minimum of 21.2 °C and a maximum of 31.1 °C (VAN KEKEM, not published), see table III.1 and figure III.3.

The average annual soil temperature at 50 cm depth is approximately the same as the average annual air temperature (DRC 1967). The soil has therefore an isohyperthermic temperature regime. The moisture regime is udic, see figure III.3.

III.1.2 Geology and geomorphology

The rocks in the southwest belong to the Precambrian Basement Complex, except for a small strip along the coast (DRC 1967). The region is characterized by a rectilinear structure of wide parallel bands with a general direction of N-NE/S-SW, see figure III.4. Those bands belong to the orogenic formations of the 'Eburnéides' complex (1.7 - 2.3 milliard YBP) alternating with the 'Libérianides' complex 2.3 - 3 milliard YBP).

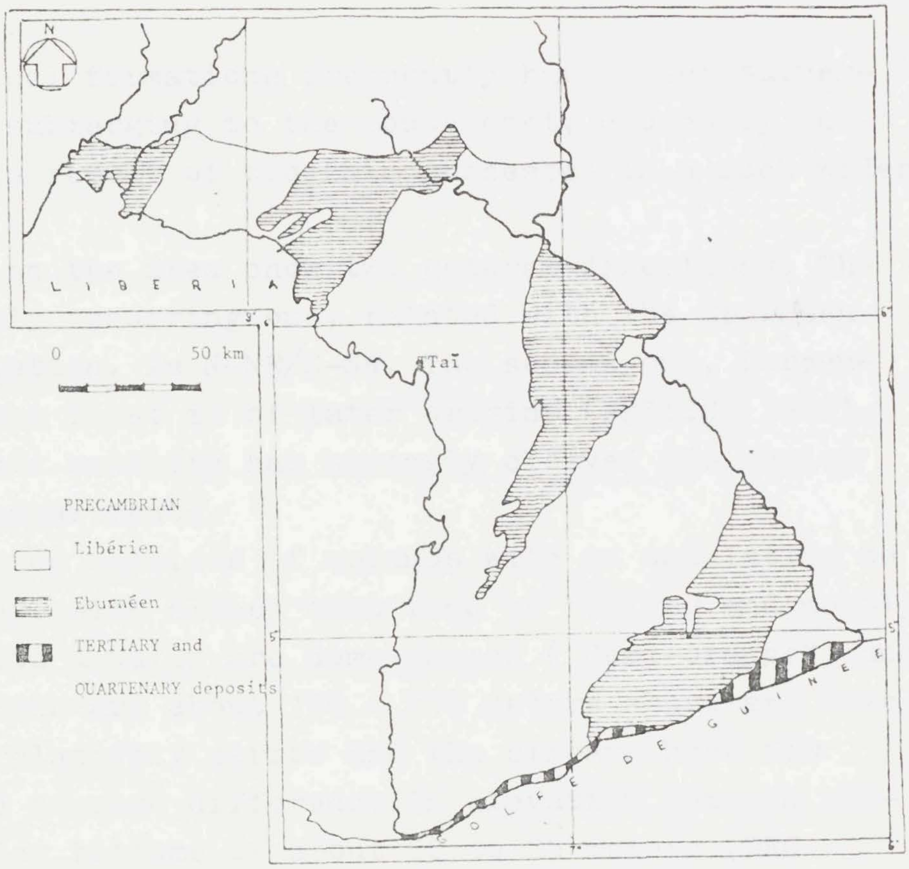


Figure III.4 Simplified Geological Map of the South-west region of Ivory Coast.
Alternating bands belonging to the orogenic formations of the 'Eburnéides' (Eburnéen) complex (1.7 - 2.3 milliard YBP) and the 'Libérianides' (Libérien) complex (2.3 - 3 milliard YBP).
Based on the DRC report, 1967.

The Geological map of Papon of 1/500,000 scale (FRITSCH 1980) places the Taï region largely in the Libérien complex. The principal rock type being migmatite*1 rich in biotite*2 with some post-tectonic granite discordant in the folded formations of the region.

*1 This is a mixed rock exhibiting crystalline textures in which a truly metamorphic component is streaked and mixed with obviously once molten material of a more or less granitic character (PARKER 1984)

*2 see next page

The geological formations frequently have clear subvertical slopes submerging to the south-east, caused by fault tectonics as a result of orogenic processes in a much wider area.

The faults in the area show two general directions. The most frequently occurring one, related with the Eburnéen mountain formation, is N-NE/S-SW. The second one, perpendiculair to the first is of later origine (FRITSCH 1980). So the tectonic activity has strongly cleaved the region in several compartments.

The Taï region consists of uplands with an undulating to rolling relief, with slopes that tend to be long and mostly convex. Summits usually are dome-shaped ("demi-orange") and their elevations are about 150 - 200 meters above sea level. Valleys are relatively narrow and the streams have few meanders. The average difference in elevation between summits and valley bottoms is about 20 to 25 meters (DRC 1967)

The uplands probably originated from an extensive peneplain, which was covered by an ironstone crust and which has been severely eroded: nowadays some remnants are still visible as well as their erosion products, ironstone gravel (DRC, 1967; FRITSCH, 1980), see figure III.5. AHN (1974) states that the lower peneplain associated with ironstone crusts is younger then the higher peneplain, thought to be of early- to mid- Tertiairy age, on which there is a layer of bauxite.

COLLINET et al. (1984) state that the ironstone crusts are relicts from climatological dryer periods (last dryer period 30,000 YBP).

On higher relief positions, these ironstone crusts are displayed at two distinct levels. The upper, oldest, most

*2 (see previous page) A dark glittering mineral belonging to the mica's, rich in iron; $K(Mg,Fe,Al,Ti)_3Si_3AlO_{10}$-$(OH,F)_2$ (PANNEKOEK et al. 1984)

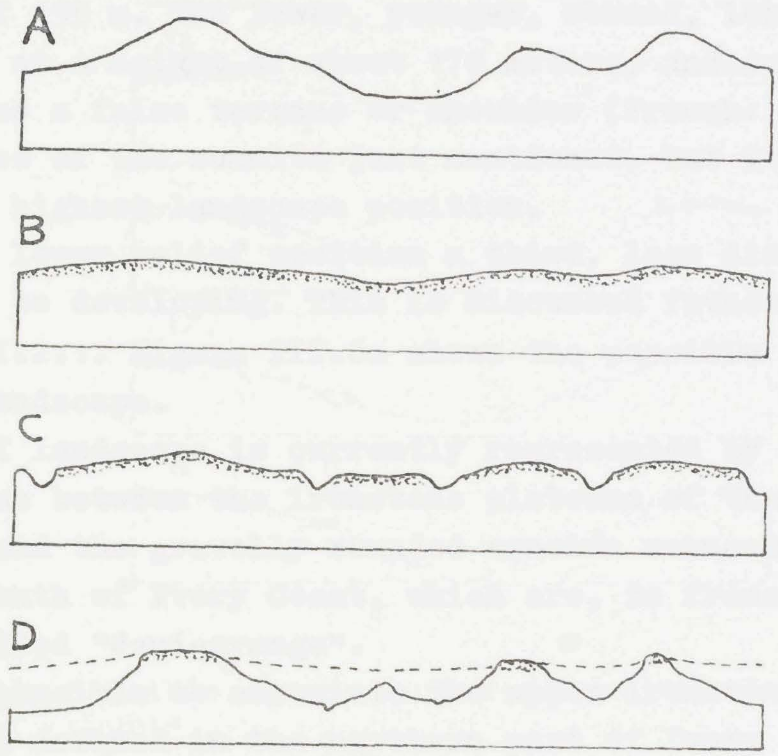


Figure III.5 Stages in the dissection of the landscape.

In diagram A a hilly landscape is undergoing erosion which, if sufficiently prolonged, will reduce it to a near flat, peneplain stage as shown in B. Old and highly weathered soils (shaded), often rich in iron, mantle the peneplain. In the third diagram C the rivers on the peneplain have been rejuvenated, usually by a rise in the land relative to sea level, and new valleys are rapidly being cut into the old landscape.

Diagram D shows a later stage at which the original peneplain surface (broken line) is represented only by the flattish summit areas of occasional hills. The highly weathered peneplain soils (shaded) survived on these summits, though perhaps in modified form, and constitute the oldest soil materials in the area. The valley slopes and floors are associated with younger soils, though these younger soils may incorporate some of the older material, as when former ironstone crusts break up to give ironstone gravel in soils lower down the slope.

After AHN (1974)

weathered level is composed of a few convex summits at a height of 195 m. The lower, younger, second, less weathered level is at a height of about 170 meters, and occurs in the terrain as a false terrace or shoulder (French: replat) on the slopes of the summits just mentioned, but it may also occur as highest landscape position.

On the lower relief position a third, less distinct level seems to be developing. This is discussed futher in paragraph III.2.1. Figure III.6a shows the possible development of the landscape.

The Taï landscape is currently represented by transitional forms between the ironstone plateaus of the nothern regions and the gravelly rounded erosion remnant of these of the south of Ivory Coast, which are, in french literature, called "demi-orange".

It is possible to associate the upper ironstone crust with that defined in the northern part of Ivory Coast by the "Haut Glacis", the second crust at 170 m. can be associated with the "Moyen Glacis" and the third with the "Bas Glacis".

The development in place and time from ironstone plateaus to gravelly "demi-oranges", see figure III.6b, is as follows:

- An increasing lowering of the topographic surface, this is accompanied by an increase of hill slopes, covered by soils having a superficial or lateral drainage (see fig. III.6a and III.9), and this explains the high run off measured by CASENAVE et al., see paragraph III.1.1.
- A lowering of the local base level (see par. III.2.1). This produces an excavating by gullies of the edges of the large watershed areas into several "demi-oranges", the appearance of a strongly branched drainage network, and the extension of the surface occupied by the valley bottoms.

A well-developed drainage system has developed, following the structural directions of the region. The pattern is strongly rectangular downstream, but is semi-dendritic upstream. The latter as a result of a new erosion cycle

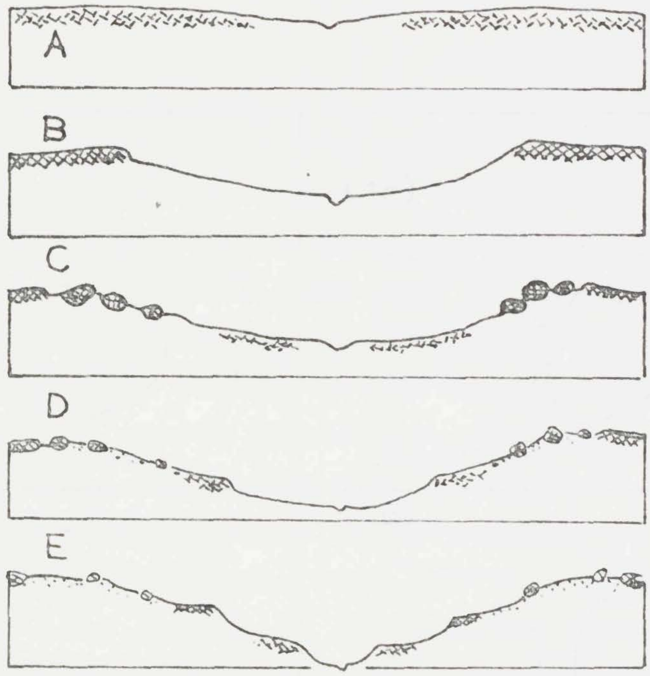


Figure III.6a Possible stages in the formation of ironstone crusts

The possible landscape changes associated with profile development are indicated in diagrams A - E, above. These show the formation of a mottled, partly indurated subsoil horizon in A, which subsequently remains as a crust capping on the hills of diagram B. In C the iron derived from the break-up of this crust moves downslope in solution and contributes to the formation of a new mottled and partly indurated horizon at a lower level. Futher dissection of the landscape by streams and rivers has exposed part of this lower indurated horizon as a 'shoulder' in diagram D, while diagram E shows succesive 'shoulders' resulting from a repetition of these processes, the older, higher shoulders have been futher indurated to become ironpan.

After AHN (1974)

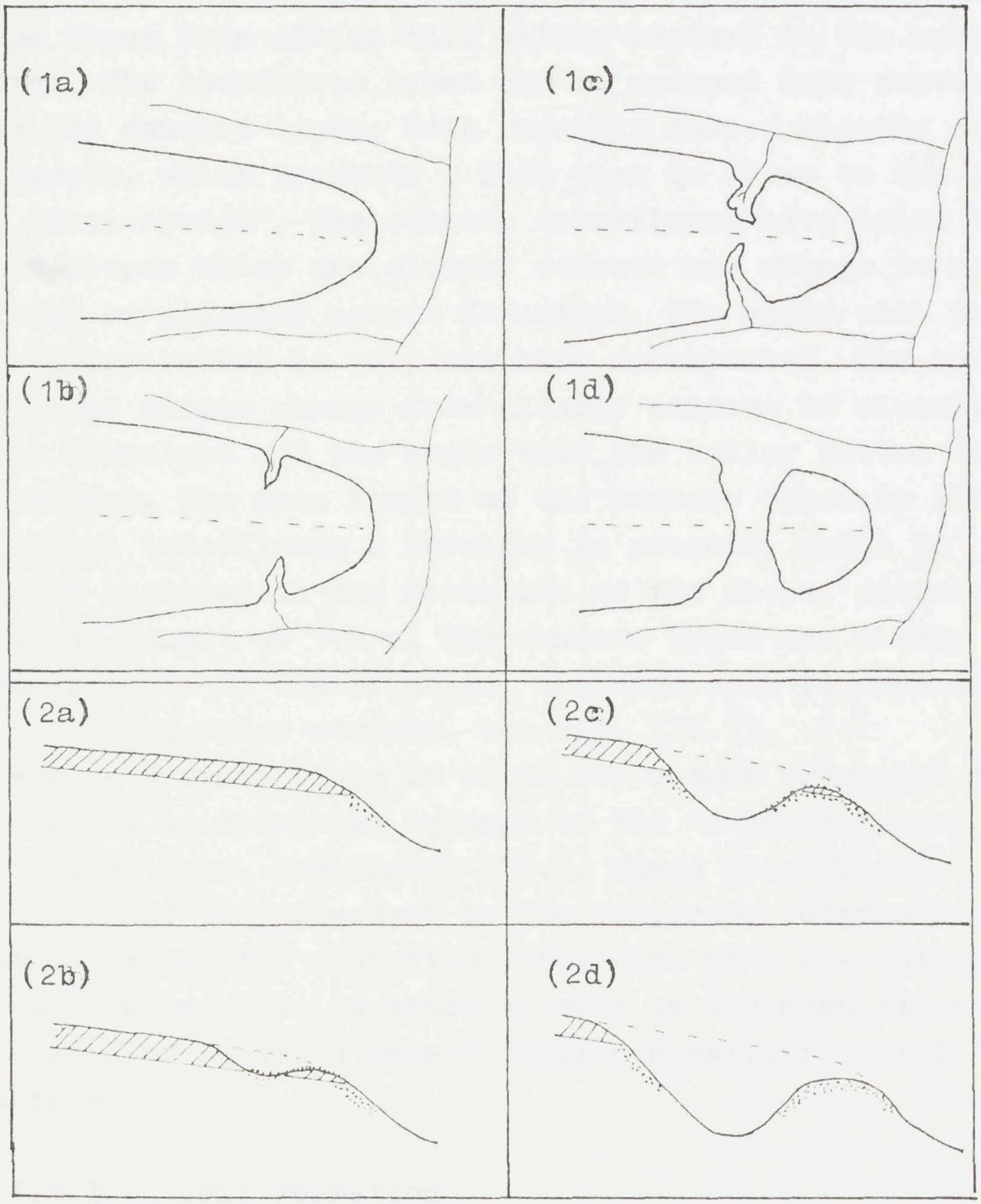


Figure III.6b The development from ironstone plateaus to gravelly "demi-oranges".
1a to 1d aerial view
2a to 2d cross section

(COLLINET 1984) is more branched and without a preferential orientation.

FRITSCH (1980) distinguised six main types of interfluves (slope types from divide till valley bottom) in the area studied. The iterfluves types can be grouped into convex types and concave types. Both usually have a clearly convex summit, which presents a form that is close to the form of a "demi-orange". The concave interfluves have below the summit slopes which are clearly concave and change to rectiliniar or slightly convex downslope. The angle with the flat valley bottom is only slightly accentuated. The convex interfluve slopes change from clearly concave to clearly convex downslope and the angle with the valley bottom is accentuated. The mean lenght of the concave types is 570 m. In several interfluves a shoulder is present, which is slightly inclined in the direction of the slope, situated below the summit at 170 m. The concave types are mostly found upstream of the principal drainage axis (Audrenisrou and the first order streams, see fig. III.1).

The type of interfluve on which the catena presented in this report is developed belongs to the "concave raised interfluve" type, see figure III.7. These interfluves, which are not very frequent in the landscape culminate at about 195 m and the elevation difference with the valley bottom is 45 m. This is twice as much as the mean elevation difference of 20 to 25 meters mentioned earlier in this paragraph.

III.1.3 Soil Formation

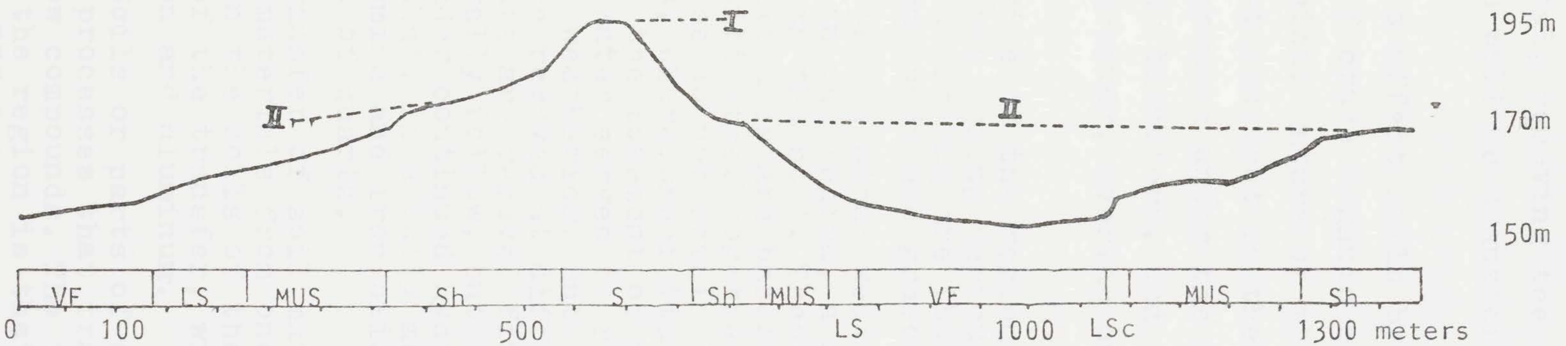
The basic changes that affected soils in the Southwest region are attributed mainly to climate, plants and animals, the dynamic agents of soil formation (DRC 1967).

Climate acts through weathering which involves both physical and chemical changes in rock and soil materials. Hydrolysis, hydratation, solution and other chemical processes soften the rock to depths of 3 to 20 m, changing it to an unconsolidated residue that may still retain much of its

Figure III.7 Transect of the studie-plot

The summit on the left gives the 'concave raised interfluve' type, with on both sides a shoulder. The summit (195 m) can be associated with the 'Haut Glacis' (= I) of the nothern part of Ivory Coast. The shoulders (170 m) can be associated with the 'Moyen Glacis' (= II) and the ironstone crusts, which occur in the lower slope position (see figure III.9) with the 'Bas Glacis). The valley floors are at 150 - 155 meters. The transect of the studie-plot is on the left of the summit at 195 m.

