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THE PEDOLOGY OF THE RED LATOSOLS OF CEYLON

BY

KINGSLEY ANTON DE ALWIS, B.SC.

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF SOIL SCIENCE

EDMONTON, ALBERTA
FALL, 1971

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "The Pedology of the Red Latosols of Ceylon" submitted by Kingsley Anton de Alwis, B.Sc., in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

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ABSTRACT

Geomorphic evidence as well as similarities in climate, vegetation, topography and age of the three major soil series of the Ceylon Red Latosols suggested that differences among the series have arisen primarily from variations in parent materials. Three profiles from each of these soil series were studied morphologically and sampled for physical, chemical, mineralogical and micro morphological analyses which were carried out to determine their characteristics and elucidate the genesis of the Red Latosols.

The Red Latosols of Ceylon are deep, highly weathered, red soils with weak horizon differentiation. Soil structures are weak in the surface horizons and nearly absent at lower depths. The primary weatherable mineral contents are very low and the sand and silt fractions consist largely of quartz, magnetite, ilmenite, sillimanite, rutile and zircon. The clay fractions are dominated by well-crystallized kaolinite, but smaller amounts of iron oxides, mica, mixed layer minerals and, in the Wilpattu Series, a vermiculite-smectite intergrade also occur. Cation exchange capacities are largely pH-dependent and generally low (3-7 m.e./100 g. soil). Base saturation percentages are low in the upper B horizons but have higher values in the A and lower B horizons. The clay contents increase with depth and in the lower B horizons, range from about 20 percent in the Wilpattu Series to nearly 50 percent in the Gambura Series with the Mullaittivu Series having intermediate values. The free iron oxides, which are mainly hematite, also increase with depth and vary in the B horizons between about

3 percent in the Wilpattu and Mullaittivu soils and 6 percent in the Gambura Series.

The Red Latosols are developed from Quaternary beach deposits which were vertically uniform but showed regional variations in mineralogy. The main pedogenic processes have been (1) advanced deep weathering with ready removal of the more soluble products, (2) transformation of released iron oxides to hematite, (3) translocation of clay and iron oxides probably by peptization and transport in suspension, (4) base depletion in the upper B horizons, (5) phytocycling of some nutrient cations and consequent resistance to leaching in the surface horizons, (6) rapid mineralization of organic matter and (7) the action of small amounts of organic matter in the A horizons to produce slight differences in colour, structure and cation exchange properties. The weak horizon differentiation in the Red Latosols results largely from weathering which is uniform to great depths the spread of illuviated materials over wide vertical distances and, to a lesser extent, soil mixing by fauna and vegetation.

Differences among the three soil series of the Red Latosol sub-group have arisen primarily from variations in the initial mineralogy of the parent materials and are reflected largely in the clay and iron oxide contents and the properties influenced by them. In terms of the soil classification used by the National Co-operative Soil Survey in the United States, all three series belong to the Ustox sub-order.

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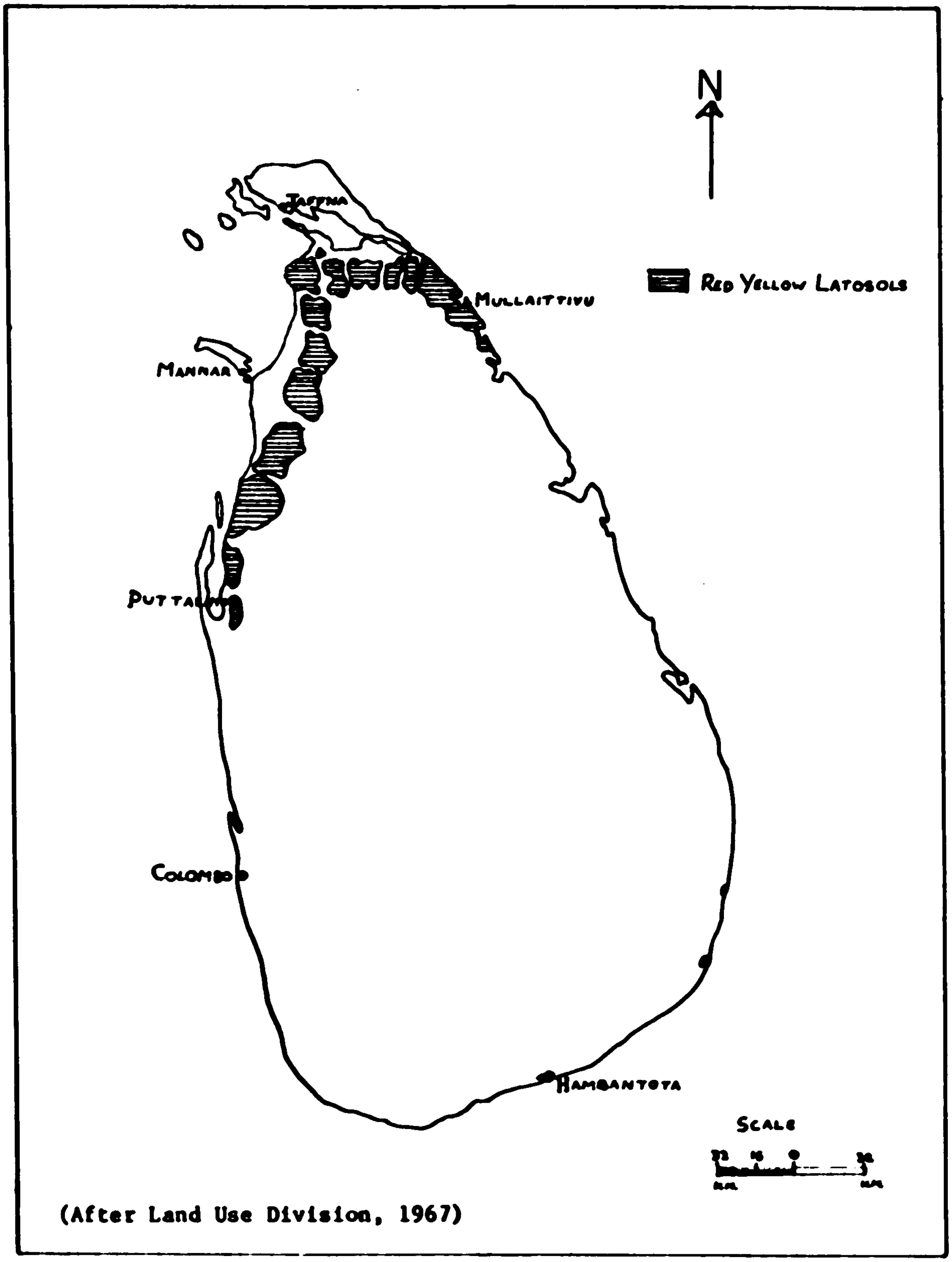
1. INTRODUCTION

This thesis is concerned with the Red Latosols of Ceylon as defined by that country's system of soil classification. The Red Latosols constitute one of the last remaining unexploited soil resources of Ceylon. They have evaded agricultural development to a large extent because of certain unique soil problems associated with their cultivation. Even shifting cultivation has hardly touched them. Since little was known about the characteristics of these soils it was felt that a detailed study should be undertaken to elucidate their nature before any major development projects were sited on them. The present investigation is part of that study. It attempts to determine the more important morphological, physical, chemical and mineralogical characteristics of the soils of the Red Latosol sub-group and to throw some light on their genesis.

The Red Latosols, a sub-group of the Red-Yellow Latosol great soil group, occur with the Yellow Latosols in a fairly narrow strip adjacent to the coast in the north-western, northern and north-eastern coast (Fig. 1). They occur under a fairly uniform climate and have essentially the same topography and landforms. Slight differences in the vegetation have been noted but they cannot be classed as separate vegetational types. Geomorphic and stratigraphic evidence indicates that the Red Earth Formation, on which the Red Latosols have developed, consists of more or less synchronal beach deposits belonging to the Quaternary. Any changes in climate and vegetation occurring



(After Land Use Division, 1967)

Figure 1. Map showing the distribution of the Red Latosols of Ceylon

during the period of soil formation are likely to have affected the relatively small area involved fairly uniformly. The factor, therefore, that is most likely to have led to differences within the Red Latosol sub-group is variation in the nature of the initial deposit, i.e. the parent material.

A preliminary study of the coastal geomorphology revealed that there are at least three broad areas in the Red Earth Formation possibly having different sources of sediment and with slightly different environments of (beach) deposition. That the three hitherto recognized soil series of the Red Latosols occur in these three regions suggested that differences in parent material may have in fact been the dominant factor in the variation of their properties. However, since samples of unaltered parent material are not available (the whole Red Earth Formation is intensively weathered) morphological studies and sampling were carried out on representative profiles of the three soil series on the assumption that detailed laboratory analyses could reveal the presence of a lithosequence of soils, and if so, would then determine the effect of variations in parent materials on soil formation.

Soils developed on old sedimentary materials have received scant attention from workers in soil genesis, mainly on account of the difficulties associated with the absence of unaltered underlying material similar to the parent material. Nevertheless, this study is based on the premise that soil scientists have now acquired such a vast body of knowledge about the processes that take place in soils and their effects on profile characteristics, that it is possible to utilize such characteristics themselves to work out the genetic processes that have given rise to a particular soil. Not only that, we may even make deductions, or at least intelligent guesses, about the environments that prevailed during soil formation. Stratigraphers and paleontologists have used a similar approach in paleonenvironmental reconstructions.

2. ENVIRONMENT(S) OF THE RED LATOSOLS

A knowledge of the environments in which soils form is essential to soil geographic correlation and helps place studies of soil forming processes in perspective. However, many soils have developed under more than one environment (especially in regions that have not undergone recent glaciation) and while there are no difficulties in characterizing the present conditions, past environments have to be inferred. In drawing such inferences, soil properties themselves often yield invaluable clues.

The following sections describe the geology (including the topography), climate and vegetation of the area in which the Red Latosols of Ceylon occur. The limited evidence available in regard to possible past climates and vegetation are presented and the origin of the deposit on which these soils have formed is discussed. The period over which soil formation has occurred will be dealt with in a later chapter.

2.1 GEOLOGY

2.11 Introduction

The Red Latosols have developed on the Red Earth Formation which occupies the coastal regions of north-west, north and north-east Ceylon (Fig. 2). This arcuate belt is generally about 20 km. wide although at its broadest point it is about 32 km. across. The outer

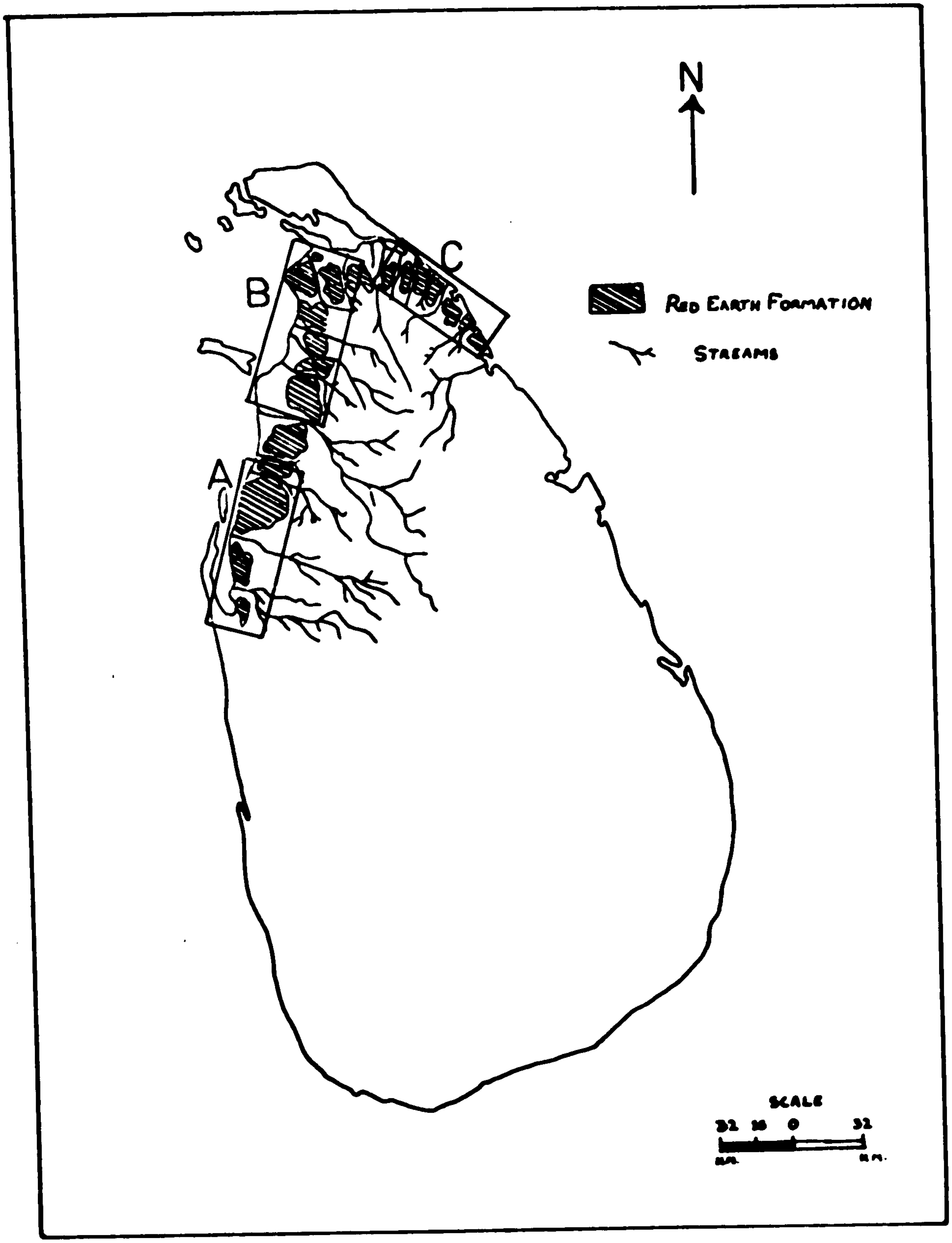
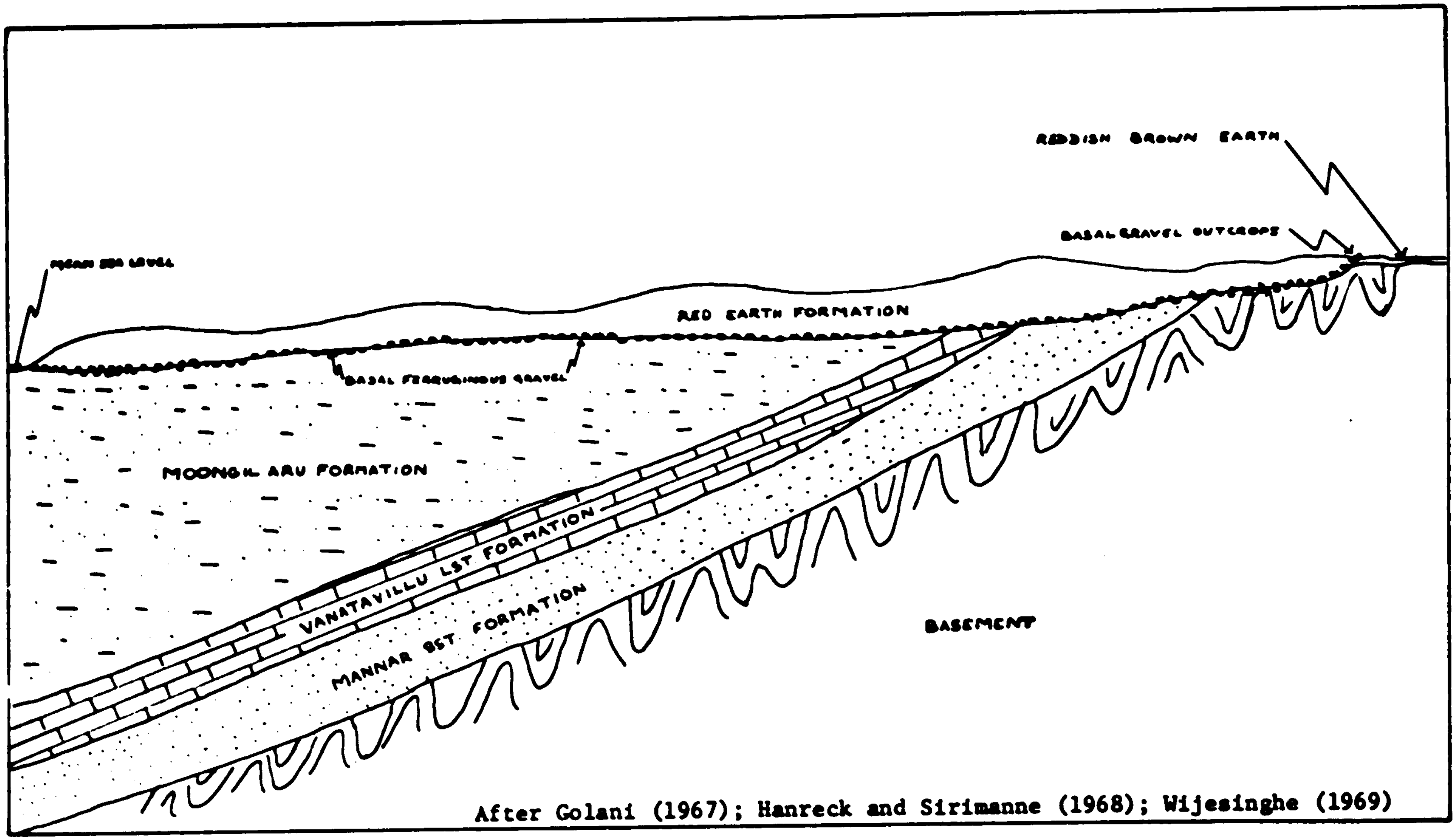


Figure 2. Map showing three areas A, B and C of the Red Earth Formation likely to have formed on different types of beach deposits

or seaward boundary consists of the present beaches, deltaic deposits and lagoons or the sea itself, while on the landward side it corresponds very approximately to the 30 m. contour. Two or three extremely small patches of Red Latosol also occur on the south-eastern coast on deposits closely resembling the Red Earth Formation. The Red Earth is composed of extremely uniform, red, earthy material containing quartz, clay and iron oxides and small amounts of ilmenite, magnetite, spinel, zircon, garnet and monazite (Cooray, 1967). It is completely free of pebbles and is extremely uniform showing no signs of stratification or bedding (*ibid*.).

