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SOIL SCIENTISTS

MINERALOGICAL AND MICROMORPHOLOGICAL
CHARACTERISATION OF TWO SOIL SEQUENCES
OF THE UNZA-FARM (ZAMBIA)

MINEROLOGISCHE EN MIKROMORFOLOGISCHE
KARACTERISATIE VAN TWEE BODEMSEQUENCES
VAN UNZA-HOEVE (ZAMBIE)

by
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DEDICATION.

THIS WORK, THOUGH NOT SO IMPRESSIVE, IS DEDICATED
TO MY PARENTS, BROTHERS AND SISTERS, FOR ALL THEIR
LOVE AND CONCERN FOR ME THROUGHOUT MY LIFE
AND MOST OF ALL,
TO CHARITY,
FOR HAVING MADE A GREAT DIFFERENCE TO MY LIFE.

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Victor Shitumbanuma,
September 1989,
Ghent.

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1. SUMMARY.

The land has been the ultimate source of nourishment and origin of man and other living organisms. Man has depended and still depends on plants and animals for his survival. These in turn depend on the earth and other organisms.

The cultivation of crops has been known to man for a long time, and the use of different techniques to manipulate the soil and plants has resulted in increased crop production. With the increased human population, the demand on the land has increased, and man has to find better and more effective means of utilizing this now scarce resource of soil.

Various disciplines of science have studied the soil from different angles, with the ultimate aim of bettering their understanding of it. As the soil is quite a heterogeneous material, its study calls for a combined approach of study.

Of the various branches of soil science, a new branch, employing the aid of microscopic and ultramicroscopic techniques has emerged. Micropedology, which aims to search for the processes responsible for the formation of soils as well as specific features both of natural and artificial origin has become an important tool in investigating into the genesis, classification and management of soil.

In this study, which was originally meant to cover two soil sequences, a soil sequence has been studied, from a mineralogical and micromorphological view, with the aim of knowing something about its genesis and management properties.

Routine physical-chemical analyses, micromorphological and mineralogical analyses were carried out on the soil samples from profiles on the sequence. It was found that there is a colour differentiation along the sequence, due to change in drainage condition. The profiles have been found to have a pellicular to bridged grain surface horizon, overlying illuvial horizons. This kind of microstructure is seen to increase with depth downslope, and this has been attributed partly to the translocation of soil material downslope. Illuviation of clay with free iron and fine organic material has been found to be evident in all the profiles in this sequence. The upper two well drained horizons, have a granular aggregate microstructure in subsurface horizons which

gives them a good permeability to water and air.

The low land soil, was found to be partly drained and with a higher content of in situ formed nodules. It was found that there was a coincidence between the presence of brown spots in the profile, with the presence of oriented reddish brown clay coatings.

The soils have been found to be depleted of most weatherable minerals and to be dominated by resistant, generally nutrient poor mineral grains. Kaolinite is the most dominant clay mineral, with mica, being the other constituent. The silt fraction, shows high amounts of quartz and mica. From the study of heavy minerals and soil thin sections, the parent material show evidence of metamorphic origin, and lateritic origin. The soils have been found to have low CEC and a relatively high amount of iron oxides. The presence of the iron oxides, and kaolinite, with micas, has been used to explain the observed low CEC.

As regards management properties, it has been found that the low CEC of these soils may be a limitation to good crop yield. The low pH of the upland soils may require application of lime to expect good response from fertilizer application. The low land soils have been found to have a limitation of aeration.

2. INTRODUCTION.

The land has been the ultimate source of nourishment and origin of all living organisms on the earth. Man, plants and animals have all depended on it for their survival and existence. From ancient times to this day, man has been trying to manipulate the surface of the land in a bid to make it more adaptable to producing his much desired crops. The increase in human population has resulted in increasing the demand on the land. This increased demand has been greatly experienced in the developing countries (FAO,1972). Unless major successful efforts in agricultural development are attained, population is bound to outstrip food production.

World food production could be increased by intensifying production on presently cultivated land by use of the currently known technology. An alternative to this method of increasing food production, is to open up new lands for cultivation. There is tremendous potential for expanding agricultural output in the tropics by bringing new land into production (SANCHEZ,1976). However, this alternative can only be applied to areas where population pressure on the land is still low. In this respect the role of soil scientists is of great importance in as far as the identification of suitable lands for different uses, and the development of management practices necessary to fully utilize the potential of these new lands are concerned.

In order for man to be able to utilize this now scarce resource of soil efficiently, a good knowledge of its properties, behaviour and composition is very important. The scientific study of soil has a relatively short history compared to other sciences and most notable works date back to the last century. The soil is quite heterogeneous and as such it's study calls for a multi-disciplinary approach. The study of the composition of the soil, concerns the geochemistry of that portion of the mantle of the earth currently exposed to the atmosphere and subjected to biotic influences (JACKSON M.L.,1964). We need to understand the processes by which rocks alter to form the soils, and how fast or slowly the processes occur in different conditions. We also need to understand the decay of plant and other organic materials in the soil and how the products of decay help make the soil a better environment for plants to grow (GREENLAND and HAYES,1981).

Different branches of soil science are involved in the study of various aspects of the soil. The methods of study differ from branch to branch. In most cases, samples of soil are taken from the field to laboratories for more intensive analysis as it is not feasible to carry out certain studies in the field. For most studies, soil samples are collected as bulk samples in which the original natural arrangement of the soil particles is lost. Thus disturbed samples are used for a number of studies in most branches of soil science. However, a relatively new branch has emerged in which undisturbed soil samples are used for studies. This new study, Micropedology, employs the aid of microscopic and ultramicroscopic techniques to identify the different constituents and to determine their mutual relationship in space and as far as possible in time. It aims to search for the processes responsible for the formation not only of soil in general, but also of specific features both natural and artificial (STOOPS and ESWARAN, 1986). As a result it has become an important tool for investigating into the genesis, classification and management of soils.

This study deals with soils of the University of Zambia farm in Lusaka, Zambia. Eight pedons have been studied with respect to their physical, chemical, mineralogical and micromorphological characteristics in view of understanding their genesis as well as getting some useful information about some of the properties that affect their management for agricultural use. Two topographic sequences were chosen for this purpose. On one, (profiles 2, 3, and 22) all the pedons are developed on the same geological deposit namely colluvial and alluvial material of the quaternary to recent age. The second topographic sequence (profiles 4, 5, 6, and 7), has pedons developed on different geological deposits. Some pedons have developed on a quartz-mica schist in the higher topographic position, while those in the lower position have developed on a hematite banded current bedded quartzite. There is an influence of the surrounding upland soils both on the development and properties of the pedons in the lower landscape.

In this study, major emphasis has been laid on the mineralogical and the micromorphological aspects, with the physical and chemical aspects being given due attention. The materials and methods employed in this study are all described or mentioned in the appropriate chapter.

3. GENERAL CHARACTERISTICS OF THE AREA.

3.1. LOCATION.

The University farm is located 25km east of Lusaka along the Great east road. It lies between latitudes 15° 21'S and 15° 24'S and between longitudes 20° 27'E and 20° 28'E at elevation of 1140m above sea level. The southern boundary is the Chalimbana River. North of the farm is the Lusaka international airport.

The Great east road to Chipata passes through the northern part of the farm. The main road to the farm from Lusaka is a gravel road which branches off the Great east road. This gravel road commonly known as Palabana Road, cuts through the southern part of the farm, very near to the farm premises. The alternative, and not so frequently used gravel road, branches off the Great east road from the northern part of the farm, and joins the Palabana Road at the main entrance to the farm premises.

The farm covers an area of 520ha, of which 450ha are potentially arable (CHINENE,1988). Figure 1 shows the general outlay of the farm.

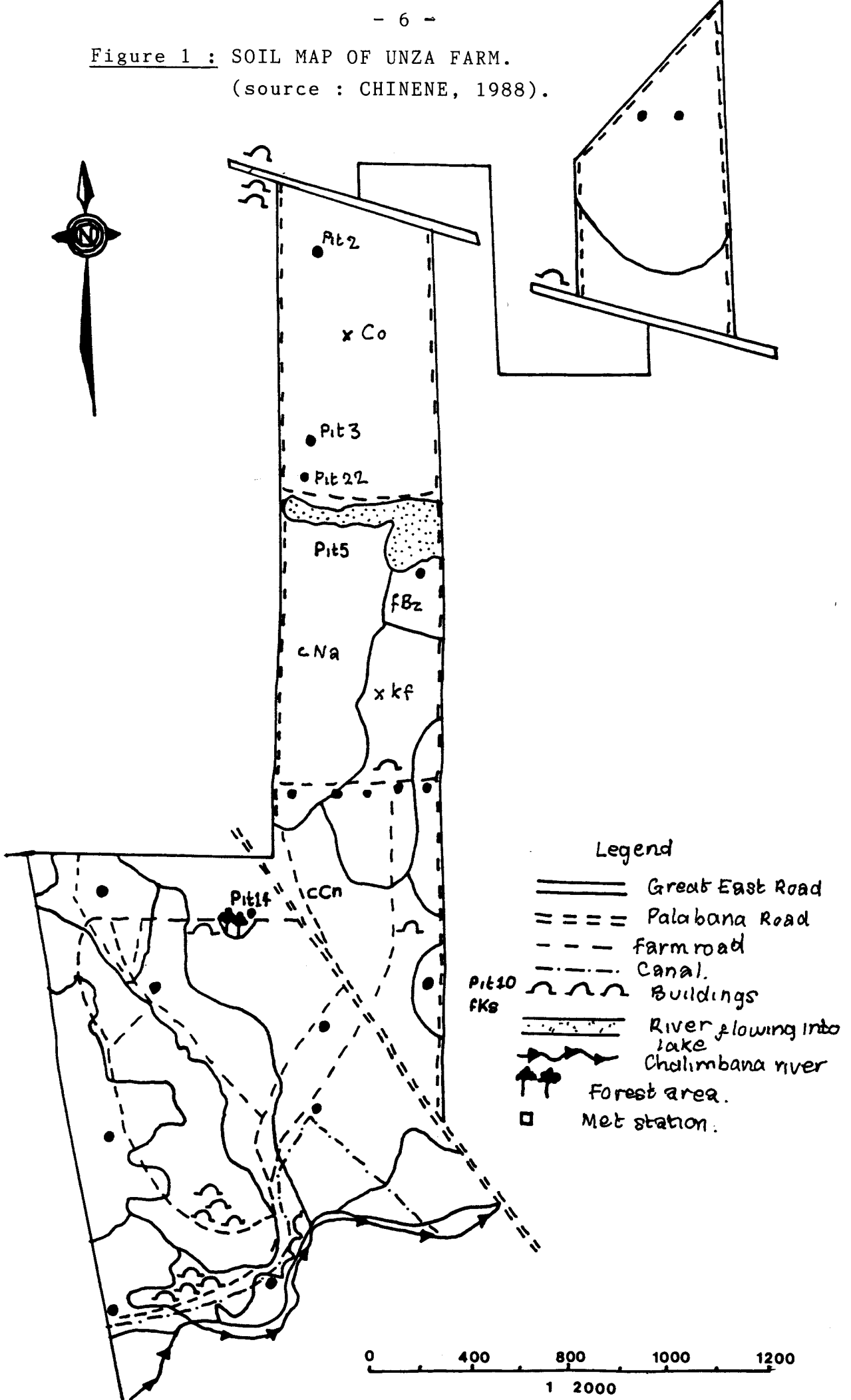
3.2. CLIMATE.

The climate is of a tropical continental type with three distinct seasons as is generally experienced over most parts of the country. A wet season from November to April, a cold dry season from May to July, and a hot dry season from August to October, characterises the general climate of the area. Under these conditions the soils have an ustic moisture regime, in which the soil moisture control section is dry for more than 90 cumulative days unless under influence of a ground water table (CHINENE,1988).

Table 1 shows climatic data based on a two year record (1985-1986) from the University farm meteorological station. The annual rainfall is 1028mm. The annual mean minimum and maximum temperatures are 13.3°C and 25°C respectively. Climatic data from the International airport 5km north of the farm gives a reliable mean annual rainfall of 889mm. Annual mean minimum and maximum temperatures are 17.5°C and 25.3°C respectively (CHINENE,1988).

Figure 1 : SOIL MAP OF UNZA FARM.

(source : CHINENE, 1988).



SOIL MAP LEGEND

Deep, dominantly well drained, gently sloping, dark reddish brown to yellowish red soils.

cCn Chakunkula sandy clay loam - clayey, weakly to strongly structured soils, slightly to medium acid, over crystalline dolomitic limestone (fine, mixed, hyperthermic Oxic Paleustalf)

cCu Chibesakunda sandy clay loam - clayey, weakly to moderately structured soils, neutral to slightly acid, over quartz - mica schist (fine, mixed, hyperthermic Oxic Paleustalf)

cCus Chibesakunda sandy clay loam, sloping variant

xCo Choma loamy sand - fine-loamy, structureless to moderately structured soils, medium to strongly acid, in alluvium and thick colluvial deposits (fine loamy, mixed hyperthermic Oxic Paleustalf)

cKw Kwana sandy clay loam - clayey, weakly to moderately structured soils, slightly to medium acid, over crystalline dolomitic limestone (fine, mixed, hyperthermic Oxic Paleustalf)

bMi Mikata sandy loam - fine-loamy, weakly to moderately structured, slightly to very strongly acid, over micaceous sandstone and hematite banded quartzite (fine-loamy, mixed, hyperthermic Oxic Paleustalf)

bMif Mikata sandy loam, fluventic variant.

cNp Mpongwe sandy clay loam - clayey, weakly to moderately structured soils, medium to strongly acid, over crystalline dolomitic limestone (fine, mixed, hyperthermic Oxic Paleustalf)

Deep, imperfectly to moderately well drained, gently sloping, dark yellowish brown to dark brown soils.

bCg Chilanga sandy loam - coarse-loamy, weakly to moderately structured soils, neutral, over quartz-mica schist (coarse-loamy, mixed, hyperthermic Typic Ustropept)

xKf Kafufufu sandy loam - sandy, structureless to weakly structured soils, strongly to very strongly acid, over quartz-mica schist (fine-loamy, mixed, hyperthermic, Arenic Paleustalf)

Deep, dominantly poorly drained, nearly level, olive gray to yellowish brown soils.

fBz Bulozzi sandy clay loam - clayey, moderately to strongly structured soils, alkaline, in alluvium and thick colluvial deposits (fine, mixed, hyperthermic Mullic Haplaquept)

fCe Chimsimbe clay - clayey, weakly to moderately structured soils, alkaline to neutral, over quartz-mica schist (fine, mixed, hyperthermic Fluventic Ustropept)

fKs Kasakula clay - clayey, moderately structured soils, neutral to slightly acid, over quartz-mica schist (fine, mixed, hyperthermic Fluventic Udic Ustrochrept).

bLo Luano sandy loam - coarse-loamy, structureless to strongly structured soils, slightly acid, in alluvium and thick colluvial deposits (fine-loamy, mixed, hyperthermic, Arenic Paleustalf)

cNa Nkula sandy clay loam - fine-loamy, weakly structured soils, neutral, in alluvium and thick colluvial deposits (Fine-loamy, mixed, hyperthermic, Udic Argiustoll).

