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Micromorphology. Pedogenesis and Soil Classification in a Catena of Soils in Chuka, Kenya.

by

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1. GENERAL.

1.1. Introduction.

The present research deals with the study of a catenary sequence of soils. This catena is located in the Eastern province of Kenya and runs from Rukuriri village (in the West) to Ishiara village (in the East). Its gradient in altitude is almost 2.000 m and involves various stages of soil development from relative young soils to strongly weathered ones.

The objective of this investigation is: i) to study how the various weathering stages relate to changes in the environmental (soil-forming) conditions resulting from changes in the altitude along the catena; ii) how they are expressed in terms of morphological, chemical and physical properties of the soils and,
iii) how these properties influence the classification of this catena of soils.

This study has both an academic and practical importance. Its results should contribute to the understanding of the pedogenesis and classification of the soils concerned and, on the other hand, allow a better understanding of its productivity and management.

1.2. The Problem Studied.

-According to Bennema, et. al. (1970) and Buringh (1977) the red clayey soils in the tropical areas occur in weathering sequences, the so called catenas, involving soils as recent as Entisols, moderately weathered soils like Alfisols and deeply weathered soils like Ultisols. This wide range of weathering results from variations of climate, parent material, relief and vegetation (soil-forming factors) along the catena, in function of the altitude.
-Strongly weathered soils of a catenary sequence display many common properties ("overlapping" properties), transitional states are often

found, and also homogenization and "paleo" features are frequent. All these features contribute to make the macromorphological expression of the soil forming processes concerned and thereby the diagnostic properties of the soils.

-The facts mentioned are illustrated by the frequent occurrence of intergrades soils between the most developed members of a catenary sequence, the difficulties being the identification of the argillic horizon; particularly the uncertainty in the identification of signs of illuviation (clay coatings), which constitutes the principal diagnostic feature for the argillic horizon, and its separation from the oxic horixon. (Soil Taxonomy, 1975).

-The increasing disagreements between the properties, displayed by the argillic horizon, in the field and those stated as standard properties (associated to the modal or central concept of the argillic horizon) has led to propose various types of argillic horizons. For example, the Kenyan Soil Survey Service has introduced a nito-argillic horizon (Sombroek and Siderius, 1981). Bullock and Thompson (1985) distinguish a "young" or "ordinary" argillic horizon and an "old" or "degraded" one, which are widely identified, respectively in young Alfisols and old Alfisols and Ultisols. Sombroek (1983) proposes the identification and use of eight subtypes of argillic horizons, "each with its own set of accessory properties".

-So, the identification of the argillic horizon under field conditions becomes uncertain. Therefore, laborious physical, chemical and mineralogical analysis are necessary to elucidate the classification of deeply weathered soils. Even so, in many cases the identification of argillic horizon remains uncertain and micromorphological analysis have to be performed in order to identify the soil-forming process concerned through the interpretation of the pedogenetic features displayed by the soil; in this way the pedogenetic history of the soil can be deduced and the classification of the soil elucidated.

-The aim of the present research is to study if the pedogenetic features displayed by the soils concerned in this catena corroborate the features summarized above. How the various weathering stages conform with changes in the weathering conditions, associated with altitude. How these various weathering degrees are expressed in terms of chemical, physical and morphological properties and to which extent these properties account for the classification of these soils.

1.3. General Description of the Area.

1.3.1. Location.

The soils under study form part of a catenary sequence, which consists of five profiles arranged in a W-E transect located in the Eastern Province of Kenya (Fig. 1). The transect starts from the South of Mount Kenya (0 21'S-37 33 E, North of the Rukuriri village) and ends near Ishiara village (0 27'S-37 47'E), covering about 30 km. Along this transect the altitude decreases from about 3.000 m in the West, to almost 800 m in the East. Fig. 2 shows the location of the profiles and the gradient in altitude of the transect.

1.3.2. Geology.

The transect sketched above extends throughout two of the most important geological formations of Kenya. The Basement System (Mozambique Belt) and the Mount Kenya Series, as shown in Fig.2. The first formation consists of Precambrian rocks, mainly gneisses and schists, and the second one consists of old (Miocene/Pleistocene) volcanics, like lava agglomerates (phonolite and trachite) and tuff (Pulfrey, 1969).

Volcanic rocks are generally medium to fine textured and vary widely with regard to their mineralogy. Phonolites, ocurring in Kenya, are predominantly of the kenyte type, which is characterized by a marked mafic character and abundant and large phenocrysts of orthoclase, nepheline, alkaly feldspars, micas (olivine and biotite), pyroxenes and (soda) amphiboles (Nockolds, 1979). These volcanics, dominantly represented by kenyte, are regarded to be the parent material of the main soils occurring in the area around Mount Kenya.

1.3.3. Physiography.

The general physiography of the area can be described as a sequence from the West to the East (Fig. 2), which involves the following features: mountain foot ridges (1) upper uplands (2), upper scarpments (3), plateaus (4) and scarps (5), all belonging to the "volcanic landscape", and an uplands/hills complex (6) on the Basement system

1.3.4. Climate and water availability.

Rainfall (r) and temperature (t) vary as function of the altitude, along the transect, (Fig 3 and 4 respectively). South of the Mount Kenya the altitude reaches about 3.000 m and the climate becomes cool and wet. South of Ishiara, where the altitude is about 800 m, the climate is sub-humid and warm; mean annual r ranges 2.000 - 800 mm in the same direction (Fig. 3), and the mean annual t oscilates between 16 and 18 C. Mean maximum and minimum values range from 22-24 C to 10-12 C in the West and from 30-36 C to 18-24 C in the East (Sombroek, 1982), as shown in Fig. 4 and Table 1.

Rainfall is concentrated in two rainy seasons. The first is warm and lasts from March to May; the second rainy season is cold and occurs from October to December. The dry season also shows seasonality; a short and cool dry season occurs in January-February and a long and warm dry one occurs from June to September (Sombroek, 1982).

Water availability, expressed as the ratio between rainfall (r) and the potential evapotranspiration (E) conforms with the changes described in rainfall and temperature as functions of the altitude (Table 2 and Fig. 3). Mountainous areas, in the West, have a humid or sub-humid climate (r/E x 100>65%). To the East the climate became more and more dry, changing from sub-humid to semi-arid.(Table 2 and Figure 5). Water availability for crop production is probably scarcer than reflected by the figures of Table 2, particularly in the east of the surveyed area. It must be kept in mind that the calculation method followed in this case does not take into account either the effect of the "Effective rainfall" (which in the area concerned accounts for about 50% of the rainfall) or the effect of the seasonality of rainfall on water availability.

1.3.5. Vegetation and land use.

The natural vegetation consists of grass, shrub, bush (more or less wooded) and forest. The two former provide grazing resources, bushes provide wood and charcoal and forest timber and wood.
The land is intensively used, most under rainfed conditions involving both inter-and mixed-cropping systems. Cropping patterns change along the catena together with the environmental conditions, as a function of the altitude. Both food and cash crops are cultivated (Bongers,1986).

In the high altitude lands (mountain foot-ridges and upper uplands) the most frequently cultivated crops are maize, beans, yams, potatoes and cassave. The most important cash crops are tea, coffee, and bananas. This pattern changes radically going to the low altitude lands, in the East of the area, where the most representative food crops are millet, sorghum, cowpeas, green yams and cassave. Cotton, tobacco and mangos are the principal cash crops. Sunflower and sugar-cane are also grown at irrigated areas (Bongers, 1986).

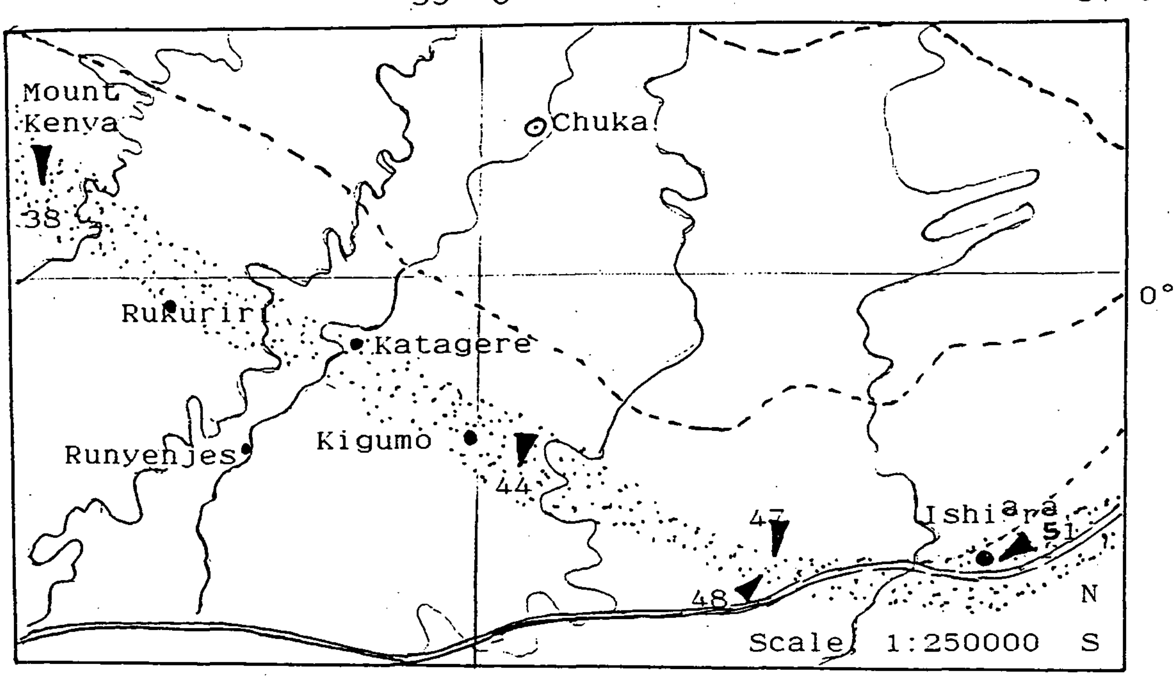


Fig. 1. Approximate location of the profiles and course of the transect Soil Survey, Kenya (1976).

Legend: [symbol] = surveyed area; [symbol] = pits; [symbol] = contour-lines; [symbol] = major roads; [symbol] = rivers.

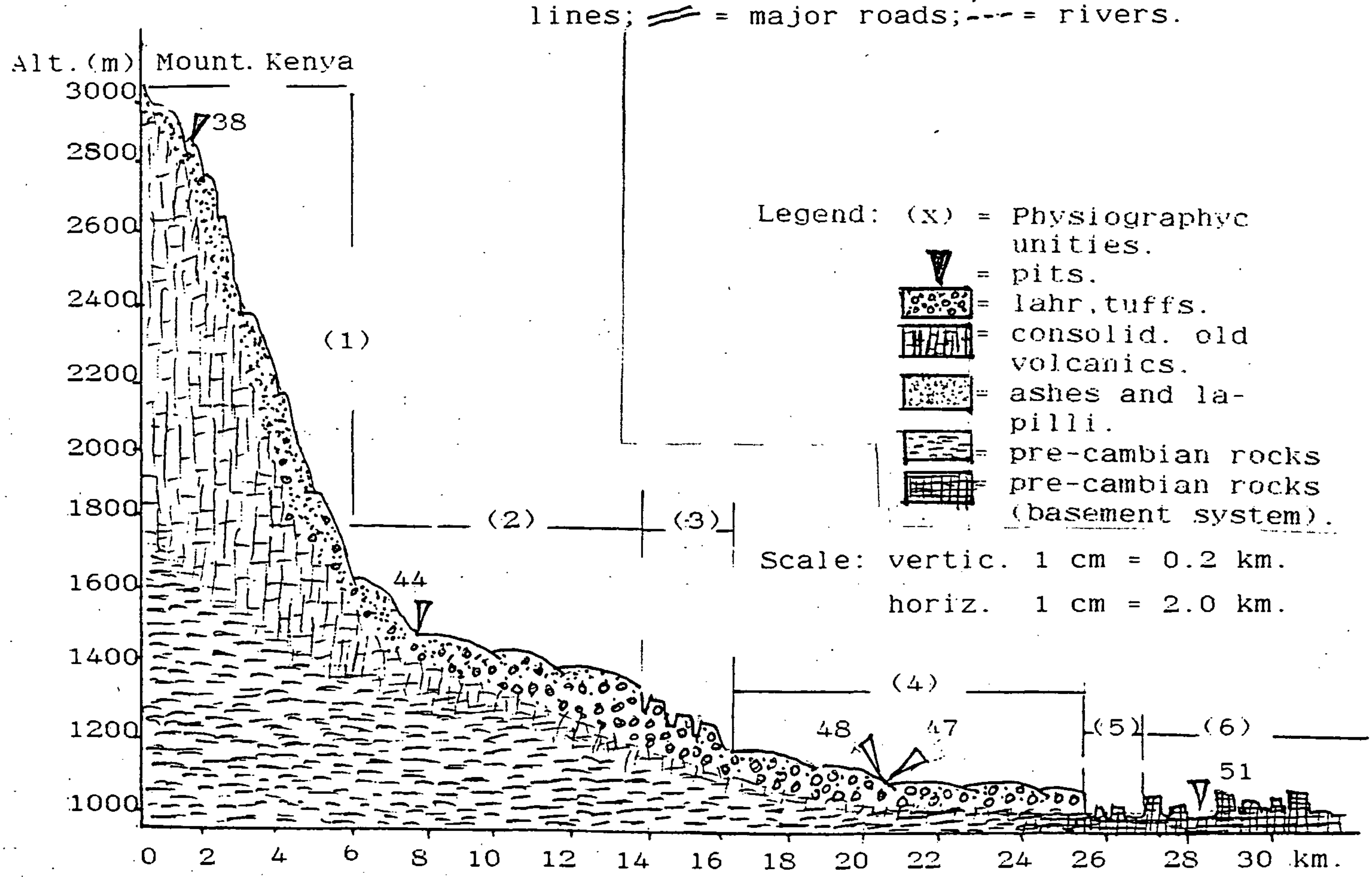


Fig. 2. Cross section of the catena. Geology, physiography and location of the profiles. Adapted from Geological Chart of Kenya (1949). Scale 1;125.000, sheet N° 44, and Survey of kenya (1976). Scale 1:250.000, sheet N° 122/4.

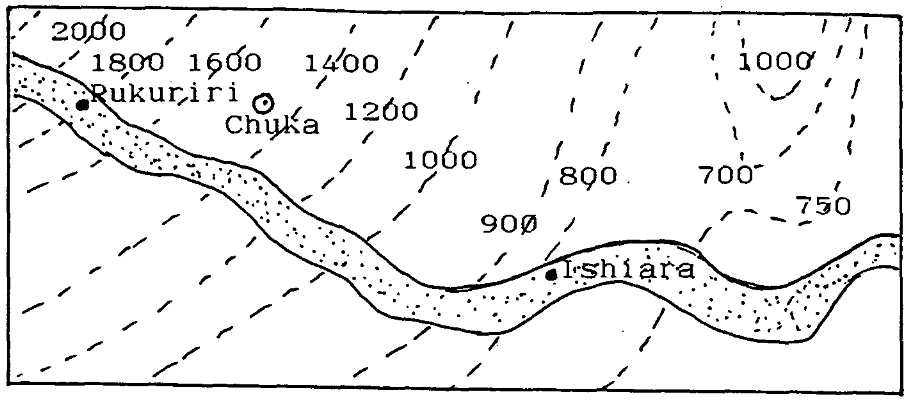


Fig. 3. Mean annual raifall (mm, Embu climatological station). Sombroek (1982).

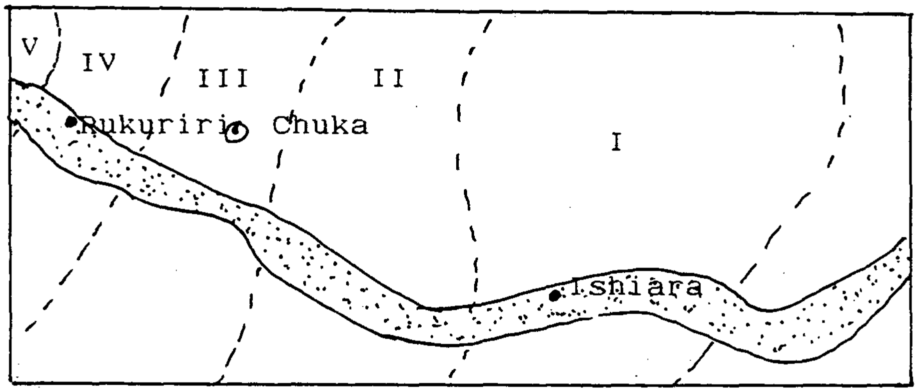


Fig. 4. Temperature zones, according to the mean values presented in Table 1.Sombroek(1982).

Table 1. Mean annual maximum and minimum temperatures (°C). Sombroek (1982).

Zone	Mean annual temp.	Mean Max. temp.	Mean min. temp.
V	16-18	22-24	10-12
IV	18-20	24-26	12-14
III	20-22	26-28	14-16
II	22-24	28-30	16-18
I	24-30	30-36	18-24

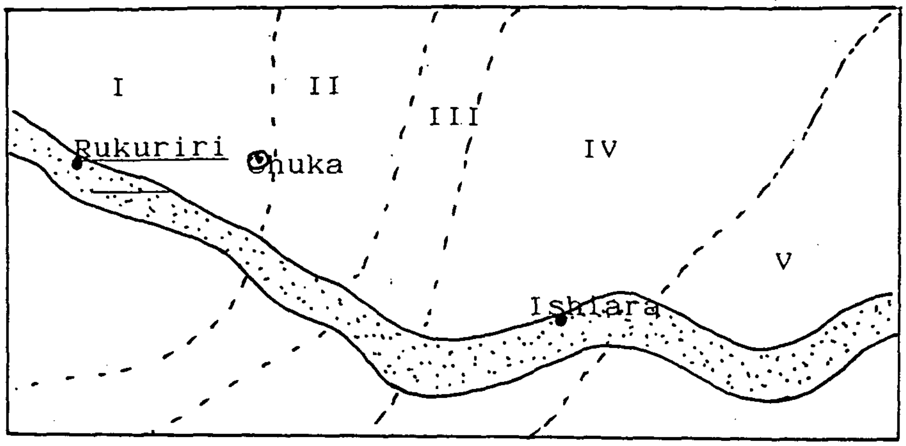


Fig. 5. Moisture availability zones, according to the values presented in Table 2.Sombroek (1982).

Table 2. Moisture availability zones. Sombroek (1982).