2.12 Stratigraphy

The Red Earth Formation is almost everywhere underlain by a relatively thin layer of what Wayland (1919) termed "plateau gravels" consisting of angular, sub-angular and rounded quartz and chert in gravel, pebble and cobble sizes cemented to a greater or lesser degree by iron-oxides and clayey material. This layer, later termed basal ferruginous gravel by Cooray (1967), outcrops at the landward boundary of the Red Earth Formation and at places where the Red Earth has been eroded or dissected by streams. It generally overlaps the Moongil Aru, Vanatavillu Limestone and Mannar Sandstone formations and extends on to the metamorphic crystalline basement. A schematic section based on structure contour and isopach maps and structure sections of Golani (1967), Hanreck and Sirimanne (1968) and Wijesinghe (1969) is shown in Fig. 3, illustrating these relationships and the general stratigraphy of much of the area under consideration.



After Golani (1967); Hanreck and Sirimanne (1968); Wijesinghe (1969)

Figure 3. Schematic cross-section showing generalized stratigraphic relationships in the northwestern coastal region of Ceylon

The Moongil Aru Formation, which thickens steadily seawards, consists of black, grey-green and yellow clays, sands and sandstones, and organic reef-type sediments intercalated with sandy limestone lenses and shows similarities to late Tertiary sediments elsewhere (Hanreck and Sirimanne, 1968). The Vanatavillu Limestone is fossiliferous and thought to be equivalent to the Jaffna Miocene beds (ibid) although Golani (1967) thought the former were Oligo-Miocene. There is a major unconformity between these limestones and the underlying Mannar Sandstones, which have been equated with the Jurassic deposits of Tabbowa (Deraniyagala, 1968). These sandstones lie non-conformably on the basement rocks. The configurations of the different formations suggest that major subsidence of the basement took place prior to or contemporaneously with the deposition of the Moongil Aru Formation. Some recent horsting has occurred in a few locations (e.g. Aruakalu) bringing the Vanatavillu Limestone to the surface and resulting in high points in an otherwise relatively flat landscape.

The ages of the Red Earth Formation and the basal gravel are uncertain but since they overlie deposits that are considered Pliocene (Deraniyagala, 1968) they are assigned to the Quaternary. Wayland (1919) found what he believed to be remains of Paleolithic man and stone implements belonging to Neolithic inhabitants in the basal ferruginous gravel and concluded that both the gravel and the overlying Red Earth were of Pleistocene age. The relatively sharp contact of the gravel with the overlying and underlying formations and its lateritic nature, however, suggest that it is a terrestrial erosion surface from a wetter climate on which the Red Earth was later deposited. The Red Earth Formation therefore could be either Pleistocene or Recent, and until further evidence is forthcoming, will be designated simply as Quaternary.

2.13 Geomorphology

The upper surface of the Red Earth Formation consists of low elongate ridges or mounds that are generally aligned more or less parallel to the coast. These ridges are commonly not more than 30 m. high and about 1 1/2 to 2 1/2 km. wide (Cooray, 1967) but their length is determined locally by the transverse drainage. The surface slopes seldom exceed 2 percent. The thickness of the deposit varies from a few to over 30 m. but most often it is 10 to 25 m. deep. As its name suggests, this formation has a striking reddish colour except in the lower-lying areas where it is yellowish or nearly white. It has excellent internal drainage and consequently the surface drainage features are absent or very poorly developed and confined to the lowest parts of the slopes. In fact, where the basal gravel is directly underlain by karstic limestone, sink holes provide the only drainage. A number of sub-parallel streams with their sources outside the Red Earth region cut across it but have their beds on the underlying formations exposing the basal ferruginous gravel on their banks.

Several indications of the origin of the Red Earth Formation can be obtained from observations of its geomorphic features. Thus, the occurrence of the deposit as a relatively narrow belt along the coast, interrupted only by streams that cut across it, is strongly suggestive of a littoral or near shore origin. The basal ferruginous gravel was found to outcrop as a more or less narrow band at the inland boundary of the Red Earth Formation in every traverse made across it. This seems to rule out wind blown and fluvial origins ascribed to it earlier (Wayland, 1919; Joachim et al., 1935-45; Moormann and Panabokke, 1961). Further evidence against fluvial deposition is obtained from the ovservation that in some areas where karstic limestone underlies the gravel layer, there is practically no surface drainage and streams disappear underground (Parkinson, 1963) but the thickness of the Red Earth is not diminished.

Cooray (1967, 1968) cites further convincing facts in favour of a beach origin for the Red Earth Formation. He discusses the striking similarity between the presently forming barrier bars and beaches of the Kalpitiya area and the elongate Red Earth ridges. He also was able to recognize a definite raised beach on the Red Earth and described the occurrence of marshes, ponds and streams occupying "flats" on the landward side of the Red Earth ridges that are due to diversions of drainage in much the same way as similar features result from diversions behind the present beaches. In the writer's opinion, the Grumusols that occur adjacent to the Red Latosols in the Tunukkai area had their beginnings as such blocked off drainage which was subsequently filled by clayey sediments, but detailed investigations will be required to verify this.

Examination of the beach and dune deposit near Hambantota on the Tangale - Hambantota road exemplifies many of the above geomorphic features. It shows a dune-backed beach behind which is an area of impounded water gradually being converted into a marsh by deposition and vegetation growth. At one point where the dune formation has been breached either artificially or naturally, the beach and dune sands gradually increase in redness and clay content with distance from the sea and grade into Red Earth-like deposits with Red Latosol characteristics in the upper part. There is a progressive decrease in the easily weatherable minerals landwards away from the beach-dune complex which consists of highly polished quartz, red garnet, ilmenite, feldspar and other minerals in smaller amounts. This sequence of maturing beach and dune sediments is, therefore, a possible mechanism by which at least some of the Red Earth was formed. Since landforms suggestive of dune origin are found in several locations on this formation and since some eolian activity is always associated with beach development in Ceylon, the Red Earth can be classified as a beach - dune - ridge formation (Schnable and Goodell, 1968).

The distributive provinces of the Red Earth cannot at present be established with any certainty, but some idea of the factors involved can be obtained from the physical features of the landscape and coastline. The streams that bring sediments directly into the sea in the vicinity of the Red Earth Formation are shown in Fig. 2. Though the drainage basins of all these streams lie in the undifferentiated Vijayan Series, this itself is a mixed group of biotite gneisses, granites and schists (Fernando, 1948) which have not been mapped in any detail. One cause of differences within the Red Earth deposit could therefore have been variations in the lithologies of these stream basins. For example, it is definitely known that the Tonigala Complex dominates the geology of the lower part of north-western Ceylon but is not so prevalent in the far north and north-east, thus contributing in larger measure to the sediments that occur in area A of Fig. 2. (Weathering differences among the drainage basins are likely to have been slight, however.)

Another possible cause of major differences in the lithology of the deposits is shore drifting which may have brought in large quantities of material from fairly distant points on the coast. Geomorphic interpretation of the present coastline definitely indicates considerable shore drift from the south along the west coast of the island as shown by the shapes of the recurved spits and barrier bars. Such transport of sediments making up the Red Earth, however, would have been dependent on winds and oceanic swells prevailing in an earlier period when they may have had different intensities and directions. But shore drift would have substantially affected the lithology of the deposit only if the sediments brought in had differed from those being supplied by the local streams, i.e. if they had transported sediments from the south. Such differences in the incoming sediments could have arisen from variations in source materials and/or from variations in hydraulic factors. In either case, the three areas marked A, B and C in Fig. 2 would have received different types of deposits from beach drift. Scouring of the near-shore sea bed and differences in the energies of the depositional environments would also have had their effects. On the basis of these factors, it seems reasonable to assume that there would have been at least three major types of deposits in the three areas A, B and C.

2.2 CLIMATE

2.21 Present climate

The present climate under which the Red Latosols of Ceylon occur is characterized by a comparatively low, temporally, unevenly distributed rainfall, high temperatures throughout the year and a pronounced dry season. Evaporation losses are high, particularly in the hot dry months when strong desiccating winds blow across this region. Some figures illustrating these and other features of the climate from three meteorological stations (Ekanayake, 1966) in the Red Latosol area appear in Table 1. The locations of the stations are shown in Fig. 4.

The average annual precipitation varies between about 950 and 1,450 mm., the highest values occurring in the Mullaittivu region, but the variability from year to year at each site is frequently greater than that between sites. In all cases more than half the annual rainfall occurs within the three months of October, November and December. The period from June to September is relatively quite dry. Intensities of rainfall are high during the rainy season as shown by the figures for the number of rain days each month. Values of several centimetres per hour have been recorded in other parts of the so-called dry zone during the convectional thunderstorms that usher in the rainy (monsoon) season (Panabokke, 1958).

Temperatures are uniform throughout the Red Latosol region and show little variation between seasons. Greater differences are

	RAINFALL						TEMPERATURE					
	MANNAR		PUTTALAM		MULLAITTIVU		MANNAR		PUTTALAM		JAFFNA	
Month	mm	Days	mm	Days	mm	Days	Min. °C.	Max. °C.	Min. °C.	Max. °C.	Min. °C.	Max. °C.
JAN	85	8	72	9	125	8	23.6	28.4	21.2	29.8	22.3	28.4
FEB	32	3	45	5	45	3	23.3	29.9	21.3	31.3	22.4	29.8
MAR	45	4	75	7	30	2	24.1	31.7	22.8	32.3	24.3	31.6
APR	88	8	135	10	70	4	25.6	32.3	24.5	31.9	26.8	32.1
MAY	48	4	98	10	60	4	27.1	31.9	26.0	31.4	27.6	31.3
JUN	5	1	22	6	15	1	27.1	31.1	26.3	30.4	27.2	30.4
JUL	8	1	18	3	38	3	26.2	30.6	25.7	30.2	26.6	30.1
AUG	15	2	20	4	68	5	25.9	30.6	25.6	30.4	26.3	30.1
SEP	22	2	35	4	72	5	26.1	30.8	25.6	30.7	26.4	30.2
OCT	165	11	170	13	208	12	25.2	30.3	24.3	30.3	25.4	29.9
NOV	240	17	250	18	390	16	24.3	29.1	22.9	29.9	23.8	29.4
DEC	200	13	150	13	325	14	23.9	28.1	21.9	29.4	22.9	28.1
TOTAL OR AVERAGE	953	74	1090	102	1446	77	25.2	30.4	24.0	30.7	25.2	30.1
PERIOD	1931 - 1960		1931 - 1960		1931 - 1960		1931 - 1960		1931 - 1960		1931 - 1960	
YRS. of OBS.	94		93		35		94		93		92	

(Ekanayake, 1966)

Table 1. Some Rainfall and Temperature Data From Meteorological Stations in the Red Latosol Regions

exhibited among the mean monthly minimum temperatures. Diurnal variations are of the order of 3° - 8° C. Evaporation data for stations in the study area are not available but figures for Anuradhapura, which has a slightly higher precipitation but otherwise very similar climate, are around 1,875 mm. annually. This indicates that in the Red Latosol area too, annual evaporation rates are probably close to or greater than the annual precipitation. The occurrence of strong winds during the dry season undoubtedly makes a significant contribution to the high evaporation rates.

The climates of Ceylon have been classified by several workers (Thambyahpillai, 1952; Koelmeyer, 1958; Thambyahpillai, 1960; Gaussen _et al_., 1964; Mueller-Dombois, 1969), but no unanimity has been reached even with regard to the main climatic regions let alone the classification of the comparatively small area occupied by the Red Latosols.

2.22 Paleoclimate(s)

Little is known about the paleoclimatology of Ceylon, the only contribution being that of Deraniyagala (1958) who, on the basis of paleontological studies and from other pieces of evidence, concluded that the Quaternary in Ceylon consisted of (a) a cool phase (The Ratnapura Phase) (b) an arid phase (Palugahaturai Phase) and (c) the present climate (Colombo Climate). Although there is general agreement that lower temperatures may have prevailed in the tropics during the glacial maxima, this effect would have been least noticeable near the equator. There is a multiplicity of views on the other hand, about the effects of glaciation on precipitation in the tropical regions (Budel, 1959; Fairbridge, 1962; Morrison, 1967). This is not surprising because local effects have undoubtedly been more important than global wind patterns in determining the paleoclimates on which some of these theories are based. Thus an examination of the climates prevailing today at any one latitude in the tropics will reveal the extremes of precipitation caused by regional or local factors even at the same altitude. It would therefore be necessary to reconstruct the paleoclimate of each area individually from the fragmentary pieces of evidence that have been preserved.

2.3 VEGETATION

The Red Latosols support a dry mixed evergreen and deciduous forest with a lower shrub storey (de Rozayro, 1956). Slight differences in species composition and growth have been noted on the Red Latosols of different regions (de Alwis and Eriyagama, 1969), although the entire area is considered as a single vegetation zone (Gaussen *et al.*, 1964). In the Mullaittivu area the forest is tall and dense and is composed of *Chloroxylon swietenia*, *Alseodaphne semicarpifolia*, *Vitex pinnata* and *Pterospermum canescens*. Of less frequent occurrence are *Strychnos nux-vomica*, *Schleichera oleosa*, *Gleniea unijuga*, *Manilkara hexandra*, *Bridelia retusa*, *Syzygium cumini*, *Careya arborea*, Hik (local name) and *Acacia chundra*. *Drypetes sepiaria* occurs only occasionally. The lower shrub storey is made up of *Phyllanthus gardneanus*, *Tarenna asiatica*, Bolpana (local name) and *Strobilanthus* spp.

In the Mannar region the stand is less dense and *Drypetes sepiaria*, *Manilkara hexandra*, *Chloroxylon swietenia*, *Vitex pinnata*, *Acacia chundra*, *Dalbergia lanceolaria*, *Gmelina asiatica*, *Bauhinia racemosa*, *Schleichera oleosa* and *Cordia* spp. are the main tree species. The shrubs are largely *Phyllanthus gardneanus*, *Zyzyphus* spp. and *Strobilanthus* spp.

The Wilpattu-Puttalam area too has a low forest, the main species of which are *Crataeva religiosa*, *Chloroxylon swietenia*, *Cassia fistula*, *Pterospermum canescens*, *Drypetes sepiaria* and *Morinda tinctoria*. Less frequently, *Salmalia malabarica*, *Acacia* *leucophloea*, Helamba (local name), *Manilkara hexandra* and *Syzygium cumini* also occur. The shrubs present are *Strobilanthus* spp., Korakaha (local name), *Randia dumetorum*, *Cassia auriculata*, Werella (local name), *Tarenna asiatica* and *Connarus monocarpus*. Unidentified creepers and lianas occur occasionally.

Although the vegetation described above has probably remained undisturbed for one or more centuries, it may still be secondary in character and was in fact regarded by de Rozayro (1956) as a subclimax. Evidence of past vegetation is scanty. Ten species of Pleistocene plant fossil from different parts of the country indicated that the flora of Ceylon during that period was not very different from that existing today, although probably differing in their distribution (Deraniyagala, 1958). The widespread occurrence of occasional fragments of charcoal in the Red Latosols down to a depth of about 150 centimetres (the approximate depth of major termite activity) suggests that fires have played an important part. However, deposition of the charcoal with the Red Earth Formation itself cannot be ruled out until radiocarbon dates are obtained.

