MICROMORPHOLOGICAL CHARACTERISTICS OF SOME NITOSOLS AND ACRISOLS IN KENYA WITH SPECIAL REFERENCE TO PROFILES OF A CATENARY SEQUENCE IN TOMBE - KISII

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by
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Kenya Soil Survey

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R.M. Kiome, Wageningen
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SUMMARY

In this study seven profiles from Kenya have been studied to find out the micromorphological differences between the profiles classified as Acrisols and those classified as Nitosols according to the Kenyan (FAO-modified) concept.
Six soils are developed from volcanic material with addition of volcanic ash and one of them (EAK12) is developed from sandstone. The profiles are located in areas with a subhumid climate, average annual precipitation of 1400 to 2500 mm. per year and average temperatures of 18 to 25°C. Six of them are in areas of altitudes between 1400 m. to 2100 m. above sea level and the other one (EAK12) is near the coast at an altitude of 200 m. above sea level. Three of the profiles are in a catena (Tombe catena) in Kisii district while the other four are situated in different places.
The physical and chemical properties indicate that the profiles are quite strongly wheathered but the Acrisol profiles have indications of stronger wheathering than the Nitosol profiles. The Nitosol profiles are more fine textured with predominantly kaolinite clay minerals.
By Kenyan (FAO-modified) concept of classification, four of the profiles (RP1, RP2, EAK26 and EAK16) are Nitosols, two (WAN2 and EAK12) are Acrisols and RP2 is a Cambisol. By the FAO-Unesco (1974) classification system five of the profiles (RP1, RP3, EAK16, EAK12 and WAN2) are Acrisols, RP2 is a Cambisol and EAK26 is a Phaeozem. There are no Nitosols because of the low CEC-clay ($\leq$ 240 mmol/kg.) hence ferric properties in all the profiles.
According to the USDA Soil Taxonomy classification system profiles RP1, RP3 and WAN2 are Humults, profiles EAK12 and EAK16 are Ustalfs, profile RP2 a Tropept and profile EAK26 a Argiudall. All are oxic or orthoxic because of the low CEC-clay.
Micromorphological investigations confirm that all the profiles studied are quite strongly wheathered. They are very porous especially in the upper part and become less porous with depth. Biological pedoturbation, perforation and homogenisation is very important for porosity and structure development. Biological activity is high in all the profiles especially in the upper 100 cm. but remains noticeable throughout the profile. All the profiles except profile RP2, have an illuvial-argillic subsurface horizon and have some degree of reorientation. Swelling, shrinking, leaching, desilication, ferrallitisation and rubefaction are the soil forming processes identified in the profiles.
Micromorphological features which show differences between the Acrisol and the Nitosol are:

i. Amount of physicogenic pores - There are more physicogenic pores in Nitosol profiles than in Acrisol profiles.
ii. Intensity and amount of reorientation - There are more masepic, vosepic and insepic reorientations in Nitosols than in Acrisols.
iii. Related distribution - The Acrisol profiles have agglomeroplasmic and intertexic related distribution while the Nitosol profiles have porphyroskelic and porphyric distribution.
iv. Profile illuviation indices - The Acrisol profiles have lower profile illuviation indices than the Nitosol profiles.
v. Presence of features indicative of shiny ped faces - (vosepic and masepic reorientations and ferri-argillans which are continuous on ped faces). The Nitosol profiles show some of these features

while the Acrisol profiles do not show them.
Some of the differences are due to textural differences between the Acrisol and Nitosol profiles and are hence coincidental.

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INTRODUCTION AND AIM OF THE INVESTIGATION

In the tropics and the subtropics tracts of land occur with soils that have very favourable physical and chemical characteristics for arable agricultural use. The high agricultural potential of these soils has been known to the farmers who live in these places for a long time. They have always sought for these soils for plantations. They have used the soils for many years without any chemical fertilizers and have obtained quite good crops and high yields.

During the preparation of the FAO-Unesco soil map of the world the need for high level separation was felt and they were called the Nitosols (connotative of Niti-shiny ped surfaces). An attempt was made to separate them from the less favourable Acrisols and Luvisols (Sombroek and Siderius, 1981). However the concept had to be broadened to conform with the diagnostic criteria of the 'pale' great group of Ultisols and Alfisols in the USA System of Soil Classification. In the USDA Soil Taxonomy (1975) classification at the sub-order level, Nitosols, Acrisols and sometimes the Luvisols, are classified together as Udalfs, Humults and Udults. Yet the differences used in the suborder category are primarily chemical or physical or genetic or mineralogical (7th Approximation, 1960).

Actually these soils occur in catena sequences with Acrisols and Luvisols in many of in their natural environment. So it is not surprising when the agriculturally favourable soils (Nitosols) are included in the less favourable ones such as the Acrisols and Luvisols of the FAO-Unesco legend (1974). The differentiating criteria of the Nitosols from the Acrisols do not always apply or are sometimes not well understood.

In Kenya these soils occur in many places of high to medium agricultural potential. Their classification has been a constant problem to the workers in the country, so that some have suggested other names for these soils while others have suggested some changes especially in the FAO-Unesco definition of the Nitosols. They are defined as Nitosols by the Kenyan soil authorities, but the name Nitosol is used in this study.

This study has been motivated by these problems. The micromorphological characteristics of some profiles are investigated in details to differentiate the Nitosols and the Acrisols. Also chemical, physical and claymineralogical properties are investigated. The genesis and classification of the soils is discussed. Seven profiles are investigated. Three of them occur in a toposequence. Two of them are developed on similar parent material while the other two are developed on somewhat different parent material but have a similar environmental setting.

1. ENVIRONMENT

1.1 Location

The Tombe catena is situated in South Nyanga Province, Kisii district of Kenya. Tombe is the nearest market centre, about 13 km. from Kisii town. The transect sampled represents a toposequence which is about 3 km. east of Tombe market and runs nearly North to South across one of the river valleys and bottomlands in the area (see figures 1.1, 1.2 and 1.3).
Profile RP1 is located near Tombe Primary School, at a high lying stable part of the transect with an altitude of 2075 m. above sea level (ASL). Profile RP2 is on the middle part which is steeply sloping, at an altitude of 1995 m. ASL. Profile RP3 is near the lower end of the slope, at an altitude of 1945 m. ASL (see figure 1.3 and 1.4).

1.2 Geology and parent material

The area consists of Precambrian rocks of the Bukoban system (Huddleston, 1951). The rocks of this system are basalts, andesites, rhyolites, felsites, quartzites, and cherts.
In many places the rocks of the Bukoban system have been covered by a thin layer of volcanic ashes and tuffs, especially in the bottomlands of the eastern part of the Kisii district. Due to erosional transport the soils are developed mainly from a mixture of these rocks.
The area sampled consists of rhyolites intercalated with andesites. The volcanic ashes cover in some parts the rhyolites and andesites. They are incorporated in the deeply developed soils. In the bottomlands in some places, layers up to 4 m. thick of volcanic ash deposits have been reported (Wielemaker and Boxem, 1982), but these were not found in the sampled area. However it is possible that the influence of volcanic ashes in the soil profiles is significant.

The table below shows the chemical composition of the rock types which form the parent material of some of the profiles investigated. The rocks have a rather high SiO_2, M_2O_3 and Fe_2O_3 composition. There is not a big difference in their composition. Granites have the highest SiO_2 composition and quite high base oxides (CaO, MgO, Na_2O and K_2O). Andesites, felsites and volcanic ashes are considered to be intermediate rocks while rhyolites and granites are acidic rocks.

Table 1.1 Chemical composition of soil parent materials.

Mass fraction of	Volcanic ashes	Felsites and Andesites	Rhyolites	Granites
SiO_2	0.61	0.67	0.62	0.77
Al_2O_3	0.14	0.13	0.13	0.12
Fe_2O_3	0.10	0.07	0.10	0.25
MnO	0.007	0.001	0.002	0.0
MgO	0.006	0.006	0.003	0.001
CaO	0.009	0.002	0.070	0.010
Na_2O	0.002	0.002		0.050
K_2O	0.002	0.060	0.030	0.030
TiO_2	0.007	0.005	0.010	0.002
P_2O_5	0.001	0.001	0.0	0.0

1.3 Geomorphology

The Tombe catena is situated in one of the high upland levels called Keroka Uplands (Wielemaker and Boxem, 1982) This corresponds to the Kisii erosional surface in the study of Wielemaker and Van Dijk (1951). It is probably of Cretaceous age but has undergone morphological changes during the formation of the East African rift valley in the Tertiary period. It became tilted and was covered by volcanic pyroclastics. Planation and erosion removed the pyroclastics in most places and left the present topography of hill ranges and deeply dissected broad valleys, through which small streams run. The slopes at the top of the hills are small (less than 10%) while the valley slopes exceed 20% and end abruptly to bottomlands with slopes of less than 2%. This combination of stable high lying hill ranges, their slopes and parts of bottomlands, which are not large enough to be separated is called the high level uplands (Keroka Uplands).

Fig. 1.1. Location of South Nyanza Province in Kenya

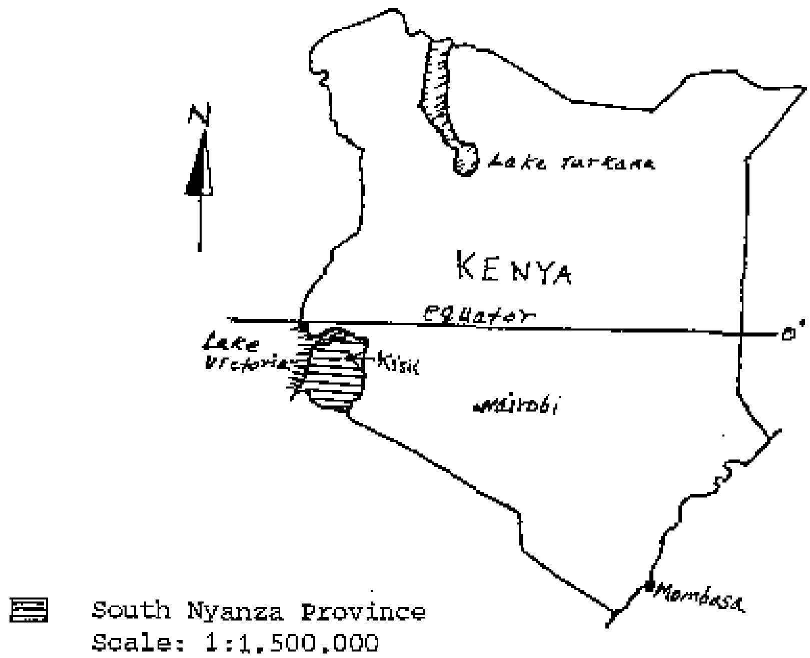


Fig. 1.2 Location of study area

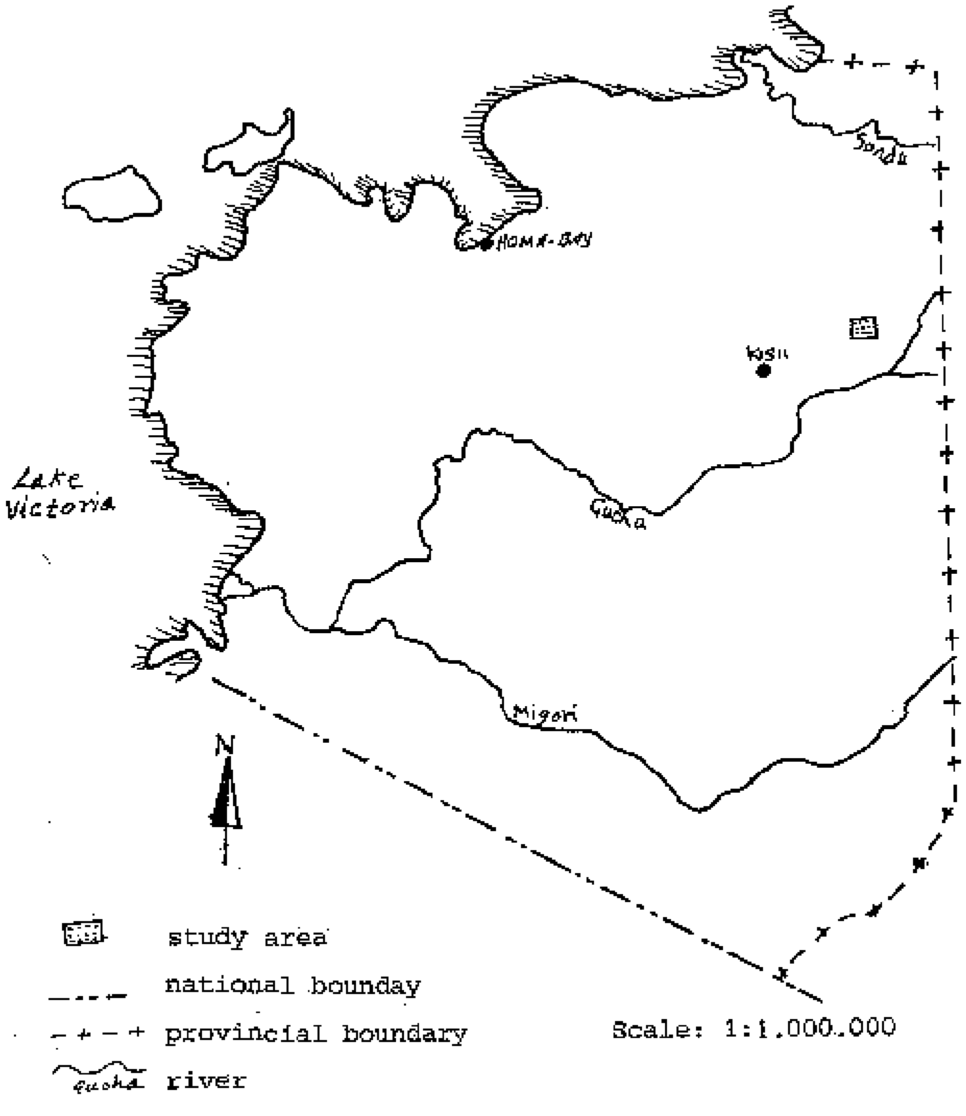
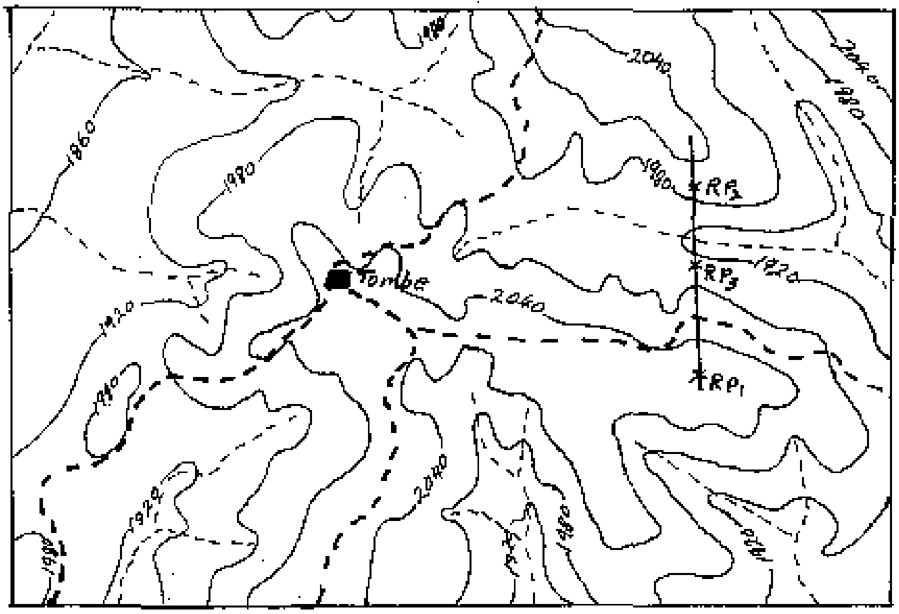


Fig. 1.3 Location of the catena



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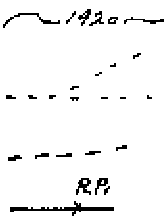


contour line (interval 60 m)

stream gurly

road

transect of the catena studied showing location of the profile pits sampled

Fig. 1.4 Crossectional profile of the transect of the catena studied

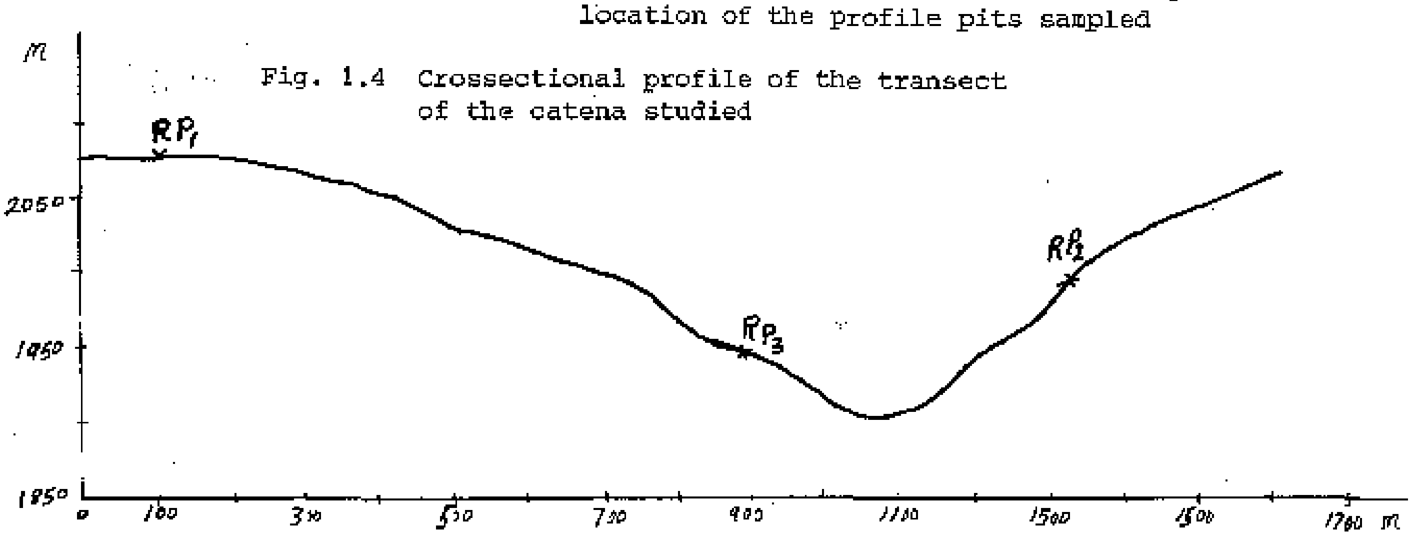
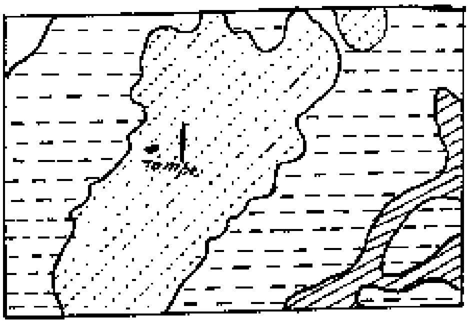


Fig. 2.1 Generalized geomorphology of Tombe area



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minor scarps

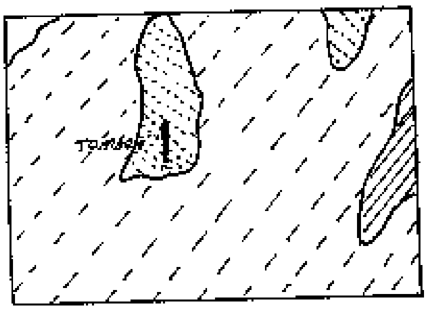
Keroka erosional surface (rolling to hilly) 1800-2150 m

Magomba erosional surface (undulating to rolling) 1700-1850 m

bottomlands

transect sampled

Fig. 2.2 Generalized geology of Tombe area



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quartzite and cherts

fersites and andesites

Rhyolites and tuffs

dolerites and lamprohyves

transect sampled

1.4 Climate

Due to a lack of a meteorological station in Tombe area meteorological data are estimated from stations in the neigbouring areas. Morumba Station number 1034032 and Kisii National Agricultural Research Station number 1034088 are the nearest ones to Tombe area, Rainfall and temperature depend very much on altitude and physiography. The relation between altitude and mean temperatures has been given by East African Meteorological Department E.A.M.D. (1970). Braun (1980) has related altitude and thermodynamic temperatures for Kenya as follows:

- mean max. temperature = 35.5 - 5.94 x
- mean min. temperature = 24.8 - 7.05 x
- mean temperature = 30.2 - 6.50 x
- absolute max. temperature = 42.5 - 5.51 x
- absolute min. temperature = 16.3 - 6.56 x

Using these equations the temperatures of Kisii N.A.R. Station and Morumba F.C.S Station are as shown in table 1.2.

Table 1.2 Calculated thermodynamic temperatures in Kisii N.A.R. Station and Morumbo F.C.S. Station in °C.

	Morumbo F.C.S. Station	Kisii N.A.R. Station
Altitude	1920	1753
mean max. Temp.	24.10	25.09
mean min. Temp.	11.26	12.44
mean Temp.	17.27	18.81
abs. max. Temp.	31.92	32.84
abs. min. Temp.	5.70	6.55

Table 1.3 Average annual rainfall (mm) of stations near Tombe area.

Station	Number	Altitude (m.)	Av. annual rainfall (mm.)
Kisii DC	9034001	1630	1790
Kisii N.A.R.	9034088	1753	2450
Morumba F.C.S.	9034032	1920	2099
Nyakoe F.C.S.	9034056	1570	1756

Morumba F.C.S. Station meteorological data are the best for Tombe area. The average monthly rainfall and evapotranspiration are shown in figures 2.3 and 2.4. The area has quite a high annual rainfall distributed in two periods in a year. The wet periods are March to June, and September to November. Only two months (January and February) are distinctly dry, when evapotranspiration is significantly higher than the precipitation.

June and December are moist and the other months in a year are wet (EAMD, 1977).

1.5 Vegetation and land use

The vegetation of the area is forest clearings and cultivation communities from moist montaine intermediate forest (Wielemaker and Boxem, 1982). It consists of undifferentiated clearings and shrubs. In Tombe area, papyrus trees, swamp grasses and reeds are dominant. Cypressus and Eucalyptus species of trees have been planted on the steeper slopes. Small pastures planted with Kikuyu grass are found at virtually every homestead.

The present land use is permanent cultivation of maize, tea, pyrethrum, and vegetables such as cabbage, spinach and peas. The landscape is characterized by a pattern of narrow strips from the valley bottoms to the hill tops, divided by fences of planted shrubs (see plate 1).

Plate 1. Showing site of RP1 and landscape of the transect sampled.

The areas occupied by the various crops could not be calculated because the parcels are very small. Data provided by the Kenya Tea Development Authorities (KTDA) of 1971-73 for 45 bigger farms in East Kitutu (Tombe area) show: tea and pyrethrum (main cash crops in the area) comprise 23.9%, maize 27.5%, grazing land 28.9%, others (vegetable and horticultural crops) 20.3% of the area. The situation has changed very much since the last 10 years due to the high rate of population growth and tendency to grow cash crops at the expense of food crops and grazing land. Thus the area with maize and grazing land has reduced while that with tea, pyrethrum and homesteads must have increased considerably since 1973.

Fig. 2.3 Average monthly rainfall (solid line) reached or exceeded in 3 out of 4 years and average monthly potential evapotranspiration (ET = 2/3 E°, broken line) in Norumba F.C.S.-station. Agroclimatic-zone IIa.

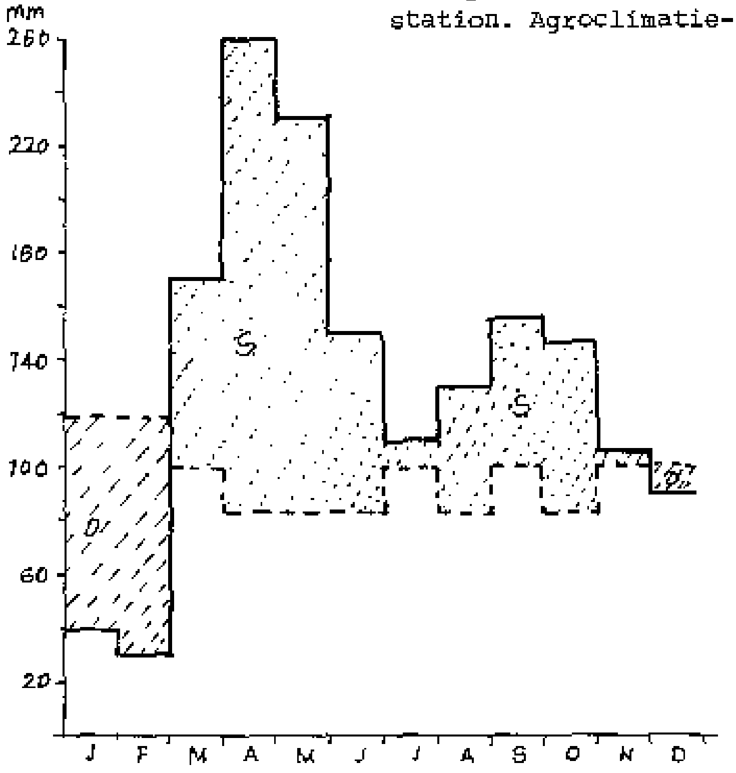
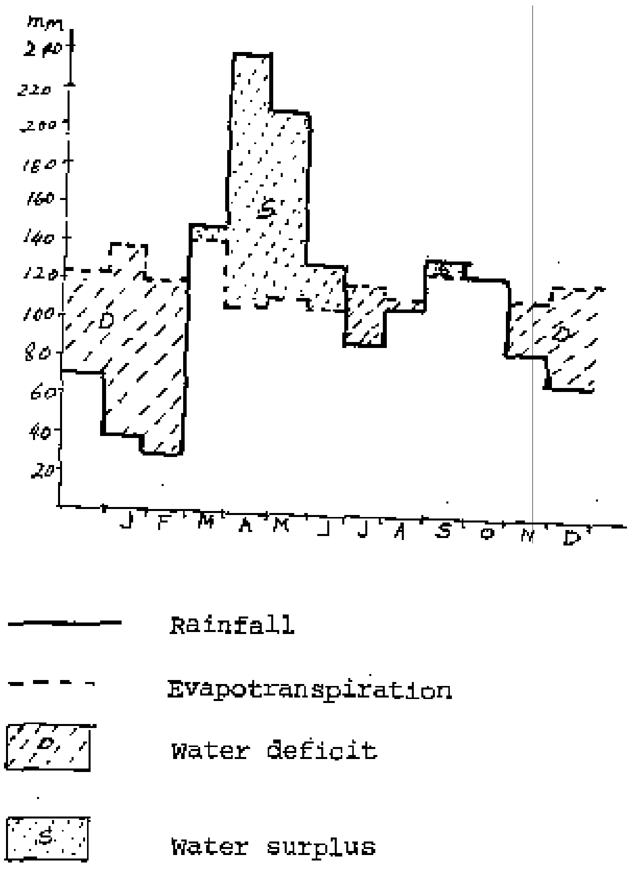


Fig. 2.4 Average monthly rainfall (solid line) and evapotranspiration (broken line) in Norumba F.C.S.-station



2. METHODS AND MATERIALS

2.1 General

The catena was selected by means of auger hole observations during a two weeks field work. The area was proposed after consultations with various relevant authorities who had done some work on the soils of Kisii area earlier. It was selected to include soils on stable hill tops; soils on the more steep slopes of the hills and the soils on the less steep foot slopes of the hills. Three profile pits on a transect of about 3 km. length were described during the field work. They were sampled at every 20 cm. depth up to 200 cm. or parent material, whichever is shallower. Undisturbed samples were taken for micromorphological investigations, mixed samples for clay mineralogy and another set of mixed samples for physical and chemical analysis.

Four other profiles of similar soils as those of the catena were selected from the profiles available at the International Soils Reference and Information Centre (ISRIC) and the department of Soils and Geology of the Agricultural University - Wageningen. These are used as reference profiles for comparison with the profiles of the catena studied and add to the information required for the research.
The profile descriptions were done according to Soil Survey Staff (1951) FAO Guidelines (FAO, 1977) and Kenya Soil Survey profile description System (KSS, 1975).

2.2 Laboratory methods

Most of the laboratory tests were done in Natural Agricultural Laboratories (N.A.L.) at Kabete in Kenya except clay mineralogy and elemental analysis of the clay fraction, which were determined at the laboratories of the department of Soils and Geology - Wageningen Agricultural University in the Netherlands. A short description of each method used is given here.

Texture. The samples were treated mechanically to remove the cementing agents; shaken with sodium hexametaphosphate and sodium carbonate in an end-over-end shaker. Silt and clay (< 0.05 mm.) are measured after 40 seconds and clay after 0.4 hours using a hydrometer. The difference (fine earth - silt and clay) is the sand fraction (Day, 1950).

PH. PH - H_2O is measured with a combined glass calomel electrode in a supernatant of 1:2.5 soil - water solution. The sample is initially shaken for two days with distilled water. PH KCl is measured in the same way but the solution used instead of water is 1M KCl.

Electrical conductivity (EC). The EC is measured in saturation extracts using Pt - electrodes. It is expressed in mm./cm.

Mass fraction of carbon (C%). The percentage of carbon is determined by the method described by Warkley and Black (Black, 1965).No correction factor to compensate for the recovery is used.

Mass fraction of nitrogen (N%). The percentage of nitrogen is determined by the semi-micro method by Kjeldahl (Black, 1965).

Exchangeable cations. The soil is leached with ammonium acetate (conc. 1M), buffered at pH - 7. Na, K and Ca are determined by emission spectrometry. Lanthanium chloride is added before determination of Ca. Mg is determined by atomic absorption spectrometry.

Cation exchange capacity (C.E.C.). The soil is washed with 15% volume fraction ethanol after leaching with NH_4O-acetate. It is percolated with acidified NaCl. Ammonia is steam distilled and titrated against 0.01M HCl (Houba et al 1979).

Moisture tensions. Measurements of mass fraction of water in saturated soil and soil after equilibrium with sand box to pF 0.4, 1.5 and 2.0 gives the moisture fraction of those pF's. A kaolin box is used for pF 2.3 and 2.7 and pressure equipment for pF's 3.0, 3.7 and 4.2 (Stokman et al, 1969).

Clay mineralogy. The clay fraction is separated by sedimentation after destruction of organic matter and cementing agents. A small portion (15 mg.) of the clay is dried on a porous ceramic plate at a reduced pressure to orient the clay. The oriented clay is saturated with Mg ions. The diffraction patterns are obtained with a computerized automatic x-ray diffractometer.

Thermo analysis. A small portion of the clay is grinded to give a fine powder. The powder is put into the tube (for DTA) or on the balance plate (for TGA) and the thermo analysis is done by a computerized thermal analyser. The loss of water or OH is determined either by differential thermal analysis (DTA) or the thermogravimetric analysis (TGA).

Elemental analysis. The elemental analysis is carried out by the x-ray fluorescence spectrophotometry of the fine earth fraction or the clay fraction. The samples are saturated with BaCl solution to avoid interference by absorbed bases.

Electron microscopy. A drop of deferrated sample of the clay fraction is placed in a grid micro-plate. The water is allowed to evaporate. The sample is analysed using the transmission electron microscope.

2.3 Micromorphological methods

Samples for micromorphology investigations are impregnated using the method by Fitz Patrick (1980). After six weeks they are cut with a saw, attached to the objective glass, sawed off to about 1 mm. thickness, and grounded off to a thickness of about 25)m before placing the cover glass on them. These are studied under polarizing microscope.
The definitions and terminology of Brewer (1964) were followed for the description of different features. The cutans and papules were quantified by means of point counting method on the thin sections using a magnification of 125. Standard deviation was calculated according to the method of Van der Plas and Tobi (1965).

The other features are semi-quantified (ranked) using the charts method of Fitz Patrick (1980). The minerals were identified on the thin sections using their optical properties. The advice of expert was sought for in this case.
The ranking of the features quantified by point counting was done as follows:
0-1% (by volume) = few; 1-2% = common; 2-4% = many; >4% = abundant.
The ranking of the features semi-quantitatively by the charts methods was as follows:
<2% = few; 2-10% = common; 10-30% = many; >30% = abundant.

3. SOIL CHARACTERISTICS

3.1 Characteristics of the soils of the catena

3.1.1 Profile descriptions

Profile code RP1: Author R. Kiome and S. Mwangi.
Site characteristics:
Location: Kisii - Tombe, 130/2-RP1, E/710.6, N/9927.5, altitude: 2075 m. ASL.
Climatic data: Derived from Morumba Station no. 9034032, 7 km north of Tombe, altitude 1920 m. ASL, agroclimatic zone IIa (see figures 2.3 and 2.4 for rainfall and evapotranspiration data and table 1.2 for temperature data).
Soil classification: FAO - Unesco (1974): Humic Acrisol*)
USDA Soil Taxonomy (1974): Orthoxic Palehumult
Agroclimatic zone: IIa
Local petrography/parent material: Rhyolites/a mixture of rhyolites, volcanic tuffs and ashes and some andesites.
Physiography (general): Upper level uplands.
Surrounding landform: Crest of a hill (Knoll), sloping to the North West within 20 m.
Macro-relief: Gently undulating to flat, 20-100 m. of slope length, nearly flat to convex slope part.
Meso/micro-relief: Sparse, 50 cm. in diameter; 20 cm.high termite mounds.
Vegetation/landuse: Tea, Kikuyu grass/permanent cultivation.
Surface stoniness: Nil.
Erosion: Very slight sheet erosion.
Slope gradient: 2% - South West.
Soil fauna: High termite activity, Krotovinas, mole holes in the upper 100 cm.
Root distribution: Abundant fine to medium in the topsoil decreasing to common, very fine to medium in the subsoil.
Drainage class: Well drained.
Moisture conditions: Moist throughout the profile, some rains in the previous day.
Depth of groundwater: Below the profile depth (2 m.) at all times of the year.
Presence of salt/alkali: Nil.
Human influence: Frequent tillage, artifacts of charcoal, school about 400 m. from site, footpath 10 m. from site.