Zones	$r/E_o \times 100$	Description.
I	>80	Humid
II	65-80	Sub-humid
III	50-65	Semi-humid
IV	50-60	Semi-humid/ Semi-arid
V	25-40	Semi-arid
VI	15-25	Arid
VII	<15	very arid

1.4. Methods and Materials.

1.4.1. Field methods.

Field work was carried out by students and staff of the Agricultural University of Wageningen, who surveyed the southern area of Chuka, at semi-detailed level (scale 1:25,000). The catenary sequence was sampled by digging a series of five pits. These were described according to the guidelines advanced by F.A.O.(1974), and soil samples were taken for routine analysis, mineralogical analysis and preparation of thin sections. Besides, soil monoliths were collected, following the procedure used by the I.S.R.I.C. (van Baren and Bomer, 1979).

1.4.2. Laboratory methods.

Various laboratory determinations and procedures were performed. This activities are listed below, and the methods used in each case are briefly described.

a. Chemical and physical determinations:

-Soil reaction (pH).	Measured in a suspension of soil in both water and KCl (1:2.5), using potentiometry.
-Electric conductivity (Ec)	Determined in a saturation extract, using Pt-electrodes.
-Organic carbon (C%)	Determinated by humid digestion, using K dicromate as oxidant, and Mohr's solution in the titration(without correction factor).
-Cation exchange capacity	Determinated at pH 7, in a NH4OAc percolate, by titration with HCl.
-Ca and Mg	These elements were extracted with NH4OAc and determined by absorption-spectrophotometry.

-K and Na — Like Ca and Mg, but using emission-spectrometry.

-Texture — Texture was determined with aid of the hydrometer, in a soil/water suspension, previously dispersed, using both physical (stirring) and chemical dispersants (hexametaphosphate and Na-carbonate).

b. Micromorphological descriptions

Mammoth-sized thin sections (15 cm x 8 cm x 30 um) were prepared following the method of Jongerius and Heintzberger(1975). These were observed under both plane and polarized light (PPL) and cross polarized light (XPL), using 30 and 79 magnifications. The microstructure, basic components, groundmass and pedofeatures were described following the "Handbook for Soil Thin Section Description", by Bullock, et al.(1985). Thin sections used are listed in the Appendix.

1.5. Interpretation Procedure.

Laboratory analysis, micromorphological descriptions and field work provided abundant and valuable information about the profiles concerned. To make this information useful to the objectives of this research a method of interpretation had to be designed. On the basis of the provisional classification of the soils, based on the profile description, the relevant "diagnostic requirements", stated in the currently most accepted soil classification systems -Soil Taxonomy, 1975 and FAO/UNESCO (1974) are arranged in tables and used as standardized "reference criteria" to judge if the properties of the profiles studied fit those "classification requirements". Such "requirements" involve epipedons, diagnostic subsurface -horizons and diagnostic characteristics. Besides this, some recent literature on these topics regarding the micromorphology of the orgillic and oxic horizons, is also used as "reference criteria" to judge to what extent these soils meet the micromorphological features regarded as "typic" for the oxic and argillic horizons. (Bullock and Thompson, 1985; Fedoroff and Eswaran, 1985; Stoops and Buol, 1985; McKeague, 1981 and Stoops, 1981).

The tables contain (coded or briefly described) the standardized criteria (macro and micromorphology, physico-chemical and mineralogical properties) and allow the entry of the information concerning the properties of the profiles investigated, enabling a direct comparison to conclude if these soils meet the "classification requirements". These standards are presented in Tables 3 a, b; 4 a,b; 5 a,b and 6, in the Appendix.

This method has been already used in the interpretation of micromorphological features of catenary soils by the Soil Micromorphology Section at the Agricultural University of Wageningen (Kiome, 1985) and also is suggested by Sombroek (1983) when discussing the "identification and use of sub-types of argillic horizons". Here the method has been adapted to the objectives of this research.

2. MORPHOLOGICAL, CHEMICAL AND PHYSICAL PROPERTIES OF THE EAK-PROFILES.

2.1. Profile EAK-51.(Chromic Acrisol F.A.O., 1974)

2.1.1. Macromorphology. Profile Description.

Date/season	:dry season.
Sheet-observation N	:124/4-33.
Coordinates	:99 49" N 36 64 60" E.
Elevation	:855 m.
Author	:Jan Kuyper.
Soil classification	:Chromic Acrisol (FAO,1974). Lithic Haplargid (ST,1975).
Geology	:Basement System.
Petrography(parent mat.)	:hornblende, biotite, gneiss.
Physiography	:upland.
Macro-relief	:undulating.
Slope gradient	:3%.
Position on slope	:upper to middle slope.
Vegetation/land use	:acacia bushland.
Erosion	:moderate sheet and rill erosion.
Rock outcrops	:fairly rocky.
Surface crusting	:30 cm strong thick crusts.
Drainage class	:excessively drained.
Ground water level	:deep (always).
Soil fauna influences	:termite burrows and ants.
Rooting depth	:70 cm.

Horizons

Bul	0-10 cm	Dark red (2.5YR 3/6 moist and dry); moderate to coarse subangular blocky structure falling apart to crumb; continuous thin clay cutans; sandy clay loam; consistence: hard when dry, very friable when

		moist, slightly sticky and slightly plastic when wet; gradual and wavy transition to:
Bu2	10-25 cm	Dark red (2.5YR 3/6 moist and dry); weak coarse subangular blocky structure, falling apart to granules and crumbs; continuous thin clay cutans; very gravelly sandy clay loam, gradual and wavy transition to:
Bu3	25-70 cm	Dark red(2.5YR 3/6 moist, 2.5YR 4/6 dry); moderate coarse angular blocky structure, continuous thin clay cutans; sandy clay loam; consistence: hard when dry, very friable when moist, slightly sticky and slightly plastic when wet; irregular and clear transition to:
R(Bu4)	70 cm +	70% biotite gneisses; 30% dark red (2.5YR 3/6 dry and moist); strong medium to coarse angular blocky structure; continuous to broken thin clay cutans; sandy clay loam; hard when dry, very friable when moist, slightly sticky and slightly plastic when wet.

2.1.2. Micromorphology.

a. Microstructure.

This is complex and weakly to moderately developed; vughy, chamber and spongy types are found. Micro aggregate structure is also frequent, which appears as loose infilled channels and chambers. Isolated aggregates consist of micro/meso sized-granules and crumbs, often welded constituting mammillated agglomerates. Voids consist mainly of micro/meso sized packing voids and vughs. Macro-sized channels and chambers are common in the whole profile. Pedality is moderately developed, in general, and porosity is relatively low (45-50%), meso and macropores accounting for 75-85%.

b. Basic Components

Coarse mineral components consist of sub-euhedral/anhedral grains, ranging from 25 um to 2 mm (c/f limit=25 um). These components represent about 40% of the thin section (c/f ratio= 40/60), are well sorted (mostly ranging 200-800 um) and display high relief, contrast and anisotropism. Coarser grains consist of rock fragments and resistent minerals like quartz, and zircon. Finer grains involve various primary minerals like hornblende (the most abundant), plagioclase, k-feldspars, epidote and some micas (biotite, mainly). The degree of alteration is moderate, physical break-down seems to be dominant, as reflected in the frequent occurrence of splinters, flakes, exfoliation and fissuration.

Fine mineral components (<25 um in size) do not occur isolated, but like a heterogeneous mixture of fine, reddish, plasma and fine mineral grains. This mixture appears dotted (with micro granules) and shaded and spreads throughout the profile, impregnating the groundmass. It consists mainly of layer-silicates (2:1 type) and some oxidated and crystallized Fe compounds, like haematite and lepidocrocite.

Organic components are very scarce, being represented by ocasional remnants of root tissues, completely altered and impregnated by dark pigments. Fine organic matter was not identified; it is assumed this occurs as amorphous material associated to ferruginous features, like nodules and coatings.

c. Groundmass.

The related distribution between coarse and fine mineral components (c/f ratio = 40/60) is dominantly (open) porphyric. Most frequent types of b-fabrics are striated, speckled, and reticulated. These display yellowish or pink red colours and moderate refringence, contrasting with the surrounding groundmass which appears brown or dusky red, under XPL.

d. Textural pedofeatures.

These are represented by coatings and aggregate pedotubules. Clay coatings occur associated to micropores, clustered rather than randomly distributed; therefore its abundance ranges from occasional to abundant. It concerns crescent/bow-like coatings and impregnative coatings which are micro sized and display moderate optical properties, like relief , birefringence and contrast; because they appear shaded and microdotted by ferruginous materials. Sometimes coatings display microlamination and clear referred orientation of the constituting material, which consists of lattice-clay and very fine silt, contaminated with Fe and, eventually, with organic materials. Ferruginous coatings, Coarse grains and often aggregates and nodules appear surrounded by fine plasma which consists of clay and appear intensely impregnated with Fe-oxides, displaying clear referred (concentric) orientation. In some areas coarse grains appear linked by this material.

Aggregate pedotubules are common and consist of macro and megasized channels and chambers which appear like loose continuous and dense,incomplete, infillings, often displaying bow-like patterns. The infilling material consists of groundmass (including mineral grains), appearing like loose (micro and meso) granules and crumbs or as mammillated entities.

e. Cryptocrystalline pedofeatures.

These pedofeatures are represented by ferruginous nodules, of which the abundance ranges from rare to occasional. Two types are found: amorphous and heterogeneous nodules. Amorphous nodules are isotropic, black and opaque; therefore they display high contrast and sharp boundaries. Shapes may be sub-angular, mammilated and even spherical. Sizes ranges from 25-400 um (mostly ranging 50 - 200 um). These nodules consist mainly of oxihydrates of Fe and Mn and organic matter. Heterogeneous nodules are scarce and weakly expressed because of weak impregnation and low heterogenity of the internal fabric. Therefore,their optical properties are low to very low.

f. Fabric pedofeatures.

These are abundant and are represented by reorientations of the groundmass, which are abundant to frequent. Two types are recognized according to the arrangement of the fabrics. First, fabrics located around voids consisting in stressed groundmass and, secondly, fabrics resulting from dense complete infillings. The former appear like domains of fine and dense packed groundmass, parallel to channel walls. The last type shows circular and arched patterns.

2.1.3. Chemical and physical properties. Soil test report.

Depth (cm)	0-15	15-95
Sand, %	56	60
Silt, %	21	13
Clay, %	23	27
Textural class	Scl 1)	Scl
Electric conductivity (Ec) mmhos/cm. mmhos/cm.	0.05	0.07
pH-H20 (1:2.5)	5.50	5.80
pH-HCl(1:2.5)	5.30	5.60
Carbon % (C%)	0.57	0.40
Organic matter,% (O.M.%)2)	0.80	0.50
Cation Exchange Capacity (C.E.C.),		
in meq/100 gr clay	41.80	36.60
Ca, meq/100 gr clay	15.20	15.90
Mg, meq/100 gr clay	13.50	15.50
K, meq/100 gr clay	0.70	0.20
Na, meq/100 gr clay	0.50	0.60
Base saturation % (V) 3)	71.60	87.90

1)Sandy clay loam 2)O.M.% = C% x 1.33(Landon,1984)
3)V=(Exch. bases/C.E.C.)x 100

Profile EAK-51 deals with a medium textured soil, medium to strongly acid (pH-H2O), with very low contents of C and organic matter. The natural fertility of this soil is also low, as reflected in a low C.E.C. value; 36.60-41.80 meq/100 gr clay (or about 9.70 meq/100 gr soil, Table 8, Ap.)

2.2. PROFILE EAK-47 (Chromic Acrisol FAO, 1974)

2.2.1. Macromorphology. Profile description.

Date/season	:31-08-1985, dry.
Sheet-observation N	:122/3-26.
Elevation	:1.000 m.
Author(s)	Jan Kuyper.
Soil classification	:Ferralo, Chromic Acrisol (FAO, 1974).
Geology	:Mt. Kenya series.
Local petrography (Parent material)	:phonolite/lahar.
Physiography	:plateau.
Macro-relief	:gently undulating.
Slope gradient	:2%.
Position on slope	:summit.
Vegetation/landuse	:small scale, rainfed annual with tree crops, maize, pigeon peas, cotton.
Surface sealing/crusting/ cracking	:1-4 mm/cracks, 20 cm apart.
Drainage class	:well drained.
Groundwater level(actual)	:very deep.
Soil fauna influences	:termite burrows.
Expected rooting depth	:very deep.

Horizons

A	0-18 cm	Dark reddish brown (5YR 3/3 moist, 5 YR 3/5 dry); moderate very coarse prisms falling apart to moderately strong very coarse subangular blocky structure (built up by crumbs); patchy thin clay cutans; clay; consistence: hard, weakly cemented when dry, very friable when

		moist, slightly sticky and slightly plastic when wet; gradual and smooth transition to:
AB	18-35 cm	Dark reddish brown (5YR 3/3 moist, 5YR 3/4 dry); moderate very coarse prisms falling apart to moderately strong very coarse subangular blocky structure (build up by crumbs); broken thin clay cutans; clay consistence hard, weakly cemented when dry, very friable when moist, slightly sticky and slightly plastic when wet; gradual and smooth transition to:
Bu1	35-85 cm	Dark reddish brown (5YR 3/4 moist, 5YR 4/6 dry); moderately strong, very coarse prisms falling apart to medium subangular blocky structure; broken thin clay cutans; clay, hard weakly cemented when dry, very friable when moist, slightly sticky and slightly plastic when wet; diffuse and smooth transition to:
Bu2	85-150 cm	Dark red (2.5YR 3/6 moist, 5YR 4/6 dry); moderately strong, very coarse prisms falling apart to very coarse subangular blocky structure; patchy thin clay cutans; clay; hard, weak cemented when dry, very friable when moist; slightly sticky and slightly plastic when wet.

2.2.2. Micromorphology.

a. Microstructure.

This pedon displays a micro-aggregate structure, which is dominantly granular and crumbly at the A-horizon, becoming less developed, with depth; locally a (sub-angular) blocky, vughy and even massive microstructure is recognizable, especially at the Bu1 horizon. The soil material appears completely disturbed by burrowing activity of the soil mesofauna; passage channels and fecal and oral pellets are frequently found. Aggregates can separate into 3 groups, according to their size and shape: microgranules and crumbs (10-100um), mesoaggregates (100-500 um consisting of welded micro-aggregates, appearing like lobular and mammillated entities) and mega/macro-sized aggregates (500 um up to 1 mm, or more). This last are associated with channels and display very irregular shapes and appear as very homogeneous domains of closely packed groundmass, located around and between channels. Voids are very abundant and of various sizes and types, occurring inter-agreggates meso-voids (compound packing voids and vughs), intra-aggregates voids (very fine vughs and cracks) and trans-aggregate voids (channels and some planar voids). Pedality is strongly developed at the A horizon and moderately at the B. Porosity is high, (55-60 %), micro and meso-voids accounting for about 70%.

b. Basic components.

Coarse mineral components, greater than 5 um in size (c/f limit=5 um) are very few (c/f=10/90) and consists of quartz grains (at time some grains of volcanics are found), which are anisotropic and sharp bounded. The degree of alteration is very advanced; corroded edges, cracks, caverns, fissuration and dissolution are frequent and clearly recognizable. Runiquartz is common in this profile. Finer grains (5-40 um) occur completely embedded in the soil plasma.

Fine mineral components. These do not occur as discrete entities, but as very homogeneous, not organized, cloudy, speckled and intensely micro-dotted plasma, which appear isotropic and brown-dark red, under PPL. This image changes to a birefringent and dusky red one, under XPL. These components consist of lattice-clays (kaolinite and some gibbsite), more or less crystalline Fe-compounds (mainly, haematite and goethite) and amorphous materials (as Fe-gels, humus and Mn-hydroxides), in as far as colours displayed by the groundmass are regarded.

Coarse organic components are abundant at the A-horizon and rare at the B. Sizes range 25-800 um, often appear intensely impregnated with dark-brown, yellowish and red pigments. So, limpidity, birefringence and constrasts are high: It deals with rests of root-hairs and root tissues like cortex, epidermis, xylem and phloem.

c. Groundmass.

The related distribution is plasmic (c/f=10/90) and the b-fabric is complex, locally undifferentiated. Most common patterns are circular (at time concentric) and speckled (mosaic). Striated (pore and grain striated) patterns are also ocassionally recognized. These patterns seems to result from the re-distribution of Fe-compounds in the groundmass.

d. Textural pedofeatures.

Only aggregatepedotubules occur. These are many and occur in the whole profile, being more well expressed and abundant beneath 80 cm, and consist of continuous and discontinuous infilled channels. Infilling material consists of groundmass which has been aggregated constituting isolated unities (granules and crumbs) and mammillated bodies (welded microaggregates).

e. Cryptocrystalline pedofeatures.

These are represented by abundant nodules, which show a wide variability in regard to their size, shape and degree of impregnation. Most display spherical or amiboidal shapes with smooth and sharp boundaries. Two types are distinguished according their degree of impregnation.

Ferruginous nodules. These are well sorted nodules, with sizes ranging 50-800 um. The host material consists of groundmass involving coarse grains and appears moderately to strongly impregnated, displaying low limpidity and refringence. Under PPL these nodules appear brown coloured and dusky red under XPL, frequently enclosed by concentric rings.

Amorphous nodules. These are very poorly sorted nodules, ranging 10-800 um in size, strongly impregnated with amorphous materials (Fe, Mn and organic compounds), completely isotropic; under the microscope these nodules display a black-opaque image, with very low optical properties. Mottles, mammilated micronodules (10-50 um) are very abundant through the whole profile, whereas mesonodules are frequent only at the top of the soil and occasional in the B-horizon.

f. Fabric pedofeatures.

These are frequent in the whole profile and consist of "compacted" groundmass, around channels, appearing as densely packed streaks which reach up to about 2 mm insize, and dense infilled channels, displaying crescent bow-like patterns.

2.2.3. Chemical and physical properties. Soil test report.

Depth	0-18	18-35	35-85	85-150
Sand, %	15	13	11	9
Silt, %	19	15	15	9
Clay, %	66	72	74	82
Textural class	C 1)	C	C	C
Electric conductivity (Ec), mmhos/cm	0.04	0.04	0.04	0.04
pH-H20 (1:2.5)	5.40	5.10	5.20	5.20
pH-KCl (1:2.5)	5.70	5.50	4.90	4.90
Carbon % (C%) 2)	1.64	1.22	0.96	0.50
Organic matter,%(O.M.%) 2)	2.20	1.60	1.30	0.70
meq/100 gr clay	34.10	27.10	18.80	13.30
Ca, meq/100 gr clay	7.70	3.90	3.40	5.60
Mg, meq/100 gr clay	5.15	5.40	3.40	2.30
K, meq/100 gr clay	2.40	0.90	0.30	1.60
Na, meq/100 gr clay	0.40	0.30	0.70	0.80
Base saturation, % (V) 3)	45.90	38.80	41.50	77.00

1) C=clay; 2) O.M.%=C% x 1.33 (Landon, 1984) 3) V=(Exch.bases/C.E.C.)x100

Particle-size distribution reveals that profile EAK-47 is a clay soil; more than 60% of the soil material (fine earth), at each horizon, consists of clay. The natural nutritional status of this soil is rather poor, this is reflected in a low % of exchangeable bases (V) and strong acidity (pH-H20). It can be stated that it deals with a depleted soil; the C.E.C. ranges from medium to low.