Table 1 : CLIMATIC DATA FOR UNZA STATION (1985-1986).
15°23'S 28°28'E 1140 m MSL

	J	A	S	O	N	D	J	F	M	A	J	J	Annu
Rainfall (mm)	0	0	0	34.1	83.1	221.5	352.2	207.8	105.0	74.1	0	0	1028
Pan evaporation (mm)	136.4	175.1	198.9	263.8	172.7	112.3	118.3	109.0	122.5	123.5	134.7	122.4	1790
Penman P.E.T. (mm)	105.1	131.7	159.4	180.2	143.3	102.2	104.2	96.1	107.5	87.9	76.2	93.1	1387
Mean max. T, °C	22.7	25.3	27.6	27.8	23.4	25.3	25.7	25.7	26.5	24.7	23.9	22.2	25.1
Mean min. T, °C	7.5	8.1	12.8	15.6	15.8	17.5	17.6	17.3	16.8	14.7	9.2	7.2	13.3
Mean soil T at 50 cm, °C	18.7	19.1	23.4	27.4	26.4	24.9	24.0	23.6	24.2	23.3	21.6	19.2	23.0
Rel. humidity %	40.8	36.9	32.1	33.7	47.7	73.7	73.6	73.1	69.8	52.9	49.6	45.2	52.4
Wind speed (m/s)	2.0	2.1	2.2	2.5	2.3	1.5	1.1	1.1	1.1	1.3	1.5	2.0	1.7
Sunshine	9.5	9.8	9.3	8.6	8.2	3.7	4.7	4.8	6.2	6.8	8.5	8.9	7.4

CHINENE determined the length of the water availability based growing period, using the method of FAO (1978/80/81) for the University farm. Assuming a soil moisture storage of 100mm and a rate of utilization of 5mm/day, he found that the growing period of the University farm begins in November and ends in May.

3.3. GEOLOGY AND GEOMORPHOLOGY.

Most of the information about the geology of the farm is based on the work of SIMPSON et al in 1963. The geology of the farm is much the same as that of other surrounding areas east of Lusaka. According to KAWAMYA of the Geological Survey Lusaka (personal communication, 1989), the Lusaka area is underlain by Precambrian metasediments (metamorphosed sediments) which have been intruded into the Katanga system (sequence of rocks older than 700 million years) and the Basement Complex (rocks older than 1700 million years). The area east of Lusaka is underlain by the lower part of the Katanga system and is composed of rocks belonging to the Chunga and Cheta formations. Figure 2 gives a summary of the structural character of the geology of the Lusaka area.

The Chunga formation overlies the Basement Complex belt and is assumed to be of lower Katanga age. This sequence of schists, flaggy psammities, quartzites and minor calcareous rocks is exposed in the south easterly fashion from Chunga to Chalimbana (covering the study area). The commonest rock type in this formation is the quartz-muscovite-biotite schist. The grade of metamorphism in this formation is not high and so rocks containing garnet are uncommon (KAWAMYA, 1989).

The quartzites of the Chunga formation are mainly current-banded fine grained muscovite quartzite with iron concretions along the planes. They consist of quartz mosaics, are occasionally feldspathic with occasional micas and stains of hematite accompanied by bluish-green and pale tourmaline.

The schists in the Chunga formation are mainly quartz-muscovite-biotite schists which grade laterally and vertically into more psammitic types consisting only of quartz and muscovite. Schists with a high proportion of biotite and occasionally garnet

Figure 2 : STRUCTURAL CHARACTERISTICS OF THE GEOLOGY OF LUSAKA.

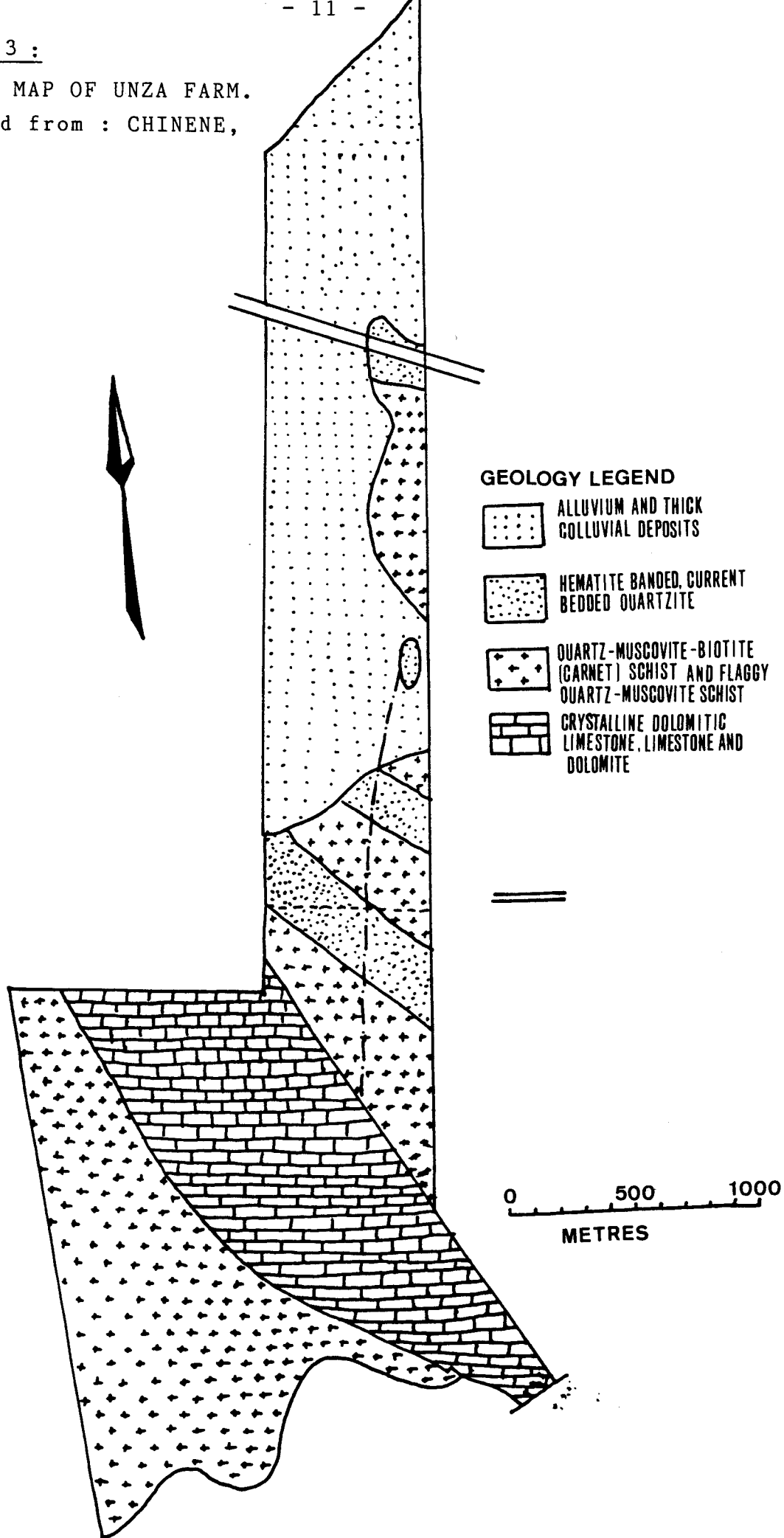
AGE	FORMATION	MINERALOGY
QUARTENARY TO RECENT	Lusaka Dolomite	Dolomite and Limestone
KATANGA SYSTEM	Cheta formation	<ul style="list-style-type: none"> -quartz-muscovite schist -greywhite and grey banded limestones and dolomites -quartz-muscovite, muscovite-chlorite schists and micaceous flags. -grey white and banded dolomite and dolomite
	Chunga formation	<ul style="list-style-type: none"> -quartz-muscovite, biotite-garnet schists and flaggy micaceous quartzite -thin impure limestones and calcic schists. -black banded current-bedded quartzite
BASEMENT COMPLEX		<ul style="list-style-type: none"> -interbanded pure quartzites micaceous quartzites, limestones, calcic-silicate rocks, biotite paragneiss and sheared gneiss

SOURCE: KAWAMYA (personal communication, 1989)

Figure 3 :

GEOLOGY MAP OF UNZA FARM.

(adapted from : CHINENE,
1988).



have been cited (KAWAMYA,1989). Tourmaline and iron ore are reported to be present as accessories. The presence of staurolite, large plagioclase crystals, alteration of biotite to chlorite, highly weathered kyanite with stains of iron oxides and micaceous schists are also cited.

The Cheta formation which is assumed to be of the upper Katanga formation is made up of two calcareous and two schist members. The lower of the two limestones is thicker. Both of the limestones range in composition from pure dolomite to pure limestone. Banded argillaceous limestone occurs in the east of Lusaka. The schists of the Cheta formation include a number of thin quartzite horizons and are of lower metamorphic grade than those of the Chunga. In these schists, biotite is subordinate to muscovite, and garnet is rare. The commonest rock type is fine grained quartzite-muscovite schist. East of Lusaka the schist is predominantly aging in a succession of grey quartzite schists and weakly foliated semi-pelitic rocks. These schists are thought to be originally the same as the schists of the Chunga formation.

The deposits of the quaternary to recent period are thought to have formed during the last 20 000 years. These superficial deposits are mainly products of decomposition of underlying rocks that have had various forms of transportation and redistribution. Schist and quartzite have been covered by thick deposits of superficial clay and quartz gravel in most parts east Lusaka.

Figure 3 shows the geology of the farm. The northern part is dominated by alluvial and colluvial deposits of the quaternary to recent age. They have given rise to a gently undulating landscape consisting of uplands and valleys. These deposits extend to cover the whole of the northern part of the farm. The southern end is dominantly underlain by rocks of the Chunga formation. These are quartz-muscovite schists and flaggy schists (CHINENE,1988).

The area on either sides of the Palabana Road up to about 100m before the farm buildings is underlain by crystalline dolomitic limestone and dolomitic rocks. These are of the Cheta formation.

The first toposequence is on the alluvial, colluvial deposit with a slope of 4-5% facing the southern direction. Pedons 2, 3, and 22 are located on this sequence. Pedon 2 occupies the highest position in the landscape, followed by pedon 3 and 22 on the lower part of the slope.

The second toposequence cuts through two different geological deposits according to the geological map of SIMPSON et al (Figure 2). This sequence has five pedons and has a west facing slope of 3-4%. Two of the pedons in this sequence lie in a poorly drained lowland area locally known as "dambo".

3.4.DRAINAGE.

The upland areas of the alluvial deposits are generally well drained. Pedons occupying lower positions in the landscape on both sequences have poorer drainage conditions than those on higher positions. The heavy textured soils of the lowland (dambos) have imperfectly to poorly drained conditions and experience occasional short periods of flooding during the rainy season.

3.5.LAND USE AND MANAGEMENT.

The soils of the upland alluvial and colluvial deposits are used for cultivation of rainfed maize. Soils derived from limestone and dolomite are used for growing of maize, soyabean, vegetables citrus, mango and irrigated wheat. The poorly drained heavy textured soils of the dambos have been left as pasture land for beef cattle.

4. MATERIALS AND METHODS.

4.1. FIELDWORK AND METHODS.

Most of the maps and figures used in this work have been adapted from the work of CHINENE et al (1988) and other persons who have worked on the farm.

The soil survey of the farm has been carried out by a number of people to come up with the soil map presented in this work. YAGER et al (1967) carried out a detailed soil survey of the area using a power auger with observations at 160m intervals. The mosaic used in the field was a 1:7000 enlargement of the July 1965 1:20 000 aerial photograph. In mid 1967 a better quality 1:130 000 enlargement of the 1962 flight became available. The data was transferred to this photograph, checked and corrected.

SICHINGA et al (1976) carried out a detailed soil survey of the farm using a grid in which predetermined augering spacings were used. Transverses were made at every 180m and augering at the same interval within each traverse. Traverse and augering points were plotted on a 1:50 000 transparent map copied from a photo mosaic of the same scale. The soil map was drawn on the basis of similarity in characteristics of the soil from the auger holes. Pits were dug in four mapping units, described and sampled for chemical analysis.

The most recent work was carried out by Dr CHINENE, the author and some members of the soil survey team from Mt. Makulu research station. It was aimed at improving the soil description, the classification as well as carrying out a land evaluation of the major land units. A free survey was carried out and augerings were made as desired to check the boundaries established by YAGER and SICHINGA and collect more information on the soil characteristics. The results of this work are contained in the soil Survey Report No 160 of the Ministry of Agriculture and Water Development of Zambia.