Soil profile
Ap 0-20 cm. Dark reddish brown (5YR moist); clay; moderate, medium, subangular blocky and moderate to strong, medium, granular; friable, slightly sticky, slightly plastic; many fine, many medium pores; clear and irregular boundary to

*) The classification is nitosol if the ferric property on basis of CEC clay is neglegted (see chapter 6).

AB 20-60 cm. Dark reddish brown (5 YR 3/2 moist); clay; moderate, fine, subangular blocky; friable, sticky, plastic; many fine, few medium pores, few thick, patchy shiny, cutans on ped faces; clear and irregular boundary to

B21t 60-100 cm. Dark reddish brown (2.5 YR 3/4 moist); clay; moderate, fine, angular blocky breaking to strong, fine, subangular blocky; friable, sticky, plastic; few fine, common medium pores; many thick, continuous shiny cutans on all ped faces; gradual and smooth boundary to

B22t 100-140 cm. Red (2.5 YR 3/6 moist); clay; moderate, medium angular blocky and subangular blocky; friable, sticky, plastic; many thick to moderately thick broken shiny cutans on all ped faces; diffuse and smooth boundary to

B23t 140-200 cm. Red (2.5 YR 4/8 moist); clay; moderate to weak, medium, angular blocky; friable, sticky, plastic; many fine pores; common moderately thick broken shiny cutans on all ped faces; about 2.5% medium, iron and manganese nodules deeper than 180 cm. depth.

Profile code: RP2; Author R.M. Kiome and S. Mwangi.
Site charateristics:
Location: Kisii - Tombe, 130/2-RP2, E/710.8, N/9928.9, altitude 1995 m. ASL.
Climate: See climate data for profile RP1.
Soil classification: FAO-Unesco (1974): Ferralic Cambisols.
USDA-Soil Taxonomy (1975): Oxic Humitropepts.
Agroclimatic zone: IIa.
Local petrography/parent material: Rhyolites/rhyolites, some volcanic tuff and andesite and volcanic ashes.
Physiography (general): Upper level uplands.
Surrounding landform: Steep part of the valley slopes.
Macro-relief: Rolling to hilly, slopes 30-35%, 100-150 m. long, linear, regular.
Meso/micro-relief: Sparse 50 cm. diameter, 20-30 cm. high, termite mounds and erosional remnants.
Vegetation/landuse: Coast grass, Kikuyu grass, wattle trees/pasture, 5% bare soil.
Surface stoniness: Nil.
Erosion: Moderate gully and rill erosion.
Slope gradient: 35%.
Soil fauna: High termite activity up to 90 cm. deep. Many termite channels. Some mole holes.
Root distribution: Very many fine to coarse roots up to about 120 cm. decreasing with depth.
Drainage class: Well drained.
Moisture conditions: Moist throughout the profile, rains previous day.
Groundwater depth: Deeper than profile depth (140 cm.) throughout the year.
Human influence: Trampling by livestock, foot path near site (10 m. away).

Soil profile:

Ap 0-15 cm. Dark reddish brown (2.5 YR 3/4 moist); clay; moderate, medium, subangular blocky and granular; friable, sticky, plastic; many fine, many medium pores; clear and smooth boundary to

AB 15-35 cm. Dark reddish brown (2.5 YR 3/4 moist); clay; coarse, subangular blocky; friable, sticky, plastic; many, fine to medium pores; clear and smooth boundary to

B21t 35-60 cm. Dark red (2.5 YR 3/6 moist); clay; moderate, coarse, subangular blocky; friable, sticky, plastic; many, fine, pores; few thin patchy, shiny cutans on some ped faces; gradual and smooth boundary to

B22t 60-112 cm. Red (2.5 YR 4/6 moist); clay; moderate, fine, angular blocky breaking to moderate, medium, subangular blocky; friable, sticky, plastic; few, medium to fine, pores; thin patchy, shiny cutans on ped faces; gradual and smooth boundary to

BC 112-140 cm. Dark red (10 YR 3/6 moist); clay; moderate, fine, angular blocky; friable, sticky, plastic; few fine pores; few thin patchy shiny cutans on ped and gravel faces; partly saprolite.

Profile code RP3; Author R.M. Kiome and S. Mwangi.
Site characteristics:
Location: Kisii - tombe, 130/2-RP3, E/710.7, N/9928.2, altitude 1948 m. ASL.
Climatic data: See climatic data for profile RP1.
Soil classification: FAO-Unesco (1974): Humic Acrisol *).
USDA Soil Taxonomy (1975): Orthoxic Palehumult.
Agroclimatic zone: IIa.
Local petrography/parent material: Rhyolites/rhyolites and a mixture of andesites, volcanic ashes and tuff.
Physiography (general): Upper level uplands.
Surrounding landform: Lower valley slopes (hill footslope) near the bottomlands.
Macro-relief: Rolling, 20-25% slope, slope length 100 m., linear and regular.
Meso/micro-relief: Sparse 20 cm. diameter, 10 cm. high termite mounds. Sparse 10 cm. high, 10 cm. in diameter tillage remnants.
Vegetation/landuse: Kikuyu grass 70%, cedar trees and bushes 20% / pastures, permanent cultivation of tea.
Erosion: Slight sheet and rill erosion on bare parts of the soil.
Slope gradient: 20%.
Soil fauna: High termite activity. Some mole holes, a few Krotoirinas in topsoil.
Root distribution: Common to many, fine to very fine, and few medium pores.

*) The classification is Nitosols if the ferric property on basis of CEC clay is neglected (see chapter 6).

Drainage class: Well drained.
Moisture conditions: Moist throughout the profile, rains in the previous day.
Depth of groundwater: Below lowest profile depth (210 cm.) throughout the year.
Presence of salt/alkali: Nil.
Human influence: Tilled previous year. Trampling by livestock. Some artifacts of charcoal.

Soils:

Ap 0-20 cm. Dark reddish brown (5 YR 3/2 moist); clay; moderate, coarse, granular and crumps; friable, sticky, plastic; common, medium, common fine to very fine pores; clear and smooth boundary to

AB 20-35 cm. Dark reddish brown (5 YR 3/3 moist); Clay; moderate, coarse, granular and moderate, medium, subangular blocky; friable, sticky, plastic; thick, patchy shiny cutans on vertical ped faces; many fine and very fine, medium pores; gradual and smooth boundary to

B21t 35-80 cm. Dark reddish brown (2.5 YR 3/4 moist); clay; strong, coarse, subangular blocky; friable, sticky, plastic; many, fine and medium pores; thick, continuous cutans on all ped faces; clear and irregular boundary to

B22t 80-120 cm. Dark red (2.5 YR 3/6 moist); clay; weak, coarse, angular blocky breaking to coarse, subangular blocky; friable, sticky, plastic; many, fine, few, medium pores; many thick, continuous shiny cutans on all ped faces; clear and smooth boundary to

B23t 120-200 cm. Red (2.5 YR 4/6 moist); clay; weak, medium, angular blocky breaking to moderate, medium, subangular blocky; friable, sticky, plastic; many, fine, common, medium pores; thick, continuous shiny cutans on all ped faces; few manganese mottles.

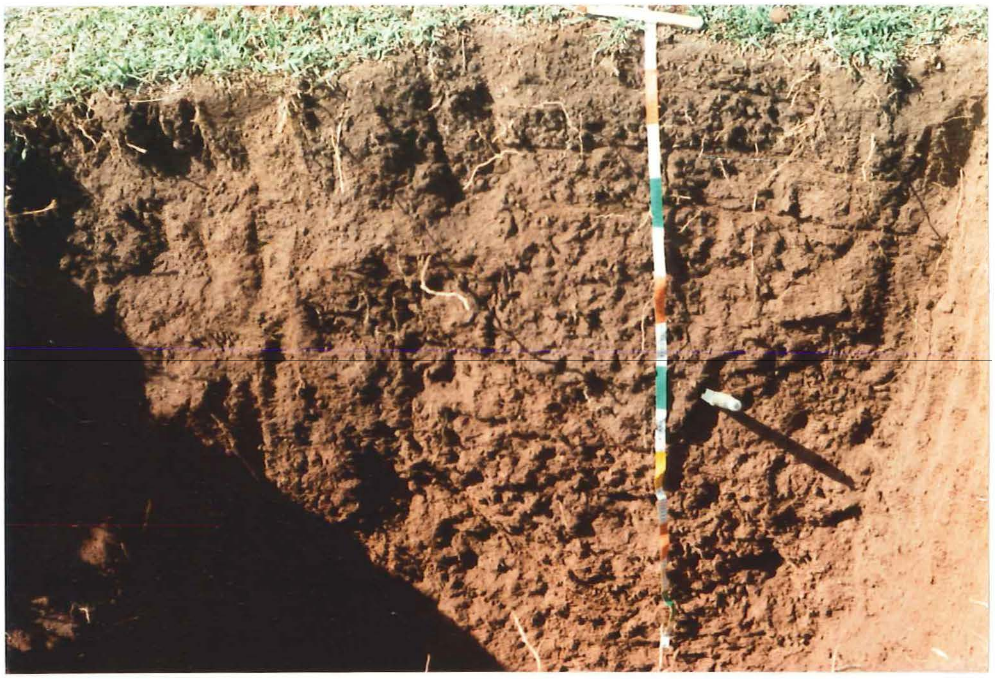


Plate 2: Profile RP1 (PEDON)

Plate 3: Profile RP2 (PEDON)
x mole holes

Plate 4: Profile RP3 (PEDON)

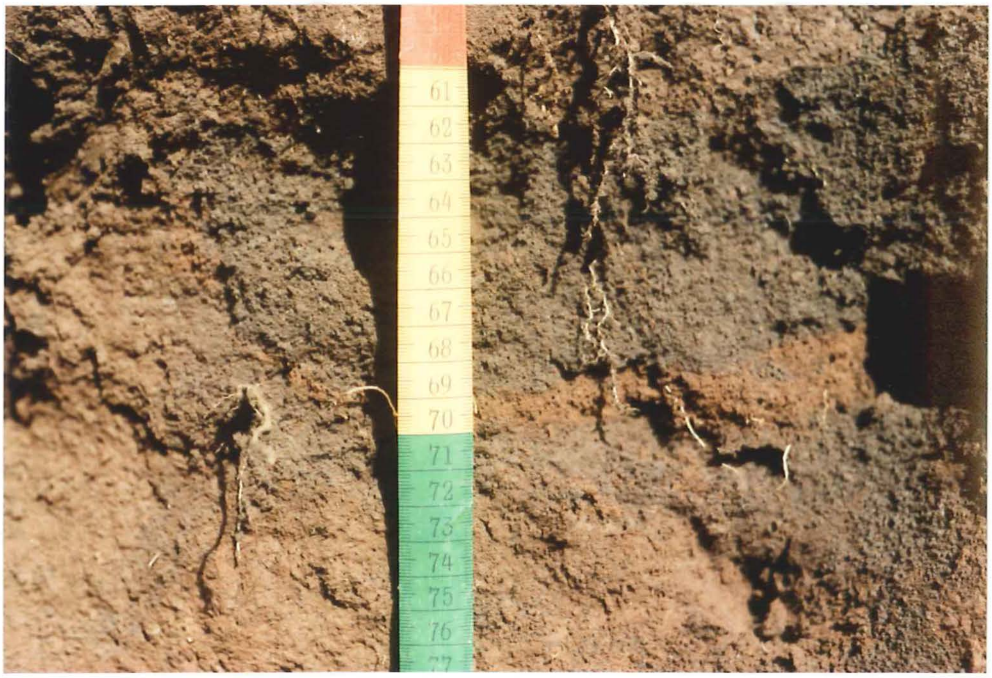


Plate 5: Close up of part of profil RP3 showing biological mixing of the soil.

3.1.2 Physical characterisitics

Particle size analysis. The results of particle size analysis are shown in table A1.1.All three profiles are clayey. Profile RP3 has higher clay content while profile RP2 has lowest clay content. The variation of sand, silt and clay content with depth are shown in figures 3.2, 3.4 and 3.6 for profiles RP1, RP3 and RP2 respectively. The clay bulge in profiles RP1 and RP3 is quite evident in these figures. No significant decrease of clay from the maximum can be seen within 200 cm. of these profiles. Lowest values of clay occur at about 40 cm. in profile RP1, and at near surface in profiles RP3 and RP2. Hence the eluvial horizon is near surface for profile RP3 and RP2 an at about 40 cm. in profile RP1. The maximum clay content is reached at 120 cm. in profile RP3 and at about 140 cm. in profile RP1.

Silt/clay ratio. The results of silt/clay ratios and their variation with depth show a clear decrease with depth. (See table A1.1 and figures 3.3, 3.5 and 3.7).
Profile RP2 has rather high values especially in the subsoil, while profile RP3 has lowest values. The values correlate with clay content.

Moisture retention. The moisture retention at pF 4.2 is rather high in all the profiles and correlates well with clay content within and among the profiles. (See table A1.1 and figure 3.1).

3.1.3 Chemical characteristics

Organic carbon. The results of the organic carbon are shown in tables A1.2, A1.3 and A1.4 for profiles RP1, RP2 and RP3 respectively. Profile RP2 has relatively low values of organic carbon and consequently low organic matter content. Profile RP3 has the highest values. The values of organic carbon relate well with the position of the profiles. profile RP2 is on a steeply sloping part of the toposequence so material, including the organic matter moves laterally quickly. Profile RP3 is in such a position that some material can be deposited. Profile RP1 is in such a position that it would not receive any material from the vicinity.
The variations of organic carbon with depth are shown in figure 3.8. A sharp decrease of organic carbon at about 30 cm. depth in profile RP3 indicates that the profile is on a receiving position. The variation of organic carbon with depth correlates with the profile description. Profile RP1 has a rather deep A horizon (about 60 cm.) as compared with profile RP2 and RP3 which have A + AB horizons of 35 cm. depth.

PH. The results of pH-H_2O and pH-KCl are shown in tables A1.2, A1.3 and A1.4. The average pH-H_2O values are low in all profiles (<5.4). Profile RP3 has the lowest pH values. The pH of the subsoil for this profile is even lower (<4.8). The variation of pH-H_2O with depth is shown in figure 3.9. A general trend of decrease with depth can be observed in profile RP3 and an increase with depth in profiles RP1 and RP2, especially in the upper 150 cm. The reverse occurs in the lower 50cm. There is an increase with depth in profile RP3 and decrease with depth in profile RP1 in the lower 50 cm. The low pH values, especially in profile RP3 in part of the subsoil, could imply high Al^{3+} activity, but the values are not low enough to be conclusive.

Cation exchange capacity. The CEC-NH_4O acetate at pH-7 is in general low in all three profiles as shown in tables A1.1, A1.2 and A1.3. Profile RP3 has lower CEC values than profile RP1 despite the high organic matter content in profile RP3. The CEC values relate to some extent with pH and clay content. The variation of CEC-NH_4O acetate with depth are shown in figure 3.10. A general trend of decrease with depth in all three profiles is shown up to 100 cm. depth.
The values of CEC-clay corrected for organic matter have been calculated and are shown in figure 3.12. The CEC-clay (corrected for organic matter) values indicate that a dominant clay mineral is 1.1.kaolinite. The value for RP1 is highest while that for RP2 is lowest. The CEC-organic matter is rather high. Profile RP3 has lowest values of CEC-organic matter. The low values of CEC-clay in profile RP3 indicate strong ferric properties in the profile.
The calculated values of CEC-clay (corrected and uncorrected for organic matter) are shown in table A1.3. Some of the values of CEC-clay corrected for organic matter are too low by this calculation.

Base saturation. The values of exchangeable bases and base saturation are shown in tables A1.1, A1.2 and A1.3. The low base saturation in all profiles indicates that the profiles are quite highly weathered. The exchange complex is dominated by calcium in all profiles and has very little magnesium. The low base saturation could also imply that the exchange complex is dominated by acidity (Al + H) especially at 40-100 cm. depth of profile RP3 and 0-60 cm. of profile RP1 and RP2.

Fig. 3.1 Variation of moisture content at PF 4.2 with depthts in profiles RP1, RP2 and RP3

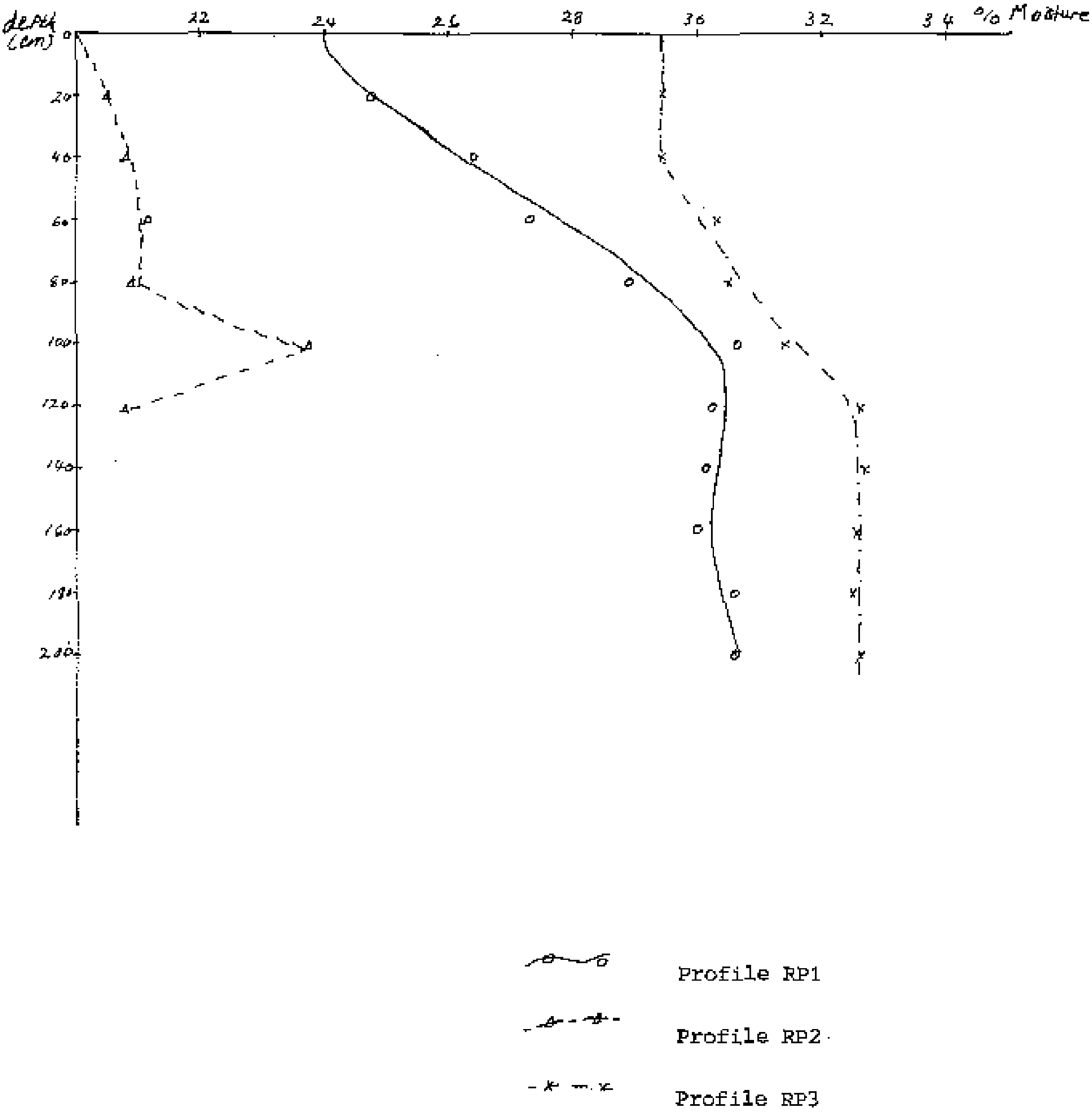


Fig. 3.2 Variation of sand, silt and clay content with depth in profile RP1

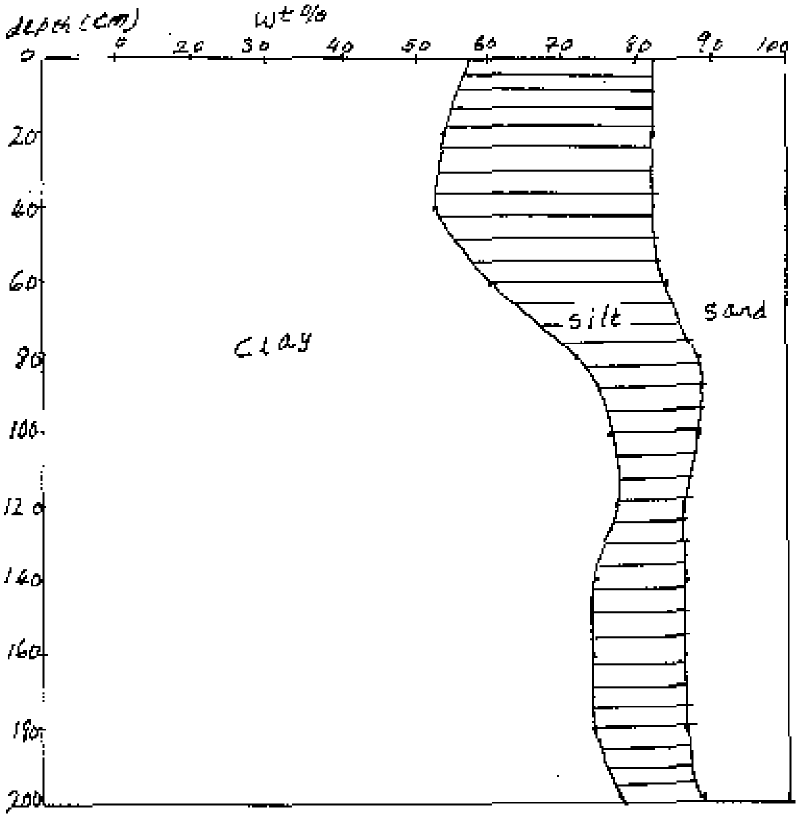


Fig. 3.3 Variation of silt/clay ratio with depth in profile RP1

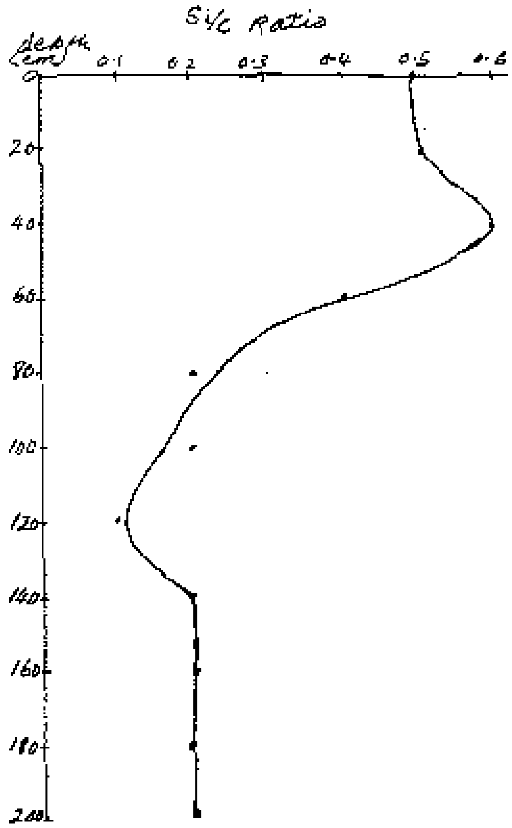


Fig. 3.4 Variation of sand, silt and clay with depth in profile RP3

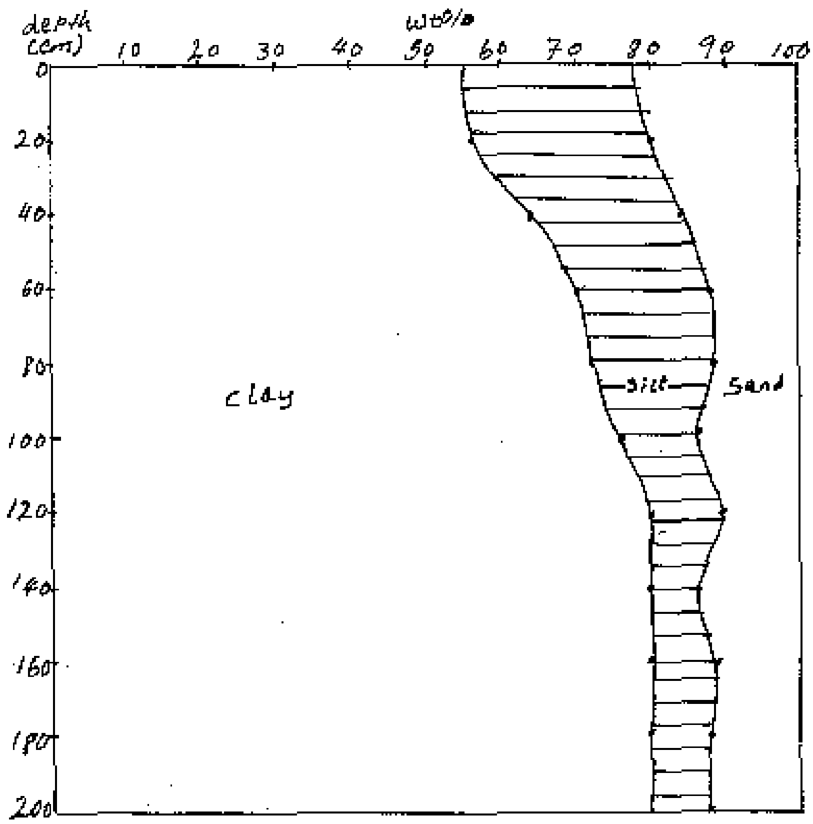


Fig. 3.5 Variation of silt/clay ratio with depth in profile RP3

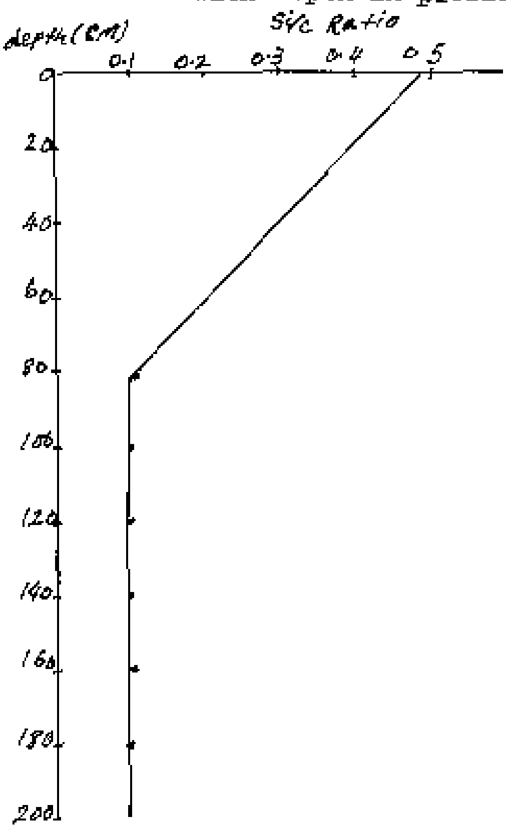


Fig. 3.6 Variation of sand, silt and clay with depth in profile RP2

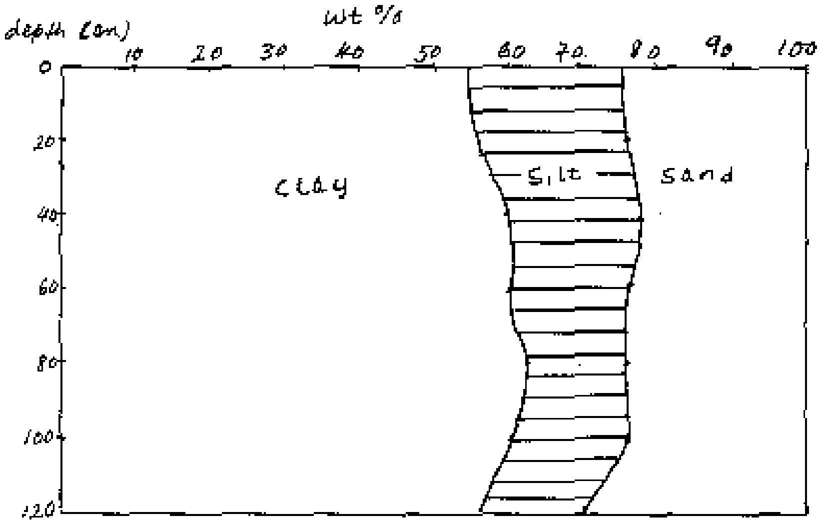


Fig. 3.7 Variation of silt/clay ratio with depth in profile RP2

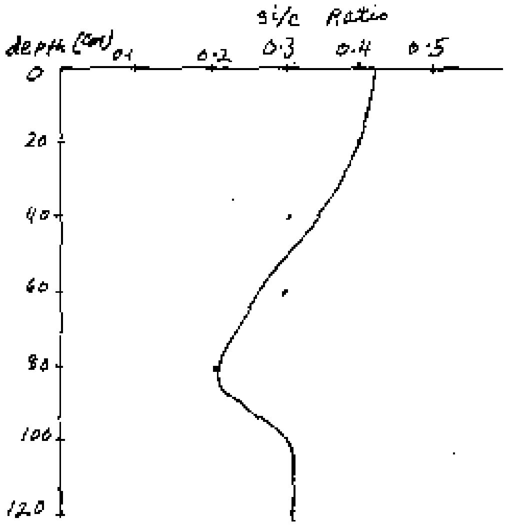


Fig. 3.8 Variation of organic carbon content with depth in profiles RP1, RP2 and RP3

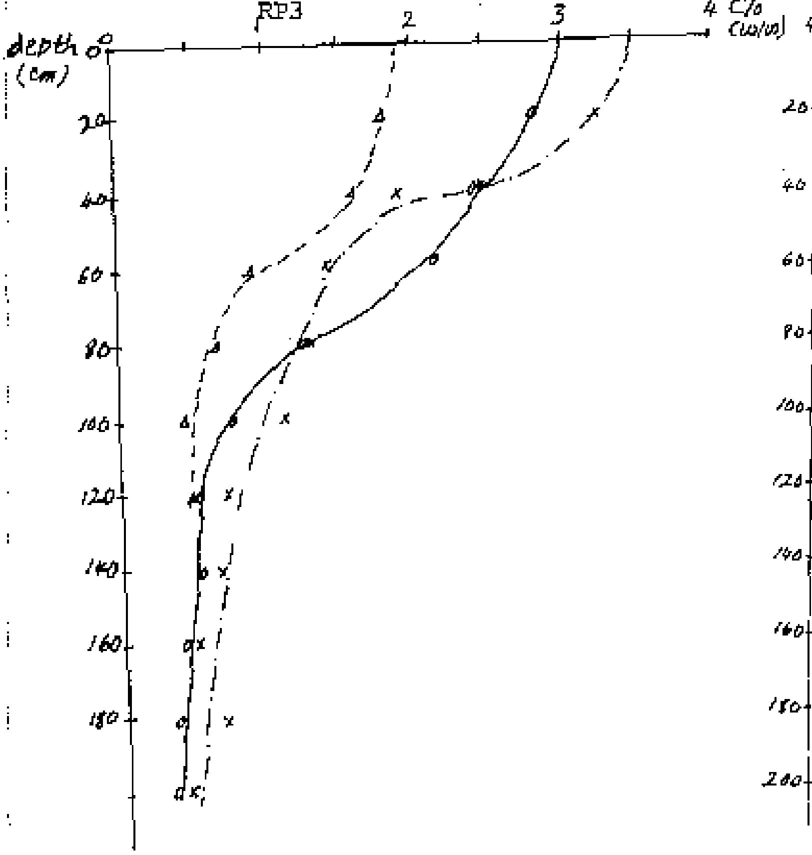


Fig. 3.9 Variation of pH-H_2O with depth in profiles RP1, RP2 and RP3

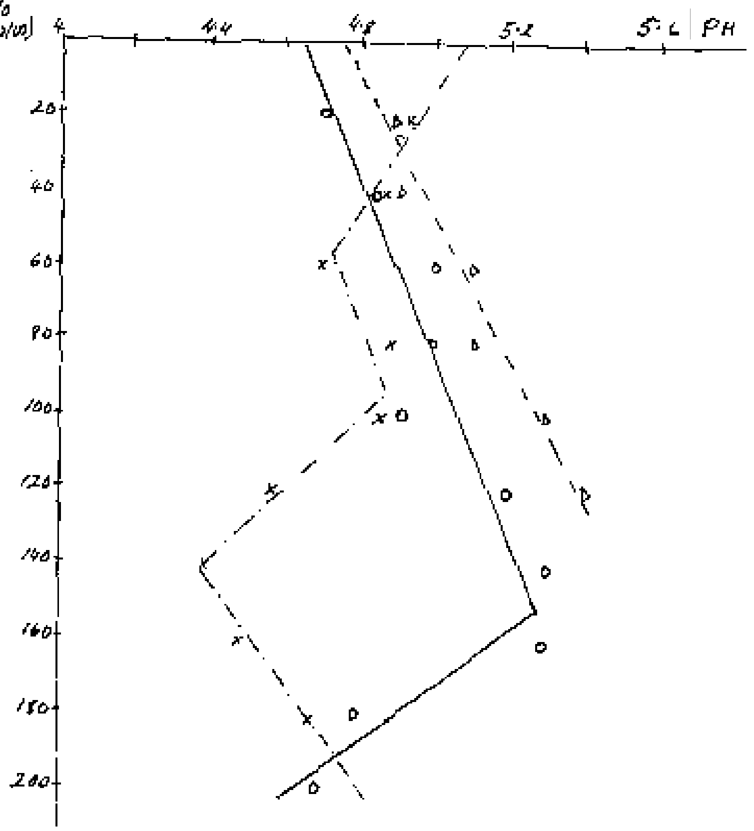


Fig. 3.10 Variation of CEC-NH4O Acetate at pH-7 with depth in profiles RP1, RP2 and RP3