3. PREVIOUS OBSERVATIONS AND INVESTIGATIONS

3.1 Historical

The first recorded reference to the soils now called Red Latosols in Ceylon was made in the Mahawamsa (Author(s) unknown, Geiger, Trans., 1964), the so-called "Great Chronicle of Ceylon" written about the 6th century A.D. It refers to the landing of King Vijaya in Ceylon (about the 5th century B.C.) and describes the event in the following terms, "When those who were commanded by Vijaya landed from their ship they sat down wearied, resting their hands upon the ground - and since their hands were reddened by touching the dust of the red earth, that region and also the island were (named) Tambapanni.", (S. tamba = copper or red coloured). The striking red colour of these soils, their great depth and uniformity have consistently aroused the curiosity of travellers to this region since then, but the first scientific observations were made by the geologist Wayland (1919) who referred to the Red Earth Formation and the underlying gravel beds as "Plateau Deposits".

Wayland believed that the Red Latosols and the Red Earth Formation were a wind blown deposit originating from the central highlands of Ceylon while the underlying gravels were of fluvial origin. He further conjectured that these "Plateau Deposits" at one time covered much of the lowland region of Ceylon and had since been largely eroded leaving only relatively widely scattered patches. Finding chipped flints and fragments of quartz that he believed to be implements and weapons of Paleolithic and Neolithic man in the gravel beds, he concluded that the gravel as well as the overlying Red Earth were of Pleistocene age.

In the mid nineteen thirties Joachim et al. commenced a systematic study of the soils of Ceylon and published a series of papers (1935-45) on the characteristics of the major soil groups of the island. However, they paid scant attention to the Red Latosols (probably due to the inaccessibility of the areas in which they occurred) and only made morphological descriptions and determined some physical and chemical characteristics of two soils now classed as Red Latosols. On the basis of the SiO_2/Al_2O_3 ratios of the clay fractions, one profile was classed as non-lateritic and the other as lateritic. These workers tended to agree with Wayland that the Red Latosols were developed on wind blown deposits although they also speculated on the possibility of an alluvial origin for the sandy non-lateritic soil.

3.2 Recent Investigations

More information on the Red Latosols became available in the early sixties as a result of reconnaissance and detailed reconnaissance soil surveys carried out by the Land Use Division (unpublished reports, 1960-66) then of the Department of Agriculture in Ceylon and by the Hunting Survey Corporation of Canada under contract on a Canada-Ceylon Colombo Plan Project (de Vries and Holland, 1963). These surveys revealed the geographical distribution of the Red Latosols and established some of their morphological and laboratory analytical characteristics. Three major soil series, viz. the Gambura, Mullaittivu and Wilpattu Series, were recognized and catenary associations of these series with the associated imperfectly drained and poorly drained soils were mapped.

Moormann and Panabokke (1961) adopted the term Red-Yellow Latosol after Kellogg (1949) who used it to describe the highly weathered, deep red and yellow soils of equatorial Africa. They recognized Red Latosol and Yellow Latosol sub-groups and also classed the red soils overlying limestone in the Jaffna peninsula as another sub-group, the Calcic Red Latosols.

The Red Latosols of Ceylon according to Moormann and Panabokke (ibid.), are extremely uniform, deep soils with weak horizon differentiation. Thin A horizons with loamy sand or sandy loam textures overly B horizons of nearly the same colour and finer texture but which cannot be regarded as argillic horizons. Structure is lacking or, at best, is very weak coarse sub-angular blocky. The fine silt (20-2) content is very low and the base saturation is less than 45 percent. In terms of the 7th Approximation System of Classification (Soil Survey Staff, U.S.D.A., 1960), these workers classified the B horizons as oxic and the soils as Oxisols. Subsequent surveys and analyses of these soils (unpublished data, Land Use Division, 1960-66) while confirming the general morphological and analytical characteristics outlined by these workers helped refine some of the criteria used in distinguishing this sub-group.

W. D. Joshua (personal communication) carried out soil moisture studies on some Red Latosols and showed from the moisture characteristic curves that most of the water in these soils is held at low tensions. Steady infiltration rates measured by him were in the region of 18 inches per hour as contrasted with 1 - 2 inches per hour for Reddish Brown Earths of similar texture. He attributed these properties of the Red Latosols to high proportions of large pores.

Kalpage et al. (1965) in a comparative study of the mineralogical composition of some great soil groups of Ceylon, found that the Red-Yellow Latosols (Red sub-group) were more highly weathered than the Reddish Brown Earths occurring in a comparable climate but less weathered than the Red-Yellow Podzolic soils which occur in the wet zone of Ceylon. They found that kandites were the dominant clay minerals with some hematite but no goethite or gibbsite. No vermiculite or smectite was detected and only traces of mica and quartz were present in the clay ($< 1.4\mu$) fraction of the Red Latosol studied.

No previous study of the genesis of the Red Latosols of Ceylon has been done although there has been much speculation about the origin of the parent deposit.

4. THE SOILS - FIELD STUDIES AND SAMPLING

4.1 General Considerations

The Red Latosols are a sub-group of the Red-Yellow Latosol great soil group which also includes the Yellow Latosols and the Calcic Red Latosols. The different soils constituting the Red Latosols occur under a fairly uniform climate, support similar vegetation, occupy the same topographic positions in the level to gently undulating landscape and have formed on parent materials that were probably deposited more or less synchronally. It is therefore likely that major differences among the soils belonging to this sub-group have arisen chiefly from variations in the lithology and texture of the initial deposits on which they have developed. Three soil series conforming to the criteria of the Red Latosols, but having important differences among themselves, have so far been recognized (unpublished reports, Land Use Division, 1960-66; Moormann and Panabokke, 1961; de Vries and Holland, 1963) and these occur in the three major regions of the Red Earth Formation likely to have received different types of sediment during deposition (see section on Geology). This is consistent with the above inference that lithological variations in the parent materials were important in bringing about differences within the Red Latosols. The three soil series belonging to this sub-group, viz. the Gambura Series, the Mullaittivu Series and the Wilpattu Series, therefore, constitute what is essentially a lithosequence of soils. Since the aims of this study were to characterize the Red

Latosols and to determine their genesis, it was possible to conveniently achieve both aims by sampling the three soil series of this lithosequence.

Although the Gambura, Mullaittivu and Wilpattu Series have been studied in both field and laboratory for soil survey purposes since 1960 (unpublished reports, Land Use Division, 1960-66) the mapping has of necessity been at a reconnaissance or detailed reconnaissance level and has relied heavily on air photo interpretation on account of the inaccessibility of the regions concerned. The areal distribution of these series shown in Fig. 4a is therefore only approximate. Also, the imperfectly drained (Yellow Latosol) and poorly drained soils associated with them in topographically low positions are not shown separately. Somewhat more detailed surveys of small areas have been carried out for specific projects on these soil series and have been of great value in elucidating the relationships of these soils to the landscape and to other associated soils.

The Red Latosols occupy the upper topographical positions of long (often over 2 km.) gently convex slopes with gradients rarely exceeding 2 percent and usually about 1 percent. Yellow Latosols are restricted to the lowerlying portions of the slopes and sandy soils with impeded drainage occur in bottomland positions but these take up only a small proportion of the total area. These relationships are illustrated in Fig. 4b and by the descriptions of the individual soil series given below.

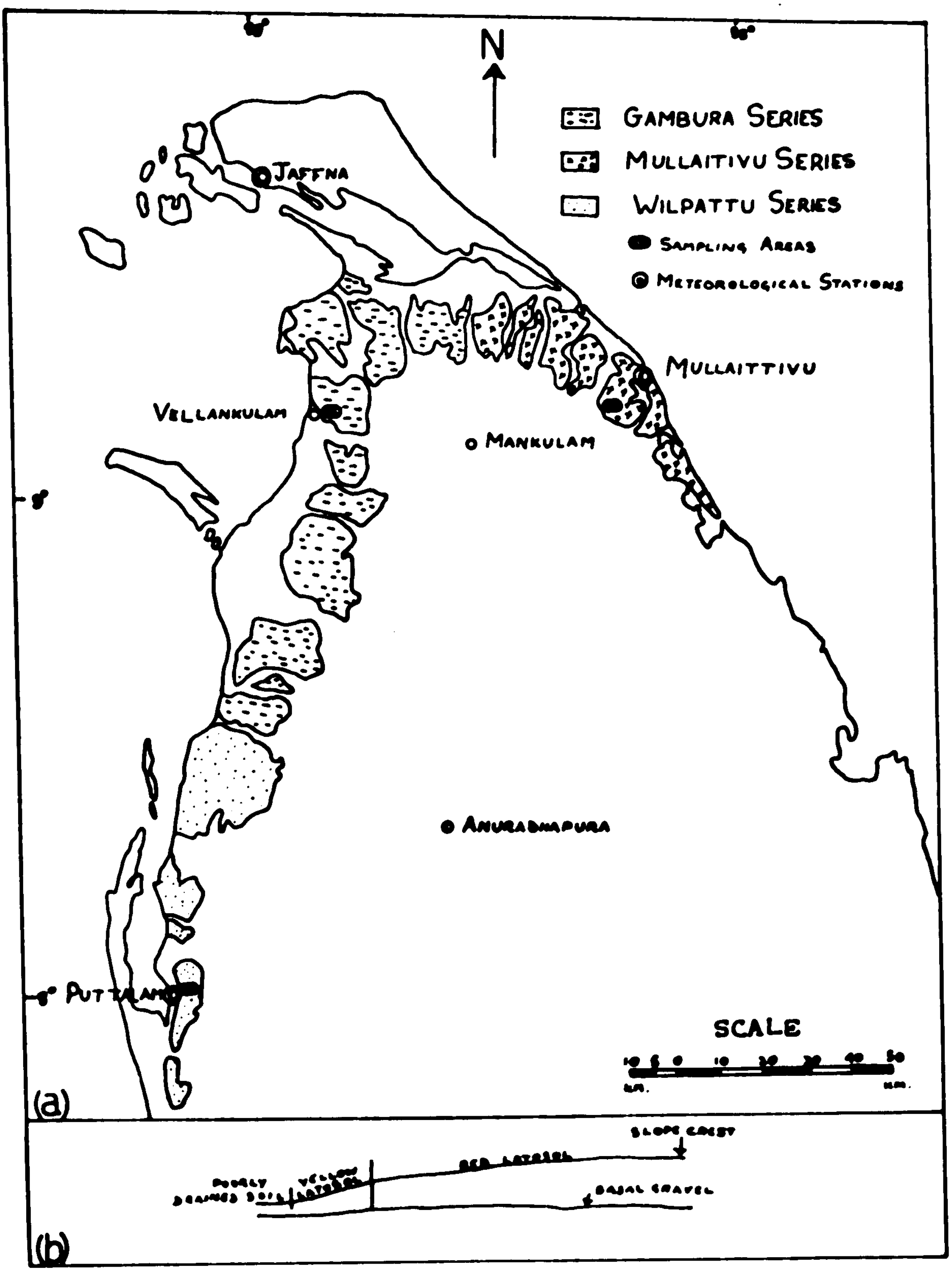


Figure 4. (a) Map showing the approximate areal distributions of the Gambura, Mullaittivu and Wilpattu Series and the sampling areas.
(b) Schematic diagram of the landscape relationships of the Red Latosols and their drainage associates.

4.2 Methods of Description and Sampling

Each of the Gambura, Mullaittivu and Wilpattu soil series was represented by three profiles spaced out within an area of about 2.5 square kilometres to ensure that aberrant features (due to tree throw, faunal activity, *etc*.) that could not be detected in the morphological examination were not being inadvertently sampled. The locations for sampling, chosen on the basis of previous soil surveys in the areas concerned, were at approximately the same distance from the coast. Profile locations are shown in Fig. 4a.

Profile pits measuring approximately 250 cm. long, 120 cm. wide and 300 - 500 cm. deep were cut in apparently undisturbed sites on the upper mid-slopes after ensuring that the soils conformed to previous series descriptions by means of auger borings. All but the lowest horizons were examined and sampled using a ladder. The depth of sampling was determined by the physical limitations of cutting deeper profiles.

Site descriptions and morphological descriptions of the soil profiles were done according to the criteria and terminology of the United States Department of Agriculture Soil Survey Manual (1951) but the pores were described according to a simplified version of that outlined by Johnson *et al*. (1960). Subdivision of the B_2 horizons was somewhat arbitrary as the changes with depth are extremely diffuse in these soils and difficult to detect in the field. Sampling was carried out only on the middle portions of the horizons as can be seen from a comparison of horizon depths and sample depths. Oriented samples of undisturbed clods were taken for micromorphological analysis avoiding large termite passages, root holes, etc. Also, much larger clods were sampled for analysis by X-radiography. Bulk density samples (5 per horizon) were obtained by coring the sides of the pits.

4.3 Descriptions of the Soils

The following brief, generalized descriptions of the Gambura, Mullaittivu and Wilpattu Series are abstracted from the detailed descriptions appearing in the Appendix. They agree well with previous descriptions of these soils (unpublished reports, Land Use Division, 1960-66; Moormann and Panabokke, 1961; de Vries and Holland, 1963) but the subdivisions of the A and B horizons are more detailed in this study.

The Gambura Series is a very deep, stone and gravel free, somewhat excessively drained soil with weak horizon differentiation. It has dark reddish brown to dark red colours (2.5 YR hues). While there is a marked increase in fineness of texture from the A to the B horizons, further increases take place very gradually. Structures are very weak in the upper horizons and nearly absent (massive) at lower depths. Termite passages and nests are commonly observed in the upper 100-125 cm. and roots, although more abundant in the upper horizons, do occur even at depths greater than 300 cm. Occasional vertical cracks extend into the lower B horizons.

A_{11}, A_{12}, B_{21}, B_{22}, B_{23}, B_{24} and B_{25} (upper and lower) horizons have been demarcated but the individual B horizons are distinguished with difficulty (owing to the very diffuse changes) and their boundaries are somewhat arbitrary. The A_{11} and A_{12} horizons, which have a combined thickness of about 25 cm., are distinguished by coarser (sandy loam to sandy clay loam) textures and slightly greyer colours (not always differentiated by the chips on a Munsell Colour Chart) than the B horizons. They also show weak sub-angular blocky structures in contrast with the B horizons which tend to be massive structureless. The consistence in the A_{11} horizon is generally very friable and in the A_{12} it is friable. The boundary with the B_{21} horizon is clear and smooth.

The B horizons have finer textures which change progressively from sandy clay loam in the B_{21} to sandy clay or even clay in the lower B_{25}. The colours are dark red (dry) and dark reddish brown (moist) throughout. Structures tend to be very weak, with only a hint of very coarse sub-angular blocky development, or absent (massive). Fine and medium pores are common. The consistence is slightly hard and friable in all the B horizons. Termite and root activity are most prevalent in the B_{21} and B_{22} horizons. The sand in the B_{25} horizon appears to be somewhat coarser than in the above horizons.

Like the Gambura Series, the Mullaittivu Series consists of very deep, somewhat excessively drained, porous, gravel free soils with weak horizon development but is distinguished from the former by somewhat finer textures, different colours and slightly better structures in the A horizons. The same horizon sequence is recognized.

The A_{11} and A_{12} horizons, which together are about 25 cm. thick, have reddish brown and dark reddish brown colours of 5 YR hues. These browner colours are probably due to higher organic matter and lower iron oxide contents. Loamy sand textures and weak crumb structures are characteristic of the A_{11} horizons while the A_{12}

commonly has sandy loam to sandy clay loam textures and weak sub-angular blocky structures. As in the Gambura Series, there is a smooth clear transition to the B_{21} horizon.

The B horizons are red to dark red when dry and dark red or dark reddish brown when moist in the 2.5 YR hues. The fineness of texture increases gradually with depth from sandy loam to sandy clay but the sandy clay textures occur at a lower depth (usually in the B_{24} and B_{25} horizons) than in the Gambura soils. Structures in all the B horizons are nearly absent (massive) and the consistence is friable throughout. Fine and medium pores are common. Occasional vertical cracks starting at the surface extend into the lower B horizons. Termite passages and roots are most prominent down to about 100 or 125 cm. but are found even at depths of 350 cm. or greater. A small percentage of gravel is present in the B_{25} horizon, in which the sand too is coarser than in the above horizons.

The soils of the Wilpattu Series have redder colours and distinctly sandier textures than the other two, but otherwise have similar morphological characteristics, i.e., they are very deep, somewhat excessively drained soils with little horizon differentiation. The same sequence of horizons as in the other two series is recognized although the B_{25} horizons were not studied due to difficulties associated with digging deeper soil pits in these soils. The A_{11} horizons are dark red or reddish brown (2.5 YR hues) in the dry state and dark reddish brown when moist and have textures that qualify as sand. The structures are very weak sub-angular blocky to single grain structureless and the consistency is loose. The A_{12} horizons have dark red or dusky red (dry) and dark reddish brown or dusky red (moist) colours. The textures are loamy sand to sand. Weak sub-angular blocky structures and very friable consistencies are also characteristic of this horizon.