For the purpose of this study specific sights were chosen and a few more profiles were dug and described by the author and Dr CHINENE in July 1987. Soil samples for micromorphological analyses were collected in 80×60×10mm kubiena boxes as described by G. STOOPS (1987). Bulk samples for physical and chemical ana-

analyses were collected as outlined in the USDA Soil Survey Investigations Report N° 1 (1972).

4.2. LABORATORY METHODS.

With the exception of the determination of free Fe, Al, Si and Mn, all the other routine soil physical and chemical analyses from the profiles dug and described by the author were carried out in the laboratories of the Soil Science Department of the School of Agricultural Sciences at the University of Zambia. The physico-chemical analysis of the other profiles described by other workers were mainly carried out in the same laboratories, with the exception of a few samples analysed at Lincoln Laboratory in Nebraska USA.

All the mineralogical and micromorphological analyses were done in the Laboratory of Mineralogy, Petrography and Micro-morphology of the Geological Institute of the State University of Gent. Following are brief descriptions of the methods employed during this study.

4.3. PHYSICAL CHEMICAL ANALYSES.

1. Particle size distribution : Bouyouco's hydrometer method.
2. pH : Measured in water (1:25) and 1N KCL (1:1) with a glass electrode.
3. Organic carbon : By WALKELY and BLACK (1934) wet digestion and titrimetric determination method.
4. Total Nitrogen : Kjeldahl digestion method.
5. Exchangeable cations : Extracted by 1N Ammonium acetate at pH 7 for 30 minutes and then determined by atomic absorption spectrophotometry for strontium chloride Ca and Mg determinations (G.W. THOMAS, 1986).
6. Al + N (exchangeable acidity) : Extracted with 1N KCL for 1 hour and determined titrimetrically (G.W. THOMAS, 1986).
7. Total free Fe and DCB extractable Si, Al and Mn : Extraction by the Dithionite-Citrate Bicarbonate (DCB) method. The elements were determined by atomic absorption (MEHRA & JACKSON, 1958).
8. Available phosphorus : Bray I method (1945).

4.4. MINERALOGICAL AND MICROMORPHOLOGICAL ANALYSES.

4.4.1. Preparation of soil thin section.

The preparation of soil thin sections was done as described by G. STOOPS (1988). The soils were dried by water replacement by acetons, after which the samples were impregnated with a polystyrene mixture and let to harden for a period of 4 weeks. After hardening the samples were sectioned, grand, polished and mounted on quarter "mammoth" size object glasses (90×60mm). The finishing was done using an automatic plane polishing machine to a thickness of about 50 μ m. The fine finish was done by hand with three different grades of corundum powder with the aid of a polarising microscope. The mounting of the cover glass, and all the other procedures were carried out as described in the above mentioned reference.

4.4.2. Preparation of thin sections for the light and heavy mineral sand fraction.

The methods employed in the preparation of the heavy and light mineral thin sections are those described by STOOPS (1987). The sand fraction was separated from the other size fractions of the soil after treatments to remove free Iron and organic matter. The separation of the two sand fractions (light and heavy) was done by density separation using bromoform. Heavy minerals were mounted onto object glasses using canada balsam. The light minerals were mounted onto object glasses using a polystyrene mixture and let to harden for two days. They were grand and polished to 30 μ m thickness using three grades of corundum powder. The thickness was controlled with the aid of a polarising microscope. They were then stained and the coverglasses finally mounted as described in the mentioned reference.

4.4.3. Study of thin sections.

All the soil thin sections and light and heavy mineral mounts were studied with Leitz petrographic microscope at magnifications of $\times 40$, $\times 10 \times 25$, and 40 for the objective lense and an ocular magnification of $\times 8$. Micromorphological descriptions were done

using the terminology of BULLOCK et al (1985).

4.4.4. X-ray Diffraction, Thermal Gravimetric Analysis (TGA) and
Differential Thermal Analysis (DTA).

X-ray diffraction samples were prepared from silt and clay fractions of the soil by the "Glass plate method for oriented aggregates" (JACKSON, 1969). The silt and clay particles were brought into suspension with water to complete dispersion, a milliliter of this sample was dropped on glass plates and let to settle and dry at room temperature. By this method the particles are assumed to preferentially orient themselves in a manner which results in enhancement of basal (00L) diffraction maxima.

Treatments of potassium (saturation), magnesium, magnesium and glycol and heating to 550 °C were carried out where necessary as described by WHITTIG and ALLARDICE (1986). For all samples with the exception of those in which it was desired to observe the influence of iron oxides, treatment with sodium dithionite to remove free iron (MEHRA and JACKSON, 1958). The measurement of the X-ray diffractions were done on a Philips Diffraction Equipment (Generator PW1730, and Goniometer PW1050/25), with a cobalt 27 target, and $K\alpha_2$ line, with wavelength 1.7927 Å.

Differential Thermal Analysis and Thermal Gravimetric Analysis, DTA and TGA respectively, were done on Dupont Instruments, (910 and 951 Thermogravimetric Analyzer). For both analyses, about 20mg samples (see graphs for exact weights) of silt and clay were used. Heating up to 1200 °C was done for the DTA, and to 1000 °C for TGA. Aluminium oxide was used as the inert reference material for the Differential Thermal Analysis. Plotting of the graphs was done on a Hewlett Packard Plotter.

5. RESULTS AND DISCUSSION.

5.1. MICROMORPHOLOGY.

Soil micromorphology which may be viewed as the study of soil morphology in the size range where optical aid is needed for the naked eye (BUOL et al, 1973) has become a major tool in the study of soil forming processes. As GLINKA wrote, the morphology of a soil is an expression of the inner, chemico-biological processes (GERASIMOV I.P. & GLASOVSKAYA, 1965). Thus from the observations made from the morphological study of a soil, a number of important informations, about the soil, as regards its genesis, and to a good extent a number of its management properties can be deduced. This deduction, however, requires the researcher or worker to have a prior knowledge and good understanding of many important causes and inner processes responsible for the formation of the observed external morphological features. This is not an easy task especially for beginners.

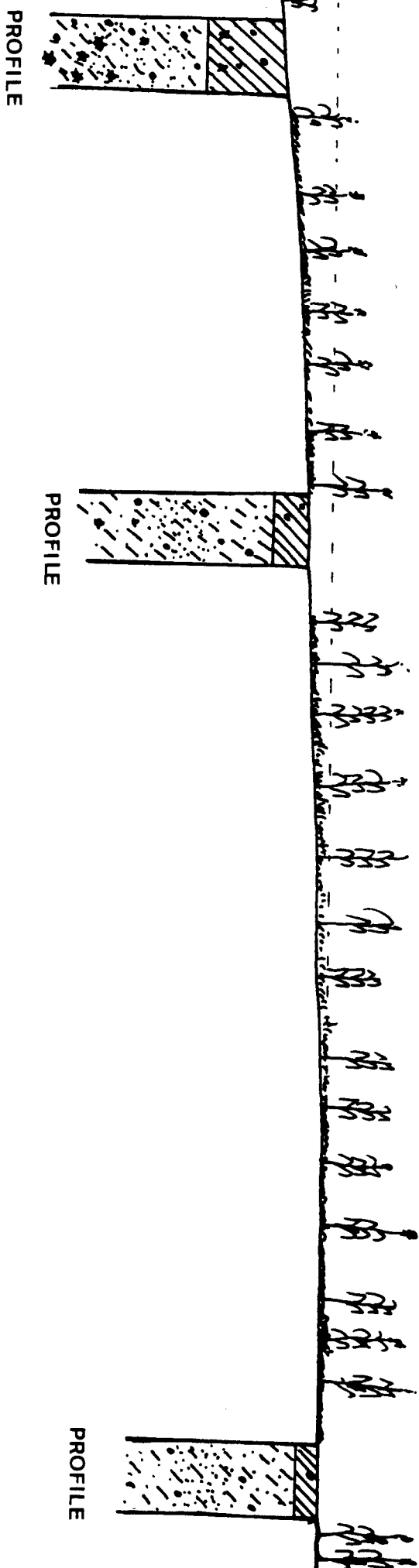
In the study, the two soil sequences have been dealt with separately, and as mentioned in the preceeding chapter, descriptions were made after the terminology of BULLOCK et al (1985). It is therefore suggested that this publication be referred to, for further clarification on some of the terms if necessary.

5.2. SEQUENCE N°1.

Figure 4 shows the general outlay of the sequence and the approximate locations of the three studied profiles on the landscape. The sequence, is on a cultivated field, on which maize and some other crops are grown in rotation. The surface horizons of all the three profiles are therefore ploughed.

One of the most striking external characteristics of the soils, that is seen to change along the sequence is the soil colour. The two profiles, on the higher side of the landscape have a characteristic red brown colour, while, profile 22, much lower in the landscape, and less well drained, than the other two, has a yellowish grey colour under thin sections. This observation is much in agreement with the generally held view, that on iron containing soils, in tropical areas, the well drained soils, normally show a redder colour than the less well drained

Figure 4 : GENERAL OUTLAY OF SOIL SEQUENCE.
(not drawn to scale).



-  Pollicular to bridged grain microstructure
-  Complex microstructure of channels and granular aggregates
-  Typic nodules
-  Impregnative nodules
-  Oriented clay coatings

soils (KELLOG, 1951). The two soil colours would have been used to classify them, into red podzolic and yellow podzolic soils respectively in the old American classification system.

The apparent colour difference, may be explained on the basis that the well drained soils generally have non-hydrated iron oxides (hematite and maghemite) which impart the reddish colour on them, and the yellow colour of less well drained soils on the presence of hydrated iron oxides (goethite and lepidocrocite Fe OOH). KRAUSKOPF (1967), however, cautions the use of colour as a guide to composition, because, it depends at least as much on the state of subdivision and on minor impurities as on the degree of hydration. It has been observed that the intensity of reddening of soils, appears to increase with age, and it may be well appreciated, if the fact that ferrous compounds upon prolonged exposure to air, are oxidized to ferric compounds, is taken into consideration.

The microstructure in this sequence is seen to change with depth along sequence. In all the three profiles, the surface horizons show a bridged to pellicular grain microstructure, with few fragments of domains of fine material comprised of fine clay, organic matter, and fine silt sized mineral grains. The depth of the pellicular to bridged grain microstructure increases downslope.

Below the bridged to pellicular grain microstructure is a complex microstructure with granular aggregates in a dominantly channel microstructure (see photo : 2). The Bt horizons show an increased degree of aggregation, due to the presence of higher amounts of clay, which provide the cementation for the mineral grains (see photo : 4). Below the Bt horizons, are pronounced granular aggregates, of sand to silt sized mineral grains coated and cemented by reddish or yellowish clay. Profile 22 has less well developed granular aggregates and shows a rather spongy appearance.

The fine material of profiles 2 and 3 are reddish brown dotted clays with a speckled b-fabric (see appendix). Profile 22 has yellowish dotted clay with a few patches of brown dotted clays. The dotted nature of the clay is taken to be an indication of the presence of finely divided organic impurities (BULLOCK et al,

1985). The Bt horizons of all the 3 profiles show the presence of oriented clay coating. There are limpid, laminated and microlaminated coatings and dotted laminated and microlaminated coatings. Limpid coatings indicate translocation of clay without coarse impurities while the dotted appearance has just been described. Laminations and microlaminations, are indicators of the successive nature of the deposition of these clay coatings (BULLOCK et al, 1985).

Many typic iron nodules containing quartz and muscovite are observed in all the profiles. Typic nodules with sharp boundary are normally indicators of the foreign nature of the nodule to the environment and may suggest the lateritic origin of part of the sediment (STOOPS, 1989). Together with these typic nodules are reddish brown iron oxyhydrate coatings on mineral grains, especially quartz. They are also seen in fissures of some cracked quartz grains. They have been termed as runiquartz (STOOPS, 1989), and are also taken as indicators of lateritic origin of the quartz grains.

The subsurface horizons of profile 22, show an increased amount of impregnative nodules. The lower mottled horizons have more of these nodules, and a closer examination of the reddish brown mottled portions, show the coincidence of these spots with reddish brown oriented clay coatings (see photo : 3). A few examined nodules from these horizons, show the presence of oriented clay coatings within their structures. According to MARSHALL (1977), the formation of iron concretions begins at sites where $\text{Fe}(\text{OH})_3$ or MnO_2 are originally present. Since the concretions show a relative abundance in brown spots with generally reddish brown oriented coatings, it may be possible that the brown portions with oriented clay coatings may be the initial sites of nodule formation. The presence of organic materials in the yellowish to grey bleached zones, further suggests a possible survive of reducing material that could be at the origin of iron movement from the bleached zones. Since mottling is a phenomenon associated with oxido-reduction it is evident, that oxido-reduction reactions are quite active in this profile.