Based on FRITSCH 1980 Transect LS



VF: Valley Floor
LS: Lower Slope, rectilinear or slightly convex
LSc: Lower Slope, clearly convex
MUS: Middle and Upper Slope
Sh: Shoulder, situated below a summit or isolated
S : Summit, strict sense and strong convex slope

original rock structure. Water continues to leach through this altered material, removing the soluble products of chemical change, as well as transferring limited amounts of solids.

Plants and animals affect soils by the addition of humus and the breakdown of crude organic materials and in certain changes in the physical nature of the soil.

The processes most manifest in the formation of soils in the region can be grouped under the general headings of additions, removals, transfers, and transformations. Some of the processes, however, overlap under two or more of these headings.

Additions: The soils of the region have experienced several kinds of additions during various stages in their development. Among the additions are those of organic matter, carbonates, iron compounds and gravel.

Removals: During the chemical weathering of migmatitic and granitic rocks in the region, a number of primary products are set free in the soil. These products of the hydrolysis of complex silicates are bases, silica, alumina, and hydrated aluminum silicates, together with iron oxide and quartz. Many of these do not remain long in the soil. In a region such as this, where precipitation exceeds evaporation (see par. III.1.1), the movement of water is mostly downward. The leaching water serves to remove from the soil the primary products of weathering. But these have different solubilities and are removed at different rates. Bases and other plant nutrients are removed first. Silica and aluminum silicates generally follow, but the oxides of iron and aliminum remain. Under continued hydrolysis and leaching, it is conceivable that, in a fully matured soil, nothing will remain but alumina and iron oxides, together with variable quantities of quartz.

Transfers: The transfer of soil material can be defined as the movement of materials from one place to another within the solum. In the soils of the region there are numerous examples of the transfer, within the soil, of clay, organic matter, iron and aluminum.

Transformation: Soils or parts of soils often are subjected to chemical processes that transform the soil or parts of it into new compounds. The transformation most common to soils of the region is that of segregation of iron, see paragraph III.2.1.

III.1.4 Vegetation and Fauna

As stated earlier, the vegetation of the Taï region is primairy humid tropical forest. In french literature this forest is qualified as ' dense humid evergreen' (FRITSCH 1980; GUILLAUMET et al. 1984), but in the DRC report (1967) it is said to be a transitional type of forest, with south-west of the Taï region the evergreen forest and north-east of it the semi-deciduous forest type. VOOREN (pers. comm.) agrees with this view and argues that in the valleys and on the lower slope positions evergreen forest types are found, while on the 'dryer' summits and shoulders the semi-deciduous types are present, see also par. III.2.4.

The forest with as dominant species, i.e. species which a are present in all or most of the vegetation sample areas, Eremospatha macrocarpa (a climbing palmtree) and Diospyros mannii (underwood shrub), is characterized by its diversity of species and the abundance of its underwood, a quite big number of lianas and the frequency of uprooted trees on the soil (FRITSCH 1980).

Like the flora, the fauna of this region is very rich and comprises many vertebrate and invertebrate species (DRC 1967). The forest areas have a numerous population of monkeys. The elephant population is diminishing rapidly, because of severe poaching. The same DRC report mentions that it is very common to see severe elephant damage caused to large fruit and latex trees. In such devasted areas there is no ground flora. And according to the DRC report this may have an effect on the acidity of the soil there. This could be due to loss of organic matter, compare o.m. content and pH of the topsoil of CI-1 and -2 with the topsoil of CI-3, -4 and -5.

Other faunal activity that has an impact on the soil in the region takes different forms. Some are little apparent (ants, little digging mammals, insect, ect.), others are more numerous and sometimes spectacular in forming a specific microrelief. The latter due to termites and earthworms, will be given more attention.

The activity of termites is shown by the presence of the large edifices, constructed by them at the soil surface. Three great types of edifices are distinguished by FRITSCH (1980) in the region by their form, and which are associated with different termite species. They are distinguished as follows:

(1) 'Mushroom'-shaped,
(2) 'Sausage'-shaped, and
(3) 'Volcan'-shaped.

The first two types have a cylindrical shape. The vertical cylinder (hight: 20-50 cm, mean diameter 10 cm) is either rounded at the top (type 2), or has a mushroom-shaped roof (type 1). Both types are observed in all topographic positions, except the valley bottom, and occur most often close to a large tree. They have a homogeneous dark brown colour and a clayey texture and consist of clay with organic matter. The third form has much larger dimensions (upto 1.5 m high) and consist of several overlapping cones, splitted up at the top, see figure III.8. These edifices are rarely observed on the summits, which are mainly gravelly, and in the valleys. On the contrary they are frequent on certain, slightly gravelly, eroded summits and on the slopes. They have a clayey texture and a colour that changes in a downslope direction from dark red to brown and via yellow to white.

The activity of the earthworm is observed in all topographic positions. It only becomes spectacular at the surface of the soil at the upper slope up to and including the valley (VF, LS and MUS in fig. III.7). By throwing up tube-like structures, preferentially around trees, the earthworms eventually create micro-hills (diameter: 0.20-2 m, hight: 0.10-0.40 m), which give the slope a typical microrelief.

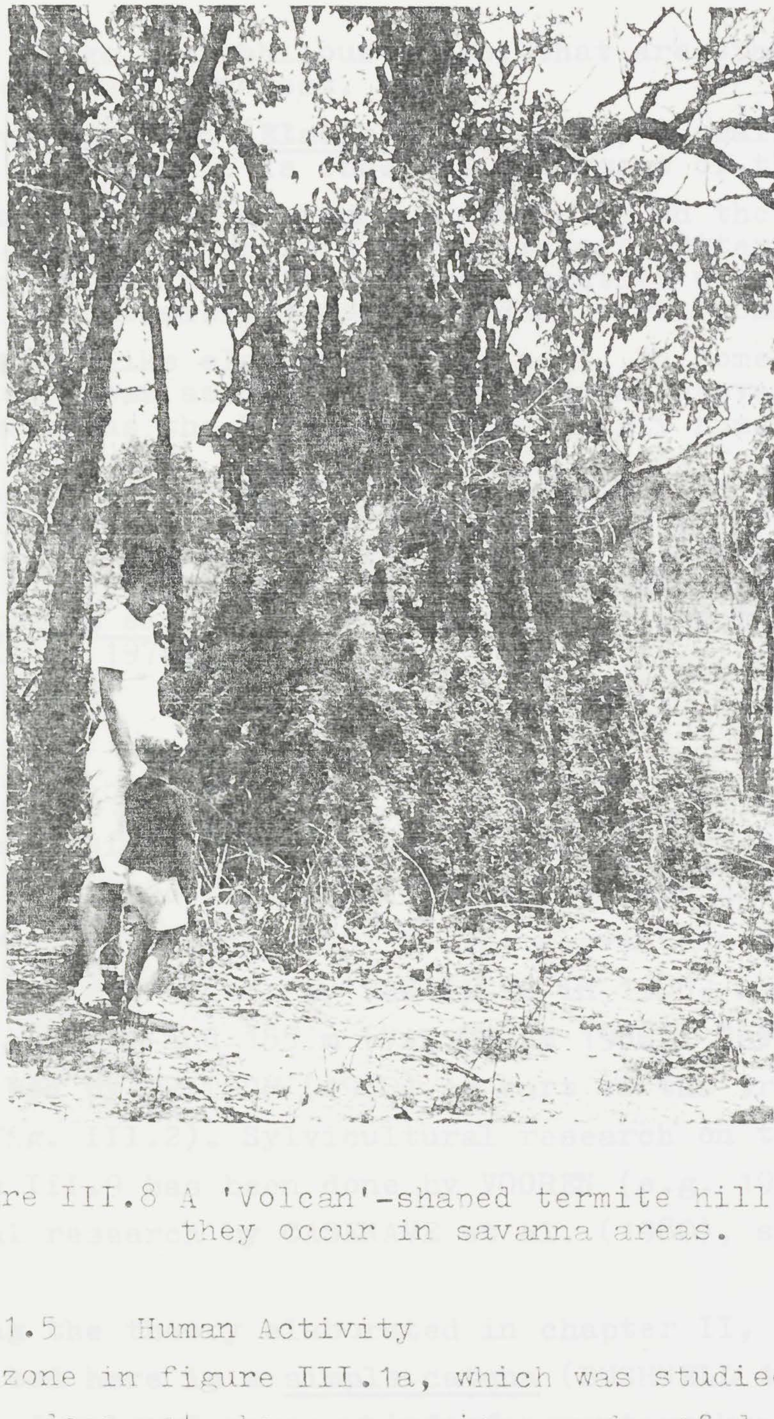


Figure III.8 A 'Volcan'-shaped termite hill as they occur in savanna areas.

III.1.5 Human Activity

The zone in figure III.1a, which was studied by FRITSCH (1980), does not show any serious marks of degradation due to human influences. Though the human impact on the natural environment is moderate, its influence is certain. Several witnesses permit to suppose or to affirm it (FRITSCH 1980). Marks of the human impact are:

- old roads and woodstocks that show a former forest exploitation. At those sites, the regeneration of the forest vegetation and the progressive return to its initial state shows that the exploitation was old.

- some large heliophilous trees, that are otherwise not present in the forest.
- scarce oil palm (Elaeis guineensis), a small group of 4 to 5 individuals is observed southwest of the Taï station.
- pottery garbage is found in two pits on the top off the divide. In one profile almost intact pottery was found at 80 cm depth in a gravel layer together with charcoal. The site was possibly a tomb (VOOREN, pers. comm.)
- charcoal-like elements in the soil. In some cases their presence was associated with marks as above, and this strengthens the hypothesis of an early human implantation.
  In most cases, however, charcoal-like bodies are found at regulary distributed sites, occurring at a depth seldom exceeding 60-80 cm, particularly on the slopes. They may have another origine. They are possibly bark fragments of Diospiros sanza minika, that are resistent to mould (MOREAU, 1979).

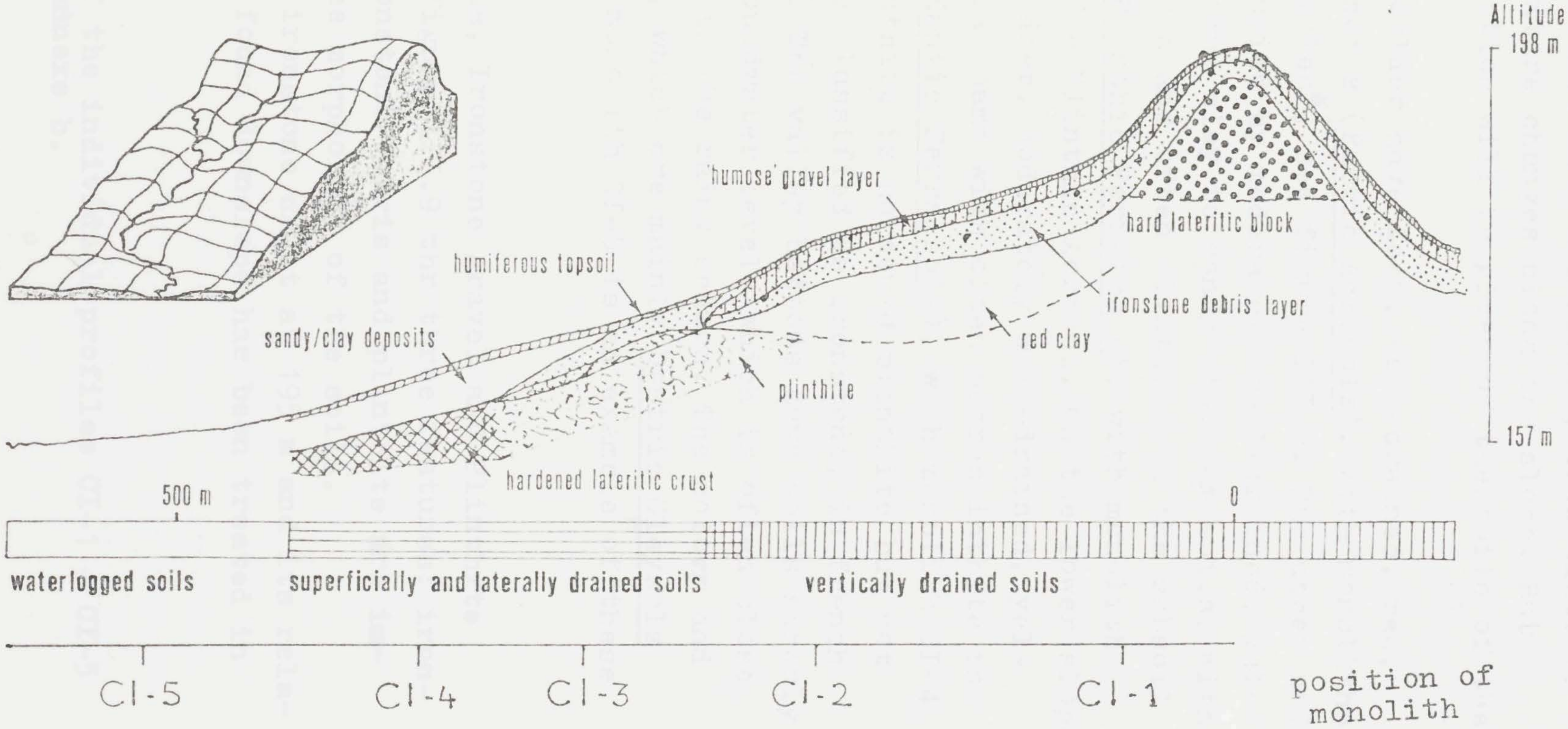
III.2 The Catena

A schematic cross-section of the catena is given in figure III.9, see also figure III.7. The topographic map coördinates are 5°53' N and 7°20' W. The elevations at which the monoliths are taken, by VAN KEKEM in 1985, are 177 m, 173 m, 165 m, 160 m, and 155 m (VAN KEKEM 1986). The catena is described by FRITSCH (1980) as part of the transekt LS (see fig. III.2). Sylvicultural research on the plot in figure III.9 has been done by VOOREN (e.g. 1985) and hydrological research by CASENAVE et al. (1980), see figure III.2.

Using the theory elaborated in chapter II, the catena described here is a simple catena (BUSHNELL 1942, YOUNG 1976), developed on one kind of parent rock: migmatite, richin biotite (par. III.1.2). And it belongs to the 'chaîne de sols faisant intervenir les transport de matière en solution ou suspension fine' as defined by DUCHAUFOUR (1983). Although, as is shown the landscape forming is dominated by erosion, the current processes can be grouped under general headings of additions,removals, transfers and transformation as has been worked out in par. III.1.3.

Figure III.9

Slope profile of the study-plot with toposequential soil series and predominanting drainage types. Soil horizons are after FRITSCH (1980, transect LS), figure from VOOREN (1985). Vertical scale is exaggerated.



In the paragraphs below several aspects of the catena will be discussed, such as the relation of ironstone, ironstone gravel and plinthite with topography; iron distribution in the soil; texture changes along the slope. But first a brief description will be given of the soils of the catena.

The hilltop and shoulder have deep, well-drained, red, very gravelly, clay soils (Ferric Acrisols), with monoliths CI-1 and CI-2 as examples*1, see figure III.9. The upper and middle slope are occupied by moderately well-drained, yellowish to reddish-brown, clay to sandy clayloam soils, with gravel at shallow depth and often plinthite in the subsoil (Plinthic Acrisols; Plinthic Ferralsols), with monolith CI-3 as an example of a Plinthic Acrisol. On the lower slope soils are moderately deep, moderately well-drained, yellowish-brown sandy clayloams with often petroplinthite in the subsoil (mainly Xantic Ferralsols), with monolith CI-4 as example. Petroplinthite is hardened plinthite but not yet hard enough to be classified as ironstone, in french literature: carapace. The valley bottoms have soils stronly influenced by the groundwater level, which is often close to or at the surface in the rainy season. The colour and texture of the soils, which are mainly Dystric Gleysols varies considerably, monolith CI-5 is an example of these soils.

III.2.1 Ironstone, Ironstone gravel and Plinthite

As can be seen in figure III.9 thr three features: ironstone (laterite), ironstone debris and plinthite are important aspects of the morphology of the soils.

The origine of the ironstone crust at 195 m and its relation with the gravel found downslope has been treated in paragraph III.1.2.

*1 Description of the individual profiles CI-1 - CI-5 are given in annexe b.

As distinct from some other interfluves, no ironstone crust is present at the 170 m level, though the shoulder is clearly visible, see also figure III.7.

Following FRITSCH's definition of slope, than the slope starts from the shoulder and is divided in a upper-, middle- and a lower-slope. In these positions plinthite is found in the subsoil. At the lower slope position the plinthite is irreversibly hardened to a material called in french literature "carapace" (opposite to "cuirasse", which is the equivalent of ironstone), and is qualified by VAN KEKEM (1986) as petroplinthite. VOOREN (pers. comm.), who discussed this with FRITSCH, assumes that the fact that soft plinthite is present immediately below the shoulders, and hardened plinthite at a lower level is due to protection, by the gravel layer, of the plinthite in the upper and middle slopes against desiccation.

The fact that gullies are actively eroding, most striking at the principal drainage axes (e.g. the Audrenisrou), and that there are rock outcrops in the area as well as several rapids in the Cavally river (on which the Audrenisrou drains) make an assumption of erosion base level lowering plausible (FRITSCH 1980).

According to AHN (1974) many of the ironstone sheets of the present-day forest soils in West-Africa are thought to have formed (hardened) under drier conditions in the Quarternary period.

Local base level lowering and/or a former dry period could explain the hardening of the plinthite in the lower slope position. Whether or not the formation of this plinthite is still going on, is not clear.

There is a difference in appearance between the old upper ironstone crust (the remainder of it), which is described by FRITSCH (1980) as scoria- or slag-like, and the younger two crusts, which are described by him as having an alveolate or vesicular appearance.

The two lower plinthite indurations, of which only the lowest one is present in the catena studied, are obviously examples of McFARLANE's 'slope bottom laterite', the genesis of which is shown in figure III.6. Vegetation is believed to play an important role in the redistribution of the iron, and there are many references to the ability of trees to soften, dissolve or break up an ironstone crust McFARLANE 1976).

The genesis of the original ironstone crust is less clear. Several exlpanations are possible. One explanation could be the formation of iron concretions in the saprolite and via several steps the formation of a massive crust (McFARLANE 1976), see figure III.10 A-E (pisoliths are iron concretions, see par. III.2.3). This theory could account for the difference in appearance between this crust and the lower two indurations. An other explanation is that the genesis is more or less the same as for the two other crusts, but a relief inversion has taken place. A 195 m high plateau, studied by FRITSCH (1980) had no ironstone crust, but had nevertheless a 'stoneline' in the subsoil. A stoneline is often considered at the border between sedentary material and colluvium, see chapter IV for futher discussion. This feature was seen by him as an indication of relief inversion. But with this theory the difference in appearence is not explained.

III.2.2 The Chemical Composition of the Soils of the Catena

Of the five monoliths, the chemical composition of the total soil (i.e. the fraction smaller than 2 mm) is analysed for the different soil horizons; the data are given in annexe b. In this paragraph the most striking aspects will be discussed.