The B horizons generally have dusky red (10R) colours (dry and moist), are more or less massive structureless and have very friable consistencies. The texture increases in fineness from sandy loam in the B_{21} horizon to sandy clay loam in the B_{24}. Vertical cracks extend from the surface into the lowest B horizons. Termite activity and roots are more prevalent in the A and upper B horizons but roots are present even at the lowest depth of sampling.

All three soil series of this sub-group have similar site and surface features. They show no signs of erosion or runoff and have no boulders, cobbles or pebbles on the surface or in the profiles. Termite mounds are common features of the microtopography but these have been generally avoided in sampling. The surface was covered with a thin layer of new leaf litter at the time of field observations (July - August, 1969); this was mainly due to leaf-shedding by deciduous trees in the latter part of the dry season. Thin patches of grass (mainly <u>Cytococcum trigonum</u>) occurred where the canopy was incomplete.

Detailed descriptions of the morphology and micromorphology of the following soil profiles are given in the Appendix:-

Soil Series:	Gambura	Mullaittivu	Wilpattu
Profile:	TP_1, TP_2, TP_3	MP_1, MP_2, MP_3	PP_1, PP_2, PP_3.

5. THE SOILS - LABORATORY INVESTIGATIONS

5.1 Introduction

Soil samples from the three major soil series of the Red Latosols were collected as described in the preceding section for physical, chemical, mineralogical and micromorphological analysis. The pH, total nitrogen and bulk density determinations and the impregnation and hardening of clods for thin sections were carried out in the laboratories of the Land Use Division of the Department of Irrigation in Ceylon. The bulk soil samples, hardened clods, large soil clods for X-radiography and miscellaneous samples of the basal ferruginous gravels, termite mounds, present beach sands, etc. were carefully packed in sealed containers, crated and shipped to the University of Alberta in Canada, where the second phase of the study took place.

The laboratory analyses of the soil samples were directed at (1) establishing the characteristics of the three soil series under study and hence of the Red Latosols in general, (2) determining the uniformity or non-uniformity of the parent materials, (3) elucidating the main soil forming processes that have contributed to the present characteristics of these soils and (4) relating these processes as far as possible to the nature of the present and past factors of soil formation. The methods used are those more or less commonly employed in soil characterization and genesis studies and modifications thereof deemed necessary in view of the peculiarities of these soils. These methods are outlined and the results obtained are presented and discussed in the following sections.

5.2 Materials and Methods

The bulk soil samples were sterilized by autoclaving in accordance with the requirements of the Plant Protection Division of the Canadian Department of Agriculture but permission was obtained to retain small portions from each sample without autoclaving, for analyses likely to be affected by this treatment. The results are reported on an oven-dry basis unless otherwise stated. The samples were air-dried and stored in glass jars for subsequent analysis. The methods used are as follows:-

Stone and Gravel

The stone and gravel (> 2mm.) percentages were determined by carefully crushing the soil in a mortar with a rubber bung, passing it through a 2mm. screen and weighing.

Bulk Density

Samples (5 per horizon) collected by coring the sides of the profile pits were oven-dried (105°C.) and weighed to obtain the bulk densities.

Particle Density

A pycnometer method (U.S. Salinity Laboratory Staff, 1954) was used to obtain the particle densities.

1/3 and 15 Bar Moisture Percentages

The moisture retentivities at 1/3 and 15 bar pressures were determined according to the procedures outlined by the U.S. Salinity Laboratory Staff (1954).

Particle Size Distribution and Separation

Preliminary analysis of the particle size distribution without the removal of iron oxides was carried out by the method of Kilmer and Alexander (1949) with modifications suggested by Toogood and Peters (1953). The distributions after removal of iron oxides were determined by separation of the different fractions according to a modified Kittrick and Hope (1963) procedure. The modifications were (1) the employment of two successive Na-citrate-dithionite-bicarbonate extractions and (2) the use of 6 and 8 centrifugings for the coarse and fine clays, respectively. The fine silt (20 - 2μ) was separated by gravity sedimentation of the coarse silt and sand, which in turn were fractionated by dry seiving.

Water-Dispersible Clay

Shaking a known weight of soil with distilled water for 16 hours followed by centrifuging was used to determine the water dispersible clay contents (U.S.D.A. Soil Survey Staff, 1967).

Total Nitrogen

Total nitrogen was determined by a semi-micro Kjeldahl procedure (Bremner, 1965) on air-dried samples, but the results are reported on an oven-dry basis.

Total Carbon

A dry combustion gravimetric procedure (Allison et al., 1965) was used to determine the total carbon. Organic carbon was assumed to be equal to the total carbon since no carbonates were present.

Soil Reaction

The soil pH was measured in water (1:1) and in 0.01 M $CaCl_2$ (1:2) (Peech, 1965) using a Beckman Zeromatic pH meter equipped with glass indicator and calomel reference electrodes, shortly after the soils were brought in from the field.

Cation Exchange Capacity

The CEC was obtained by two methods, viz. (1) ammonium saturation using neutral NH_4OAc (Chapman, 1965) and (2) summation of the total exchangeable cations and exchange acidity which were determined as described below.

Exchangeable Cations

Exchangeable cations were determined by leaching with neutral ammonium acetate and obtaining the amounts of Ca, Mg, Na and K in the leachate by atomic absorption spectrophotometry.

Exchange Acidity

The barium chloride-triethanolamine method of Mehlich (1939) as modified by Peech et al. (1962) was employed in the exchange acidity determinations.

Exchangeable Aluminium

Exchangeable aluminium was estimated by extracting with 1N KCl and titrating the extracts with sodium hydroxide according to the procedure described by McLean (1965).

Extractable Iron and Aluminium

Iron and aluminium were determined in extracts obtained using (1) Na-citrate-dithionite-bicarbonate (Mehra and Jackson, 1960) and (2) acid ammonium oxalate (McKeague and Day, 1966). The Fe extracted in each case was determined by atomic absorption spectrophotometry. Al was determined in the Na-citrate-dithionite-bicarbonate extracts colorimetrically with aluminon (Hsu, 1963) after a pretreatment suggested by Weaver et al. (1968). The Al contents of the oxalate extracts were obtained directly by the aluminon procedure.

Aluminum was also extracted with ammonium acetate at pH 4.8 according to the method of McLean (1965) and determined colorimetrically.

Mineralogical Analysis of the Fine Sands

The iron oxide-free fine (0.25 - 0.1 mm.) sands from the particle size analyses were separated quantitatively into heavy (S. G. > 2.96) and light (S. G. < 2.96) fractions using S-tetrabromoethane. Magnetite was removed from the heavy fraction using a permanent magnet and determined gravimetrically. The magnetite-free heavy fraction was then mounted in Aroclor (R. I. = 1.67) on petrological slides and studied microscopically with counting (400 grains per slide) to establish the relative frequencies of the minerals. The light sand fraction was mounted in Caedax (R. I. = 1.54) for general examination and in Castolite (R. I. = 1.54) as described by Pettapiece (1970) for staining. The staining was for Al with hematein and was carried out after etching with HF vapour. Counts (400/slide) of the grains were made microscopically.

Micromorphological Analysis

Undisturbed soil clods collected from the middle portions of each horizon were marked so that vertical orientation could be maintained, and impregnated with the polyester, Castolite, according to the procedure of Acton (1961) but fewer drops of catalyst and higher impregnating temperatures (60° - 70° C.) than recommended were found to give better results with these soils. The clods were sectioned, mounted on 27 x 46 mm. petrological slides with Lakeside 70 and polished to thicknesses of 20 - 30μ. Coverslips were attached with Permount and the slides were examined under a petrological microscope after the Permount had set. The fabrics, pedological features and s-matrices were described according to the terminology of Brewer (1964) and point counts were made of the areas represented by voids, matrix and skeletal grains. Four hundred points were counted using 8 random parallel traverses of 50 points each.

X-ray Diffraction Analysis

Oriented clay samples mounted on glass slides (30 mg. per slide) were subjected to X-ray diffraction analysis employing a Philips X-ray diffractometer unit with nickel-filtered CuKα radiation generated at 40 kv. and 20 ma. The scanning rate was 1° 2θ per minute.

Fine ($<$ 0.2μ) and coarse (2 - 0.2μ) clays with and without the iron oxides removed were selectively subjected to the following treatments before analysis:-

(1) Mg saturation and air-drying
(2) Mg saturation and glycolation
(3) Mg saturation and glycerol solvation
(4) K saturation and air-drying
(5) K saturation and heating to 550°C. for 2 hrs.

Fine and coarse clay residues after removal of amorphous materials by NaOH dissolution and of kaolinite + halloysite + amorphous material by heating to 550° C. and NaOH dissolution were also analysed by X-ray diffraction.

Fine silts (20 - 2μ) were mounted on glass slides using benzene for X-ray diffraction analysis.

Differential Thermal Analysis

An Aminco Thermal Analyzer (Model 4-4442) was utilized for the differential thermal investigations of Mg-saturated, iron oxide-free fine and coarse clay samples with calcined alumina as the inert reference material. Samples from which the iron oxides had not been removed were also analyzed by this technique but were heated only up to 500°C. A heating rate of 16°C/min. and sample weight of 300 mg. was used in all cases.

Chemical Analysis of Major Components of the Clay Fractions

Fine (<0.2μ) and coarse (2 - 0.2μ) fractions of selected samples were analysed by NaOH dissolution for amorphous materials, and by heating followed by NaOH dissolution for kaolinite + halloysite, according to procedures outlined by Alexiades and Jackson (1966). Mica was determined by HF/HCl dissolution (Pawluk, 1967) of NH_4-saturated samples followed by determination of K and Na by atomic absorption.

Electron Microscopy

Small quantities of < 2mm. soil from the A and B horizons of the three soil series were shaken up with 1:700 ter-butylamine (Beutelspacher and van der Marel, 1968; Serwatzky, 1962) to peptize the clays and then centrifuged to settle out the silt and sand particles. The supernatant was siphoned out, its clay concentration was determined and it was diluted to the range 0.005 - 0.01 percent clay. Another set of clay samples remaining from particle size separations with and without removal of iron oxides, was treated with H_2O_2, washed with water and dispersed in 1:700 ter-butylamine and diluted as before.

Droplets of these suspensions were placed on carbon coated formvar films supported on 200 mesh copper grids, drained by touching an absorbent paper at the edge of the grid, allowed to dry and examined under a Philips EM 200 transmission electron microscope.

X-radiography

Large intact clods of soil (approx. 14 x 6 x 3 cm.) were impregnated with the epoxy resin Scotchcast No. 3 by the method of Innes and Pluth (1970) and sliced to give uniform slabs 2 to 8 mm. thick. The slabs were polished to remove minor irregularities and subjected to X-radiography in a Philips 3-phase medical X-ray fluoroscopy unit since no industrial type machine was available. The slabs were taped to the photographic plate holders and the time of exposure for each slab, which varied according to its thickness, was determined empirically with the aid of the image on a cathode ray tube. Details of sample preparation and general methodology were adapted from Bouma (1969).

5.3 RESULTS AND DISCUSSION

5.31 Soil Reaction

The pH values, determined in 1:1 suspensions in water and 1:2 suspensions in 0.01M $CaCl_2$ are given in Tables A10-18 of the Appendix. The values in water were slightly higher than those in calcium chloride, but the latter gave much more reproducible results probably due to reduction of double layer and junction potential effects.

In all the soils, the pH reduces more or less sharply (more sharply in the Gambura and Mullaittivu soils and less sharply in the Wilpattu soils) from the A to the B horizons and then increases gradually again with depth. The relatively higher pH near the surface (in the range 5 - 6 in 0.01M $CaCl_2$) is attributed to the higher base status of these horizons resulting from decomposition of organic matter and possibly some evaporation. The pH drops to a minimum (about 4 - 5 in 0.01M $CaCl_2$) in the B_{21} or B_{22} horizons in the Gambura and Mullaittivu soils. The subsequent slow increase with depth could result from increasing base saturation due to the greater cation content of the leaching solutions. In the case of the Wilpattu Series, the initial reduction as well as the subsequent increase are more gradual and the pHs are slightly higher, possible consequences of the lower clay contents and higher base saturation, respectively.

In general the Red Latosols have somewhat lower pH values than those of the Reddish Brown Earths of similar clay content (6.5 to 7.0 in water; Moormann and Panabokke, 1961), which are well-drained soils on residual parent materials occurring under the same climate. This would indicate greater intensities or longer periods of leaching or both for the Red Latosols. Yet they have distinctly higher pHs than the (Red-Yellow Podzolic) soils of South Western Ceylon, where the temperature is similar but the rainfall is much higher (unpublished data, Land Use Division, 1960-66).

5.32 Carbon, Nitrogen and the Carbon:Nitrogen Ratio

High temperatures and low rainfall militate against the accumulation of organic matter and make for narrow C/N ratios (Buckman and Brady, 1969). The organic carbon (assumed equal to total carbon) and nitrogen contents and the C/N ratios of the Red Latosols (Tables A10-18) bear this out. The temperatures in which these soils occur are high and although the mean annual rainfall is 950 to 1,450 mm., most of it is concentrated over a few months and long dry periods with high evapotranspiration have tended to minimize its effect.

The surface (A_{11}) horizons have the highest contents of organic carbon and nitrogen with values ranging from 0.55 to 1.28 percent and 0.08 to 0.16 percent, respectively. There are no appreciable differences among the three series but the highest carbon and nitrogen values occur in the Mullaittivu soils which also have the most luxuriant vegetation. The organic matter contents of the A_{12} horizons are only slightly less, but the lower horizons have much smaller amounts. The C/N ratios are very narrow (less than 9 in all the soils) and comparable with the C/N ratios for other well-drained soils of the same climatic region in Ceylon (Moormann and Panabokke, 1961).

The effect of these small amounts of organic matter on the soil colour is not particularly pronounced. In the Gambura Series there is practically no difference in colour in going from the A to the B horizons. The Mullaittivu Series shows a change of hue from 5YR to 2.5YR with a slight increase in chroma at the same time, while the Wilpattu Series changes from 2.5YR to 10R (with no consistent change in value or chroma) across the A - B boundary. Factors other than the organic matter content may, however, have been partly responsible for these colour changes in the A horizons.

The modest amounts of organic matter in the A_{11} and A_{12} horizons tend to encourage weak granulation and decrease the bulk density, but the most noticeable effect it has is on the accumulation of cations, particularly calcium, in these horizons. This is probably an important part of the cycle by which the vegetation holds calcium against leaching away out of reach. That the organic matter peptizes some of the clays and iron oxides leading to their subsequent translocation is shown in a later section. The extent to which cheluviation (chelation by organic compounds followed by eluviation and deposition lower down) was responsible for the movement of iron oxides down the profile is uncertain but this will be discussed at greater length in a later section.

5.33 Bulk Density, Particle Density and Pore Space Determinations

The results by bulk and particle density determinations and calculated pore space values are given in Table 2 and the means and ranges of the bulk densities are shown graphically in Fig. 5.