The sand and silt fractions, show quartz as the most dominant mineral grain. Muscovite follows quartz in abundance. Fragmented tourmaline and kyanite frequently occur. Zircon is frequently

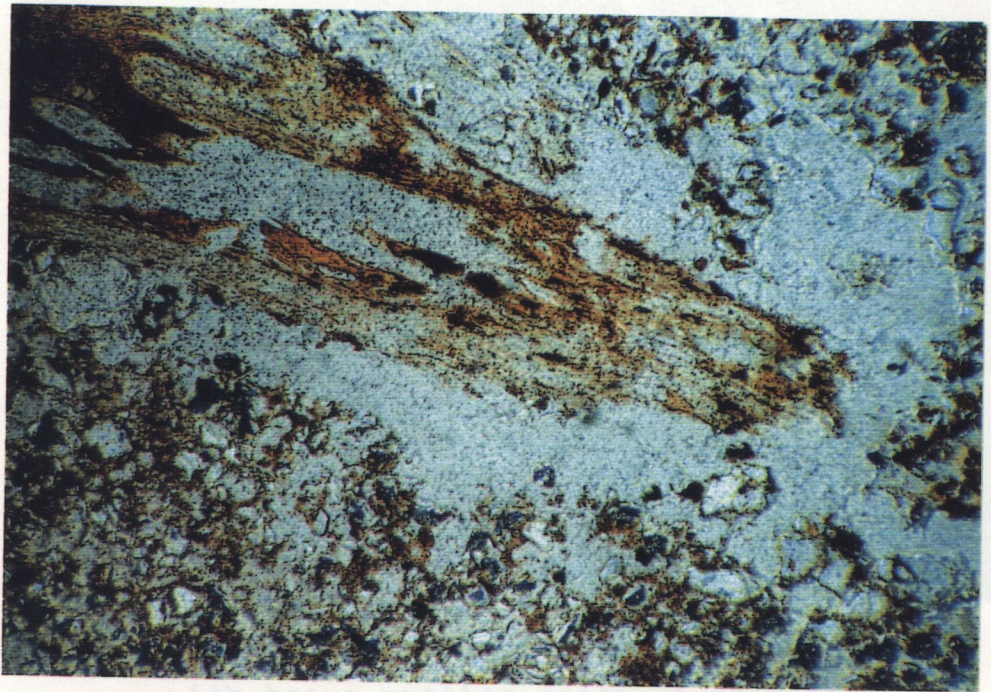


Photo1: Pellicular to Bridged grain microstructure
of Ap horizon with a section of a root.
(Profile 2: 0- 10cm). Magnification: $2.5 \times 1.25 (PL)$

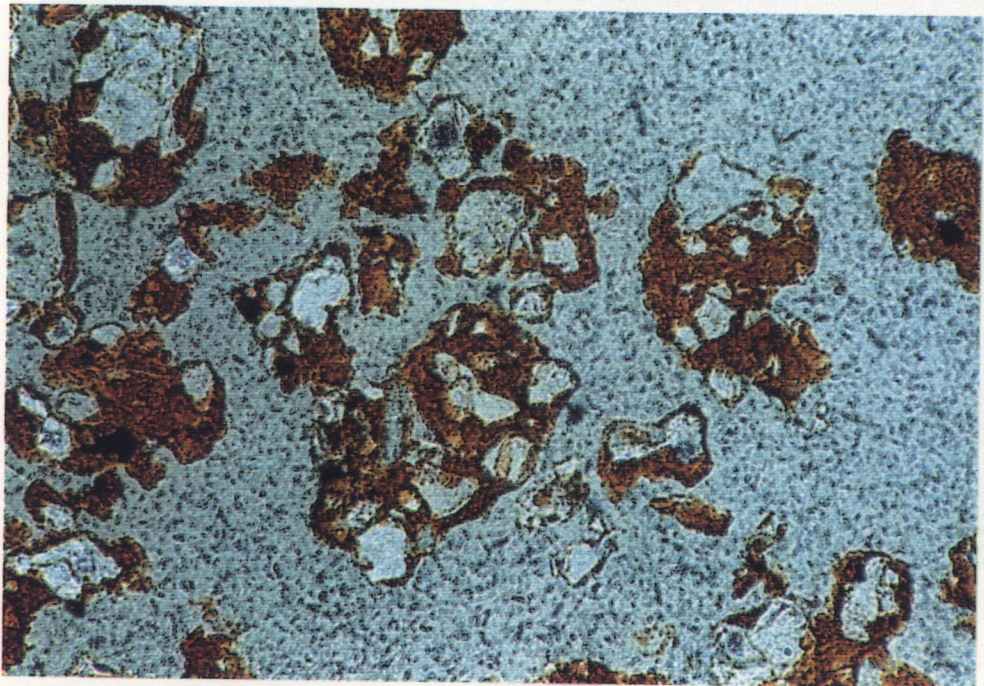


Photo 2: Granular aggregates. (E horizon, Profile 3
30-35cm) Magnification: $6.3 \times 1.25 (PL)$

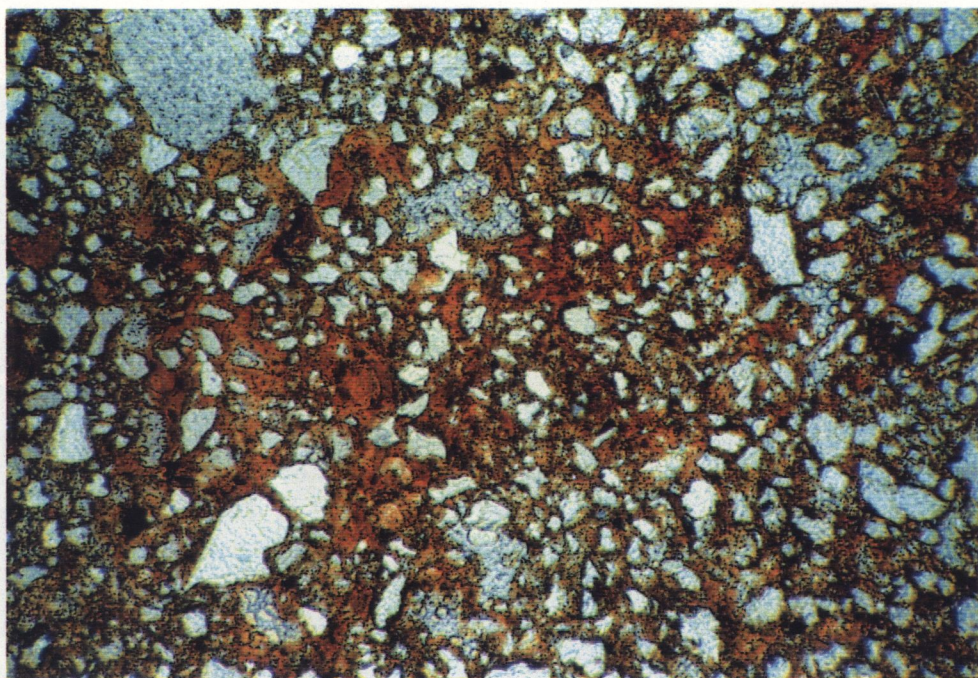


Photo 3: Coincidence of reddish brown oriented clay with brown mottled spots. (Bt g horizon, Prof 22; 125-135cm) Magnification 2.5x1.25 (PL)

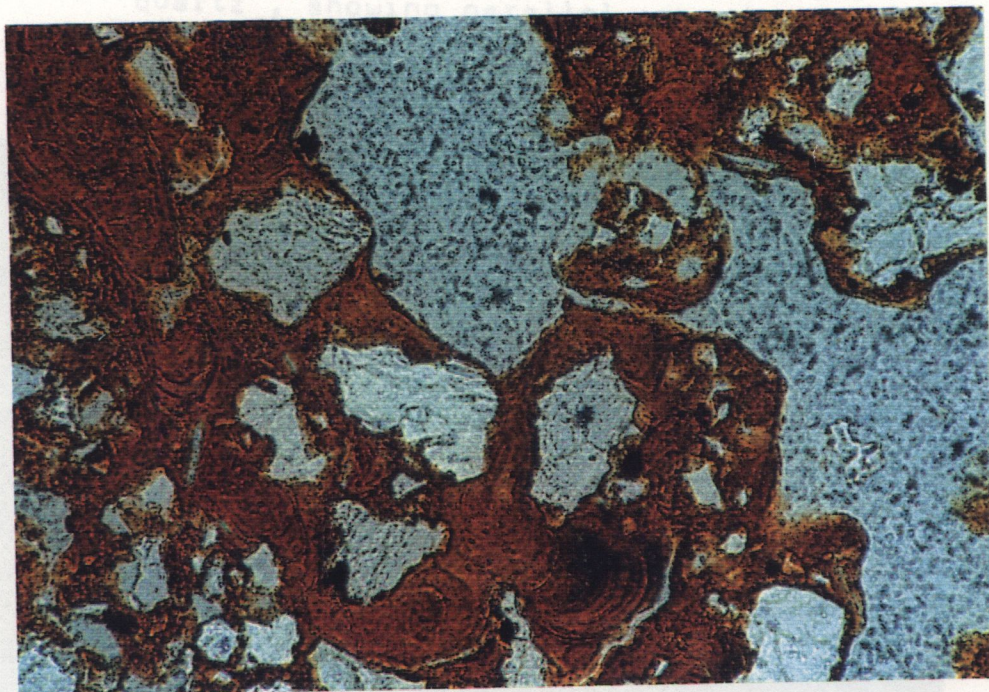


Photo 4: Thick reddish brown oriented clay coatings around mineral grains (Bt horizon 51-91 cm) Magnification : 6.3x1.25 (PL)

Photo 6: Impregnative nodules in poorly drained Btg horizon. (Profile 22, 125 - 135cm) Magnification: 2.5x 1.25 (PL)



Photo 5: Rock fragment containing muscovite and quartz, showing parallel arrangement of minerals, typical of metamorphic rocks. (E horizon Profile 3, 30-35cm)
Magnification: 6.3x 1.25 (PPL)

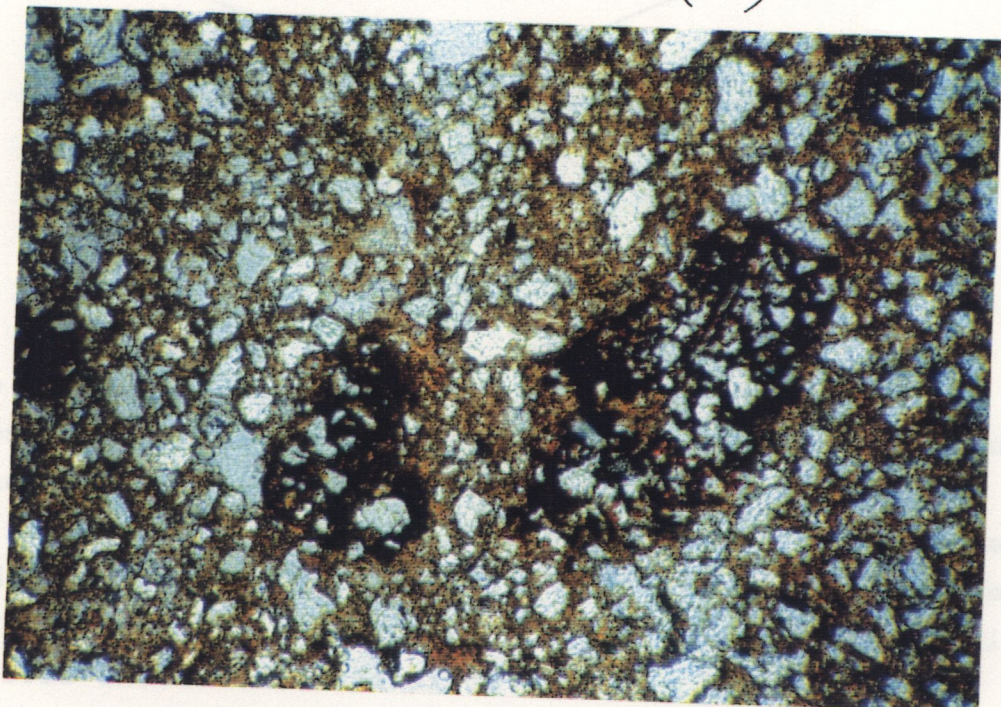
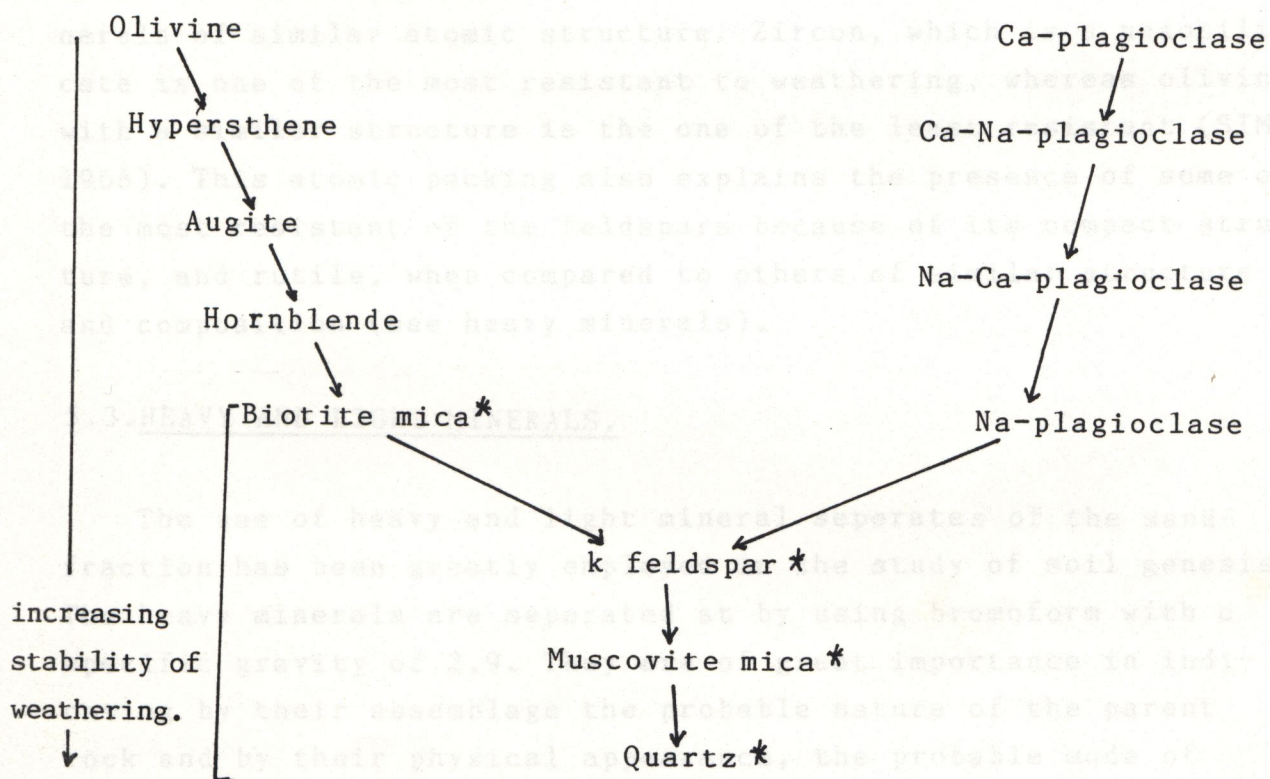


Photo 6: Impregnative nodules in poorly drained Btg horizon. (Profile 22, 125 - 135cm)
Magnification: 2.5x 1.25 (PL)

observed. Few amounts of biotite, microcline, zoisite, and garnet are also observed. Quartz, muscovite, tourmaline, and kyanite are all cited as belonging to the most resistant minerals to weathering, by several authors. Rock fragments, containing quartz and muscovite are frequent. Few other mineral associations, as these of biotite and garnet have been observed in the rock fragments.