An interesting element in this catena is <u>iron</u>, which with alumininium is an important constituent of ironstone and plinthite. Figure III.11 shows that the total iron (Fe_2O_3)

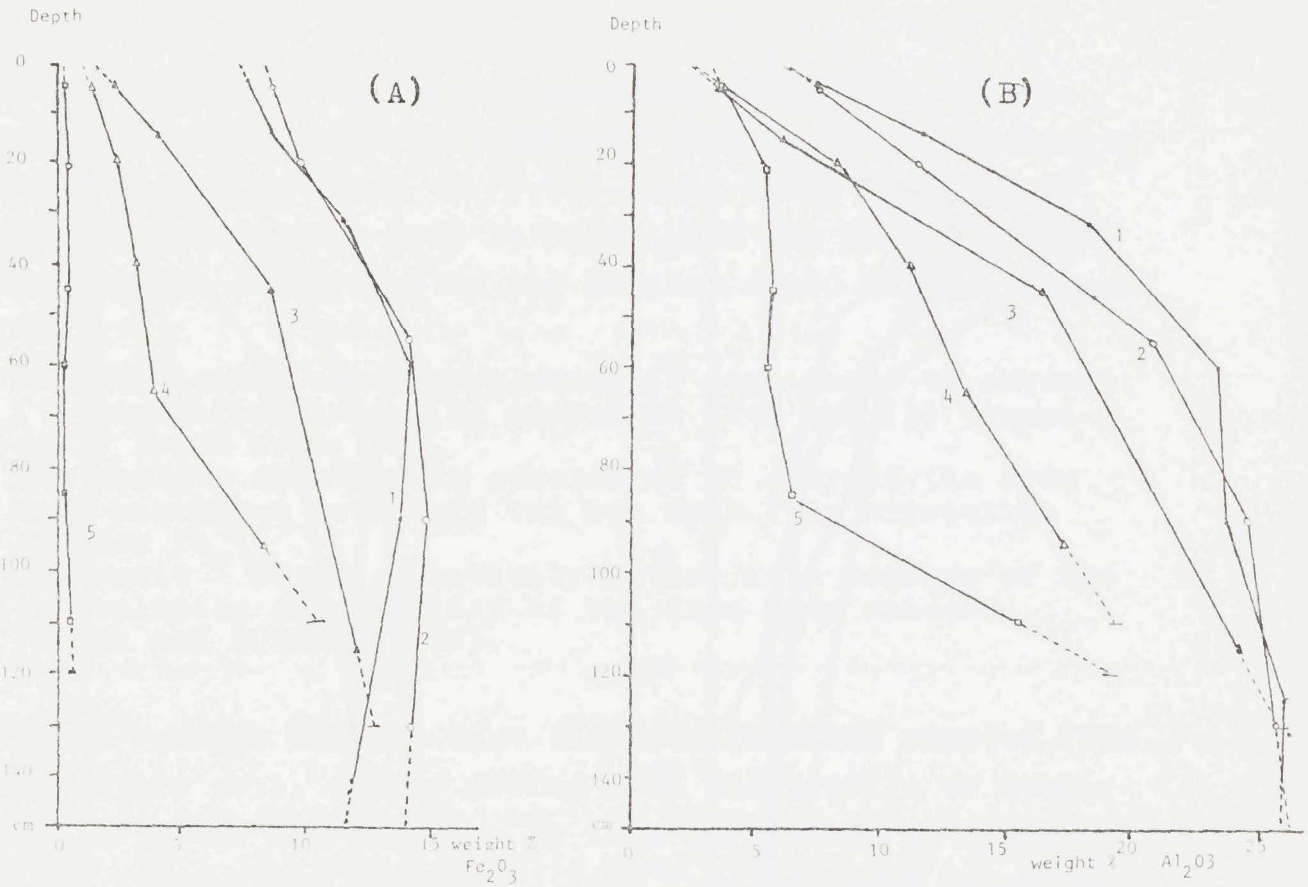


Figure III.11A (left) and B (right)

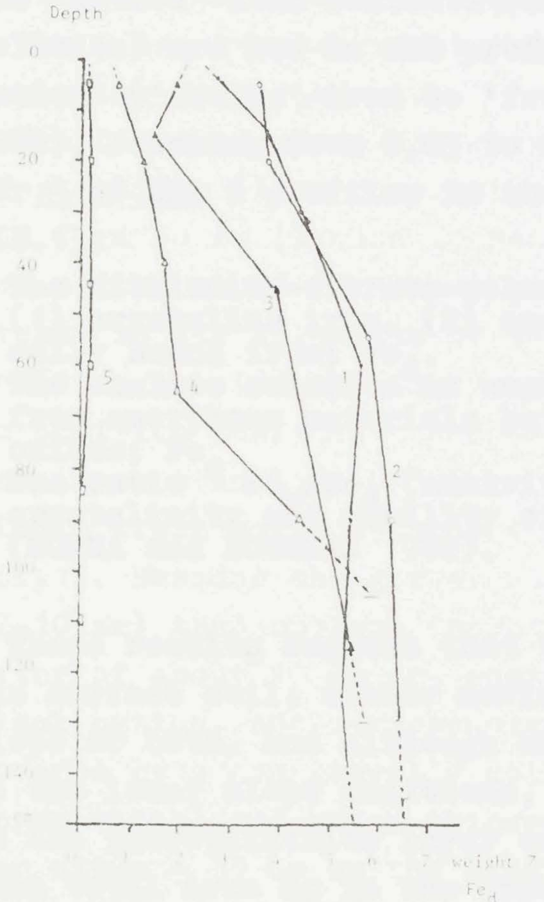
(A) Total iron (Fe_2O_3) content of the soil fraction < 2 mm. Change with depth for the five monoliths.

(B) Total aluminium (Al_2O_3) content of the soil fraction < 2mm. Change with depth for the five monoliths.

- · monolith CI-1, summit
- ∘ monolith CI-2, shoulder
- ▴ monolith CI-3, upper slope
- ▵ monolith CI-4, lower slope
- ▫ monolith CI-5, valley bottom
- ⍀ depth to which profile is described

and aluminium (Al_2O_3) contents are decreasing downslope. In all profilles, except for the valley bottom one, which is completely depleted of iron, the surface soils are having lower iron and aluminium contents then the subsoil.

A similar increase with depth is observed for 'free'-iron (extracted by a dithionote-citrate solution) as well as a similar decrease along the slope, see figure III.12.



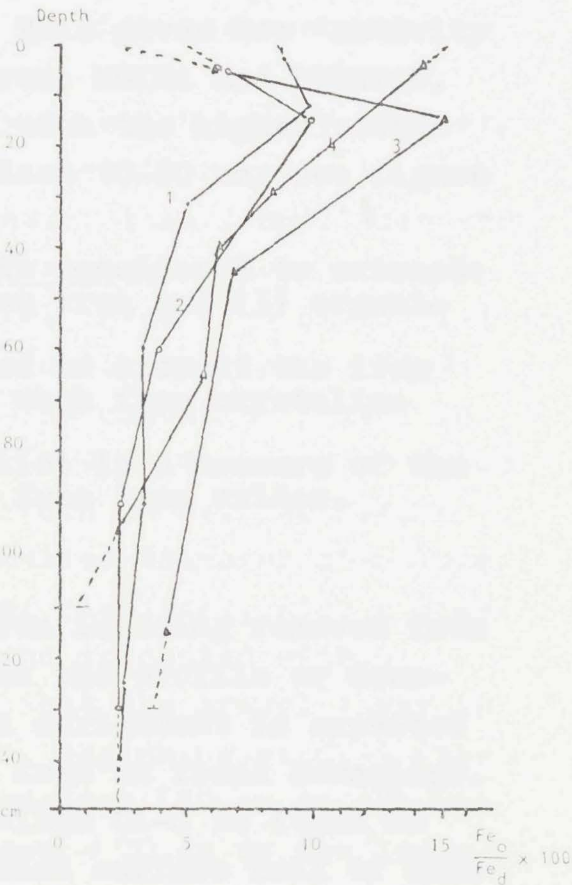


Figure III.12 (left)

Free iron (Fe) content (extracted by a dithionite-citrate solution). Cange with depth for the five monoliths.

Figure III.13 (right)

Activity ratios x 100 for the five monoliths (Fe_o/Fe_d, see text). Cange with depth.
For CI-5 the ratio is 1 (or ratio x 100 = 100).

· monolith CI-1, summit
∘ monolith CI-2, shoulder
▴ monolith CI-3, upper slope
△ monolith CI-4, lower slope
▫ monolith CI-5, valley bottom
⊥ depth to which profile is described

The 'active'-iron contents (extracted by an acid oxalate solution) are low in all profiles. This gives low 'activity ratios' ('active'-iron to 'free'-iron; MOKMA and BUURMAN, 1982), reaching from 0,03 to 0,15, with the higher ratios for 3 of the 5 profiles in the horizon 10-20 cm, see figure III.13.

The dithionite-citrate solution is considered to extract: (1) crystaline iron, (2) amorphous iron and (3) organically bound iron; Fe_d.
The oxalate solution is considered to extract the iron from amorphous materials but not much from crystaline oxides; Fe_o
The ratio Fe_o/Fe_d (activity ratio) is a measure of the crystalinity and mobility of the free iron oxides. (MOKMA and BUURMAN 1982).

These results suggest that the iron is being removed from the surface soil, either moving down the profile or downslope or both, and although an iron enrichment is expected in the lower slope positions, less iron is found downslope. In the petroplinthite layer of monolith CI-4 is found as much total iron as in the impoverished surface soil of monolith CI-1 and CI-2 (8.36 % for the first and 7.66 and 8.65 % for the second and third). This problem will be dicussed in chapter IV.

The total aluminium content (fig. III.11B) shows a course comparable to that of the clay content (see fig. III.15): an increase with depth and a decrease along the slope.

The SiO_2 content gives the opposite picture of that for the aluminium content; a decrease with depth and an increase downslope. This is comparable to the sand fraction distribution. The assumtion that the course of the SiO_2 content is due to the course of the sand fraction is strengthen by the observations in the available thin sections (see annexe d) that the sand fraction mainly consists of quartz grains.

Contents of MnO, CaO, MgO, P_2O_5, K_2O and Na_2O are very low.

III.2.3 Texture, Gravel and Clay Distribution

There are two important features in this toposequence regarding this subject.

The first concerns the gravel layer, which mainly consists of pisoliths (iron concretions sufficiently regular in size and form to be likened to peas, greater than 2 mm), with very few medium sized (2-10 mm) quartz fragments. There is a decrease in the thickness of the gravel layer (115 cm in CI-1 to 60 cm in CI-3 and then disappearing), see figure III.9. In addition there is a decrease in the amount of gravel in the layer downslope (75 % in CI-1, 60 % in CI-3 and 50 % for middle slope soils according to FRITSCH 1980), see figure III.14. Besides the gravel has a smaller diameter downslope (2-10 mm) than upslope (here coarser pisoliths, with a diameter of about 10 mm are common), and is coated with a black patina. Another phenomenon is that the gravel layer is covered by a non-gravelly colluvium, beginning at CI-3 (the upper slope) and which thickens downslope (10 cm on the upper slope → 35 cm on the middle slope → 70 cm on the lower slope, FRITSCH 1980; in the case studied no gravel is present on the lower slope), see figure III.9.

The second feature concerns the texture of the profiles, which becomes sandier downslope, see figure III.15. All soils have an increase in clay content with depth, and although only the summit (CI-1) and the shoulder soil (CI-2) show more or less a bulge of the type shown in figure III.16, in their profile, the upper slope soil (CI-3) is also classified as a soil in which clay illuviation occurs. This because in the thin sections abundant clay cutans (old and new) have been observed.*1

It should, however, be noted that the bulge seen in figure III.15 for CI-1 and -2 disappears if we look at the

*1 See annexe d for thin sections present at the International Soil Reference and Information Centre.

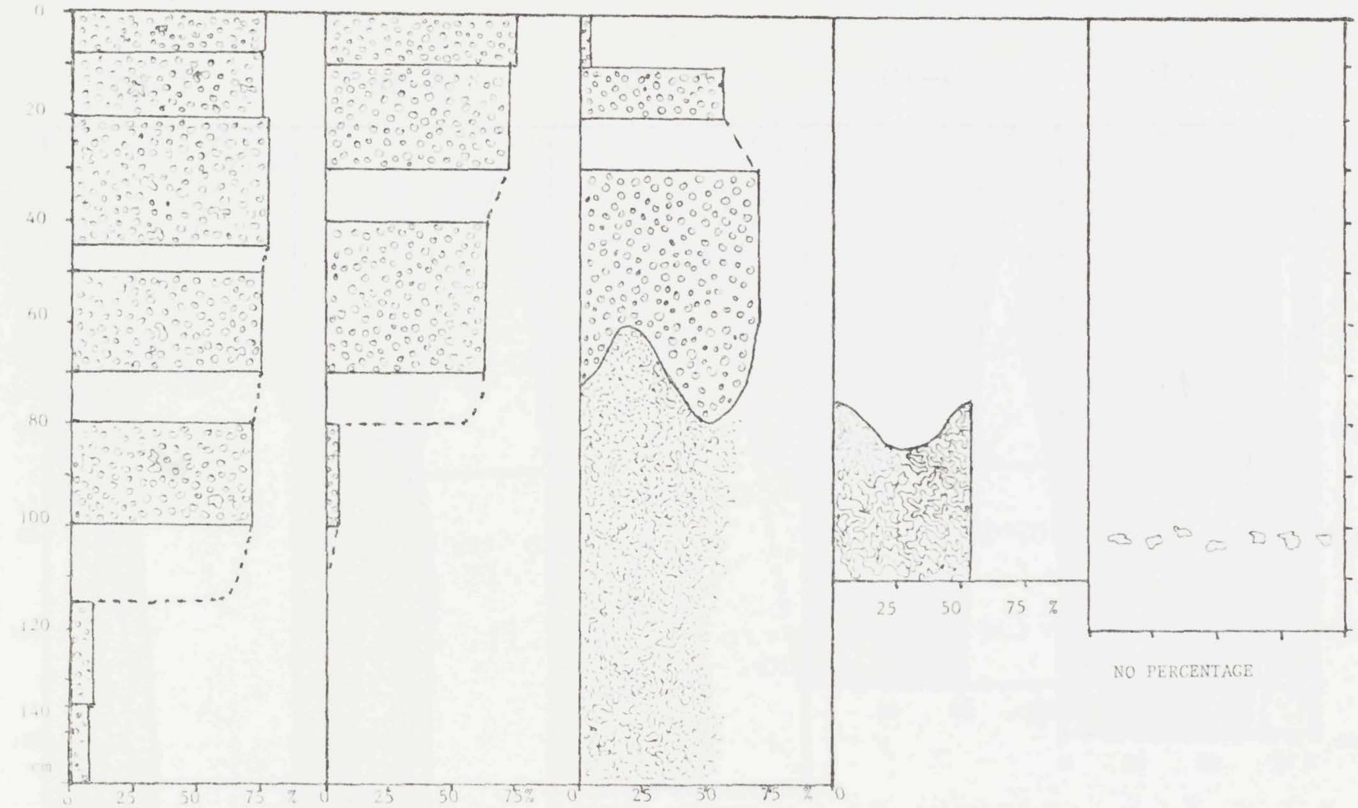
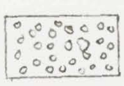
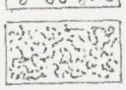
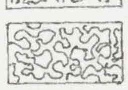
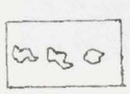


Figure III.14 Gravel percentage, (petro-)plinthite and stoneline presence for the five monoliths of the study-catena.


Gravel, mainly pisolith (see text)


(soft) plinthite


petro-plinthite, only 46 % soil, rest ironstone breaking up into a few hundred gravels (2-10 mm), irregularly formed, strongly coherent iron concentrations, (porous)massive, not continuously indurated.


Stone line, coarse (1 - 5 cm) subangular quartz gravel.

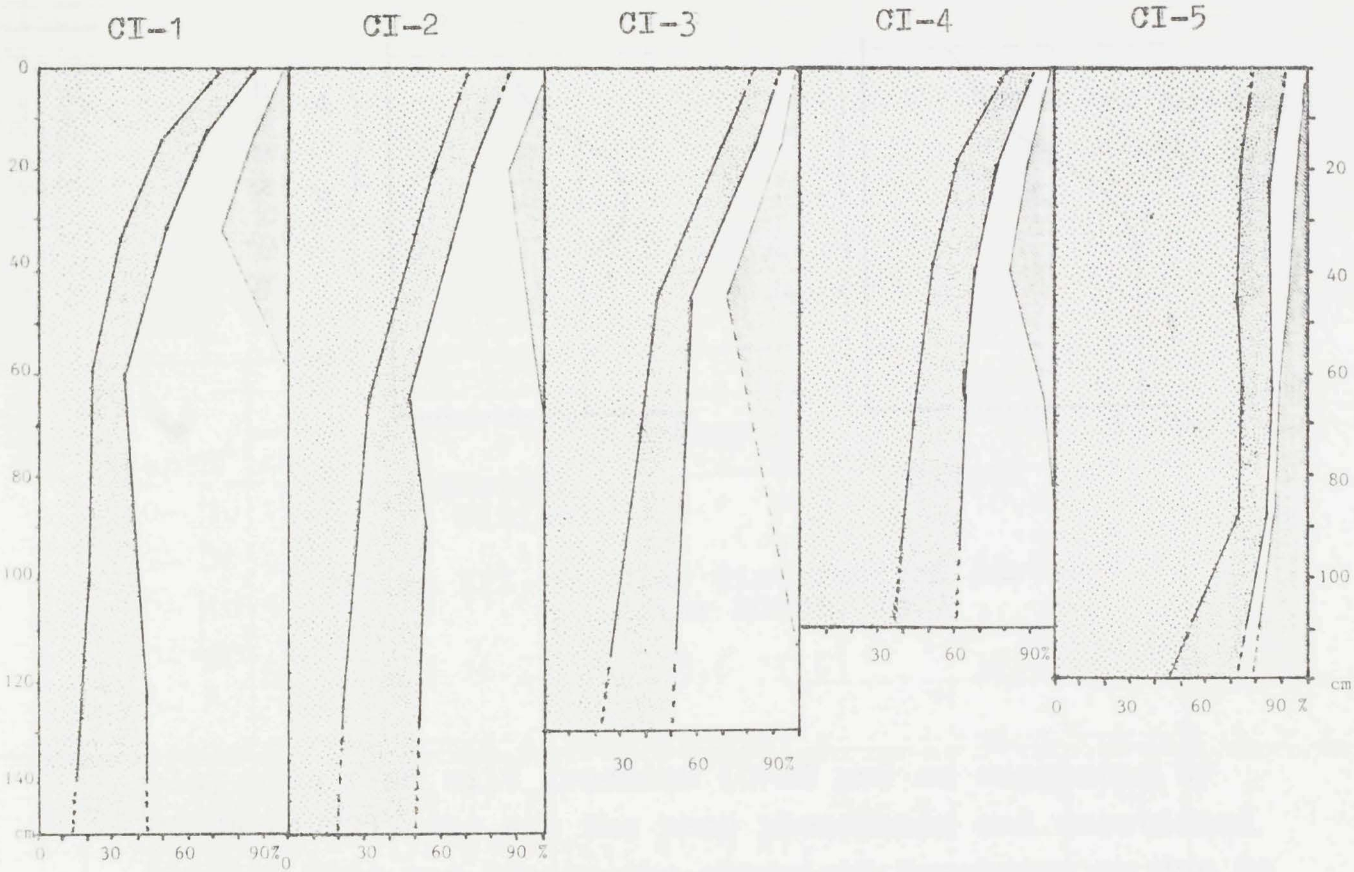


Figure III.15 Texture diagrams for the five monolith of the study-catena.

Sand fraction (50 - 2000 µm)

Silt fraction (2 - 50 µm)

Clay fraction (<2 µm), the water dispersable clay exclusive.