2.3. Profile EAK-48 (Plinthic Acrisol FAO, 1974)

2.3.1. Macromorphology. Profile Description.

Date/season	:30-08-1985, dry season.
Sheet/obs. N	:122/3-53.
Elevation	:900 m.
Author	:Jan Kuyper.
Soil classification	:Plinthic Acrisol (FAO, 1974), Plinthustult (ST,1975).
Geology	:Mt. Kenya Series.
Petrography(parent material)	:phonolite/lahar.
Physiography	:plateau.
Macro-relief	:undulating.
Slope(length, shape, pattern, gradient, and position	:300 m, straight, single, 7%, midslope.
Vegetation/land use	:small scale rainfed annual crops:jembe, maize, pigeon peas and cotton.
Rock outcrops	:little rocky.
Surface cracking	:cracks of 4 mm, 40 cm apart.
Drainage class	:well drained.
Groundwater level	:+130 cm.
Soil fauna influence	:termite burrows.
Expected rooting depth	:+130 cm.

Horizons:

Ah	0-11 cm	Dark reddish brown (5YR 3/4, moist; 5Y 3/2, dry) moderate, medium to very coarse subangular blocky falling apart to fine crumb structure; patchy thin clay cutans; silty clay; slightly hard when dry, very friable when moist; sticky and slightly plastic when

		wet; very few, medium, hard, spherical iron manganese concretions; abrupt and smooth transition to:
Bu1	11-90 cm	Yellowish red (5YR 4/6 moist, dry); moderate very coarse subangular blocky; broken thin clay cutans; silty clay; slightly hard when dry, very friable when moist, sticky and slightly plastic consistence when wet; very few, medium hard spherical iron manganese concretions.
Bu2	90-130 cm	Yellowish red (5YR 4/6, moist; 5YR 5/8, dry); weak medium to coarse subangular blocky falling apart into single grain structure; patchy thin clay cutans; very gravelly to gravelly silty clay; loose when wet, loose when dry; dominant medium to large hard spherical iron manganese concretions; few partly weathered phonolites.

2.3.2. Micromorphology.

Much features displayed by this pedon, regarding microstructure, basic components and groundmass, are similar to that displayed by profile EAK-47. Therefore, in the present description general features are briefly referred, and specific features are fully described.

a. Microstructure

This is complex, because of pedoturbation. So, it deals with a microaggregate structure, which is very well expressed at the B-horizon (90-130 cm). Whereas, at the A-horizon (0-11 cm) it is rather a subangular blocky structure than a granular/crumbly one. Aggregates are very abundant, consisting of micro-sized unities (10-150 um, granules and crumbs), meso-sized aggregates (150-500 um) and macro-aggregates (stressed domains around channels). Voids are dominated by micro-pores (10-100 um), consisting of very fine (inter) packing voids and (intra) fine vughs and cracks. Meso voids (150-500 um) consist of inter-related compound voids, the macro-pores; these are frequent at the B-horizon. Pedality is highly developed at the B-horizon and moderate at the top of the profile and, even, weakly developed at the stressed domains. Porosity is high (50-55%); micro-porosity accounting for about 65-70%

b. Basic Components

Coarse mineral components are very few (c/f limit= 5 um and c/f limit= 10/90 um) and moderately sorted. Consisting of coarse silt and fine sand grains (5-250 um) and occur, to a large extent, embedded in the soil plasma. Coarser grains are rare and can reach about 1.5 mm in size. These occur randomly spreadthrough the whole profile and consist mainly of quartz. Some phonolite, nepheline and epidote grains are also found. Alteration is advanced. Fine grains consist of splinters of plagioclases and flakes of muscuvite, mainly.
Fine mineral components consist of fine silt and clay-sized particles (< 5 um) which do not occur as discrete entities, but as very fine plasma made up of kaolinite and some gibbsite, appearing completely impregnated with haematite and goethite, displaying a yellowish-red, cloudy and intensely micro-dotted, under PPL; therefore limpidity and birefringence are very low.
Coarse organic components are very scarce in this profile, being occasional at the A-horizon (+130 cm). It concerns remnants of root tissues (150-800 um), strongly impregnated and, at time, strongly metamorphose, making part of nodules.

c. Groundmass.

The related distribution pattern is plasmic or undifferentiated (c/f=10/90) and appears moderately anisotropic and birefringent (brown/dusky red under XPL), micro-granulated and cloudy. The bi refringent pattern is complex, being dominantly striated (circular, parallel and pore-striated), and speckled (mosaic).

d. Textural Pedofeatures.

Textural pedofeatures are represented by clay and ferruginous coatings. Clay coatings are only found at the A-horizon and not at the B. "skins" are mainly coatings and occur clustered, associated with micro-pores being very small (50-500 um length and < 10 um wide), discontinuous, with very irregular surfaces. Coatings are neither layered nor micro-laminated and frequently appear shaded by Fe compounds which hinders their identification. These consist of fine silt and kaolinite.

Ferruginous coatings are rare and cappings are occasional, both occur at the A-horizon and at the top of the B. The fine plasma coats partially, at time completely, the coarser grains and aggregates constituting more of less fine "skins", at while displaying a concentric pattern. Colour is dominantly red, with dark, brown dusky and yellowish tones, under XPL. These consist mainly of haematite and goethite.

Infillings. Clay infilling are few and occur at the A-horizon, only. Its properties conform, considerably, with that of clay coatings. Besides these display crescent pattern, layering and a coarser texture (silt).

Aggregatepedotubules. These constitute very outstanding features in this profile; they are very abundant, specially, at the B-horizon. It regards with loose discontinuous infillings, consisting of pelleted ground mass which appear like globular and ovoidal micro-aggregates or as mammillated meso-aggregates, containing all components of the groundmass.

e. Cryptocrystalline pedofeatures.

Nodules constitute the most outstanding pedofeature of this pedon, because of their abundant and wide variability regarding with size, shape, colour and interne fabric. According to their degree of impregnation various types are recognizeable.

Amorphous nodules . These are many and moderately sorted; sizes range from 20 to 500 um, though most nodules have about 20-250 um. Two types are recognizeable: isotropic nodules which are black and opaques (both under PPL and XPL), consisting of Fe-oxids, Mn-oxi-hydrates and fine organic matter (humus); and strongly anisotropic nodules which are brown under PPL and very coloured and bright under XPL, displaying red, yellow and green colours. It is regarded these involve highly weathered grains and rock fragments (Fe-bearing minerals).

Heterogeneous nodules. It regards with partial impregnated or pseudomorphosed nodules. Two sub-types are identifies:moderately heterogeneous nodules which are many with sizes ranging 10-300 um, red coloured, sometimes showing a clear concentric pattern resulting from alternating brownish, yellowish and dusky-red rings. The "host" material consists of groundmass involving mineral grains. Limpidity is low and birefringence is moderate. These correspond to the so called "ferruginous nodules". The second sub-type consists of high heterogeneous, macro/mega-sized nodules which are high coloured sharp contrasted (combinations of orange, ywllow, red, black and even green colours are very common). The internal fabric is also very heterogeneous, involving weathered mineral grains, rock fragments, and rests of vegetal tissues, besides "in situ" crystallized gibbsite and segregated (more or less crystalline) Fe-compounds, which at time appear clearly oriented around pores and grains.

e. Fabric pedofeatures

These are very frequent and can be grouped into 2 types: those consisting of stressed groundmass and those resulting from dense infilled channels (already described, under 1.1.6., EAK-47).

2.3.3. Chemical and physical properties. Soil test report.

Depth (cm)	0-11	11-90	90-180
Sand, %	15	14	46
Silt, %	16	8	6
Clay, %	66	78	48
Textured class 1)	C	C	SC 1)
pH-H20 1:2.5	6.20	5.20	5.80
pH-KCl 1:2.5	5.10	4.90	5.30
Electric conductivity (EC), mmhos/cm	0.03	0.01	0.03
C %	1.70	0.70	0.60
Organic matter,%(O.M.%) 2)	2.30	0.90	0.80
Cation Exchange Capacity (C.E.C.), meq/100 gr clay	42.00	27.50	33.40
Ca, meq/ 100 gr clay	6.40	1.50	2.00
Mg, meq/100 gr clay	5.20	0.60	1.00
K, meq/100 gr clay	2.60	0.90	1.50
Na, meq/100 gr clay	0.20	0.30	0.40
Base saturation % (V) 3)	34.30	12.00	14.70

1) Sc=sandy clay; 2) OM% = C% x 1.33 (Landon, 1984);
V= (Exch. bases/C.E.C.) x 100.

Profile EAK-48 consists of a relative poor soil, regarding its chemical properties; the C.E.C. ranges from medium to low values and the content of organic matter ranges from low to very low. The base saturation % points to a strongly depleted soil, strongly to slightly acid.

2.4. Profile EAK-44 (Humic Nitosol FAO, 1974)

2.4.1. Macromorphology. Profile description.

Date/season	:25-07-1985.
Sheet-observation N	:122/23-2
Elevation	:1410 m.
Author	:Jan Kuyper.
Soil classification	:Humic Nitosol (FAO), typic Haplohumult (ST).
Geology	:Mt. Kenya Series.
Petrography (parent material)	:lahar/phonolite/volcanic ash.
Physiography	:mountain footridge (crest).
Macro-relief	:undulating.
Slope characteristics	:100 m, linear, single, regular slope.
Slopegradient	:3%.
Position on slope	:upper slope.
Land use	:small scale rainfed, coffee and jembe.
Surface cracking	:few cracks, 5 mm.
Drainage class	:well drained.
Ground water level	:very deep, +170 cm.
Soil fauna influences	:termite burrows.
Expected rooting depth	:+170 cm. very deep.

Horizons

Au1	0-35 cm	Dusky red (2.5YR 3/2, moist, 5YR 3/2 dry); weak coarse to very coarse subangular blocky falling apart to moderate fine granules; patchy thin clay cutans; clay; soft when dry, very friable when moist, sticky and slightly plastic when wet, gradual and wavy transition to:

AB	35-80 cm	Dark brown (7.5YR 3/2 moist, 5YR 3/4 dry); moderately strong very coarse subangular blocky structure; broken thin clay cutans; clay; slightly hard to hard when dry, friable when moist, sticky and slightly plastic when wet; gradual and wavy transition to:
B	80-150 + cm	Dusky red (2.5YR 3/2 moist, 5YR 3/4 dry); moderately strong very coarse subangular blocky structure; continous moderately thick clay cutans (shiny pedfaces); hard weakly cemented when dry, firm when moist, sticky and slightly plastic when wet.

2.4.2. Micromorphology.

a. Microstructure.

This is dominantly a microaggregate structure specially at the A-horizon, changing with depth to a complex one; beneath 80 cm. various types can locally be found like vughy, crack, (subangular) blocky and even prismatic structure.
Aggregates. According with their morphology and sizes, three types are identified: microaggregates (20-300 um) consisting in granules and crumbs of soil material chewed by, or, passed through the digestive tube of the soil mesofauna. Meso-aggregates (300 um-1mm) made up of welded microaggregates, showing very irregular shapes and surfaces. The last type involve macromegasized domains of very homogeneous, stressed groundmass. Voids. Various types are found. Most are micro/meso-sized (vughs, compounds packing voids, cracks and some planar voids). Macro-sized voids are represented by many channels and chambers. Microporosity dominates at the B-horizon and macro porosity at the A and A/B horizons. Pedality. is moderately developed at the B-horizon and strongly developed at the other horizons. Porosity is guessed to be, respectively about 40% and 55% , macroporosity account for about 50-60%.

b. Basic components.

Coarse mineral components involve anhedral and sub-euhdral grains, ranging 5-100 um in size (c/f limit =5 um) which spread uniformly through the whole profile. These consists of mainly well contrasted (bright, milky white or pale) quartz grains. Alteration is moderate to weak, except for rare, composed grains of volcanics which display evidences of strong alteration, as reflected in their very coloured and contrasting image.

Fine mineral components involve soil material smaller than 5 um in size which is dominant (c/f=10/90) appearing as a yellowish brown mass spreaded through the whole profile (becoming dark-reddish brown at the top of the profile) and displaying a cloudy and isotropic appearance, intensely micro-dotted, resulting in a shaded and dirty image. It consists of low activity lattice clay, impregnated with goethite and haematite. Fe and Mn oxihydrated also seem to be involved.

organic components These are rare at the B-horizon, and abundant at the A-horizon, consisting of remnants organs (roots) and tissues; cortex and vascular structures are clearly identified (sizes ranges from 50-500 um). Most appear completely broken down, reimaining hardly cortex and cell walls. At time, strongly impregnated by dark (red or brown) Fe-compounds. Fine organic components are not recognizeable in this profile.

c. Groundmass.

This appears as a dark/reddish brown plasma, intensely dotted and shaded, lowly to moderately refringent and strongly contrasted by abundant, fine and bright pink-red nodules and bright micro grains. The b-fabric pattern, varies from speckled to striated; the first dominated at the A/B horizon, whereas the second dominates at the B-horizon. Pore and aggregates-striated patterns are common at the B-horizon, being associated to clay and Fe accumulations. Parallel (longitudinal) striated patterns like circular and bow-like patterns are occasionally recognized. All these features display a bright, light yellowish colour under XPL.

d. Textural pedofeatures.

Clay coatings. These are rare at the A horizon, ocassionally at A/B (40-60 cm) and abundant at the B-horizon, and are associated with micro and meso voids and it deals with typic coatings (crescent and bow-like types) and hypocoatings. Most are discontinous, very thin and its optical properties are interfered by Fe-compounds (occurring as dark microdots and or juxtapossed bands). Therefore clay coatings display a shaded yellowish colour, low limpidity and moderate refringence. In spite of this, microlamination and extinction (radial) zones are at time recognizeable. It deals with a very fine material, "contaminated" with Fe-oxihydrated. Occasionally, aggregate coatings are found, at the A/B horizon and consists of very fine, mostly discontinuous, clay "films" around structural elements.

Clay infillings. These pedofeatures are very well expressed at the A/B horizon wherein they are frequent. Clay infillings are associated with micropores (vughs mainly) which appear completely sealed by clay. Physical and optical properties of the clay infillings conform, to a great extent, with that of clay coatings.

Aggregate pedotubules constitute a very striking feature in this pedon. These are very frequent at the B-horizon and are not recognizeable at the A-horizon. It deals with macro and mega-sized channels and chambers, more or less continously infilled with loose micro-aggregates, pelleted by the soil meso-fauna. Often these occur welded giving rise to meso aggregates or even larger agglomerates; bowlike and circular patterns are clearly and frequently observable.

Ferruginous coating. These are restricted to the A and B horizons. Their abundance is occasional and appear as hypocoatings, impregnating the ground mass or juxtaposed to clay coatings (amorphous, dark red or dark brown Fe-oxihydrates). Occasionally at the top of this profile, ferruginous coatings occur around structural entities.

e. Cryptocrystalline pedofeatures.

Nodules are many in this profile, occuring both ferruginous and amorphous types. Sizes ranges 10-200 um, most being micro-nodules (20-100 um). These occur clustered rather than randomly spread and associated with Fe segregation, conferring therefore a dirty appearance to the ground mass, where they are located. Ferruginous nodules are many and appear reddish brown under PPl and dark/red nodules are densely micro-dotted. Impregnation varies from weak to strong. The host material consists of ground mass, more or less pseudomorphosed.

f. Fabric pedofeatures.

These are represented by two features: stressed or compacted groundmass around voids (clannes, chambers and planar voids) and streaks where the groundmass appear more openly packed. Both feature are very frequent at the A and A/B horizons and are rare at the top of the soil. The first correspond to pressured groundmass along passage channels and the second one, to complete infilled channels (aggropedotubules); showing at time bow-like patterns are recognized, as mentioned under 5.2.3.

2.4.3. Chemical and physical properties. Soil test report.

Depth (cm)	0-25	40-60	60-90	90-150
Sand, %	16	10	6	6
Silt, %	24	25	20	12
Clay, %	60	68	74	82
Textural class	C 1)	C	C	C
pH-H20 1:2.5	5.9	6.1	6.3	6.4
pH-KCl 1:2.5	5.1	5.3	5.5	5.6
Electric conductivity (Ec) m mhos/cm	0.11	0.13	0.11	0.08
Carbon % (C%)	1.79	1.29	0.67	0.47
Organic matter,% (O.M.%)2)	2.40	1.70	0.90	0.60
Cation Exchange Capacity (C.E.C.), meq/100 gr clay	42.50	33.00	23.80	22.30
Ca, meq/100 gr clay	8.10	5.10	3.40	1.60
Mg, meq/100 gr clay	2.00	2.30	2.00	1.50
K, meq/100 gr clay	4.20	2.00	2.10	1.40
Na, meq/100 gr clay	0.10	0.40	0.10	0.10
Base saturation % (V) 3)	33.90	28.80	32.50	20.60

1) C=clay; 2) OM%= (C% x 1.33) x 100 (Landon, 1984)
3) V = (Exch. bases/C.E.C.) x 100.

Profile EAK-44 consists of a clay soil which is slightly to medium acid, with a medium C.E.C. and low base saturation %. The organic matter content ranges from medium to very low, decreasing with depth.

2.5. Profile EAK-38 (Mollic Andosol FAO, 1974)

2.5.1. Macromorphology. Profile Description.

Date/season	:14/09/1985, beginning of the warm season.
Sheet-observation N	:121/2-1.
Coordinates	:99 81 N, 3 28 8 E.
Elevation	:2925 m.
Authors	:Jan Kuyper.
Soil classification	:Mollic Andosol.
(FAO,soil taxonomy)	Andic Haploboroll.
Geology	:Mt Kenya-series.
Local petrography (parent material)	:volcanic ashes, lapilli.
Physiography	:mountain.
Macro-relief	:rolling to hilly.
Slope (length, shape and pattern	:convex.
Vegetation/landuse	:bamboo-Hagenia forest, forestry, game reserve
Drainage class	:well drained.
Groundwater level(actual)	:very deep.
Soilfauna influences	:mole, rat crotovinas.
Expected rooting depth	:130 cm.