The Gambura and Mullaittivu soils have maximum bulk densities in the A_{12} horizons. This may be attributed to translocation of clay from these horizons with simultaneous loss of structure and closer packing of sand grains (see section on micromorphology). In the A_{11} horizons, this effect is less pronounced, probably being masked to some extent by the higher organic matter contents. The low bulk densities and high pore space values in the middle B (B_{22} and B_{23}) horizons of these two soils needs some explanation. Normally, the opposite trend would be expected to prevail in moving from an eluvial to an illuvial horizon, i.e. bulk density should increase and pore space decrease with respect to the eluvial zone. While this bulk density "minimum" in the middle B horizons is partly relative due to the high bulk densities (caused by other factors) in the overlying and underlying horizons, the higher pore space percentages probably result, in the main, from the more frequent occurrence of termite passages in these (middle B) horizons. This is borne out by the fact that similar high pore space (void) values were not observed for the B horizons in the micromorphological analysis of thin sections made from clods that were free of visible termite passages. Better micro-aggregation due to higher colloidal contents (than in the A horizons) may have also contributed to the lower bulk densities (Baver, 1956) but no experimental evidence is available to confirm or disprove this. In the

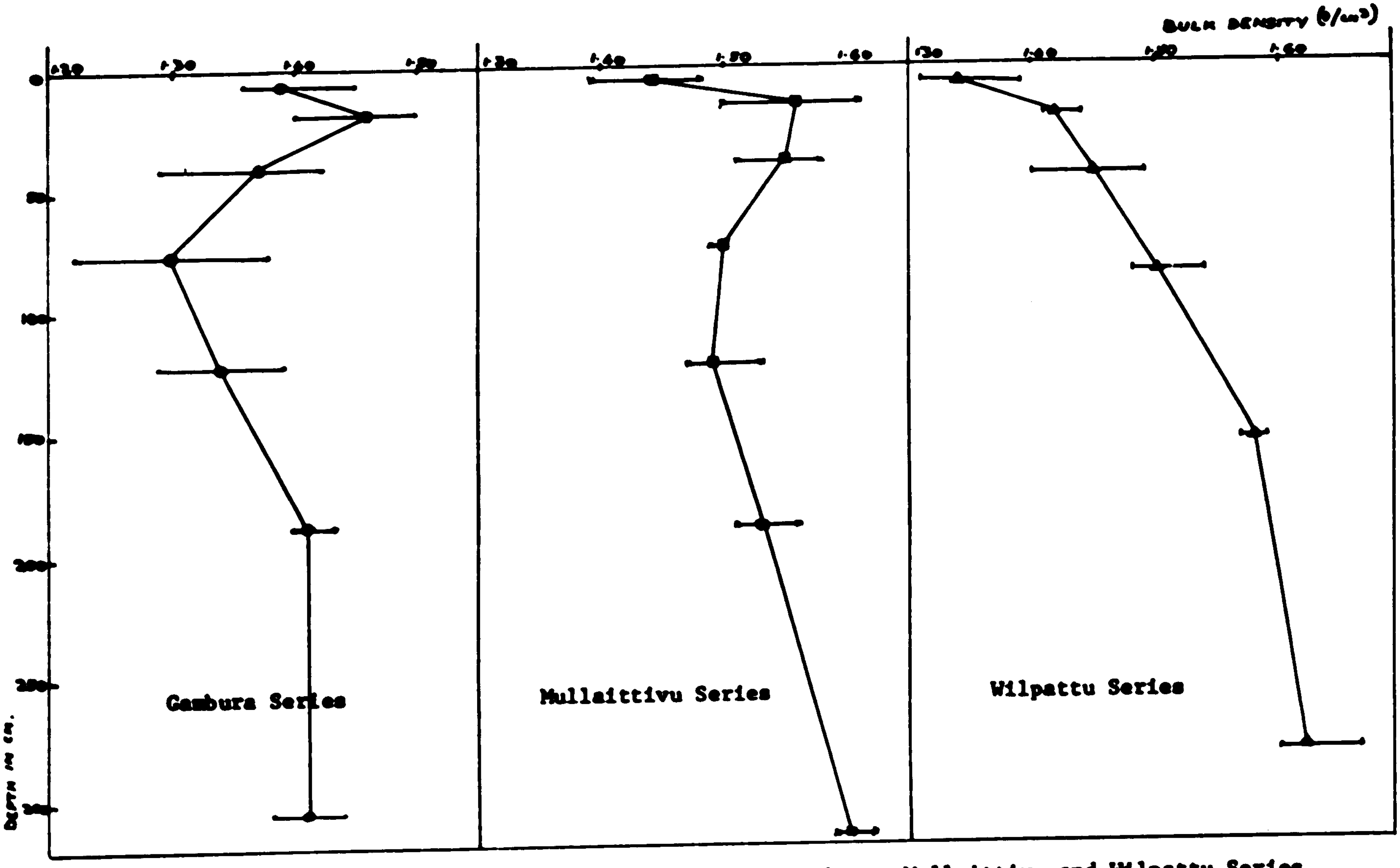


Figure 5. Means and ranges of the bulk densities of the Gambura, Mullaittivu and Wilpattu Series.

lower B horizons, of these two series there is again an increase in bulk density with depth, in all probability resulting from the increasing pressure of the overburden, less organic matter and termite activity and the smaller extent of disruption by roots. In the Gambura Series, the bulk density reaches a fairly constant value in the B_{24} horizon, but this does not occur within the depth of sampling in the Mullaittivu soil.

The Wilpattu Series shows an entirely different type of depth distribution of bulk density with values increasing at a diminishing rate down the profiles. The comparatively low bulk densities near the surface are doubtless caused in part by the slightly higher organic content of these horizons and by faunal and plant activity, but the eluviation of clay without much compaction of the sand grains (see section on micromorphological analysis) may be a more important factor. The increasing bulk density values with depth could be ascribed to the filling of pores by illuviation, increasing pressure, and less activity by termites and roots in the lower horizons.

The general increase in bulk densities from the Gambura through the Mullaittivu to the Wilpattu Series reflects the decreasing fineness of texture. Total pore space is, of course, negatively correlated with the bulk densities.

Table 2. Bulk Density, Particle Density, Pore Space and Water-Physical Properties

Profile and Horizon		Sampling Depth (cm.)	Bulk Density[1] (g/cm.^{3})	Particle Density[2] (g/cm.^{3})	Pore Space Percent[3]	1/3 Bar Percentage[4]	15 Bar Percentage
TP_1	A_{11}	2-10	1.36	2.70	50	6.2	4.8
	A_{12}	15-22	1.40	2.70	48	8.7	6.9
	B_{21}	30-50	1.42	2.72	48	12.4	10.4
	B_{22}	65-90	ND	2.72	ND	12.6	10.8
	B_{23}	110-135	ND	2.70	ND	14.2	12.3
	B_{24}	175-205	ND	2.71	ND	12.6	10.5
	B_{25}(u)	335-345	ND	2.72	ND	13.8	11.7
TP_2	A_{11}	2-10	1.45	2.66	45	8.3	6.4
	A_{12}	12-22	1.50	2.69	44	8.8	7.2
	B_{21}	30-50	1.29	2.71	52	11.2	9.2
	B_{22}	65-90	1.22	2.71	55	12.5	10.1
	B_{23}	110-135	1.29	2.72	63	13.9	11.6
	B_{24}	175-205	1.40	2.72	49	13.7	11.0
	B_{25}(u)	275-305	1.38	2.73	49	13.8	10.9
	B_{25}(l)	345-360	ND	2.73	ND	13.9	11.3
TP_3	A_{11}	2-8	1.37	2.70	49	6.1	3.9
	A_{12}	12-25	1.48	2.72	46	5.6	3.9
	B_{21}	32-45	1.40	2.73	49	9.8	6.9
	B_{22}	60-85	1.38	2.74	50	11.7	9.5
	B_{23}	105-130	1.39	2.75	49	12.3	9.7
	B_{24}	165-200	1.43	2.75	48	12.5	10.0
	B_{25}(u)	260-310	1.44	2.74	48	12.6	9.4
	B_{25}(l)	370-385	ND	2.75	ND	13.6	10.4
MP_1	A_{11}	0-5	1.48	2.66	44	5.4	3.5
	A_{12}	8-15	1.50	2.69	44	7.1	4.8
	B_{21}	22-42	1.50	2.70	42	9.9	7.5
	B_{22}	57-82	1.49	2.72	45	11.8	8.6
	B_{23}	102-128	1.48	2.70	45	13.2	9.9
	B_{24}	170-200	1.53	2.70	43	11.9	9.8
	B_{25}(u)	300-330	1.59	2.70	41	12.5	9.5
	B_{25}(l)	485-492	ND	2.72	--	12.4	9.5

1. Mean values from 5 cores.
2. One in five determinations duplicated.
3. Calculated.
4. Average of duplicates.
5. One in four values duplicated.

Table 2. (Continued) Bulk Density, Particle Density, Pore Space and Water-Physical Properties

Profile and Horizon		Sampling Depth (cm.)	Bulk Density[1] ($g/cm.^3$)	Particle Density[2] ($g/cm.^3$)	Pore Space Percent[3]	1/3 Bar Percentage[4]	15 Bar Percentage[5]
MP_2	A_{11}	2-8	1.39	2.64	47	6.5	4.9
	A_{12}	10-20	1.61	2.66	39	7.7	5.3
	B_{21}	28-48	1.56	2.69	42	10.2	7.5
	B_{22}	62-85	1.50	2.70	44	12.5	9.8
	B_{23}	108-135	1.47	2.70	46	12.9	9.6
	B_{24}	172-202	1.51	2.70	44	11.4	9.2
	B_{25}	300-330	1.62	2.69	40	12.5	9.5
MP_3	A_{11}	2-8	1.45	2.65	45	6.6	4.7
	A_{12}	10-22	1.57	2.69	42	8.9	6.2
	B_{21}	30-50	1.51	2.68	44	11.5	8.4
	B_{22}	65-90	1.50	2.70	44	12.6	9.3
	B_{23}	110-135	1.53	2.70	43	11.4	8.9
	B_{24}	175-205	1.56	2.69	42	11.8	9.7
	B_{25}	300-338	1.60	2.69	41	11.7	9.3
PP_1	A_{11}	0-8	1.32	2.71	51	3.2	2.6
	A_{12}	10-15	1.44	2.73	47	4.0	3.3
	B_{21}	22-42	1.49	2.74	46	5.7	4.6
	B_{22}	60-82	1.54	2.75	44	7.4	5.2
	B_{23}	125-150	1.58	2.76	43	8.8	6.4
	B_{24}	250-300	1.60	2.75	42	8.8	7.1
PP_2	A_{11}	2-12	1.39	2.71	49	4.4	3.2
	A_{12}	18-25	1.41	2.74	48	5.4	4.2
	B_{21}	35-65	1.45	2.74	47	7.4	5.0
	B_{22}	82-110	1.49	2.74	46	7.1	4.9
	B_{23}	150-175	1.59	2.74	42	8.6	6.7
	B_{24}	225-250	1.67	2.75	39	8.5	6.9
PP_3	A_{11}	0-12	1.31	2.69	51	5.4	4.0
	A_{12}	15-30	1.42	2.71	48	5.7	4.5
	B_{21}	38-58	1.40	2.74	49	4.8	3.9
	B_{22}	75-95	1.48	2.72	46	6.0	4.6
	B_{23}	125-175	1.57	2.71	42	6.5	5.1
	B_{24}	312-350	1.60	2.72	41	7.4	6.3

5.34 1/3 and 15 Bar Percentage

The values of the 1/3 and 15 bar (gravimetric) moisture percentages are given in Table 2. These indicate that the available water holding capacities of all the soils are probably quite low regardless of texture although the individual 1/3 and 15 bar moisture percentages are related to the clay contents. Moisture characteristic curves for other red soils of similar texture (W.D. Joshua, personal communication) show that they have comparable water retentivities at the higher tensions and higher water retentivities (than the Red Latosols) at lower tensions, indicating that the Red Latosols have a high proportion of large pores which drain under very low tensions. This is reflected in the good aeration and excessive drainage of these soils and probably indicates that the Red Latosols are well aggregated.

Good agreement has been found between the values of 2.5 x 15 bar water and clay percentage in many Oxisols (Soil Survey Staff, U.S.D.A., 1967) but the clay percentages are much higher than 2.5 x 15 bar water in the Red Latosols.

5.35 Particle Size Distribution Analysis

Preliminary analysis of the particle size distributions without prior removal of free iron oxides was carried out on all samples and the results are reported in Tables A2 to 5 of the Appendix. They show silt contents which are considerably lower and clay contents that are higher than those reported by Moormann and Panabokke (1961), but are in agreement with the results of subsequent analyses done on these soils (unpublished data, Land Use Division, 1960-66). The somewhat high silt contents reported earlier are probably due to incomplete dispersion arising from the use of sodium hydroxide as the dispersing agent.

Fig. 6 illustrates the mean depth distributions of clay ($< 2\mu$) in the three soil series with some indication of the range of variation in each horizon. The change in percent clay with depth generally follows a pedogenic pattern without any notable discontinuities. In all cases there is a marked increase in clay-size particles downwards, until nearly constant values are reached in the Gambura and Mullaittivu Series, while in the case of the Wilpattu soil this does not occur within the depth of sampling. Examination of the clay distributions in the individual profiles of the Gambura and Mullaittivu soils, however, show a slight, diffuse positive bulge or maximum (where sampling has been carried out to an adequate depth) suggesting some clay illuviation. The clay content, the absolute increase in clay with depth from the surface and rate of increase itself all follow the order Gambura Series > Mullaittivu Series > Wilpattu Series. The marked differences among the three soils in their clay contents suggest that they had different parent materials, since they occur in similar environments.

More detailed particle size separations of selected samples were carried out according to a modified Kittrick and Hope (1963) procedure after removal of free iron oxides and the results are shown in Tables A 6, 7 in the Appendix. Fig. 7 illustrates the distribution of iron oxide-free clay ($<2\mu$) with depth in profiles TP$_1$, MP$_1$ and PP$_2$.

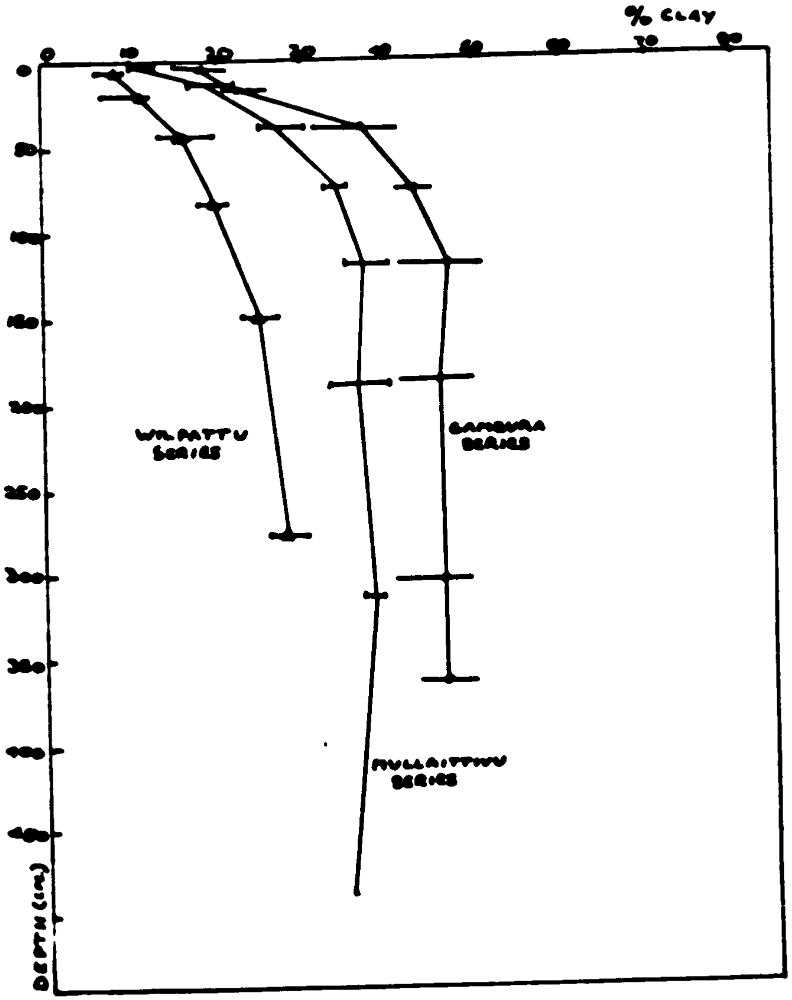


Figure 6. Mean depth distributions of clay (<2μ) without removal of iron oxides, in the Gambura, Mullaittivu and Wilpattu Series.

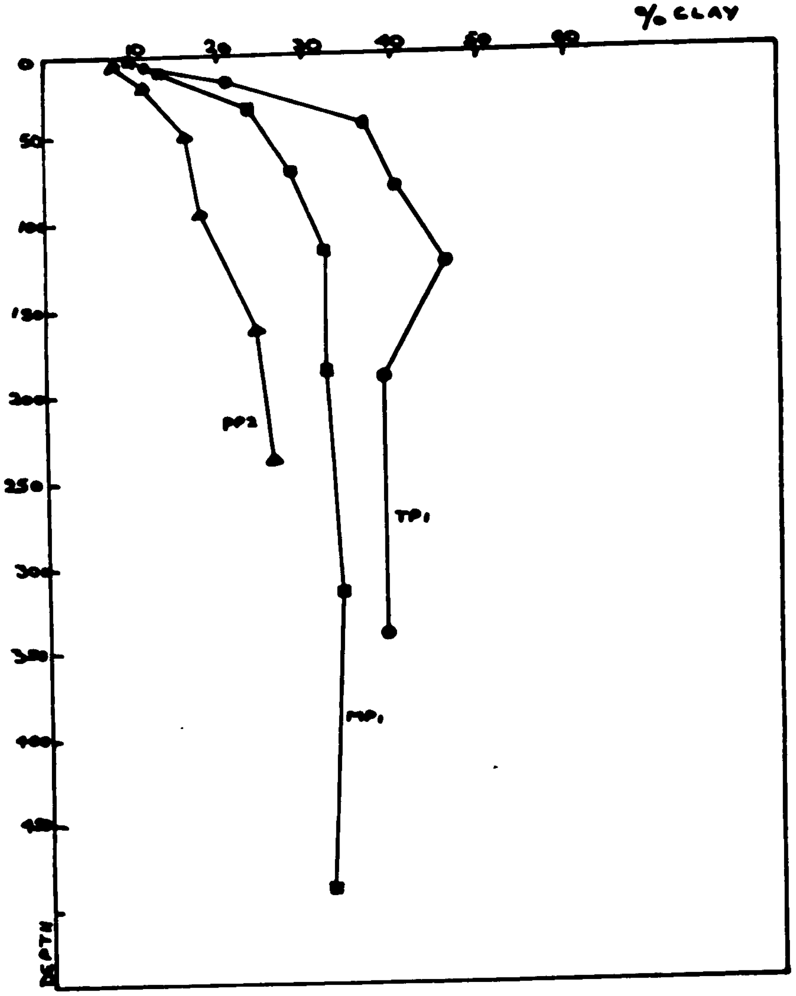


Figure 7. Depth distributions of clay (<2μ) with free iron oxides removed in the TP_1, MP_1 and PP_2 profiles.