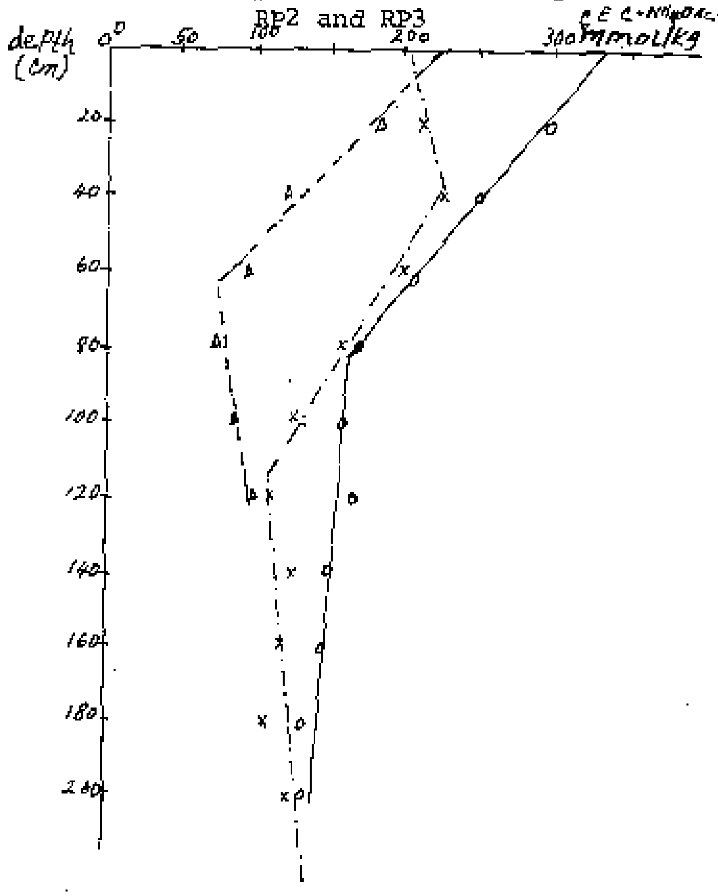
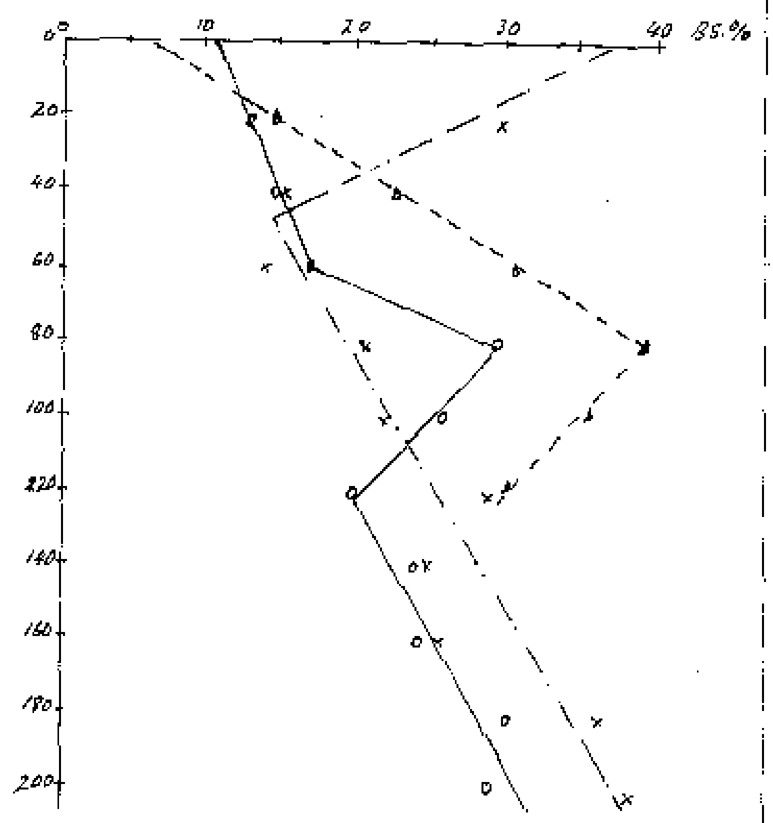


Fig. 3.11 Variation of base saturation with depth in profiles RP1, RP2 and RP3

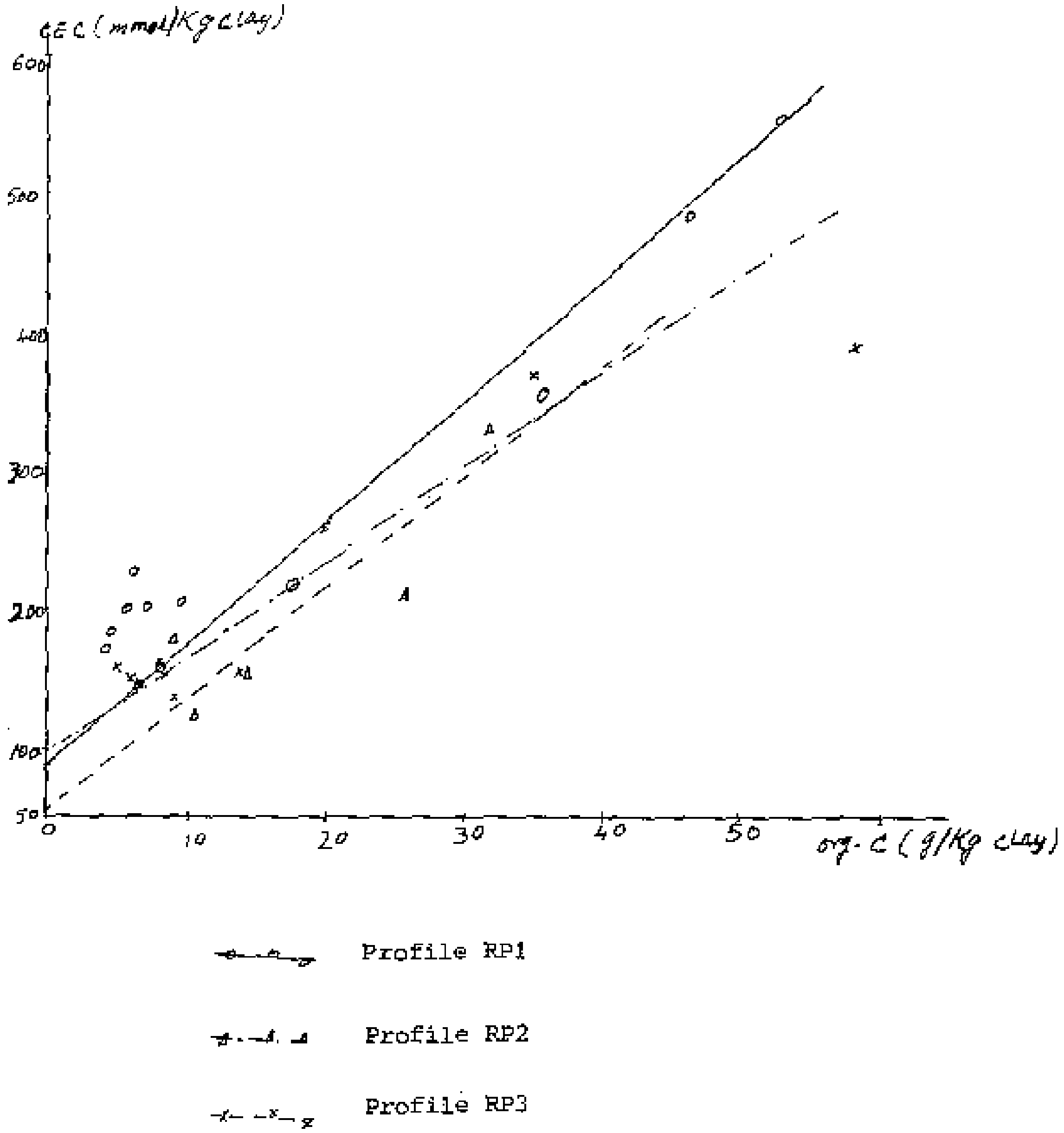


Profile RP1

Profile RP2

Profile RP3

Fig. 3.12 Linear regressions of CEC-clay and organic carbon (g/1000 g clay) in profiles RP1, RP2 and RP3



3.1.4 Mineralogical characteristics

X-ray diffraction. The results of the x-ray diffraction are the same for all the samples of all three profiles. The x-ray diffractographs of one of the samples are shown in Appendix 3.1, 3.2 and 3.3.
A 0.72 µm peak indicates predominance of kaolinite. All samples have more than 80% kaolinite which is rather poorly crystallized and tends to halloysite. Deferraction (removal of iron) increased the intensity of this peak, indicating that iron and not amorphous material lowered the intensity of the 0.72 µm. peak.
A 1.00 µm. peak indicates presence of a small amount of mica in all the samples. Traces of a vermiculite like mineral is indicated by a low intensity 1.40 µm. peak which disappears on heating to 575°C. Quartz and poorly crystallized goethite are also present in small amounts.

Thermal analysis. The differential thermal analysis (DTA) and thermogravimetric analysis (TGA) were very much the same for all the samples. A small DTA peak at about 300°C indicates presence of some amorphous material, probably allophane, in the soil. (See Appendix 3.4). The strong peak at about 500°C is an endothermic peak of kaolinite-OHS and indicates the predominance of kaolinite.

Elemental analysis. The x-ray fluorescence spectrophotometry analysis of all the samples are expected to be the same since the x-ray diffractometry and thermo analysis are so much the same. The results show a content of MgO oxide compared to CaO and a high Fe_2O_3 content. The derived molar ratios are: $SiO_2/\frac{1}{2}Al_2O_3$ = 1.15, Al_2O_3/Fe_2O_3 = 2.94 and $SiO_2/\frac{1}{2}Fe_2O_3 + \frac{1}{2}Al_2O_3$ = 0.86. The $SiO_2/\frac{1}{2}Al_2O_3$ ratio is nearly 1 indicating a predominance of 1.1 clay mineral in the clay fraction. The Al_2O_3/Fe_2O_3 indicates a high iron content in the soils. See table 3.1 below.

Table 3.1 Elemental analysis (mass % of oxides) of the clay fraction of a mixed sample of profiles RP1, RP2 and RP3.

Oxide	Percentage
Fe_2O_3	17.74
MgO	0.31
SiO_2	45.20
Al_2O_3	33.26
CaO	0.05
TiO_2	1.68
MnO	0.20
P_2O_5	0.23
K_2O	0.60
BaO	0.014
H_2O	0.00
Sum	99.50

Electron microscopy. Plates 6 and 7 show photographs from the transmission electron microscopy of samples of RP1 and RP3 respectively. The photographs show the minerals of tabular form (1), which are the halloysite and the rounded spherical forms (2) which are poorly crystallized kaolinite. Most of the kaolinite, (the gley, rounded ones) are very poorly crystallized and hence confirm the rather broad 0.72 nm. peak seen in the x-ray diffractographs.

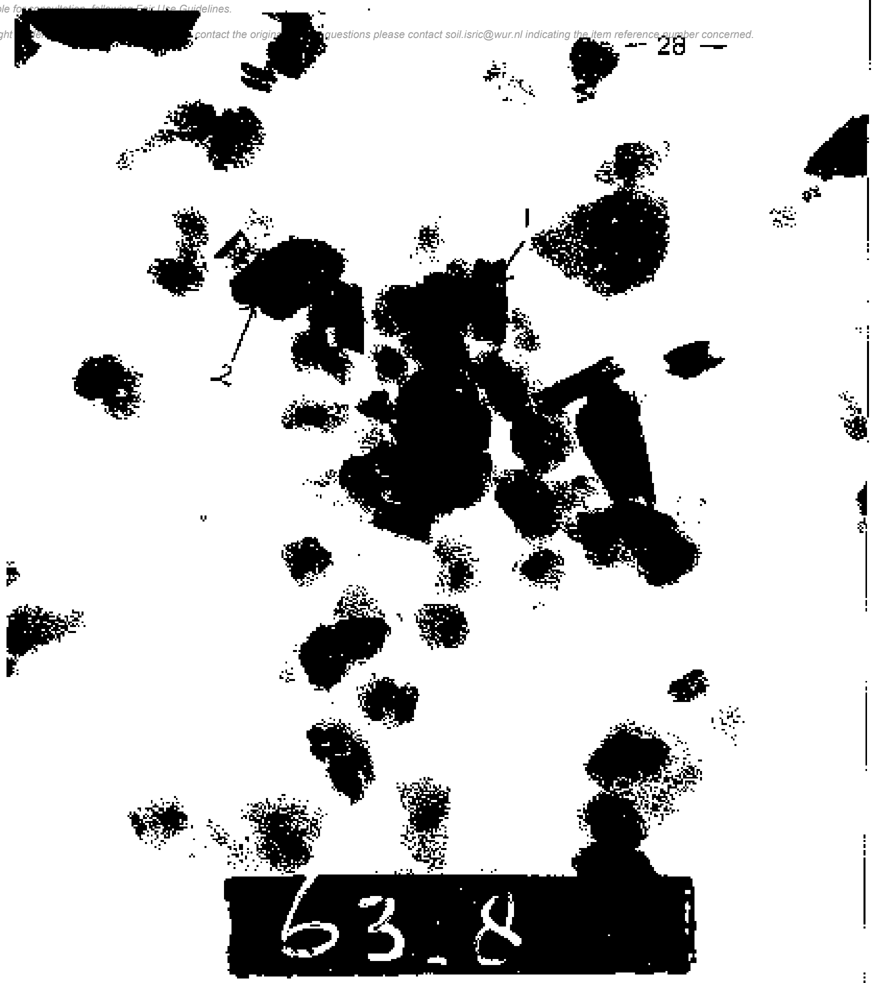


Plate 6. Electro microscopic photograph of the clay fraction of the subsoil of profile RP1

Electro microscopic photograph of the clay fracti

3.1.5 Comparison of physical and chemical characteristics within the catena

Table 3.2 shows some chemical and physical properties of the catena in the topsoil (0-40 cm.) and subsoil (80-160 cm.) depths. The characteristics of profile RP2 are different because it is on a very steeply sloping part and may be truncated. Profile RP1 and RP3 may be compared. The chemical characteristics of the topsoil of the two profiles do not differ very much but indicate that profile RP1 is slightly more weathered and leached than RP3 (lower BS, Σ cat, % clay, and exchangeable Ca in RP1 than RP3). The Si/C ratio is higher in RP1 than RP3 topsoil.
The reverse is indicated by the properties of the subsoil. Profile RP3 has lower pH, low Σ cat, lower exchangeable Ca and lower Si/C ratio. Hence profile RP3 shows more 'acric' properties than profile RP1. It is also showing more 'oxic' properties than RP1. This can be explained by its position in the catena. Being in a position where it is receiving some material by colluviation and where there is a high rate of lateral and vertical movement of material within the profile, it receives already reworked material which continues to be weathered rapidly. Profile RP1 is at such a position that it does not receive much material and movement of material within the profile is only vertically downwards. Hence weathering is slower in profile RP3.
The high CEC in profile RP3 may be due to high organic matter content. The properties in profile RP2 show clearly that it is less weathered than the other two.

Table 3.2 Some topsoil and subsoil characteristics of profiles of the catena.

Depth	Charact.	Profile code		
0-40 (topsoil)		RP1	RP2*	RP3
	$pH-H_2O$	4.8	4.9	4.9
	CEC[1]	278	157	224
	BS[2]	16	18	23
	org.C[3]	2.6	1.7	2.6
	Σ Cat[4]	43	28	51
	½ Ca[5]	38	22	42
	% clay	53	58	60
	Si/C	0.6	0.4	0.4
80-160 (subsoil)				
	$pH-H_2O$	5.2	5.3	4.6
	CEC[1]	159	88	122
	BS[2]	24	36	26
	org.C[3]	0.5	0.5	0.7
	Σ Cat[4]	38	31	31
	½ Ca[5]	33	27	27
	% clay	75	54	80
	Si/C	0.2	0.3	0.1

The values for every 20 cm. are summed and the average is recorded.

* 60-120 cm. depth for subsoil.
1 CEC-NH_4OAc at pH 7 in mmol/kg. soil.
2 Base Saturation percentage by sum of cations.
3 organic carbon by weight percentage.
4 Sum of exchangeable cations ($½Ca^{2+}$, $½Mg^{2+}$, K^+, Na^+) in mmols/kg. soil.
5 exchangeable calcium in mmols/kg. soil.

3.2 Characteristics of reference profiles

3.2.1 Profile descriptions

Profile code: EAK26; Author J.H.M. Scholten.
Site characteristics:
Location: Kisii - Magombo, 130/2-EAK 26, E/714.9, N/9926.6, altitude 1880 m. ASL.
Soil classification*: FAO-Unesco (1974): Humic Nitosol.
USDA Soil Taxonomy (1975): Palehumult.
Agroclimatic zone: IIa.
Climate: Isothermic, about 200 mm./year rainfall.
Local petrography/parent material: Andesite.
Physiography (general): Upper level uplands.
Surrounding landform: Saddle between hilltops.
Macro-relief: Rolling to hilly, 5-30% slopes, length 500 m.
Vegetation/landuse: Pastures.
Slope gradient: 5%.
Root distribution: Fine and very fine throughout the profile.
Drainage class: Well drained.
Moisture conditions: Moist throughout the profile.
Groundwater depth: nd.

Soil profile:

A11 0-50 cm. Dark reddish brown (5 YR 3/2 moist); very fine clay; moderate, fine, subangular blocky; very friable moist, slightly sticky, slightly plastic when wet; many fine, and very fine, common medium and few coarse pores; clear and smooth boundary to

A12 50-79 cm. Dark reddish brown (5 YR 3/3 moist); very fine clay; moderate, fine, subangular blocky to angular blocky; friable, slightly sticky, slightly plastic; many, very fine and fine, common, medium pores; gradual and smooth boundary to

B21t 79-270 cm. Dark reddish brown (5 YR 3.5/4 moist); very fine clay; moderate fine angular to subangular blocky; friable, slightly sticky, slightly plastic; shiny, moderately thick, broken clay cutans; many very fine and fine, few medium pores; few small soft manganese concretions from 205-210 cm.

Profile code WAN2; Author S. Slager and H. van Reuler.
Site characteristics:
Location: Kisii - Irigongo, 130/1-WAN2, 34°41'53"E, 0°37'58"S, altitude 1634 m. ASL.
Soil classification: FAO-Unesco (1974): Humic Acrisol.
USDA Soil Taxonomy (1975): Orthoxic Tropohumult.
Physiography: Upper part of a footslope, just beneath the steep hisslope to the top.
Surrounding landform: Rolling to hilly.

* field classification.

Meso-relief: Flat scattered granite boulders.
Micro-relief: Termite mounds up to 30 cm. high.
Slope: 12%.
Parent material: Wanjare granite.
Vegetation/landuse: Dense bushland with trees. 15% trees, 60% shrubs, 15% herbs, 40% grasses (5% bare soil)/grazing land.
Surface stoniness: Nil.
Drainage class: Somewhat excessively drained.
Soil fauna: Termites, ants, some beetles and worms.

Soil profile

A1 0-22 cm. Dark brown to brown (7.5 YR 4/2 dry), dark brown (7.5 YR 3/2 moist); gravelly (angular) loamy sand; strong granular; abundant, very fine, biopores; soft, very friable, slightly sticky and slightly plastic; gradual and smooth boundary to

B2t 22-40 cm. Yellowish red ((5 YR 5/6, dry), yellowish red to red (5 YR 4/6 - 2.5 YR 4/6 moist); gravelly (angular) loamy sand; no macrostructure; abundant, very fine biopores (many aggrotubules filled with A1 material); soft, very friable, non sticky and non plastic; abrupt and broken boundary to

R 40-45/71 cm. Rotten rock with hard nucleus of unweathered granite, abrupt and broken boundary to

11B21t 45/71-85 cm. Yellowish red (5 YR 4/6 dry), dark red (2.5 YR 3/6 moist); very gravelly sandy loam; few rotten rock pieces, no macro structures, many, very fine biopores; hard friable, non sticky and non plastic; gradual and smooth boundary to

11B22t 85-135 cm. Yellowish red (5 YR 4/6 dry), yellowish red to dark red (5 YR 3/6 to 2.5 YR 3/6 moist); very gravelly (angular) sandy loam with few completely rotten rock pieces up to 15 cm. diameter; no macrostructure, many, very fine biopores; hard, friable; non sticky and non plastic; gradual and smooth boundary to

11C 135-165 cm. Yellowish red (5 YR 5/6 dry), yellowish red to red (5 YR 4/6 to 2.5 YR 4/6 moist); very gravelly (angular) sandy loam with few completely rotten rock pieces up to 15 cm. diameter; no macrostructure; common, very fine biopores; hardened material with iron/manganese concretions after 155 cm.; 20% distinct brown mottles (10 mm. diameter); 60% distinct red mottles (10 mm. diameter); 20% prominent black mottles (15 mm. diameter); platy structures, few aggrotubules filled with A1 material; hardly breakable; abrupt to and smooth boundary to

11R +165 cm. Weathered granite, partly fresh.

Profile code: EAK12; Author anonymous.
Site characteristics:
Location: Kwale district, 200/4-325; E/28.3, N/24.1, altitude 233 m. ASL.
Soil classification: Ferral* Chromic* Acrisol.
Climate: nd.
Agroclimatic zone: III.
Parent material: Coarse grained sandstone.
Physiography (general):Coastal uplands.
Relief (general): Undulating.
Vegetation/landuse: Open grassland/cultivation.
Erosion: Nil.
Surface stoniness: Nil.
Slope gradient: 2%.
Drainage calass: Well drained.

Soil profile:

Ap 0-15 cm. Dark reddish brown (5 YR 5/4 dry, 5 YR 2/3 moist); sandy loam; porous massive, slightly hard when dry, friable moist, slightly sticky, non plastic when wet; many very fine, common fine, many medium roots; high biological activity; clear and smooth boundary to

B1t 15-45 cm. Dark reddish brown (2.5 YR 3/4 dry and moist); sandy clay loam; weak, coarse, subangular blocky; few thin cutans; common, fine and medium pores, common, medium, few fine roots; high biological activity; clear and smooth boundary to

B2t 45-260 cm. Red (2.5 YR 4/8 dry and moist); sandy clay; weak, coarse, angular blocky to subangular blocky; very hard when dry, friable moist; sticky and plastic when wet; common, thin clay cutans; common, fine and medium pores; common, medium, few fine roots; high biologiveal acrivity.

Profile code: EAK16; Author: anonymous.
Site characteristics:
Location: KARI Laboratories, Muguga, altitude 2170 m. ASL.
Soil classification: FAO-Unesco (1974): Humic Nitosol**
USDA Soil Taxonomy (1975): Oxic Paleustalf.
Parent material: Limuru trachyte.
Climate (soil): Ustic, isothermic.
Agroclimatic zone: III.
Physiography (general): Volcanic uplands.
Vegetation: Trees 40%, shrubs 20%, herbs 40%.

Soil profile:

A1 0-10 cm. Dark reddish brown (2.5 YR 2.5/4 moist); clay loam; very fine and fine crumps; very friable, slightly sticky, slightly plastic; many fine and medium roots; clear and smooth boundary to

* Field classification according to proposed Kenyan concept.
** Field classification before consideration of analytical data.

AB 10-35 cm. Dark reddish brown (2.5 YR 3/4 moist); clay; moderate, fine, medium and coarse subangular blocky; few, thin cutans; very friable, sticky, plastic; many fine, many medium roots, some charcoal fragments; gradual and wavy boundary to

B21t 35-100 cm. Dusky red (10 R 3/3 moist); clay; moderate fine, medium and coarse angular blocky; common, thick clay cutans; very friable, sticky, plastic; pores as in AB, many fine, common medium roots; gradual and smooth boundary to

B22t 100-150 cm. Dusky red (10 R 3/6); clay; strong, medium and coarse angular blocky; common, thick cutans; very friable, sticky, plastic; very few soft sesquioxides; many fine, common medium pores; common fine and medium roots.

3.2.2 Physical characteristics

Bulk density. The bulk densities of all the profiles are relatively high (see table A2.1). Profile EAK26 has the lowest values. The bulk density decreases slightly with depth. Profile WAN2 has the highest values (1.44-1.51 g./cm.^{3})

Moisture retention. The moisture contents at various pF's are shown in table A2.1. The coarse textured profiles (EAK12 and WAN2) have relatively low values. The moisture retention relates well with clay content, (especially moisture retention at pF 4.2) within and among the profiles.

Particle size analysis. The variation of sand, silt and clay fractions with depth are shown in figures 3.13, 3.14, 3.16 and 3.18 for profiles WAN2, EAK26 and EAK16 respectively. A clay bulge is shown to start at about 70 cm. depth for profiles EAK16 and EAK26 and at about 50 cm. for profiles EAK12 and WAN2. The latter are coarse textured profiles with over 50% sand content. A maximum clay content is reached at 70 cm. depth in profile WAN2, 90 cm. in profile EAK12 and below 150 cm. in profiles EAK26 and EAK16. The minimum clay contents are at 40 cm. depth in profile EAK26 and EAK16, 30 cm. in profile EAK12 and almost at the surface in profile WAN2.

Silt/clay ratio. The variation of silt/clay ratios with depth are shown in figures 3.17 and 3.15. The topsoil has generally higher values than the subsoil in all the profiles. A steady decrease in si/c ratio with depth is evident. Profile EAK26 has rather high values while profile EAK16 has low values.

Fig. 3.13 Variation of sand, silt and clay with depth in profile EAK26

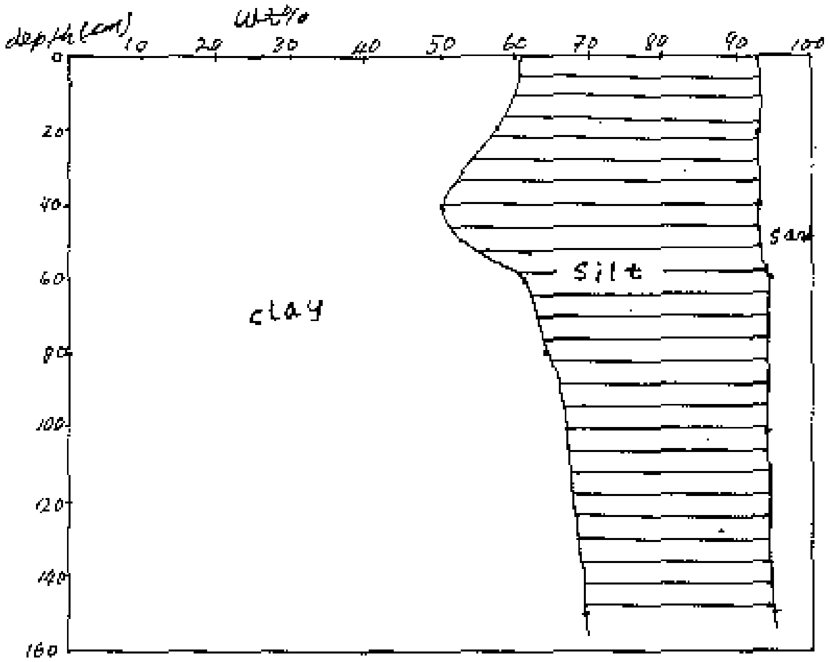


Fig. 3.15
Variation of silt/clay ratio with depth in profiles EAK16 and EAK26

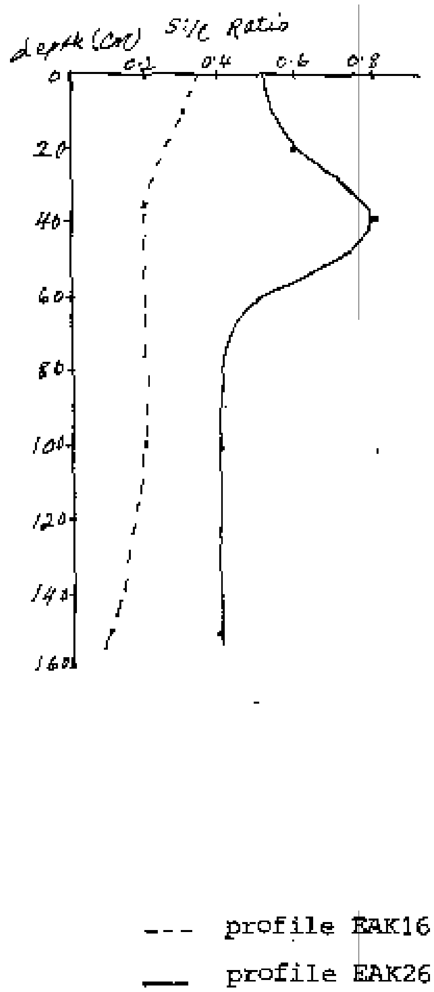


Fig. 3.14 Variation of sand, silt and clay content with depth in profile EAK16

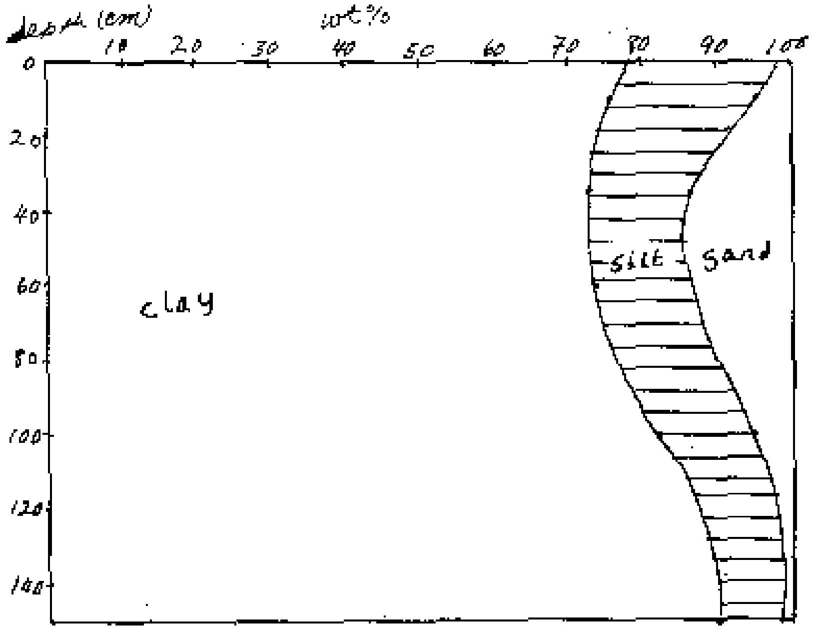


Fig. 3.16 Variation of sand, silt and clay content with depth in profile WAN2

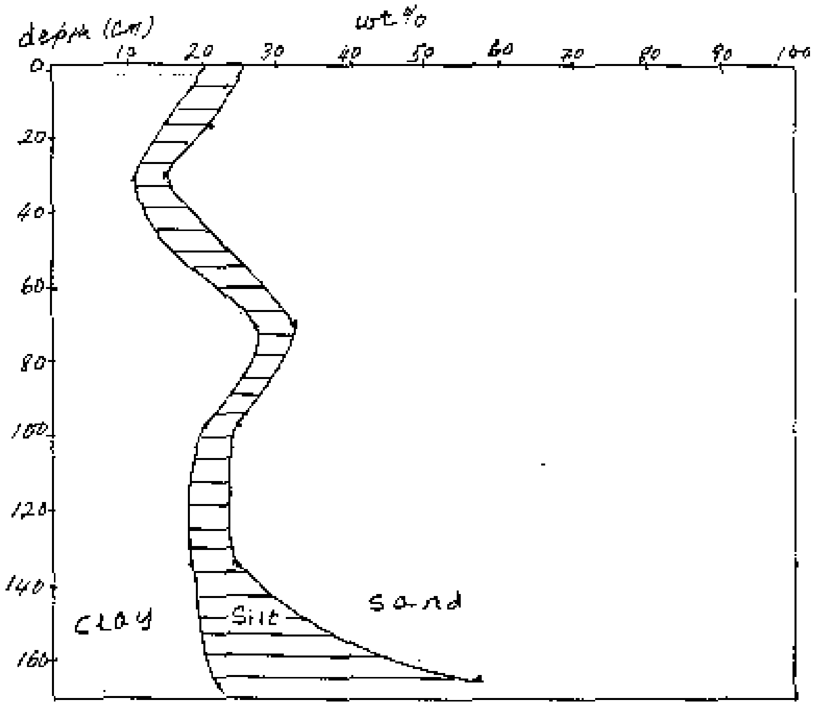


Fig. 3.17 Variation of silt/clay ratio in profile WAN2 and EAK12

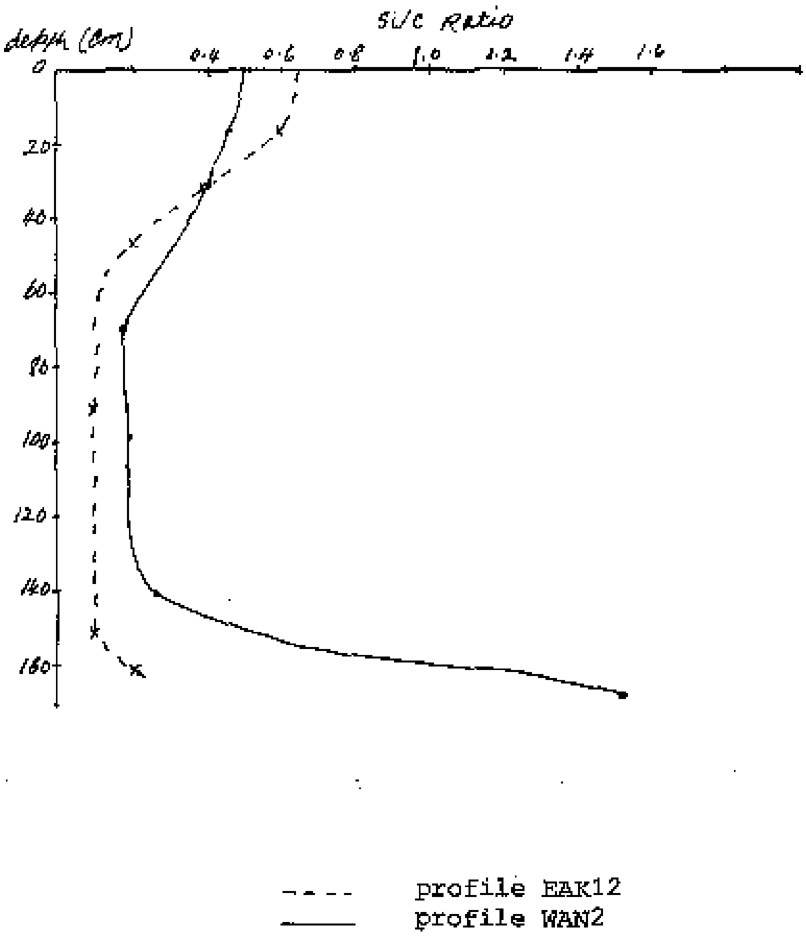
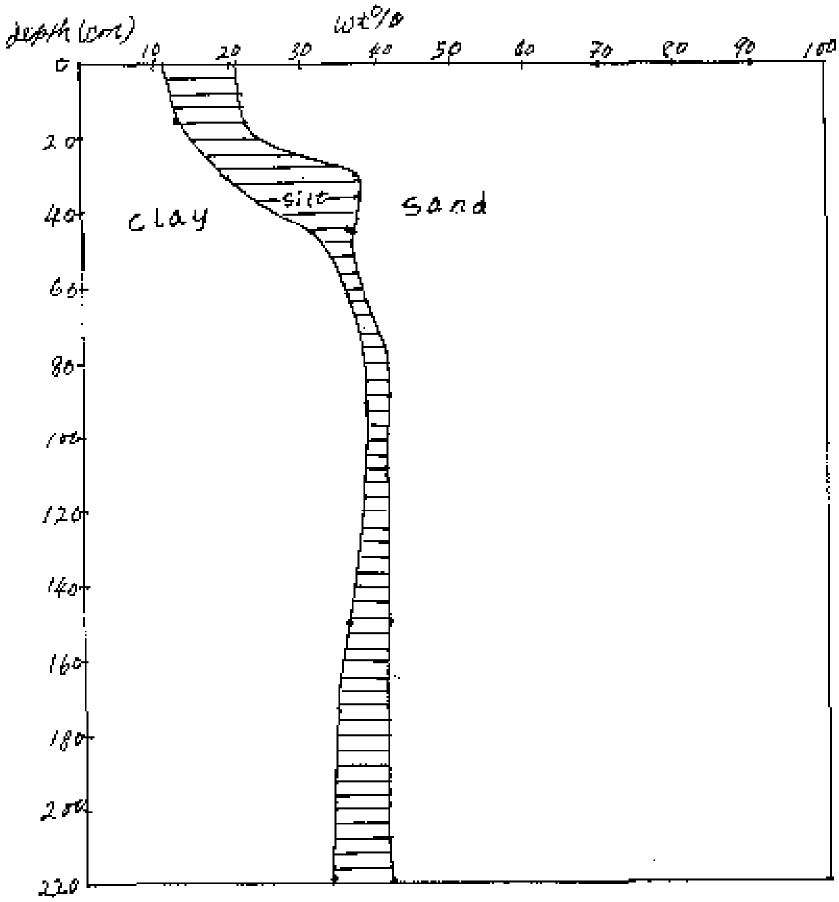


Fig. 3.18 Variation of sand, silt and clay content with depth in profile EAK12



3.2.3 Chemical characteristics

PH. The soil reaction is acidic in most profiles except profile EAK16. The values of pH-H_2O and pH-KCl are shown in table A2.2. The variations of pH-H_2O with depth are shown in figures 3.19 and 3.23. The pH decreases with depth in all the profiles except in profile WAN2. This profile has lowest pH values. The acidity correlates with CEC and base saturation.