Horizons

0	+2 - 0 cm	Black (10YR 2/1, moist); slightly gravelly organic matter; clear and smooth transition to:
Au1	0 - 14 cm	Black (10YR 2/1, moist); moderate fine crumbs; patchy thin clay cutans; slightly gravelly silty clay; friable when moist; non to slightly sticky and slightly plastic when wet; clear and smooth transition to:

Au2	14 - 37 cm	Black (10YR 2/1, moist); moderate coarse angular blocky structure falling apart to crumbs; broken thin clay-humus cutans; slightly gravelly silty clay; friable when moist, non to slightly sticky and slightly plastic when wet; abrupt and smooth transition to:
C	37 - 53 cm	Dark yellowish brown (10 YR3/6, moist); weak very coarse subangular blocky structure falling apart to granules; patchy thin clay cutans; slightly gravelly sand; very friable when moist, non sticky and non plastic when wet; abrupt and smooth transition to:
Abu1	53 - 56 cm	Dark yellowish brown (10YR 3/6, moist); moderate coarse to very coarse angular blocky structure, continuous thin clay cutans; silty clay; friable when moist, slightly sticky and slightly plastic when wet; abrupt and wavy transition to:
Abu2	56 - 62 cm	Yellowish red (5 YR 5/8, moist); moderate coarse to very coarse angular blocky structure; continous thin clay-humus cutans; silty clay; friable when moist, slightly sticky and slightly plastic when wet; abrupt and wavy transition to:
Abu3	62 - 66 cm	Black (7.5 YR 2/0, moist); moderate coarse to very coarse angular blocky structure; continous thin clay-humus cutans; silty clay; friable when moist, slightly sticky and slightly plastic when wet; clear and wavy transition to:
ABb	66 -116 cm	Dark brown (10 YR 3/3, moist); moderate coarse angular blocky structure; abundant thin clay cutans; silty clay; friable when moist, slightly sticky and slightly plastic when wet; clear and wavy transition to:

Cbul	116 -130 cm	Dark brown (7.5YR 4/4, moist); common medium to coarse distinct clear dark yellowish mottles (5YR 5/8, moist); moderate very coarse angular blocky structure; continuous to broken thin clay cutans; silty clay; friable when moist, slightly sticky and slightly plastic when wet; clear and wavy transition to:
Cbu2	130 -150+cm	Light olive brown (2.5YR 5/6, moist); many coarse prominent diffuse very dark grayish brown mottles (2.5Y 3/2, moist); weak very coarse angular blocky structure falling apart to granules; slightly stony to stony silt; friable when moist, slightly sticky and slightly plastic when wet.

2.5.2. Micromorphology.

It is emphasized that profile EAK-38 involves a "volcanic" soil, which is clearly layered and contains a "buried" profile, as reflected by the sequence A-C-Ab-A/Bb-Cb.

a. Microstructure.

This appears strongly influenced by zoogenic pedoturbation and changes according to the above mentioned sequence: at the A-horizon it is a micro-aggregate structure, whereas at the C it is a grain one (pellicular and bridged). At the top of the "buried" profile (Ab and a/Bb) the microstructure is complex, besides the micro-aggregate type, vughy, spongy and vesicular types are locally recognized, but at the Cb-horizon it becomes, again, a grain structure, showing locally a clear apedal character (low organization degree of the very scarce soil plasma). <u>Aggregates</u> are most micro-aggregates, corresponding to excremental and oral "pelleted" groundmass. <u>Voids</u> involve various types and sizes of pores; micropores (channels and chambers) are dominant at the C-horizons, whereas micro-pores (vughs, packing voids and cracks) are dominant at the A-horizons. Pedality is strongly developed at the C and Cb-horizons. Porosity is very high in the whole pedon, ammounting 60-65% of the thin section area.

b. Basic components.

The c/f limits and c/f ratios of the basic mineral components vary widely, as function of the horizon-sequence, respectively 10, 40, 20, 40 and 20 um; 40/60. 90/10, 20/80, 30/70 and 90/10. Coarse mineral components are represented by fragments of volcanics, feldspars and grains of gibbsite. Volcanics display gray greenish colours, low anisotropisme, euhedral shapes and sizes reaching up to some mm. Volcanics consist of phonolite, nepheline and sanidine and are abundant and coarse textured at the A and C-horizons and occasional and very fine textured at the A/Bb. K-feldspars occur as acicular and euhedral grains (20-200 um) and result from the fragmentation (physical weathering) of volcanics, being very abundant at the Cb-horizon. Gibbsite occurs clustered, consisting of anhedral grains (20-200 um), which appear milk-white, bright, and radial striated. Their abundance increases from occasional, at the Ab-horizon, to very abundant at the Cb. It is regarded that gibbsite is formed "in situ". Alteration is advanced. In spite of the abundant occurrence of primary minerals, dissolution, segregation, corrosion and fissuration are frequently recognized.

Fine mineral components do not occur as discrete entities, but as a very fine plasma which appear intensely micro-dotted, shaded and dirty; isotropic rather than refringent (dark brown to dark red colours). At the C and Cb-horizons, wherein the plasma is scarse it occurs constituting micro-granules and "skins", around grains. This plasma is organo-mineral in nature, consisting of some hallosyte, kaolinite, crystalline and amorphous hematite and goethite, amorphous organic matter, allophane and Mn-oxihydrates. The quantitative occurrence of each one conforms with the weathering degree, at each horizon.

Basic Organic components consist of meso-macro sized rests of roots, root-hairs and mycelia likewise rests of tissues (cortex, central cylinder and parenchyma), occuring only at the A and Ab-horizons. At the A-horizon these are abundant and correspond to live organs and fresh rests, displaying high relief; very bright yellowish-white colours. At the Ab-horizon these components are common and appear completely metamorphosed by dark-red and dark-brown compounds. Fine organic matter appears as discrete, isolated, micro-granules and as (humus) impregnating the fine groundmass, specially at the A and Ab-horizons.

c. Groundmass.

The groundmass of profile EAK-38 is to a large extent undifferenciated, weakly or poorly organized, except at the A/Bh-horizon where a weakly, speckled/striated b-fabric is found. The related distribution varies in function of the horizon sequence (A-C-Ab-A/Bb-Cb) being in the same order, open porphyric, gefuric, gefuric, undulic/isotic, double spaced porphyric and close porphyric.

d. Textural pedofeatures.

These are represented by ferruginous, gibbsitic and allophanic coatings, being not associated with soil porosity but with grains and voids occurring within weathered volcanic fragments. Ferruginous coatings display colours ranging from red to yellow, strong referred orientation and, at time, clear layering and even micro-lamination. Gibbsitic coatings consist of very fine and equigranular "skins", which commonly appear superimposed by Fe-compounds. Both types of coatings occur in the "buried" horizons, being more abundants at the A/Bb. Allophanic coatings are abundant at the Cb-horizon and consist of a jelly like material which occurs enveloping grains and coating pore-walls. Allophane often appear mixtured with yellowish-red compounds and -or with amorphous organic matter. Coatings are, in general, micro-sized, discontinuous and display low optical properties because they occur intensely micro-dotted.

Aggregate pedotubules are occasionally observed, but there is evidence that the great part of the groundmass has passed through the digestive tract of the soilmesofauna or has been chewed by this; back-filling material is found all over the profile. It regards loose continuous and dense incomplete infilled channels and chambers, showing at time crescent bow-like patterns. The internal fabric consists of loose micro-aggregates and mammillated aggregates, which appear darker than the surrounding groundmass. Fecal pellets are commonly observed.

e. Cryptocrystalline pedofeatures.

These features are represented by nodules, which abundance varies from occasional to many and occur through the whole profile, except at the Cb horizon. At the top of the profile (A and C horizons typic ferruginous, and amorphous black, nodules occur. Whereas, at the "buried" horizons (redish and yellowish nodules are found. Sizes ranges from some tenths to about 300 um and the optical properties are low, because of the occurrence segregation, micro-dotting, humus and oxihydrates of Mn. So, nodules are rather isotropics. Ferruginous nodules consist of groundmass (involving grains) more or less impregnated with crystalline haematite and goethite. Amorphous nodules contain humus, Mn-oxhydrates and crystallized haematite.

2.5.3. Chemical and physical properties. Soil test report.

Depth cm	Horizon cm	Clay %	Silt %	Sand %	pH(1:2.5) H2O	KCl
0-37	A	13.60	35.71	50.70	5.70	4.56
37-53	C	1.30	6.60	91.80	5.70	5.60
53-66	Ab	16.15	63.67	19.25	5.55	4.2
66-116	A/Bb	13.80	59.95	25.20	5.30	4.05
116-150	Cb	3.30	77.60	19.10	5.30	5.80

Particle-size distribution analysis reveals that the texture of profile EAK-38 varies as function of the horizon sequence, from loam/sand (A and C horizons) to loam/silt loam (at the buried horizons).

The reaction of the soil is acid, ranging from medium acid, at the top zone of the profile (A and C horizons), to strongly acid in the buried soil.

3. INTERPRETATION OF THE EAK-PROFILES. PEDOGENESIS AND SOIL CLASSIFICATION.

3.1. Profile EAK-51.

3.1.1. Weathering.

Physical features like a relative high c/f limit (25 um) and a low c/f ratio (40/60) are indicating that this profile is a moderately weathered soil; about 60 % of the soil material consists of sand. Chemical properties (2.1.3.) are also pointing to a moderate weathering degree as reflected in a high base saturation % (71.60-87.90) and a medium CEC value, of the clay fraction (41.80 - 36.60 meq/100 gr clay). This last is suggesting that the concerned secondary layer silicates do not belong to the low-activity type, but to 2:1 or intermediate types; which also constitutes an evidence supporting the view that a moderately weathered soil is concerned.

The occurrence of a moderate weathering degree conforms with the fact that the parent material of this soil consists of very resistent material (Precambrian rocks) and with a shortage of humidity passing through the profile, because a considerable part of the scarce rainfall (800 mm, annual mean) is lost by evapotranspiration and run-off, resulting from respectively, the semi-arid characters of the climate and give severe erosion of the soil, which appears truncated and sealed (2.1.1.); besides, this soil rest directly over rocks (Photograph 1,p 63). The occurrence of these environmental conditions allows to assume that the effective rainfall is really very low.

3.1.2. Ferruginization.

Ferruginization refers to the accumulation of "oxides" (mainly, oxides, hydroxides and hydrated oxides of Fe and Al) in the solum, their progressive dispersion, oxidation or hydration, which confers to the soil typical colors (brownish, reddish brown and red, respectively) and a set of particular physico-chemical properties (Buol, Hole and McCracken, 1973).

Features associated with ferruginization are absent of this profile. Because weathering, in general, has proceeded at low rate, it is inferred that ferruginization has also done so, because the first implies that not enough Fe and Al have been released from the primary minerals. On the other hand, as ferruginization is rather related with the chemical state of the Fe and Al than with their quantity it can be concluded that the soil concerned does not have suitable conditions for ferruginization. This assumption seems to be supported by the fact that the groundmass displays dominantly, the appearance associated with oxidated Fe (crystallized haematite) which in turn corroborate the previously suggested soil moisture scarcity. So, it is assumed that some processes involved in the ferruginization, like dispersion, hydration and hydratation are interfered by dryness. Profile EAK-51 does not display under the microscope the typic cloudiness and jelly-like appearance associated with ferruginization.

3.1.3. Homogenization.

This soil-forming process refers to the homogenization and churning of the solum by biologic or physical agents.
Signs of pedoturbation are very outstanding features in profile EAK-51. It regards mainly with bioturbation caused by termites and ants; aggregate pedotubules as well as re-oriented groundmass around channels and chambers are frequently found and can be observed even without help of lens (2.1.2. d and e).

3.1.4. Illuviation.

Illuviation consists in the removal of fine soil material in suspension or solution from a soil layer (the eluvial horizon) and their deposition or precipitation in another soil layer (the illuvial horizon). Clay illuviation refers to the vertical removal of clay from an overlying to an underlying one and the accumulation of clay on pedo surfaces and pore walls in the illuvial horizon, giving rise to typic micro morphological features (like clay coatings, clay infillings and eventually papules) and causes strong textural change between the horizons concerned. So, clay illuviation promotes the morphological, physical and chemical differentiation of the soil.

Clay coatings are occasionally found in profile EAK-51. These occur associated with micropores and locally, where micropores are abundant, they are also abundant and occur clustered (2.1.2.d). These features allow to conclude that this profile exhibits clear signs of clay illuviation.

However, because only one thin section was available (45-55 cm depth, the bottom of the B horizon) and because this profile appears severely eroded (truncated and sealed by a crust of about 30 cm thick) the pedogenetic significance of the observed signs of clay illuviation is uncertain. It could be that the coatings present in profile EAK-51 represent a recent feature related with the degradation of the soil rather than with its formation. It can be postulated that the recognized coatings have resulted from the deposition of clay particles released by erosion, which are easily translocated by percolating water, through meso and macropores and deposited in the bottom of the B horizon, where particles are sieved by micropores, etc.; such process hardly can be regarded as a pedogenetic process.

In this paragraph the occurrence of clay coatings in profile EAK-51 and their uncertain significance in pedogenetic terms, are only stipulated. The question to what extent the coatings found in profile EAK-51 are really expression of clay illuviation, in a pedogenetic sense, is discussed under paragraph 3.1.5. devoted to the classification of this soil.

3.1.5. Soil classification.

The classification of pedon EAK-51 is a complicated subject because of various facts, some already mentioned: a) severe erosion, b) the B horizon, (the only genetic horizon occurring in this profile) is very homogeneous with regard to texture, chemical properties and morphology, therefore any genetic relationship between this and the lost A horizon has to be inferred, c) the availability of only one thin section, representing the lower zone of the B horizon does not allow to conclude if illuviation signs occur in the rest of the horizon and d) additional trouble rises from the fact that "reference criteria" regarding macro and micromorphology (listed in Tables 4 and 5, Ap) refers to heavy, clayey soils, and not to medium textured ones, like profile EAK-51; it is well known that the expression of clay illuviation varies according to the texture of the soil. In spite of these shortcomings, the properties displayed by profile EAK-51 are compared with those stated as "standard", presented in Tables 3,4, and 5 (Ap) aiming a first approach.

a. Does the B horizon of profile EAK-51 fit the general properties to qualify for an argillic or an oxic horizon?

When the general properties displayed by the B horizon of profile EAK-51 are compared with those stated as general diagnostic requerements for the orgillic horizon (Table 3a two general facts are observed. Firstly, the comparison of various properties has no sense ("n.s") like texture (points a, a1 and a2 in table 3a), thickness (point b) and the characteristics of the boundaries (point c), because the A horizon has been lost and only the B horizon remains. Second, profile EAK-51 fits just the general clay-illuviation requirements as stated in Table 3a, under c .

On the other hand, when the general properties of the B horizon present in profile EAK-51 are compared with the general properties of an oxic horizon it is seen that the first does not meet the most important demands to qualify for an oxic horizon. (Table 3b, points b,c and f).

Other general properties of profile EAK-51 (2.1.3.),like the texture (about 60% of the soil material consists of sand), the C.E.C. value (medium: 36.60-41.80 meq/100 gr clay) and the base saturation % (high: 71.60-87.90%) are also pointing to an argillic horizon rather than to an oxic one.

b. Does the B horizon of profile EAK-51 meet the macromorphological properties to qualify for an argillic or oxic horizon?

The comparison of the macromorpholofical properties displayed, in the field, by the sub-horizon concerned with those exhibited by the argillic horizon (Table 4a) reveals that the horizon of profile EAK-51 just meets the requirements regarding with clay illuviation and structure, as stated in Table 4a (points a and c). On the contrary, the comparison of the macromorphological properties displayed by the sub-horizon of profile EAK with those displayed by the oxic horizon (Table 4b) reveals that the sub-horizon concerned does not meet important diagnostic features demanded to qualify for an oxic horizon, (like: absence or scarcity of clay skins, scarcity of weatherable mineral and thickness, respectively points f, d and g in Table 4 a, Appendix).

c. Does the B horizon of the profile EAK-51 meet the micromorphological properties to qualify for an argillic or an Oxic horizon?

The comparison of the micromorphological features recognized in the sub-horizon of the profile EAK-51, with those micromorphological features states as typic, or diagnostic features, for the argillic and the oxic horizon, clearly reveals that this B horizon does not meet most of the micromorphological requirements demanded to qualify for an oxic horizon (Table 5b, Appendix), but fits all the requirements to qualify for an argillic horizon, as stated under 5a, Appendix.
On the basis of the results of these comparisons it can be concluded that an argillic horizon is present in profile EAK-51. However, this conclusion is not very consistent, because the occurrence of various shortcoming, already mentioned, impeding a more convincing interpretation of the clay coatings observed in this profile. Because these impediments the question remains if an argillic or an oxic horizon is present in profile EAK-51. The elucidation of this question is here attempted in the light of literature on this topic.

In the Soil Taxonomy (USDA, 1975, p 25-26) the identification of the argillic horizon in sandy textured soils, without any overlaying horizon and without textural differences between its upper and lower zones, is specifically discussed. The following is stated:

-..."if there is skins that are thick enough to obscure fine grains on the 10-15% of peds surface.

-..."if some pores have nearly continous clay skins, or

-..."if thin sections show oriented clay coatings in some 1% of some part of the horizon, the horizon is considered to be an argillic horizon".

On the oher hand, Bullock and Thompson (1985, p 21-23) state the following micromorphological features as expression of the argillic horizon in light-medium textured soils.

- clay coatings are easily identifiable because there is good contrast between coatings and groundmass.
- coatings display strong orientation, sharp boundaries, textural contrast with the surrounding groundmass, and laminated appearance.
- rarely uniformly distributed, but clustered.
- grains are coated and often bridged by clay.

A mindfull lecture of the foregoing statements and its comprarison with features regarding clay illuviation, and the properties of the coatings themselves(2.1. 2,d and microphot. N 1) allows to accept that the signs of illuviation displayed by profile EAK-51 fit most of the criteria advanced by the above quoted authors. So, on the basis on the features observed and taking into account the information on this subject, provided by the consulted literature, it is concluded that an argillic horizon is present in profile EAK-51. This horizon constitutes the main and the sole diagnostic feature occurring in this pedon.

Profile EAK-51 was classified as an Acrisol under field conditions. However, this classification is in fact wrong, because of its relative high C.E.C., its high base saturation %, and its sandy texture (2.1.3.) and its high content of weatherable minerals. (c/f=40/60) The magniture of these parameters are pointing to a Luvisol and, as far as the dominant red colour and its high chroma values (2.5 YR 3/6) are regarded, these soil is further classified as Chromic Luvisol (FAO/UNESCO, 1974).

According to the Soil Taxonomy (1975) profile EAK-51 can be placed both in the Alfisols and Ultisols (relative old Alfisols and relative young Ultisols). The criteria provided by the Soil Taxonomy to separate these Orders (p 95 and 349) refer to the value of the base saturation % and the content of weatherable minerals. Alfisols exhibit moderate to high base saturation % (>35%), whereas Ultisols, being older soils, exhibit low base saturation % (<35%). So, because profile EAK-51 displays a high base saturation %, (80%, mean value), a relative high content of weatherable minerals reflected in a high c/f ratio (40/60), a relative high C.E.C. (39 meq/100 gr clay, mean value) and a sandy texture (58% sand, mean value) it is classified as Alfisol.
Alfisols are classified at second level (sub-order) on the basis of their soil moisture regime. In the case of profile EAK-51, the information presented in Fig. 3 and Table 2 (1.3.4) make it evident that Aquic and Udic soil moisture regime are not involved. Under 3.1.1 it was assumed that profile EAK-51 presents a severe moisture deficit, because more than 50% of the rainfall is lost by both evapotranspiration and run-off. In addition, the fact that this soil rests over rock makes insignificant the eventual contribution of the ground water to the humidity of the soil. So, taking into account all these conditions it is concluded that an ustic soil-moisture regime is concerned in profile EAK-51. Therefore, this profile can be classified as Ustalf and given its high chroma-red color, as Rhodustalf.