Water dispersable clay fraction

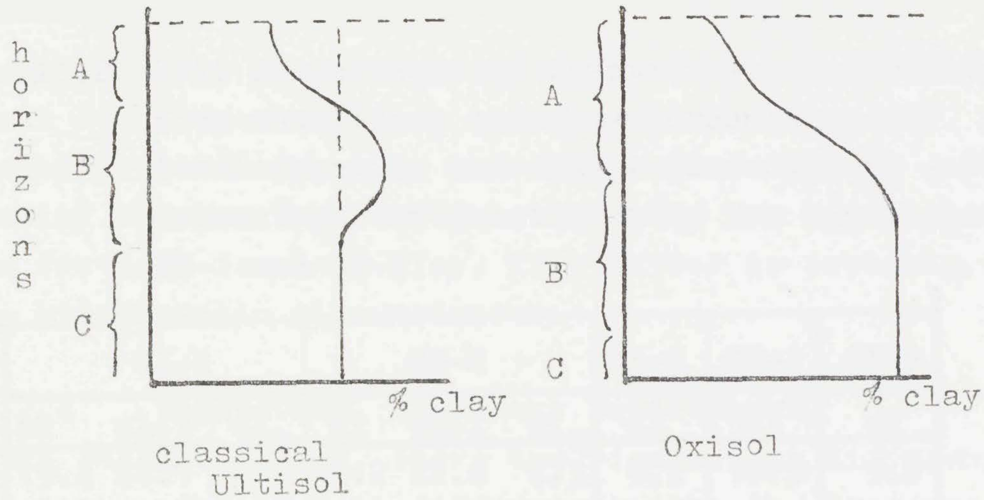


Figure III.16 Clay distribution curves
After ROOSE, 1977

clay plus fine silt fraction (0-20 µm) as suggested by ROOSE (1977), who saw the same phenomenon and questioned whether this was due to the classical lessivage or due to an impoverishment favoured by faunal activity. This disappearence also occurs if we take into account the gravel fraction, see table III.2. These two exercises were done to show the complications that occur when we studie clay illuviation in soils which are not as homogeneous as e.g. loess soils.

A fraction needing some more attention is the water dispersable clay, see figure III.15. Comparable with what is done for iron in the paragraph before, the 'activity'-ratio will be studied. The 'activity-ratio being the ratio water dispersable clay to total clay, see table III.3. As can be seen the ratios are high (0.40-0.60) between 10 and 50 cm depth for all soils, but while the CI-1, -2, -3 and -4 soils have low ratios in the layer below (at 60 cm almost zero), the valley bottom soil, CI-5, has very high values (0.80) below 60 cm. The slope soils CI-3 and CI-4 appear to have somewhat higher values then the summit and shoulder soils, CI-1 and CI-2.

So the soils seem to loose clay from their surface soil, either by vertical clay transport down the profile or by

Table III.2 Clay percentages of fraction < 2mm for all five monoliths, and clay percentages of total fraction and clay + fine silt (0 - 20μm) percentages of fraction < 2mm for monoliths CI-1 and CI-2

	CI-1			CI-2			CI-3	CI-4	CI-5
depth+	cl	cl+l	cl_t	cl	cl+l	cl_t	cl	cl	cl
0- 10	19.4	24.7	4.7	17.2	22.4	4.3	9.2	10.5	9.8
10- 20	33.4	40.1	8.4	26.6	33.3	8.3	15.7	22.8	14.8
20- 40	50.1	57.1	11.6				41.7	31.7	15.0
40- 60	64.8	72.3	16.2	52.9	58.8	19.6		36.5	14.4
60- 80									
80-100	62.5	72.7	18.2	45.8	61.4	43.5		38.3	16.0
100-120	57.2	73.2	52.7				48.5		24.6
120-150	57.5	75.8	53.4	48.7	65.9	47.7			

+ in cm, this is not the exact sampling depth, which is given in annex b.

cl: clay% of fraction < 2 mm; cl+l: clay + fine silt (0 - 20μ) % of fraction < 2 mm; cl_t: clay% of total sample (=fine earth + coarse fragments)

Table III.3 Ratios for water dispersable clay to total clay

depth (cm)	CI-1	CI-2	CI-3	CI-4	CI-5
0- 10	0.27	0.14	0.26	0.36	0.18
10- 20	0.43	0.47	0.37	0.49	0.36
20- 40	0.54		0.67	0.60	0.55
40- 60	0.01	0.01		0.13	0.76
60- 80					
80-100	0.01	0.01		0.00	0.81
100-120	0.00		0.01		0.81
120-150	0.00	0.00			

+ this is not the exact sampling depth, see annexe b.

lateral transport downslope. Although we suppose a clay movement downslope has taken place, soils are sandier. This is a similar tendency as we have observed for iron. Another similarity is that the valley bottom soil has high 'activity' ratios for both iron and clay. This latter is probably due to the hydromorphic circumstances.

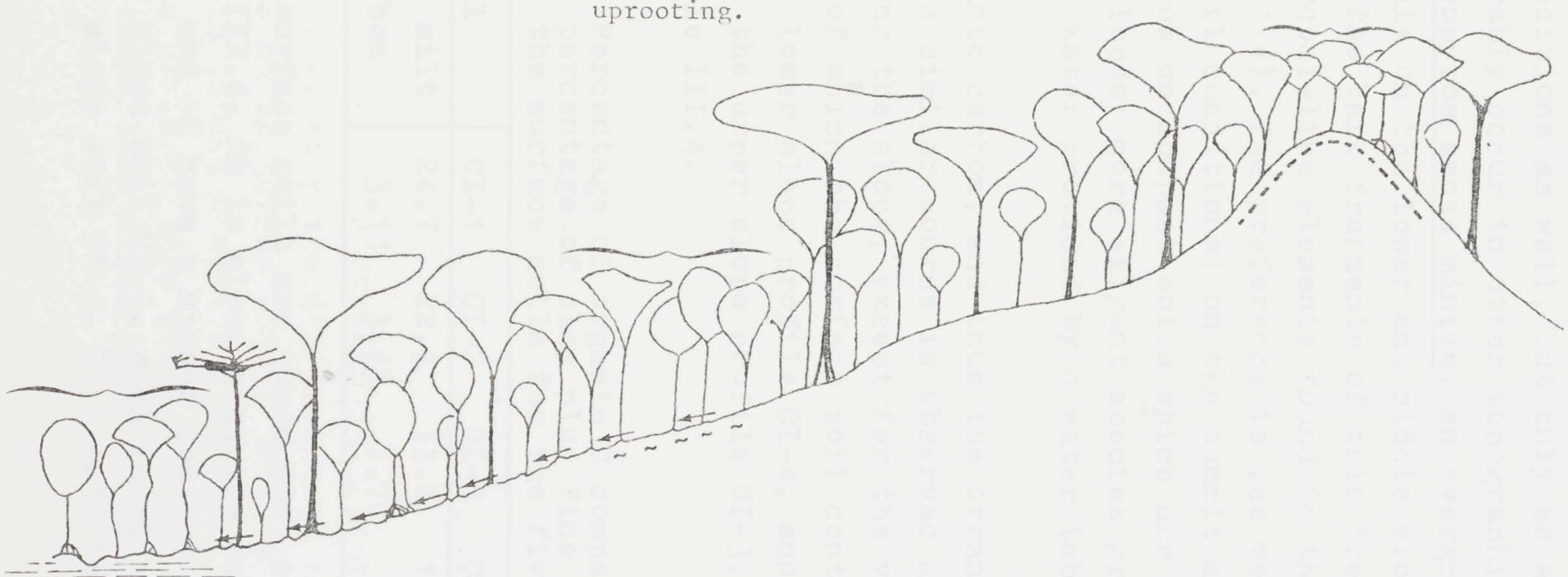
III.2.4 Vegetation, and Humus Development

In the catena studied, there are significant differences in vegetation due to soil differences like the presence or absence of a (semi-)indurated layer and the thickness and the amount of gravel of the layer above it. On the successive topographic positions of the catena, there are distinct differences in floristic richness, in population density, there are species occurring exclusively or preferentially on a certain site, and there are variations in the number of canopy gaps or 'chablis' due to a difference in uprooting.

A phenomenon, mentioned earlier in paragraph III.1.3, concerning the occurrence of tree types is that in the valley and on the lower slope evergreen forest types are found, while on the summit and the shoulder semi-decidious types are present. This indicates that the former positions are the wetter and the latter positions are the drier (VOOREN, pers. comm.). The extreme topographic positions appear to be poorer from the floristic viewpoint, CI-1 versus CI-5. The shoulder has the highest biomass (560 ton of dry matter per ha.) and the valley the lowest (360 ton of d.m. per ha.). The values for the other positions are in between, but are not significantly different from each other nor from the values mentioned for the shoulder or valley (HUTTEL 1977).

Another feature, reported by VOOREN (1985) is the occurrence of sites with a mature low-canopy forest, see figure III.17. Thes sites have impeded drainage by water logging (valley bottom) or have superficial plinthite or ironstone formations (middle slope and summit, above CI-1). Frequent

Figure III.17 Imbrication of forest canopy layers on slopes. Sites with impeded drainage by waterlogging (valley bottom) or with superficial plinthite or ironstone formations (middle of the slope, summit) support mature low canopy forest (braces). Excessive superficial run-Off in the inferior slope section (arrows) causes frequent uprooting.



(After VOOREN 1985)

uprooting on the lower slope is caused by excessive superficial run off (see also paragraph III.2.7).

Huttel (1977) has observed that certain species occur exclusively in the valley (Gilbertiodendron splendidum, Uapaca paludosa while other valley species occur in other topographic positions as well, but only as a mino ity. Other species preferably occur in other topographic positions. An example is Diospyros sanza minika, an evergreen forest type, occurring mainly on the lower and middle slope (VOOREN, pers. comm.). The bark fragments of this tree are thought to be the charcoal-like elements found in the soil (see paragraph III.1.4). The preference is ,as mentioned associated with soil conditions: on the summit and shoulder: "ability to grow on compact soils which are rich in gravel"; on the lower slopes: more exigent species growing on colluvial soil with water provided by a water table.

For the organic carbon, and thus the organic matter or humus content a similar course is observed as for the amount of biomass along the slope, except for the valley bottom profile CI-5, of which the surface soil contains more organic C than the lower slope profile CI-4, and contains the same amount as the upper slope profile CI-3, see figure III.18 and table III.4.

Table III.4 Percentage of organic C compared with percentage of clay plus fine silt for the surface soils for the five monoliths.

surface soil	CI-1	CI-2	CI-3	CI-4	CI-5
clay + fine silt	24.7	22.4	13.2	15.3	14.6
organic carbon	3.11	3.45	1.78	0.93	1.57

If only the surface soils are taken into account as is done in table III.4, it is clear that the summit and shoulder soils CI-1 and -2 have a higher content of organic C than the upper slope soil CI-3, wich is richer in organic C than the lower slope soil CI-4. It should be kept in mind

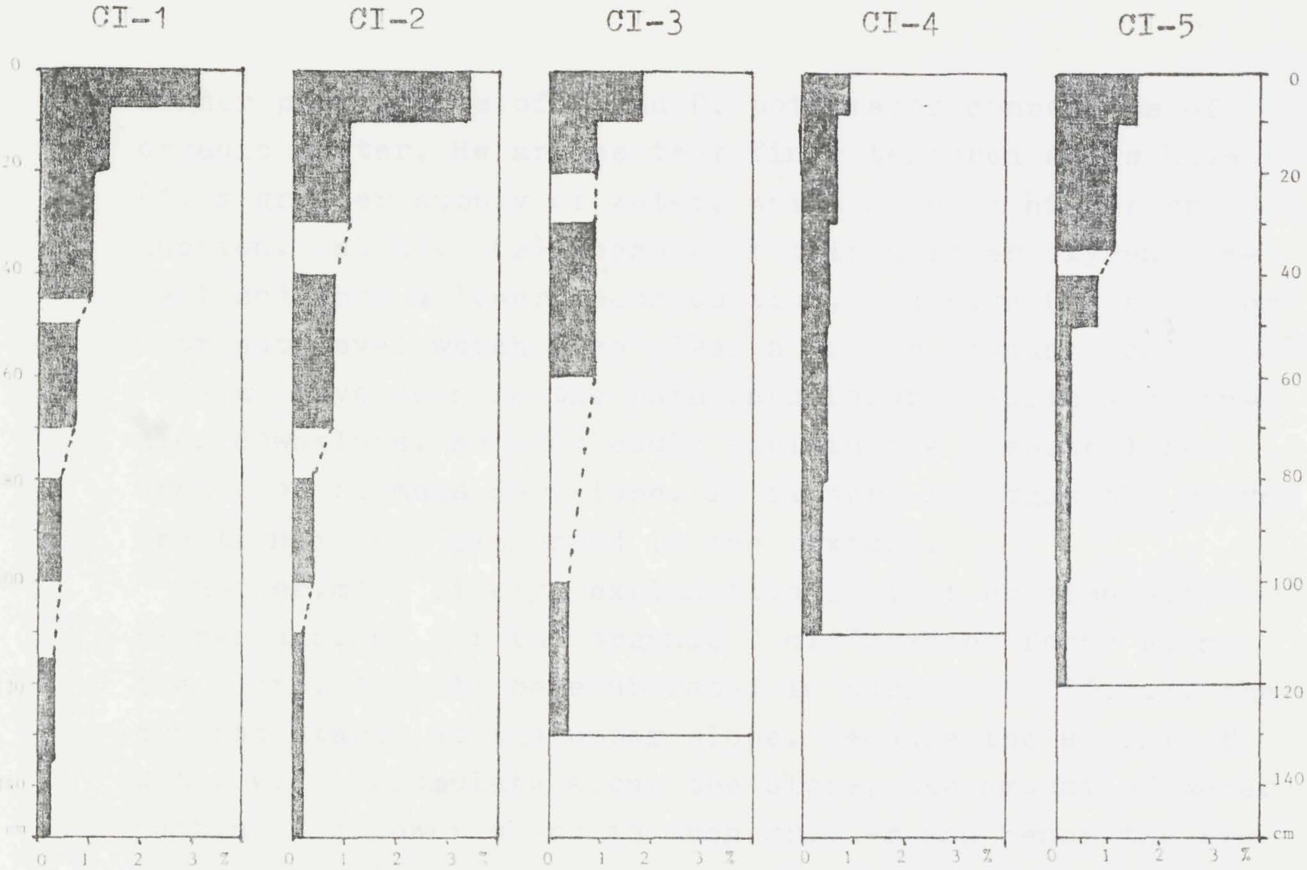


Figure III.18 Organic carbon distribution for the five monoliths of the study-catena.

Organic carbon content for the given horizon.

not sampled horizon

that for CI-1 and -2 the gravel fraction is not taken into account, if this was done organic C percentages would be very low.

Several hypotheses could explain this course of the organic C downslope. Firstly the difference in biomass along the slope as found by HUTTEL (560 → 360 ton per ha, see above). But this is not a real explanation, because one should find the cause of this biomass difference.

VOLK (19.2) shows that finer textured soils generally have higher percentages of N and P, both major components of organic matter. He argues that finer textured soils have (1) a greater supply of water, which gives a higher production, and have (2) because of this a lower oxygen content and thus a lower decomposition, and have (3) a higher nutrient level which also gives a higher produchtion.

As we have seen in the paragraph before, soils are sandier downslope, so this could explain the (assumed) decrease of biomass downslope. If it were not that the gravel fraction is not expressed in the texture.

Another,more likely, explanation is that erosion differences account for the organic C differences found along the slope. As will be elaborated in paragraph III.2.7, the erosion starts at the upper slope. Because the amount of water will accumulate along the slope, the amount of water passing the lower slope is much greater and hence the erosion here will be stronger and more a.o. organic matter is carried away. So CI-1 and -2 have hardly any erosion and show high o.m. contents, CI-3 has some erosion and shows a moderate o.m. content, and CI-4 has much erosion and shows a low o.m. content.

The moderate o.m. content found in the valley bottom soil CI-5 could be explained by enrichment from higher (CI-3, -4) sites, but this is not very likely after what we have observed for iron and clay in the preceding paragraphs. More likely is that the valley bottom with its high ground water levels (varying between 40 and 80 cm) and which is during the rainy season sometimes flooded, has low oxygen levels and thus lower decomposition rates.

III.2.5 The Adsorption Complex and the pH

The Taï forest soils are highly weathered and kaolinitic, see clay mineralogy annexe b. These are soils with variable charge. Although the clay content, as we have seen in paragraph III.2.3, increases with depth, this is neither reflected in the CEC (cation exchange capacity) nor in the

ECEC (effective CEC, see below), see table III.5. An important part of the CEC is provided by the organic matter. And the CEC in the surface soil has a trend similar to that of the organic carbon content, see table III.6

Table III.6 Organic carbon percentage and clay plus fine silt fraction compared with the CEC (pH=7) for the surface soil of the five monoliths.

surface soils	CI-1	CI-2	CI-3	CI-4	CI-5
clay + fine silt	24.7	22.4	13.2	15.3	14.6
organic carbon	3.11	3.45	1.78	0.93	1.57
CEC (pH=7) in meq/100g	8.9	9.6	6.2	2.3	4.7

With profile CI-3 the influence of both clay and organic matter will be demonstrated, because it is most clearly in this profile, see table III.5. Horizon 2 (10-20 cm) of CI-3 has 1.7 times as much clay as horizon 1 (0-10 cm) of this profile, but only 50 % of the amount of organic matter, and there is a 25 % decrease in CEC. Horizon 3 (30-60 cm) has 2.7 times as much clay and the same amount of o.m., and the CEC is 1.7 times as high. Horizon 4 (100-130 cm) has again more clay (1.15 x as much) but only half of the o.m., which gives a decrease of 17 % in the CEC. This shows the importance of the organic matter in these soils.

Although for classification purposes the CEC and BS (base saturation) are determined at pH 7, the actual situation is better reflected by the ECEC and BSe (BS when using the ECEC instead of the CEC). The effective CEC, adopted by several laboratories in Africa and America, involves the summation of bases in an 1 M NH_4OAc (pH 7) extract plus the 1 M KCl (unbuffered) exchangeble acidity (PARFIT 1980). This method is suitable for routine analyses, and the results show close agreement with net charge measurements (GALLEZ et al. 1976). In the monoliths studied, the ECEC can be as much as 2.5 times as low as the CEC.