Cation exchange capacity. The CEC-NH_4O acet. values at pH 7 are rather low in all the profiles. The lowest values are in profile EAK12 and WAN2 (< 100 mmol/kg.) while relatively high values are shown in profiles EAK16 and EAK26 (> 120 mmol/kg.). (See table A2.2). The variations of the CEC with depth are shown in figures 3.21 and 3.24. A general decrease with depth up to 40 cm. is shown in profiles EAK16, EAK26 and WAN2. The CEC correlates with the organic matter (organic carbon) content. The very high values in profile EAK16 and EAK26 in the topsoil are due to the high organic matter content.
The CEC-clay (corrected and uncorrected for organic matter) have been calculated using linear regressions and are shown in table A2.4 and A2.5. The CEC-organic matter has also been calculated using the slopes of the regression lines. Profile WAN2 and EAK26 have higher values of CEC-clay (corrected and uncorrected for organic matter). Profile EAK16 and EAK12 have rather low values. The values in profile WAN2 and EAK26 (230 and 198 mmol/kg. respectively) are rather high for a soil with clay mineralogy of kaolinite predominantly. Hence the soils could have some amorphous material or halloysitic kaolinite. The values shown for the other profiles (< 150 mmol/kg clay) indicate a predominance of kaolinite.
The CEC-organic matter are rather low in profiles EAK26 and WAN2. This correlates with the high acidity levels in these profiles since the CEC-organic matter depends strongly on the pH.

Organic matter content. The organic carbon contents are shown in table A2.2. The variations of organic carbon with depth are shown in figures 3.20 and 3.26. A steady decrease with depth can be observed in profiles EAK26 and EAK12. A sharp decrease in the upper 40 cm. is shown in profile EAK16. This implies a high rate of decomposition or a high rate of homogenisation in profiles EAK26 and EAK12 and a low rate of decomposition or a low rate of homogenisation in profile EAK16.

Base saturation. The base saturation of profiles EAK26 and EAK16 is rather high while that of profile WAN2 is low. The very high value (> 100%) at 150-220 cm. depth of profile EAK12 implies accumulation of bases at these depths. (See table A2.2). The low base saturation in the topsoils of profiles EAK12 and WAN2 indicates a high degree of leaching in the profiles. The variations with depth are shown in figures 3.22 and 3.26. A sharp decrease is observed at about 30 cm. in profile EAK26 and WAN2 and at about 60 cm. in profile EAK26. An increase with depth occurs up to about 40 cm. in profile EAK12. The values decrease to a minimum at about 60 cm in profile EAK16, 80 cm. in profile EAK26, 40 cm. in profile WAN2 and 110 cm. in profile EAK12.
The values of exchangeable bases are shown in table A2.2. Calcium is the dominant exchangeable cation in all three profiles. Magnesium is rather high in profile EAK26 and potassium is rather high in profile EAK16.

Profile EAK16 has the highest values of all exchangeable bases of the four profiles, while profiles EAK12 and WAN2 have rather low amounts of exchangeable bases. This indicates stronger leaching in these two latter profiles. However it may also be due to their sandy texture.

3.2.4 Mineralogical characteristics

Element analysis. Elemental composition (expressed as percentage of major oxides) of fine earth fraction and of clay fraction are shown in table A2.3 for profile WAN2 (fine earth fraction) and EAK12 and EAK16 (clay fraction). The derived molar ratios calculated from the elemental composition are also shown.
The SiO_2 content is rather high in profile WAN2. No pattern can be observed with depth due to homogenisation and pedoturbation by biological activity. Hence $SiO_2/\frac{1}{2}Al_2O_3$, Al_2O_3/Fe_2O_3 and $SiO_2/\frac{1}{2}Al_2O_3$ and $SiO_2/\frac{1}{2}Al_2O_3 + \frac{1}{2}Fe_2O_3$ do not provide useful information in these profiles. However it can be observed that SiO_2 is highest in all profiles but higher in profiles EAK12 and EAK16. Relatively high values of Al_2O_3 are observed in these profiles and indicate a predominance of Al as compared to Fe.
The derived molar ratios of the clay fraction of $Si_2O_3/\frac{1}{2}Al_2O_3$ are about one in all profiles, indicating the predominance of 1.1 clay minerals. The Al_2O_3/Fe_2O_3 ratios are low in profile EAK16 due to high Fe_2O_3 content.

Clay mineralogy. The clay mineralogy data for the profiles are not available systematically. Breimer and Van Reuler (1978) suggest that in profile WAN2 there is a high percentage of 2.1 clay minerals and low 1.1 kaolinitic minerals in the upper 55 cm. Kaolinite predominates in the 55-135 cm depth and a very high content in the 160-165 cm. depth. This is in contradiction to what is observed micromorphologically and by the chemical data.
The x-ray report of profile EAK12 indicates predominantly a well crystallized kaolinite and traces of iron. A clear absence of 2.1 clay minerals is reported for this profile.
The mineralogical analysis of the clay fraction in profile EAK16 is shown in table 3.3 below.

Table 3.3 Ranking of mineralogical composition of the clay fraction in profile EAK16.

Depth	Kaol.	Mi/ill.	Feld.	Goeth
0- 10	++	tr +	x	x
10- 35	++	tr +	x	x
35-100	++	tr tr	-	x
100-150	+++	tr tr	-	x

+++ = very high   tr = traces   Kaol. = kaolinite
++ = high   x = present   Mi/ill. = mica/illite
+ = low   - = absent   Feld. = feldspars
Goeth = goethite

A predominance of kaolinite and traces of micas and illite is observed throughout the profile. Goethite and feldspars are present in small amounts but feldspars are lacking in the subsoil.
The x-ray report of profile EAK26 indicates a predominance of kaolinite and small amounts of quartz and feldspars. No micas or illite is reported.

Fig. 3.19 Variation of $pH\text{-}H_2O$ with depth in profiles EAK26 and EAK16

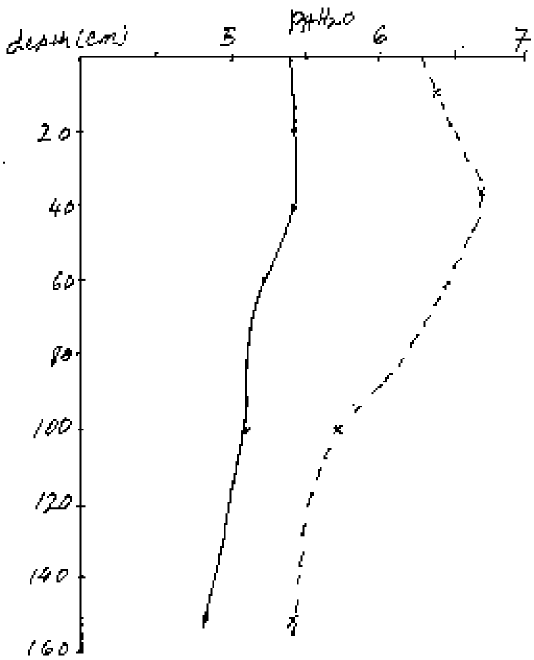
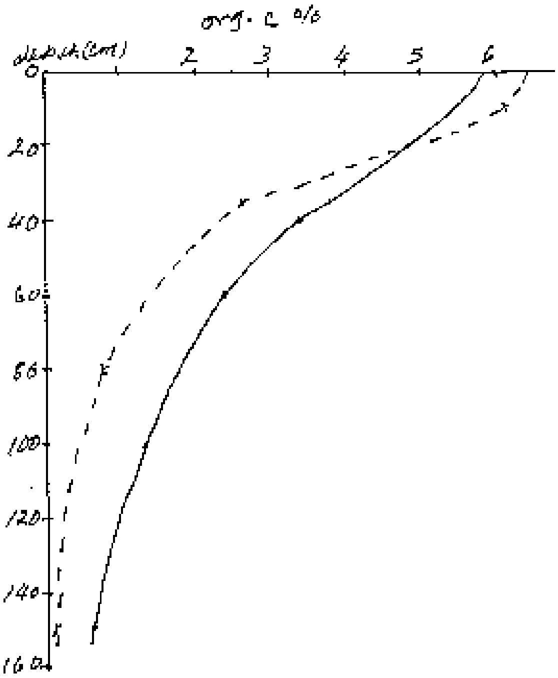


Fig. 3.20 Variation of organic carbon content with depth in profiles EAK26 and EAK16



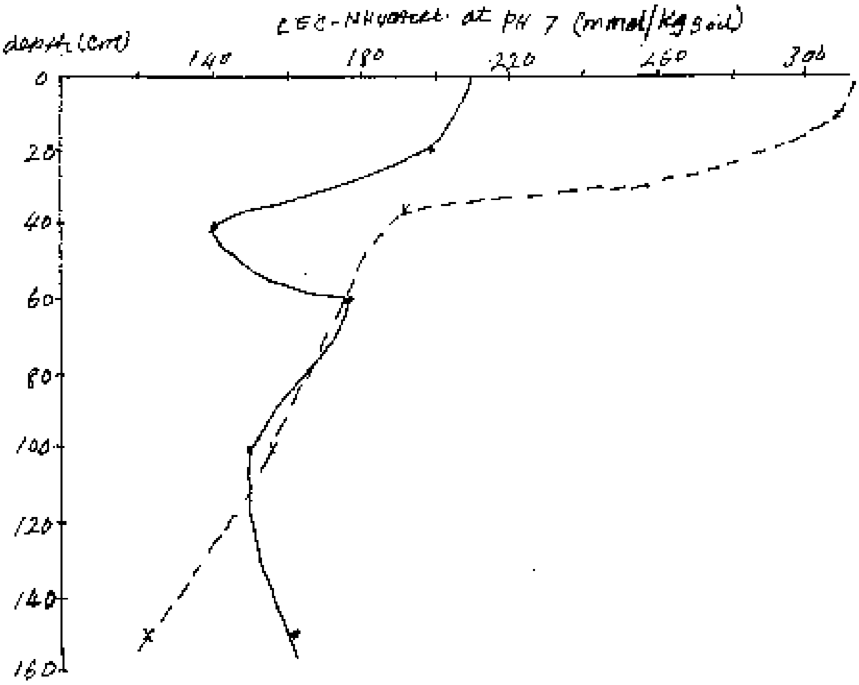


Fig. 3.21 Variation of CEC-NH4OAcetate at pH-7 with depth in profiles EAK26 and EAK16

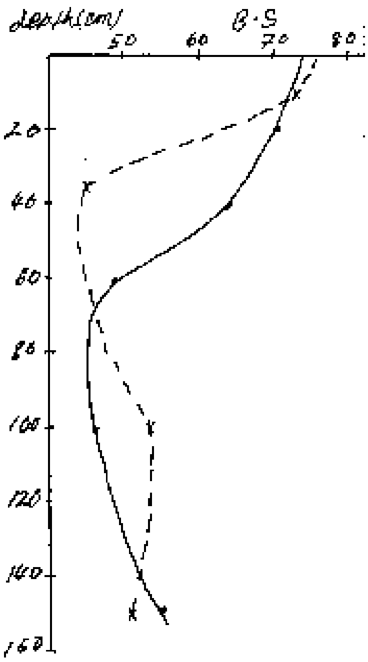


Fig. 3.22 Variation of base saturation with depth in profiles EAK26 and EAK16

- - - - profile EAK16

——— profile EAK26

Fig. 3.23 Variation of pH_2O with depth in profiles EAK12 and WAN2

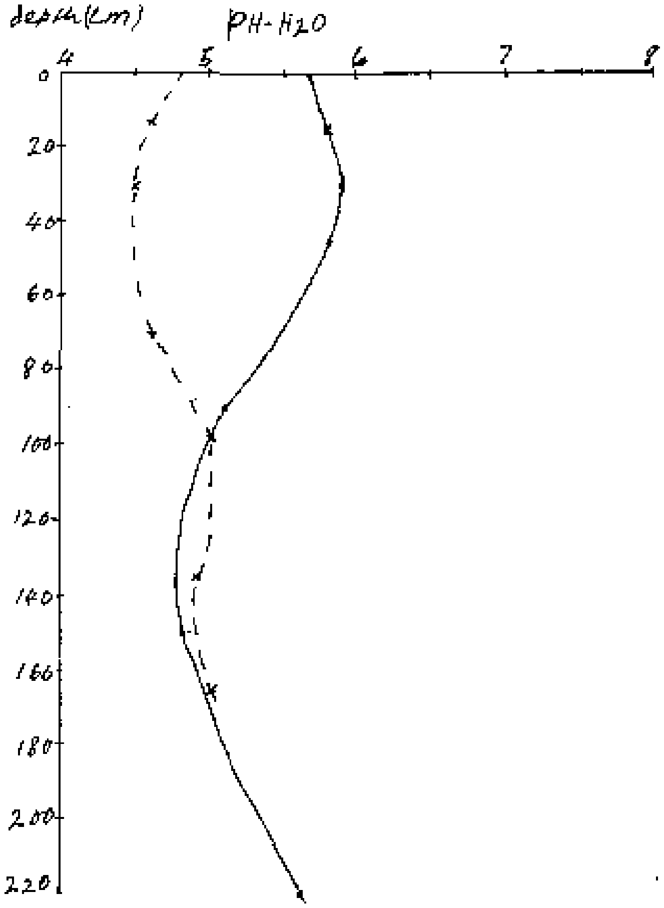


Fig. 3.24 Variation of CEC-NH_4 - Acetate at pH-7 with dept in profiles EAK12 and WAN

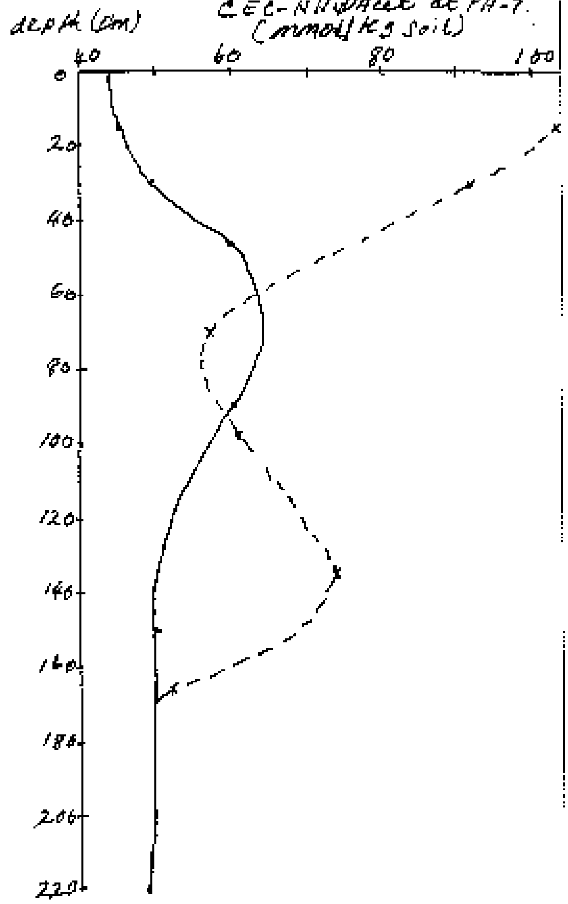


Fig. 3.25 Variation of base saturation with depth in profiles EAK12 and WAN2

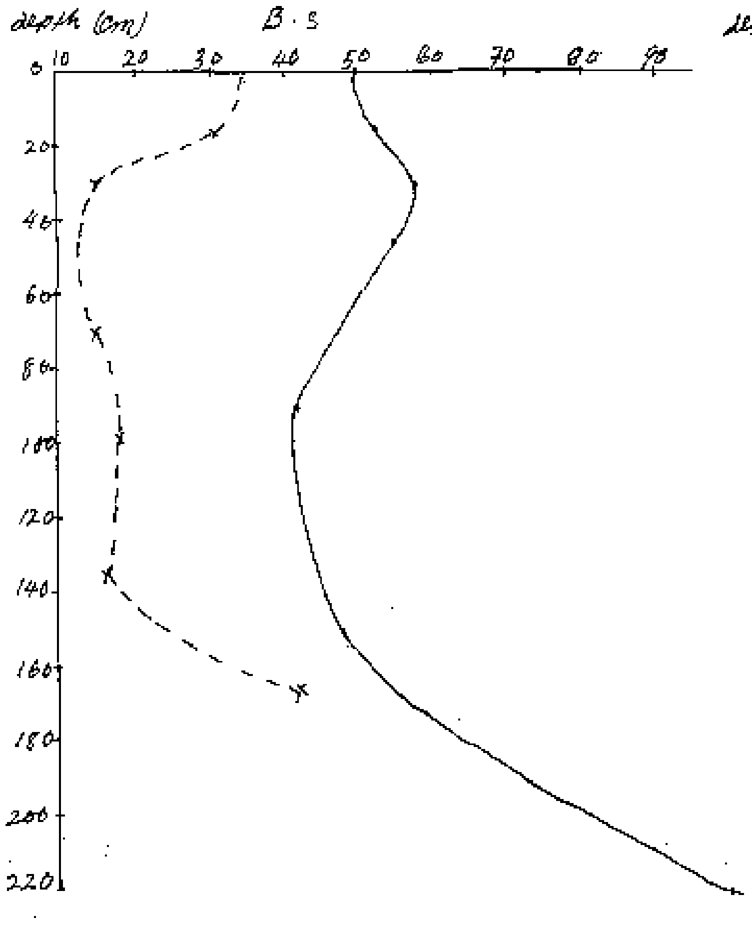
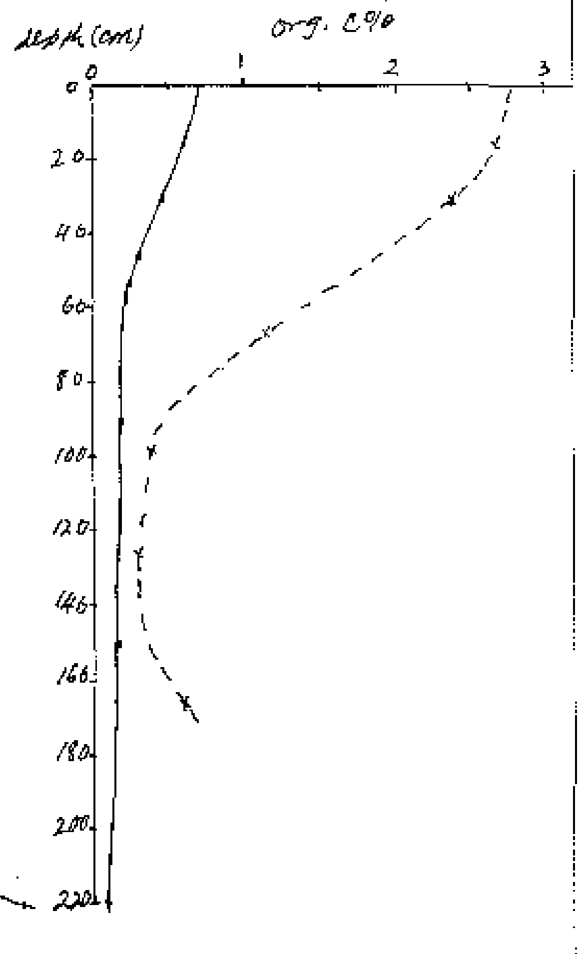


Fig. 3.26 Variation of organic carbon with depth in profiles EAK12 and WAN2



- - - WAN2
—— EAK12

4. MICROMORPHOLOGICAL CHARACTERISTICS

4.1 Profile RP1

Macroscopic observations
The profile is dark brown to reddish brown in colour. The upper 50 cm. is dark brown to red. It is porous throughout but the porosity decreases considerably with depth. Planes (cracks) and channels with diameters up to 2 mm. occur throughout the profile increasing with depth. The structure is granular to subangular blocky in the upper 60 cm. and becomes angular blocky to subangular blocky in the subsoil. A few fragments of charcoal occur in the upper 60 cm. and ferric nodules occur throughout the profile.

Microscopic observations (Summary, figs. 4.1 and 4.2).
Groundmass (Summary, fig. 4.1).

Skeleton grains. Very few rounded, coarse (> 500 µm.) skeleton grains occur randomly distributed throughout the profile. Few to common, subrounded and some euhedral fine to medium (< 500 µm.) skeleton grains occur randomly distributed throughout the profile. Most of them are quartz and cherts but some are sanidine feldspars and volcanic glass. The cracks are filled with red plasma material. Some are weathering to yellowish plasmic material.

Voids. Most of the voids are biogenic; compound packing voids, vughs and channels are predominant and abundant in the topsoil and decreasing with depth. Craze, skew and joint planes with diameters up to 1 mm. occur throughout the profile and increase in the lower 100 cm.

Plasma - plasmic fabric. The plasma is predominantly undulic throughout the profile. Sepic parts occur starting from 60 cm.

Special features (Summary, fig. 4.2)
Reorientation. Few to common, faint to distinct, 10-50 µm. in diameter, glaesepic, masepic, vosepic, skelsepic and insepic reorientations occur randomly distributed starting from about 40 cm. Most of them have diffuse boundaries. They increase and become more distinct with depth.

Ferri-argillans. Distinct, 10-60 µm. in diameter, normal, channel and skew plane ferri-argillans occur starting from about 60cm. depth. Most of them are clustered but some are randomly distributed. They have sharp boundaries and some are continuous along ped faces. The maximum amount is reached at 100-120 cm. depth (see table 4.1). Most of the ferri-argillans are translocated and show quite strong birefringence.

Papules. Distinct, 10-40 µm. in diameter, papules occur randomly distributed starting from about 60 cm. depth. They have sharp boundaries and the larger ones have different shades of brown.

Nodules. Distinct, 30-150 µm. in diameter, rounded and spherical, ferric nodules occur throughout the profile. Most of them have sharp boundaries and are separated by small cracks from the plasma but the smaller ones have rather diffuse boundaries. Some are associated with weathering rock fragments.

Pedotubules. Faint, 0.5-3 mm. in diameter, matric ortho aggrotubules occur throughout the profile. They are abundant to many in the topsoil and decrease considerably with depth. Some have slightly more organic matter than the matrix.

Fecal pellets. Faint, 30-100 µm. in diameter, matric fecal pellets occur throughout the profile decreasing with depth. Most of them are welded and are randomly distributed in the profile, but some are clustered in the aggrotubules. Smnall ones, 10-20 µm. in diameter from mites occur clustered in the partly decomposed plant remains.

Inherited features. A few, 300-800 µm. in diameter rock fragments and volcanic glass occur throughout the profile. Some are partly weathered to red material. A few plant remains occur in the upper 60 cm. decreasing with depth.

GROUNDMASS

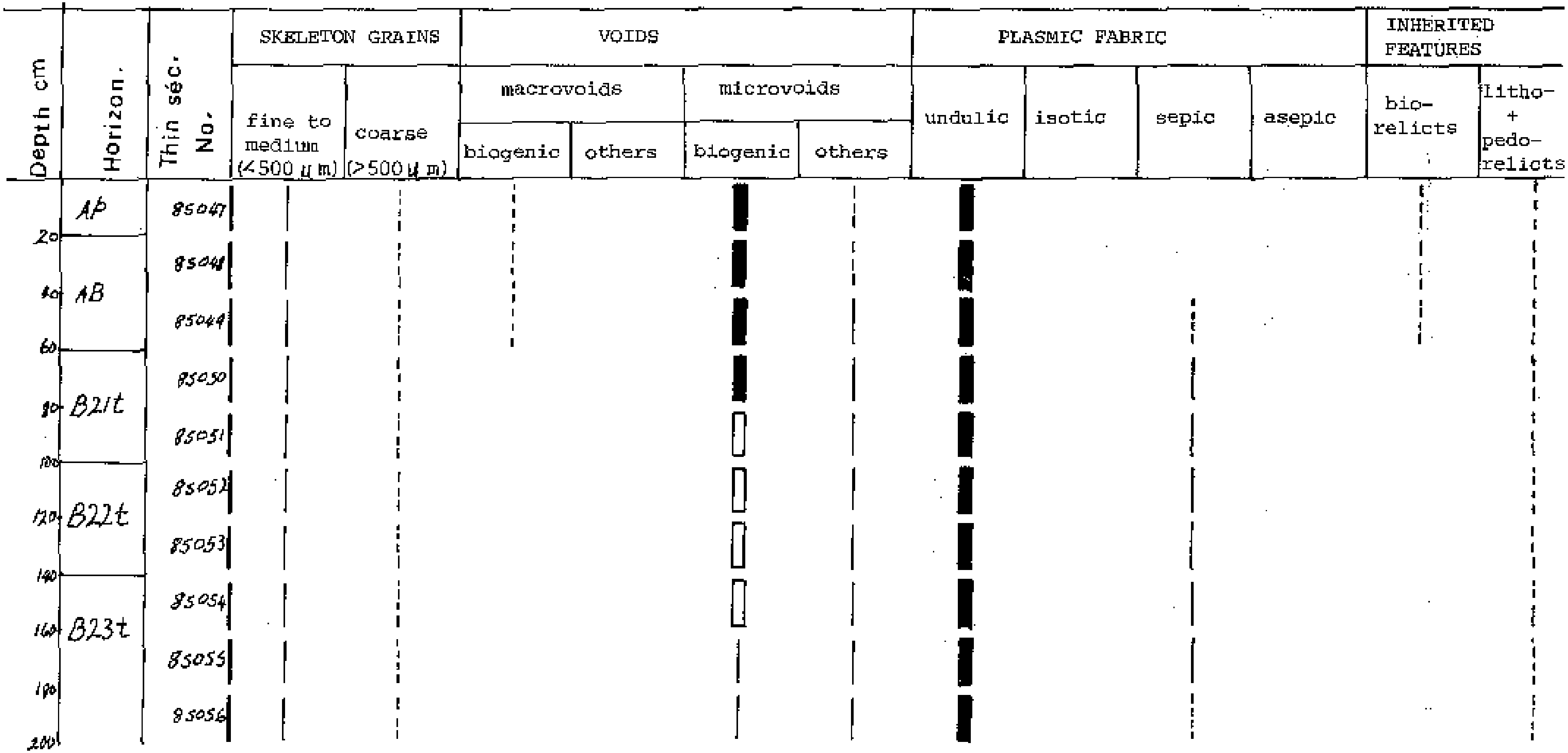


Fig. 4.1 Summary of micromorphological groundmass observations in profile RP1

Ranking of features

abundant — many — common — few (for skeleton grains, void and inherited features

predominant — present (for plasmic fabric)

SPECIAL FEATURES

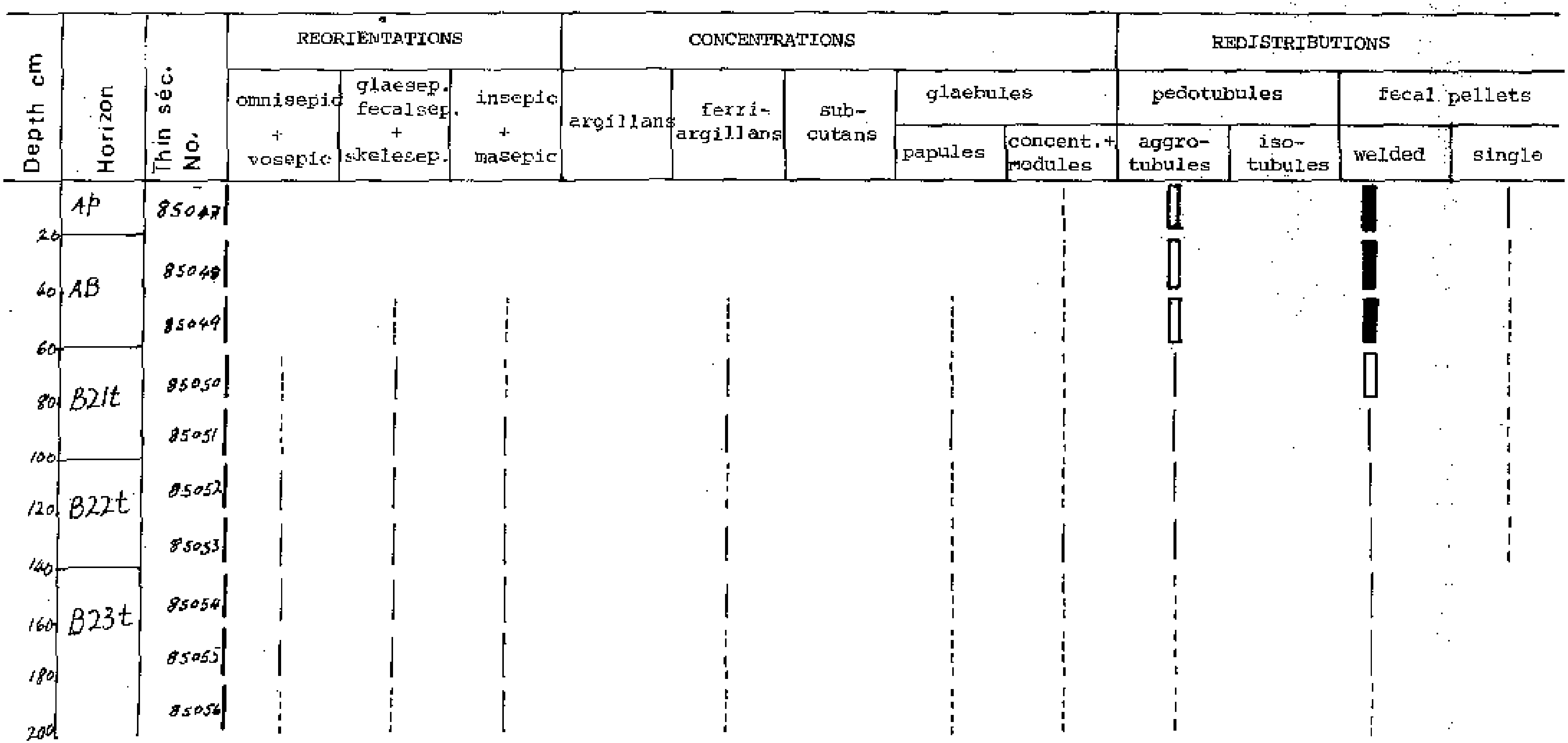


Fig. 4.2 Summary of micromorphological special features in profile RP1

Ranking of the features

abundant many common few

Table 4.1 Degree of illuviation and degree of biological reworking in profile RP1 (per thin section)

Depth (cm)	Thin sect. number	Horizon	Total % illuv.clay	Degree of illuv.	In situ % of illuv.	% illuv. reworked biologically	Rel.% of illuv. reworked	Degree of reworking
0- 20	85047	Ap	0		0	0	0	
20- 40	85048	AB	0		0	0	0	
40- 60	85049	AB	0		0	0	0	
60- 80	85050	B21t	0.6 ± 0.2	weak	0.3 ± 0.1	0.3 ± 0.1	50	moderate
80-100	85051	B21t	1.9 ± 0.4	moderate	1.2 ± 0.3	0.7 ± 0.2	34	moderate
100-120	85052	B22t	2.4 ± 0.3	moderate	1.6 ± 0.4	0.7 ± 0.2	30	weak
120-140	85052	B22t	2.0 ± 0.3	moderate	0.9 ± 0.2	1.1 ± 0.3	59	moderate
140-160	85053	B23t	2.4 ± 0.5	moderate	1.5 ± 0.4	0.9 ± 0.3	38	moderate
160-180	85054	B23t	1.1 ± 0.3	moderate	0.4 ± 0.2	0.7 ± 0.2	64	moderate
180-200	85056	B23t	< 0.3	negligeable	< 0.1	< 0.1	negligeable	weak

The degree of illuviation and degree of biological reworking have been classified on the basis of point counting of argillans, and/or ferri-argillans, plus papules respectively. The counting is done on 18x15 cm. x 25 μm thin sections at a magnification of 125. The standard deviations have been calculated according to nomographs and formulae of Van der Plas and Tobi (1965).