From the above minerals observed, it is evident that most of the weatherable minerals are not present. As seen below, all the minerals observed in the above soils belong to the lower portion of GOLDRICH'S weathering stability table.



Biotite ($(\text{K}(\text{Mg Fe})_3 \text{AlSi}_3\text{O}_{10}(\text{OH})_2$) is the least weatherable of the observed minerals in this sequence. The presence of iron in this mineral is one attribute that accounts for its easier weatherability as compared to its non-ferrous counterpart muscovite (BARSHARD, 1964). Weathering of iron-bearing minerals commonly releases Fe^{2+} which in contact with aggregated water, is oxidized and forms an oxide or hydroxide of iron. The presence of biotite partly explains the presence of the observed colour of the soil. The iron in soil, may also have been observed from other relatively weatherable mafic minerals, that may have been present in the original sediments.

Many explanations and theories, regarding the weatherability of minerals have been proposed by several scientists. Of these, the atomic structure of minerals has been found to be very important, in predicting the weatherability of minerals. Generally it has been observed that with increasing sharing of oxygens, between adjacent silica tetrahedra in silicates an increase in resistance to weathering is observed (BIRKELAND, 1974). This appears to correlate well with GOLDRICH'S stability table.

This prediction, however, does not always appear to be true for some minerals. The atomic packing and strong bonding of some minerals makes them more resistant to weathering, than other minerals of similar atomic structure. Zircon, which is a nesosilicate is one of the most resistant to weathering, whereas olivine with a similar structure is the one of the least resistant (SIMPSON, 1966). This atomic packing also explains the presence of some of the most resistant of the feldspars because of its compact structure, and rutile, when compared to others of similar structure and composition (see heavy minerals).

5.3. HEAVY AND LIGHT MINERALS.

The use of heavy and light mineral separates of the sand-fraction has been greatly employed in the study of soil genesis. The heavy minerals are separated at by using bromoform with a specific gravity of 2.9. They are of great importance in indicating by their assemblage the probable nature of the parent rock and by their physical appearance, the probable mode of transport and length of time they have been subjected to that transport. Great caution is however required in interpreting the information yielded by these minerals for they may only indicate, a portion of the whole process that has been going on in a soil (SIMPSON, 1966).

Several authors have suggested the use of index minerals, which is assumed to be resistant to weathering and immobile. By the comparison of the amounts of this mineral with depth up to the parent material, with respect to other less resistant minerals, the rate of weathering can be predicted (BIRKELAND, 1974). But not all soils are formed in situ, and as such its use becomes limited (BARSHARD, 1964).

Table 2 shows the relative amounts of the heavy and light minerals of profiles 2, 3 and 22. Zircon appears to be the most abundant mineral of the transparent heavy minerals in profiles 2 and 3. Tourmaline, is second, and followed by kyanite and rutile. Other minerals identified include sillimanite, epidote, zoisite, and staurolite. Although staurolite is not shown to be present on this table, it was later identified that staurolite was the dominant of the minerals termed as "others". Profile 22 shows rutile to be the most dominant, followed by kyanite, tourmaline and zircon.

The above mineral assemblage, shows the presence of minerals that are peculiar or typical of metamorphic rocks. According to JACKSON (1970) when the following minerals are common as accessory minerals in sands they are indicative of metamorphic origin :

actinolite	kyanite
andalusite	tremolite
garnet	sillimanite
glaucofane	staurolite

Zoisite, staurolite, sillimanite and kyanite are exclusively minerals of metamorphic origin (SIMPSON, 1966). Tourmaline and zircon are resistant accessory minerals, not confined to a specific rock type. The metamorphic rocks contain in addition to feldspars and quartz such minerals as amphiboles, chlorites, micas, garnets, andalusite, staurolite, kyanite and sillimanite which have been formed under conditions of pressure and temperature induced by the metamorphism. The minerals produced by metamorphism are said to be generally very resistant to weathering (CARROL D., 1970).

Zircon grains were found to have a variety of shapes. Some had well rounded edges, a few approaching a spherical shape, and some had sharp edges. The rounded ones in addition showed abrasion marks. This rounding of edges is generally taken to be evidence of abrasion, due to transportation. While relatively sharp edged grains are taken to be less subjected to abrasion. It can be deduced from the shape of some of these grains, that some of them have been subjected to some transportation, while others are relatively fresh, and may be taken to have come from fresh material, recently deposited and not transported over a long distance. Again the above heavy minerals are of the resistant group to

Table 2 : HEAVY AND LIGHT MINERALS OF THE PROFILES 2, 3 AND 22.

LOCATION	Opaque	Zircon	Rutile	Tourmaline	Epidote	Kyanite	Sillimanit	Zoisite	Staurolite	Others	LIGHT MINERALS		
											Quartz	K-feld-spar	Ca-feld-spar
<u>Profile 2</u>													
0- 10cm	75	48	6	29	1	8	1	-	-	4	98	1	1
10- 25cm	85	44	14	15	2	15	3	1	-	4	99	1	-
25-65cm	78	30	8	10	2	30	14	2	-	4	97	2	1
<u>Profile 3</u>													
0-20cm	40	30	18	22	1	19	8	1	-	2	99	1	-
20-30cm	64	22	11	42	-	17	3	1	-	4	98	1	1
51-92cm	74	39	18	14	-	21	2	-	-	6	99	1	-
100-141cm	91	41	24	5	-	21	6	-	-	3	100	-	-
<u>Profile 22</u>													
0-20cm	22	11	25	7	1	36	10	4	-	6	98	2	-
20-30cm	40	10	30	15	-	30	5	2	-	10	97	2	1
30-65cm	47	12	22	22	-	15	1	2	-	8	99	1	-
65-125	36	12	17	17	-	26	6	1	-	3	98	1	1
125-185cm	47	10	24	24	-	21	1	2	-	8	98	1	1

weathering. So it can be inferred that there has been a great amount of weathering of the easily weatherable minerals as has been discussed in the section on micromorphology.

The light minerals, show quartz as the only mineral surviving to an appreciable amount. The feldspars only comprise about 1-2% of the light minerals. This further confirms the earlier assertion that the soils are quite depleted of weatherable minerals. The few weatherable microclines observed in soil thin sections, are negligible when compared with quartz. With these observations, it is clear that this soil sequence must be quite poor in potential chemical fertility. The majority of the minerals observed in this sequence, apart from being quite resistant to weathering, are rather poor in plant nutrients.

5.4. X-RAY DIFFRACTION.

X-ray diffraction of some samples from these profiles, shows kaolinite and micas, to be the only minerals present in the clay fraction of these soils. The presence of peaks at $7.2 \text{ \AA}$, $3.58 \text{ \AA}$ which disappear upon heating to 550°C confirms the presence of kaolinite. The micas have $10 \text{ \AA}$ and $5 \text{ \AA}$ peaks which persist after heating to 550°C , see figure 5.

The silt fractions from the profiles also show a predominance of mica, with $10 \text{ \AA}$ and $5.0 \text{ \AA}$ peaks, some kaolinite, a high amount of quartz with strong peaks at $4.26 \text{ \AA}$ and $3.34 \text{ \AA}$. The latter being more intense. Short peaks at $3.25 \text{ \AA}$ confirm the presence of feldspars.

5.5. THERMOGRAVIMETRIC AND DIFFERENTIAL THERMAL ANALYSES (TGA AND DTA).

Figure 6 shows the TGA and DTA curves for the clay and silt fractions obtained from profile 3. The TGA curve for the silt fractions shows a weight loss between 400 and 600°C , which is due to the dehydroxylation of the kaolinite still present in the sample. This same weight loss is well pronounced in the TGA curve for the clay fraction. From the weight loss in the clay TGA curve a calculation made to determine the amount of kaolinite, gave 72% as the content of kaolinite in the clay fraction of this horizon. This confirms the dominance of kaolinite in the clay fraction, as well as its presence in the silt.

Figure 5 : X-RAY DIFFRACTOGRAMS FOR SOME HORIZONS OF PROFILES 2, 3 AND 22.

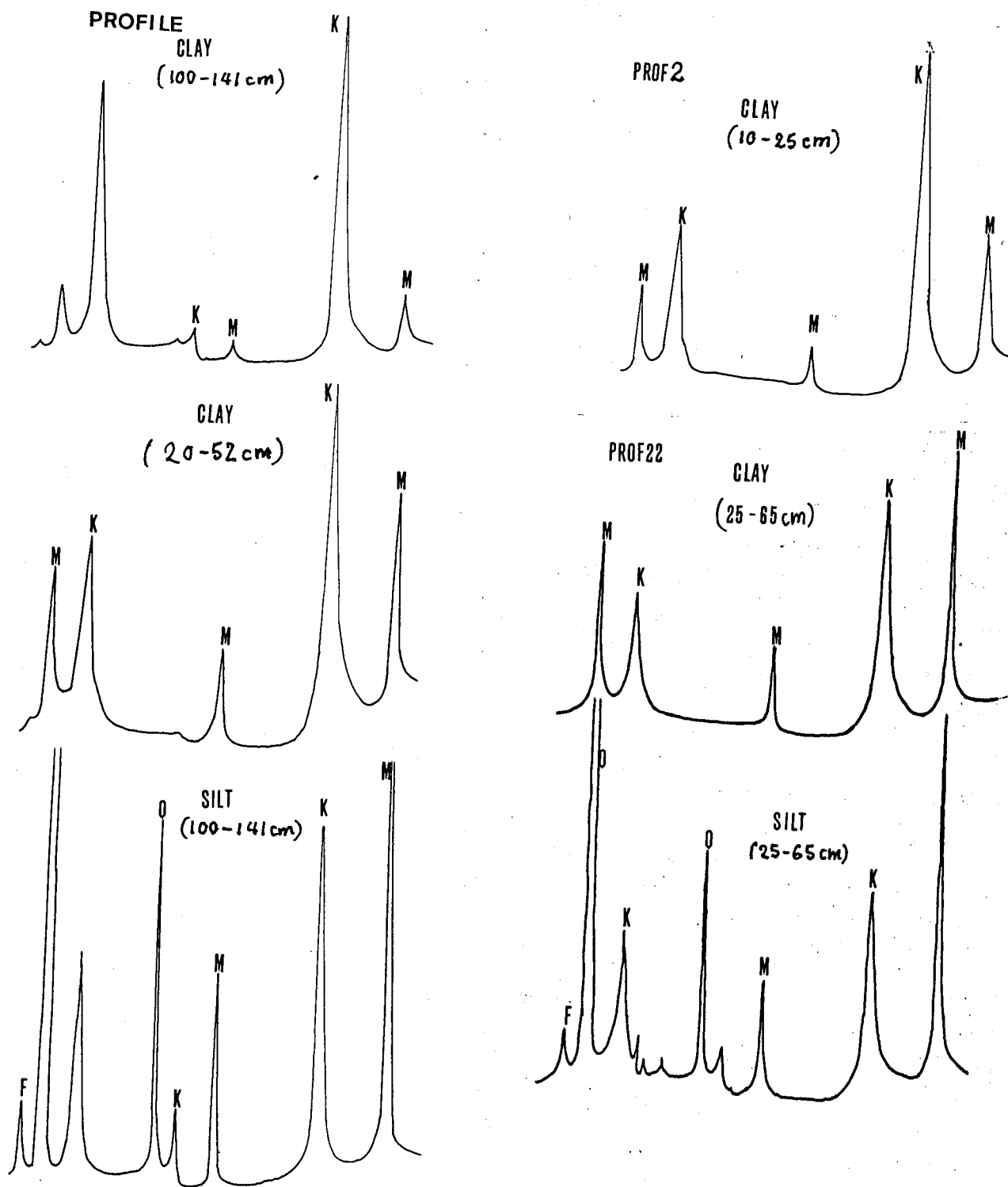
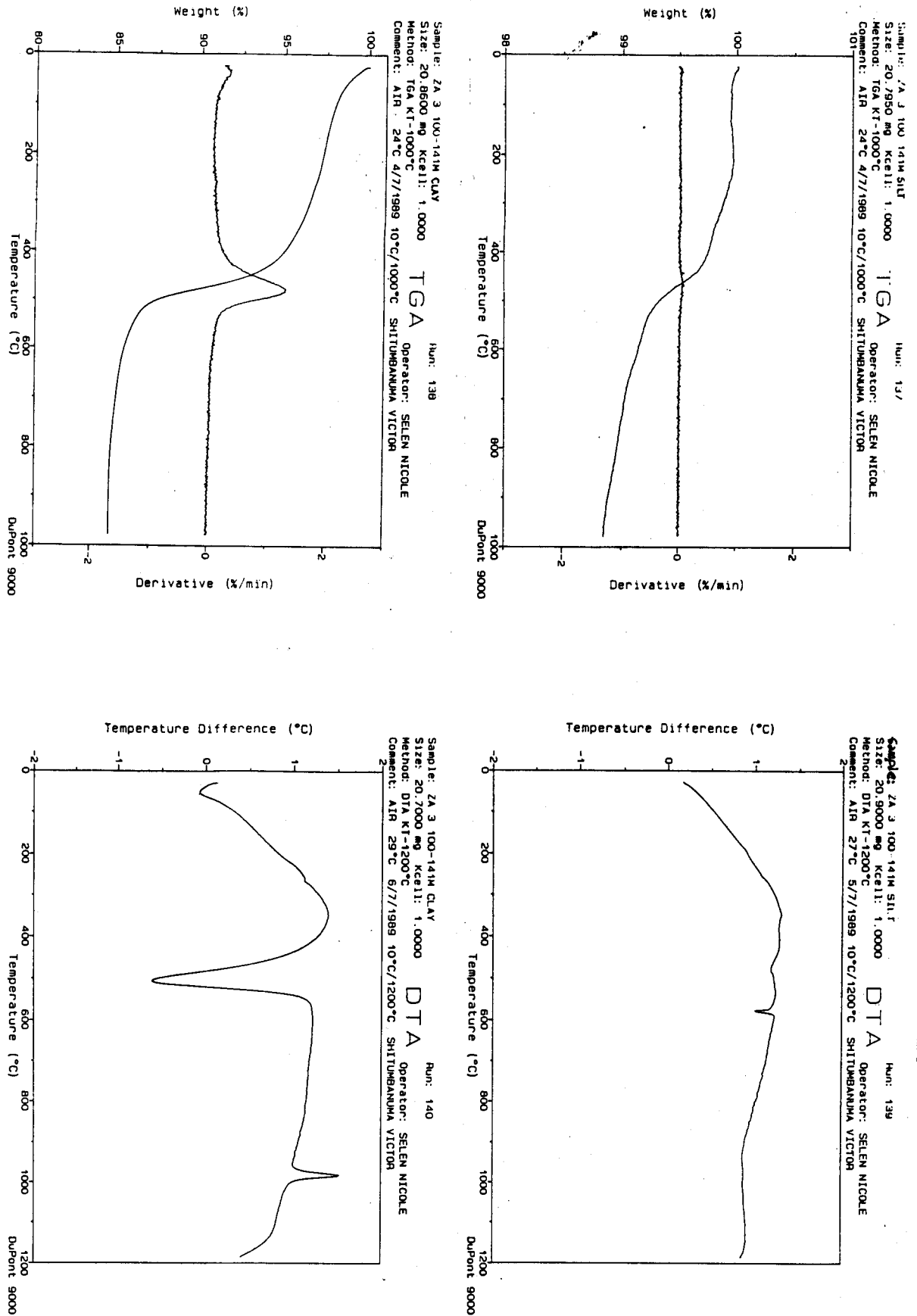