Profile TP_1 (Gambura Series) displays a distinct bulge in the region 75 - 185 cm. implying an accumulation of clay. The clay content of profile MP_1 (Mullaittivu Series) rapidly increases to a nearly constant value, while profile PP_2 (Wilpattu Series) exhibits a more subdued rate of increase which gradually reduces with depth. Independent plots of fine clay and coarse clay percentages versus depth (Fig. 8) demonstrate that the downward increase in clay is accounted for largely by the fine clays. The small initial increase in the coarse clays is probably due to the relatively greater weathering (both physical and chemical) in the surface horizons and/or some short range translocation of the coarse clay. Illuviation of fine clay is shown up even more dramatically when the fine clay/coarse clay ratio is followed down the profiles (Fig. 9). The magnitude of this ratio increases with depth and then decreases in the Gambura and Mullaittivu profiles confirming that clay movement has indeed taken place. Deeper sampling will be required to confirm the same process for the Wilpattu soil but the initial increase seems to indicate that it is different only in degree and depth of clay movement. Another interesting feature is that the fine clay/coarse clay ratio reaches its maximum value at the smallest depth in the finest textured Gambura soil, further down in the Mullaittivu soil and apparently at a still lower depth in the relatively coarse textured Wilpattu profile. This is in accord with the concept of soil as a leaching column, in which texture determines to a large extent the vertical distance moved by the suspended clay. The reduction of the fine to coarse clay ratio in the lowest horizon of the Gambura profile (TP_1) to a value approximating

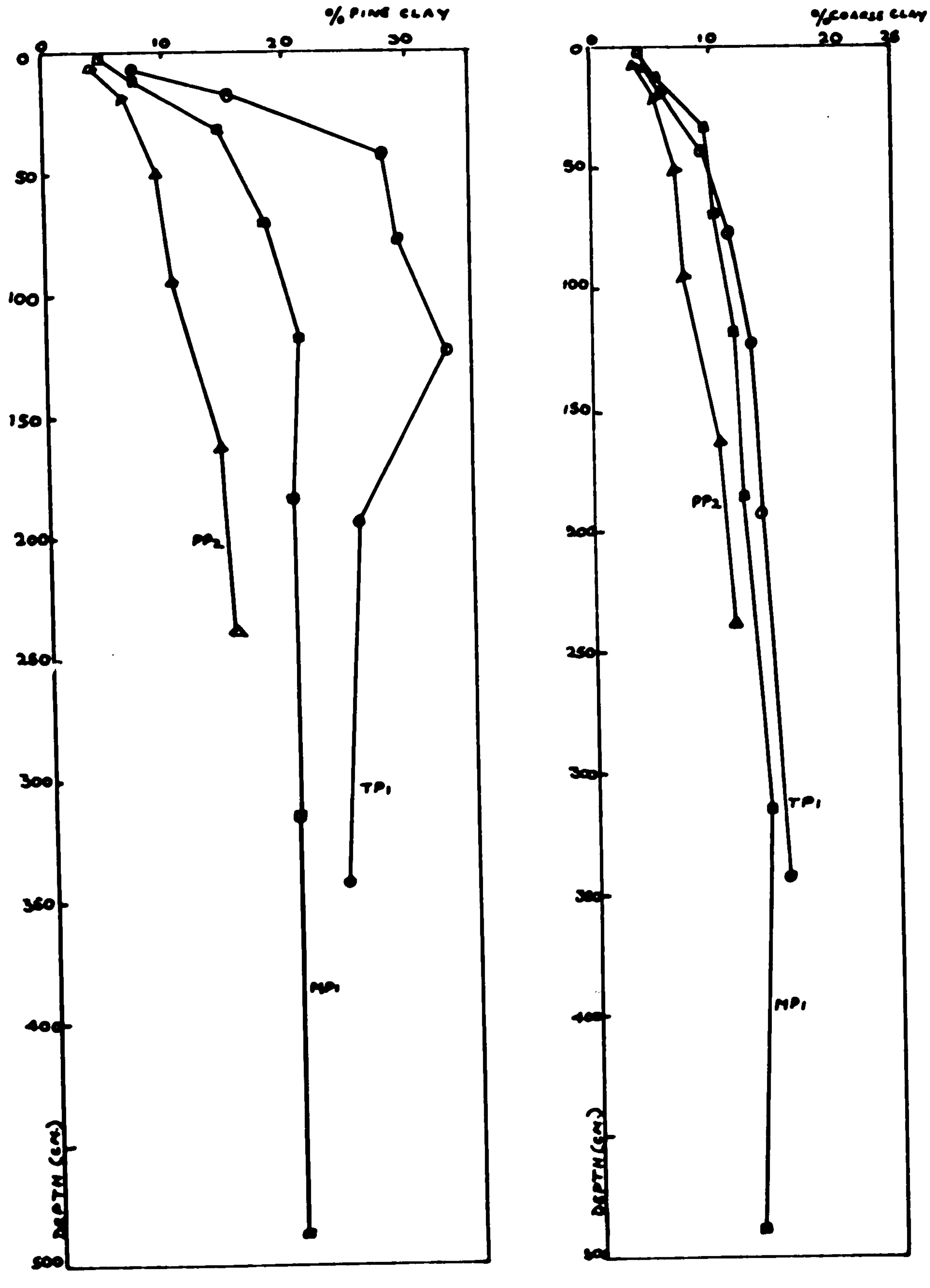


Figure 8. Depth distributions of (a) fine (<0.2μ) clay and (b) coarse clay (2-0.2μ) in profiles of the Gambura, Mullaittivu and Wilpattu Series. (Iron oxides removed.)

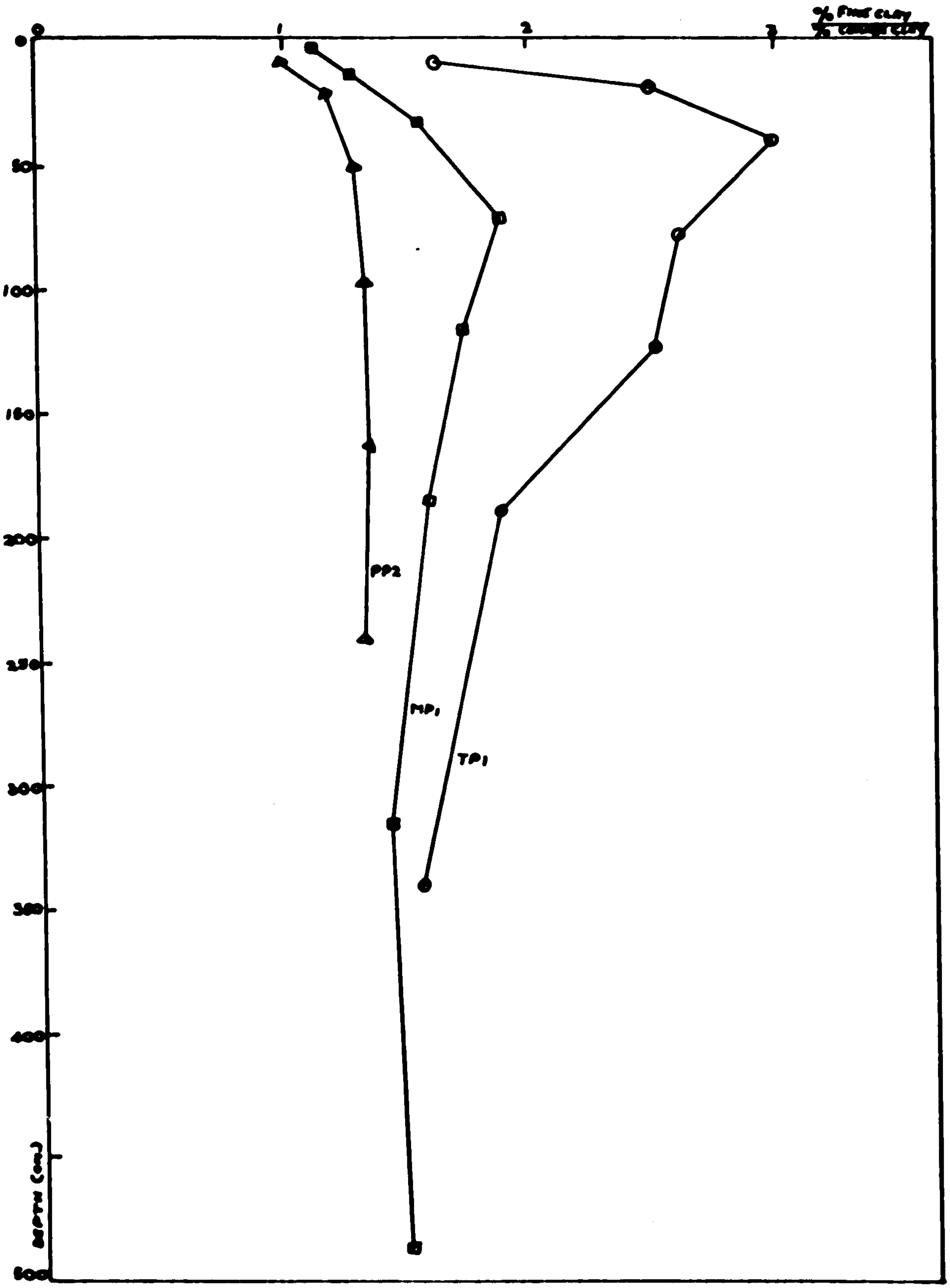


Figure 9. Depth distributions of fine clay to coarse clay ratios (Free iron oxides removed).

that in the surface horizon could be due to a differential weathering effect in the residual coarse clays of these horizons, i.e. the coarse clay undergoes weathering or comminution to a finer size to a greater extent in the surface horizons. Alternatively, it could be that some of the fine clay is growing to a larger size in the B_{25} horizon. The former explanation seems more plausible, however, when the depth distribution of coarse clay is examined.

Comparison of particle size analyses data with and without the removal of free iron oxides with citrate-dithionite (Tables A6, 7 in the Appendix) discloses that the iron oxides are largely concentrated in the clay fractions of the Red Latosols. They do not apparently play a significant role in cementing the clays into non-dispersible aggregates but exist as individual particles as in every case there was a substantial reduction in the clay percentage after their removal. This is contrary to findings by some workers (Cockroft, 1956; Mehra and Jackson, 1958) who have observed increases in the clay fractions on citrate-dithionite treatments to remove free iron oxides from soils. Recent work (Deshpande _et_ _al_., 1968; Greenland _et_ _al_., 1968) has indicated, however, that the increases in clay contents observed in such cases when iron oxides are removed are due to the fortuitous extraction of aluminium oxides (which are much more effective in cementing clays) at the same time, and that the iron oxides are present to a large extent, as discrete particles. The fact that the Red Latosols contain only very small amounts of free aluminium oxides and considerable amounts of iron oxides would, therefore, be consistent with the observed decrease in the clay fraction on oxide removed by the citrate-dithionite method.

One of the striking features of the particle size distribution of the Red Latosols is the very low silt content. The silt percentages are particularly small in the Wilpattu Series. Low silt contents and low silt/clay ratios are generally recognized as being indicators of advanced weathering due either to the prolonged action of the weathering agents or their strong intensity or both. In the Red Latosols both conditions are satisfied, the former on account of the age of the deposit and the latter due to high temperatures and seasonally high rainfall. This may not be the only factor responsible for the low silt contents, however. It is also possible that the contents of very fine sands, coarse silt and fine silt were low in the parent materials initially. Thus the silt contents are lowest in the soils with the highest amounts of resistant minerals, viz. the Wilpattu Series. The silt contents and silt/clay values are somewhat higher in the lowest horizons of the Gambura and Mullaittivu soils probably as a result of less severe weathering at these depths.

The particle size distributions of the sands, determined by sieve analysis, are given in Table 3 as percentages of the total sand. They show general uniformity, with depth within each profile, and among profiles of the same series. The higher amounts of very coarse sand in the lowermost horizons are in all likelihood attributable to the lower rate of physical breakdown of the larger quartz particles, although differences in sedimentation cannot be ruled out. In general, however, it may be concluded that the parent materials were reasonably uniform within each soil series and distinctly different among series

Table 3. Sand Fractions as Percentages of Total Sand

Series	Profile	Horizon	Sample Depth (cm.)	Very Coarse Sand 2-1mm.	Coarse Sand 1-0.5 mm.	Medium Sand 0.5-0.25 mm.	Fine Sand 0.25-0.1 mm.	Very Fine Sand 0.1-0.05 mm.
Gambura Series	TP_1	A_{11}	2-10	3	35	25	28	9
		A_{12}	15-22	6	32	22	31	9
		B_{21}	30-50	7	32	22	29	10
		B_{22}	65-90	6	32	22	30	10
		B_{23}	110-135	10	32	20	28	10
		B_{24}	175-205	12	32	20	27	9
		B_{25}(u)	335-345	14	30	13	30	13
	TP_2	A_{11}	2-10	6	36	25	27	6
		A_{12}	12-22	6	34	24	28	8
		B_{21}	30-50	7	32	23	29	9
		B_{22}	65-90	8	32	20	31	9
		B_{23}	110-135	7	32	21	30	10
		B_{24}	175-205	10	32	21	27	10
		B_{25}(u)	275-305	12	32	19	26	11
		B_{25}(l)	345-360	17	29	16	27	11
	TP_3	A_{11}	2-8	3	33	27	30	7
		A_{12}	12-25	4	31	24	34	7
		B_{21}	32-45	6	34	23	29	7
		B_{22}	60-85	5	32	20	35	8
		B_{23}	105-130	6	33	24	29	8
		B_{24}	165-200	8	32	20	31	9
		B_{25}(u)	260-310	12	30	22	28	8
		B_{25}(l)	370-385	17	30	14	29	10
Mullaittivu Series	MP_1	A_{11}	0-5	3	27	26	36	8
		A_{12}	8-15	2	24	25	39	10
		B_{21}	22-42	4	23	22	40	11
		B_{22}	57-82	4	25	22	38	11
		B_{23}	102-128	11	29	20	30	10
		B_{24}	170-200	14	32	19	26	9
		B_{25}(u)	300-330	16	27	18	28	11
		B_{25}(l)	485-492	20	22	15	30	13
Termite Mound Near MP_1				2	16	23	46	13

Table 3. (Continued) Sand Fractions as Percentages of Total Sand

Series	Profile	Horizon	Sample Depth (cm.)	Very Coarse Sand 2-1 mm.	Coarse Sand 1-0.5 mm.	Medium Sand 0.5-0.25 mm.	Fine Sand 0.25 0.1 mm.	Very Fine Sand 0.1-0.5 mm.
Mullaittivu Series	MP_2	A_{11}	2-8	2	29	29	34	6
		A_{12}	10-20	2	23	26	39	10
		B_{21}	28-48	3	25	23	38	11
		B_{22}	62-85	4	24	19	41	12
		B_{23}	108-135	7	27	22	33	11
		B_{24}	172-202	10	29	21	30	10
		B_{25}	300-330	15	25	17	32	11
	MP_3	A_{11}	2-8	4	30	25	33	8
		A_{12}	10-22	3	24	20	41	12
		B_{21}	30-50	4	24	18	40	14
		B_{22}	65-90	7	26	16	38	13
		B_{23}	110-135	7	27	20	34	12
		B_{24}	175-205	13	31	12	32	12
		B_{25}	300-338	16	27	16	28	13
Wilpattu Series	PP_1	A_{11}	0-8	1	13	43	40	3
		A_{12}	10-15	1	13	42	41	3
		B_{21}	22-42	1	15	41	40	3
		B_{22}	60-82	1	15	39	41	4
		B_{23}	125-150	1	12	34	47	6
		B_{24}	250-300	1	16	38	40	5
	PP_2	A_{11}	2-12	1	16	38	42	3
		A_{12}	18-25	1	12	34	48	5
		B_{21}	35-65	1	13	33	48	5
		B_{22}	82-110	1	13	33	47	6
		B_{23}	150-175	1	12	32	49	6
		B_{24}	225-250	1	18	34	42	5
	PP_3	A_{11}	0-12	1	17	40	39	3
		A_{12}	15-30	Tr	14	36	46	4
		B_{21}	38-58	Tr	13	36	46	5
		B_{22}	75-95	Tr	14	33	48	5
		B_{23}	125-175	Tr	13	32	49	6
		B_{24}	312-350	1	18	34	42	5

as evidenced by the particle size distribution within the total sands.