3.1.6. Conclusion

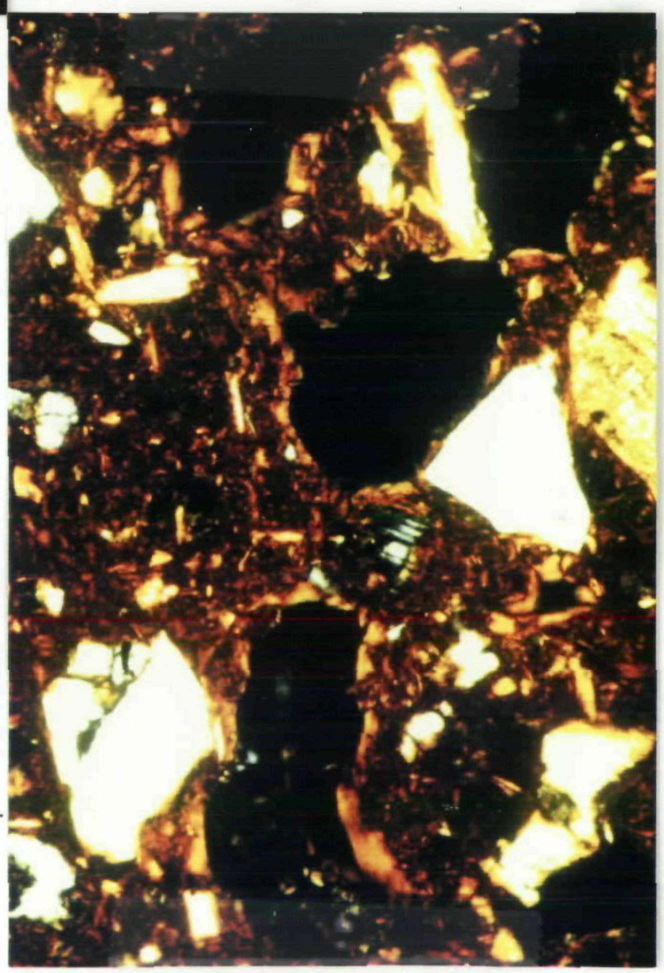
Profile EAK-51 is a medium textured moderately weathered soil. Severely eroded, moderately structured. Currently it consist of an undifferentiated B horizon overlying rock, with its upper zone severely disturbed constituting a thick crust. It is concluded that

these facts have drastically interfered the hydrological conditions within the profile giving rise to a marked soil moisture deficit.
The study of the chemical, physical, macro and micromorphological properties of this profile suggest that its pedogenesis involves a moderate degree of weathering (reflected in low to weak rate of desilication), leaching of bases, weak ferruginization, intensive pedoturbation and, probably clay illuviation.
Signs of clay illuviation recognized in the lower zone of the B-horizon are quantitatively and qualitatively well expressed. However, they are not enough to prove definitely that an argillic horizon is involved in this profile, because coatings could result from the mere deposition of the fine soil material detached at the surface by erosion. The doubt remains as thin sections of the rest of the profile were not available. Information provide by literature on this subject allows to conclude that an argillic horizon should be involved, this conclusion remains as an assumption.
Pedon EAK-51 is classified as Rhodustalfs, (Soil Taxonomy, 1975) or on the basis of its chemical and physical properties, soil moisture regime and chroma-red color and as a Chromic Luvisol (FAO, 1974).

Photograph N°1. Truncation and surface in profile EAK/51. Only the B horizon remains, resting directly on Pre-cambrian rocks.

Microphot. N°1.Fine clay coatings and clay infillings in profile EAK-51, showing lamination and bow-like patterns (XPL, 79 magnifications).

—— 37 um.



3.2. Profile EAK-47.

3.2.1. Weathering.

Both macro and micromorphological features reveal that it concerns with a massive, very homogeneous and deeply weathered profile (Photogr. N 2, p 59). This fact is reflected in features like: a very low c/f limit (5 um), a very narrow c/f ratio (10/90), the nature of the fine mineral components (consisting mainly of kaolinite and oxides, a weak differentiation of the b-fabric and weak horizon differentiation (Photogr. 2.)

General chemical properties (2.2.3.) support the view that profile EAK-47 deals with a deeply weathered soil; the C.E.C. and base saturation reaches rather low than medium values (respectively 23 meq/100 gr clay and 49%, mean values) and the strongly acid reaction of the soil (pH-H20=5.2, mean value).

The advanced degree of weathering displayed by profile EAK-47 seems to conform with the predominant environmental (soil-forming) conditions in the area where it is located: occurrence of a relative "soft", porous (vesicular) parent material (phonolite/trachyte) rich in volcanic glas (glas-silica) relative high rainfall (about 900 mm, annual mean), alternating wet and dry seasons and well drained conditions evolve. Under these tropical conditions the volcanic glas is intensively weathered evolving to kaolinitic end products.

3.2.2. Ferruginization.

The study of the thin section reveals that ferruginization is a very outstanding soil-forming process in this profile, being very well expressed in the composition of the fine mineral components (kaolinite, heamatite and goethite), the occurrence of runiquartz, Fe-cappings around coarser grains and occasional Fe-nodules. The whole groundmass appears to be impregnated with Fe-compounds, more or less crystalline, conferring to the soil the typic yellowish and reddish colours of "oxic" or "ferric" material. So, these features lead to accept that ferruginization has also been a very dynamic process; favoured by the occurrence of Fe-bearing parent material, sufficient humidity (necessary for hydrolysis, hydration and leaching) and alternating dry and wet seasons which favour the chemical attack of the minerals and dynamizes the oxi-reduction cycle of the iron.

3.2.3. Homogenization.

Pedoturbation is also a very outstanding soil-forming process in profile EAK-47, being directly recognizeable under PPL, even, without help of the microscope. This process is very well represented by various micromorphological features: a)micro-aggregate structure, b)aggregate pedotubules, c)stressed groundmass around passage channels and d)complex and weakly developed b-fabric. The external morphology and sizes of the micro-aggregates suggest that the great part of the groundmass has passed through the digestive tract of the soil meso-fauna (termites, worms, etc.). Therefore, it is stated that pedoturbation has a zoogenic origin. Besides, microstructuration, associated to the occurrence of "ferritic peds" is also identified, locally. This result from the re-distribution of the Fe-compounds (cementing agents) and appears as weak, circular or speckled (light red or orange red) b-fabrics. Microphot. 2 (p 59) and 3 show some features related to microstructure and pedoturbation occurring in profile EAK-47. However, it must be kept in mind that a lack of illuviation signs only prove that recent clay illuviation has not happened, but it does not deny an eventual contribution of illuviation, at earlier stages of the pedogenetic history of this profile. It should be that identification features, (like clay coatings, papules and clay infillings) have disappeared because of pedoturbation and/or masking effect of the Fe-compounds.

3.2.5. Soil classification.

Profile EAK-47 was classified as an Acrisol (Ultisols), under field conditions. So, the major diagnostic feature occuring in this pedon is an argillic horizon, which "per definition" is "an illuvial horizon in which the layer-lattice silicate clays have accumulated by illuviation" (Soil Survey Staff, 1975). However, as it was already pointed out the study of the thin sections did not reveal signs of clay illuviation. Therefore, the doubt rises if an argillic horizon is really present in this profile.

a. Does the B-horizon of profile EAK-47 meet the general properties to qualify for an argillic or oxic horizon?

According to the definition of the argillic horizon advanced by FAO (1974) the occurrence of this horizon, in not truncated soils, is associated with the presence of : a depleted A horizon and/or an E horizon and/or an abrupt textural change. This refers to an increasing in the clay content of the B horizon of at least 20% (or 8% according to the Soil Taxonomy, 1975), with respect to the overlying horizon, which has to take place within a vertical distance of 30 cm.

Profile EAK-47, which is not truncated, does not display an E-horizon nor signs of depletion. Regarding with textural change, under 2.2.3. it is seen that the difference between the clay content of the A/B horizon and the B reaches only 2% and 9% if the difference between the clay content of the A horizon and B horizons together -(66+72):2- and the B, as a whole, -(74+82):2- is computed,; a difference which magnitude falls within the limits of the analytical error. A greater textural change results if the clay content of the lower part of the B horizon (Bu2) is compared with that of the A or/and A/B horizons, but in these cases the vertical distance involved largely exceeds the 30 cm demanded as limit. So, it is concluded that the B horizon present in profile EAK-47 does not meet the requirements regarding the textural change, as stated by FAO (1974) and Soil Taxonomy (1975), to qualify as an argillic horizon. (Table 3a; points a1 and a2).

In spite of the occurrence of high pedality and microporosity (2.2.2.a) profile EAK-47 does not display oriented "clay skins" as stated in Table 3a, under c1; on the contrary, in Table 3b it can be seen that the B horizon present in profile EAK-47 meets almost all the features demanded to qualify for an oxic horizon, regarding with texture, morphology of its boundaries, content of primary minerals and content of rocky material. These last are regarded insignificant, given the low c/f limit (5 um) and c/f ratio (10/90), high homogenety and depth displayed by profile EAK-47.

The sole point deserving a brief explanatory comment is the C.E.C. value at the B horizon; 16 meq/100 gr clay, which is just the upper limit demanded to a sub-horizon to qualify for an oxic horizon. It is regarded that this value is overestimated because the C.E.C. was determined in buffered soil extract at pH 7 (1.4.2.); which is a very well known fact in soils having pH dependent charge (soil exchange complex dominated by 1:1 aluminosilicates and oxides), like profile EAK-47.

b. Does the B horizon of profile EAK-47 meet the macromorphological properties to qualify for an argillic or an oxic horizon?

The comparison of the macromorphological properties shown by profile EAK-47 in the field, with those states as "standard" macromorphological properties of the argillic horizon allows to constate that, the profile regarded does not fulfill the macromorphological features demanded to qualify for an argillic horizon.
The first requirement, in Table 4a, refers to the identification in the field of clay coatings occurring on ped surfaces. As matter of fact, the soil surveyor described the occurrence of "clay cutans". However, because the study of the thin sections did not corroborate this

finding and because the frequent occurrence of re-oriented groundmass (2.2.2, a, f and Microphotogr. N 2), it is regarded that what the surveyor described like "patchy thin" and "broken thin clay cutans" correspond indeed to stressed fine soil material. It also could result from the re-distribution of Fe-compounds and impregnation of the aggregates with these compounds which can form polished and shiny surfaces.

On the other hand, Table 4b, shows that profile EAK-47 fits all the requirements to qualify for an oxic horizon, in terms of macro and microstructure, homogeneity of the solum, boundaries, depth, absence of clay illuviation signs and low status regarding with weatherable minerals. So, the macromorphological features recognized in profile EAK-47 reveal that its B horizon does not qualify for an argillic but for an oxic horizon.

c. Does the B horizon of profile EAK-47 meet the micromorphological characteristics to qualify for an argillic or an oxic horizon?

The sub-horizon of profile EAK-47 does not fit most of the micromorphological features demanded as diagnostic features to qualify for an argillic horizon. This fits only two out of six of these requirements (color, and b-fabric of the groundmass and nature of the skeleton grains, respectively points e and f in Table 5a, Appendix. These requirements are not key features to separate definitely an old argillic horizon from an oxic one; because the general appearance of the groundmass as well as the b-fabric pattern are strongly influenced by the chemical state of the Fe-compounds and by the activity of the soil mesofauna. On the other hand, the skeleton grains, in deeply weathered soils, usually consist of resistent minerals, mainly quartz and zircon and, besides primary minerals like feldspars, plagioclases and micas which occur "envelopped" with Fe-compounds; therefore protected from the action of chemical weathering agents.

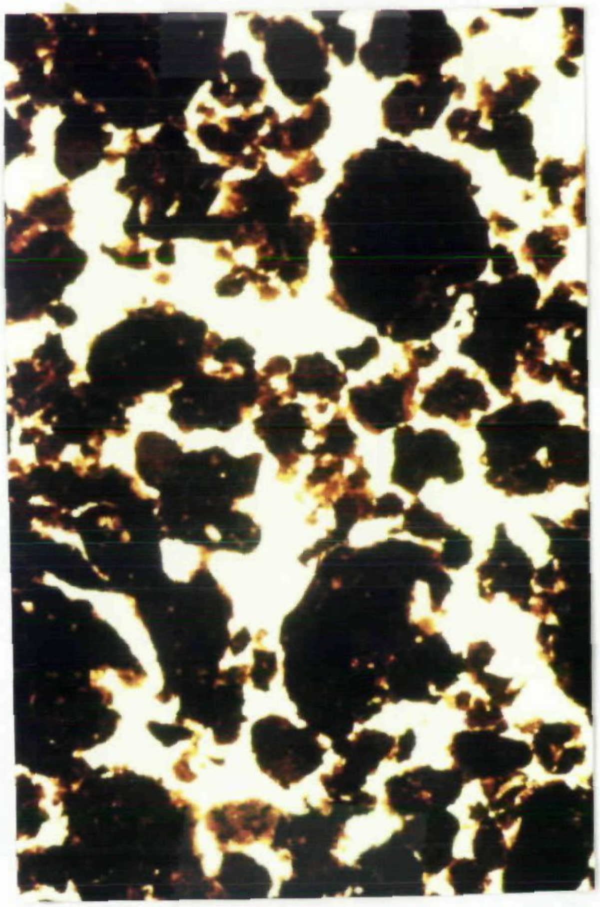
In Table 5b, it can be seen that the B horizon present in profile EAK-47 clearly fulfills all the micromorphological requirements demanded to qualify for an oxic horizon; amongst these some very relevant and key features, which really make possible the separation of an old argillic horizon from an oxic one, like those regarding with: microaggregate structures (resulting from the activity of the soil mesofauna and re-distribution of the Fe in the groundmass), pedofeatures (aggregate pedotubules, displaying bow-like patterns and lack clay illuviation evidences) and cryptocrystalline features (neo-cutans and great variability of ferruginous nodules).

On the basis of these results it is concluded that an oxic and not an argillic horizon is present in profile EAK-47. Consequently, this soil is classified as an Oxisol (Ferralsol) and not as an Ultisol (Acrisol). The assumption that the profile concerned might represent a deeply weathered Ultisol is here rejected, on the basis of both the micromorphological features displayed by this profile and some criteria on this topic, provided by recent literature: Fedoroff and Eswaran (1985) state that gibbsitic coatings, papules and Fe-segregations constitutes key identification features for "old" Ultisols. None of these features was recognized in the thin sections belonging to profile EAK-47.

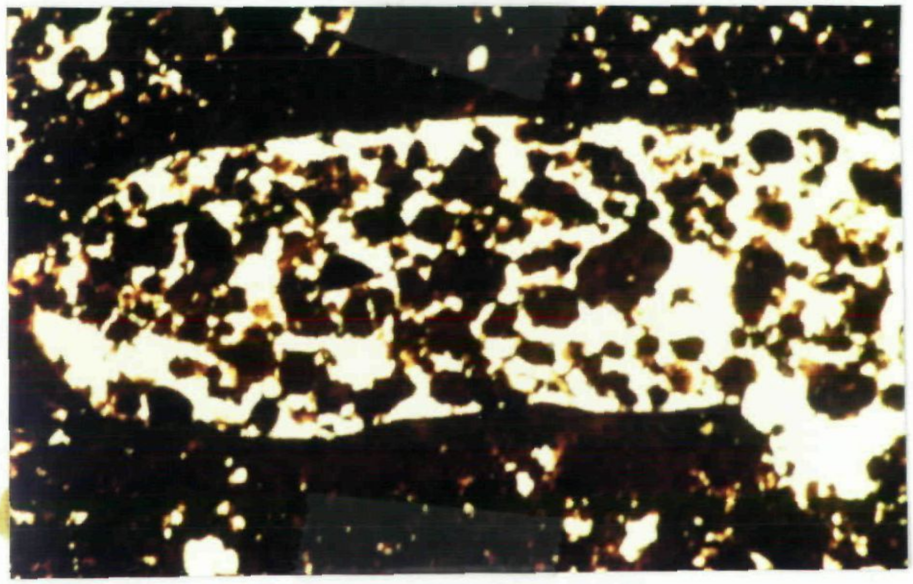
3.2.6. Conclusion.

Profile EAK-47 can be characterized as a very deep and strongly weathered soil, completely pedoturbated, displaying a microaggregate structure. The soil material shows a weak degree of organization and consists of low activity aluminosilicate clay (kaolinite, mainly), appearing strongly impregnated with Fe-compounds, mainly heamatite and goethite.

Photograph N°2. High homogenety in profile EAK-47,resulting from deep weathering and pedoturbation.



Microphot. N°2.Microaggregate structure in profile EAK-47. Granules,crumbs and "ferritic" peds are recognizeable (XPL, 79 magnifications).



Microphot. N°3. Soil-mesofauna activity in profile EAK-47.Infilled channels and stressed groundmass around passage channels (XPL, 79 magnifications).

Desilication, leaching, ferruginization and homogenization (bio-pedoturbation) are the most striking soil-forming processes in this soil.

All the available information on profile EAK-47 does not support the assumption that an argillic horizon is present in this soil, but an oxic horizon. Therefore, this soil is classified, at the highest level, as Ferralsol (Oxisol). Taking into account the lack of epipedons and the occurrence of other diagnostic characteristics(Table 6) like red color (hue 5YR and chromas ranging 3/3-3/6 dry and 3/4-3/6, moist), ustic soil misture regime, as regarded from rainfall data and soil moisture availability (1.3.4.) and a isothermic soil temperature regime the profile is finally classified as Rhodic Ferralsol (FAO, 1974) or Ustox, problably an Haplustox. (Soil Taxonomy, 1975).

3.3. Profile EAK-48.

Profile EAK-48 is located near Profile EAK-47, therefore the general environmental conditions are the same for both profiles, in terms of parent material, climate and relief. However, its situation in the landscape is different; EAK-47 is situated at the summit on a gently undulating plateau, whereas profile EAK-48 lies at the middle of a 300 m-length slope (7%) on an undulating plateau, situated 100 m lower than EAK-47 (2.3.1.)