Figure 6 : TGA AND DTA CURVES FOR PROFILE 3.



The DTA curve for the silt fraction, showed an endothermic reaction between 550 and 600 °C. This corresponds to the inversion temperature of quartz from its α to β form (573 °C). The DTA curve for the clay fraction, showed an endothermic peak, between 400 and 600 °C, which corresponds to the dehydroxylation temperature for kaolinite (GRIM , 1964), and an exothermic peak at close to 1000 °C, corresponding to the temperature of re-crystallization of kaolinite. From the above data, it is evident, that kaolinite is the dominant clay mineral present in the soil clay fraction, and that quartz is present in the silt.

5.6. PHYSICAL CHEMICAL ANALYSES.

Figure 7 shows the particle size distribution of profiles 2, 3 and 22. There is an apparent increase in amount of clay with depth in each of the 3 profiles. Horizons of clay accumulation in the profiles 2 and 3 are well pronounced, while this is much less in profile 22. This observation is much in agreement with the general expectations, in a sequence, assumed to be the same age. Profile development is more pronounced on fairly flat upland soils than these in lower sloping landscape.

Profile 22 has a high clay content in the surface horizon and a higher sand or rather coarse texture in the subsurface. This rather abrupt change in texture, in this profile, could be a possible indication of deposition of material by erosion from profiles located higher in the landscape.

Table 3 shows the chemical data for the 3 profiles in this sequence. The CEC is quite low in all the 3 profiles and shows no special trend along the profile. The dominance of kaolinite in the clay fraction and rather low organic matter content of these soils explains partly the reason for these observations. The presence of mica in the clay fraction, is generally expected to increase the CEC beyond the low CEC of kaolinite. Micas have a moderate cation exchange capacity and are usually suppliers of potassium (GRANT and HANAWAY, 1968). The cation exchange capacity depends on two variables, namely the amount and kind of exchange material present (KELLEY, 1948). The relatively high amount of kaolinite in these soils, may be responsible for the rather low CEC values observed. JACKSON and AGUERA, 1953).

Figure 7 : PARTICLE SIZE DISTRIBUTION FOR PROFILES 2,3 & 22.

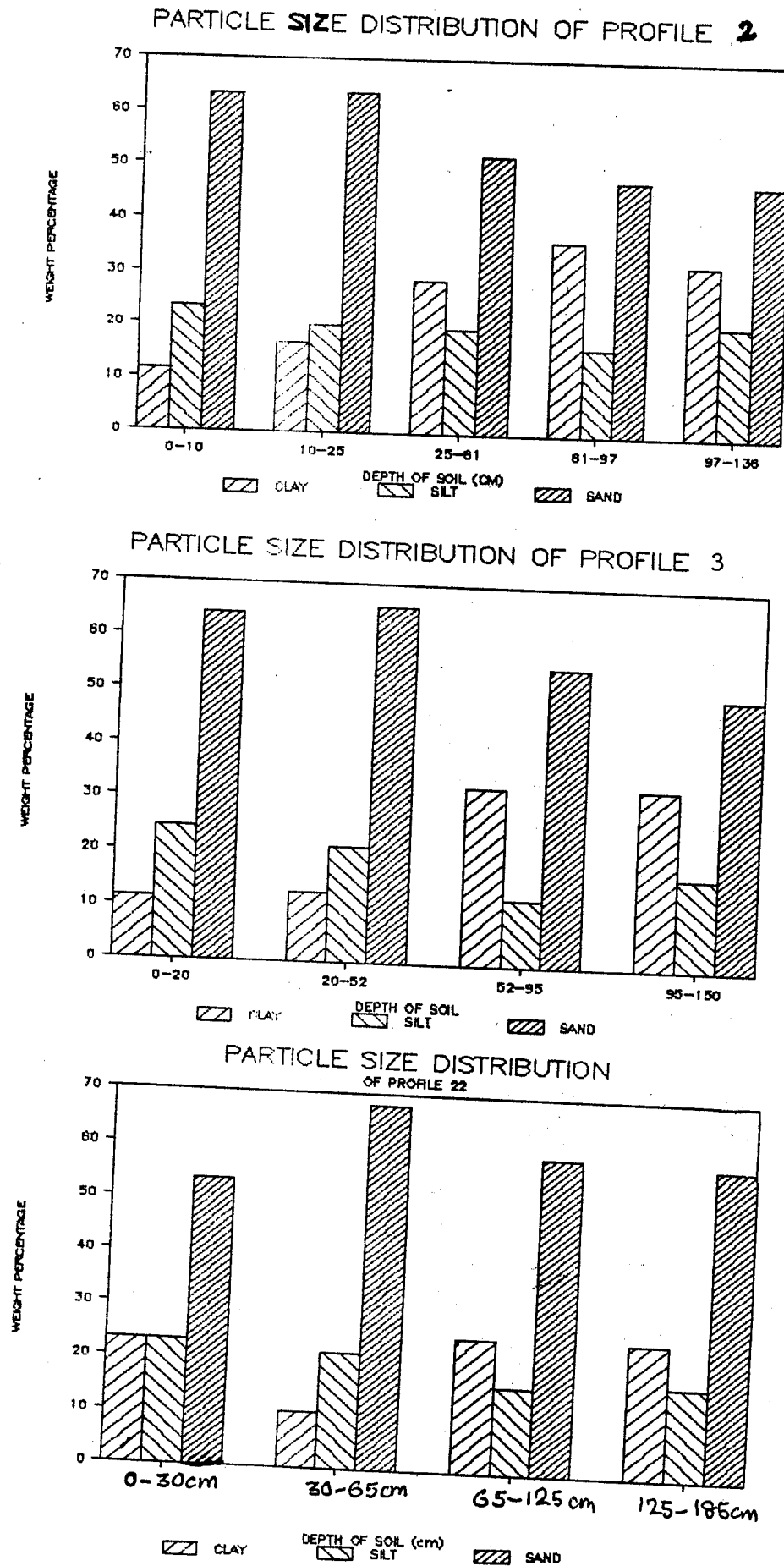


Table 3 : SUMMARY OF CHEMICAL DATA FOR PROFILES 2, 3 AND 22.

LOCATION	Percentage per 100g Soil							
	Mn	Fe ₂ O ₃	Al	Si	CEC	Org C	CEC/100g clay	pH CaCl
<u>Profile 2</u>								
0-10cm	0.00	2.00	0.11	0.06	5.00	0.22	46	3.0
10-25cm	0.00	2.00	0.10	0.08	2.00	0.53	10	3.9
25-65cm	0.00	3.90	0.12	0.04	4.00	0.35	13	4.3
<u>Profile 3</u>								
0-20cm	0.00	2.00	0.12	0.04	4.00	0.74	35	5.5
20-30cm	0.00	1.00	0.12	0.04	4.00	0.19	28	5.8
30-51cm	--	--	--	--	--	--	--	--
51-92cm	0.00	4.00	0.26	0.08	4.00	0.45	12	4.8
100-141cm	0.00	4.00	0.19	0.04	4.00	0.19	13	5.5
<u>Profile 22</u>								
0-30cm	0.00	1.65	0.03	0.12	4.00	0.73	17	5.8
30-65cm	0.01	2.77	0.50	0.14	2.50	0.15	24	5.6
65-125cm	0.00	1.34	0.17	0.10	3.30	0.19	13	6.0
125-185cm	0.00	0.78	0.28	0.41	4.00	0.15	16	6.9

have reported the effect of iron oxides on reducing the CEC of soils. The free iron content though apparently low per 100 grams of soil is quite substantial when expressed per 100 g of clay. These oxides may also contribute to the reduction of the CEC. In addition the presence of free iron oxides, increases the degree of aggregation in soil, and the amount of pseudo silts and sands, which give oxisoils, an apparent sandy texture in the field (SYS, 1988). The presence of iron oxides, also reduces the disperse ability of clays and other properties, such as plasticity and stickness (KELLOG, 1951). As a result, these soils have a stable granular microstructure, which also gives it a porous nature. The stable aggregates allow the soils to remain relatively permeable to water even in wet conditions, due to the reduced disperseability induced on the clay by the iron oxides. Kaolinite and micas, are by virtue of the atomic structure, not very easily expansible, even when wetted (DE CONINCK, 1989).

The pH shows an increase downslope. The organic cation content apart from showing a decrease with depth within each profile, shows no special trend along the sequence.

5.7. BRIEF COMMENTS ABOUT SOME MANAGEMENT PROPERTIES OF THESE SOILS.

The noted pellicular to bridged grain microstructure of the surface horizons and the granular aggregate microstructure of the soils on this sequence, give a good permeability to water and air. Profile 22, shows partly drained conditions, not because of its poor structure, but by virtue of its physiographic. The soils in the upper landscape as far as the physical characteristics are concerned, have no major limitation to ploughing (workability) and root penetration.

The low CEC of the soil, implies a low nutrient retaining ability of these soils. This may affect their response to fertilization. The application of fertilizer, may have to be altered to split application, depending on the crop being grown and its growing period. High fertilizer applications may result in losses of nutrients, especially under condition of high rainfall, due to leaching. The natural chemical fertility of the soils on this sequence is low, as has been seen from the study of minerals, and for good yields, supplemental nutrients application is necessary.

The pH of the soil, in profile 2, is on the acidic side, and coupled with the high free iron content of the soils, may pose a possible problem to phosphate fertilizers. So proper care, and even liming may be necessary to raise the pH of the soil if any good response to the fertilizer application can be realized for crops grown on the upland soil.

The low land soil (profile 22) shows poor drainage conditions. This may affect root development of crops and since the poor drainage conditions are due to the presence of high water table, it may be advisable to grow crops with greater tolerance to poor drainage conditions. Nitrogen fertilizers can also be easily lost in this soil due to reduction, by microorganisms, when conditions are wet.

6. CONCLUSION.

From this study the following conclusions have been drawn :

- the soils in this sequence show a colour differentiation from red to yellow, attributed to the change in drainage conditions..
- the weathering of biotite and other iron bearing minerals accounts for the observed colours in these soils.
- the increase in depth of the pellicular to bridged grain microstructure downslope, is attributed partly to lateral movement of soil material downslope by erosion.
- illuviation of clay together with free iron and fine organic material is occurring in all the profiles.
- the presence of typic nodules throughout the sequence suggests the presence of originally laterized material in the parent material of these soils.
- oxido-reduction reactions of the poorly drained soils may be at the origin of the many impregnative nodules in these soils.
- the heavy mineral assemblage and observed rock fragments indicate a metamorphic origin, from which at least part of the sequence is derived.
- the soils are depleted of most of the weatherable minerals and are only remaining with resistant and generally nutrient poor minerals.
- the soils of this sequence show good physical characteristics for plant growth and cultivating crops, except for the poor drainage of low land soil. The low CEC of the soils may affect fertilizer management programmes. The upland soils may need liming for improved response to fertilizer application.

7. APPENDICES.

7.1. APPENDIX 1 : PROFILE DESCRIPTIONS.

7.1.1. Pedon : 2.

Mapping unit : xCo
 Series : Choma Loamy sand Permeability : Moderate
 UTM Coord. : PP564017 Depth to ground-water : 138cm
 Physiography : Upland Drainage : Well
 Slope : 1-3% Parent material : Alluvium and thick
 colluvial deposits

Erosion : Slight sheet erosion

Classification : Land use : Maize

USDA : Fine-loamy, mixed, hyperthermic oxic Paleustalf

FAO : Ferric Luvisol

Described by : V.R.N. Chinene, O.I. Lungu and K.S. Gill

date : 5/86

<u>Horizon</u>	<u>Depth(cm)</u>	<u>Description</u>
Ap	0-10	Reddish yellow (7.5YR 6/6) dry; dark brown (7.5YR 4/4) moist; loamy sandy; weak fine subangular blocky structure; slightly hard dry; friable moist; non-sticky; non-plastic; common fine and medium pores; rapid permeability; many fine and medium roots; clear smooth boundary.
AE	10-25	Strong brown (7.5YR 5/6) dry; yellowish red (5YR 4/6) moist; loamy sand; few faint gray mottles (not due to drainage but material from above); weak medium subangular blocky structure; slightly hard dry; friable moist; non-sticky; non-plastic; dry; no pores; slowly permeable; few fine roots; clear smooth boundary.
Bt1	25-61	Yellowish red (5YR 5/6 dry, 4/6 moist); sandy loam; moderate medium subangular blocky structure; slightly sticky; slightly plastic; dry; patchy thin cutans; few fine common medium pores; moderately slow permeability; very few fine roots; gradual smooth boundary.