Since post-depositional weathering has almost certainly altered the size frequency distributions, albeit uniformly, no attempt was made to use statistical parameters of the present distributions to ascertain the environment of deposition. It may be noted in passing, however, that the Gambura and Mullaittivu sands are bimodal while the Wilpattu sands have only one mode (in the 3ϕ region). In considering the present size distribution of the sands it is interesting to observe that analysis of sand from a termite mound in the vicinity of profile MP_1 (Table 3) indicated that termites may possibly discriminate against coarse sand in favour of fine and very fine sand in making their mounds, but further detailed work will be required to draw any conclusions in regard to the effects of their activities on the particle size distributions of soils.

5.36 Water Dispersibility of Clays

The dispersibility of the soil clays in distilled water was determined as a criterion for classification according to the methods of the National Co-operative Soil Survey of the United States (Soil Survey Staff, Soil Conservation Service, U.S.D.A., 1970) and the results are given in Table A8. of the Appendix. Since appreciable amounts of clay were dispersed in the surface and some upper B horizons, it is likely that clay migration in suspension is still a viable process in the Red Latosols.

5.37 Mineralogical Analysis of the Fine Sand Fractions

The aims of the mineralogical analyses carried out on the fine sand fractions were (a) to check uniformity of parent material - with depth within profiles as well as among profiles of the same series (b) to determine if different source areas have given rise to different parent materials, i.e. whether we are in fact dealing with soils developed on three distinct parent materials and (c) to assess the effects of weathering and soil formation on the mineralogy of these soils.

Separation of Heavy and Light Minerals

The fine sand fraction of all the horizons of profiles TP_1, MP_1 and PP_2 and selected horizons from other profiles of the same series (TP_2, MP_2 and PP_3) were separated into heavy (S.G. $>$ 2.96) and light (S.G. $<$ 2.96) fractions using S-tetrabromoethane. The relative proportions by weight are given in Table 4. The Gambura Series has the lowest percentage of heavy minerals with 4-5 percent, the Mullaittivu Series has an intermediate value of 6-9 percent and the Wilpattu Series contains 14-17 percent of 'heavies' in the fine sand fractions. This suggests that three different parent materials are involved (Carol, 1937). Further, the heavy mineral percentages remain more or less constant down the profiles, which fact is a consequence of the near-absence of easily weatherable minerals in both the heavy and light fractions. This and other details of the compositions of these two fractions are brought out in the following sections.

The Heavy Minerals (S.G. $>$ 2.96)

The heavy fractions of the fine sands were studied separately

Table 4. Percentages of Heavy and Light Minerals in Selected Fine Sands (100 - 250μ)

Series	Profile	Horizon	Sample Depth (cm.)	Heavy Minerals S.G. > 2.96 % w/w	Light Minerals S.G. < 2.96 % w/w
Gambura	TP_1	A_{11}	2-10	5.0	95.0
		A_{12}	15-22	4.9	95.1
		B_{21}	30-50	4.5	95.5
		B_{22}	65-90	4.3	95.7
		B_{23}	110-135	4.1	95.9
		B_{24}	175-205	4.5	95.5
		B_{25}	335-345	4.8	95.2
	TP_2	A_{11}	2-10	4.3	95.6
		B_{21}	30-50	4.9	95.1
		B_{25}	275-305	3.9	96.1
Mullaitt-ivu	MP_1	A_{11}	0-5	6.0	94.0
		A_{12}	8-15	9.2	90.8
		B_{21}	22-42	8.7	91.3
		B_{22}	57-82	8.0	92.0
		B_{23}	102-128	8.3	91.7
		B_{24}	170-200	8.0	92.0
		B_{25}(u)	300-330	7.8	92.2
		B_{25}(l)	485-492	7.8	92.2
	MP_2	A_{11}	2-8	7.4	92.6
		A_{12}	10-20	7.5	92.5
		B_{24}	172-202	6.9	93.1
Wil-pattu	PP_2	A_{11}	2-12	14.5	85.5
		A_{12}	18-25	14.9	85.1
		B_{21}	35-65	15.9	84.1
		B_{22}	82-110	15.9	84.1
		B_{23}	150-175	16.9	83.1
		B_{24}	225-250	16.8	83.2
	PP_3	A_{11}	0-12	13.6	86.4
		B_{21}	38-58	14.6	85.4
		B_{24}	312-350	14.9	85.1

One third of the samples were determined in duplicate; values agreed to within 0.5% (absolute).

using magnetic, optical and X-ray diffraction methods. A preliminary quantitative separation of strongly magnetic minerals, consisting essentially of only magnetite, was made using a permanent magnet. The identity of the magnetite was confirmed by X-ray diffraction. The weight percentages of magnetite in the heavy fractions are given in Table 5. These show that the magnetite content is fairly constant within each profile and differs only slightly, if at all, from other profiles of the same series. Further, the amounts of magnetite are clearly different in the three soils, decreasing from the Gambura to the Mullaittivu Series, adding to the weight of evidence that the three parent materials were lithologically distinctly different, though quite uniform within themselves.

The weakly magnetic and non-magnetic heavy minerals were studied in Aroclor mounts and counts (400/slide) made to obtain the percentage compositions. The mineral assemblages are comparatively simple and consist of opaques (nearly all ilmenite), sillimanite, rutile and zircon with small amounts of other components like garnet, monazite, spinel and tourmaline. The identities of the major constituents were confirmed by X-ray diffraction. The complete absence of amphiboles, pyroxenes and other easily weatherable mineral groups indicates that intensive abrasion and/or weathering have taken place or that the sediments are re-worked. The presence of sillimanite reflects the metamorphic sources. The most noteworthy feature of the assemblages, however, is that while they differ in the relative amounts of the various components, the minerals present are the same.

Table 5. Percentages of Magnetite ($^{w}/_{w}$) in the Heavy Fractions of Some Fine Sands

Horizon	Series and Profile					
	Gambura Series		Mullaittivu Series		Wilpattu Series	
	TP_1	TP_2	MP_1	MP_2	PP_1	PP_2
A_{11}	42	42	14	12	30	25
A_{12}	45		14	20	30	
B_{21}	45	43	15		30	28
B_{22}	44		14		32	
B_{23}	41		15		31	
B_{24}	45	43	15	17	32	27
B_{25} (upper)	41		16			
B_{25} (lower)			15			

This suggests that hydraulic factors were more significant in producing differences in the parent material than were differences in lithology of the source areas. A plot of mineral specific gravities against mineral abundance in the different areas gives a straight line (excepting sillimanite) lending further support to this view (Folk, 1961). The zircons are highly polished and generally sub-angular, sub-rounded, and angular, indicating a multiple source. The garnet grains are rounded and show greatest abundance in the Wilpattu soil.

The percentages (by count) once again demonstrate the degree of uniformity of the parent material of each soil series and differences between the series (Table 6). The relatively invariable composition of the heavy mineral assemblage in each area, with no indications of concentration into placers, is suggestive of relatively uniform and rapid formation of the beach deposits.

The Light Minerals (S. G. < 2.96)

The light mineral fraction consists almost exclusively of quartz. Only traces or very small quantities of other minerals, chiefly feldspar and muscovite, are found. In all cases the quartz grains show various degrees of roundness and sphericity indicating multiple sources. The grains show polish, but the lack of rounding in a majority of them would imply rapid shoreline fluctuation and beach build up resulting in insufficient time for rounding to occur. Similar situations have been known to occur elsewhere (Folk, 1961). Some of the angular fragments have apparently resulted from the fracturing of larger grains.

Staining for feldspars (and other Al-containing minerals) with hematein followed by counting showed their extreme paucity in these soils (Table 7). Since only 400 counts were made on each slide and the percentages of feldspars are low, no definite quantitative deductions may be made. Nevertheless, visual inspection as well as the results of the counts, do show a slight trend towards higher contents of feldspars with depth - probably reflecting the higher intensity of weathering near the surface. Thus, it may be concluded that *in situ* weathering has been responsible for at least part of the clay present in these soils (i.e. all the clay was not inherited).

Table 6. Percentage Mineral Compositions (by count[1]) of the Magnetite-free Heavy Fractions of Selected Fine Sands

Series	Profile	Horizon	Opaques[2]	Sillimanite	Zircon	Rutile	Others[3]
Gambura	TP_1	A_{11}	55	25	10	6	4
		A_{12}	54	24	12	8	2
		B_{21}	54	24	10	8	3
		B_{22}	56	21	14	6	3
		B_{23}	58	21	12	7	2
		B_{24}	52	24	15	6	3
		B_{25}	54	25	10	8	3
	TP_2	A_{11}	61	21	10	5	2
		B_{21}	55	23	13	7	2
		B_{24}	55	25	12	6	2
Mullaittivu	MP_1	A_{11}	60	21	6	11	2
		A_{12}	62	21	4	11	2
		B_{21}	61	21	3	12	3
		B_{22}	60	22	4	12	2
		B_{23}	60	19	6	13	2
		B_{24}	64	20	4	10	2
		B_{25}(u)	63	23	2	9	3
		B_{25}(l)	60	22	3	14	1
	MP_2	A_{11}	60	17	5	15	3
		A_{12}	66	14	3	15	2
		B_{24}	61	18	4	15	2
Wilpattu	PP_2	A_{11}	61	15	4	9	11
		A_{12}	64	11	5	9	11
		B_{21}	60	15	5	9	11
		B_{22}	63	13	6	9	9
		B_{23}	64	10	6	9	11
		B_{24}	61	15	4	8	11
	PP_3	A_{11}	57	19	5	7	12
		B_{21}	58	19	4	9	10
		B_{24}	61	16	5	7	11

1. 400 counts per slide - one slide per sample.
2. Almost entirely ilmenite.
3. Garnet, Spinel, Monazite, Tourmaline.

Table 7. Percentages of Grains Stained by Hematein in the Light (S. G. < 2.96) Fractions of Some Fine Sands.

Profile	Horizon	% Stained	Profile	Horizon	% Stained	Profile	Horizon	% Stained
TP_1	A_{11}	<1	MP_1	A_{11}	0	PP_2	A_{11}	< 1
	B_{21}	<1		B_{21}	1		B_{21}	<1
	B_{23}	<1		B_{23}	2		B_{24}	5
	B_{25}	5		B_{25}(L)	2			
TP_2	A_{11}	< 1	MP_2	A_{11}	0	PP_3	A_{11}	< 1
	B_{21}	<1		A_{12}	<1		B_{21}	1
	B_{25}(u)	3		B_{24}	<1		B_{24}	1

1. Four hundred grains/sample counted.

Most of the other non-stained grains counted were quartz with opal showing up occasionally in the surface horizons.

5.38 Micromorphological Studies

Detailed micromorphological descriptions for each profile are given with the macromorphological field descriptions in the Appendix. The terminology used is that outlined by Brewer (1964). Photomicrographs under transmitted light representing some of the fabrics and pedological features described appear on the following pages. They do not, however, always show adequate detail due to the strong contrast in light intensity between the skeletal grains (which are mostly quartz) and the matrixes (which are stained by organic matter and/or iron oxides), a contrast that is better accommodated by the eye than the photographic film. Further, many of these features are visible only at high magnification and extreme light intensities. The following are brief, generalized descriptions of the micromorphological features of the three soil series and interpretations of their significance in soil formation.

The A horizons of the Gambura Series have inundulic intertextic fabrics with porphyroskelic areas. The voids are interconnected vughs and channels, and free and embedded grain argillans are observable at high magnifications. Phytoliths, sesquioxidic soil nodules and organic remains may be present. Organic matter and iron oxide render the plasma opaque at low magnifications and low light intensities. With increasing depth, the proportion of plasma increases and void argillans start appearing until in the B horizons a skel-vo-insepic (or skel-vo-insepic inundulic) mixed porphyroskelic and agglomeroplasmic fabric prevails. The plasma is redder and more translucent and the voids consist largely of irregular vughs and skew planes. Both

Plate 1. Photomicrograph of a mixed agglomeroplasmic and porphyroskelic fabric from the B_{23} horizon of a Gambura Series soil.

Plate 2. Photomicrograph of a mixed porhyroskelic and intertextic fabric from the B_{21} horizon of a Gambura Series soil.

Plate 3. Photomicrograph of Ganumular fabric from the A_{11} horizon of a Wilpattu Series soil. Note sesquioxidic soil nodule.

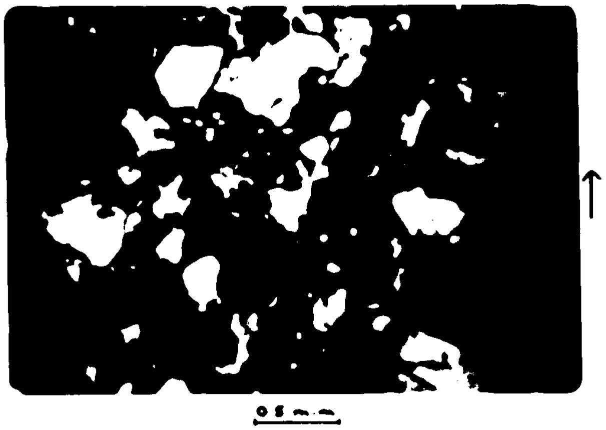


Plate 1. Photomicrograph of a mixed agglomeroplasmic and porphyroskelic fabric from the B$_{23}$ horizon of a Gambura Series soil.

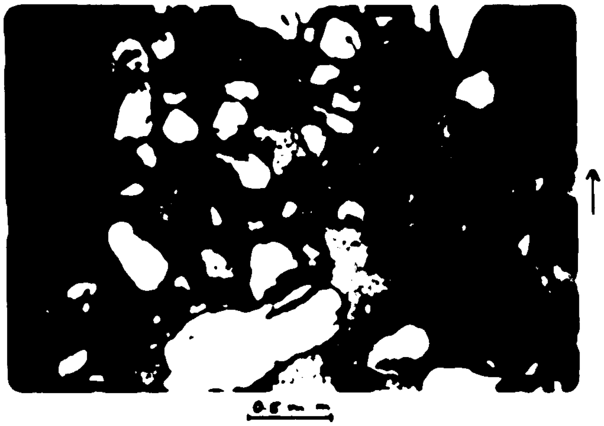


Plate 2. Photomicrograph of a mixed porhyroskelic and intertextic fabric from the B$_{2}$[illegible] horizon of a Gambura Series soil.

Plate 3. Photomicrograph of Granular fabric from the A$_{1}$[illegible] horizon of a Wilpattu Series soil. Note sesquioxidic soil nodule.

Plate 4. Photomicrograph of an isotic plasmic fabric from the A_{11} horizon of a Mullaittivu Series soil. Crossed nicols.

Plate 5. Photomicrograph of an inundulic plasmic fabric from the A_{11} horizon of a Gambura Series profile. Crossed nicols.

Plate 6. Photomicrograph of a skel-vo-insepic inundulic plasmic fabric from the B_{2s} horizon of a Gambura Series profile. Crossed nicols.

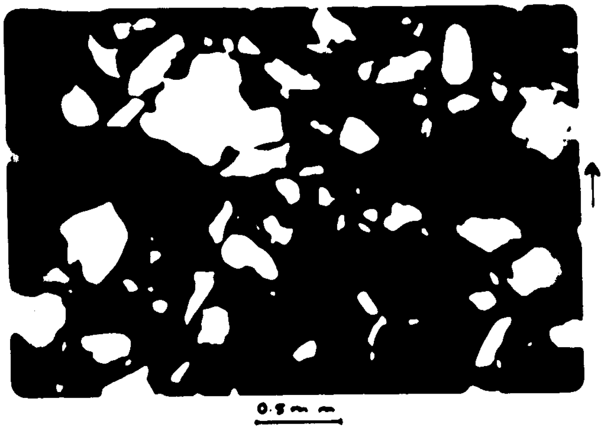


Plate 4. Photomicrograph of an isotic plasmic fabric from the A_{11} horizon of a Mullaittivu Series soil. Crossed nicols.

Plate 5. Photomicrograph of an inundulic plasmic fabric from the A_{11} horizon of a Gambura Series profile. Crossed nicols.

Plate 6. Photomicrograph of a skel-vo-insepic inundulic plasmic fabric from the B_{2g} horizon of a Gambura Series profile. Crossed nicols.

Plate 7. Photomicrograph of weak grain argillans visible only at high magnifications. Crossed nicols.