3.3.1. Weathering.

Parameters closely related to the weathering process, like the mineralogy of the fine mineral fraction (kaolinite, gibbsite, heamatite and goethite), the related distribution (c/f=5/90 and c/fx=5 um), the high clay content (48-78%), low base saturation and occurrence of gibbsite, reveal that it concerns with a strongly weathered profile. It is inferred that on one hand outwashing of silica and bases, and accumulation of Fe and Al, on the other hand, have proceeded intensely, in profile EAK-48. Chemical data, like the base saturation (12.00-24.30%) and pH (4.9-5.3, KCl) also support the assumption that a depleted profile is regarded. However, the C.E.C. value seems too high (27.50-42.00 meq/100 gr clay), for an strong weathered soil which mineralogy is dominated by low activity lattice-clay. Such a too high C.E.C. value can result from the occurrence of "allophane" (traces of this high activity material probably occur given the occurrence of some grains of volcanics, 2.3 and 2.6) and humic organic matter (another high activity material). Even, the method used in the determination of the C.E.C. can lead to an overestimation of this soil parameter, as already stated (3.2.5, a).

3.3.2. Ferruginization.

Ferruginization is a very clear feature in this profile, in terms of both macro and micromorphological features. In field, the dominant yellowish red colour, of the whole profile and the occurrence of "iron-manganese concretions" (2.3.1.) are the most relevant facts, in this respect. At micromorphological level (2.3.2) the occurrence of heamatite and goethite (impregnating the ground mass, coating grains and filling fissures and cavernes), segregations of Fe and abundant nodules showing a wide degree of heterogenity, are the most outstanding signs of the iron dynamic in profile EAK-48. The groundmass appear-sunder PPL as yellowish-red, non organized (jelly-like), intensely dotted and isotropic. This image is indicating that besides crystal-lized Fe-compounds, amorphous Fe-compounds (hydrated oxides) are concerned. On other hand, the very abundant occurrence of dark micro-granules (2.3.2,c) and ferruginous nodules (2.3.2,e) suggests that a process of redistribution, crystallization and accumulation of Fe-compounds is operating, which account for the occurrence of iron concretions, iron segregation and abundant and very heterogeneous ferruginous nodules. All these features, in turn, reveal that a plin-thization process is concerned in profile EAK-48.

Plinthization in this case, does not regard with continuous, indurated plinthite, but with concretionary or gravelly plinthite. It is expressed through the "medium to large, hard, spherical manganese-iron concretions" mentioned in the Profile Description (2.3.1.)and illustrated in Photog. N 3 (p 68) and through the occurrence of many nodules, displaying under the microscope a wide variability regarding size, shape, colors, degree of impregnation, host material and internal fabric. However, the most relevant feature regards the occurrence of macro/mega-sized nodules which exhibit a very complex fabric, involving grains or fragments of weathered rock, heamatite, goethite, gibbsite and of vegetal tissues. Grains constitute the nuclei around which these materials are concentrated, showing often, strong orientation and exhibiting a very colored and contrasting image. These bodies correspond to what Fedoroff and Eswaran (1985) refer as "complex impregnative plinthite". Microphot. 4 illustrates these features. It is assumed that plinthization, in this case, is closely associated to the particular situation of profile EAK-48 in the landscape, from which results a particular weathering environment, regarding the internal-hydrological conditions of the soil and the supply of iron, both essential to plinthization. Main requirements for formation of plinthite are an abundant supply of iron and a set of hydrological conditions guaranteeing on one hand, the translocation of the Fe, its precipitation and accumulation around the nuclei and, eventually, the hardening of the resulting concretions, on the other hand. These conditions relate, mainly, with an abundant supply of water and an oscillating ground water level.

In the present case, iron has been provided by weathering of the parent material (Fe-rich volcanics) and, besides by sub-surface water, running from higher lands to low areas, and colluvial materials. So, this lateral supply of water represents an extra source of Fe and, also, contributes to the rise the ground water level at the lower part of the slope (during the rainy season), generating hydromorphyc conditions which, in turn, cause the reduction (solubilization of the Fe in the soil.

Precipitation, deposition and eventual hardening of the accumulated Fe involves mainly dehydratation, crystallization, and flocculation. These processes are closely associated to low ground water levels and alternating warm and cold seasons. So, under conditions of humidity shortage and high temperatures dry-warm season plinthization and hardening of the accumulated iron are promoted.

In the light of the general features above sketched, it is assumed that the climate of the area where profile EAK-48 is located meets just characteristic that promote plinthization: alternating wet with dry and warm with cold seasons (1.3.4.). Such rainfall regime, not only promotes the formation of plinthite (Fe-rich, more or less indurated soil material) during dry seasons (oxidating conditions), but also the segregation and re-distribution of the Fe-compounds during rainy season (reducing conditions), when drainage conditions become poor, at lower part of the slope where profile EAK-48 is situated.

3.3.3. Homogenization.

Profile EAK-48 appears completely pedoturbated; biopedoturbation is observable in field and in the thin section, even without aid of lens. Pedoturbation is very well expressed in the occurrence of a dominant micro-aggregate structure, shape and morphology of the aggregates (granules and crumbs) and voids (packing voids, vughs and channels). The occurrence of aggregate pedotubules, fabric pedofeatures, and weakly developed (speckled and circular) b-fabrics is also pointing to a very intensive pedoturbation. The human activity and cracking also have contributed to pedoturbation, at least in the top soil.

3.3.4. Illuviation.

Coatings were only ocasionally found in the A horizon of profile EAK-48, both clay coatings and ferruginous "cappings" were recognized. Coatings appears like very thin, discontinous and no microlaminated coatings, displaying very low optical properties. Because all this and because coatings consist mainly of silt and occur only at the A horizon (0-11 cm) it is regarded that these features does not reflect a process of clay illuviation in a pedogenetic sense, but a mere, temporary, deposition of fine soil particles (silt and coarse kaolinite) detached in the surface of the soil by the human and animal activity an erosion. So, the "thin clay cutans" mentioned in the field description of this soil (2.3.1.), are regarded "no real clay illuviation coatings".

3.3.5. Soil classification.

Profile EAK-48 was classified as an Acrisol (Ultisols) under field conditions; this means that the main diagnostic feature concerned is the argillic horizon. In order to assess to what extent the sub-horizon present in this profile meets the requirements to qualify for an argillic horizon or for an oxic horizon, its properties are compared with those stated as diagnostic properties for each of these horizons, listed in Table 3,4 and 5, Appendix.

a. Does the sub-horizon of profile EAK-48 meet the general properties to qualify for an argillic or an oxic horizon?

In Table 3a it is seen that the subhorizon regarded does not meet very important requirements to qualify for an argillic horizon. Besides, the lack of clay illuviation signs (already discussed, under 3.3.4.) in this profile does not fit the demand regarding the textural change, as stated by FAO (1974) and, in addition, the B horizon concerned (considered as a whole) does not have more clay than the A horizon. The increase in the clay content, going from the A horizon to the upper zone of the B horizon amounts 12%; fitting the percentage demanded by the Soil Taxonomy (1975), regarding the "textural change", however, this is a doubtful result because it is not possibe to verify the distance within which the increase takes place.

Table 3b shows that the sub horizon studied fits some of the requirements demanded to qualify for an oxic horizon. The most outstanding in this profile is that it does not meet the requirements regarding with the C.E.C. value, although meets the requirement stipulated in b1 (Table 3b) under 2.3.3. is seen that exchangeable bases of the B horizon (11-180 cm) do not reach 5 meq/100 gr clay). The C.E.C. of the clay, at the B horizon (27.50-33.40 meq/100 gr clay) is in fact too high, compared with upper C.E.C. limits stated for oxisols (< 16 meq/100 gr clay). This fact can be explained in the occasional ocurrence, in this profile, of volcanics which produce as weathering product the so-called allophane, a very active secondary silicate.

b. Does the B horizon of profile EAK-48 meet the macromorphological properties to qualify for an argillic or an oxic horizon?

Table 4b reveals that the sub-horizon concerned in profile EAK-48 meets most of the macromorphological properties demanded to qualify for oxic horizon, except those relating boundaries (between the horizons A and B). Type, class and grade of the (macro) structure, as described in the field (2.3.1.) conform to a considerable extent with what is stated as identification properties, regarding with macrostructure. The same can be said about the appearance and depth of the profile, plasticity and friability. On the contrary, Table 4a shows that this sub-horizon meets only one of the requirements to qualify for an argillic horizon; which regards with the occurrence of primary secondary and tertiary structure.

c. Does the B horizon of profile EAK-48 meet the micromorphological properties to qualify for an argillic or an oxic horizon?

When the microstructure of the sub-horizon studied is compared with the micromorphological features used as "reference criteria", it is also verified that this meets plenty all the requirements to qualify as Oxisol (Table 5b). Because of the B horizon concerned does not display clay coatings, it does not fit other requirements associated to clay illuviation (Table 5b). On the base of these results it is concluded that an oxic and not an argillic horizon is concerned. Therefore, profile EAK-48 is classified as Oxisol.

Further, profile EAK-48 is classified according the diagnostic criteria listed in Table 6 and 7, Appendix. In these Tables it is seen that this profile meets the features to qualify for a Plinthic Ferralsol, like a "petric phase" (FAO, 1974 p 6 and 30). A direct translation of this classification into the Soil Taxonomy nomenclature is not possible, because in the Soil Taxonomy the occurrence of plinthite is associated with an Aquic soil moisture regime and the concept of plinthite, refers to "plinthite forming a continuous phase" and not to concretionary plinthite (or petroplinthite). Secondly, the already mentioned deficient drainage conditions, derived from the low situation of the profile, do not affect the whole profile; they are temporary (rainy season) and affect only the lower zone of the solum, (starting from about 1 m depth concretions increase clearly as shows Photograph N 3). So, Haplustox, according to the classification criteria listed in Tables 6, Appendix, a further classification of these profile is not possible in the light of the available data.

3.3.6. Conclusion.

The study of the macro and micromorphological features displayed by profile EAK-48 and its chemical and physical properties allows to conclude that:

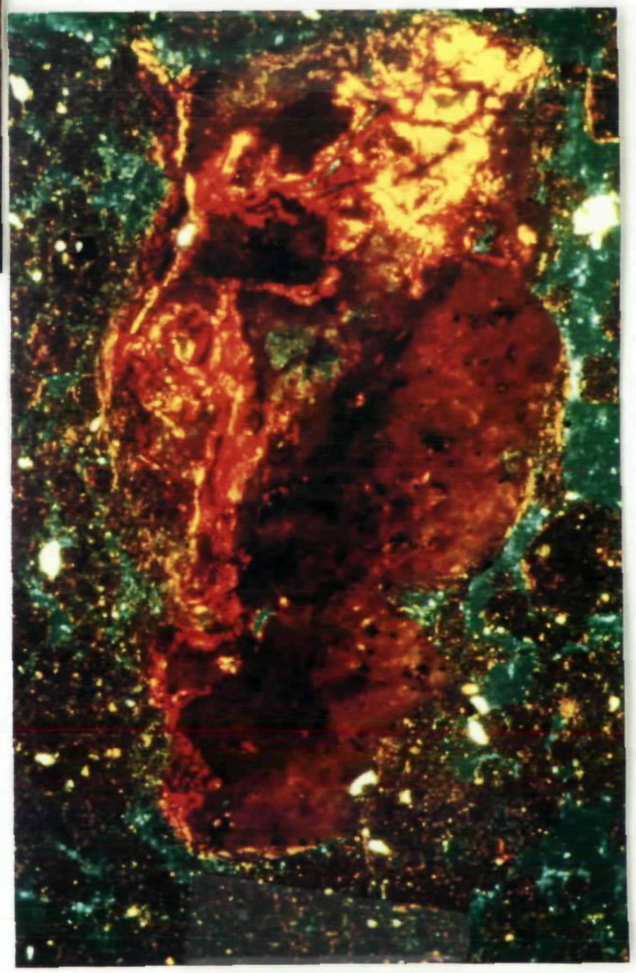
-it regards with a deeply weathered soil, strongly depleted and pedoturbated.

-the profile displays a clear and definitive "oxic" and "petric" character, which refers to the occurrence of concretionary plinthite (FAO, 1974; p 6)

-evidences regarding with the occurrence of an illuvial B horizon were not found.

-a process of plinthization is operating, which is closely associated with the low situation of the profile in the landscape, from which results to specific conditions promoting the plinthization process, like fluctuation of the ground water level and abundant supply of Fe.
The pedogenetic history of this soil involves the following soil-forming processes: desilication, leaching, ferruginization, plinthization and homogenization.
Profile EAK-48 is classified as Plinthic Ferralsol according to FAO (1974) and as Haplustox (Soil Taxonomy, 1975).

Photograph N°3. Concretionary (gravelly) plinthite in profile EAK-48, consisting of manganese-iron concretions.



Mocrophot. N°4. Impregnative plinthite, conprising: weathering grains, segregated Fe-compounds and gibbsite. These last appear oriented and sharply constrasted (XPL, 79 magnifications).

—— 79 um.

3.4. Profile EAK-44.

3.4.1. Weathering.

Various evidences reveal that a deeply weathered soil is concerned in profile EAK-44, like those regarding with the related distribution of the soil material (c/f limit=5 um, c/f+=10/90 b-fabric patterns; dominantly speckled/striated types), the mineralogy of the fine mineral components (consisting of kaolinite and Fe-compounds, mainly) and leaching (base saturation ranges from 20.60-33.90%).

A high weathering degree conforms with the climatic conditions predominant at the high-altitude lands where this profile is located and with the occurrence of a low resistent parent material, like volcanic ash and lahar. The rainfall is abundant (about 1.600 mm, annual mean) and the temperature also oscillates strongly during the year. So, the alternation of dry and rainy seasons and warm and cold periods promote the attack of the parent material by weathering agents; the abundant precipitation guarantees the removal of silica (desilication) and the removal of bases out of the weathering zone (leaching) intensifying in this way the whole process of weathering and ensuring the supply of Fe and Al indispensable for ferruginization.

3.4.2. Ferruginization.

This process is very well expressed through features like the cloudy and microdotted appearance of the groundmass, the mineralogy of the fine mineral components (involving sesquioxides which display various degrees of crystallization), the abundant occurrence of ferruginous micro-nodules and the dominance of speckled and striated b-fabric patterns. It is concluded that this profile meets completely the two basic conditions for ferruginization: abundant supply of Fe and oxi-reduction conditions in the soil. The first requirement is satisfied through chemical break-down of the Fe-rich parent material. The second one results from the oscillation of the ground water level, as consequence of the seasonal distribution of the rainfall.

Another feature related to ferruginization and also present in profile EAK-44 regards segregation of Fe. This is expressed through Fe-coatings, Fe-cappings, ferruginous nodules and juxtaposition of Fe-compounds to clay coatings. All this confers a dirty and shaded appearance to the groundmass.
From the above mentioned features a question arises regarding the cause of Fe-segregation, as far as this is associated with poor drainage conditions and profile EAK-44 is described as a well drained soil (2.4.1.). However, given the seasonality of the rainfall and the fact that clay infillings seal micropores (2.4.2,d), the circulation of the percolating water can be impeded, giving rise to temporary hydromorphic conditions above the argillic horizon. On the basis of the available antecedents no other explanation can be given.

3.4.3. Homogenization.

Pedoturbation has proceeded very intensively in Profile EAK-44 and is expressed through the microstructure (microaggregates consisting of pelleted and chewed groundmass), the frequent occurrence of aggregate pedotubules, stressed groundmass (around passage channels) and fabric pedofeatures (consisting in complete infilled channels and chambers). All these evidences lead to conclude that this profile has been deeply pedoturbated and that homogenization results from the digging and burrowing activity of the soil mesofauna (Photogr. N 4, p 89).

3.4.4. Illuviation.

Frequent signs of clay illuviation are found in profile EAK-44, and consist of clay coatings (in voids and around aggregates) and clay infillings. These features consist of kaolinite and exhibit clear basic and referred orientation and microlamination (2.4.2,d). So, it is concluded that clay illuviation is, both qualitative and quantitative, a very well expressed soil-forming process in this profile (Microphot. N 5, p 89).

On the other hand it is regarded that both the climate and the soil itself meet the necessary conditions for clay illuviation: the dispersion of clay is favoured by the alternation of rainy and dry seasons and by the slightly acid reaction of the soil; the abundant rainfall ensure the translocation of the dispersed materials and the abundance of micropores (accounting for about 50% of the porosity in this soil) guarantees its deposition and accumulation.

3.4.5. Soil Classification.

Profile EAK-44 was classified as Nitosol (FAO, 1974) or as Ultisol (Soil Taxonomy, 1975), under field conditions. Therefore, it is assumed that an "old" argillic horizon is concerned in this profile. In the following paragraphs it is assessed to which extent an argillic and not an oxic horizon, is really concerned. It must be emphasized that the sole occurrence of clay coatings is not enough to qualify a sub-horizon as an argillic one; besides the quantity and quality of the illuviation features the magnitude of the textural changes associated to clay illuviation also accounts for such a qualification.

a. Does the B horizon of profile EAK-44 meet the general properties to qualify for an argillic or an oxic horizon?

Table 3b shows that the sub-horizon present in profile EAK-44 fits all the general properties demanded to qualify as an oxic horizon, except those regarding with the CEC (about 22 meq./100 gr clay). In fact this parameter exceeds the value stated as low limit for the oxic horizon (16 meq./100 gr clay). However, this difference is small and can be explained in both the occurrence of allophane and the method used in the determination of the CEC,as already mentioned under 3.2.5,a.

On the other hand, in Table 3a it can be seen that the sub-horizon concerned fits 4 out of the 8 requirements stated as identification features for the argillic horizon; amongst them those refering to oriented clay skins on peds; these were recognized both macro- and micro-morphologically (respectively 2.4.1. and 2.4.2,d).
The analysis of the soil texture (2.4.3.) reveals that the clay content increases gradually with the depth, from 60 to 82%. If the mean clay content of the B horizon (78%) is compared with that of the overlying horizon (A/B) the increase in texture reaches 12%; fitting in this way the magnitude of the textural change stated in the Soil Taxonomy (1975). Although, it is not clear if this change in texture takes place within a vertical distance of 30 cm, as demanded. Even so, the study of the general properties displayed by profile EAK-44 seems to suggest that an argillic horizon rather than an oxic one is present in this profile.

b. Does the B horizon of profile EAK-44 meet the macromorphological properties to qualify for an argillic or an oxic horizon?

In spite of the textural change mentioned above, neither a clay "depleted A horizon" nor an "eluvial horizon", as stated in Table 4a, under points b and d, were recognized in profile EAK-44. However, the sub-horizon concerned fits two key demands regarding clay illuviation and structure to qualify as an argillic horizon (points a and c in Table 4a). On the other hand, Table 4a shows that profile EAK-44 meets all the requirements to classify for an oxic horizon, except those regarding clay illuviation; clay coatings are absent or are very scarce in Oxisols, whereas they are frequent, very well expressed in profile EAK-44; besides, they are not restricted to pores only, but they also occur on ped surfaces. So, this also suggest that an argillic horizon is present in this profile.

c. Does the B horizon of profile EAK-44 meet the micromorphological properties to qualify as an argillic or an oxic horizon?