Classes of degree of illuviation:
> 7% = very strong 7-4% = strong 4-1% = moderate 1-0.3% = weak < 0.3% = negligible

Classes of biological reworking:
< 30% = weak 30-70% = moderate 70% = strong

4.2 Profile RP2

Macroscopic observations.
The upper 20 cm. is dark brown while the subsoil is reddish brown to red in colour. The profile is fine textured and quite porous. The porosity decreases with depth and the groundmass is denser in the lower 80 cm. Channels and vughs with diameter of 1 to 2 mm. are common in the upper 30 cm. and decrease with depth. Granular and subangular blocky structure is predominant in the upper 20 cm. while subangular blocky structure predominates in the subsoil. Specks of iron nodules and rock fragments occur throughout the profile. Plant remains and organic aggregates occur especially in the upper 40 cm. and decrease with depth.

Microscopic observations (Summary, figs. 4.3 and 4.4).
Groundmass (Summary, fig. 4.3).

Skeleton grains. Coarse (> 500 μm.) skeleton grains which are subrounded with low sphericity occur randomly distributed throughout the profile increasing slightly with depth. Most of them are quartz and chert, coated partly by iron, but some are rock fragments. Medium to fine skeleton grains are common and occur randomly distributed throughout the profile. Some are subrounded while others are euhedral. Most of them are quartz and chert but some are sanidine feldspars, volcanic glass and plagioclase feldspars.

Voids. Most of the voids are biogenic compound packing voids, channels and vughs with diameter of 100-1000 μm., which occur randomly distributed throughout the profile decreasing with depth. A few have diameters of 1-2 mm. and a few craze, skew and joint planes occur especially in the subsoil.

Plasma - plasmatic fabric. The plasmic fabric is predominantly undulic in the upper 30 cm and asepic in the subsoil. Some sepic parts occur starting from about 40 cm. depth.

Related distribution. The upper 40 cm. have agglomeroplasmic while the subsoil has porphyroskelic to porphyric related distribution.

Special features (Summary fig. 4.4).
Reorientation. A few, faint, 10-30 μm. in diameter, glaesepic, skelsepic and insepic reorientations occur randomly distributed starting from about 40 cm. depth. Most of them have sharp outer boundaries and diffuse inner boundaries and are weakly expressed.

Nodules. Distinct, 30-150 μm. in diameter, rounded, spherical, ferric nodules occur randomly distributed throughout the profile increasing slightly in the lower 20 cm. They have sharp boundaries and some are separated from the plasma by small cracks around them.

Pedotubules. Faint, 0.5-3 mm. in diameter matric, ortho-aggrotubules occur randomly distributed throughout the profile. They are abundant in the upper 40 cm. and decrease with depth. They have rather smooth boundaries.

Fecal pellets. Faint, 50-100 µm. in diameter welded matric fecal pellets occur randomly distributed throughout the profile. They are abundant in the upper 80 cm. and decrease considerably with depth. A few distinct, 30 µ . in diameter single organic fecal pellets occur clustered inside some plant remains.

Inherited features. A few, 0.2-2 mm. in diameter, fragments of rhyolite and andesite rocks occur throughout the profile increasing slightly with depth. A few partly decomposed plant remains also occur especially in the upper 40 cm. Some of the ferric nodules are weathering rock fragments especially in the lower 20 cm depth.

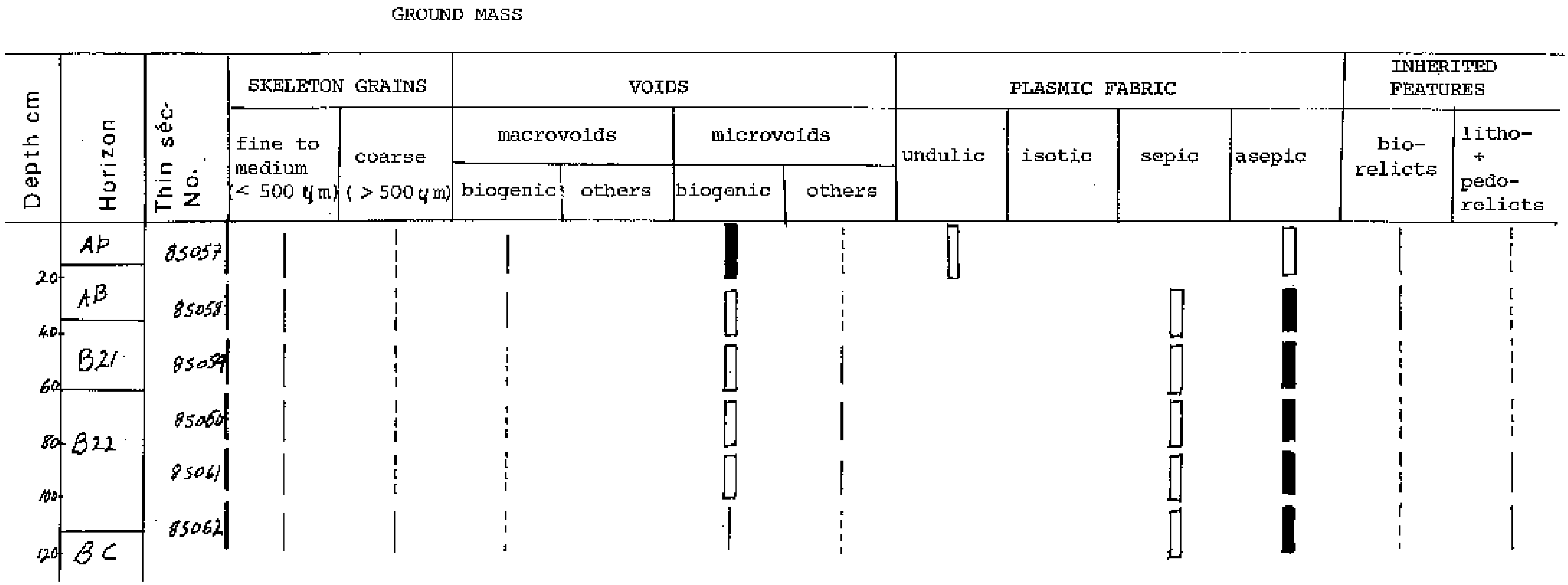


Fig. 4.3 Summary of micromorphological groundmass observations in profile RP2

Ranking of features

abundant　many　common　few

predominant　present

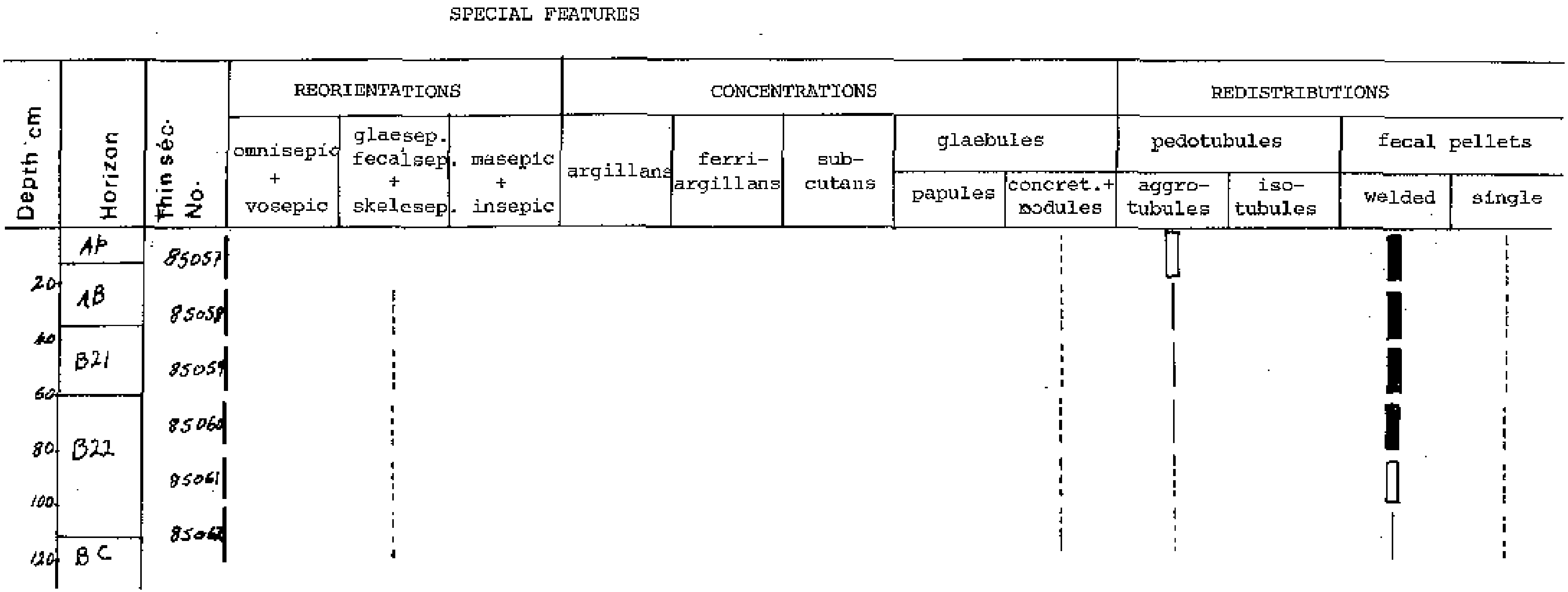


Fig. 4.4 Summary of micromorphological special features in profile RP2

Ranking of the features

abundant   many   common   few

4.3 Profile RP3

Macroscopic observations.
The profile is dark brown in the topsoil and reddish brown to red in the subsoil. It is very porous in the upper 80 cm. and the porosity decreases with depth to relatively dense subsoil. Channels and planes with diameter up to 5 mm. occur throughout the profile. The upper 60 cm. has subangular blocky to granular structure while the subsoil has strong angular blocky to subangular blocky structure. Dark specks of charcoal occur throughout the profile.

Microscopic observations (Summary, figs. 4.5 and 4.6).
Groundmass (Summary, fig. 4.5).

Skeleton grains. Coarse (> 500 µm. in diameter) rounded skeleton grains are few and occur randomly distributed throughout the profile. Most of them are quartz, chert, and rock fragments. Few to common, medium to fine (< 500 µm. in diameter) are predominantly quartz, chert and volcanic glass and occur randomly distributed in the profile.

Voids. Abundant to common biogenic voids occur throughout the profile. These are predominantly compound packing voids, vughs and channels with diameter up to 2 mm. Craze, skew and joint planes with diameter up to 1 mm. occur in relatively less amount and decrease with depth.

Plasma - plasmic fabric. The plasma is predominantly undulic. The topsoil tends to isotic due to high organic matter. Sepic parts occur throughout the profile increasing with depth.

Related distribution. The profile has porphyroskelic related distribution throughout. It is more open with higher porosity in the topsoil than in the subsoil.

Special features (Summary, fig. 4.6).
Reorientation Faint to distinct, 10-80 µm. in diameter, insepic, glaesepic, skelsepic, vosepic and masepic reorientations occur throughout the profile. In the upper 40 cm only a few insepic and glaesepic reorientations occur. They all increase with depth and are common in the lower 120 cm.

Ferri-argillans. A few faint to distinct, 10-30 µm. in diameter ferri-argillans occur randomly distributed starting from 80 cm. depth. They are rather small and the maximum amount of only 0.4 percent by volume is reached at about 100-140 cm. depth. Most are broken and appear to be in the process of being degraded.

Papules. Distinct, 10-30 µm. in diameter, papules occur randomly distributed starting from about 80 cm. depth. Some of them may be inherited while others may be in situ weathering. However most of them are translocated.

Nodules. Few to common, 30-250 µm. in diameter, distinct, ferric nodules occur throughout the profile. Most of them have sharp boundaries and are separated from the groundmass by small cracks. The smaller ones have diffuse boundaries.

Pedotubules. Faint, 0.5-4 mm. in diameter, matric and a few organic, ortho and meta aggrotubules occur throughout the profile. They are many in the upper 60 cm. and decrease considerably with depth.

Fecal pellets. Faint, 50-100 µm. in diameter, fecal pellets occur throughout the profile. They are abundant to many in the upper 80 cm. and decrease with depth. Most of them are welded but some are single. A few distinct 30 µm. in diameter, organic fecal pellets occur clustered in some plant remains.

Inherited features. A few partly decomposed plant remnants occur especially in the upper 60 cm. and decrease with depth. A few, rather fresh and some other weathering rock fragments occur throughout the profile. The fresh ones occur more frequently in the topsoil while the weathering ones occur in the subsoil.

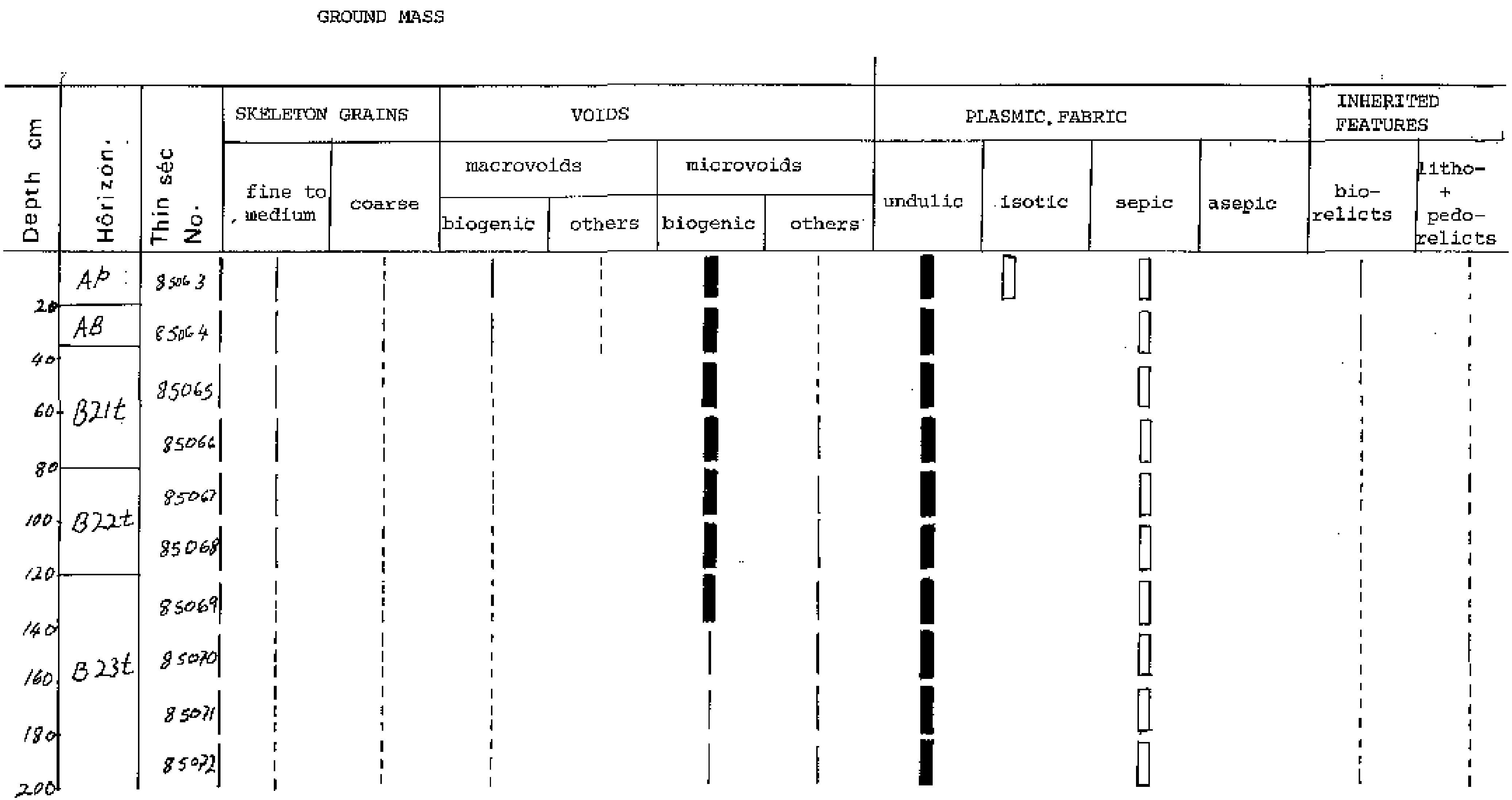


Fig. 4.5 Summary of micromorphological groundmass observations in profile RP3

Ranking of features

abundant   many   common   few (for skeleton grains, voids and inherited features)

predominant   present (for plasmic fabric)

SPECIAL FEATURES

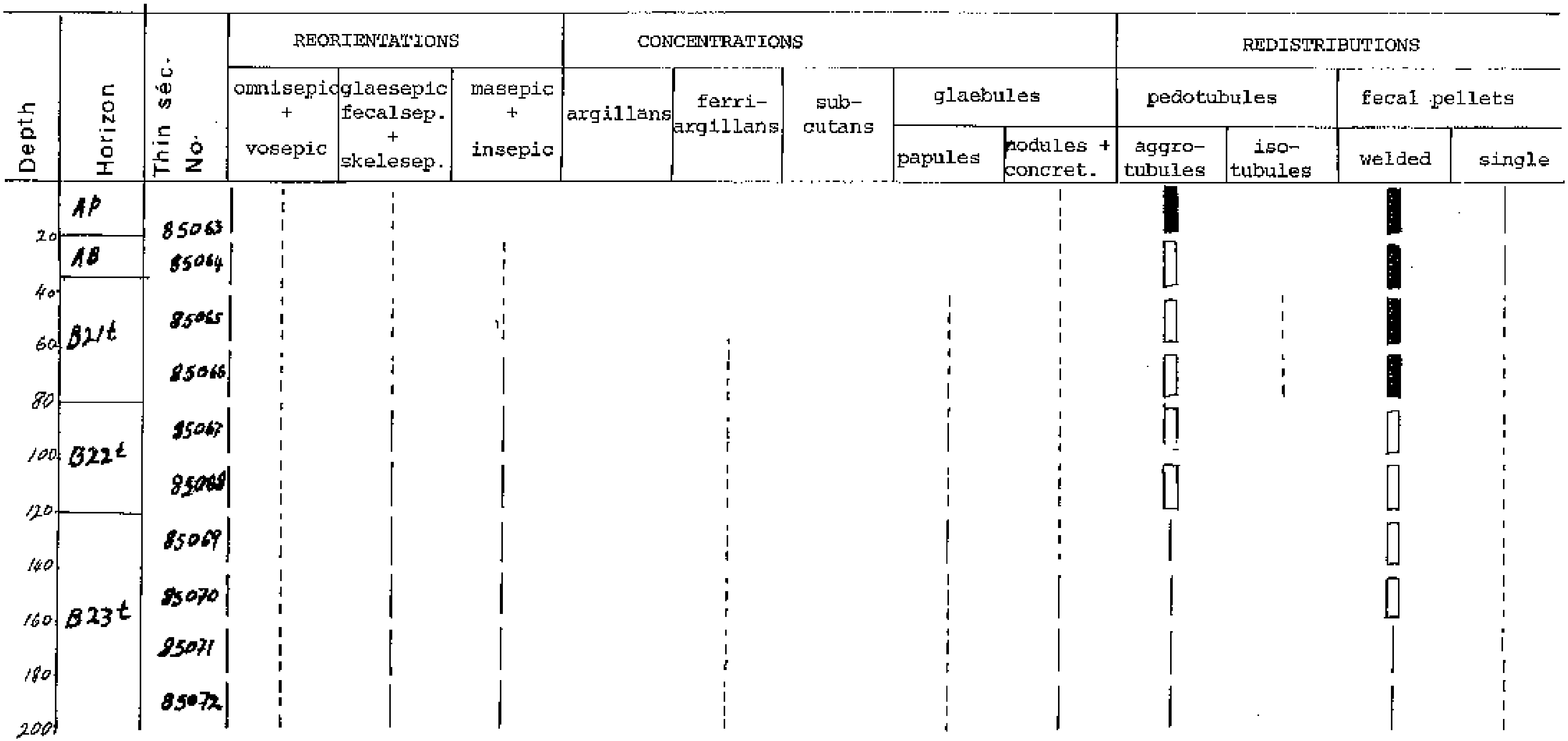


Fig. 4.6 Summary of micromorphological special features in profile KP3

Ranking of features

abundant many common few

Table 4.3 Degree of illuviation and biological reworking in profile RP3 (per thin section)

Depth (cm)	Thin sect. number	Horizon	Total % illuv.clay	Degree of illuv.	In situ % of illuv.	% illuv. reworked biologically	Rel.% of illuv. reworked	Degree of reworking
0- 20	85063		0.0		0.0	0.0	0.0	
20- 40	85064		0.0		0.0	0.0	0.0	
40- 60	85065		0.0		0.0	0.0	0.0	
60- 80	85066		0.3 ± 0.1	low	0.0	0.3 ± 0.1	100	total
80-100	85067		0.8 ± 0.3	low	0.3 ± 0.1	0.5 ± 0.2	60	
100-120	85068		0.9 ± 0.3	low	0.4 ± 0.2	0.5 ± 0.2	56	
120-140	85069		0.9 ± 0.3	low	0.4 ± 0.2	0.5 ± 0.2	56	
140-160	85070		1.5 ± 0.4	moderate	0.4 ± 0.2	1.0 ± 3	63	
160-180	85071		0.9 ± 0.3	low	0.3 ± 0.1	0.6 ± 0.2	67	
180-200	85072		0.2 ± 0.1	negligeable	0.0	0.2 ± 0.1	100	

For explanation see table 4.1.

4.4 Profile EAK26

Macroscopic observations.
The groundmass is brown to dark brown in colour; predominantly fine textured and pedal. Strong granular and subangular blocky structure predominates in the topsoil while the subsoil is mainly subangular to angular blocky. The groundmass is denser with depth. Large voids (>1 mm) are abundant in the upper 50 cm. These are mainly biogenic and decrease with depth. Cracks up to 3 mm. in diameter are present in the subsoil. Reddish brown ferric nodules of diameter up to 2 mm. are common throughout the profile. They are smaller and less distinct in the lower 50 cm. Material of the subsoil (reddish in colour) forms patches in the darker topsoil. Pedotubules and channels of about 3 mm. in diameter occur in the upper 70 cm.

Microscopic observations (Summary, fig. 4.7 and 4.8).
Groundmass (Summary, fig. 4.7).

Skeleton grains. The coarse grains (diameter > 500 µm.) are subrounded to angular, of low sphericity, and are randomly distributed throughout the profile. They consist of mainly quartz and chert grains. The fine and medium skeleton grains (diameter < 500 µm.) are generally subrounded and are randomly distributed in the profile. Some are euhedral and others form long crystals. They consist of predominantly chert and quartz but the euhedral ones are sanidine feldspars and plagioclase feldspars while the long crystals are volcanic glass. Most of the skeleton grains are partly coated with reddish haematite and clay material.

Voids. Most of the voids are biogenic with diameter 1 mm. to 200 µm. In the upper 70 cm. most of them are 1 mm. to 500 µm., form a complex pattern of compound packing voids, interconnected and separate vughs. Channels and craze planes occur throughout the profile but predominate in the lower 50 cm. The voids decrease with depth leading to a somewhat denser subsoil.

Plasma - plasmic fabric. The plasmic fabric is predominantly undulic to isotic in the topsoil and undulic to sepic in the subsoil. Some asepic parts occur throughout the profile increasing with depth. Patches of asepic plasmic fabric are included in more undulic topsoil as material from the subsoil.

Related distribution. The related distribution is porphyroskelic throughout the profile but grades to porphyric in the subsoil. Skeleton grains are embedded in the groundmass and small cracks separate some of the skeleton grains due to desication.

Special features (Summary, fig. 4.8).
Reorientation. Features of reorientation start at about 20 cm. depth and increase with depth. At about 160 cm. they are common. There are distinct, 20-100 µm. in diameter glaesepic, omnisepic, masepic and insepic reorientations, randomly distributed in some parts marking the walls of channels (vosepic). The omnisepic and masepic reorientations are relatively few.

Argillans. Distinct, 10-50 µm. in diameter, channel, normal and plane ferri-argillans with sharp boundaries occur randomly distributed and somewhat clustered starting from 100cm depth (see plate 8). In some parts they are clustered around places with fecal pellets which are somewhat welded. The argillans do not occur on the relatively older (welded) fecal pellets and on the single ones. The results of point counting are shown in table 4.4. The maximum value is reached at 100-115 cm. depth (3.9% total illuviation).

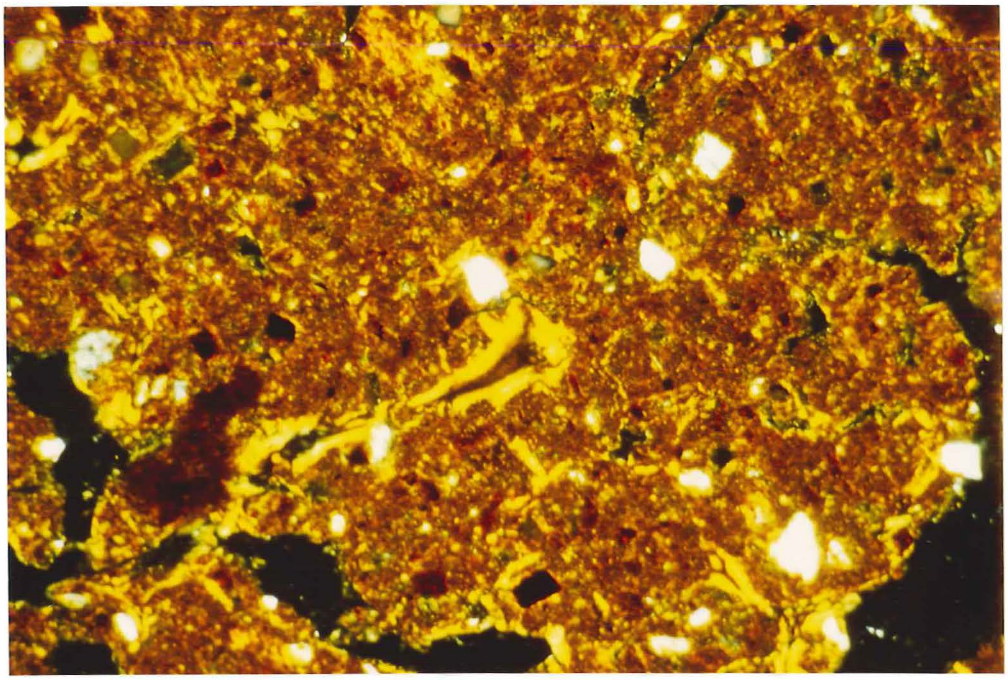


Plate 8 Normal ferri-argillan; polarized light.
From 110-115 cm. depth, profile EAK26.

Papules. Distinct, 10-50 µm. in diameter papules with diffuse boundaries occur throughout the profile. Some are associated with weathering skeleton grains and others with fecal pellets. They are generally randomly distributed in the lower (100-160 cm) depths. The results of point counting are shown in table 4.4 (10% of illuviation reworked). A maximum is reached at 100-115 cm depth.

Nodules and concretions. Distinct, 100-500 µm. in diameter rounded, highly spherical ferric nodules occur throughout the profile. Most have sharp boundaries but a few smaller ones in the lower depths have diffuse boundaries. Some are associated with weathering grains.

Pedotubules. Distinct, 0.5 to 3 mm in diameter, matric and organic, ortho and meta aggrotubules occur randomly distributed throughout the profile (see plate 9). They are abundant by chart ranking in the upper 50 cm. and decrease with depth to a few at 150 cm. Most are matric meta aggrotubules, A few matric meta and ortho isotubules are present in the topsoil as brown patches in a darker groundmass.

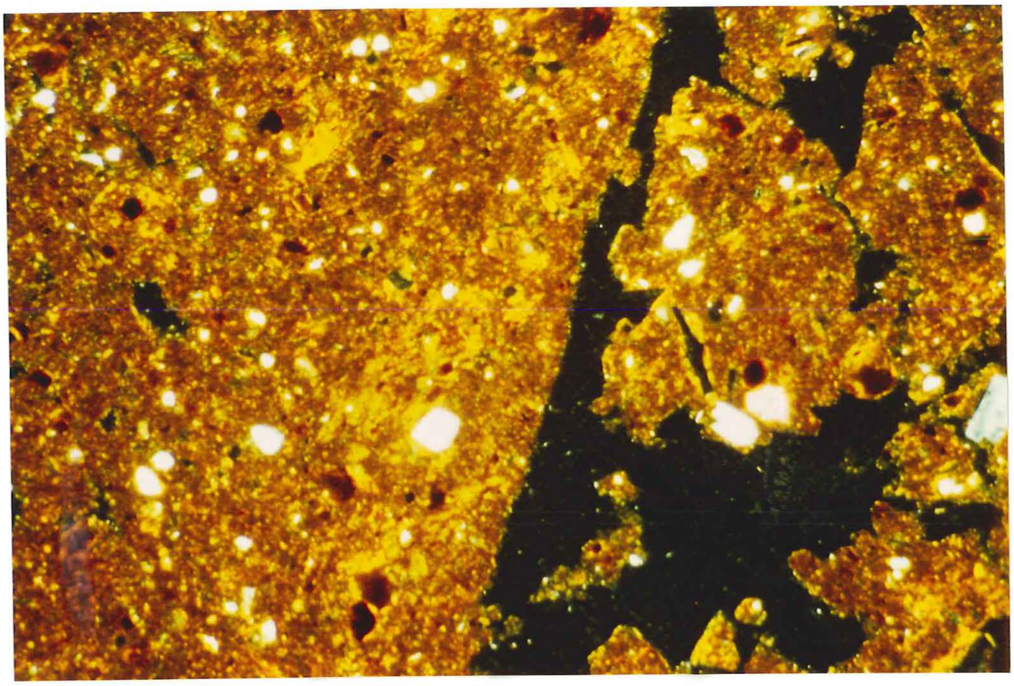


Plate 9 Wall of matric ortho-aggrotubule (1),insepic plasmic fabric (2) and inside aggrotubule; polarized light. From 110-115 cm. depth, profile EAK26.

Fecal pellets. Two sizes of fecal pellets can be distinguished; distinct, 60-100 µm. in diameter, welded and single, matric ones occur randomly distributed throughout the profile. These are the predominant ones and decrease with depth. They form about 80% of the topsoil. Distinct 50 µm. in diameter ellipsoidal fecal pellets also occur clustered in plant remains. They appear rather fresh and recent.

Inherited features. Some rock fragments of quartzite and rhyolite occur randomly distributed throughout the profile. Some clusters of volcanic glass also occur in the profile.
Some partly decomposed plant remains occur in the profile and decrease with depth to very few. Artifacts of charcoal occur in the upper 100 cm.