Bt2	61-97	Red (2.5YR 4/6) dry; dark red (2.5YR 3/6) moist; sandy clay; moderate coarse subangular blocky structure; slightly hard dry; friable moist; sticky; plastic; dry; patchy moderately thick cutans; common fine and medium pores; moderately permeable; no roots; gradual smooth boundary.
Bt3	97-138	Yellowish red (5YR 5/6) dry; dark red (2.5YR 3/6) moist; sandy clay loam; moderate coarse subangular blocky structure; slightly hard dry; friable moist; slightly sticky; slightly plastic; dry; patchy thin clay cutans; common fine and medium pores; mode- rately permeable; no roots.

Pedon 2 : Analytical data

Depth (cm)	Horizon	Texture	Clay % 2 m	Silt % 2-50 m	Sand % 50 m
0-10	AP	SL	11.4	23.4	63.2
10-25	AE	SL	16.6	19.8	63.6
25-61	Bt1	SCL	28.6	19.4	52.0
61-97	Bt2	SC	36.2	16.0	47.8
97-136	Bt3	SCL	32.2	20.6	47.2

Depth (cm)	Horizon	Exch. cations (meq/100g soil)						Avail. P (ppm)
		K	Na	Ca	Mg	Al	H	
0-10	AP	0.52	0.22	0.35	0.08	1.68	2.36	5.6
10-25	AE	0.35	0.23	0.25	0.08	0.54	0.14	
25-61	Bt1	0.81	0.28	0.80	0.25	0.72	0.88	
61-97	Bt2	0.44	0.25	1.15	1.08	0.20	0.20	
97-136	Bt3	0.49	0.24	0.55	0.83	0.28	0.40	

Depth (cm)	Horizon	CEC meq/100g soil	CEC meq/100g clay	Base sat. %	Al+H sat. %
0-10	AP	5	46	23	76
10-25	AE	2	10	57	43
25-61	Bt1	4	13	57	43
61-97	Bt2	3	9	88	12
97-136	Bt3	3	9	76	24

Depth (cm)	Horizon	pH H2O	pH CaCl2	Total N %	Org. C %	Fe2O3 % DCB extract
0-10	AP	4.8	4.0	0.035	0.82	2
10-25	AE	4.4	3.9	0.015	0.53	2
25-61	Bt1	4.7	4.3	0.015	0.35	3
61-97	Bt2	5.2	5.1	0.005	0.05	2
97-136	Bt3	5.5	4.8	0.003	0.11	4

7.1.2. Pedon : 3.

Series : Choma Loamy sand	Mapping unit : xCo
UTM Coord. : PP568006	Permeability : Moderate depth to
Physiography : Upland	Depth to ground-water : 150cm
Slope : 1-3%	Drainage : Moderately well
	Parent material : Alluvial and thick colluvial deposits

Erosion : Slight sheet erosion

Classification : Land use : Maize

USDA : Fine-loamy, mixed, hyperthermic Arenic Paleustalf

FAO : Ferric Luvisol

Described by : V.R.N. Chinene, O.I. Lungu and K.S. Gill

date : 5/86

<u>Horizon</u>	<u>Depth(cm)</u>	<u>Description</u>
Ap	0-20	Yellowish brown (10YR 5/4) dry; dark brown (10YR 4/3) moist; loamy sand; weak medium subangular blocky structure; slightly hard dry; very friable moist; non-sticky; non-plastic; dry; common fine pores; rapid permeability; many fine and medium roots; clear smooth boundary.
E	20-52	Dark brown (7.5YR 4/4) moist; loamy sand; structureless; very friable moist; non-sticky; non-plastic; moist; common fine pores; rapid permeability; many fine roots; clear smooth boundary.
Bt1g	52-95	Dark red (2.5YR 3/6) moist; sandy clay loam; common distinct yellowish brown (10YR 5/4) mottles; strong coarse subangular blocky structure; friable moist; sticky; slightly plastic; moist; broken thick cutans; few medium many fine pores; moderately permeable; few fine roots; clear smooth boundary.

Bt2	95-150+	<p>Red (2.5YR 4/6) moist; sandy clay loam; few faint yellowish brown (10YR 5/4) and gray (2.5YR 6/0) mottles; weak medium subangular blocky structure; friable moist; sticky; slightly plastic; moist; patchy thin cutans; few fine pores; moderately permeable; few fine roots.</p>
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Pedon 3 : Analytical data

Depth (cm)	Horizon	Texture	Clay % 2 m	Silt % 2-50 m	Sand % 50 m
0-20	AP	SL	11.4	24.4	64.2
20-52	E	SL	12.8	21.4	65.8
52-95	Bt1g	SCL	32.6	12.4	55.0
95-150+	Bt2	SCL	32.8	17.0	50.2

Depth (cm)	Horizon	Exch. cations (meq/100g soil)						Avail. P (ppm)
		K	Na	Ca	Mg	Al	H	
0-20	AP	0.54	0.24	2.45	0.58	0.08	0.08	5.6
20-52	E	0.46	0.24	1.15	0.50	0.88	0.32	
52-95	Bt1g	0.75	0.23	2.05	0.58	0.12	0.16	
95-150+	Bt2	0.63	0.28	1.35	0.83	0.38	0.74	

Depth (cm)	Horizon	CEC meq/100g soil	CEC meq/100g clay	Base sat. %	Al+H sat. %
0-20	AP	4	35	96	4
20-52	E	4	28	66	34
52-95	Bt1g	4	12	93	7
95-150+	Bt2	4	13	73	27

Depth (cm)	Horizon	pH H2O	pH CaCl2	Total N %	Org. C %	Fe2O3 % DCB extract
0-20	AP	6.3	5.5	0.045	0.74	2
20-52	E	6.6	5.8	0.005	0.19	1
52-95	Bt1g	6.3	4.8	0.030	0.45	4
95-150+	Bt2	5.8	5.5	0.115	0.19	4

7.1.3. Pedon : 22.

Authors : V. Chinene & V. Shitumbanuma.
Date of
examinations : 10/06/87.
Profile No : 22.
Location : Wheat field on the southern side of the Great
East road, UNZA farm, Lusaka, just next to the
gate on road from the dambo.
Parent material : colluvial and alluvial deposits.
Physiographic
position : on slope, just at the edge of a dambo.
Slope : 2-3%.
Drainage : imperfectly drained.
Moisture regime : ustic.
Temperature : isothermic.
Land use : ploughed wheat field (irrigated).
Elevation :
Classification : (not classified).

AP 0-30cm (10YR 5/3) dry, (10YR 3/2) moist.

Sandy loam, sticky, non-plastic, friable (moist), firm
(dry), 1mm crack, moderate fine and medium subangular
blocky, common fine pores, many fine roots, clear smooth
boundary, moderate permeability.

B1 30-65cm (10YR 5/6) dry, (10YR 4/4)

Loamy sandy, non-plastic, non-sticky, friable (moist),
1mm cracks, moderate medium angular blocky, few fine
pores, few fine roots, moderate permeability, clear
smooth boundary.

Bt2 65-125cm (2.5Y 5/4) moist. (moist horizon).

Sandy clay loamy, slightly sticky, slightly plastic,
moderate medium and coarse angular blocky, common fine
pores, few fine roots, many distinct coarse mottles
(5YR 4/4).

ANALYTICAL DATA.

Profile № : 22.

PARTICLE SIZE DISTRIBUTION.

Depth cm	Clay %	Silt %	Sand %	Texture (USDA)
0-30	23.2	23.2	53.6	SCL
30-65	10.4	21.6	68.0	SL
65-125	24.8	16.0	59.2	SCL
125-185	24.8	17.2	58.0	SCL

CHEMICAL DATA.

Depth cm	Ex.Ca m.e.%	Ex.Mg m.e.%	Ex.Na m.e.%	Ex.K m.e.%	Ex.acidity m.e.%	CEC m.e./100g soil	Al sat. %
0-30	2.50	0.58	0.01	0.78	0.14	4.01	2.5
30-65	1.28	0.63	0.00	0.47	0.14	2.52	5.6
65-125	1.98	0.54	0.01	0.64	0.14	3.28	4.3
125-185	2.58	0.91	0.01	0.42	0.12	4.04	8.0

Depth cm	Org C %	Total N %	Avail. P ppm	pH (CaCl ₂)	pH (H ₂ O)	Base sat.%	Free Fe ppm
0-30	0.73			5.9	6.2	97.5	
30-65	0.15			5.9	6.6	94.4	
65-125	0.19			5.6	6.1	95.7	
125-185	0.15			5.7	6.4	97.0	

7.2.APPENDIX 2 : MICROMORPHOLOGICAL DESCRIPTIONS.

7.2.1. Profile : 2.

Slide N° 19.010.

Depth 0-10 cm (AP).

Microstructure and Porosity :

complex structure, with dominantly pellicular grained to bridged grained microstructure, with compound packing pores 30% and a number of channels.

Groundmass.

C/f limit : 10 μ m.

Organic material :

highly birefringent root sections, decomposed and partially decomposed reddish to black plant tissues (0.5-2.3 mm), and highly birefringent pieces of straw.

Coarse material :

weathering biotite flakes (0.02 mm), dominance of subangular quartz grains (0.01-0.8 mm) 30%, tourmaline (0.02-0.3 mm), fragmented and rounded zircon, microcline, fragmented kyanite grains, weathering muscovite flakes (0.01-0.09 mm) 2-5% and rock fragments containing weathering muscovite grains.

Fine material :

reddish to dark brown dotted clay with an undifferentiated to speckled b-fabric.

C/f related distribution :

mainly chitonic to gefuric, with patches of close porphyric.

Pedofeatures :

very dark reddish brown clay dotted oriented clay coatings around mineral grains, with extinction lines perpendicular to the orientation planes. Red to black typic iron nodules containing quartz and muscovite grains. Fragments and coatings of red iron oxyhydrates (0.2 mm) and black opaque coatings are very frequent 2-5%. Patches of domains fine material (dotted clay, fine muscovite and fine organic fragments) occurs scattered throughout the groundmass.

Slide N° 19.011.

Depth 10-25 cm E.

Microstructure and Porosity :

dominantly bridged to pellicular grained microstructure.

Groundmass.

C/f limit : 10 μ m.

Organic material :

reddish to black partly decomposed plant fragments and few birefringent root sections.

Coarse material :

as above.

Fine material :

reddish brown clay with speckled to random striated b-fabric.

C/f related distribution :

chitonic to gefuric.

Pedofeatures :

very few reddish brown oriented dotted clay coatings, with extinction lines perpendicular to orientation planes < 2%. Many reddish to black (opaque) coating of iron oxyhydrates on mineral grains, and free fragments in the groundmass (0.01-0.1 mm).

Slide N° 19.012.

Depth 25-65 cm Bt1.

Microstructure and Porosity :

complex structure, with dominantly channel structure and granular aggregates (0.1-0.2 mm). Granules of mineral grains cemented by reddish brown clay and granules of clay without any mineral grains occurs (0.1 mm). Pore space 40-50%.

Groundmass.

C/f limit : 10 μ m.

Organic material :

few dark brown sections of roots in the channels.

Coarse material :

as above with rock fragments containing biotite, quartz and grains of garnet coated with dark reddish brown to black opaque material, and microcline.

Fine material :

yellowish orange to dark reddish brown finely dotted clay with a speckled b-fabric.

C/f related distribution :

dominantly close porphyric.

Pedofeatures :

thick (0.2 mm) oriented, limpid and sometimes dotted clay coatings < 2%. Weakly impregnative dark brown to yellowish iron nodules with quartz grains and deep red birefringent material coating partially weathering, muscovite flakes. The same deep reddish material occurs in form of fragments within the ground-mass and as coatings on mineral grains. Very few reddish to dark brown typic impregnative nodules (0.7 mm) < 2%. Thick streaks of limpid clay coatings (0.1 mm long) occur as curved or bow like heterogeneous fine striated clay material. Continuous dense infillings.

Slide N° 19.013.

Depth 100-141 cm Bt2.

Microstructure and Porosity :

complex structure with channel structure, and granular aggregate structure. The granular structure is well developed and well pronounced. Granules of clay (0.06-0.1 mm), and those of clay cementing mineral grains (0.09-0.02 mm). The larger mineral grains are coated by thick (0.04-0.1 mm) reddish brown clay material. There are many compound packing pores 40-50%.

Groundmass.

C/f limit : 10 μ m.

Coarse material :

as above, with rock fragments of weathering muscovite and quartz grains coated with reddish to black coating of iron oxyhydrates.

Fine material :

dominantly deep reddish brown finely dotted clay with speckled b-fabric.

C/f related distribution :

chitonic to close porphyric.

Pedofeatures :

disjointed iron nodule, with deep reddish fine material mixed with clay covering mineral grains. Reddish to black amorphous to opaque coating of iron on mineral grains as well as free fragments in the soil 2%. This is the same material seen in

the disjointed nodule. Loose discontinuous infilling of a root channel. Zones of high oriented clay coatings, cementing all grains in the region occur and seem to have clear boundary from surrounding granular (could possibly be beginning of nodule formation). Dark brown typic impregnative nodule with clear smooth boundary.

INTERPRETATION OF ABOVE OBSERVATIONS.