In Tables 5a and 5b it is again seen that the sub-horizon studied fits most of the requirements to qualify for both an argillic or an oxic horizon; the sole diagnostic requirements not fitted by profile EAK-44 are those related to clay illuviation features and very specific micromorphological features for Oxisols, like the occurrence of runi-quartz and grain cappings ("envelopes"). These results allow to draw two conclusions.

Firstly, an argillic and not an oxic horizon is present in profile EAK-44; clay illuviation signs (clay coatings on ped surfaces, mainly) are observed both macro- and micro-morphologically. These features, specially clay skins and infillings display under the microscope all characteristics associated with illuviated clay, like basic and referred orientation, microlamination and outstanding optical properties; medium to high birefringence and sharp contrast (2.4.2,d).

Secondly, if a highly weathered soil is concerned, like profile EAK-44, the general and macromorphological properties of the soil do not constitute useful identification features to separate it from other highly weathered soils, like Oxisols. In this case, the micromorphological study of the textural pedofeatures (clay coatings, clay infillings and papules, mainly), from both a quantitative and qualitative point of view, provides the most valuable and useful diagnostic criteria for the classification of these deeply weathered tropical soils (often referred to as clay well drained red soils).

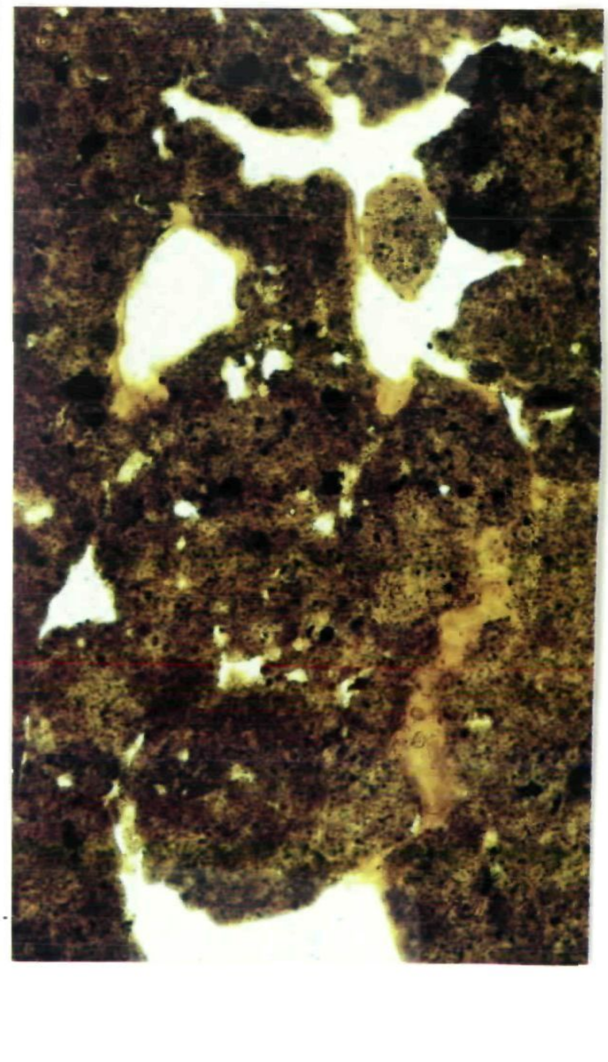
In accordance with the foregoing results and taking into account other diagnostic characteristics displayed by profile EAK-44 (listed in Table 6, Ap.) it is concluded that this qualifies for a Humic Nitosol (FAO, 1974), accepting in this way the classification performed under field conditions. The humic character of this soil results from the accumulation of humified organic matter at the A horizon, where the content in organic carbon reaches 1.79%, which can be regarded like a relative high content for deeply weathered tropical soils. However, the content in organic carbon, in the upper 15 cm of the B horizon (0.11-0.08%) is too low to classify this soil as Humults; according to the Soil Taxonomy (1975, p 351) this content must amount 0.9% or more. The other criterion to separate Ultisols, at sub-order level, is the soil moisture regime. On the basis of the climatological information regarding with the area where profile EAK-44 is located (1.3.4, Tables 1 and 2; Figs. 3 and 5), it is concluded that an Ustic soil moisture regime is concerned. Consequently, this profile is classified as Ustults. At great-group level this qualifies rather for a Rhodustults than for a Haplustults, because of its predominant reddish color (hue:5YR). In fact, this soil fits all the requirements regarding with the color value (Soil Taxonomy, 1975, p 369 and 372) to be classified as Rhodustults. Probably, a Typic Rhodustults is concerned in profile EAK-44.

3.4.6. Conclusion.

Profile EAK-44 deals with a typic tropical red soil, deeply weathered and depleted; its mineralogy consists of low-activity clay minerals, mainly kaolinite and Fe and Al sesquioxides. Desilication, leaching, ferruginization, clay illuviation and homogenization are the most outstanding soil-forming processes displayed by this profile. The micromorphological characteristics and the general chemical and physical properties of profile EAK-44, and even most of its micromorphological features, conform with those exhibited by a typic Oxisol. This fact, together with the occasional occurrence of Fe-segregations (expressed like ferruginous coatings juxtaposed to clay skins and covering both peds and mineral grains) suggests that likely an early transitional stage, from an old Ultisol to an Oxisol, is concerned in profile EAK-44.

In spite of the features mentioned above, the soil studied qualifies for an "argillic soil", because the clay illuviation process is clearly expressed, both quantitative and qualitative, and conforms completely with the classical concept of clay illuviation, in a pedogenetic sense.

PhotographN°4. Profile EAK-44 appears deeply as result of burrowing activity of the soil-mesofauna.



Microphot. N°5. Illuviated clay in profile EAK-44.Clay coatings and clay infillings are abundant and display referred orientation and microlamination (XPL,79 magnifications).

——— =79 um.

Profile EAK-44 is classified like Humic Nitosol (FAO, 1974) or as Rhodustults according to the Soil Taxonomy (1975).

3.5. Profile EAK-38.

3.5.1. Weathering.

Profile EAK-38 deals with a relative young soil, clearly layered as result of successive depositions of volcanic materials (Photogr. N 5,p 82); a buried soils and various degrees of weathering are concerned. Weathering ranges from weak to moderate, like reflected in the texture (sand to loam), the wide variation of the c/f limit and c/f ratio (respectively, 10-40 um and 30/70 - 10/90) and the dominantly related distribution pattern mainly, phyric).

Currently, weathering proceeds intensively as reflected in the occurrence of abundant splinters and flakes of feldspars and fissuration of coarse grains (physical weathering). Chemical break-down is also intense and clearly expressed in the composition of the fine mineral fraction, which involves mainly allophane, sesquioxides and gibbsite, besides some kaolinite and halloysite.

The occurrence of lattice aluminium silicates, like kaolinite, gibbsite and halloysite, can not be associated in this case, with an advanced degree of soil development, but with specific weathering conditions which have make possible that the synthesis of these secondary minerals proceeds through a more direct, and therefore, rapid pathway; these particular conditions result from the physical properties of the parent material and from the climatic conditions predominant at the high altitude lands (above 2.000 m). The parent material concerns finely fragmented and very porous volcanics, consisting of lapilli and ashes. Rainfall is high (about 2.000 mm, annual mean) and markedly seasonal.

So, it is regarded that these features, regarding the parent material and the climate, have favoured the physical and chemical break down of the primary minerals, and out-washing of the released silica and bases.

This last process together with the turn-over of the organic matter (forest soil) confers to the weathering environment an acid reaction. High degree of fragmentation of the parent material, acidity, alternating humidity conditions and rapid interne drainage are mentioned, in the relevant literature, amongst the factors promoting the synthese of kaolinitic materials and gibbsite, in the weathering process of volcanics under tropical conditions (Besoain, 1985).

3.5.2. Ferruginization.

Profile EAK-38 displays various features which are reflecting an intense dynamic of both the Fe and Al in the soil, like ferruginous nodules (showing a wide heterogenity) and very well expressed Fe and gibbsitic coatings. However, the typic features associated to ferruginization, like cloudy (jelly-like) appearance, brownish or reddish color, ferruginous cappings and micro-dotting (reduced Fe) are not recognized in this profile. Therefore it is concluded that ferruginization is not concerned in profile EAK-38, in terms of soil formation.

It is well known that amorphous compounds of Fe and Al (sesqui-oxi-hydrated oxides) are produced in the early stages of weathering in volcanic soils, evolving with time to cryptocrystalline and crystalline ones, like goethite, haematite and gibbsite. As already suggested the alternation of rainy and dry seasons, high rainfall and free drainage conditions promote the weathering process as a whole and the synthesisof these secondary minerals. Because these conditions are just stated like basic requirements for ferruginization, under humid tropical conditions, it can be said that the basic conditions for ferruginization are present in this profile and that probably a initial stage, of ferruginization, is starting currently.

3.5.3. Homogenization.

Profile EAK-38 displays clearly various macro- and micromorphological evidences that it deals with a strongly pedoturbated soils. Under field conditions mole and rat crotovines are observed (2.5.1.). Under the microscope, the main evidence of zoogenic pedoturbation is represented by a dominant microaggregate structure and pelleted groundmass. However, aggregate pedotubules and fabric pedofeatures are rarely identified and exhibit very low optical properties, because of shading resulting from melanization (2.5.2,b).
The great part of the organic matter appears strongly altered end humified. Humification is a very outstanding process in this profile; the humus appears intimately mixed with allophane, and Fe and Al compounds, constituting the so called organo-mineral complexes. These complexes cause the melanization of this soils (darkening of the soil material), conferring to this profile a "mullic appearance"; a dirty, dark opaque image.

3.5.4. Illuviation.

Coatings are common features in profile EAK-38. However, these are clay coatings, but ferruginous, allophanic, gibbsitic and even humic coatings (Microphot. N 6, p 82). The first two appear associated with holes occurring in weathering fragments of volcanics, whereas the others are associated with mineral grains rather than with voids. Therefore, it is doubtful if these features result from a process of illuviation (2.5.2,d). It is concluded that clay illuviation, is not present in this profile.

3.5.5. Soil classification.

Profile EAK-38 was classified as a Mollic Andosol (FAO, 1974) or as an Andic Haploboroll (Soil Taxonomy, 1975), under field conditions.

So, the major diagnostic feature concerned in this profile is the mollic epipedon.

The concept of mollic epipedon is the same for the two soil classification systems, quoted above; it regards a thick (>30 cm), dark colored (value 3.5-5.5 and chroma < 3.5), humus rich (org. C % >2.5) and coarse (prismatic) structured epipedon. According to the field description (2.5.1) profile EAK-38 fits, in general, these identification properties.

However, it must be born in mind that the umbric horizon also fits the general properties of a mollic epipedon, so that these horizons can not be separated on the basis of their general characteristics, but on the basis of their chemical properties. The main criterion to identify these epipedons is the base saturation (amounting to more than 50% in the mollic epipedon and less than 50% in the umbric one). Other auxiliar criteria refer to the composition of the exchangeable bases are dominated by Ca and Mg, the reaction is basic, the clay fraction dominated by 2:1 lattice clays and the C.E.C. value is medium to high.

The lack of both chemical and mineralogical data hinders the classification of profile EAK-38, because it is not possible to elucidate if a mollic or an umbric epipedon is concerned. However there are some (indirect) evidences indicating that an umbric rather than a mollic epipedon is present in profile EAK-38. This is deduced from the following facts:

- the reaction of the soil is acid (pH-H20 ranges 5.8-5.6 at the A horizon).
- lattice aluminium silicates are represented by kaolinite and gibbsite and not by smectites. The formation of kaolinite and gibbsite, in volcanic soils, is associated with acid soil conditions and depletion of Ca and Mg.
- given the texture in this profile is dominated by sand (50 % sand and 13 % clay, at the A horizon) it can be inferred that the C.E.C. ranges from low to very low, in terms of meq/loo gr soil. On the other hand, the C.E.C. of the amorphous compounds, supposedly low, because in this

case the greater part of these constitute organo-mineral complexes, which are well known by its high stability and low reaction.

-the umbric horizon is associated to an acid-mull epipedon, formed under forest, under cool and humid conditions, at high altitude. Whereas, the mollic epipedon is associated to steppe and grass vegetation, under sub-humid and semi-arid conditions and high base saturation status.

The nature of the parent material (consisting of volcanic ash and lapilli), the abundance of allophane and volcanics fragments (recognized under the microscope) and the texture of this profile (dominated by sand and silt) allow to assume that the great part (more than 60% of the sand + silt fraction) cosists of "volcanic sand and other pyroclastics". So, profile EAK-38 qualifies for Andosol, according to FAO (1974). If the presence of an Umbric epipedon is accepted this soil qualifies for an umbric Andosol. If it is accepted that the great part of the soil material consists of pyroclastic materials, then this profile qualifies as for Andepts, according to the Soil Taxonomy (1975). A further classification is not possible on the basis of the available information, because the separation of the Inceptisols at Great-group level is made on the basis of its mineralogy, chemical properties and soil temperature regime. This information is not available, at the moment.

Finally, in the light of the arguments presented in the foregoing paragraphs, it is concluded that the soil concerned does not classify for a Mollisol. If in spite of the arguments already discussed, it is accepted that a Mollic epipedon is present in profile EAK-38, even so, the placement of this soil amongst the Mollisols is quite uncertain, because the sole occurrence of a mollic epipedon is not enough to classify a soil like a Mollisol, but this has to meet seven additional requirements, all of which have to join the presence of the Mollic epipedon. Profile EAK-38 fits definitely only one of these seven demands, the most general ("7. do not have a spodic horizon that has its upper boundary within 2 m of the surface", Soil Taxonomy, 1975; p 271-272), which does not contribute to elucidate the question under discussion

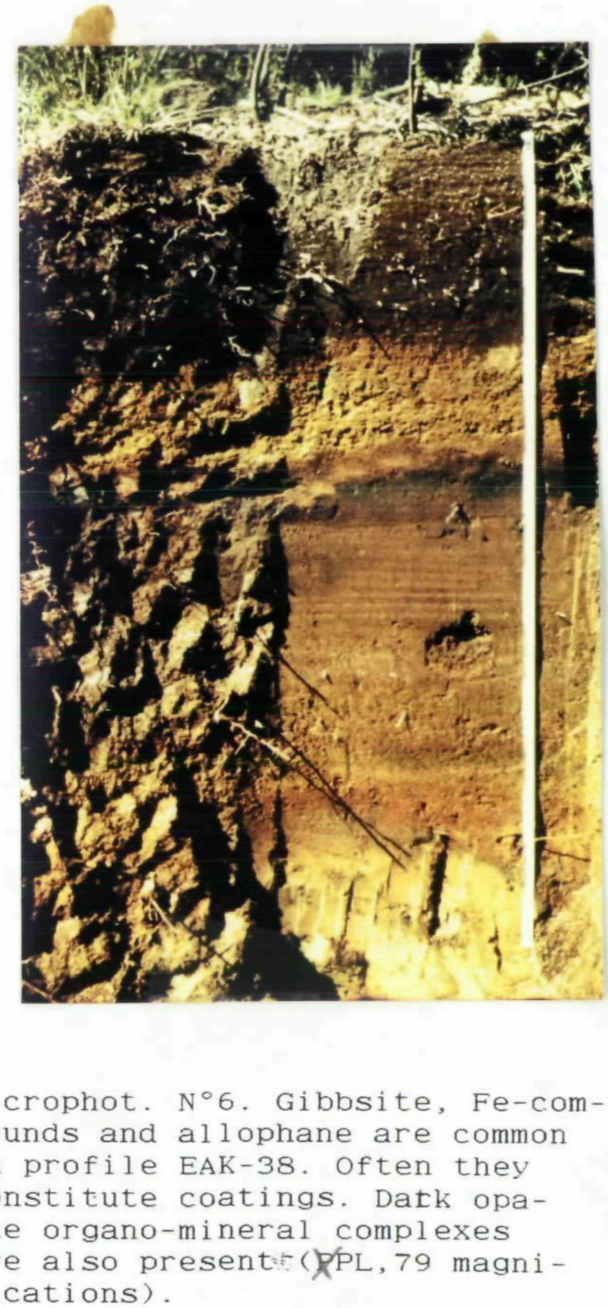
3.5.6. Conclusion.

Pedon EAK-38 involves a buried soil (A-C-Ab-A/Bb-Cb), as result of volcanic ash deposition. Therefore various weathering degrees are found in this profile. The current development degree of this soil is rather moderate than an advanced one, which is reflected in the predominance of sand and silt; the texture ranges from loam to silty loam, with exception of the horizon C, where 90% of the soil material consists of sand. Currently, most universal soil forming process, like break-down of minerals, turn over of the organic matter, desilication and leaching are proceeding at high rate, as reflected in the occurrence of kaolinitic lattice clays, segregated Fe, allophanes, gibbsite, goethite and haematite (secondary minerals).

The occurrence of kaolinite may not be regarded like an expression of the maturity (ripeness) of this soil. It results from particular weathering conditions, promoting the formation of kaolinite, that are present in this soil, like acidity, intense leaching of bases, and high supply of Si and Al. In all cases the occurrence of clay minerals is low, as reflected in the soil texture (2.5.1.).

The classification of pedon EAK-38 has become intrincated because of the lack of chemical and mineralogical data, so that it can not be elucidated if an umbric or mollic horizon is involved. In all cases, the occurrence of a mollic epipedon is doubtful given the strong acid reaction of the A-horizon, likewise the whole profile, the absence of 2:1 clay minerals and low C.E.C.,etc.

On the other hand, taking into account the nature of the parent material and the texture of this soil (dominated by sand and silt) it is assumed that the great part of the soil material consists of "volcanic sand, cinders or other pyroclastic materials". This line of reasoning leads to classify profile EAK-44 as an Umbric Andosol (FAO, 1974) or as Andepts (Soil Taxonomy, 1975).



Photograph N°5. Profile EAK-38 deals with buried soil, as reflected in the sequence A-C-Ab-A/Bb-Cb, resulting from sucessive volcanic-ash deposits.

Microphot. N°6. Gibbsite, Fe-compounds and allophane are common in profile EAK-38. Often they constitute coatings. Dark opaque organo-mineral complexes are also present (XPL,79 magnifications).

⟶ =79 um.

4. GENERAL DISCUSSION AND CONCLUSIONS.

Because only partial chemical and physical and micromorphological data were available and mineralogical data are lacking, the conclusions drawn here should be regarded as general tendencies, only.