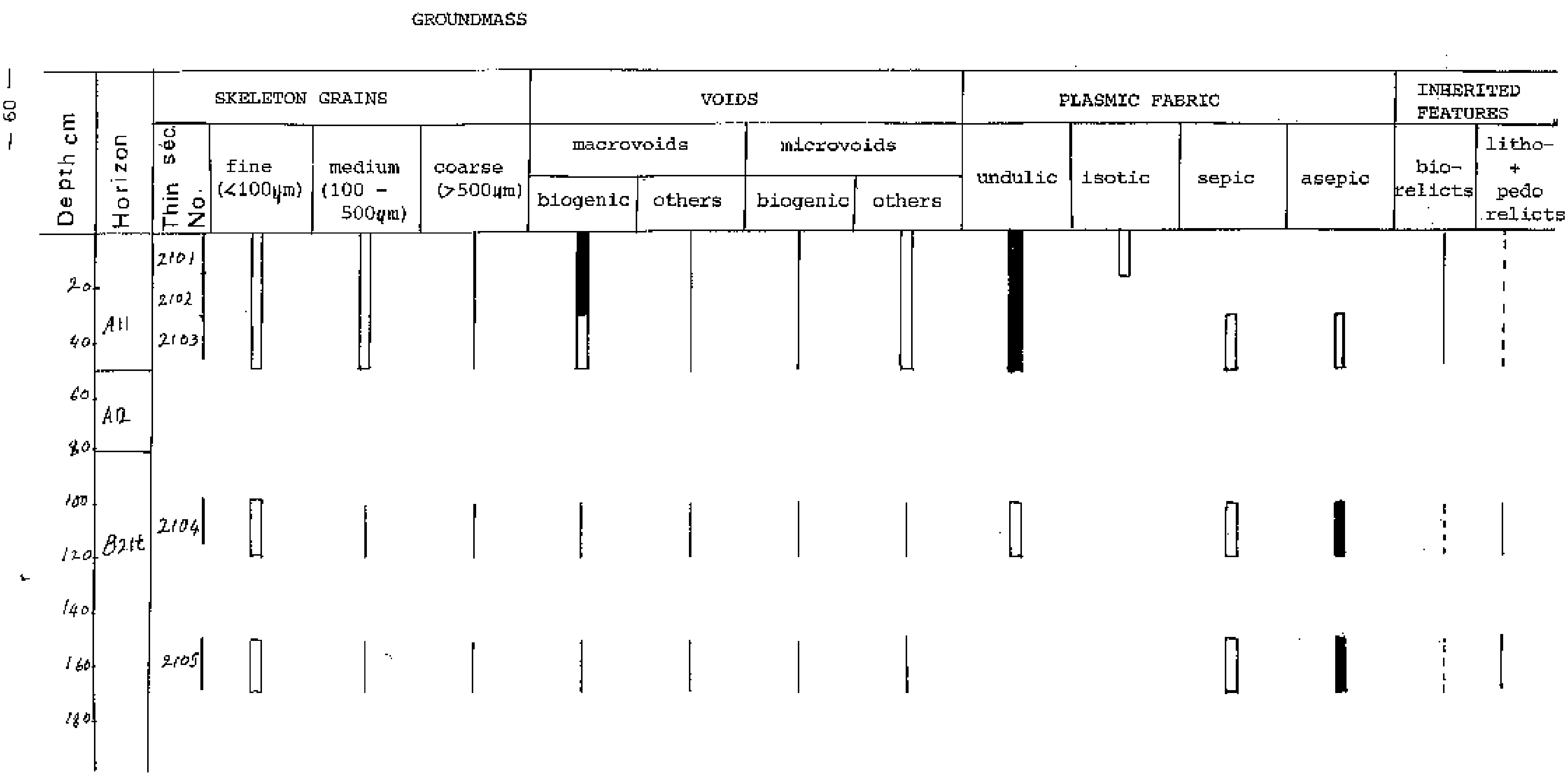


Fig. 4.7 Summary of micromorphological groundmass observations in profile EAK26

Ranking of features: abundant   many   common   few (for skeleton grains, voids and inherited features)

predominant   present (for plasmic fabric)

SPECIAL FEATURES

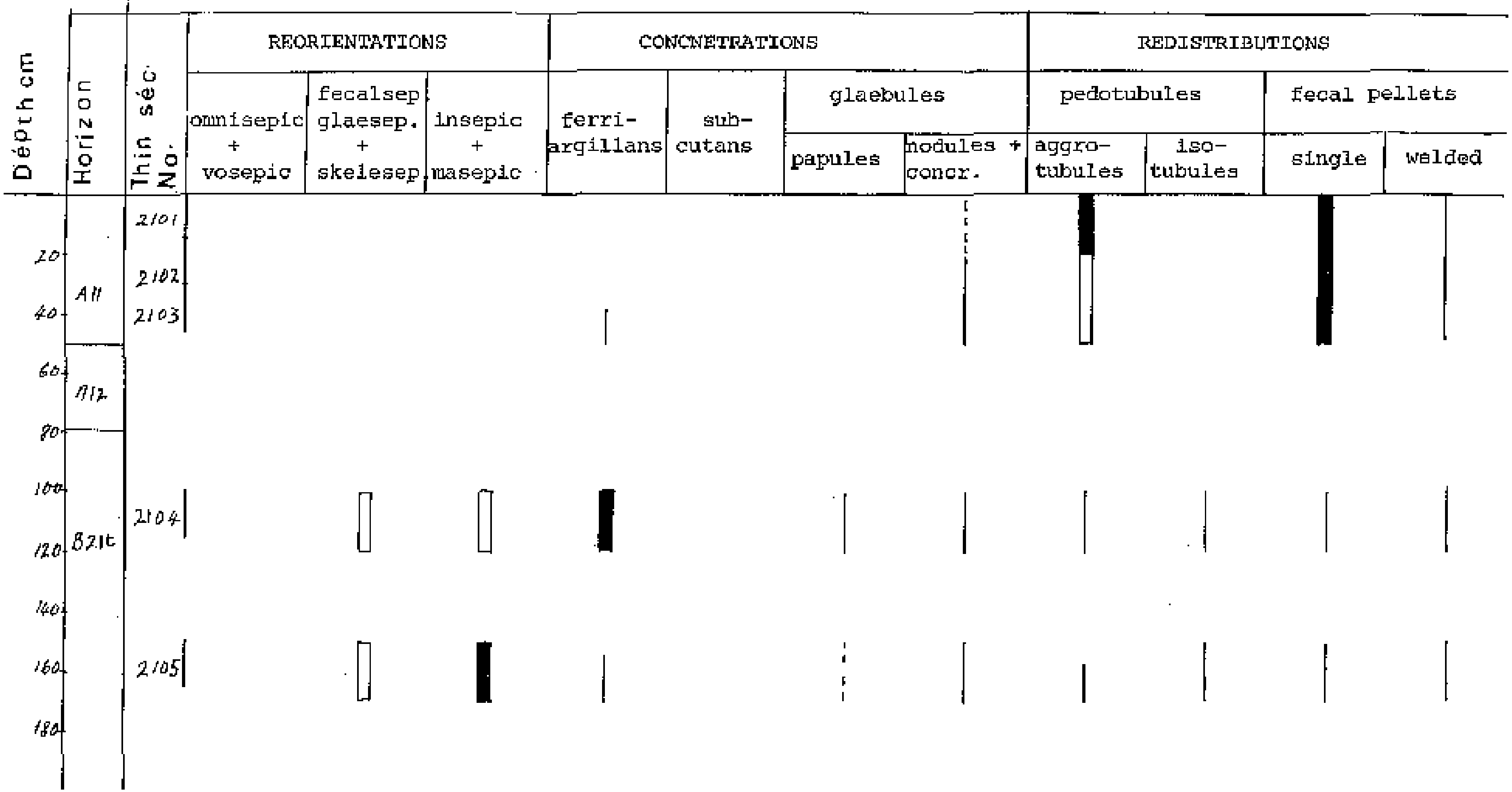


Fig. 4.8 Summary of micromorphological special features in profile EAK 26

Ranking of features: abundant many common few

Table 4.4 Degree of illuviation and degree of biological reworking of illuviated clay per thin section in profile EAK26.

Depth (cm)	Thin sect. number	Horizon	Total % illuv.clay	Degree of illuv.	In situ % of illuv.	% illuv. reworked biologically	Rel.% of illuv. reworked	Degree of reworking
1- 16	2101	A11	0.0		0.0	0.0	0	
16- 31	2102	A11	0.0		0.0	0.0	0	
31- 46	2103	A11	0.0		0.0	0.0	0	
100-115	2104	B21t	3.9 ± 0.6	moderate	2.8 ± 0.6	1.1 ± 0.3	28	weak
150-165	2105	B21t	1.4 ± 0.4	moderate	1.1 ± 0.3	0.3 ± 0.2	27	weak

For explanation see table 4.1.

4.5 Profile WAN2

Macroscopic observations.
The profile is coarse textured. The voids can not be differentiated from the skeleton grains especially in the topsoil. The coarse skeleton grains are predominant. The upper 20 cm. has crumbly to granular structure and the rest of the profile appears macrostructureless. The matrix is dark brown in the upper 40cm. and reddish in the subsoil. The plasma is little in the topsoil but increases with depth.Reddish brown and dark brown ferric nodules occur deeper than 100 cm. Artefacts of black charcoal are present in the upper 100 cm. At 160 cm. depth aggrotubules can be distinguished which are 1-3 mm. in diameter. The groundmass has different shades of yellow and brown to reddish brown colours.

Microscopic observations (Summary, figs. 4.9 and 4.10).
Groundmass (Summary, fig. 4.9).

Skeleton grains. The coarse skeleton grains are angular to subrounded and of low sphericity. They are randomly distributed in the profile and constitute the major part of the coarse fraction. They consist of quartz and a few of chert and feldspars. (See plate 10).
The medium and fine skeleton grains are angular. A few are somewhat rounded and have low sphericity. They increase with depth while the coarse ones decrease with depth. They consist of quartz, chert, volcanic glass and feldspars. Quartz and chert are predominant.

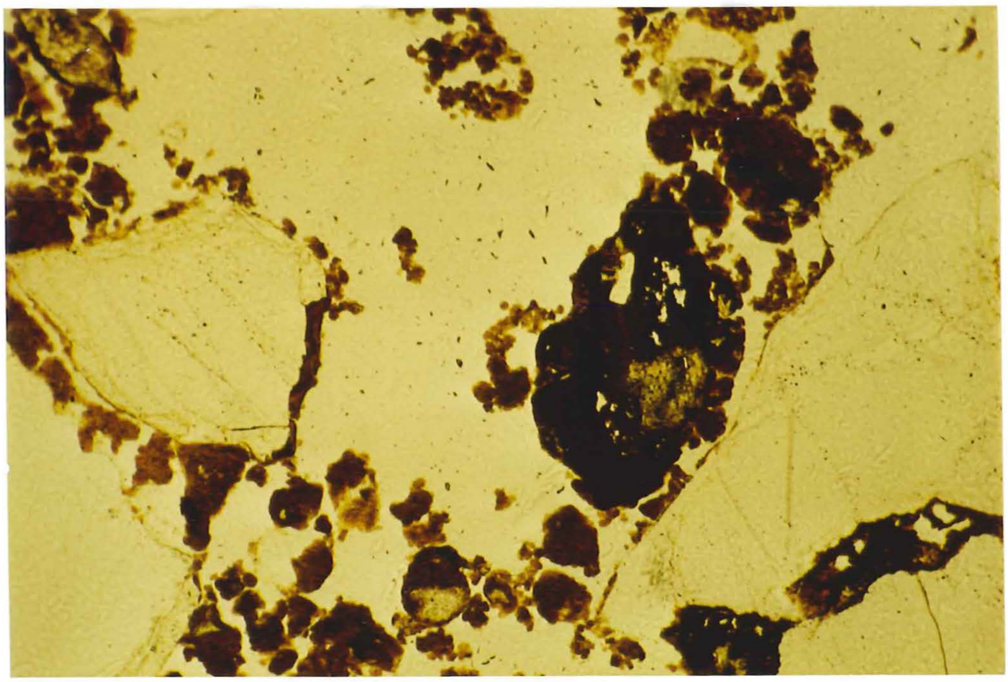


Plate 10 Skeleton grain (1), micro aggregate (2), and fecal pellets; normal light.
From 55-70 cm. depth, profile WAN2.

Voids. Voids greater than 2 mm. are few and are mainly interconnected vughs and chambers. Voids less than 2 mm. are abundant in the upper 40 cm. and decrease to common in the subsoil. They comprise mainly of interconnected vughs, chambers, channels and compound packing voids. Some craze and skew planes occur.

Plasma - plasmic fabric. Undulic plasmic fabrics predominate in the 0-40 cm. depth, undulic to asepic in the 40-140 cm. and asepic in the 140-165 cm. depth. Some separt (insepic) occur associated with channels, skeleton grains and fecal pellets starting from 55 cm. depth.

Related distribution. The related distribution is intertexic to agglomeroplasmic in the upper 20 cm., agglomeroplasmic to porphyric in the 20-60 cm. and intertexic to porphyroskelic at lower depths.

<u>Special features</u> (Summary, fig. 4.10).
Reorientation. Faint 20-130 µm in diameter, masepic-insepic, skelsepic, and fecal sepic reorientations with diffuse to somewhat sharp boundaries occur randomly distributed starting from about 25 cm. depth.. The size and quantity increase with depth due to increase of plasma.

Argillans. Distinct, 20-100 µm. in diameter, channel, normal, plane and embedded grain ferri-argillans occur clustered starting at about 50 cm. depth.A few of the ferri-argillans are associated with ped faces. Most of them are associated with biological activity (fecal pellets) of a certain generation. The single and strongly welded (rather recent and older) fecal pellets are not affected by the illuviation. The larger ferri-argillans are cracked and have different shades of brown. Some are yellowish brown while others are yellow. A few distinct 10-20 µm. in diameter argillans occur adjacent to ferrans at 160 cm. depth (see plate 11). The maximum quantity of 3.9% by volume is reached at about 83-98 cm. depth.

Subcutans. Distinct, 10-30 µm. in diameter plane neoferrans with diffuse boundaries occur at 160-165 cm. depth. They occur adjacent to argillans.

Papules. Distinct, 20-100 µm in diameter papules with sharp boundaries occur randomly distributed and some clustered starting from about 50 cm. depth. They have different shades of brown. Some are associated with weathering grains, especially in the subsoil. The maximum amount is reached at 83-94 cm depth (see table 4.5).

Nodules and concretions. Distinct to faint 10-50 µm. in diameter round ferric and manganese nodules and concretions with sharp and some with diffuse boundaries occur randomly distributed, starting from about 85 cm. The amount increases with depth but they are few up to about 160cm. depth.

Pedotubules. Distinct to faint, matric, ortho and meta- aggrotubules occur randomly distributed throughout the profile. They range from 0.5 to 3 mm. in diameter and are abundant in the topsoil decreasing with depth. Most are matric-meta-aggrotubules, difficult to distinguish, especially in the topsoil, from the matrix. Some are affected by illuviation. A few organic ortho-aggrotubules of material derived from the topsoil occur in the subsoil.

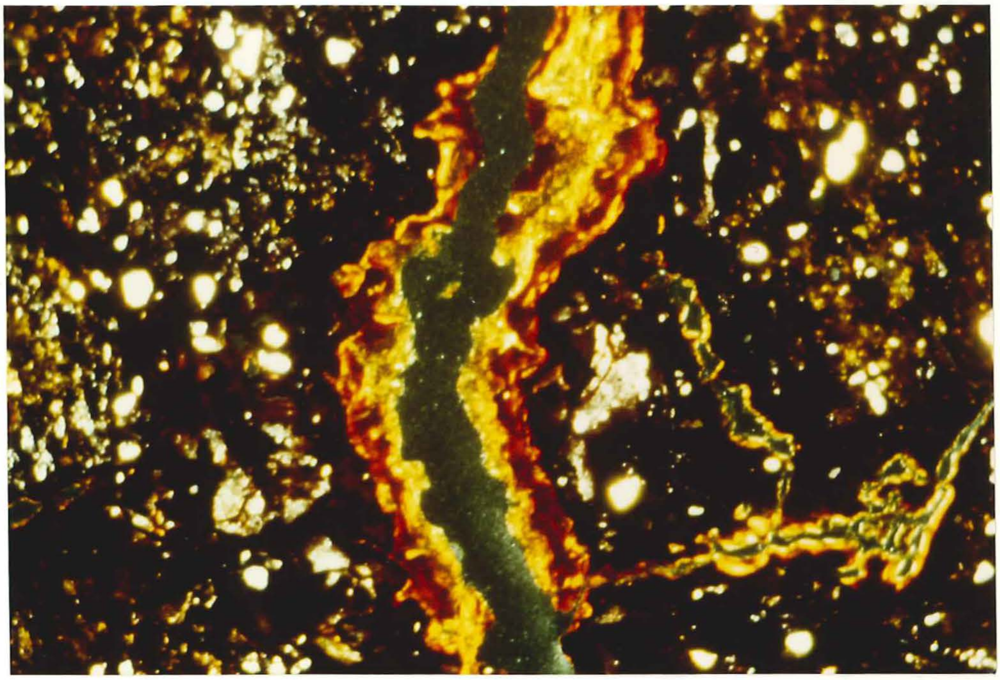


Plate 11 Plane neo ferran (1) and ferri-argillan (2), indicative of gleying; polarized light. From subsoil of profile WAN2, 160-165 cm. depth.

Fecal pellets. Three types of fecal pellets can be distinguished on the basis of diameter:
- Rather faint, greater than 90 µm. in diameter, mainly welded ones. These are micropeds molded by biological activity;
- Distinct, 40-60 µm. in diameter, some single and some welded ones and the third type are
- 10-20 µm. in diameter and mainly single.

All occur randomly distributed in the profile except the smallest ones which are clustered in plant remnants. In the subsoil (160 cm.) they occur only in the aggrotubules.

Inherited features. A few angular rock fragments of granite occur throughout the profile but are more in the subsoil. A few partly decomposed plant remains occur mainly in the upper 50 cm. Some artifacts of charcoal occur in the upper 100 cm.

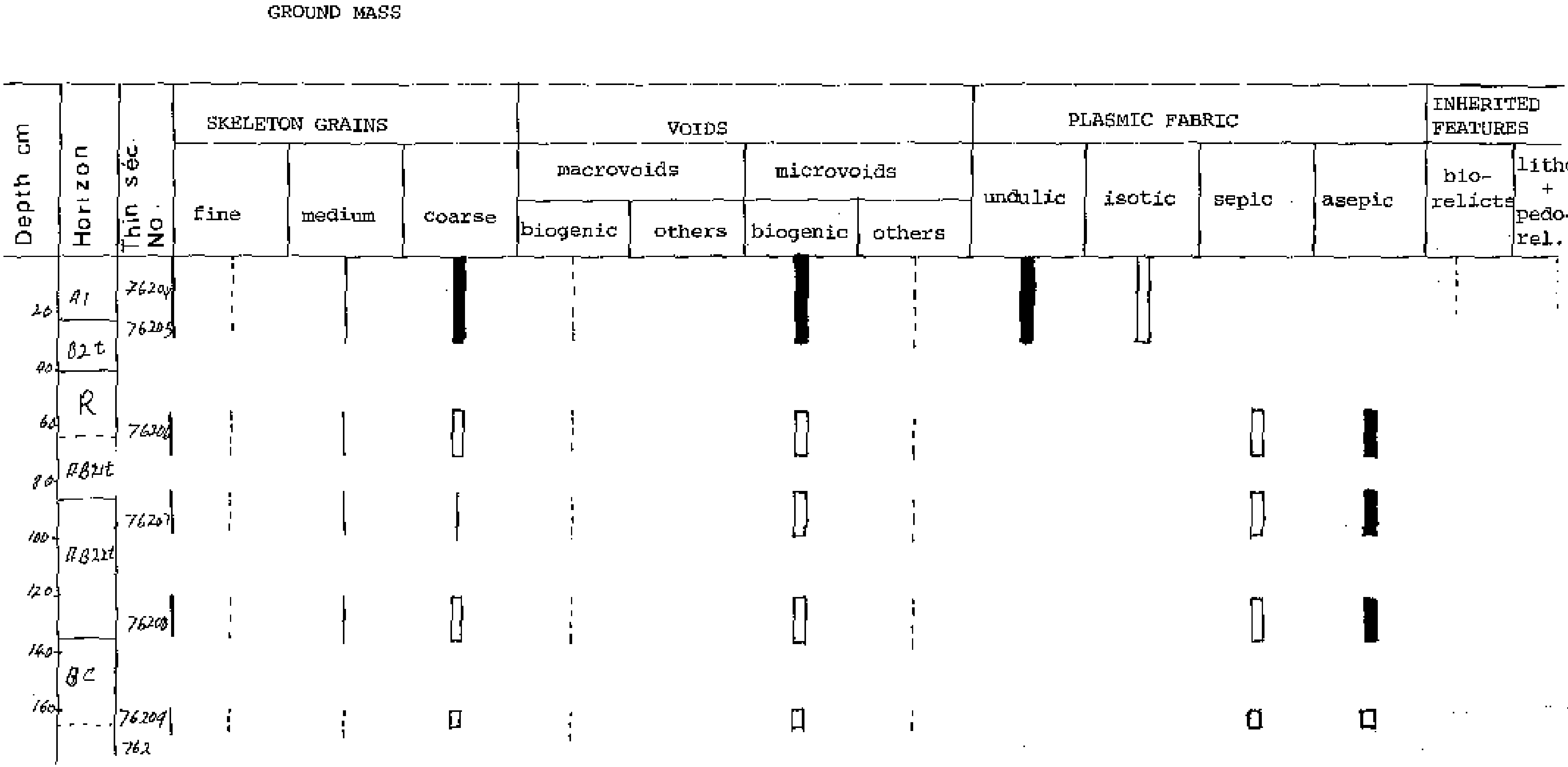


Fig. 4.9 Summary of micromorphological groundmass observations in profile WAN 2

Ranking of features

abundant — many — common — few (for skeleton grains, voids and inherited features)

predominant — present (for plasmic fabric)

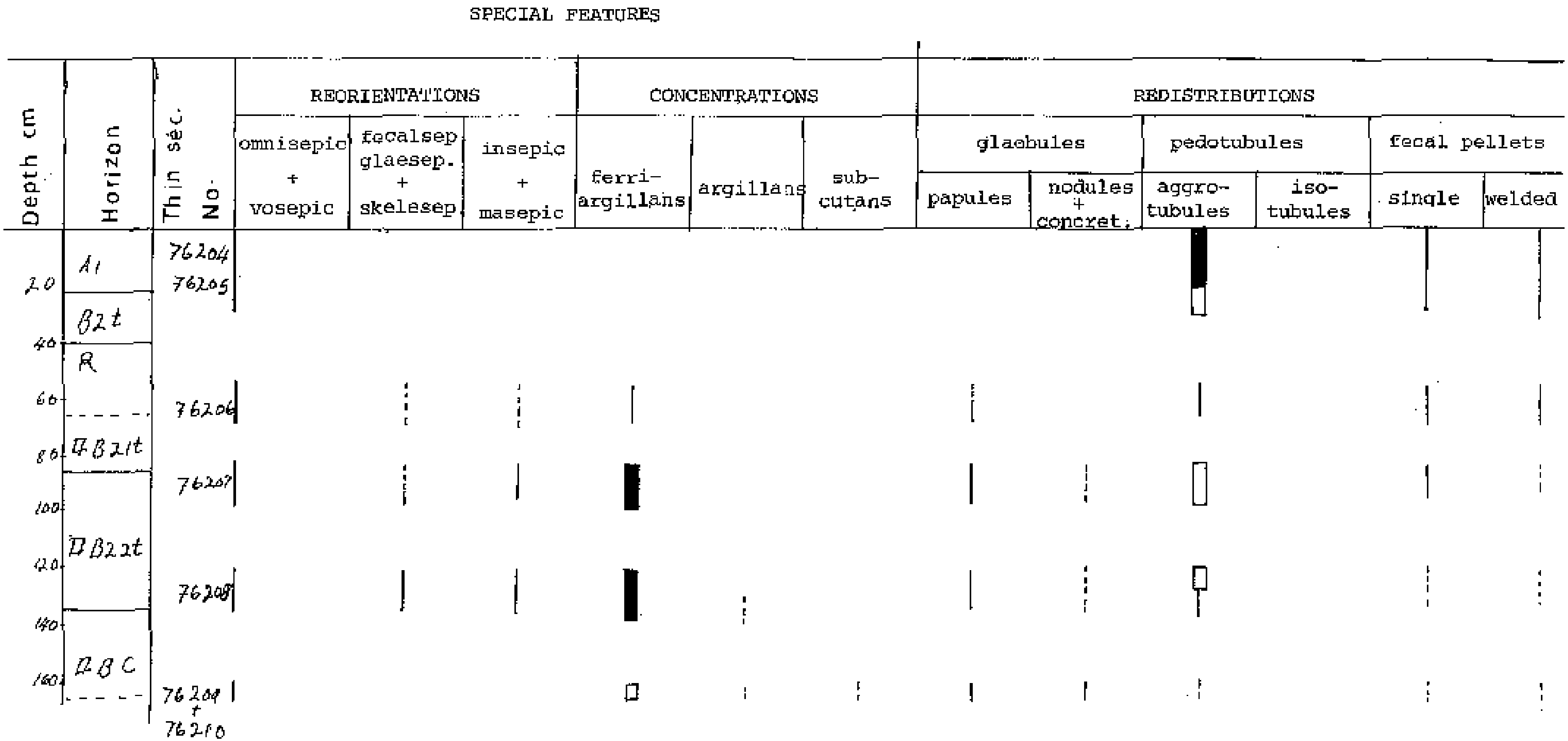


Fig. 4.10 Summary of micromorphological special features in profile WAN 2

Ranking of the features

abundant many common few

Table 4.5 Degree of illuviation and degree of biological reworking per thin section in profile WAN2.

Depth (cm)	Thin sect. number	Horizon	Total % of illuv.clay	Degree of illuv.	In situ % of illuv.	% of illuv. reworked biologically	Rel.% of illuv. reworked	Degree of reworking
1- 16	76204	A11	0.0		0.0	0.0	0.0	
15- 30	76205	A/B2t	0.0		0.0	0.0	0.0	
55- 70	76206	IIB21t	1.8 ± 0.9	moderate	1.2 ± 0.7	0.6 ± 0.3	33	moderate
83- 98	76207	IIB22t	3.4 ± 1.3	moderate	2.6 ± 1.1	1.3 ± 0.6	28	weak
120-135	76208	IIB22t	3.6 ± 1.2	moderate	2.3 ± 1.0	1.3 ± 0.6	30	weak
160^+	76209+ 76210	BC	nd	nd	nd	nd	nd	nd

For explanation see under table 4.1.

4.6 Profile EAK12

Macroscopic observations.
The profile is coarse textured but the skeleton grains are difficult to distinguish from the pores in the thin section of the upper 50 cm. The upper 30 cm. has granular structure and the subsoil appears macro-structureless. The matrix is dark brown in the upper 30 cm. and reddish brown to red in the subsoil. A few large voids (2-5 mm. in diameter) are present in the surface 40 cm. Some aggrotubules also occur in the upper 30 cm. The fine matrix and plasma increase with depth and become relatively dense starting from 45 cm. depth.

Microscopic observations (Summary; figs. 4.11 and 4.12).
Groundmass (Summary. figure 4.11).

Skeleton grains. The coarse skeleton grains (> 500 µm.) are angular, with low sphericity and occur randomly distributed throughout the profile. They are many to abundant in the topsoil and decrease with depth. The medium (500-100 µm.) and the fine (< 100 µm.) are somewhat rounded to subrounded and are rather spherical. The fine ones increase with depth. Some are clustered around aggrotubules and channels marking the boundaries of these features .
The skeleton grains consist of mainly clean quartz and a few are feldspars. A few are cracked and the cracks are filled with reddish plasma.

Voids. Large voids (> 2 mm. in diameter) are quite few and decrease with depth. They are channels and interconnected vughs randomly distributed in the profile. Voids less than 2 mm. are abundant in the topsoil and decrease with depth. These are channels, vughs, compound packing voids, chambers, skew and craze planes and some simple packing voids. Channels, chambers and interconnected vughs are predominant in the top 30 cm. while channels and craze planes predominate in the subsoil.

Plasma - plasmic fabric. The plasma is undulic to isotic at 0-30 cm., undulic to asepic at 30-60 cm. and predominantly asepic in the subsoil. Some sepic parts occur beginning from 15 cm. The sepic parts are associated with channels and aggrotubules. Others occur in matrix.

Related distribution. The related distribution pattern is agglomeroplasmic to intertexic at 0-30 cm.; agglomeroplasmic to porphyric at 30-45 cm. and agglomeroplasmic at 60-100 cm. In some parts the related distribution pattern can not be well described due to clustering of medium and fine skeleton grains.

Special features (Summary, fig. 4.12).
Reorientation. Faint, 10-50 µm. in diameter masepic-insepic and skelsepic reorientation occurs beginning from 30 cm. depth. Most of them have diffuse boundaries. They increase slightly with depth but the amount is little (few) throughout the profile. Some are associated with fecal pellets and are called fecal sepic. These occur clustered on the fecal pellets which are strongly welded.

Argillans. Distinct, 10-100 µm. in diameter, channel, normal, and embedded grain ferri-argillans occur in a clustered pattern beginning from 15 cm. to 60 cm. depth. Most of them are normal and channel ferri-argillans and embedded grain ones are very few in the 30-60 cm. depth. They form bands and tubules which are horizontally somewhat parallel. They have sharp boundaries and have strong birefringent. The larger ones (> 50 µm.) are cracked. The ferri-argillans are associated with a certain generation of biological activity. They are stained with different shades of brown giving them a brownish to yellowish colour. Some are associated with fecal pellets and micropeds. The maximum amount is reached at 30-45 cm. (see table 4.6) and they do not occur at 80-95 cm. depth. Thus they only occur at 15-60 cm. depth.

Papules. Distinct, 20-80 µm. in diameter, rounded papules occur randomly distributed beginning from 15 to 60 cm. depth. They have sharp boundaries and decrease with depth from 45 cm. The maximum amount is reached at 30-45 cm. Unlike the in situ ferri-argillans, they occur associated with all generations of biological activity.

Nodules and concretions. Distinct, 20-150 µm. in diameter, rounded and spherical nodules occur randomly distributed throughout the profile. The larger ones have sharp boundaries while the smaller ones have diffuse boundaries. Very few occur in the upper 15 cm. They increase slightly with depth but remain few throughout the profile.

Pedotubules. Faint, 0.5 to 3 mm. in diameter, matric ortho-aggrotubules occur randomly distributed throughout the profile. They increase with depth but can not be distinguished at the upper 30 cm. The boundaries are somewhat compacted and consist of a concentration of medium and fine grains embedded in the plasma. Some isotubules occur at lower depths but are difficult to distinguish from the groundmass.

Fecal pellets. Faint, 100-200 µm. in diameter, welded to single matrix fecal pellets occur randomly distributed throughout the profile. Some are associated with the ferri-argillans. They decrease with depth but remain many throughout the profile.

Inherited features. A few partly decomposed plant remains occur in the upper 30 cm. A few lithorelicts of quartzite and nodules occur throughout the profile. The few weathering grains of sanidine and feldspars are also part of the parent material.

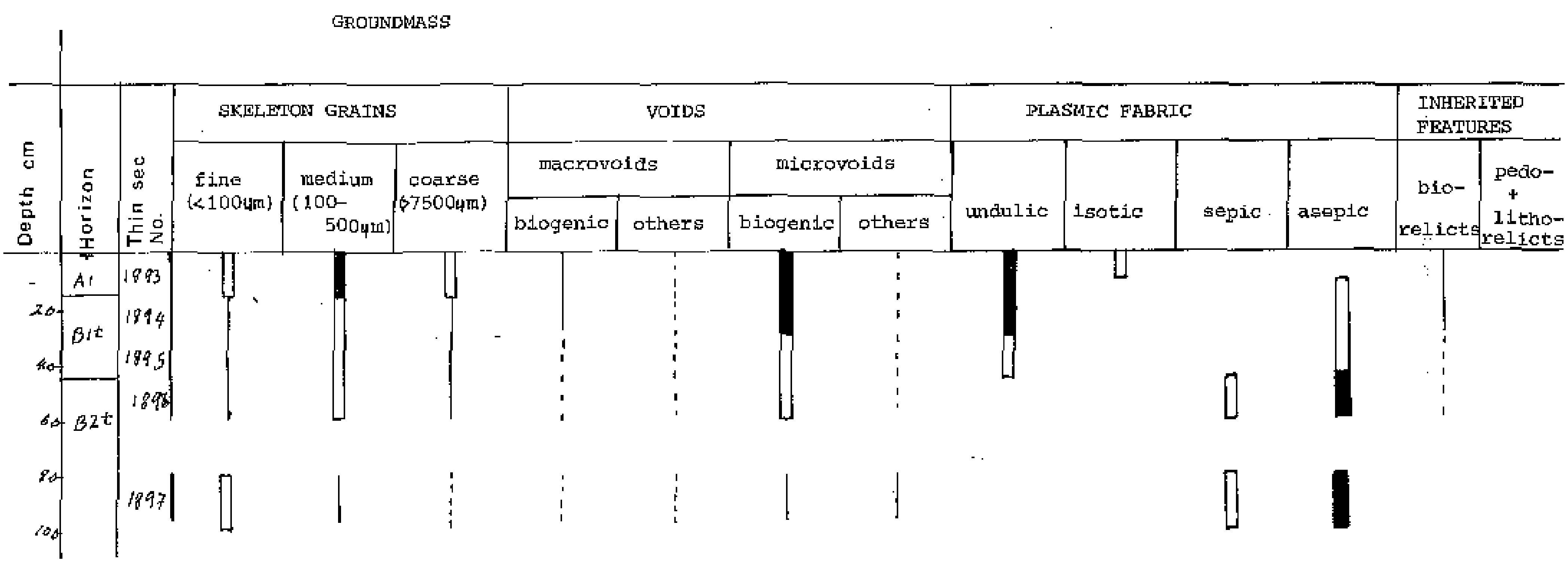


Fig. 4.11 Summary of micromorphological groundmass observations in profile EAK12

Ranking of the features:

abundant — many — common — few (for skeleton grains, voids and inherited features)

predominant — present (for plasmic fabric)

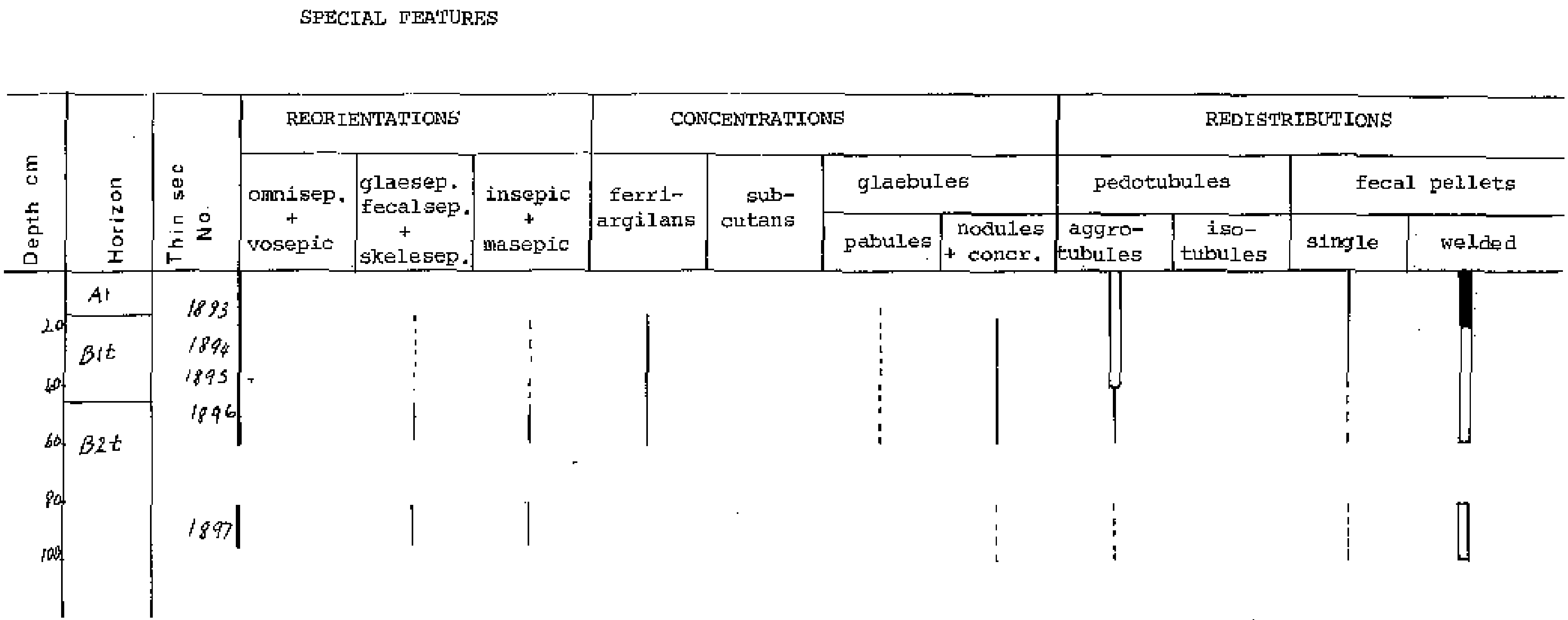


Fig. 4.12 Summary of micromorphological special features in profile EAK12

Ranking of the features

abundant many common few

Table 4.6 Degree of illuviation and degree of biological reworking of illuviated clay per thin section in profile EAK12.