This profile shows a change in soil characteristics from the surface to the bottom horizon. A look at the microstructure reveals a transition from a complex microstructure with mainly pellicular and bridged grain structure with compound to simple packing pores in the top horizon to more channel structure with granular aggregates. Much in the same line is the change in the C/f related distribution which shows a transition from dominantly chitonic to geforic distributions in the top horizons to a dominance of close porphyric distribution in the deeper layer.

There is an observed increase in the amount of fine material with depth. The presence of oriented clay coatings from the top horizon to the deepest horizon, which appear to increase in frequency and size with depth, indicates the presence of the process of illuviation in this profile. The dotted appearance of some oriented clay coatings may indicate a possible translocation of clay with fine amorphous organic and inorganic impurities. The granular aggregates of the deeper horizons show two different types of granule, namely those of clay and mineral grains, cemented together and aggregates of clay alone. Frequently seen are deep reddish to black oxyhydrates of iron which sometimes coat mineral grains and at times appear as separate units in the groundmass. A disjointed nodule in the thin section, shows a concentration of these fragments in the nodules together with clay, as cementing material for mineral grains. This observation seems to point to the initial stage of nodule formation in the profile or in situ nodule formation. The well rounded dark reddish brown, impregnative nodules, with sharp boundaries may be interpreted as being inherited origin of these nodules from lateritic deposits.

The mineral grains observed show a dominance of quartz. Biotite and microcline are also observed, in very low frequency,

together with rock fragments with biotite, and garnet. Muscovite, tourmaline, fragmented kyanite, and zircon are more frequently observed compared to the earlier two mentioned minerals. Fragments of rocks of muscovite and quartz grains are frequently observed.

7.2.2. Profile : 3.

Slide N° 19.014.

Depth 0-20 cm.

Microstructure and Porosity :

pellicular to bridged grain microstructure, with a few channels and dominantly compound packing pores 50%.

Groundmass.

C/f limit : 10 μ m.

Organic material :

highly birefringent sections of roots, partially decomposed dark brown plant tissues and other fragments (humified).

Coarse material :

subangular quartz grains (0.01-0.6 mm) 30%, muscovite flakes (< 0.1-0.6 mm), with high evidence of weathering 3%. Fragmented tourmaline grains (0.01-0.2 mm), zircon, and fragmented kyanite grains.

Fine material :

dark brown dotted clay mainly mixed with fine organic material with an undifferentiated to speckled b-fabric.

C/f related distribution :

gefuric to chitonic.

Pedofeatures :

amorphous material fragments and coatings on mineral grains < 2%. Local concentration of fine organic material, silt size quartz grains (0.01-0.03 mm) and thin muscovite flakes (0.1 mm and less) occur as domains scattered within the groundmass. Dark brown well rounded typic iron nodules with quartz and muscovite grains (1 mm).

Slide N° 19.015.

Depth 20-30 cm.

Microstructure and Porosity :

as above.

Groundmass.

C/f limit : 10 μ m.

Coarse material :

as above and rock fragments containing fresh and partly weathering muscovite and quartz mineral grains (2 mm). Muscovite grains (0.01-0.06 mm thick) > 5%.

Fine material :

as above, but with more reddish brown domains, and an undifferentiated to speckled b-fabric.

C/f related distribution :

chitonic to close porphyric.

Pedofeatures :

reddish brown oriented dotted clay coating around mineral grains with extinction lines perpendicular to their orientation planes (0.06-1 mm) < 2%. The oriented clay coatings have a redder colour than surrounding non-oriented clays. Dark amorphous material (0.01-0.06 mm) 2-5% occur as coatings on mineral grains, and as free fragments in the groundmass.

Slide N° 19.017.

Depth 30-35 cm.

Microstructure and Porosity :

complex microstructure with channels, and a dominantly granular aggregate structure (0.1-2 mm) channels (0.7-4 mm) 30%. Pore space 40-50%.

Groundmass.

C/f limit : 10 μ m.

Organic material :

highly birefringent root fragments (2 mm).

Coarse material :

as above.

Fine material :

mainly very reddish brown finely dotted clay and less yellowish dark brown clay with a speckled b-fabric.

C/f related distribution :

close to single spaced porphyric.

Pedofeatures :

deep reddish brown oriented dotted and laminated clay coatings (0.02-0.06 mm) < 2%. Reddish brown to black amorphous

material (< 0.01 - 0.01 mm) occur as coatings on mineral grains and free fragments in the groundmass. Loose discontinuous infillings of mineral grains coated with yellowish brown clay appear in channels.

Slide N° 19.016.

Depth 52-91 cm.

Microstructure and Porosity :

complex microstructure with dominance of channels, and a granular aggregate structure, with patches of bridged to pelli-cular grained microstructures, within the voids. Pore space 40-50 %.

Groundmass.

C/f limit : $10 \mu\text{m}$.

Organic material :

highly birefringent root fragments (0.5-4 mm) and dark brown to black partially decomposed to humified fragments (0.2-1.0 mm).

Coarse material :

as above, but with larger kyanite grains, and more rock fragments containing muscovite quartz and tourmaline with amorphous reddish to black coatings (0.9-3 mm). Many muscovite flakes 5%.

Fine material :

reddish brown finely dotted clay with speckled b-fabric.

C/f related distribution :

dominantly close porphyric, with patches of gefuric to chitonic.

Pedofeatures :

many oriented dotted microlaminated, and laminated continuous clay coatings around voids and mineral grains (0.01-0.1 mm) 2-5%. The coatings are generally redder than surrounding non-oriented clay, dotted coatings are darker than surrounding material, and laminated coatings show alternating bands of very dark to black, and deep reddish.

loose mineral grains with dark clay-organic matter fine material appear in former channels (infillings). These infillings are to be rich in black amorphous (probably organic) material (0.2-0.06 mm). Many phytolites (0.01 mm) $< 2\%$.

INTERPRETATION OF ABOVE OBSERVATIONS.

This profile has a pellicular to bridged grain microstructure with a few channels. The subsurface horizon and deeper horizons have a dominantly channel structure with granular aggregates. The soil has a very porous structure.

The fine material is dark brown dotted clay mixed with organic material with an undifferentiated to speckled b-fabric. With depth there is an observed increase in oriented clay coatings, with the deepest horizon, having about 2-5%. Typic iron nodules containing muscovite and quartz are observed in all the horizons. There is evidence of translocation of clay with iron and fine organic material and high amount of phytolites.

The coarse material shows quartz as the most dominant mineral in the sand sized fraction. Tourmaline, muscovite, and kyanite are the next most abundant minerals. Zircon, and biotite are also observed. The above mentioned minerals are mostly quite resistant to weathering and they are quite poor in most plant nutrients, with the exception of biotite, and tourmaline. So this soil has a low potential chemical fertility.

The above mentioned microstructure is quite porous and hence we may expect a very good infiltration rate in these soils. With the soils being dominantly kaolinitic and with the rather higher presence of sesquioxides, we can expect a rather low cation exchange capacity. In addition the organic matter content is not that high and as such we may not expect a very high amount of nutrient retention and water holding capacity in the surface horizon.

7.2.3. Profile : 22.

Slide N° 19.039.

Depth 0-30 cm.

Microstructure and Porosity :

bridged to pellicular grained microstructure with compound packing pores 50%.

Groundmass.

C/f limit : 10 μ m.

Organic material :

highly birefringent root sections and plant tissues, partly decomposed dark brown plant fragments and humified material 10%.

Coarse material :

subangular quartz grains (0.01-0.3 mm) 30%, muscovite (0.01-0.03 mm) 2%, tourmaline (0.03-2 mm) < 2%, microcline, biotite, kyanite (0.02-0.1 mm) and rock fragments containing muscovite and quartz sometimes coated by opaque oxides of iron.

Fine material :

dark brown organic matter-clay mixture with undifferentiated to speckled b-fabric.

C/f related distribution :

chitonic.

Pedofeatures :

many patches of dark brown fine organic material mixed with highly weathered fine muscovite flakes. Typic iron nodules with quartz grains (0.4-1.3 mm). Reddish brown amorphous fragments and coatings on mineral grains.

Slide N° 19.040.

Depth 25-65 cm.

Microstructure and Porosity :

as above but with channels and planes.

Groundmass.

C/f limit : 10 μ m.

Organic material :

few dark humified fragments.

Coarse material :

as above, but with orthoclase.

Fine material :

dark brown to yellowish brown dotted clay, with random striated b-fabric.

C/f related distribution :

chitonic.

Pedofeatures :

few scattered yellowish brown dotted oriented clay coatings with extinction lines perpendicular to the orientation planes $< 2\%$ (0.03 mm). Nucleic iron nodules with sharp well rounded boundaries containing quartz and muscovite grains (2-5 mm). There is evidence of presence of oriented clay coatings with the nodules.

Slide N^o 19.041.

Depth 65-125 cm.

Microstructure and Porosity :

complex structure, with dominantly channel structure, a few patches of bridge grained microstructure and weakly developed granular structure.

Groundmass.

C/f limit : 10 μ m.

Organic material :

none evident.

Coarse material :

as above.

Fine material :

yellowish to reddish brown dotted clay with speckled to random striated b-fabric.

C/f related distribution :

close porphyric to chitonic.

Pedofeatures :

oriented, yellowish brown dotted clay coating with extinction lines perpendicular to orientation planes 2%. Nucleic iron nodules with sharp rounded boundaries (0.5-2 mm). Dark brown amorphous thin coating along channel wall (0.04 zone, which lies in between the channel wall and main groundmass which is reddish brown (probably depletion feature)(circled portion). Weakly impregnative nucleic nodules with smooth gradual boundaries (0.3 mm).

Slide № 19.042 (62).

Depth 125-135 cm.

Microstructure and Porosity :

complex structure, with a dominantly channel microstructure, some single grained to bridge grained structure, and weakly developed granular to subangular blocky structure.

Groundmass.

C/f limit : 10 μ m.

Organic material :

non evident.

Coarse material :

as above, and rock fragments with quartz and muscovite grains arranged in a banded manner (3 mm).

Fine material :

the horizon shows two different types of fine material due to mottling, a yellowish dotted clay fine material with random striated b-fabric and a reddish brown material with the same b-fabric in the mottled patches. Distribution is about 50% of each type.

C/f related distribution :

close porphyric, and chitonic.

Pedofeatures :

yellowish limpid to dark dotted oriented clay coatings and reddish brown limpid to dotted and microlaminated clay coatings around grains and voids (0.02-0.2 mm) 5%. Reddish amorphous coatings on mineral grains, and fragment of same material appear as fragments in matrix. The same reddish fragments are found to be major cementing material of nodules. Mottled portions seem to be richer in these fragments. Nucleic well rounded, iron nodules (2-4 mm). In mottled portion oriented clay coatings seem to be redder than surrounding non-oriented clay.

INTERPRETATION OF ABOVE OBSERVATIONS.

Profile 22 shows a surface horizon of mainly single grains covered by thin coatings of fine material and this structure is seen up to 65 cm depth. From 65 cm depth the soil has mainly a granular aggregates, with a dominantly channel microstructure. This is also seen in the change in the C/f related distribution

which changes from chitcnic in the top horizons to porphyric in the deeper horizon.

There is evidence of clay illuviation as seen by the oriented clay coatings in the second and third horizon. With depth also, is an observed increase in mottling. The change from a dominantly yellowish dotted fine material to more yellowish with patches of reddish brown material is seen. This is also evidence of oxido-reduction reactions going on the soil.

There appears to be a relation between the reddish brown mottles and presence of reddish brown oriented clay coatings. The reddish brown clay is interpreted as having translocated with free iron. The microlaminated clay coatings also indicate successive deposition of these coatings, while the dotted clay may be interpreted as being due to the translocation of clay with organic matter.

The coarse material shows quartz as the dominant mineral in the sand fraction. Muscovite follows quartz and abundance and tourmaline and fragmented kyanite rank third. Few highly weathered flakes of biotite are also observed. Microcline and orthoclase are also seen. As seen in other profiles in this sequence, these minerals are relatively resistant to weathering, with the exception of biotite and the two mentioned potassium feldspars. So in terms of potential fertility this soil is relatively low.

8. LIST OF FIGURES.

- 1 : SOIL MAP OF UNZA FARM.
(Source : CHINENE, 1988).
- 2 : STRUCTURAL CHARACTERISTICS OF THE GEOLOGY OF LUSAKA.
- 3 : GEOLOGY MAP OF UNZA FARM.
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(not drawn to scale).
- 5 : X-RAY DIFFRACTOGRAMS FOR SOME HORIZONS OF PROFILES 2, 3 AND 22.
- 6 : TGA AND DTA CURVES FOR PROFILE 3.
- 7 : PARTICLE SIZE DISTRIBUTION FOR PROFILES 2, 3 & 22.

9.LIST OF TABLES.

1 : CLIMATIC DATA FOR UNZA STATION (1985-1986).

15°23'S 28°28'E 1140 m MSL

2 : HEAVY AND LIGHT MINERALS OF THE PROFILES 2, 3 AND 22.

3 : SUMMARY OF CHEMICAL DATA FOR PROFILES 2, 3 AND 22.

10. LIST OF PHOTOS.

- 1 : Pellicular to Bridged grain microstructure of Ap horizon with a section of a root (Profile 2 : 0-10 cm). Magnification : 2.5×1.25
- 2 : Granular aggregates (E horizon, Profile 3 : 30-35 cm). Magnification : 6.3×1.25
- 3 : Coincidence of reddish brown oriented clay with brown mottled spots (Btg horizon, Prof. 22 : 125-135 cm). Magnification : 2.5×1.25
- 4 : Thick reddish brown oriented clay coatings around mineral grains (Bt horizon, 51-91 cm). Magnification : 6.3×1.25
- 5 : Rock fragment containing muscovite and quartz, showing parallel arrangement of mineral, typical of metamorphic rocks. (E horizon, Profile 3 : 30-35 cm). Magnification : 6.3×1.25
- 6 : Impregnative nodules in poorly drained Btg horizon (Profile 22 : 125-135 cm). Magnification : 2.5×1.25

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