Table III.5 Data related to the adsorption complex and the pH for the different horizons of the five monoliths (from transect LS).
+ For abbriviations, see text

Profile	Depth (cm)	Clay %	Org. C %	CEC pH=7	ECEC	Base meq / 100g	Exch.Ac meq / 100g	BS	BSe	Exch.cat. meq/100g Ca	Mg	Na	K	Al	pH 1:2.5 H_2O	KCl
CI-1	0- 7	19.4	3.11	8.9	6.6	6.5	0.1	73	98	5.3	1.0	0.0	0.1	0.0	5.9	4.8
	7- 20	33.4	1.32	5.1	2.6	1.4	1.2	28	54	0.8	0.5	0.1	0.0	1.1	4.9	3.8
	20- 45	50.1	1.05	5.9	3.2	0.3	2.9	6	9	0.0	0.2	0.1	0.0	2.7	4.4	3.6
	45- 70	64.8	0.68	5.3	3.1	0.2	2.9	4	7	0.0	0.2	0.0	0.0	2.4	4.6	3.7
	80-100	62.5	0.40	3.9	2.1	0.1	2.1	3	5	0.0	0.1	0.0	0.0	2.0	4.7	3.8
	115-135	57.2	0.26	3.9	2.5	0.3	2.1	7	14	0.0	0.1	0.2	0.0	2.0	4.6	3.8
	135-150	57.5	0.21	3.5	2.4	0.1	2.3	2	4	0.0	0.0	0.0	0.0	2.3	4.7	3.8
CI-2	0- 10	17.2	3.45	9.6	5.4	5.0	0.4	53	93	3.3	1.3	0.3	0.2	0.2	5.6	4.2
	10- 30	28.6	1.08	5.4	2.2	0.8	1.4	15	36	0.2	0.3	0.2	0.1	1.1	4.7	3.8
	40- 70	52.8	0.79	5.1	2.3	0.3	2.0	6	13	0.0	0.1	0.2	0.0	1.8	4.6	3.8
	80-100	45.8	0.43	5.1	2.5	0.4	2.1	8	16	0.0	0.1	0.2	0.0	1.8	4.6	3.8
	110-150	48.7	0.22	4.8	2.5	0.2	2.3	5	8	0.0	0.1	0.1	0.0	1.8	4.5	3.7
CI-3	0- 10	9.2	1.78	6.2	2.1	1.0	1.1	16	48	0.6	0.2	0.1	0.1	0.7	4.5	3.6
	10- 20	15.7	0.89	4.7	1.8	0.5	1.3	11	28	0.4	0.0	0.1	0.0	0.9	4.7	3.8
	30- 60	41.7	0.91	7.5	2.8	1.7	1.1	22	61	1.4	0.1	0.1	0.0	0.7	5.1	3.9
	100-130	48.4	0.43	6.2	1.9	0.6	1.3	10	32	0.4	0.2	0.1	0.0	0.9	5.0	3.9
CI-4	0- 8	10.5	0.93	2.3	1.3	0.5	0.8	23	38	0.2	0.2	0.0	0.1	0.7	4.3	3.8
	8- 30	22.8	0.65	3.0	1.5	0.2	1.3	6	13	0.0	0.2	0.0	0.0	1.2	4.4	3.8
	30- 50	31.7	0.50	3.2	1.7	0.1	1.6	4	6	0.0	0.1	0.0	0.0	1.6	4.4	3.8
	50- 80	36.5	0.47	2.8	1.7	0.1	1.6	5	6	0.0	0.1	0.0	0.0	1.6	4.5	3.8
	80-110	38.3	0.38	3.0	1.6	0.1	1.5	4	7	0.0	0.1	0.0	0.0	1.4	4.7	4.0
CI-5	0- 10	9.8	1.57	4.7	2.8	1.7	1.1	37	61	1.2	0.2	0.3	0.1	0.7	4.2	3.7
	10- 35	14.8	1.18	3.2	2.9	1.7	1.2	55	59	1.4	0.2	0.1	0.0	0.7	4.4	3.9
	40- 50	15.0	0.82	3.0	2.4	1.6	0.8	54	67	1.0	0.2	0.3	0.1	0.4	4.7	4.0
	50- 75	14.4	0.25	1.6	2.0	1.2	0.8	74	60	1.0	0.1	0.1	0.0	0.4	4.6	3.9
	75-100	16.0	0.27	4.0	2.0	1.2	0.8	29	60	1.0	0.1	0.1	0.0	0.4	4.7	3.9
	100-120	24.6	0.23	3.3	3.6	2.0	1.6	59	56	1.4	0.3	0.2	0.0	1.1	4.7	3.8

Exchangeble acidity, which is mainly aluminium, is high in these soils, only the surface soil of the summit and shoulder soils (CI-1 and -2) have negligible amounts. The BS is extremely low in the subsurface of all soils, except for the valley bottom one, see figure III.19. The surface soil of the summit and shoulder soils have relatively high BS, the soils of the slope, CI-3 and -4, have a very low BS and the valley bottom soil, CI-5 has an intermediate BS.

The pH of the surface soil , decreases downslope from medium acid (pH 5.9) to extremely acid (pH 4.2). the subsoil of all profiles is very strongly acid to extremely acid, except for CI-3 which has a strongly acid subsoil, see figure III.20. The difference between pH-H_2O and pH-KCl ranges from 0.5 to 1.4 units, the higher ΔpH found in the surface soil of CI-1 and -2 and the subsoil of CI-3 (1.1 - 1.4), and the lower values found in the surface soil of CI-4 and -5 (0.5).

Remarkable are the relatively high BS values for the CI-5 horizons at pH levels comparable with those of the subsurface horizons of the other profiles, which have much lower BS values.

III.2.6 Soil Colour and Drainage

The soil colour of the subsurface soil changes from red (2.5 YR) in the summit and shoulder soils, through yellowish brown (10 YR) with mottling in the lower solum (2.5 YR), slope soils, to light gray and white (5 Y- 10 Y) in in the valley, see figure III.21.

It is probably the change in iron crystallization which is responsable for this colour change. Formerly this change in hue with slope was attributed to the fact that soils lower on the slope remained moist for longer periods, with consequent hydratation of iron minerals. Haematite which forms under strongly oxidizing conditions causes a red colour, both CI-1 and -2 are red, wll drained soils.

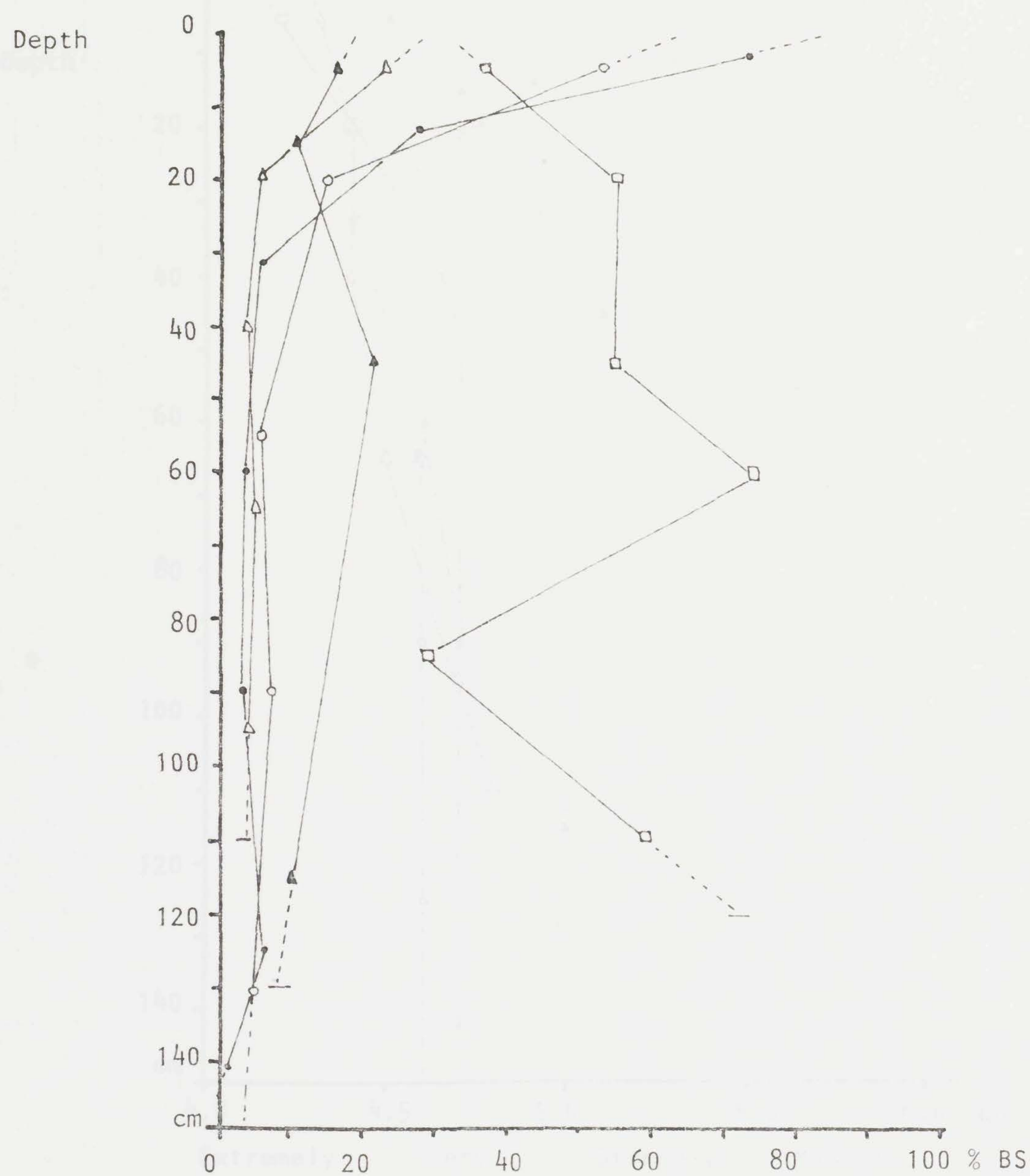


Figure III.19 Base Saturation (BS) with depth for the five monoliths of the catena studied.

- • monolith CI-1, summit
- o monolith CI-2, shoulder
- ▲ monolith CI-3, upper slope
- △ monolith CI-4, lower slope
- □ monolith CI-5, valley bottom
- depth to which profile is described

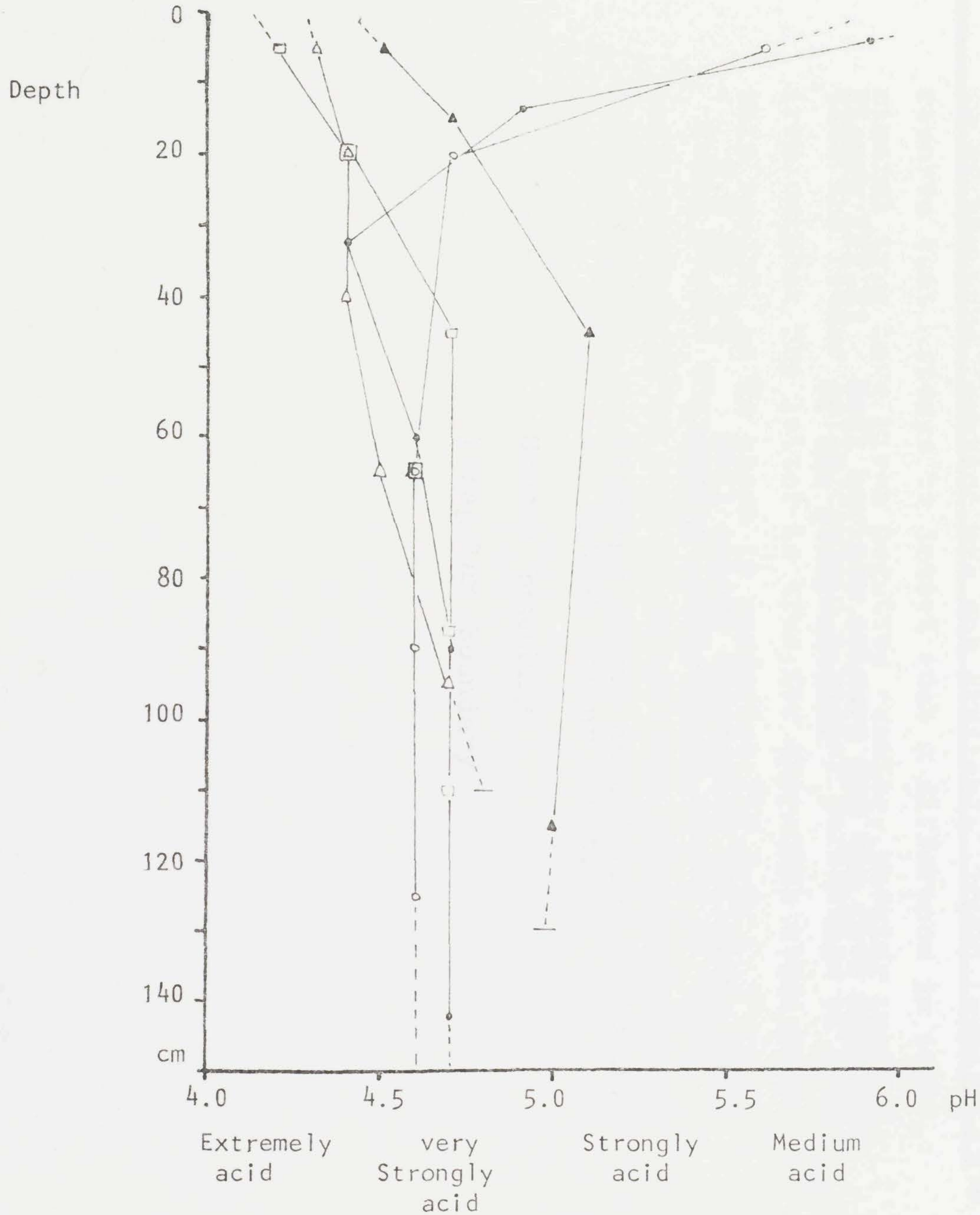


Figure III.20 pH-H_2O with depth for the five monoliths of the catena studied.

- • monolith CI-1, summit
- o monolith CI-2, shoulder
- ▲ monolith CI-3, upper slope
- Δ monolith CI-4, lower slope
- □ monolith CI-5, valley bottom
- depth to which profile is described

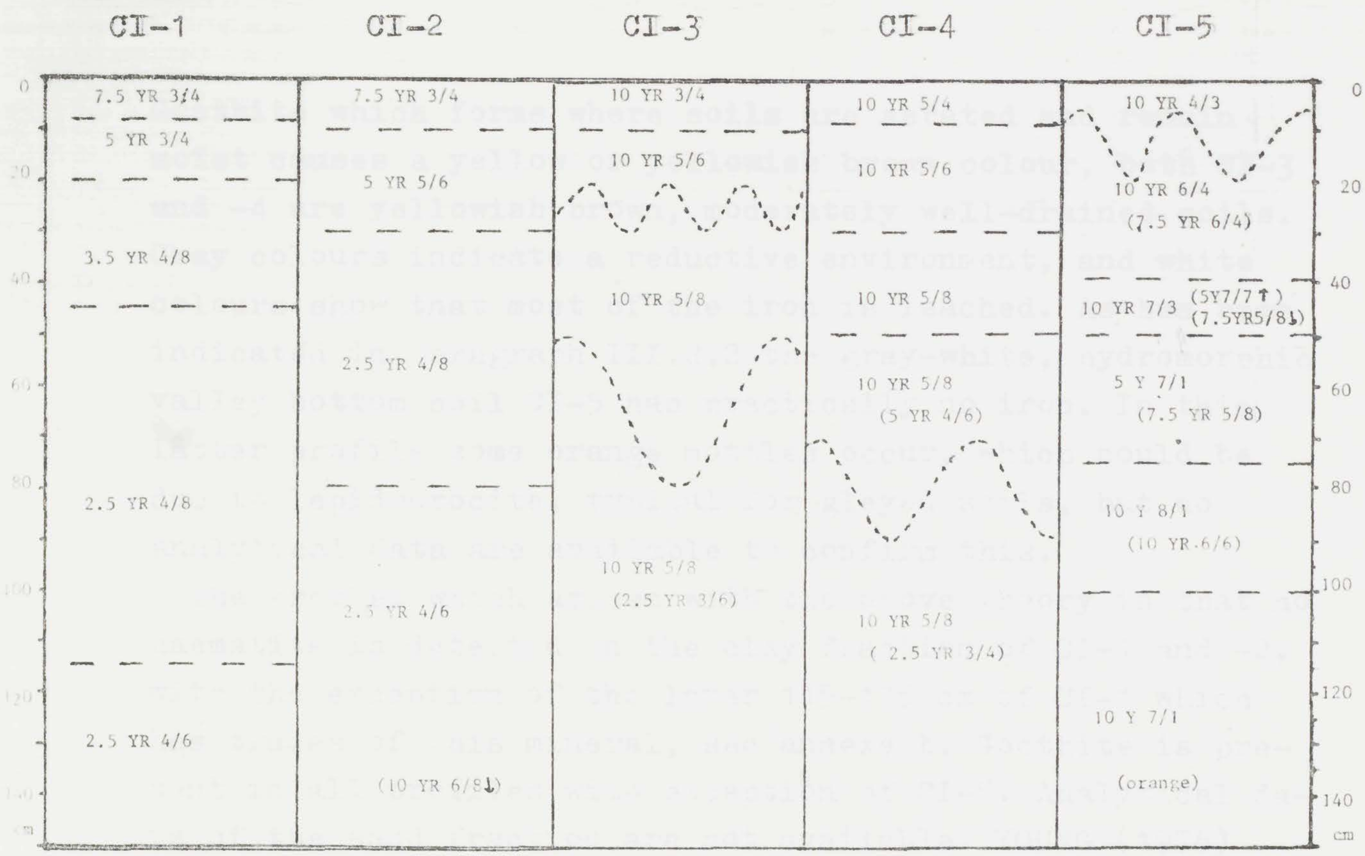


Figure III.21 Soil horizon colours for the five monolith of the study-catena.

2.5 YR 3/6	Soil colour desciption following the MUNSEL colour chart.
(10 YR 6/8)	Mottling colour description following the MUNSEL colour chart.
- - - -	Smooth boundary
∿∿	Irregular boundary

Goethite which forms where soils are aerated and remain moist causes a yellow or yellowish brown colour, both CI-3 and -4 are yellowish brown, moderately well-drained soils. Gray colours indicate a reductive environment, and white colours show that most of the iron is leached. As has been indicated in paragraph III.2.2 the gray-white, hydromorphic valley bottom soil CI-5 has practically no iron. In this latter profile some orange mottles occur, which could be due to lepidocrocite, typical for gleyed soils, but no analytical data are available to confirm this.

The problem which arises with the above theory is that no haematite is detected in the clay fraction of CI-1 and -2, with the exception of the layer 115-135 cm of CI-1 which has traces of this mineral, see annexe b. Goethite is present in all profiles with exception of CI-5. Analytical data of the sand fraction are not available. YOUNG (1976) reports that attemps to detect such a difference in iron mineral type have given negative results, showing instead that the redder soils contain a higher percentage of free iron oxides. The latter is true for the soils studied in this report, as is shown in paragraph III.2.2.

Young states that red colours can be caused by quite small quantities of very finely-divided amorphous iron oxides, which coat other minerals, including goethite.

The other constituent which is a colouring agent is organic matter and it is reflected in the dark brown (7.5 YR 3/4 and 10 YR 4/3) surface horizons. CI-4 with a low organic carbon content, see paragraph III.2.4, has a yellowish brown (10 YR 5/4) surface horizon. Some mottling due to organic matter occurs in the valley bottom soil along the roots.

III.2.7 Drainage and Erosion

The summit, CI-1 and the shoulder, CI-2 soils are well drained. No erosion or run off is observed near CI-1 and there is a fine textured dendritic surface drainage. Although CI-2 is situated where the slope gradient is smaller (5 % instead of 10 %), very slight sheet erosion and slow run off is seen, this is probably due to the fact that CI-2 is lower on the slope and the erosion starting above CI-2 is gaining momentous when CI-2 has been reached. There is a similar surface drainage.

The upper slope, CI-3 soil is moderately well-drained, with an initially rapid infiltration. Moderate splash erosion and slow run off are observed. Slight depositions occur, slope gradient and surface drainage are as above.

The lower slope, CI-4 soil is moderately well-drained. Moderate splash erosion and some white sand depositions are observed. There is a moderately fast run off and the infiltration is moderately rapid. The surface drainage is as for the others.

The valley bottom, CI-5 soil is poorly drained, though infiltration is rapid. Moderate splash erosion and rainwash occur and some sand depositions are observed. Flooding rarely occurs in the rainy season. There is slow run off, and the surface drainage is as for the others. The slope gradient is 4 %.