Depth (cm)	Thin sect. number	Horizon	Total % illuv.clay	Degree of illuv.	In situ % of illuv.	% illuv. reworked biologically	Rel.% of illuv. reworked	Degree of reworking
0- 15	1893	A1	0.0		0.0	0.0	0	
15- 30	1894	B1t	1.7 ± 0.4	moderate	1.1 ± 0.3	0.6 ± 0.3	35	moderate
30- 45	1895	B1t	1.8 ± 0.4	moderate	1.5 ± 0.4	0.3 ± 0.2	17	weak
45- 60	1896	B2t	1.6 ± 0.4	moderate	1.1 ± 0.3	0.5 ± 0.3	33	moderate
80- 95	1897	B2t*	traces	negigible	traces	traces	0.0	negligible

For explanation see under table 4.1.

* Not a micromorphological B2t horizon.

4.7 Profile EAK16

Macroscopic observations.
The groundmass is dark brown in colour in the upper 20 cm. and reddishness increases with depth to almost red at 100 cm. The material is very porous throughout the profile but is dense in the subsoil. Aggregates of red masses occur starting from 125 cm. depth. The upper 30 cm. has granular and subangular blocky structure while the 100 cm. has subangular to angular blocky structure. A few channels and aggrotubules with diameter up to 3 mm. occur throughout the profile decreasing with depth. A few isotubules can be observed in the upper 45 cm. The walls of channels and aggrotubules are comparted. A few cracks with diameter of up to 2 mm. occur starting at 15 cm.

Microscopic observations (Summary, figs. 4.13 and 4.14).
Groundmass (Summary, fig. 4.13).

Skeleton grains. There are a few skeleton grains throughout the profile. The coarse ones (> 500 µm.) are present but rare. Most of the skeleton grains are fine and medium and decrease slightly with depth. They consist of mainly quartz and sanidine feldspars. Some volcanic glass and plagioclase feldspars also occur in small amounts. The grains are all rather angular and of low sphericity. Most of them are coated with reddish iron and clay. A few are weathering to reddish material.

Voids. Most of the voids are biogenic. Voids with diameter > 2 mm. consist of a complex pattern of compound packing voids and channels which decrease considerably with depth. Smaller voids (diameter < 2 mm.) comprise of compound packing voids, channels, vughs and a few craze planes. These are randomly distributed and decrease with depth. Skew planes are more common in the section representative of the B2t horizon, especially within the dense masses.

Plasma - plasmic fabric. The plasmic fabric is predominantly undulic with sepic and asepic parts. The topsoil undulic plasma is predominantly due to organic matter while in the lower depths (> 1 m. deep) it is due to accretion of iron. Sepic parts occur from 30 cm. consisting of insepic, masepic, vosepic and omnisepic. Some fecal sepic parts also occur. The most prominent and common are the insepic and masepic plasmic fabric.

Related distribution. The related distribution is porphyroskelic to porphyric throughout the profile. It is more open in the upper 60 cm. than at lower depths.

Special features (Summary, fig. 4.14).
Reorientation. Few to common, 10-40 µm. in diameter, insepic and masepic reorientations occur clustered at the walls of channels and pedotubules, beginning at 30 cm. depth. Some are also in the groundmass and randomly distributed in the profile. Most have rather diffuse boundaries and increase considerably with depth. Some skelsepic, glaesepic, omnisepic and vosepic reorientations occur from about 45 cm. and increase with depth.

Argillans. Distinct, 10-80 µm. in diameter, channels, normal, and plane ferri-argillans occur somewhat clustered, beginning from 15 cm. The size increases with depth. At 15-60 cm. most of them are 10-50 µm. while at 125-140 cm some up to 100 cm. can be found. At this depth long continuous ferri-argillans and reorientations can be seen well associated with ped surfaces, especially in the denser, reddish matrix. The highest amount is reached at 45-60 cm. depth and continue to be high at the section of 125-140 cm. depth. The ferri-argillans have strong birefringence and are somewhat related to a certain phase of biological activity (see table 4.4).

Papules. Distinct, 10-50 µm. in diameter, rounded papules occur randomly distributed from 15 cm. depth. They have sharp boundaries and increase slightly with depth up to 60 cm. where they decrease with depth.

Nodules and concretions. Distinct, 30-150 µm. in diameter, iron and a few manganese nodules occur throughout the profile. Most are relicts inherited from the parent material but some in the subsoil (125-140 cm.) are concretions, others are iron concretions. Most have sharp boundaries but a few smaller ones have somewhat diffuse boundaries.

Pedotubules. Distinct, 0.5 to 4 mm. in diameter, matric, ortho and meta aggrotubules occur throughout the profile. Some have more organic matter than the surrounding mmatrix. There are a few faint isotubules which are not easy to distinguish from the groundmass. The aggrotubules decrease with depth but are relatively many throughout the profile. The boundaries are comparted and have vosepic to omnisepic reorientations. The older ones are affected by reorientation and illuviation while the recent ones are not affected.

Fecal pellets. Faint to distinct, 30 µm. in diameter and 100-300 µm. in diameter, welded and single fecal pellets occur throughout the profile. The larger ones are micro-aggregates (micropeds) which have been moulded by the biological activity. The amount decreases with depth but remains relatively high. Some are affected by illuviation while others are not.

Inherited features. A few partly decomposed plant remains occur throughout the profile but are more in the upper 60 cm. Aggregates of organic material form brownish specks in the upper 60 cm. and in the aggrotubules of up to 80 µm. in diameter. A few lithorelicts of volcanic glass, weathering rock fragments and ferric nodules occur throughout the profile increasing slightly with depth.

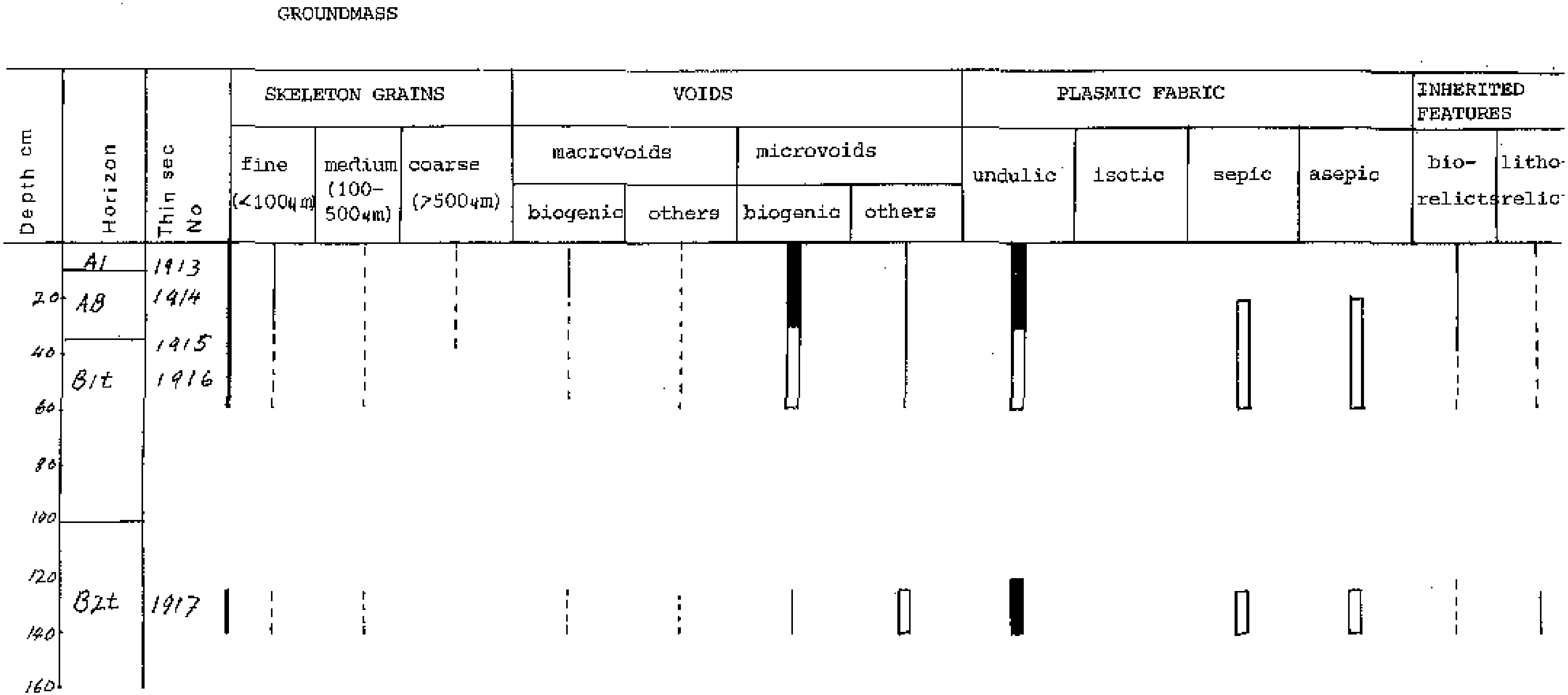


Fig. 4.13 Summary of micromorphological groundmass observations in profile EAK 16

Ranking of the features

abundant   many   common   few (for skeleton grains, voids and inherited features)

predominant   present (for plasmic fabric)

SPECIAL FEATURES

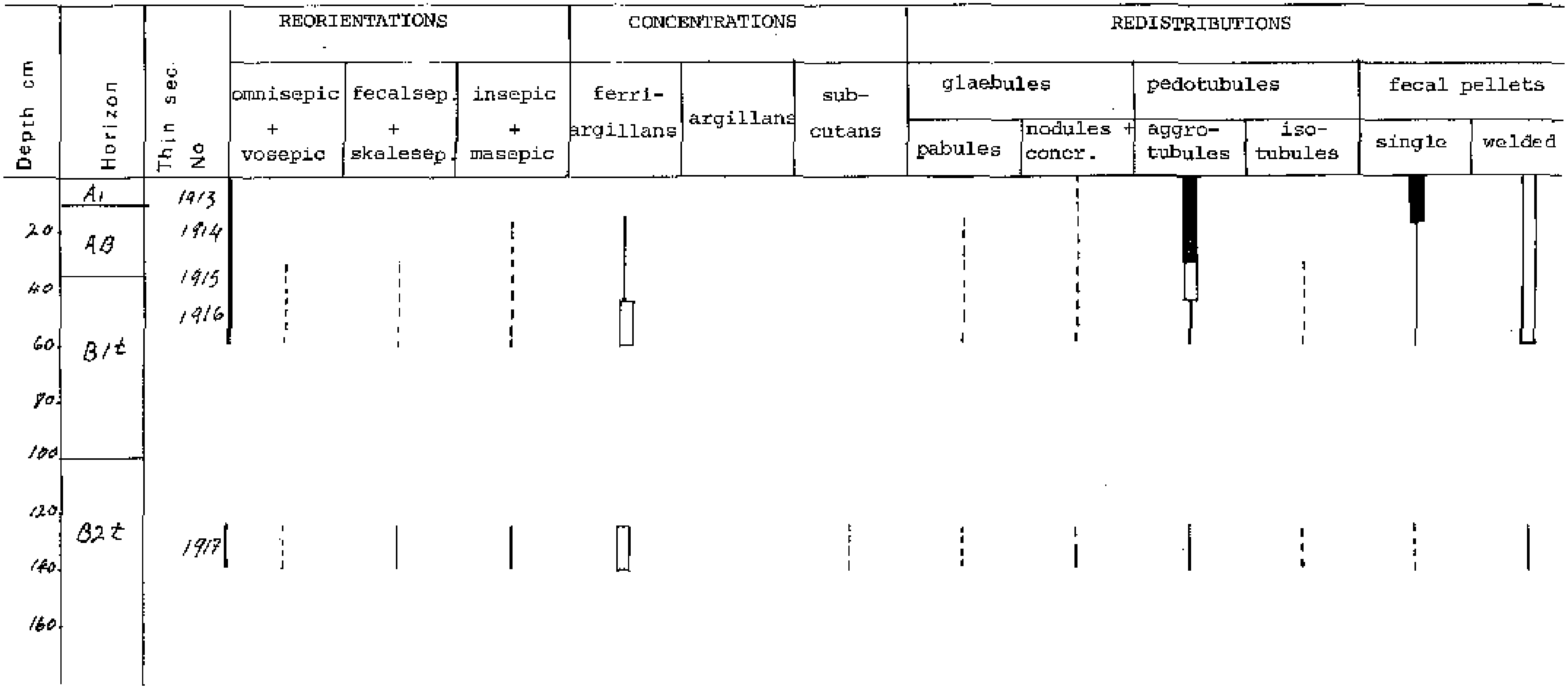


Fig. 4.14 Summary of micromorphological special features in profile EAK16

Ranking of the features

abundant many common few

Table 4.7 Degree of illuviation and biological reworking per thin section in profile EAK16.

Depth (cm)	Thin sect. number	Horizon	Total % illuv.clay	Degree of illuv.	In situ % of illuv.	% illuv. reworked biologically	Rel.% of illuv. reworked	Degree of reworking
0- 15	1913	A	0.0		0.0	0.0	0	
15- 30	1914	AB	1.3 ± 0.4	moderate	0.8 ± 0.2	0.5 ± 0.2	38	moderate
30- 45	1915	Ab/B1t	1.8 ± 0.4	moderate	1.1 ± 0.3	0.7 ± 0.3	38	moderate
45- 60	1916	B1t	2.4 ± 0.5	moderate	1.5 ± 0.3	0.9 ± 0.3	37	moderate
125-140	1917	B2t	2.4 ± 0.5	moderate	1.9 ± 0.4	0.5 ± 0.2	21	weak

For explanation see under table 4.1

5. SOIL CLASSIFICATION AND INTERPRETATION OF THE CHARACTERISTICS

5.1 Requirements of the Nitosols and Acrisols and classification of the profiles studied

The two classification systems which are most widely used are the FAO-Unesco legend (1974) and the USDA-Soil Taxonomy (1975). The Kenyan authorities experienced problems in using these two classifications for their soils and have suggested some modifications especially on the FAO-Unesco system. The profiles under investigation are classified using those two systems and the Kenyan concept as indicated by Sombroek and Siderius (1981). (See table 5.2)

A summary of the requirements of the Nitosols and Acrisols and how they are fulfilled by the profiles studied is shown in table 5.1. The classification of the profiles is shown in table 5.2.

Profiles RP1, RP2 and RP3 have umbric epipedons. Profile EAK26 has a mollic epipedon. Profiles WAN2, EAK12 and EAK16 have an orchric epipedon. All the profiles have an argillic subsurface horizon except profile RP2 which has a cambic B horizon.
Profiles RP1, RP3, EAK26 and EAK16 have the niti-argillic subsurface horizon. Most of the profiles have ferric properties due to CEC-clay being less than 240 mmol/kg.

Using the FAO-Unesco system most profiles are Acrisols because they have ferric properties except profile RP2, which is a Cambisol because it has a cambic B horizon, and profile EAK26 is a Phaeozem because it has a mollic epipedon. According to the Kenyan concept, ferric property on the basis of CEC-clay is not accepted and Nitosols are placed before Phaeozems, so they may have a mollic epipedon. Profiles RP1, RP3, EAK26 and EAK16 are Nitosols while profile WAN2 and EAK12 are Acrisols.

Chemical and particle analysis of profile RP3 indicate an argillic subsurface horizon but the micromorphological observations do not show enough illuviated clay for an argillic horizon. The horizon does not qualify for an oxic horizon because it has more than traces of weatherable minerals and CEC-clay (NH_4O-acetate at pH 7) is more than 160 mmol/kg. in most parts of the subsurface horizon. Hence it may be an intergrade of a Nitosol and Ferralsol.

By the USDA system all the profiles are oxic because of the CEC-clay (< 240 mmol/kg.) requirement. This indicates that they are strongly weathered and grade to Oxisols. However, the biological activity which is nowhere considered, counteracts degradation and weathering of the profiles. The rather high acidity in some of the profiles (RP3 and WAN2) does not show in the classification.

Key to table 5.1.

ST	=	USDA Soil Taxonomy (1975). [Requirements for Humults have been taken for Acrisols; Humults, Udalfs and Ustalfs for Nitosols].
FAO	=	FAO-Unesco legend (1974).
KEN	=	Kenyan concept (FAO-Unesco modified).
MO	=	Mollic epipedon.
Um	=	Umbric epipedon.
Ochr	=	Ochric epipedon.
A	=	Argillic (diagnostic horizon as defined in ST).
N-A	=	Niti-argillic variant of argillic horizon (Sombroek and Siderius, 1981).
Bs1	=	Base saturation (< 35 mmol/100 g.) within the depth defined in ST.
Bs2	=	Base saturation - NH_4O acetate (< 50 mmol/100 g.) within the depths defined in FAO.
Txp	=	Textural profile (no decrease of clay by more than 20% from its maximum within 1.5 m.
Rc	=	Red colours as defined in ST.
Pl	=	Plinthite as defined in ST and FAO.
Us	=	Ustic moisture regime.
Ud	=	Udic moisture regime.
Vert	=	Vertic property as defined in FAO.
Fer	=	Ferric property as defined in FAO.
Horg	=	High organic matter as defined in ST.
Isot	=	Iso-temperature regimes.
Cc	=	Illuviated clay cutans as in ST.
St	=	Subangular blocky to angular blocky structure with shiny pedfaces (Sombroek and Siderius, 1981).
*	=	must have
+	=	may or may not have
o	=	has
-	=	lacks
(-)	=	must lack

Table 5.1 Summary of the requirements of Acrisols and Nitosols in FAO-Unesco legend (1974), USDA Soil Taxonomy (ST, 1975) and Kenyan modification of FAO-Unesco system (KEN) and their fulfillments by the profiles studied.

	EPIPEDON									SUBSURFACE HORIZON			
	ST			FAO			KEN			ST	FAO	KEN	
	Mo	Um	Oc	Mo	Um	Oc	Mo	Um	Oc	A	A	A	N-A
Acrisols	+	+	+	(-)	+	+	(-)	+	+	*	*	*	+
Nitosols	+	+	+	-	+	+	+	+	+	*	*	*	*
Profile:													
RP1	-	o	-	-	o	-	-	o	-	o	o	o	o
RP2	-	o	-	-	o	-	-	o	-	-	-	-	-
*RP3	-	o	-	-	o	-	-	o	-	o	o	o	o
EAK26	o	-	-	o	-	-	o	-	-	o	o	o	o
WAN2	-	-	o	-	-	o	-	-	o	o	o	o	-
EAK12	-	-	o	-	-	o	-	-	o	o	o	o	-
EAK16	-	-	o	-	-	o	-	-	o	o	o	o	o

* See chapter 6 for discussion.

Table 5.1 continued.

OTHER CHARACTERISTIC REQUIREMENTS

ST									FAO					KEN					
Bs1	Txp	Rc	Pl	Horg	Ud	Us	Isot	Cc	Bs2	Txp	Pl	Vert	Fer	Bs2	Txp	Pl	Vert	Fer	St
*	+	+	+	*	+	+	+	+	*	+	+	+	+	*	+	+	+	+	+
+	*	+	(-)	+	+	+	+	+	+	*	(-)	(-)	(-)	+	*	(-)	(-)	+	*
o	o	-	-	o	o	-	o	o	o	o	-	-	o	o	o	-	-	o	o
o	-	-	-	o	o	-	o	-	o	-	-	-	o	o	-	-	-	o	-
o	o	-	-	o	o	-	o	o	o	o	-	-	o	o	o	-	-	o	o
o	o	-	-	o	o	-	o	o	o	o	-	-	o	o	o	-	-	o	o
o	-	-	-	-	o	-	o	o	o	-	-	-	o	o	o	-	-	o	-
-	-	-	-	-	-	o	o	o	o	-	-	-	o	o	-	-	-	o	-
-	o	-	-	o	-	o	o	o	o	o	-	-	o	-	o	-	-	o	o

Table 5.2 Complete classifications of the profiles studied according to: USDA-Soil Taxonomy (1975), FAO-Unesco (1974) and Kenyan-FAO-Unesco modified, systems.

Profile	USDA-Soil Taxonomy	FAO-Unesco	Kenyan
RP1	Fine, clayey, kaolinite, isothermic, orthoxic, Palehumult.	Humic Acrisol	Humic Nitosol
RP2	Fine, clayey, kaolinite, isothermic, oxic, Humitropept.	Ferrolic Cambisol	Dystric Cambisol
RP3	Very fine, clayey, kaolinite, isothermic, orthoxic, Palehumult.	Humic Acrisol	Humic Nitosol
EAK26	Fine, clayey, kaolinite, isothermic, oxic, Argilldall.	Luvic Phaeozem	Mollic Nitosol
WAN 2	Loamy, skeletal, mixed, isohyperthermic, orthoxic, Tropohumult.	Ferric Acrisol	Humic Acrisol
EAK12	Coarse, loamy, mixed, isohyperthermic, oxic, Paleustalf.	Ferric Acrisol	Orthic Acrisol
EAK16	Very fine, clayey, kaolinite, isothermic, oxic, Paleustalf.	Ferric Acrisol	Humic Nitosol

5.2 Interpretation and discussion of the physical and chemical characteristics of the profiles studied.

Chemical and physical characteristics of the profiles studied are shown in appendix A1 and A2. The differences between the Acrisols and Nitosols (according to the Kenyan concept) are cited hereafter.

PH. The soil acidity is said to be high if pH - H_2O is less than 5. It is high in all the profiles except profile EAK16. However, the Acrisol profiles have generally lower pH's than the Nitosol profiles especially in the subsoil. Although the connotation of Acrisols is "high" acidity, some profiles (EAK12) have pH - H_2O higher than 5 throughout the profile while some of the Nitosol profiles (RP3, EAK26) have pH lower than 5 in most parts of the profile depths.

Base saturation and exchangeable cations. The base saturation is required to be less than 50% (by NH_4O-acetate) in at least a part of B horizon within 125 cm. for Acrisols in FAO-Unesco (1974) and < 35% within defined depths (critical depths) for Ultisols in USDA-Soil Taxonomy (1975). The limits are not necessary for Nitosols. The base saturation is low in most of the profiles except profile EAK16. Profile EAK12 does not qualify to be a Humult because it has base saturation higher than 35% in most parts of the B horizon. The Acrisol profiles have generally lower base saturation in at least parts of the B horizon than the Nitosol profiles. But Nitosol profiles with low pH have rather low values also. The sum of the exchangeable cations shows a good difference between the Acrisol and the Nitosol profiles (see tables A1.2 and A2.2).

Cation exchange capacity. The CEC-NH_4O-acetate at pH 7 of the topsoil varies very much from profile to profile due to its dependence on organic matter content. no specific CEC limits are stated for Nitosols or Acrisols in all classification systems used here. The CEC in the subsoil is generally higher in the Nitosol profiles than the Acrisol profiles. The Nitosol profiles have CEC higher than 120 mmol/kg.soil throughout the profiles while the Acrisol profiles have values lower than 100 mmol/kg.soil in most parts of the subsurface horizons.
The CEC-clay is required to be less than 24 mmol/100 g. (240 mmol/kg.clay) for oxic intergrade in USDA-Soil Taxonomy (1975) and same value for the ferric property in FAO-Unesco (1974). The Nitosol profiles have CEC-clay (corrected for organic matter) higher than 130 mmol/kg.clay while the Acrisol profiles have values which are lower than 130 mmol/kg.clay in at least part of the subsurface horizons. The CEC-clay, uncorrected for organic matter is higher than 160 mmol/kg. in the Nitosol profiles and lower than 140 mmol/kg. in the Acrisol profiles within the critical depths.
It should be noted that there is no direct method for measurement of CEC-clay. It is calculated on the basis of clay content, CEC-soil, and organic matter content. This method may not be good for some soils, especially those with high organic matter content, very high clay content and high alluminium and iron oxides.

Organic matter content. The organic matter content (on the basis of organic carbon) vary from profile to profile in the upper 50 cm. High organic matter content (> 0.9% org. carbon, or 12 kg. org. carbon/m^3 [4]

is required for Humults in USDA-Soil Taxonomy (1975). There is significant difference between the Acrisol and Nitosol profiles except profile EAK16, which has quite a high organic matter content in the topsoil. This is in contradiction to the ochric epipedon found due to the colour requirements of the mollic and umbric epipidon which are not satisfied.

Particle size analysis. The niti-argillic horizon is required to have clay content higher than 35% throughout its depth. The Nitosols should not have clay profiles that decrease by more than 20 % from its maximum within 150 cm. depth. The Nitosol profiles have much higher clay content than the studied Acrisol profiles.The clay bulges to depths greater than 150 cm. in the Nitosol profiles and not in the Acrisol profiles. The studied Nitosol profiles have more than 50% clay while the Acrisol profiles have less than 35% clay throughout the profile depths.

Moisture retention. The moisture contents at various pF values depend on the clay content. The Nitosol profiles have higher moisture contents at various pF values than the Acrisol profiles. The moisture contents at pF 4.2 correlates very well with clay content within and among the profiles.

Silt/clay ratio. The silt/clay ratio is required to be less than 0.4 for the niti-argillic horizon. Most profiles have low silt/clay ratios (< 0.4) in the subsurfece horizon. No difference can be shown between the Nitosol and Acrisol profiles.

Mineralogy of the clay fraction. All the profiles have kaolinite as the predominant clay mineral. They have low amounts or traces of illite and smectite. Goethite, feldspars and quartz are present in most of the profiles as traces or very low amounts according to x-ray analysis.
Thermal analysis and electron microscopy reveal that there is a large proportion of the clay fraction which consists of halloysite in profiles RP1, RP2 and RP3. This explains the micro-reorientations observed micromorphologically, since halloysite is capable of swelling and shrinking to a small extent. It also confirms the effect of volcanic glass on these soils since halloysite usually forms from volcanic ash.

5.3 Interpretation of the micromorphological observations

Introduction

The interpretation of morphological and micromorphological features has to be aided by a set of chemical, mineralogical and physical data on each sample to arrive at an understanding of the soil (Caby, 1973). The kinds of soil forming processes that have been operative can be inferred directly from the micromorphological structure and fabric if sufficient background data are available (Brewer, 1964).
The profiles studied here are relatively old and hence might have undergone several cycles of soil formation. Several soil forming processes can be inferred from the micromorphological structures and fabric analysis. The processes which are more or less clearly interpretable by the observed features and the way in which they are seen in the Nitosol and Acrisol, (according to the Kenyan concept) are briefly described hereafter.

Weathering and soil formation. Physical and chemical weathering are the initial soil forming processes which continue to operate at different rates for a long time. The intensity of weathering (both physical and chemical) is estimated from the ranking and presence of the following features:

1. presence of weatherable minerals such as volcanic glass, micas, feldspars and pyroxenes,
2. presence of lithorelicts,
3. appearance of the skeleton grains (whether clean, coated or filled in the cracks, partings and cleavages).

In addition, the horizon sequence is considered to indicate the degree of soil development.
All the profiles have a ABC horizon sequence. They all have a few weatherable minerals especially feldspars and volcanic glass except profile EAK12 which does not have volcanic glass. They all have a few lithorelicts and the skeleton grains appear quite weathered except in the subsoil of profile WAN2. (See figures 4.1 to 4.14). Hence the profiles are rather strongly weathered. The presence of lithorelicts and weatherable minerals is due to biological homogenisation and pedoturbation. No difference can be distinguished between the Acrisol and the Nitosol profiles except that in profile EAK12 there are relatively fewer lithorelicts and the skeleton grains are rather bare. The profile appears more strongly weathered but this may be due to the rather poor parent material.

Biological activity. Soil faunal and floral activity is inferred from the following features.

1. biogenic pores (compound packing voids, vughs, channels, and chambers);
2. papules, as an indication of biological reworking of clay illuviation,
3. pedotubules and fecal pellets,
4. plant remains (biorelicts) and organic matter aggregates as an indication of floral activity.

The biological activity is high in the topsoil of all the profiles and decreases with depth. Faunal homogenisation and pedoturbations are observed up to the sampled depth in all the profiles. Floral activity is relatively less in profile EAK12. The biological activity counteracts the degree of weathering by bringing the less weathered material from subsoil and saprolite depths to the upper parts of the profiles, hence somewhat rejuvenating the profiles . No differences can be observed between the Acrisol and the Nitosol profiles in the degree of biological activity. However if depths are considered, biological activity operates over greater depths in Nitosols than in Acrisols.

Illuviation. Illuviation is inferred from the argillans and ferri-argillans which have been quantified in chapter 4. Papules are also an indication of illuviation and are summed up with ferri-argillans to give the total illuviation indication.
Table 5.3 shows the illuviation indexes calculated according to Miedema and Slager (1972). the upper limit of the illuvial horizon is assumed to be the beginning of the Bt horizon as described in the field and the lower limit is saprolite depth or depth at which the linearly extrapolated line of the amount of illuviation intersects the depth axis.

Table 5.3 Illuviation indices of the studied profiles, according to Miedema and Slager (1972).

Profile	Class.	In situ illuv.index	Reworked illuv.index	Total illuv.index	Designation
EAK26	M-N	166	41	207	low
RP1	H-N	118	86	204	low
RP3	H-N	36	72	108	low
EAK16	H-N	321	98	418	moderately high
WAN2	H-A	192	86	278	low
EAK12	O-A	52	26	78	low
RP2	D-C	0	0	0	

Class. = classification
M-N = Mollic Nitosol
H-A = Humic Acrisol
D-C = Dystric Cambisol.
illuv. = illuviation
H-N = Humic Nitosol
O-A = Orthic Acrisol

Illuviation is significant in all profiles. In some profiles (WAN2, EAK12, and EAK26) illuviation features are associated with a certain generation of biological activity. The older and mosty recent biological activity is not affected by the illuviation features. The ferri-argillans are all assumed to be translocated by illuviation but in profile WAN2 some of ferri-argillans and papules are derived directly from the weathering in situ skeleton grains. Ferri-argillans which are distinctly continuous along ped faces are observed only in profile EAK16, RP1 and RP3.
In the other profiles the ferri-argillans are associated with voids but are not distinctly indicative of shiny ped faces. The maximum amounts per thin section are greater than 1.5 in all the profiles except profile RP2 and no difference in amount can be shown between the Acrisol and the Nitosol profiles. The illuviation indices are higher in the Nitosol profiles than the Acrisol profiles. The high illuviation index in profile WAN2 may be due to the over estimation of the amount of illuviation due to ferri-argillans derived from the skeleton grains weathering in situ. The maximum amount of illuviation is reached at less than 100 cm. in Acrisol and lower than 100 cm. in Nitosol profiles (see table 4.1 to 4.7).

Leaching, desilication and ferrallitisation. These three processes occur together. Leaching (loss of bases) and desilication (loss of silicates and silica) leads to enrichment of the profile with iron and alluminium oxides which may concentrate to form nodules if conditions are favourable (ferrallitisation). These processes can be inferred from the following features:

1. undulic and isotic plasmic fabric, which can not be attributed to organic matter,
2. presence of reddish aggregates as an indication of rubefaction,
3. illuviation and degree of weathering: a profile which is undergoing illuviation must have undergone leaching and

eluviation at least in the upper parts and a strongly weathered profile is usually strongly leached and desilicified,

4. presence of recrystallized silica in the subsoil.

All the profiles have undulic plasmic fabric which is stronger in the topsoil. They are all iluviated. Profiles WAN2 and EAK26 have some recrystallized silica in the form of chert. Features of rubification are observed in most profiles and are rather distinct in profile EAK16. Hence the profiles are quite higly leached and desilicified. The rather higher base saturation in profiles EAK12 and EAK16 contradicts this interpretation. In profile EAK16 it may be attributed to the enrichment of the profile with volcanic ash. There is no difference that can be shown between the Acrisol and Nitosol profiles. Ferrallitisation is significant in all the profiles. The degree of ferrallitisation may be higher in the Acrisol than in the Nitosol profiles considering the intensity of the undulic plasmic fabric in the subsoil.

Swelling and shrinking. The features attributed to swelling and shrinking are:

1. masepic, vosepic, skelsepic and omnisepic plasmic fabric,
2. skew planes and joint planes (physiogenic pores),
3. micro-cracks in the ferri-argillans.

All the profiles show some degree of weak swelling and shrinking. The features are better expressed in Nitosol profiles, where a few vosepic and masepic plasmic fabrics occur, than in Acrisols, where these features are lacking or rare. There is more insepic fabric in Nitosol than in Acrisol profiles.

Gleying and pseudogleying. The following features are indicative of gleying and pseudogleying.

1. neoferrans,
2. ferric and/or manganese nodules with diffuse boundaries.

All the profiles are well drained except profile WAN2 in which some gleying features (neoferrans) are seen at 160 cm depth. However, all the profiles have a few small ferric nodules with somewhat diffuse boundaries. These may be due to pseudogleying but they may also be due to rubification.
No difference can be shown for the Acrisol and the Nitosol profiles but it can be stated that Nitosol profiles do not show any significant gleying or pseudogleying within 150 cm. depth.

Chronosequence of the processes. The sequence in which the soil forming processes take place is similar in all the profiles. it is evident that biological activity preceeds the illuviation because some illuviation features occur in biogenic voids. Normally leaching and desilication preceeds illuviation and ferrallitisation. Physical and chemical weathering is necessary to create porosity before leaching, desilication and illuviation takes place. A phase of biological homogenisation and pedoturbation follow illuviation because some of the illuviation features are reworked (papules). Hence the sequence of the processes is postulated as follows:

1. initial physical and chemical weathering of the parent material;
2. biological perforation;
3. leaching and desilication;

4. swelling and shrinking;
5. illuviation, eluviation, rubefaction and ferrallitisation;
6. biological homogenisation and pedoturbation;
7. gleying of the subsoil.