Soils derived from the same parent material (volcanics) constitute, clearly, a weathering sequence which involves weakly, moderately and strongly weathered soils; respectively, Andosols (Inceptisols), Nitosols (Ultisols) and Ferralsols (Oxisols).
The less developed "members" of the soil sequence studied are located at the "extremes" of the catena, where also "extreme" soil-forming conditions are present; at high altitude (2.900 m, foot ridge landscape) the rainfall is very abundant (> 2.000 mm/year), the temperature is low and the parent material consists of unconsolidated volcanics (ashes and lapilli).
Here Andosols have been formed. On more weathered soils, Nitosols and Ferralsols, occur at the undulating plateau and uplands, where the climate exhibits clear weathering promoting characteristics, like relative high rainfall (800-1.600 mm/year) and wide range of temperature (both showing strong seasonality) and the parent material consists of a deep mantle of lahar and tuffs (complicated volcanics).
It is the location of the profiles along the catena which most influences the pedogenesis of the soils studied. However, the particular situation of a profile, at a given altitude, can strongly control the direction of the soil-forming processes. This can be infered from the comparison between profile EAK-47, located on a gently undulating plateau, and profile EAK-48, on a middle slope, 100 m lower than the first one; both profiles show and advanced degree of weathering and ferruginization, but profile EAK-48 exhibits, in addition, a clear process of plinthization. It is assumed that plinthization, in this case, is closely associated with the specific situation of this profile, which promotes the gains of Fe (through seepage water) and the

oxidation-reduction conditions in the soil (as consequence of oscillations of the ground-water level).

On basis of these general features the following can be stated:

1. The rate and direction of weathering corroborate, largely, changes in the environmental (soil-forming) conditions, resulting from changes in altitude. Climate, closely associated with altitude and relief, is the most active soil-forming factor. Under conditions of abundant rainfall (800-1.600 mm/year) and intermediate altitude (900-1.400 m) ferruginization and homogenization (bio-pedoturbation) are the principal soil forming processes, in the catena studied. Clay illuviation can not be regarded as a dominant process in the pedogenesis in this catena of soils; the argillic horizon, as defined in the Soil Taxonomy (1975) was found only in one profile (EAK-44). Although profile EAK-51 also exhibits clay coatings, it is doubtful whether these coatings are really reflecting the occurrence of an (illuvial) argillic horizon, as far as only one thin section was available and the soil is severely eroded (truncated) and sealed.

2. In the catena studied both oxisols and ("young" and "old") argillic soils occur. Most deeply weathered soils (Ustoxs; profiles EAK-47 and EAK-48 and Ustulsts; profile EAK-44) can not be separated on the basis of its general chemical, physical and macromorphological properties (Table 7, Appendix). All of them can be characterized as chemically poor, base depleted and acid soils, which reactivity (C.E.C.), largely confined to the top-soil, can be ascribed to the organic matter rather than to its general mineral clay fraction.

   On the other hand, the general characteristics of the soils studies, specially its chemical properties and texture, allow the separation of the soils with an argillic horizon, into "young" and "old" argillic soils; respectively Ustalfs (profile EAK-51) and Ustults (profile EAK-44). Profile EAK-51 (Rhodustalfs) can be regarded like a moderate nutritional-status soil because of its relative high C.E.C. (39 meq/100 gr clay) and base saturation (79.80%); this in spite of its low to very low content in organic matter (0.70 %, mean value) and light texture (about 25% clay). On the contrary, profile EAK-44 (Rhodustults) is a clayey soil (60-80 % clay), chemically poorer than profile EAK-51; its C.E.C. and base saturation ranges respectively 23.00 meq/100 gr clay and 26.60 % (mean values for the B horizon, Table 7, Appendix).

When the macromorphological properties displayed by these soils, under field conditions, are examined no clear differences are observed (Table 8,Appendix). All clayey profiles exhibit dominantly a sub-angular moderate to very coarse blocky structure. Neither the examination of the horizon boundaries (in terms of wideness and topography) nor the study of the consistence (in terms of friability, stickyness and plasticity) reveal indications to separate the red soils concerned in this catena. Neither are differences in colors involved; profiles are dominantly yellowish red (2.5-10YR) with low values (3) and chromas ranging 2-6. So, in the light of these results the question posed under 1.2 ("The problem studied") can be answered as it follows:

3. The weathering degrees occurring along this catena are weakly expressed in terms of the chemical and physical properties of the soils. So, the less weathered member of the catena can be separated on the basis of these parameters, but not Ultisols and Oxisols. In terms of macro-structure, color, horizon boundaries and consistence, the various degrees of soil development are not apparent in these soils. Pedoturbation, microstructuration, and ferruginization account for the overlapping of properties, like structure, boundaries and color. Therefore, these general properties hardly can account for classification of the soils studied.

4. The study of the micromorphological features and pedofeatures displayed by these profiles reveals some important facts:

First, although most of the pedofeatures are common to the four profiles (overlapping, with slight differences) there are few but key differences which allow the identification of these profiles. For instance, the occurrence of clay coatings makes it possible to separate "argillic" from "oxic" soils. The microstructure, related distribution (and associated c/f limit and c/f ratio) and amorphous cryptocrystalline pedofeatures allow differentiation within the "argillic" soils; the "young" ones display weakly developed (vughy, spongy) microstructure, porphyric related distribution and rare to occasional nodules; weakly impregnated and showing low heterogenity (Table 8, Ap). Whereas, the "old" argillic soil exhibits microaggregate structure, undifferentiated related distribution and has many, moderately impregnated, ferruginous nodules.

Secondly, the "oxic" soils display micromorphological properties which are very similar between them, even so its separation is possible on the basis of quantitative and qualitative differences shown by amorphous cryptocrystalline pedofeatures. Profile EAK-48 contains abundant to very abundant ferruginous nodules, showing great variability in size, shape, impregnation and internal fabric. Whereas, Profile EAK-47 displays these properties at lower level. All these facts lead to the following conclusions:

5. In spite of the masking effect resulting from microstructuration, ferruginization and bioturbation, the various degrees of weathering involved in this catena have a relative good, and very useful, expression in terms of micromorphological features and pedofeatures, which make the identification and separation possible of the strongest weathered soils of this catena. In this case, the occurrence of clay coatings was a key feature, regarding with the classification of these profiles. Whether no clay coatings were recognized the identification of these profiles should become very difficult, even impossible, with the available data.

6. Regarding soil classification, the uncertainty of the usefulness of the general properties of the soils in the catena studied, also concerns most of the micromorphological features and pedofeatures. This uncertainty becomes greater if strongly weathered soils are involved and clay coatings are not, quantitatively and qualitatively, well expressed. In this case the establishment of well defined categories of argillic horizons, on basis of a wide and rigorous selected, sets of properties, as advanced by Sombroek (1983), seems to be very necessary. Such an excercise is outside the scope of this research.

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APPENDICES

List of the thin sections used. Numbers and depth (cm).

Numbers.	EAK-51	EAK-47	EAK-48	EAK-44	EAK-38
M 3013	40 - 55				
M 3019		5 - 20			
M 3020		20 - 35			
M 3021		80 - 95			
M 3022		140 -155			
M 3023			5 - 20		
M 3024			40 - 55		
M 3025			80 -100		
M 2994				15 - 30	
M 2995				45 - 60	
M 2996				80 - 95	
M 2997				115 -130	
M 3030					0 - 15
M 3031					32 - 46
M 3032					53 - 68
M 3034					102 -116

List of the photographs and microphotographs used.

	Profiles	Page	Demonstrates.
Photographs.			
N 1	EAK-51	51	Truncation and rock.
2	EAK-47	58	Depth and homogenity.
3	EAK-48	67	Concretionary plinthite.
4	EAK-44	74	Ferruginization and homogenization.
5	EAK-38	81	Horizon sequence.
Microphotogr.			
N 1	EAK-51	51	Clay coatings.
2	EAK-47	58	Microstructure.
3	EAK-47	58	Reorient. and aggregate pedotubules.
4	EAK-48	67	Impregnative nodules (plinthite)
5	EAK-44	74	Clay coatings.
6	EAK-38	81	Gibbsite, ferruginous and allophanic coatings.

Table 3a. General properties of the argillic horizon, according to the Soil Taxonomy (1975, p 26-27) and degree to which the B-horizons concerned in the EAK-profiles conform with these properties (conform = +, doesn't = -).

Properties.	EAK-51	EAK-47	EAK-48	EAK-44
The argillic horizon should have:				
a1. If an overlying horizon remains B has more clay as follows:	"n.s"	+	+	+
a2. If the overlying horizon has >40% clay,must have:>8% clay(1) or >20% clay(2). This increase has to take place within a vertical distance of 30 cm.	"n.s"	-	-	-
b. Should be, at least, one tenth as thick as the sum of the thickness of the overlying horizon.	"n.s."	+	+	+
c. If peds are present the argillic horizon should have				
c1. oriented clay skins on ped surfaces and/or on fine pores (>1%).	+	-	-	+
c2. meet a a1 or b and have broken or irregular upper boundary.	"n.s."	-	-	-
c3. if meets a2,and is caolinitic its lower part has blocky or prismatic structure.	+	+	+	+
c4. if consists of 2:1 clay, no clay skins are displayed, but slickensides and stressed surfaces, also planar voids.	-	-	-	-

B, refers to the argillic horizon; "n.s", refers the comparison has "no sense"; (1) and (2) designate respectively, the Soil Taxonomy (1975) and FAO (1974).

Table 3b. General properties of the oxic horizon. According to Soil Taxonomy (1975, p 39-41) and the Legend of the Soil Map of the World (1974, p 27). Degree to which the EAK-profiles meet these properties (meet = +, doesn't = -).

Properties	EAK-51	EAK-47	EAK-48	EAK-44
The oxic horizon is:				
a. at least 30 cm thick	+	+	+	+
b. a C.E.C. < 16 meq/100 gr clay, or (b1) < 10 meq exch. bases (+ Ala extractable)/100 gr clay.	-	+	-	-
c. no more than traces of primary minerals, like silicates, micas and Fe and Mn-minerals.	-	+	+	+
d. a sandy loam or finer texture; a clay content >15%.	+	+	+	+
e. gradual and diffuse boundaries and	+	+	-	+
f. a volume showing rock structure < 5%.	-	+	+	+

Table 4a. Identification characteristics of the argillic horizon in the field (Fedoroff and Eswaran, 1985) and degree to which the B horizons concerned in profiles EAK fulfill these characteristic (fulfil = +, doesn't = -).

Characteristics	EAK-51	EAK-47	EAK-48	EAK-44
The argillic horizon should display one or more of the following:				
a. Clay coatings observable on ped surfaces and/or pores.	+	-	-	+
b. presence above the argillic horizon of a clay depleted horizon.	"n.s."	-	-	-
c. Primary structure with secondary or tertiary blocky structure.	+	+	+	+
d. Presence of an eluvial horizon, above the argillic one, which exhibits free packed skeleton grains.	"n.s."	-	-	-

Table 4b. Identification characteristics of the oxic horizon, in the field (Soil Taxonomy, 1975) and degree to which profiles EAK fulfil these properties (fulfil = +, doesn't = -).

Properties.	EAK-51	EAK-47	EAK-48	EAK-44
The oxic horizon must have:				
a. Massive appearance prismatic or blocky structure	+	+	+	+
b. Aggregates crush easily to very fine granules. Low plasticity and high friability.	+	+	+	+
c. Boundary between the oxic and overlying horizon is normally diffuse.	"n.s."	+	-	+
d. Deep, reaching some even meters, without apparent changes except when plinthite or stone lines are present.	-	+	+	+
e. No or very gradual changes regarding texture and color.	+	+	+	+
f. Clay skins absent or very scarce being restricted to pores.	-	=	+	-
g. Weathering minerals absent or account 5%, in vol., unless coated by Fe oxides.	-	+	+	+

Table 5a. Micromorphological properties for diagnostic of the B horizon in clayey well drained, red tropical soils (Ultisols), according to Fedoroff and Eswaran (1985), an degree to which the EAK-profiles meet these properties (meet = +, doesn't = -).

Properties.	EAK-51	EAK-47	EAK-48	EAK-44
a. Clay coatings identified in field, on ped surfaces by color and lustre.	+	-	-	+
b. Clay coatings are associated with voids (mainly, meso-voids, vughs and planes). Coatings also occur around concretions, grains and nodules.	+	-	-	+
c. Abundance of clay coatings, at the B horizon varies from few to a very high percentage.	+	-	-	+
d. Clay coatings display at the B horizon, very well expressed microlamination, orientation, moderate birefringence and sharp extinction.	+	-	-	+
e. Plasma is waxy, dark/brown or yellowish red. The b-fabric is speckled, striated or undifferentiated.	+	+	+	+
f. Skeleton grains consist of resistent minerals like quartz, zircon, feldspars, plagioclases, and micas. Its abundance varies from occasional to common.	+	+	+	+

Table 5b. Micromorphological properties for diagnostic of the oxic horizon, according to Stoops and Buol (1985) and degree to which the EAK-profiles meet these properties (meet = +, doesn't = -.

Properties.	EAK-51	EAK-47	EAK-48	EAK-44
a. Microaggregate structure resulting from soilmeso fauna activity and microstructuration.	-	+	+	+
b. Coarse grains are few, often displaying infilled fissures and cappings, kuniquartz is frequently found.	-	+	+	-
c. Fine mineral components appear constituting a waxy, cloudy, dotted, yellowish or reddish plasma.	+	+	+	+
d. Groundmass appears weakly organized, homogeneous. Undifferentiated, circular speckled or striated b-fabrics. Narrow c/f ratios.	-	+	+	+
e. Frequent aggregate pedotubules associated to dense discontinuous infilled channels showing, at time, crescent bow-like patterns (e1) and	+	+	+	+
no real coatings of illuviation are observed (e2).	-	+	+	+
f. Often Fe-segregations are found (neocutans) (f1), and also	-	+	+	+
nodules showing high variability regarding its internal fabric and gibbsitic cutans are recognizeable (f2).	-	+	+	+

Table 6. Diagnostic requirements for the classification of Acrisols, Nitosols, Ferralsols and Andosols, at high and low level, according to the Soil Taxonomy (1975) and the Legend of the Soil Map of the World (FAO, 1974). Fulfillment of these requirements by the EAK-profiles.

1. Epipedons.

	Soil Taxonomy (1975)				FAO (1974).			
Pedons.	Mo.	Um.	Ar.	Ox.	Mo.	Um.	Ar.	Ox.
Acrisols	+	+	o	/	/	+	o	/
Nitosols	+	+	o	/	/	+	o	/
Ferralsols	+	+	/	o	/	+	/	o
Andosols	+	+	/	/	+	+	/	/
Profiles								
EAK-51	-	-	x	-	-	-	-	-
EAK-47	-	-	-	x	-	-	-	-
EAK-48	-	-	-	x	-	-	-	x
EAK-44	-	-	x	-	-	-	x	-
EAK-38	-	x	-	-	-	x	-	-

2. Other requisites.

Pedons.	cc	rc	pl	us	is	vp		pl	fe	pv	
Acrisols	+	+	+	+	+	+		+	+	/	
Nitosols	+	+	/	+	+	/		/	/	/	
Ferralsols	+	+	+	+	+	/		/	/	x	
Andosols	/	+	/	+	+	x		/	/	x	
Profiles.											
EAK-51	x	x	-	x	-	-	Rhodustalfs.	-	-	-	Chromic Luvisols.
EAK-47	-	x	-	x	x	-	Haplustox.	-	-	-	Rhodic Ferralsols
EAK-48	-	x	-	x	x	-	Haplustox.	x	x	-	Plinthic Ferralsols.
EAK-44	x	x	-	-	x	-	Typic Haplustox.	-	-	-	Humic Nitosols.
EAK-38	-	-	-	-	-	x	Andepts.	-	-	x	Umbric Andosols.

Mo, Um, Ar and Ox refers, respectively to mollic, umbric, argillic and oxic epipedons. vp= volc. and pyrocl. materials, >60% of the soil material; += may or may not have; o=must have; /=must lack; -=lack; x=have.cc=clay coatings; rc=red color, pl=plinthite, us=ustic moist. reg., is=isotherm. temp. reg., fe=ferritic material.

Table 7. Physical and chemical properties of the EAK-profiles related to some environmental conditions, like relief, altitude and rainfall.

	EAK-51	EAK-47			EAK-48		EAK-44		
Location and relief	Undulat. upland	Gently undulat. plateau, slope 3%			Plateau, middle slope (7%)		Footridges, upper slope 3%		
Altitude (m)	855	1.000			900		1.400		
Rainfall (mm/year)	800	900			900		1.600		
(Horizons)	B	A	AB	B	A	B	A	AB	B
Sand, %	58	15	13	10	15	30	16	10	6
Silt, %	17	19	15	13	16	7	24	25	16
Clay, %	25	66	72	76	66	63	60	68	78
Text. class	scl	c			c		c		
pH, KCl	5.5	5.7	5.5	4.9	5.1	5.1	5.1	5.3	5.6
Base saturation %	79.8	45.9	38.8	59.0	34.3	13.4	33.9	28.8	26.6
C.E.C., meq/100 gr clay	39.2	34.1	27.1	16.0	42.0	30.5	42.5	32.0	23.0
Organic matter,%	0.7	2.2	1.6	1.0	2.3	0.9	2.4	1.7	0.8
Colour	2YR 3/6M	5YR 3/2-3/6 M 5YR 3/4-3/6 D			5YR 3/2-4/6 M 5YR 3/2-5/2 D		2.5YR 3/2 M 5YR 3/4 D		
Classification	Chromic Luvisols	Rhodic Ferralsols			Plinthic Ferralsols		Humic Nitosols		

c=clay; scl=sandy clay loam.

Table 8. Macromorphological and micromorphological features and pedofeatures displayed by the EAK-profiles.

Features and Pedofeatures	EAK-51	EAK-47	EAK-48	EAK-44
Clay skins observed in the field	yes	yes	yes	yes
Structure				
Type	sub-angul.	sub-angul.	sub-angul.	sub-angul.
Grade	mod/very coarse.	mod-very coarse.	mod-very coarse.	mod-very coarse.
Boundaries:				
Width and topography	gradual wavy.	gradual smooth.	abrupt smooth.	gradual wavy.
Consistence:				
friability.	friable.	very friable.	very friable.	very friable.
stickeness.	sl. sticky.	sl. sticky.	sl. sticky.	sticky.
plasticity.	sl. plastic.	sl. plastic.	sl. plastic.	sl. plastic.
Microstructure	w.d.spongy vughy.	st.d.complex.	st.d.complex.	st.d.complex.
c/f limit(um).	25	5	5	5
c/f ratio.	60/40	10/90	10/90	10/90
Related distribution.	porphyric.	plasmic, undiff.	plasmic, undiff.	plasmic, undiff.
b-fabric patt.	str. speck.	str. speck.	str. speck.	str. speck.
pedofeatures:				
clay coatings	x	-	-	x
Aggr. pedotub.	x	x	x	xx
amorph. cryptoc.	x	x	x	x
fab. pedofeat.	x	x	x	x

sl=slightly; w.d.=weakly developed; st.d.=strongly developed; str.= striated; speck=speckled; x=present; -=absent.