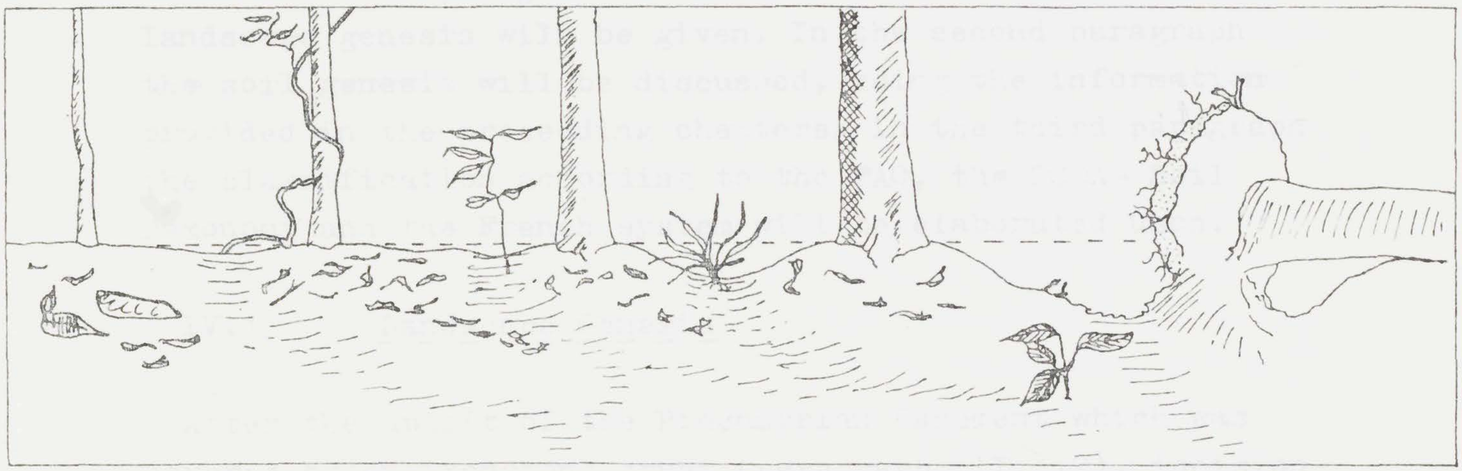
FRITSCH (1980) states that the upper part of the catena consist of vertically drained soils (CI-1 and -2), while the middle part, where the plinthite is near the surface consists of superficially and laterally drained soils (CI-3 and -4) and the lower part, the valley bottom consists of water-logged soils (CI-5), see figure III.9.

This difference in drainage has important consequences for the erosion, especially as they consider the aggressivity of the climate to be high. The calculated erosive capacity FRITSCH 1980, who quoted FOURNIER) is 52 (see *1 next page). Because the upper members of the catena have good permeability and internal drainage hardly any erosion is occurring. But the moderately drained, superficially and laterally draining slope soils lead to the occurrence of a marked erosion, during the rainy season. It concerns:

- sheet erosion, shown by a lighter colour of the surface soil by a concentration of coarser elements and by the exposure of the upper rootsheet.
- rill erosion that is observed by greater accumulation of coarser elements and by a total absence of litter after heavy rain storms.
- gully erosion. On the study-plot (figure III.9) VOOREN (1985) reports that a small gutter was initiated 50 m below the summit and gained in importance further down hill by gully erosion. It finally constituted a steep-sided ravine of 6 m deep and 10 m wide at the foot of the hill. According to FRITSCH (1980) gullies are numerous in the landscape.

VOOREN (1985) descibed another typical erosion process that causes uprooting in this forest and is found in the marshy valley bottoms and on its margins. Surface run off water creates on this flat sandy terrain a network of shallow streams, meandering around the bases of the larger trees. This slow process of surface water erosion places medium sized trees with their root-systems on micro-hillocks. They topple over in a final stage (figure III.22). This latter event may be triggered by a loss of soil cohesion during heavy rainfall.

*1 $C = p^2 / P$ C= erosive capacity of the climate;
p= precipitation of the most humid month;
P= mean annual precipitation.



Developmental series of micro-hillock formation by surface water erosion at the bases of middle-sized trees in the inferior slope section. Trees finally topple over (see text). Plates 7 and 8 illustrate the last two stages.

Figure III.22 (After VOOREN 1985)

IV SOIL GENESIS AND CLASSIFICATION

In the first paragraph of this chapter a summary of the landscape genesis will be given. In the second paragraph the soil genesis will be discussed, using the information provided in the preceeding chapters. In the third paragraph the classification according to the FAO, the USDA- Soil Taxonomy and the French system will be elaborated upon.

IV.1 Landscape Genesis

After the uplift of the Precambrian Basement which was covered by an ironstone crust (paragraph III.1.2), incision took place and gravel, eroded from the crust, was distributed along the slope (figure III.6, page 16). After a second uplift further incision took place and ironstone gravel moved downslope by further weathering and erosion of the older cap. Presumably, the very highly weathered soil material which covered the ironston crust moved down too and is now found on the slope, covering the gravel and filling the valley. In the valley bottom profile (CI-5) a stone line of quartz gravel is found at 100 cm depth of about 5 cm thick, AHN (1974) states that stonelines are marking the boundarey between overlying colluvial material and the underlying weathered substratum.

In the lower slope a plinthite layer was formed. Under drier climatic conditions than at present, the plinthite which was not covered by the ironstone gravel hardened and a new ironstone hardpan was formed. Actual erosion by gullies and rapids in the Cavally river make it plausible that a new base level lowering (i.e. relative uprise of the area) has occurred. This could have contributed to the hardening of the plinthite layer too.

IV.2 Soil Genesis

Under the current tropical rainy climate the soil forming processes are mainly ferralitic (FRITSCH 1980), i.e. intense chemical weatering with complete breakdown of all minerals except quartz. Complete leaching of soluble salts and carbonates, strong leaching of silica and to lesser extent iron and aluminium oxides. Sometimes deposition of hardening of iron oxides as concretions. Synthesis of kaolinite with some goethite and gibbsite, sometimes haematite in concretions, but not montmorillonite. Clay translocation absent in iron-rich soils, present in others. Formation of weak blocky structure, superimposed on fine crumb structure in iron-rich soils (YOUNG 1976, see paragraph III.1.3 as well).

In the upper part of the catena the red kaolinitic subsoil extends at the expense of the saprolite, and these soils are partly protected against erosion by their gravelly upper solum. As mentioned in paragraph III.2.3, clay eluviation and illuviation is taking place in thes vertically drained soils. Clay illuviation occurs also in the lower members of the catena, as was ascertained in the thin sections, but only in very small amounts.

The most striking feature of the middle and lower part of the catena is erosion. These superficially and laterally drained soils, probably caused by the plinthite or the laterite in the subsoil, are characterized by a highly impoverished colluvium covering a gravel or (petro)plinthite layer. The erosion measured by CASENAVE et al. (1980) was roughly 1 metric ton/ ha/ year. This has to come from the middle and lower part of the catena. In the valley hardly any enrichment is found apart from a somewhat higher base saturation and organic matter content. This is probably due to the fact that the valley is studied in the upstream part of the drainage basin (see figure III.2, page 8), and erosion is still remarkable.

IV.3 Classification

All soils of the catena are highly weathered and are classified by FRITSCH (1980, using the French system of the 'Commision de Pédologie et de Cartographie des Sols' from 1967) as "sol ferralitique fortement désaturé", except for the valley bottom which is classified as "sol hydromorph". The exact classification is given in table IV.1, in which the classification of the soils of the study-catena according to the French, the American (USDA-Soil Taxonomy, 1975) and the FAO (1974) system are compared.

Using Soil Taxonomy, these soils belong either to the paleo and plinthic great group of the Ultisols or to the Oxisols. Although the summit (strict sense) and the valley bottom soils are made up of very highly weathered material (in the latter only traces of illite are found) they are classified in other orders. The summit (SS, above CI-1) soil being a Troporthent because of the shallow soil layer om the ironstone hardpan and the valley bottom soil being a Tropaquent because of the sandy character (lee than 15 % clay) which excludes it from being an Oxisol.

In the FAO system the soils are Acrisols and Ferralsols, with in the valley Gleysols and on the summit (SS) a Regosol.

The American and FAO systems are quite well comparable, only for the summit slope (CI-1) and the shoulder (CI-2) soils a difference is found: Humults would be expected to correlate with Humic Acrisols, but this does not work out well in our case, because of different criteria for the content of organic carbon. In Soil Taxonomy a percentage of 0.9 in the upper 15 cm of the argillic horizon is sufficient to classify a soil as Humult, while in the FAO system a percentage of 1.5 is needed in the upper part of the B horizon to classify it as a Humic Acrisol.

The difference between the two systems above and the French system is rather striking. The latter has used the pedogenetic or inherited degree of strong weathering at a

Table IV.1 Comparising of classification of the soils in the study-catena, between the French, American and the FAO system.

Position in catena	monolith number	French system	American system	FAO system
Summit strict sense	non	sol ferrallitique fortement désaturé, rémanié, induré.	Typic Troporthent, clayey-skeletal, kaolinitic, isohyperthermic	Dystric Regosol
Summit Slope	CI-1	sol ferrallitique fortement désaturé, rémanié modal	Orthoxic Palehumult, clayey-skeletal, kaolinitic, isohyperthermic	Ferric Acrisol
'shoulder'	CI-2	sol ferrallitique fortement désaturé, rémanié, faiblement appauvri	Orthoxic Palehumult clayey-skeletal, kaolinitic, isohyperthermic	Ferric Acrisol
Upper and Middle slope	CI-3	sol ferrallitique fortement désaturé, à recouvrement plus ou moins appauvri	Plinthudult (--Plinthic Haplorthox) clayey-skeletal, kaolinitic, isohyperthermic	Plinthic Acrisol (--Plinthic Ferralsol)
Lower slope	CI-4	sol ferrallitique fortement désaturé, induré appauvri, hydromorph	Tropeptic Haplorthox fine loamy over loamy-skeletal, mixed, isohyperthermic	Xantic Ferralsol
Valley bottom	CI-5	sol hydromorph, peu humifère, à amphigley à nappe phreatique profond	Tropaquent, coarse loamy, mixed, isohyperthermic	Dystric Gleysol

high catagorical level, while in Soil Taxonomy the presence of the argillic horizon is recognized as a diagnostic property at the highest (order) level (MOORMANN, unpublished paper). The presence of the argillic horizon, as studied in paragraph III.2.3, was difficult to determine. Increase in clay content was significant in all soils and whether or not the clay cutans seen in the thin sections are enough to classify as argillic is difficult to decide for soils with low amounts in the lower part of the B horizon and with difficulties to sample the very gravelly horizons above.

V AGRICULTURAL CONSTRAINTS AND QUALITIES

The list of constraints mentioned by FRITSCH (1980) for the soils on the study-catena and in the region is long, nevertheless these soils have some qualities too.

An important constraint is the gravel layer, which is thick, rich in gravel and at the surface in the upper part of the catena. An extra restriction for the summit (strict sense) soil is the ironstone hardpan at shallow depth. For the upper and middle slope (CI-3) the restriction in relation to the gravel is somewhat less, as the layer is thinner, less gravelly and covered by a non-gravelly colluvium. In the lower slope no gravel is present, but here petroplinthite forms a constraint.

A second, common constraint is the low organic stock, which is very low from the upper slope down. Although somewhat higher in the upper part of the catena, the stock is mainly limited to the upper 10 cm.

Other constraint are: (1) a sandy surface soil; (2) a poor structure; (3) a low waterholding capacity, this holds true for both the shoulder and summit (SS) soils; (4) manifestation of hydromorphism, especially in the valley bottom soils, which have a groundwater level oscillating between 40 and 80 cm. These soils have in addition a somewhat porous massive subsoil.

The qualities stated by FRITSCH (1980) are different for the different soils. The summit slope soil (CI-1) has a relatively favorable structure compared with the other soils, notably the layers cloured by organic matter. It has a better waterholding capacity and a good internal drainage. The red slightly gravelly subsoil of the shoulder soil has thes qualities too. The quality of the lower slope soil (CI-4) is the absence of gravel, which holds true for the valley bottom soil (CI-5) as well.

Other, more chemical, contraints are, as we have seen in paragraph III.2.5, the low to very low CEC values, the low content of exchangeable bases and the high aluminium saturation of the adsorption complex of most soils. The Al saturation values are given in table V.1.

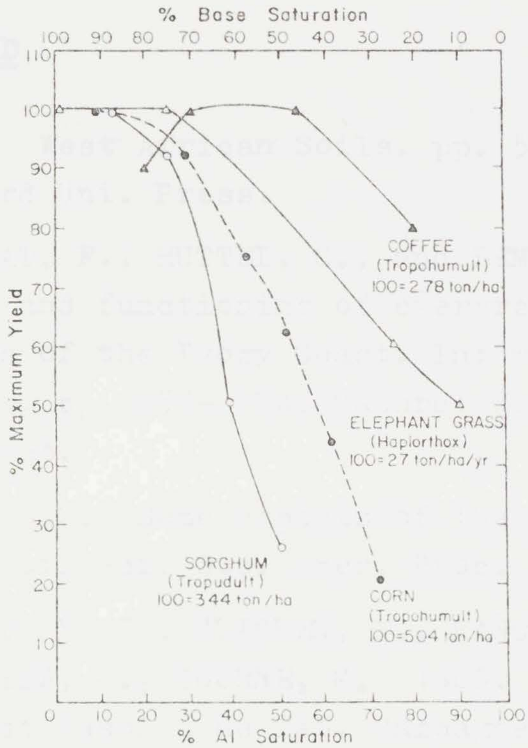
Table V.1 Aluminium Saturation Percentage for the five monoliths of the study-catena at different depth.

depth/mon. no.	CI-1	CI-2	CI-3	CI-4	CI-5
0- 10	0	4	33	54	25
10- 20	42	50	50	80	24
20- 40	84		25	94	17
40- 60	77	78		94	20
60- 80					
80-100	97	72		93	20
100-120	80		47		31
120-150	96	72			

+ in cm, this is not the exact sampling depth

SANCHEZ (1976) shows how poor crop growth in acid soils can be directly correlated with aluminium saturation. Figure V.1 illustrates this for several crops, and indicates that liming would resolve the problem.

So although the high Al-saturation is a restriction for all soils, except the valley bottom one, with liming this could be neutralized.



Yield responses to liming in Puerto Rican Oxisols and Ultisols. *Source:* Compiled from Abruña et al. (1964, 1965, 1975).

Figure V.1 (After SANCHEZ 1976)

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ANNEX A

DESCRIPTION OF INDIVIDUAL SOIL PROFILES

IV Profile Description:

O 3 to 4 layers of leaves in various stages of decomposition.

Ahcs 0- 7 Dark brown (7.5 YR 3/4, moist), very gravelly sandy loam; moderate fine and medium subangular blocky; slightly sticky, slightly plastic when wet and friable when moist; very frequent medium and large hard spherical ironstone concretions; very few medium quartz fragments; many very fine to fine interstitial and few micro to fine tubular pores; many fine to coarse roots; clear smooth boundery; medium acid, pH 5.9.

BAcs 7- 20 Dark reddish brown (5 YR 3/4, moist), very gravelly sandy clay loam; structure as above; sticky, plastic when wet and friable when moist; concretions, fragments and pores as above; common fine to coarse roots; gradual smooth boundery; very strongly acid, pH 4.9.

Btcs 1 20- 45 Red (3.5 YR 4/8, moist), very gravelly clay; moderate medium angular blocky; skeletans; consistance, concretions, fragments and pores as above; few fine roots; diffuse smooth boundery; extremely acid, pH 4.4.

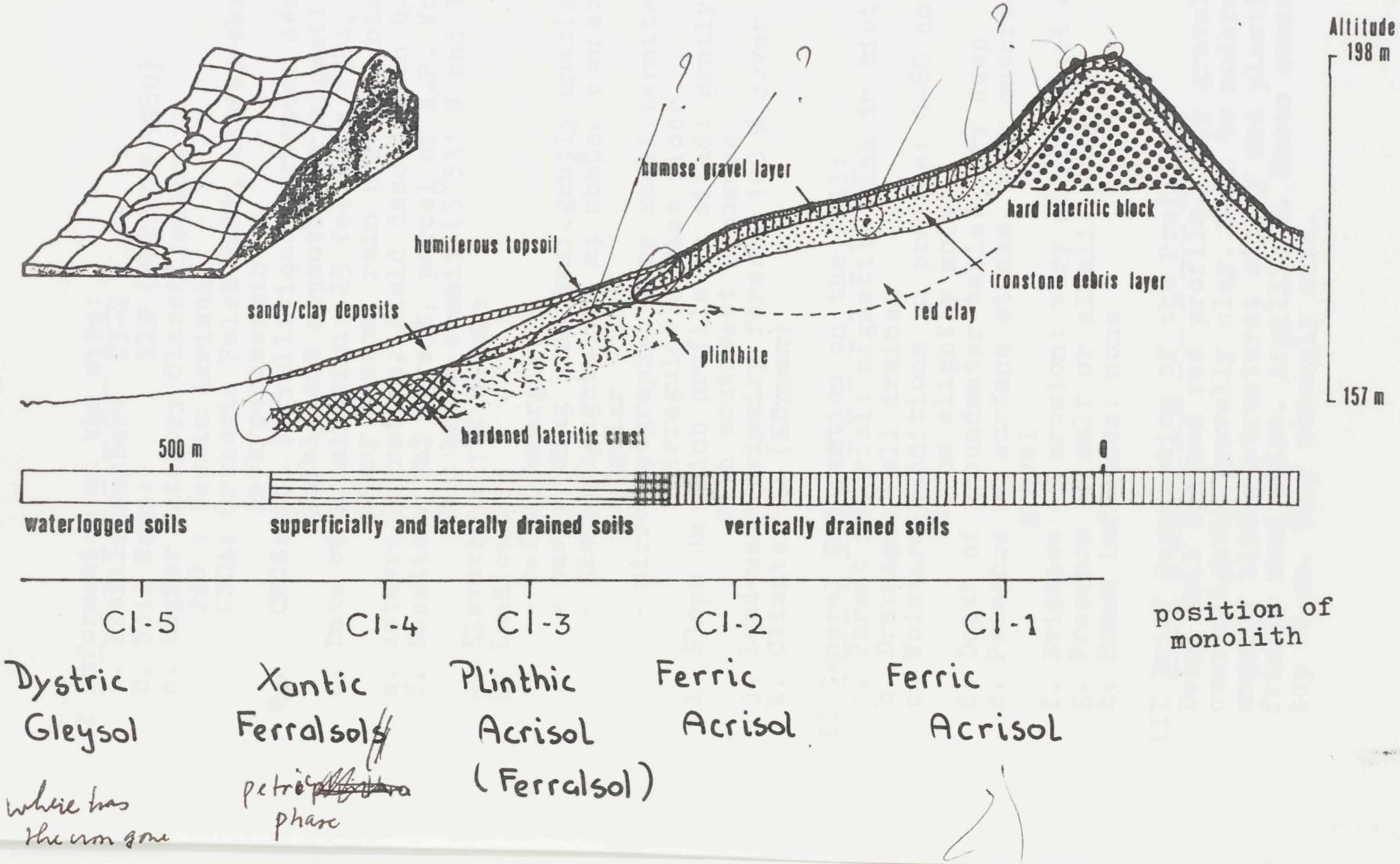
Btcs 2 45-115 Red (2.5 YR 4/8, moist), very gravelly clay; structure, cutans, consistance, fragments as above; common very fine to fine interstitial and few micro to very fine pores; very few very fine roots; gradual smooth boundery; very strongly acid, pH 4.6.

2Btcs3 115-135 Red (2.5 YR 4/6, moist), slightly gravelly clay; moderate fine subangular blocky; cutans and consistance as above; few medium and large hard spherical ironstone concretions; common very fine and many fine tubular pores; very few very fine roots; clear smooth boundary; very strongly acid, pH 4.6.

2Bws 135-160 Slightly gravelly clay; moderate very fine and fine angular blocky; broken thin clay-iron cutans; consistance as above; few medium hard spherical ironstone concretions; few very fine tubular pores; very few very fine roots; very strongly acid pH 4.7.