Biological homogenisation and pedoturbatiuon delays the degradational processes while biological perforation enhances other processes such as leaching and desilication. In profiles EAk26, WAN2, RP1, RP2 and RP3 addition of volcanic ash is observed from the presence of volcanic glass. This interrupted the soil formation and rejuvenated the profiles. The profiles are polygenetic and may have undergone several cycles of soil formation.

6. DISCUSSION AND CONCLUSIONS BASED ON MICROMORPHOLOGICAL OBSERVATIONS

Macroscopic observations.
The Nitosol profiles show a difference in some macroscopic observations, from the Acrisol profiles. While the Acrisol profiles may have a macro-structureless topsoil and part of the subsoil horizons, the Nitosol profiles have strong granular, subangular blocky to angular blocky structure throughout the profiles up to 1.5 m. depth.

Groundmass.
In the profiles studied the Acrisol profiles are very light textured while the Nitosol profiles are rather heavy (clayey) textured. This difference has an effect in most groundmass fabric analyses. It should be noted that Acrisols can also be clayey and this difference in texture is just a coincidence. However, Nitosols are usually clayey. Light textured Nitosols have not been reported.

Voids. The groundmass is very porous in all the profiles. The pores are predominantly biogenic but the Nitosol profiles have most physiogenic pores especially in the subsoil. This may be due to higher plasma content in the Nitosol than in the Acrisol profiles.

Plasma. The plasmic fabric is undulic to sepic and asepic in all the profiles. The anistrophy is due to organic matter in the topsoil and more due to weathering and rubefaction in the subsoil. The Nitosol profiles have more in amount of sepic plasma than the Acrisol profiles in the subsoil. The intensity if orientation is also stronger in the Nitosol profiles than in the Acrisol profiles.

Related distribution. The Acrisol profiles have agglomeroplasmic and intertexic to porphyric related distribution. The Nitosol profiles lack agglomeroplasmic and intertexic distribution and instead have porphyric to porphyroskelic related distribution. This may be attributed to the texture rather than to genesis. The high amount of plasma in Nitosol profiles would not allow intertexic related distribution.

Special features.
Reorientation. As stated in chapter 5.3 reorientation features are more in amount and well expressed in the Nitosol profiles than in the Acrisol profiles. Hence micro swelling and shrinking is more significant in the Nitosol than in the Acrisol profiles. These may be responsible for the strongly developed structure in the Nitosol profiles. Some of the re-orientation features as vosepic and masepic plasmic may be the features described as shiny ped faces.

Redistribution. no difference can be shown between the Nitosol and Acrisol profiles in amount and degree of redistribution. However, biological homogenisation and pedoturbation can be observed up to depths greater than 1.5 m. in Nitosol profiles. In some of the Acrisol profiles the biological homogenisation is limited by the profile depth.

Glaebules. No difference can be shown between the Nitosol and Acrisol profiles in amount or appearance of nodules except that the Nitosol profiles do not show significant gleying within 1.5 m. Profile WAN2

(Acrisol) shows some gleying features within 160 cm. depth. The nodules may be indicative of ferric property. In this case they should be well defined to indicate the ferric limit.

Concretions (argillans and ferri-argillans). The amount of oriented translocatedclay (% by point counting) does not show a difference between the Acrisol and the Nitosol profiles. The appearance, thickness and distribution pattern of the ferri-argillans is more or less the same in all the profiles. However the profile illuviation index (in cm.) is higher in some of the Nitosol profiles than in the Acrisol profiles. The profile illuviation index is greater than 200 (except in profile RP3) in Nitosol profiles and can be lower than 200 in the Acrisol profiles (e.g. profile EAK12). Some of the Nitosol profiles (EAK16 and RP3) have channel and plane ferri-argillans which are long and continuous on ped faces. These features have not been seen on Acrisol profiles. All the Nitosol profiles have strong masepic and vosepic reorientations. These are rare or lacking in Acrisol profiles.
This type of ferri-argillans and the masepic and vosepic reorientations may be the so called shiny ped faces. They occur clustered in the denser parts of the thin sections. The amount is relativelysmall and may not account for the shiny ped faces described in the field profile description. Further investigations are necessary to identify and quantify the shiny ped faces and find out whether they can be used to characterize and differentiate the Nitosols.

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APPENDIX A1

Table A1.1 Physical characteristics of profiles RP1, RP2 and RP3

Depth (cm.)	Particle size analysis (weight %) sand	silt	clay	si/c ratio	Moisture content at pF 4.2 (weight %)
Profile RP1					
0- 20	18	28	54	0.5	24.7
20- 40	18	30	52	0.6	26.4
40- 60	16	24	60	0.4	27.3
60- 80	12	16	72	0.2	28.9
80-100	12	12	76	0.2	30.6
100-120	14	10	76	0.1	30.2
120-140	14	12	74	0.2	30.9
140-160	14	12	74	0.2	29.9
160-180	14	12	74	0.2	30.6
180-200	12	12	76	0.2	30.6
Profile RP3					
0- 20	20	24	56	0.4	29.4
20- 40	16	20	64	0.3	29.4
40- 60	12	18	70	0.3	30.3
60- 80	12	16	72	0.2	30.5
80-100	14	10	76	0.1	31.4
100-120	10	10	80	0.1	32.6
120-140	14	6	80	0.1	32.7
140-160	12	8	80	0.1	32.6
160-180	12	8	80	0.1	32.5
180-200	12	8	80	0.1	32.6
Profile RP2					
0- 20	24	20	56	0.4	20.5
20- 40	22	18	60	0.3	20.8
40- 60	24	16	60	0.3	21.1
60- 80	24	14	62	0.2	20.9
80-100	24	16	60	0.3	23.7
100-120	30	14	56	0.3	20.8

APPENDIX A1

Table A1.2 Chemical characteristics of profile RP1.

Depth (cm.)	Org.C (%)	N (%)	C/N ratio	pH H_2O	pH KCl	EC[1)]	Exchangeable bases (mmol/kg.) ½Ca^{2+}	½Mg^{2+}	K^+	Na^+	Sum	CEC[2)]	BS (%)
0- 20	2.87	0.32	9	4.7	3.9	0.05	33	0.8	2.6	2.5	39.9	304	13
20- 40	2.42	nd	nd	4.9	4.1	0.05	42	0.6	2.8	1.9	46.9	252	18
40- 60	2.13	nd	nd	5.0	4.8	0.05	42	0.6	2.4	1.7	46.7	214	22
60- 80	1.27	nd	nd	5.0	4.2	0.05	42	0.8	2.4	1.0	46.6	156	30
80-100	0.73	nd	nd	4.9	4.3	0.05	38	1.0	2.2	1.0	42.2	166	26
100-120	0.44	nd	nd	5.2	4.3	0.02	32	0.5	1.8	1.2	35.5	170	20
120-140	0.50	nd	nd	5.3	4.1	0.02	30	0.2	2.4	1.5	35.5	148	24
140-160	0.41	nd	nd	5.3	4.3	0.02	30	0.2	2.8	1.8	37.1	152	24
160-180	0.35	nd	nd	4.8	4.1	0.03	34	1.0	2.6	1.9	39.5	128	31
180-200	0.32	nd	nd	4.7	4.2	0.03	32	1.5	2.4	1.6	37.5	128	29

1) in mmhos/cm.
2) CEC NH_4O-acetate at pH 7 in mmol/kg.
nd = not determined.

APPENDIX A1

Table A1.3 Chemical characteristics of profile RP2.

Depth (cm.)	Org.C (%)	N (%)	C/N ratio	pH H_2O	pH KCl	EC[1]	Exchangeable bases (mmol/kg.) ½Ca^{2+}	½Mg^{2+}	K^+	Na^+	Sum	CEC[2]	BS (%)
0– 20	1.8	0.2	8.2	4.9	3.8	0.05	20	0.9	4.2	1	26	186	14
20– 40	1.6	nd	nd	4.9	3.8	0.02	24	1.0	2.2	1.8	29	128	23
40– 60	0.9	nd	nd	5.1	4.1	0.01	24	1.0	2.0	1.8	29	94	31
60– 80	0.6	nd	nd	5.1	4.2	0.01	28	1.0	1.6	1.6	30	76	40
80–100	0.5	nd	nd	5.3	3.9	0.01	26	1.4	1.8	1.9	31	88	35
100–120	0.5	nd	nd	5.4	4.8	0.01	26	1.1	1.6	2.0	31	100	31

1) in mmhos/cm.
2) CEC NH_4O-acetate at pH 7 in mmol/kg.
nd = not determined.

APPENDIX A1

Table A1.4 Chemical characteristics of profile RP3.

Depth (cm.)	Org.C (%)	N (%)	C/N ratio	pH H_2O	pH KCl	EC[1)]	Exchangeable bases (mmol/kg.) ½Ca^{2+}	½Mg^{2+}	K^+	Na^+	Sum	CEC[2)]	BS (%)
0- 20	3.24	0.33	10	4.9	4.1	0.15	54	5.1	4.0	3.2	66.2	216	31
20- 40	1.92	nd	nd	4.9	4.0	0.05	30	1.3	3.2	2.3	36.7	232	15
40- 60	1.39	nd	nd	4.7	4.0	0.04	26	0.9	1.6	1.0	29.5	206	14
60- 80	1.27	nd	nd	4.9	3.9	0.02	30	0.8	1.5	1.8	34.1	158	22
80-100	1.09	nd	nd	4.9	3.9	0.02	24	0.8	1.5	1.6	27.9	126	22
100-120	0.71	nd	nd	4.6	3.9	0.04	30	Tr	1.6	1.0	32.6	110	30
120-140	0.65	nd	nd	4.4	3.9	0.07	28	0.6	1.8	1.8	32.2	130	25
140-160	0.47	nd	nd	4.5	4.0	0.07	28	0.8	1.4	1.2	31.4	122	26
160-180	0.65	nd	nd	4.7	4.0	0.04	37	Tr	1.6	1.5	40.1	106	38
180-200	0.41	nd	nd	5.5	4.0	0.02	44	0.8	2.2	2.0	48	128	38

1) in mmhos/cm.
2) CEC NH_4O-acetate at pH 7 in mmol/kg.
nd = not determined.

APPENDIX A1

Table A1.5 CEC-clay for profiles RP1, RP2 and RP3:
1) uncorrected for organic matter
2) corrected for organic matter.

Profile	Depth (cm.)	CEC-clay 1) (mmol/kg)	Org.carbon (g/kg clay)	CEC-clay 2) (mmol/kg)
RP1	0- 20	553	53	153
	20- 40	485	46	135
	40- 60	352	35	86
	60- 80	217	18	80
	80-100	205	10	129
	100-120	224	6	170
	120-140	200	7	147
	140-160	205	6	159
	160-180	180	5	142
	180-200	168	4	138
RP2	0- 20	332	32	66.4
	20- 40	213	26	3*
	40- 60	157	15	33
	60- 80	125	10	40
	80-100	147	8	89
	100-120	178	9	103
RP3	0- 20	386	58	17*
	20- 40	369	30	81
	40- 60	311	20	119
	60- 80	219	18	46
	80-100	156	14	22
	100-120	138	9	52
	120-140	162	8	85
	140-160	152	6	95
	160-180	132	8	55
	180-200	160	5	112

* Too low values.

APPENDIX A2

Table A2.1 Physical characteristics of profiles WAN2, EAK26, EAK12 and EAK16.

Depth (cm.)	Bulk density ($g.cm^{-3}$)	Particle size analysis (W%) Sand	Silt	Clay	Si/c ratio	Moisture content at pF 2	3	4.2
			Profile WAN2					
0- 16	nd	78.9	6.7	14.4	0.5	23.7	12.9	8.8
15- 30	1.49	85.3	4.1	10.4	0.4	21.4	10.4	8.0
55- 70	1.44	69.7	4.9	26.8	0.2	nd	nd	nd
83- 98	1.51	76.1	3.8	26.1	0.2	22.1	15.0	9.4
120-135	nd	76.2	4.9	18.7	0.3	nd	nd	nd
160-165	nd	42.2	35.2	22.2	1.6	nd	nd	nd
			Profile EAK26					
0- 20	1.20	5.3	36.2	56.8	0.6	38.2	nd	18.3
20- 40	1.17	7.1	42.7	50.2	0.8	40.5	nd	nd
40- 60	1.14	6.1	32.4	61.4	0.5	40.5	nd	nd
60-100	1.10	5.9	27.5	66.7	0.4	40.5	nd	27.0
100-150	nd	5.0	26.6	68.5	0.4	nd	nd	24.9
			Profile EAK12					
0- 15	1.31	80.4	6.8	12.8	0.5	13.7	nd	6.6
15- 30	nd	72.4	8.1	19.0	0.4	nd	nd	nd
30- 45	nd	63.9	5.1	31.3	0.2	nd	nd	nd
45- 90	1.33	59.0	3.6	37.4	0.1	nd	nd	nd
90-150	nd	58.8	4.4	36.8	0.1	37.0	nd	14.3
150-220	nd	59.7	6.6	33.6	0.2	nd	nd	nd
			Profile EAK16					
0- 10	nd	3.9	19.3	74.8	0.3			
10- 35	nd	11.8	15.6	72.6	0.2			
35-100	nd	5.4	13.0	81.6	0.2			
100-150	nd	1.5	8.2	90.3	0.1			

nd = not determined.

APPENDIX A2

Table A2.2 Chemical characteristics of profiles WAN2, EAK26, EAK12 and EAK16.

Depth (cm.)	Org.C 1)	pH-H_2O	pH-KCl	Exchangeable cations 2) ½Ca	½Mg	K	NA	Sum	CEC 3)	BS
				Profile WAN2						
0- 16	2.7	4.6	3.9	22	6	4	nd	32	104	31
15- 30	2.4	4.5	3.7	9	2	3	nd	14	92	15
55- 70	nd	4.6	3.9	5	1	2	nd	8	57	15
83- 98	0.4	5.0	3.8	6	3	2	nd	11	61	18
120-125	0.3	4.9	3.8	5	3	4	nd	12	74	16
160-165	0.6	5.0	4.1	10	10	2	nd	22	52	42
				Profile EAK26						
0- 20	4.87	5.4	4.5	105	15	20	nd	140	199	70
20- 40	3.42	5.4	4.4	47	37	8	nd	92	141	64
40- 60	2.40	5.3	4.5	45	34	8	nd	87	176	49
60-100	1.39	5.1	4.5	31	27	13	nd	71	149	48
100-150	0.64	4.8	4.2	57	23	9	nd	59	161	55
				Profile EAK12						
0- 15	0.61	5.8	5.2	12	9	2	1	24	45	53
15- 30	0.45	5.9	5.2	16	7	4	1	28	49	57
30- 45	0.31	5.8	4.8	22	7	1	3	33	60	55
45- 90	0.18	5.1	4.1	10	12	1	3	26	60	42
90-150	0.16	4.8	4.6	12	8	2	2	24	50	48
150-220	0.11	5.1	4.3	32	16	7	1	30	49	100+
				Profile EAK16						
0- 10	6.17	6.4	5.3	128	81	29	0	228	309	77
10- 35	2.66	6.7	4.0	32	28	23	1	84	186	45
35-100	0.86	5.7	4.3	40	33	10	1	84	147	57
100-150	0.12	5.4	4.0	24	31	8	0	63	122	52

1) in mass %.
2) in mmols/kg.
3) CEC-NH_4O-acetate at pH 7.

nd = not determined.

Table A2.3 Elemental analysis and derived molar ratios of fine earth (for profile WAN2) and clay fraction (for profiles EAK12 and EAK16).

Depth (cm.)	Mass % of some oxides			Derived molar ratios		
	SiO_2	Al_2O_3	Fe_2O_3	SiO_2/ ½Al_2O_3	Al_2O_3/ Fe_2O_3	SiO_2/ ½Al_2O_3 + ½Fe_2O_3
Profile WAN2 (in fine earth fraction)						
0- 16	79.1	9.3	3.1	7.1	4.7	5.9
15- 30	80.4	9.4	3.2	7.2	4.6	5.9
55- 70	81.0	10.4	3.6	6.5	4.5	5.4
83- 98	73.6	14.4	3.1	4.3	7.3	3.7
120-135	78.4	11.2	4.6	5.9	4.4	4.8
160-165	nd	nd	nd	nd	nd	nd
Profile EAK12 (in clay fraction)						
0- 15	40.3	31.6	8.8	1.1	5.6	0.9
15- 30	40.8	32.7	8.6	1.1	5.9	0.9
30- 45	40.9	33.5	8.4	1.0	6.2	0.9
45- 90	41.0	33.3	8.2	1.0	6.4	0.9
90-150	41.0	33.7	8.1	1.0	6.5	0.9
150-220	40.4	33.3	8.2	1.0	6.4	0.9
Profile EAK16 (in clay fraction)						
0- 10	39.1	28.9	16.5	1.2	2.9	0.7
10- 35	40.2	30.4	16.3	1.1	2.9	0.8
35-100	38.5	29.9	16.3	1.1	3.1	0.8
100-150	37.5	31.6	14.6	1.0	3.4	0.8

nd = not determined.

APPENDIX A2

Table A2.4 Calculated CEC-clay and organic carbon per kg.clay: (1) uncorrected for organic matter and (2) corrected for organic matter.

Profile	Depth (cm.)	CEC-clay (1) mmol/kg.clay	Org.carbon g./kg.clay	CEC-clay (2) mmol/kg.clay
WAN2	0- 16	722	188	197
	15- 30	885	230	242
	55- 70	215	nd	nd
	83- 98	303	20	247
	120-135	396	16	351
	160-165	234	27	154
EAK26	0- 20	350	86	202
	20 40	281	68	164
	40- 60	287	39	220
	60-100	224	21	188
	100-150	235	9	219
EAK12	0- 15	352	48	122
	15- 30	259	24	144
	30- 45	192	10	144
	45- 90	160	5	136
	90-150	133	4	117
	150-220	145	3	131
EAK16	0- 10	413	82	136
	10- 35	256	37	131
	35-100	180	11	142
	100-150	135	1	132

Table A2.5 linear regression values of CEC-clay and CEC-organic matter.

Profile	Corr.coef.	CEC-clay (meq./kg.)	CEC-organic matter (meq./kg.)
WAN2	0.97	239	1620
EAK26	0.90	198	499
EAK12	0.99	132	2784
EAK16	0.99	135	1457
RP1	0.98	136	4357
RP2	0.89	55	4814
RP3	0.88	96	4041

APPENDIX A3

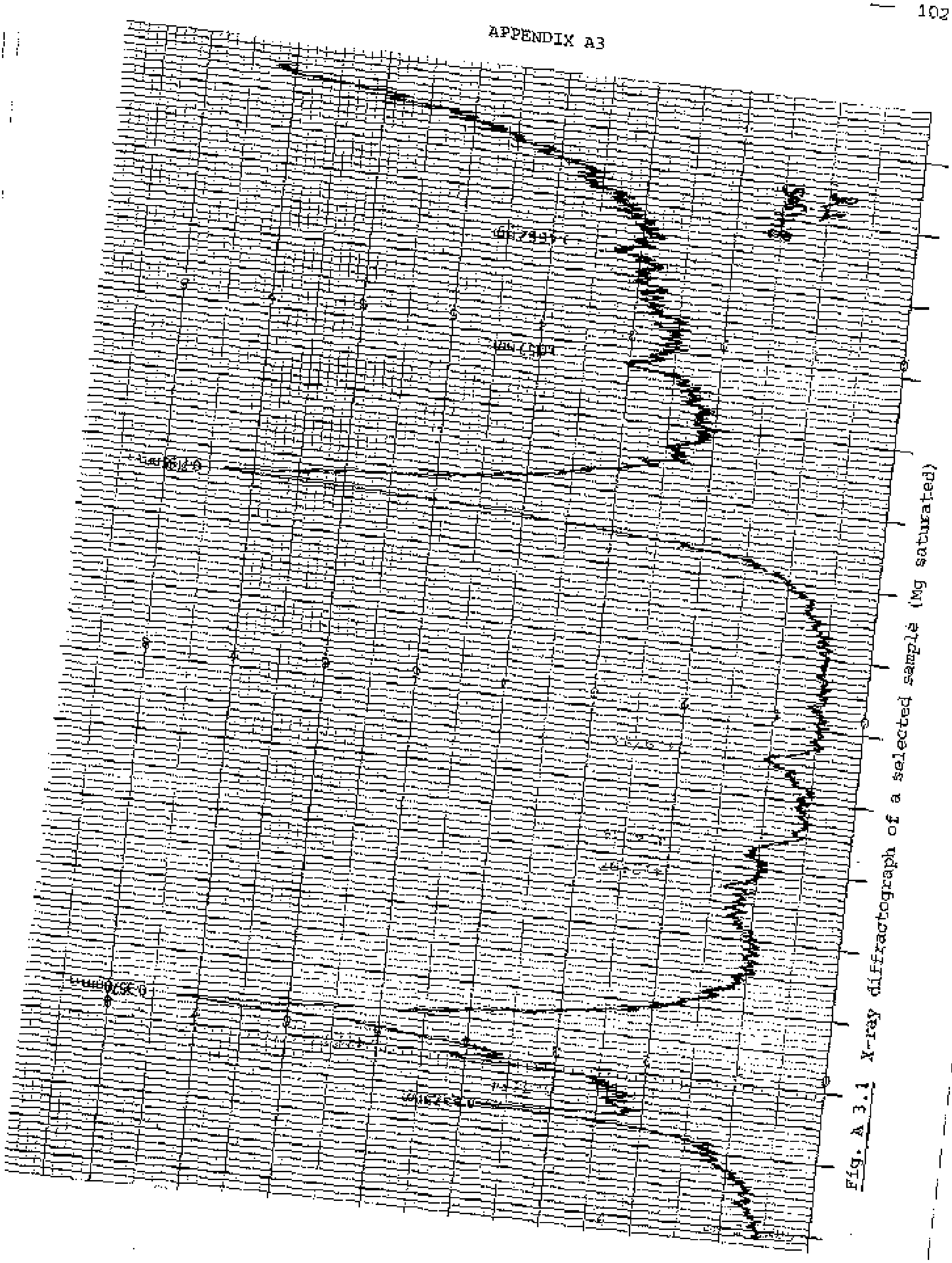

Fig. A 3.1 X-ray diffractograph of a selected sample (Mg saturated)

APPENDIX A3

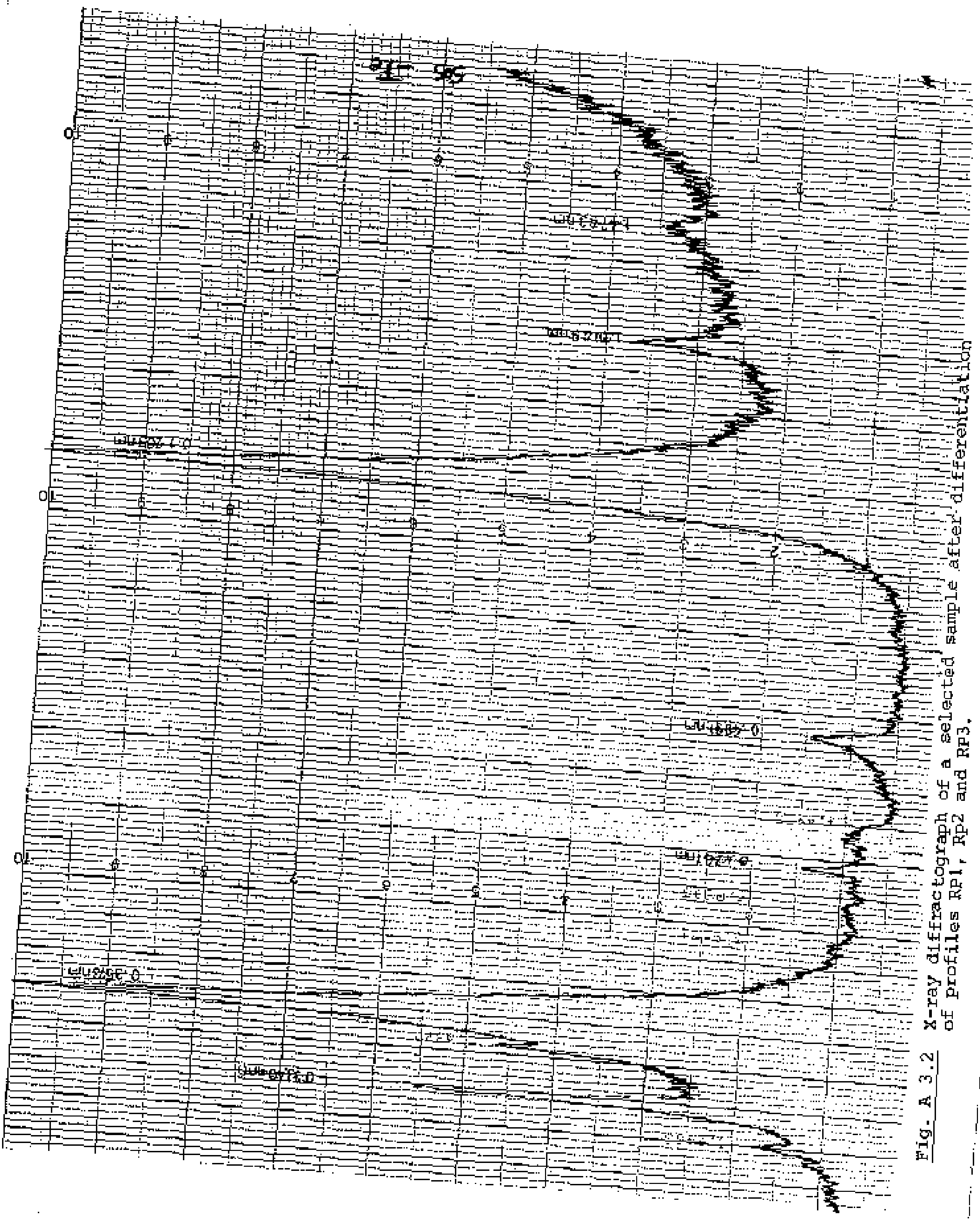

Fig. A 3.2 X-ray diffractograph of a selected sample after differentiation of profiles Rp1, Rp2 and Rp3.

APPENDIX A3

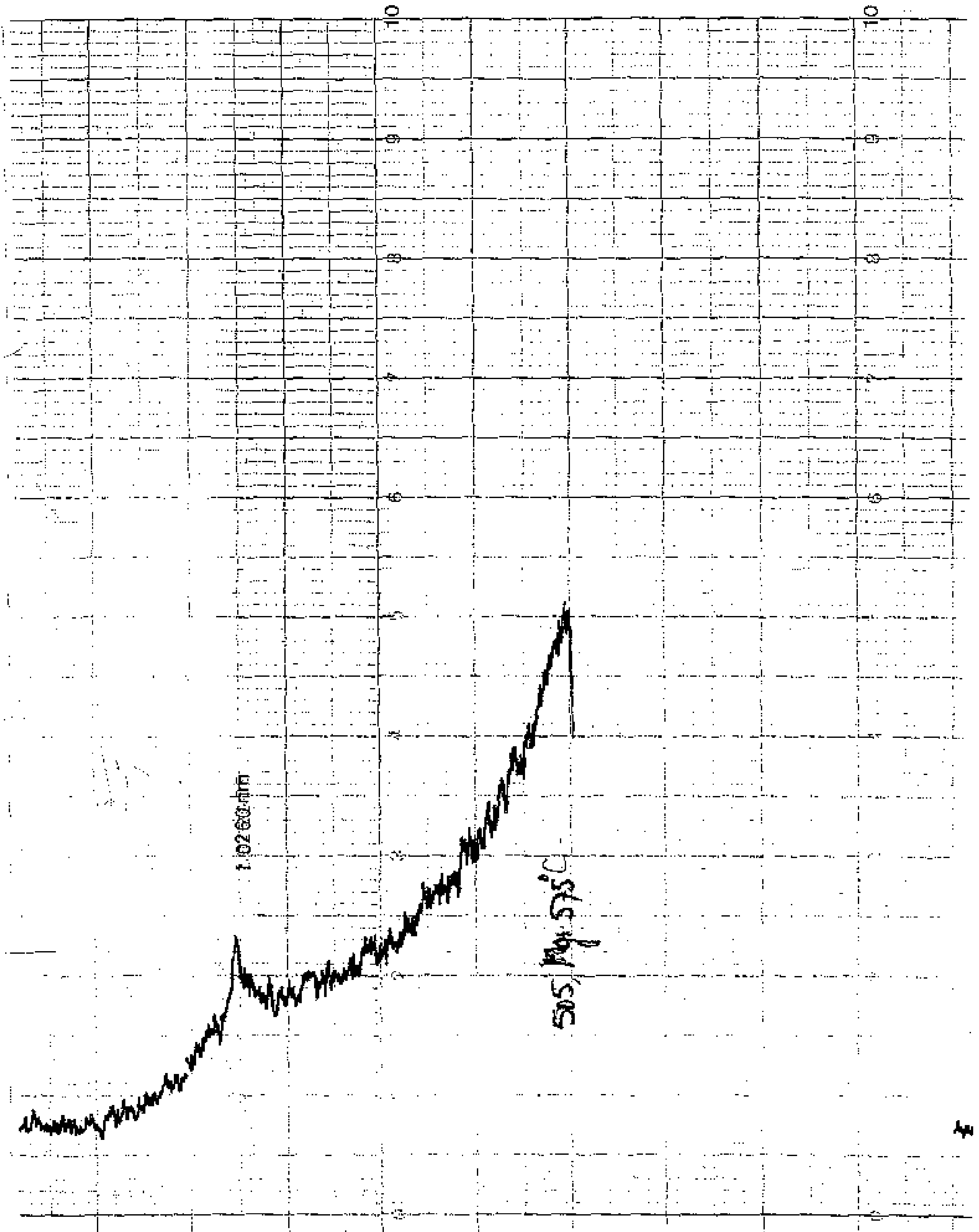

Fig. A 3.3 X-ray diffractograph of a selected sample after heating at 575 °C, of profiles RP1, RP2 and RP3.

APPENDIX A3

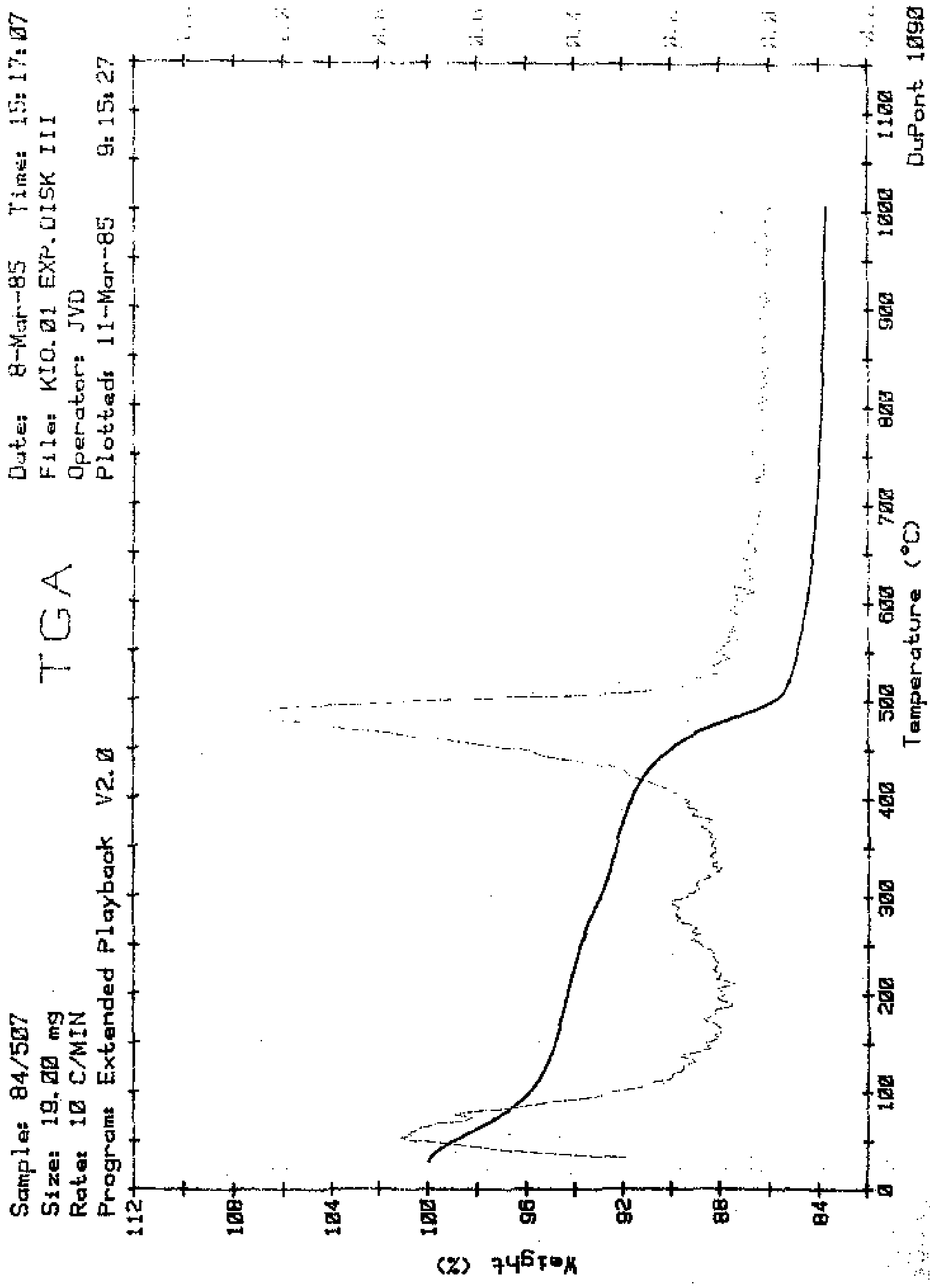

Fig. A 3.4 Thermal gravimetric (TGA, bold line) and differential thermal analysis (DTA) graph of a mixed sample of profiles RP1, RP2 and RP3.