Figure III.9

Slope profile of the study-plot with toposequential soil series and predominanting drainage types. Soil horizons are after FRITSCH (1980, transect LS), figure from VOOREN (1985). Vertical scale is exaggerated.



A Study of a Catena in the Taï Forest, Ivory Coast

25

Dico Fraters

14 november 1986

PROFILE CI-2

I Information on the site:
a. Profile number: CI-2
b. Soil Name: IIB (FRITSCH 1980)
c. Higher Category Classification:
FAO : ferric Acrisol
USDA: Orthoxic Palehumult, clayey-skeletal, kaolinitic isohyperthermic
CPCS: Sol Ferrallitique fortement désaturé, rémanié, faiblement appauvri sur migmatites
d. Date of Examination: 29 february 1984, beginning of the rainy season, rain previous night
e. Author: B Fraters, field description by A J van Kekem
f. Location: Taï forest, parcel of A.P. Vooren, on shoulder below summit (5°53' N and 7°20' W)
g. Elevation: 173 meters
h. Landform:
- relief energie:
- surrounding landform: gently undulating to rolling
- slope: lenght= 500 m; shape= concave; pattern= regular
- microtopography: some small termite mounds (<60 cm), irregular forest floor
i. Slope on which profile is sited: gently sloping (5 %), with southwest exposure
j. Land-use: primairy forest, 100 % cover
k. Climate: Aw (Köppen)

II General Information on the Soil:
a. Parent material: migmatite rich in biotite
b. Drainage: well drained
c. Moisture conditions in profile: 0-80 cm moist and below 80 cm slightly moist
d. Depth of groundwater table: very deep
e. Presence of surface stones, rock outcrops: ironstone gravel
f. Evidence of erosion: very slight sheet erosion
g. Presence of salt or alkali: none
h. Human influence: none

III Brief Description of the Profile:
Deep, well drained red profile, very gravelly clay (80 cm) over slightly gravelly clay. Weak to moderate fine (sub) angular blocky structure; sticky and plastic when wet, friable when moist. Argillic B. Roots concentrated in the top 20 cm. Very strongly acid.

IV Profile Description:

O 2 to 3 layers leaves, rapidly decomposing.

Ahcs 0- 10 Dark brown (7.5 YR 3/4, moist), very gravelly sandy loam; weak fine subangular blocky; slightly sticky, slightly plastic when wet and very friable when moist; very frequent medium and large hard spherical ironstone concretions with black patina; many micro interstitial and medium tubular pores; many fine, medium and coarse roots; clear smooth boundary; medium acid, pH 5.6.

Bcs 10- 30 Yellowish red (5 YR 5/6. moist), very gravelly sandy clay loam; moderate fine subangular blocky; sticky, plastic when wet and friable when moist; concretions as above with dark reddish brown (5 YR 3/2) inside colour; common fine and medium exped intertitial and many micro to fine inped and exped tubular pores; few fine roots; gradual smooth boundary; very strongly acid, pH 4.7.

Btcs 30- 80 Red (2.5 YR 4/8, moist), very gravelly clay; structure, consistance and concretions as above; many very fine and fine discontinuous interstial and tubular pores; very few fine roots; diffuse smooth boudary; very strongly acid, pH 4.6.

2Bt 80-150 Red (2.5 YR 4/6, moist), slightly gravelly clay; few fine prominent clear brownish yellow (10 YR 6/8) mottles; moderate fine and medium angular blocky; broken and continuous moderately thick clay-iron cutans; sticky, plastic when wet and friable to firm when moist; few medium slightly hard angular clay and iron concretions with red (2.5 YR 4/6) colour; common very fine tubular and interstitial pores; very few fine roots; very strongly acid, pH 4.6.

PROFILE CI-3

I Information on the site:
a. Profile number: CI-3
b. Soil Name: III (FRITSCH 1980)
c. Higher Category Classification:
FAO : plintic Acrisol
*1 USDA: Plinthudult, clayey-skeletal, kaolinitic, iso-hyperthermic
d. Date of Examination: Mars 1 1984, beginning of the rainy season, dry
e. Author: B Fraters, field description by A J van Kekem
f. Location: Taï forest, parcel of A.P. Vooren, upper - slope below shoulder (5°53' N and 7°20' W)
g. Elevation: 165 meters
h. Landform:
- relief energie:
- surrounding landform: gently undulating to rolling
- slope: lenght= 500 m; shape= concave; pattern= regular
- microtopography: few small termite mounds, irregular forest floor with earthworm casts
i. Slope on which profile is sited: gently sloping (5 %), with southwest exposure
j. Land-use: primairy forest, 100 % cover
k. Climate: Aw (Köppen)

II General Information on the Soil:
a. Parent material: migmatite rich in biotite
b. Drainage: moderately drained, mainly superficially and laterally
c. Moisture conditions in profile: slightly moist troughout
d. Depth of groundwater table: unknown (deep ?)
e. Presence of surface stones, rockoutcrops: ironstone gravel, fairly to slightly gravelly
f. Evidence of erosion: moderate splash erosion, slight deposition
g. Presence of salt or alkali: none
h. Human influences: none

III Brief Description of the Profile:
Deep, moderately drained yellowish brown profile, very gravelly sandy clay over clay; moderate fine (sub)angular blocky structure; from nonsticky and non plastic to sticky and plastic when wet, and from very friable to friable when moist. Argillic B on plinthite. Rootsconcentrated in the upper 10 cm; very strongly to strongly acid.

*1 CPCS: Sol Ferrallitique fortement désaturé, remanié, à recouvrement plus ou moins appauvri sur les alterations de migmatites en place

IV Profile Description:

O Fast decomposing leaves, $\approx \frac{1}{2}$ cm

Ah 0- 10 Dark brown (10 YR 4/3, moist), slightly gravelly loamy sand; weak fine subangular blocky; non sticky, non plastic when wet and very friable when moist; few medium hard ironstone spherical concretions with black patina coating; many micro tubular and medium interstitial pores; many fine, medium and coarse roots; clear smooth boundary; very strongly acid, pH 4.5.

BAcs 10- 20/28 Yellowish brown (10 YR 5/6, moist), very gravelly sandy loam; moderate fine subangular blocky; slightly sticky, slightly plastic when wet and very friable when moist; very frequent medium hard spherical dark reddish brown (2.5 YR 3/4) ironstone concretions with black patina; many very fine and fine continuous tubular and inped interstitial pores; very few fine roots; gradual irregular boundary; very strongly acid, pH 4.7.

Btcs 20/28- 50/80 Yellowish brown (10 YR 5/8, moist), very gravelly sandy clay; moderate very fine and fine angular to subangular blocky; sticky and plastic when wet and friable when moist; concretions as above; very few small weathered quartz fragments; many very fine discontinuous tubular and fine inped and exped interstitial pores; roots as above; clear irregular boundary; strongly acid, pH 5.1.

2Bs 50/80-150 Yellowish brown (10 YR 5/8, moist), clay; many coarse distinct clear dark red (2.5 YR 3/6) mottles; weak to moderate fine falling apart to very fine angular blocky; clay-iron cutans around gravel; consistance as above; very frequent medium and large slightly hard irregular clay-iron nodules (PLINTHITE); at 120 cm quartz vein, broken 2-4 mm; many very fine and fine discontinuous inped and exped tubular and interstitial pores and few medium and coarse exped interstitial pores; roots as above; strongly acid, pH 5.0 (the big pores are lined with humus and clay cutans).

PROFILE CI-4

I Information on the site:
  a. Profile number: CI-5
  b. Soil Name: IVA (FRITSCH 1980)
  c. Higher Category Classification:
     FAO : xantic Ferralsol
     USDA: Tropeptic Haplortox, fine loamy over loamy-skeletal, mixed, isohyperthermic
     CPCS: Sol Ferrallitique fortement désaturé, induré, appauvri, hydromorphe, sur colluvions recouvrant les alterations de migmatites
  d. Date of Examination: March 1 1984, beginning of rainy season, dry
  e. Author: B Fraters, field description by A.J.van Ke m
  f. Location: Taï forest, parcel of A.P. Vooren, lower-slope (5°53' N and 7°20' W)
  g. Elevation: 160 meters
  h. Landform:
     - relief energy:
     - surrounding landform: gently undulating to rolling
     - slope: lenght= 500 m; shape= rectilinear; pattern= regular
     - microtopography: very many earthworm casts, 5 cm high
  i. Slope on which profile is sited: gently sloping (5 %), with southwest exposure
  j. Land-use: primairy forest, 100 % cover
  k. Climate: Aw (Köppen)

II General Information on the Soil:
  a. Parent material: colluvium on altered migmatite rich in biotite
  b. Drainage: moderately drained, mainly superficially and laterally
  c. Moisture conditions in profile: moist throughout
  d. Depth of groundwater table: highest (?) 80 cm, lowest very deep
  e. Presence of surface stones, rock outcrops: none
  f. Evidence of erosion: moderately splash erosion, some white sand deposition
  g. Presence of salt or alkali: none
  h. Human influences: none

III Brief Description of the Profile:
Moderately deep, yellowish brown, moderately drained profile. Sandy clay loam over very gravelly clay loam. Moderate medium angular falling apart to weak very fine subangular blocky structure over massive strongly coherent; sticky, plastic and friable over very firm, very compact. Oxic B over petro-plinthite. Roots concentrated in the upper 30 cm. Extremely acid.

IV Profile Description:

0 2 to 3 leaves, rapidly decomposing.

Ah 0- 8 Yellowish brown (10 YR 5 4, moist), sandy loam; moderate very fine and fine subangular blocky; non sticky, non plastic when wet and very friable when moist; many micro interstitial and many fine tubular pores; many fine, medium and coarse roots; gradual smooth boundery; extremely acid, pH 4.3.

Bws1 8- 30 Yellowish brown (10 YR 5/6, moist), sandy clay loam; weak fine subangular blocky; slightly sticky,plastic when wet and friable when moist; many fine interstitial and many very fine tubular pores; few fine and medium roots; gradual smooth boundary; extremely acid, pH 4.4.

Bws2 30- 50 Yellowish brown (10 YR 5/8, moist), sandy clay loam; sticky, plastic when wet and friable when moist; moderate fine and medium angular falling apart to weak very fine subangular blocky; pores and roots as above; diffuse smooth boundary; extremely acid, pH 4.4.

Bws3 50- 70/90 Yellowish brown (10 YR 5/8, moist),few fine faint clear yellowish red (5 YR 4/6) mottles; sandy clay; moderate medium angular falling apart to weak very fine subangular blocky; consistence as above; few small soft and hard spherical ironstone nodules; many very fine and common fine tubular and intertitial pores; roots as above; abrupt irregular boundary; very strongly acid, pH 4.7.

Bms 70/90-110 Yellowish brown (10 YR 5/8, moist), very gravelly clay loam; massive, strongly coherent, slightly cemented; sticky, plastic when wet and very firm, very compact when moist; very frequent medium and large hard irregular ironstone concretions (inside colour: dark reddish brown (2.5 YR 3/4); few very fine and fine discontinuous vesicular pores; few fine and medium roots; very strongly acid, pH 4.7.

Petro-plinthite, in the field described by Van Kekem as having only 20 % soil,the rest being ironstone breaking up into hundreds of gravels (2-10 mm), irregular formed, strongly coherent iron concretions (porous) massive, not continuously indurated.

PROFILE CI-5

I Informatin on the site:
a. Profile number: CI-5
b. Soil Name: VA (FRITSCH 1980)
c. Higher Category Classification:
FAO : dystric Gleysol
USDA: Tropaquent, coarse loamy, mixed, isohyperthermic
CPCS: Sol Hydromorphe peu humifère, à amphi-gley, à nappe phréatique profonds sur colluvions
d. Date of Examination: January 26 1985, dry season, rain once a week
e. Author: B Fraters, field description by A.J.van Kekem
f. Location: Taï forest, parcel of A.P. Vooren, valley bottom (5°53' N and 7°20' W)
g. Elevation: 155 meters
h. Landform:
- relief energy
- surrounding landforms: gently undulating to rolling
- slope: lenght= 500 m; shape= concave; pattern= regular
microtopography: irregular forest floor
i. Slope on which profile is sited: gently sloping (4 %), with northeast exposure
j. Land-use: primairy forest, 100 % cover
k. Climate: Aw (Köppen)

II General Information on the Soil:
a. Parent material: colluvium on altered migmatites rich in biotite
b. Drainage: poorly drained
c. Moisture conditions in profile: moist throughout
d. Depth of groundwater table: high= 40 cm, low= 80 cm
e. Presence of surface stones, rock outcrops: none
f. Evidence of erosion: moderately splash erosion and rainwash, some depositions
g. Presence of salt or alkali: none
h. Human influences: none

III Brief Description of the Profile:
Deep, poorly drained, light yellowish brown over light gray profile. Sandy loam, porous massive, weakly coherent structure, slightly sticky, slightly plastic when wet and very friable when moist. Strong brown mottling. Water table between 40 and 80 cm. Roots concentrated in the upper 20 cm. Very strongly acid.

IV Profile Description:

O Few leaves, rapidly decomposing.

Ah 0- 5/20 Dark brown (10 YR 4/3, moist), sandy loam; moderate very fine to medium subangular blocky; non sticky, non plastic when wet and very friable when moist; many micro tubular and fine interstitial pores; many very fine and coarse roots; gradual irregular boundary; extremely acid, pH 4.2.

Bws 5/20- 37 Light yellowish brown (10 YR 6/4, moist), sandy loam; mottling increases with depth to few fine faint diffuse strong brown (7.5 YR 5/8) mottles; weak fine subangular blocky; slightly sticky, slightly plastic when wet and very friable when moist; many micro and fine tubular pores; common fine, medium and coarse roots, along them often organic matter mottles; gradual smooth boundary; extremely acid, pH 4.4.

BCg 37- 50 Very pale brown (10 YR 7/3, moist), sandy loam; from common fine distinct diffuse yellow (5 Y 7/7) to many fine distinct clear strong brown (7.5 YR 5/8) mottles; porous massive, weakly coherent; consistence as above; common micro and fine tubular pores; few fine and medium roots; clear smooth boundary; very strongly acid, pH 4.7.

Cr 1 50- 75 Light gray (5 Y 7/1, moist), sandy loam; commen fine prominent clear strong brown (7.5 YR 5/8) mottles; structure, consistence and roots as above; common micro and very fine tubular pores; gradual smooth boundary; very strongly acid, pH 4.6.

Cr 2 75-100 White (10 Y 8/1, moist), sandy loam; few very fine distinct diffuse brownish yellow (10 YR 6/6) mottles; structure and consistance as above; few micro and very fine tubular pores; very few very fine and fine roots; clear smooth boundary; very strongly acid, pH 4.7.

2Cr 100-120 White (10 Y 7/1, moist) sandy clay loam; very few very fine orange mottles and few organic mottles ; structure and consistance as above; at 100-105 cm layer of coarse (1-5 cm) quartz gravel, subangular; common very fine and fine tubular pores; no roots; very strongly acid, pH 4.7.

ANNEX B

LABORATORY ANALYSES

Analyses are done by the International Soil Reference and Information Centre laboratory.

I.S.M. CI-1 YEAR 1985 Country Ivory Coast

	Depth cm	Gravel >2 mm	Particle size distribution (um in weight %) sand 2000–1000	sand 1000–500	sand 500–250	sand 250–100	sand 100–50	silt 50–20	silt 20–2	clay <2	Water disp. clay	pH 1:2.5 H$_2$O	pH 1:2.5 KCl	CaCO$_3$ %	SpS m^2.g^{-1}			Org. Matter C %	N %
7	0-7	76 %	4.9	2.9	17.0	29.2	12.7	8.5	5.3	19.4	5.3	5.9	4.8					3.11	
8	7-20	75 %	3.0	1.8	11.6	22.6	11.2	9.5	6.9	33.4	14.5	4.9	3.8					1.32	
9	20-45	77 %	3.5	2.5	7.5	12.5	7.6	9.3	7.0	50.1	27.2	4.4	3.6					1.05	
0	50-70	75 %	4.8	1.5	4.0	6.6	4.4	6.4	7.5	64.8	0.5	4.6	3.7					0.68	
1	80-100	71 %	5.4	1.6	3.9	6.4	4.2	5.8	10.2	62.5	0.5	4.7	3.8					0.40	
2	115-135	8 %	1.3	1.1	3.9	6.3	4.2	9.9	16.0	57.2	0.0	4.6	3.8		75			0.26	
3	135-150	7 %	0.9	0.6	3.3	5.7	4.3	9.5	18.3	57.5	0.0	4.7	3.8					0.21	

…th diffraction

…no.	sand 2000–50	silt 50–20	silt 20–2	clay <2
352	17.7	6.7	18.0	57.6

corr: 1.3

Exchangeable cations meth.: EXTRACTOR pH: 7.0

Sample no.	Ca	Mg	Na	K	sum	CEC	CEC cl.	B.S. (%)	EC 1:2.5 mS/cm	Na-Dit extr. Fe	Na-Dit extr. Al	Na-Dit extr. Si	Mn	Amm.Ox. extr. Fe	Amm.Ox. extr. Al	Amm.Ox. extr. Si	Na-[illegible] extr. Fe	Na-[illegible] extr. Al
	-(meq/100g)-									--- % ---								
5/347	5.3	1.0	0.0	0.1	6.5	8.9		73	0.16	2.66	0.36	0.07	0.01	0.23	0.07	0.01	n.a.	n.a.
/348	0.8	0.5	0.1	0.0	1.4	5.1		28	0.05	3.67	0.57	0.09	0.00	0.36	0.09	0.01	n.a.	n.a.
/349	0.0	0.2	0.1	0.0	0.3	5.9		6	0.03	4.37	0.79	0.08	0.01	0.22	0.11	0.01	n.a.	n.a.
/350	0.0	0.2	0.0	0.0	0.2	5.3		4	0.02	5.53	0.92	0.11	0.01	0.18	0.12	0.02	n.a.	n.a.
/351	0.0	0.1	0.0	0.0	0.1	3.9		3	0.02	5.30	0.82	0.11	0.01	0.18	0.12	0.02	n.a.	n.a.
/352	0.0	0.1	0.2	0.0	0.3	3.9		7	0.02	5.21	0.69	0.11	0.01	0.13	0.09	0.02	7.29	0.87
/353	0.0	0.0	0.0	0.0	0.1	3.5		2	0.02	5.44	0.74	0.15	0.01	0.13	0.10	0.03	n.a.	n.a.

(n.a.=not analysed)

4 mg 2g Soil 3g DCK

Code ISM CI-1 Year 1985 Country Ivory Coast

Lab. no.	depth cm	SiO_2	Al_2O_3	Fe_2O_3		CaO	MgO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	BaO	ign. loss	Σ	SiO_2/Al_2O_3	SiO_2/Fe_2O_3	SiO_2/R_2O_3	Al_2O_3/Fe_2O_3
		elemental composition of the total soil (weight %)														Molar ratios			
347	0-7	75.93	7.21	7.66		0.22	0.08	0.04	0.0	0.78	0.03	0.06	0.00	8.34	100.35	17.9	26.3	10.6	1.5
348	7-20	70.09	11.82	8.59		0.01	0.08	0.05	0.0	1.05	0.02	0.05	0.00	7.48	99.24	10.1	21.7	6.9	2.2
349	20-45	59.95	18.15	11.52		0.00	0.10	0.06	0.0	1.36	0.03	0.07	0.00	9.51	100.75	5.6	13.8	4.0	2.5
350	50-70	49.19	23.27	14.18		0.00	0.09	0.05	0.0	1.50	0.03	0.08	0.00	11.13	99.52	3.6	9.2	2.6	2.6
351	80-100	49.41	23.84	13.86		0.00	0.11	0.05	0.0	1.44	0.03	0.06	0.00	10.66	99.46	3.5	9.5	2.6	2.7
352	115-135	48.26	26.03	12.47		0.00	0.10	0.08	0.0	1.47	0.03	0.05	0.00	10.91	99.40	3.1	10.3	2.4	3.3
353	135-150	49.37	25.91	11.89		0.00	0.10	0.09	0.0	1.44	0.03	0.06	0.00	10.86	99.75	3.2	11.0	2.5	3.4

Lab. no.		SiO_2	Al_2O_3	Fe_2O_3		CaO	MgO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	BaO	ign. loss	Σ	SiO_2/Al_2O_3	SiO_2/Fe_2O_3	SiO_2/R_2O_3	Al_2O_3/Fe_2O_3
		elemental composition of the clay fraction (weight %)														Molar rations			

Code ISM CI-1 Year 1985 Country Ivory Coast

Lab. no.	Depth cm	Kaol	Mi/Ill	Verm	Soil- Chlor	Smec	Mix	Quar	Feld	badly cryst Gibb	Goeth	Hem
5-347	0-7	+++		tr-+	tr.					tr-x	x	
348	7-20	+++		tr.	tr-+					tr-x	x	
349	20-45	+++		0-tr.	tr-+					tr-x	x	
350	50-70	+++		–	+					tr-x	x	
351	80-100	+++		–	+					tr-x	x	
352	115-135	+++		–	tr-+					tr-x	x	tr
353	135-150	+++		–	tr-+					tr-x	x	

Sand mineralogy

Lab. no.	

Code ISM CI-2 Year 1985 Country Ivory Coast

Lab. no.	depth cm	SiO_2	Al_2O_3	Fe_2O_3		CaO	MgO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	BaO	ign. loss	Σ	SiO_2/Al_2O_3	SiO_2/Fe_2O_3	SiO_2/R_2O_3	Al_2O_3/Fe_2O_3
		elemental composition of the total soil (weight %)														Molar ratios			
-354	0-10	75.32	7.38	8.65		0.07	0.09	0.04	0.0	0.75	0.04	0.05	0.00	9.03	101.42	17.3	23.1	9.9	1.3
355	10-30	70.54	11.47	9.78		0.00	0.07	0.04	0.0	0.94	0.02	0.04	0.00	6.97	99.87	10.4	19.2	6.8	1.8
356	40-70	52.59	20.94	14.11		0.00	0.10	0.04	0.0	1.34	0.03	0.05	0.00	10.19	99.39	4.3	9.9	3.0	2.3
357	80-100	48.39	24.73	14.89		0.00	0.06	0.07	0.0	1.42	0.02	0.03	0.00	10.99	100.60	3.3	8.6	2.4	2.6
358	110-150	49.75	25.65	14.22		0.00	0.07	0.08	0.0	1.44	0.02	0.03	0.00	10.79	102.05	3.3	9.3	2.4	2.8

Lab. no.		SiO_2	Al_2O_3	Fe_2O_3		CaO	MgO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	BaO	ign. loss	Σ	SiO_2/Al_2O_3	SiO_2/Fe_2O_3	SiO_2/R_2O_3	Al_2O_3/Fe_2O_3
		elemental composition of the clay fraction (weight %)														Molar rations			

Code ISM GI-2 Year 198- Country Ivory Coast

Soil

Lab. no.	Depth cm	Kaol	Mi/Ill	Verm	Chlor	Smec	Mix	Quar	Feld	Gibb	Goeth	Hem
85-354		+++		tr	tr.					tr-x	X	
355		+++		0-tr	tr.-+					tr.-x	X	
356		+++		-	tr.-+					tr.-x	X	
357		+++		-	tr.-+					tr.-x	X	
358		+++		-	tr.-+					tr.	X	

Sand mineralogy

Lab. no.	

[illegible]CI-3 YEAR 1985 Ivory Coast

Depth (cm)	Gravel >2 mm	Sand 2000–1000	Sand 1000–500	Sand 500–250	Sand 250–100	Sand 100–50	Silt 50–20	Silt 20–2	Clay <2	Water disp.	pH 1:2.5 H_2O	pH 1:2.5 KCl	$CaCO_3$	Exch Acid $H^+ + Al$ in KCl	Exch Al in KCl	[illegible]	Org. Matter C* %	[illegible]
0-10	3%	3.3	4.2	21.2	36.6	13.9	8.8	3.0	9.2	2.4	4.5	3.6		1.1	0.7		1.78	
10-20	56%	6.1	3.1	16.0	32.2	13.8	9.2	4.0	15.7	5.8	4.7	3.8		1.3	0.9		0.89	
30-60	70%	7.7	4.1	9.1	15.8	8.3	6.7	6.6	41.7	28.1	5.1	3.9		1.1	0.7		0.91	
100-130		2.6	2.6	5.8	9.9	4.7	9.3	16.6	48.4	0.5	5.0	3.9		1.3	0.9		0.43	
Bulk 0-20																		

Particle size distribution (in weight %)

* [illegible]

Exchangeable cations

Sample no.	Ca	meth.: pH:7 Mg	Na	K	sum	CEC	CEC cl.	B.S. (%)	EC 1:2.5	Na-Dit extr. Fe	Al	Si	Mn	Amm.Ox. extr. Fe	Al	Si	Na-Pos extr. Fe	Al
	-(meq/100g)-							(%)		--- % ---								
85-360	0.6	0.2	0.1	0.1	1.0	6.2	67.6	16	0.29	1.80	0.16	0.05	0.00	0.11	0.05	0.01	n.a.	n.a.
-361	0.4	0.0	0.1	0.0	0.5	4.7	29.1	11	0.03	1.39	0.20	0.04	0.00	0.21	0.07	0.01	n.a.	n.a.
-362	1.4	0.1	0.1	0.0	1.7	7.5	18.2	22	0.03	3.85	0.56	0.07	0.00	0.26	0.12	0.01	n.a.	n.a.
-363	0.4	0.2	0.1	0.0	0.6	6.2	12.8	10	0.02	5.43	0.64	0.11	0.01	0.23	0.14	0.03	n.a.	n.a.

(n.a.=not analysed)

Code ISM *CI-3* Year *1985* Country *Ivory Coast*

Lab. no.	depth cm	elemental composition of the total soil (weight %)														Molar ratios			
		SiO_2	Al_2O_3	Fe_2O_3		CaO	MgO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	BaO	ign. loss	$\sum$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
360	0-10	88.35	3.41	2.17		0.00	0.05	0.03	0.0	0.31	0.01	0.01	0.00	3.78	98.12	44.0	108.2	31.3	2.5
361	10-20	84.43	6.04	3.99		0.00	0.06	0.03	0.0	0.49	0.01	0.02	0.00	4.03	99.10	23.7	56.2	16.7	2.4
362	30-60	64.84	16.51	8.55		0.02	0.09	0.07	0.0	0.96	0.0	0.02	0.00	8.18	99.25	6.7	20.2	5.0	3.0
363	100-130	52.48	22.88	11.99		0.00	0.08	0.06	0.0	1.11	0.01	0.02	0.00	9.93	98.56	3.9	11.6	2.9	3.0

Lab. no.		elemental composition of the clay fraction (weight %)														Molar rations			
		SiO_2	Al_2O_3	Fe_2O_3		CaO	MgO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	BaO	ign. loss	$\sum$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$

Code ISM CI-3 Year 198 Country Ivory Coast

Soil

Lab. no	Depth cm	Kaol	Mi/Ill	Verm	Chlor	Smec	Mix	Quar	Feld	Gibb	Goeth	Hem
85-360		+++		tr.	tr.					tr.-x	tr.-x	
361		+++		tr.	tr.-+					tr.-x	tr.-x	
362		+++		tr.	tr.					tr.-x	tr.-x	
363		+++		0-tr.	tr.					tr.	tr.-x	

Sand mineralogy

Lab. no.	

I.S.M. CI-4 YEAR 1985 Ivory Coast

Particle size distribution (as in weight %)

Depth cm	Gravel >2 mm	sand 2000-1000	1000-500	500-250	250-100	100-50	silt 50-20	20-2	clay <2	Water disp.	pH 1:2.5 H	pH 1:2.5		SpS m².g⁻¹			Org. Matt. C% *	
0-8		0.5	3.5	22.3	37.7	12.8	8.0	4.8	10.5	3.8	4.3	3.9		10			0.93	
8-30		0.8	2.7	16.5	29.5	11.6	10.5	5.7	22.8	11.2	4.4	3.9		33			0.65	
30-50		0.9	2.4	13.2	23.9	10.5	11.2	6.2	31.7	10.9	4.4	3.9		42			0.50	
50-80		1.8	2.6	11.7	19.7	9.8	11.6	6.4	36.5	4.6	4.5	3.9		40			0.47	
80-110	54%	4.9	2.9	8.5	15.1	8.2	12.8	9.2	33.3	0.0	4.7	4.0		63			0.38	
Bulk 0-20																		

[illegible]

m.no.	sand 2000-50	silt 50-20	20-2	clay <2
-369	37.2	8.4	7.3	47.0

* C corr. 1.3

Exchangeable cations

mple	Ca	Mg	Na	K	sum	CEC	CEC cl.	B.S. (%)	EC 1:2.5 mS/cm	Na-dit extr. Fe	Al	Si	Mn	Amm-ox extr. Fe	Al	Si	Na-pyr extr. Fe	Al	Na-D * %Fe	%Al
	meth.:EXTRACTOR		pH:7.0											--%--						
	-(meq/100g)-																			
/365	0.2	0.2	0.0	0.1	0.5	2.3		23	0.13	0.7	0.2	n.a.	0.0	0.1	0.0	0.0	n.a.	n.a.		
/366	0.0	0.2	0.0	0.0	0.2	3.0		6	0.05	1.2	0.3	n.a.	0.0	0.1	0.1	0.0	n.a.	n.a.		
/367	0.0	0.1	0.0	0.0	0.1	3.2		4	0.03	1.6	0.4	n.a.	0.0	0.1	0.1	0.0	n.a.	n.a.		
/368	0.0	0.1	0.0	0.0	0.1	2.8		5	0.03	1.8	0.4	n.a.	0.0	0.1	0.1	0.0	n.a.	n.a.		
/369	0.0	0.1	0.0	0.0	0.1	3.0		4	0.02	4.3	0.5	n.a.	0.0	0.1	0.1	0.0	n.a.	n.a.	6.81	0.63

n.a.=not analysed

* mg [illegible] g Soil [illegible]

Code ISM GT-4 Year 1985 Country Ivory Coast

lab. no.	depth cm	elemental composition of the total soil (weight %) SiO_2	Al_2O_3	Fe_2O_3		CaO	MgO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	BaO	ign. loss	Σ	Molar ratios $\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
5-365	0-8	91.36	3.75	1.26		0.00	0.06	0.03	0.0	0.33	0.00	0.00	0.00	2.97	99.76	41.3	192.7	34.0	4.7
366	8-30	84.90	8.18	2.37		0.00	0.07	0.04	0.0	0.57	0.00	0.01	0.00	4.39	100.53	17.6	95.2	14.9	5.4
367	30-50	78.29	11.12	3.08		0.00	0.07	0.05	0.0	0.71	0.00	0.01	0.00	5.35	98.68	11.9	67.6	10.2	5.7
368	50-80	76.34	13.39	3.95		0.00	0.08	0.05	0.0	0.83	0.00	0.01	0.00	6.11	100.76	9.7	51.4	8.1	5.3
369	80-110	64.23	17.44	8.36		0.00	0.08	0.05	0.0	1.03	0.01	0.02	0.00	7.93	99.15	6.2	20.4	4.8	3.3

lab. no.		elemental composition of the clay fraction (weight %) SiO_2	Al_2O_3	Fe_2O_3		CaO	MgO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	BaO	ign. loss	Σ	Molar rations $\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$

Code ISM GI-4 Year 1985 Country Ivory Coast

Lab. no.	Depth cm	Kaol	Mi/Ill	Verm	Soil Chlor	Smec	Mix			Quar	Feld	Gibb	Goeth	Hem
85-365	0-8	+++		tr.	tr.-+							tr.-x	tr.-x	
366	8-30	+++		tr.	tr.-+							tr.-x	tr.-x	
367	30-50	+++		-	+							tr.-x	tr.-x	
368	50-80	+++		-	+							tr.-x	tr.-x	
369	80-110	+++		-	+							tr.-x	tr.-x	tr.

Sand mineralogy

Lab. no.	

1. . . CI-5 YEAR 1985 Jurry Coast

No.	Depth cm	Gravel >2 mm	sand 2000–1000	sand 1000–500	sand 500–250	sand 250–100	sand 100–50	silt 50–20	silt 20–2	clay <2	water disp.	pH 1:2.5	pH		Exch. Acid. H⁺+Al in KCl	Exch Al in KCl		Org. Matt. C %	
1	0-10		0.3	4.5	24.7	33.4	14.5	8.0	4.8	9.8	1.8	4.2	3.7		1.1	0.7		1.57	
2	10-35		0.4	6.7	25.8	28.5	12.0	6.8	5.1	14.8	5.3	4.4	3.9		1.2	0.7		1.18	
3	40-50		0.8	5.5	24.6	29.0	11.9	6.7	6.5	15.0	8.2	4.7	4.0		0.8	0.4		0.82	
4	50-75		1.2	7.7	27.3	27.8	10.2	6.3	5.0	14.4	10.9	4.6	3.9		0.8	0.4		0.25	
5	75-100		1.6	9.2	27.6	25.8	8.8	6.1	5.0	16.0	12.9	4.7	3.9		0.8	0.4		0.27	
6	100-120		2.2	8.3	21.1	16.7	5.9	5.7	15.6	24.6	19.9	4.7	3.8		1.6	1.1		0.23	
7	Bulk 0-20																		

Exchangeable cations

Sample	Ca	Mg	Na	K	sum	CEC	CEC cl.	B.S. (%)	EC 1:2.5	Na-Dit extr. Fe	Al	Si	Mn	Amm.Ox. extr. Fe	Al	Si	Na-Pos extr. Fe	Al
	meth.:extractor pH:7 -(meq/100g)-									--- % ---								
/371	1.2	0.2	0.3	0.1	1.7	4.7		37	0.14	0.10	0.04	0.00	0.00	0.10	0.04	0.00	n.a.	n.a.
/372	1.4	0.2	0.1	0.0	1.7	3.2		55	0.08	0.16	0.05	0.02	0.00	0.18	0.06	0.01	n.a.	n.a.
/373	1.0	0.2	0.3	0.1	1.6	3.0		54	0.06	0.15	0.03	0.00	0.00	0.18	0.04	0.00	n.a.	n.a.
/374	1.0	0.1	0.1	0.0	1.2	1.6		74	0.04	0.16	0.02	0.01	0.00	0.05	0.03	0.00	n.a.	n.a.
/375	1.0	0.1	0.1	0.0	1.2	4.0		29	0.03	0.01	0.01	0.02	0.00	0.02	0.03	0.00	n.a.	n.a.
/376	1.4	0.3	0.2	0.0	2.0	3.3		59	0.03	0.01	0.02	0.03	0.00	0.02	0.03	0.00	n.a.	n.a.

(n.a.=not analysed)

Code ISM CI-5 Year 1985 Country Ivory Coast

elemental composition of the total soil (weight %) — Molar ratios

Lab. no.	depth cm	SiO_2	Al_2O_3	Fe_2O_3		CaO	MgO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	BaO	ign. loss	Σ	SiO_2/Al_2O_3	SiO_2/Fe_2O_3	SiO_2/R_2O_3	Al_2O_3/Fe_2O_3
5-371	0-10	93.13	3.42	0.36		0.00	0.04	0.05	0.0	0.17	0.00	0.01	0.00	3.60	100.78	46.2	687.5	43.3	14.9
372	10-35	88.88	5.39	0.54		0.00	0.04	0.05	0.0	0.23	0.00	0.01	0.00	3.58	98.72	28.0	437.4	26.3	15.6
373	40-50	90.98	5.84	0.56		0.00	0.04	0.05	0.0	0.26	0.00	0.01	0.00	3.15	100.89	26.4	431.8	24.9	16.3
374	50-75	91.61	5.54	0.38		0.00	0.03	0.05	0.0	0.24	0.00	0.00	0.00	2.53	100.38	28.1	640.7	26.9	22.8
375	75-100	89.36	6.72	0.40		0.00	0.04	0.04	0.0	0.27	0.00	0.00	0.00	2.88	99.71	22.6	593.7	21.7	26.3
376	100-120	76.55	15.71	0.73		0.00	0.05	0.06	0.0	0.43	0.00	0.01	0.00	6.13	99.67	8.3	278.7	8.0	33.7

elemental composition of the clay fraction (weight %) — Molar rations

Lab. no.		SiO_2	Al_2O_3	Fe_2O_3		CaO	MgO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	BaO	ign. loss	Σ	SiO_2/Al_2O_3	SiO_2/Fe_2O_3	SiO_2/R_2O_3	Al_2O_3/Fe_2O_3

Code ISM CI-5 Year 1985 Country Ivory Coast

Lab. no.	Depth cm	Kaol	Mi/Ill	Verm	Chlor	Smec	Mix			Quar	Feld	Gibb	Goeth	Hem
					soil									
85-371		+++	0-tr.		tr.-+					tr.				
372		+++	-		tr.-+					tr.				
373		+++	-		tr.-+					tr.				
374		+++	-		tr.-+					tr.				
375		+++	-		tr.-+					tr.				
376		+++	-		tr.-+					0-tr.				

Lab. no.	Sand mineralogy

ANNEX C

CALCULATION OF POTENTIAL EVAPOTRANSPIRATION

Table of data used in the TURC formula to calculate the potential-evapotransperation.

Unit / Month	Jan.	Feb.	Mar.	Apr.	Mai	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
t (^{o}C)	26.1	27.1	27.3	27.4	26.8	25.7	24.7	25.3	25.9	26.5	26.2	25.3
h (hrs/day)	6.24	6.13	6.63	6.42	5.25	3.64	2.75	2.74	4.36	4.89	5.36	5.10
H (hrs/day)	11.8	12.0	12.0	12.2	12.3	12.4	12.3	12.2	12.1	12.0	11.9	11.8
Iga ($cal/cm^2/day$)	828	879	913	910	879	858	861	888	907	885	843	812

t= monthly mean temperature (Van Kekem, unpublished)
h= insolation in hours per day, calculated from mean monthly insolation data given in an unpublished paper of Van Kekem.
H= astronomic lenght of the day in hours, from table 4.2, page 83, Irrigation, Practice and Design 2d ed. Withers,B and Vipon,S.
Iga= solar radiation energy which would reach the earth in the absence of atmosphere; calculated from table 4.1, page 82, as above.

The PET (potential evapotransperation) is now calculated with the TURC-formula as given by BERNHARD-REVERSAT et al. 1978.

$$PET = 0.4 \frac{t}{t+15}\left[\left(0.62 \frac{h}{H} + 0.18\right) Iga + 50\right]$$

ANNEX D

THIN SECTION CODES

Extant thin sections of the monolith studied in this paper. Both the thin sections and the monoliths are on view at the International Soil Research and Information Centre .

Monolith	depth	code	
CI-1	120-135 cm	M 2954	summit slope
CI-2	30- 45 cm	M 2956	shoulder
	90-105 cm	M 2958	
	115-130 cm	M 2959	
CI-3	5- 20 cm	M 2960	upper slope
	85-100 cm	M 2962	
	117-132 cm	M 2963	
CI-4	5- 20 cm	M 2964	lower slope
	22- 37 cm	M 2965	
	50- 65 cm	M 2966	
	64- 79 cm	M 2967	
CI-5	30- 45 cm	M 2969	valley bottom
	55- 70 cm	M 2970	
	80- 95 cm	M 2971	