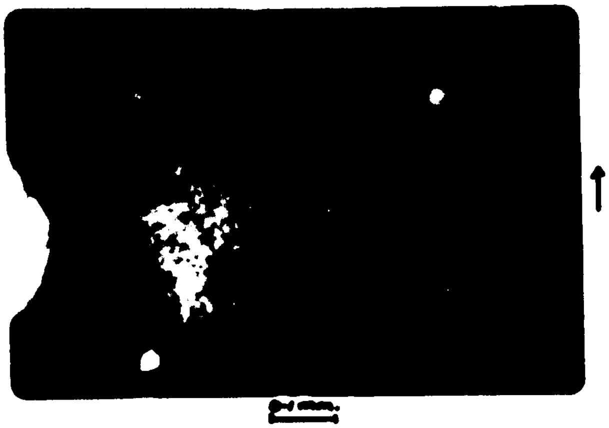


Plate 8. Photomicrograph of void and grain argillans visible at high magnifications. Crossed nicols.

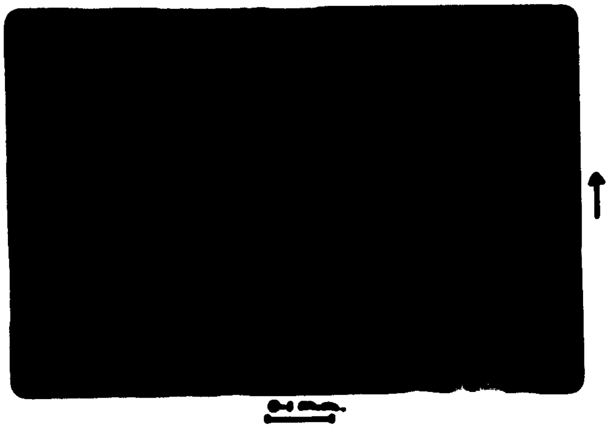


Plate 9. Photomicrograph showing outline of grain weathered <u>in situ</u>. Crossed nicols.

Plate 7. Photomicrograph of weak grain argillans visible only at high magnifications. Crossed nicols.

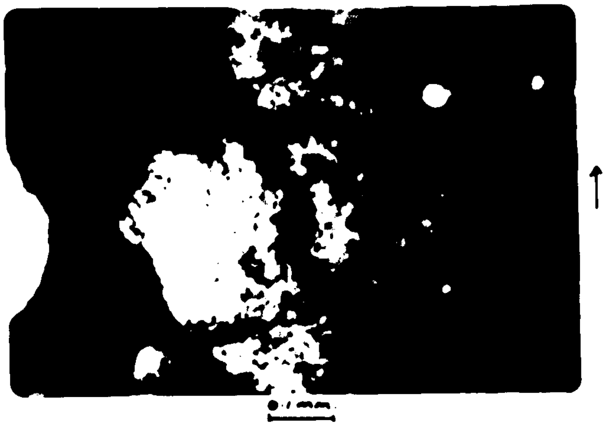


Plate 8. Photomicrograph of void and grain argillans visible at high magnifications. Crossed nicols.

Plate 9. Photomicrograph showing outline of grain weathered in *situ*. Crossed nicols.

embedded grain and void argillans are common. Skeletal grains can be seen decomposing in place. At greater depths (B_{25} horizons) the void argillans become less frequent and the fabric changes gradually to inundulic porphyroskelic with smaller agglomeroplasmic areas. The voids are irregular or acicular vughs and skew planes and the individual skeletal grains are somewhat larger.

The Mullaittivu Series has A horizons which have isotic intertextic fabrics with small agglomeroplasmic or porphyroskelic islands. The voids are irregular and interconnected vughs and occasional channels. Weak free grain cutans are evident as are phytoliths and organic remains. As in the Gambura Series there is an increasing proportion of plasma with depth until in the B horizons, skel-vo-insepic inundulic porphyroskelic fabrics with small intertextic or agglomeroplasmic areas predominate. The voids are largely irregular vughs, skew planes and channels, and void and grain argillans are common. The plasma is more translucent and mineral grains decaying in situ may be observed. Phytoliths occur, though rather infrequently, in the upper B horizons. In general anisotropic domains tend to be less developed than in the Gambura Series. At greater depths, void argillans tend to become scarcer. The fabric is mixed porphyroskelic and agglomeroplasmic with a skel insepic inundulic s-matrix. Fine sesquioxidic nodules may occur.

Granular or isotic granular to intertextic fabrics characterize the A horizons of the Wilpattu Series. They have strongly interconnected vughs and weak free grain argillans. Organic remains and phytoliths are present.Sesquioxidic soil nodules occur infrequently. The increase in plasma with depth is much more gradual than in the other two series. The B horizons possess vo-skel-insepic intertextic and porphyroskelic fabric although skel-vo-insepic and skel-vo-mosepic plasmic fabrics may also occur. The voids are interconnected vughs and, at greater depths, irregular vughs. Phytoliths may be present. Free grain, embedded grain and vugh argillans are present throughout. Grains decomposing in place may also be observed.

In all three soils there is an increasing incidence of void argillans with depth, probably reflecting illuviation of clay from the upper horizons. On the other hand, void argillans constitute only a disproportionately small part of the plasmic material and could not possibly account for all the clay that has moved. This is not surprising, however, as similar anomalous situations are common to many (if not most) soils and no consistent correlation has been found between the frequency of illuviation argillans and degree of illuviation (Brewer and Sleeman, 1969). In the case of the Red Latosols, periodic termite pedoturbation may well account for the relatively low proportion of void argillans in the s-matrix.

Free grain argillans, which are common in the A (and sometimes B) horizons of all the soils, could have resulted from alternate wetting and drying or be relic embedded grain cutans remaining after removal of the surrounding plasma. Further work on the nature of the different cutanic types will be required to distinguish between these two mechanisms. Embedded grain cutans have been attributed to inheritance (Brewer and Sleeman, 1969; Hoffer, 1960; Ruhe _et al._, 1961), but the nature of this deposit (beach and dune) argues against such an origin in this case. Alternate wetting and drying is a more likely explanation.

The sepic character of the fabrics generally follows the order Gambura Series > Mullaittivu Series > Wilpattu Series and is thus probably related to the clay contents and extent of clay movement. Although plasma with preferred orientation is present in sufficient amounts to justify grouping of these fabrics as sepic, a high proportion of unoriented domains occur in all three soils and these appear to have resulted from the weathering of mineral grains. The isotic character of the surface horizons of the Mullaittivu Series (and to a lesser extent of the Wilpattu Series) may reflect the slightly higher percentage of organic matter. It therefore seems that organic matter is more effective in producing isotic fabrics than are iron oxides.

A number of significant pedological features occur in all three soil series. Soil nodules with varying contents of sesquioxides are found in many of the surface horizons. The fact that they have undifferentiated fabrics implies that wetting and drying cycles have not been extreme during their formation. This is also supported by the very weak cementation they show. Their exclusive occurrence in the A horizons suggests that they are pedogenic and not inherited. A different type of very fine (< 1 mm.) iron oxide rich nodule without any skeletal grains, occurs in the lowest horizons of the Gambura and Mullaittivu Series. These are apparently formed _in situ_ by segregation of iron oxides. Phytoliths, most of them opaline, are common in all of the surface horizons and some B horizons which is in accord with findings of other workers on well-drained tropical soils elsewhere (Riquier, 1960; Stace _et_ _al_., 1968). Organic remains present in the A and upper B horizons consist almost exclusively of plant fragments (usually roots) with yellow-brown and red colourations and with their structures more or less intact. Some fecal pellets and very occasional pedotubules are also found, but these occurrences are highly localized. The presence of skeletal grains decomposing in place provide evidence for _in_ _situ_ decomposition of at least a considerable proportion of the weatherable minerals. The occurrence of channels and chambers attest to the activities of termites and other soil fauna. Areas of intertextic to granular fabric with sharp boundaries with the porphyroskelic or agglomeroplasmic fabric of some of the B horizons are in all likelihood a result of infillings of termite holes and passages or of root holes.

The mineral grains which, consist largely of quartz, display all degrees of roundness and sphericity indicating a multiple source. This is further confirmed by the fact that the zircons generally show a greater degree of roundness than the quartz grains (see section on mineralogical analysis of the fine sands). The low degree of roundness of the majority of mineral grains of this beach deposit indicates that the shoreline fluctuation (and beach build up) was quite rapid (Folk, 1961).

The quartz generally shows single grain straight or slightly undulose extinction but composite grains showing slightly undulose or strongly undulose extinction occur. Occasionally, semi-composite grains with strong to slightly undulose extinction are also met with.

This shows again the varied source of the deposit which according to the interpretation of Folk (ibid.) probably consists of injected and pressure metamorphics with some vein quartz thrown in. This ties in well with the regional geology since the Vijayan Series, which is the main source of these sediments, is a mixed group of polymetamorphic rocks displaying injection, recrystallization and pressure metamorphism (Cooray, 1967).

Point counts of voids, plasma and skeletal material were made on the thin sections and the results are given in Table A9 of the Appendix and depicted graphically in Fig. 10. It has been shown (Anderson, 1961) that areal proportions established by point counting or measuring lengths of line segments in thin sections can be used as estimates of volumetric ratios of the different constituents. The point counts for voids, plasma and skeletal material may, therefore, be accepted as representing the actual volumetric proportions in the soil with certain qualifications. Thus, the samples for sectioning were selected from soil volumes that did not contain large cracks, root holes or termite passages (which are all fairly common in these soils) and therefore, the results doubtless underestimate the actual total pore space. This is borne out by the pore space values obtained from bulk density measurements. Also, some shrinking of the soil clods would have occurred during oven drying before impregnation, further reducing the pore volume and possibly the matrix volume. The counting procedure itself may tend to discriminate against constituents occurring in very minute sizes unless high magnifications are used. Bearing these limitations in mind, it is possible to draw some tentative inferences

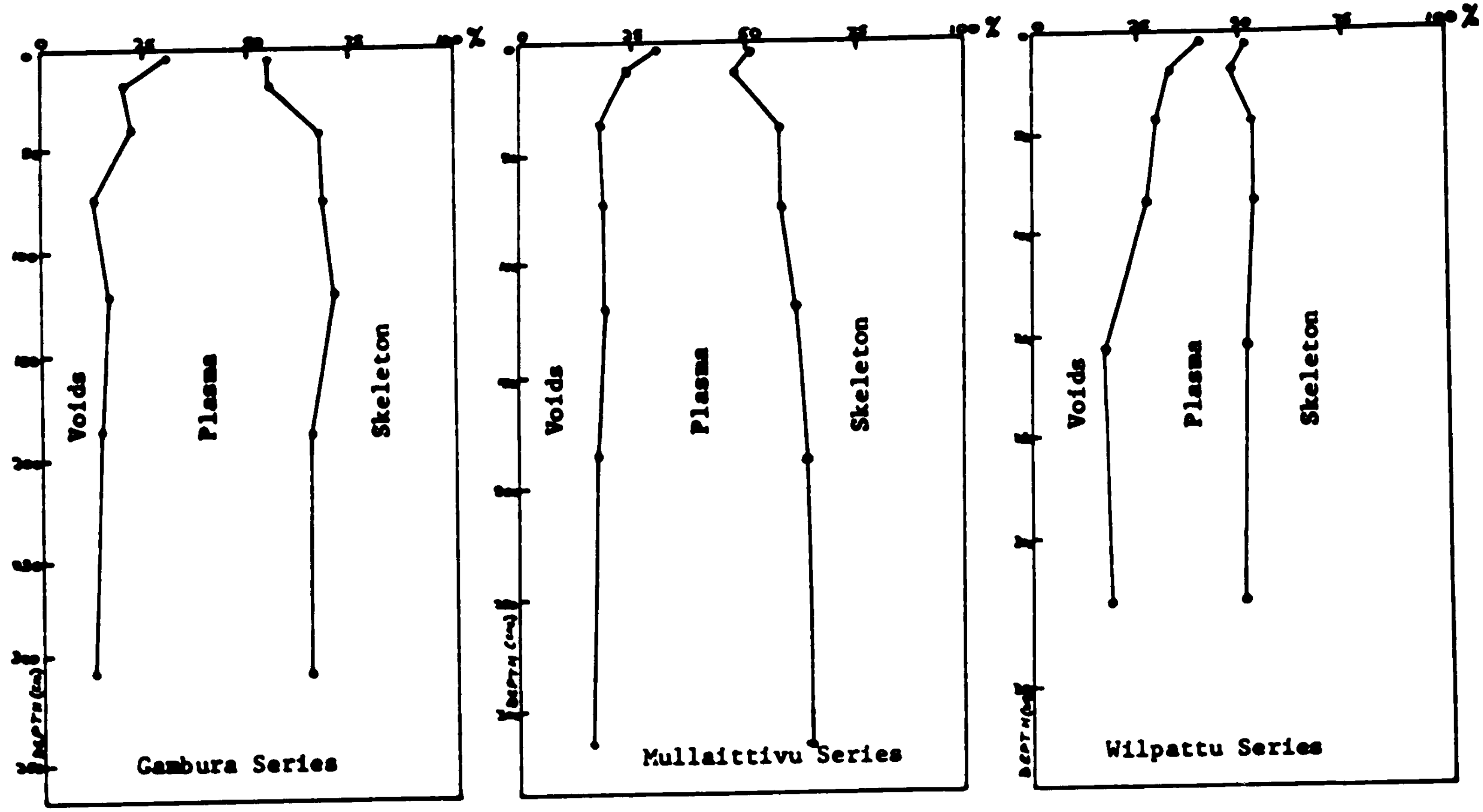


Figure 10. Mean variations of voids, plasma and skeleton with depth in the Gambura, Wilpattu and Mullaittivu Series expressed as cumulative percentages.

from these results.

In all three soils there is a slight decrease in skeletal content from the A to the B horizons indicating that the grains have moved closer together in the former probably as a consequence of clay eluviation. Destruction of clay by weathering could also have aided this process while incorporation of organic matter and faunal activity would have retarded it. The greatest difference in skeletal volume between the A and B horizons is shown by the Gambura Series while the Wilpattu Series shows the least. The magnitude of clay movement as shown by particle size distribution studies follows the same order. Voids decrease with depth quite sharply in the Gambura and Mullaittivu soils and more gradually in the Wilpattu Series. This reflects the more gradual increase in clay content in the latter soil, i.e. the eluviation-illuviation zone is spread out over a longer distance on account of its sandier texture.

5.39 Cation Exchange Studies

Cation Exchange Capacity

Cation exchange capacities were determined at pH7 (C.E.C.-7) by leaching with 1N NH_4OAc and by summation of the exchangeable bases and the $BaCl_2$ - tri-ethanolamine exchange acidity (C.E.C.-S). The results are shown in Tables A10-18 of the appendix.

Considerably lower values were obtained by the NH_4OAc method in agreement with other determinations on soils containing high proportions of 1:1 type clay minerals (Mehlich, 1945). The low values could be attributed to the pH-dependence of charge due to changes in the reactivity of organic matter with pH (Fiskell, 1970) or less complete replacement of hydroxy-Al ions (Chapman, 1965) or incomplete deprotonation of interlayer hydroxy-Al units (de Villiers and Jackson, 1967) or reaction of NH_4^+ with vermiculite-type minerals (Page et al., 1967) or any combination of these. The use of 95 percent ethanol to leach the ammonium saturated soil could also have resulted in the loss of some ammoniated organic constituents (Peech et al., 1962) as shown by the fact that the sum of the exchangeable bases exceeds the CEC-7 in many of the surface horizons.

The CEC-S, calculated as the sum of the exchangeable cations at pH7 and the exchange acidity at pH8.3, has been found to agree very well with the cation exchange capacity determined at pH8.3 by Na-saturation for a wide variety of soils (Coleman, et al., 1959; Fiskell, 1970). It can therefore be taken as a measure of the total "permanent" plus "pH-dependent" C E C. In the Red Latosols, CEC-S is frequently about 75 to more than 100 percent greater than CEC-7 indicating that a high proportion of the exchange sites in these soils are pH-dependent and probably blocked by Al- (and Fe-) hydroxy ions (Coleman and Thomas, 1967). Since the amounts of Al extractable by KCl or NH_4OAc at pH4.8 are negligible or very small, the exchange acidity values should approximate the pH-dependent exchange capacity (Fiskell, 1970).

In the following discussions of the exchange properties of the Red Latosols, CEC-S will be used in preference to CEC-7 because it gives a truer representation of the exchange capacities of acid soils (Chapman, 1965; Fiskell, 1970).

Fig. 11 illustrates the depth functions of cation exchange capacity in the different soil series. The values in the A horizons are obviously influenced by the organic matter contents (which follow the same order), more so in the Wilpattu and Mullaittivu soils with smaller clay contents than in the Gambura soils. This is brought out more strikingly by the variation of the calculated CEC per 100 grams clay with depth which indicates that a large part of the cation exchange capacity of the surface soils is due to organic matter. Small amounts of 2:1 clays that decrease with depth also probably add to this effect.

An increase in CEC from the upper to the lower B horizons would be expected on the basis of increasing clay content. But the actual increase is slight or absent probably being masked by contributions from the small amounts of organic matter present in the upper B horizons, the greater fine clay percentages in the middle B horizons and the increasing percentage of relatively inert iron oxides with depth. The small decrease in CEC/100 g. clay with depth in the

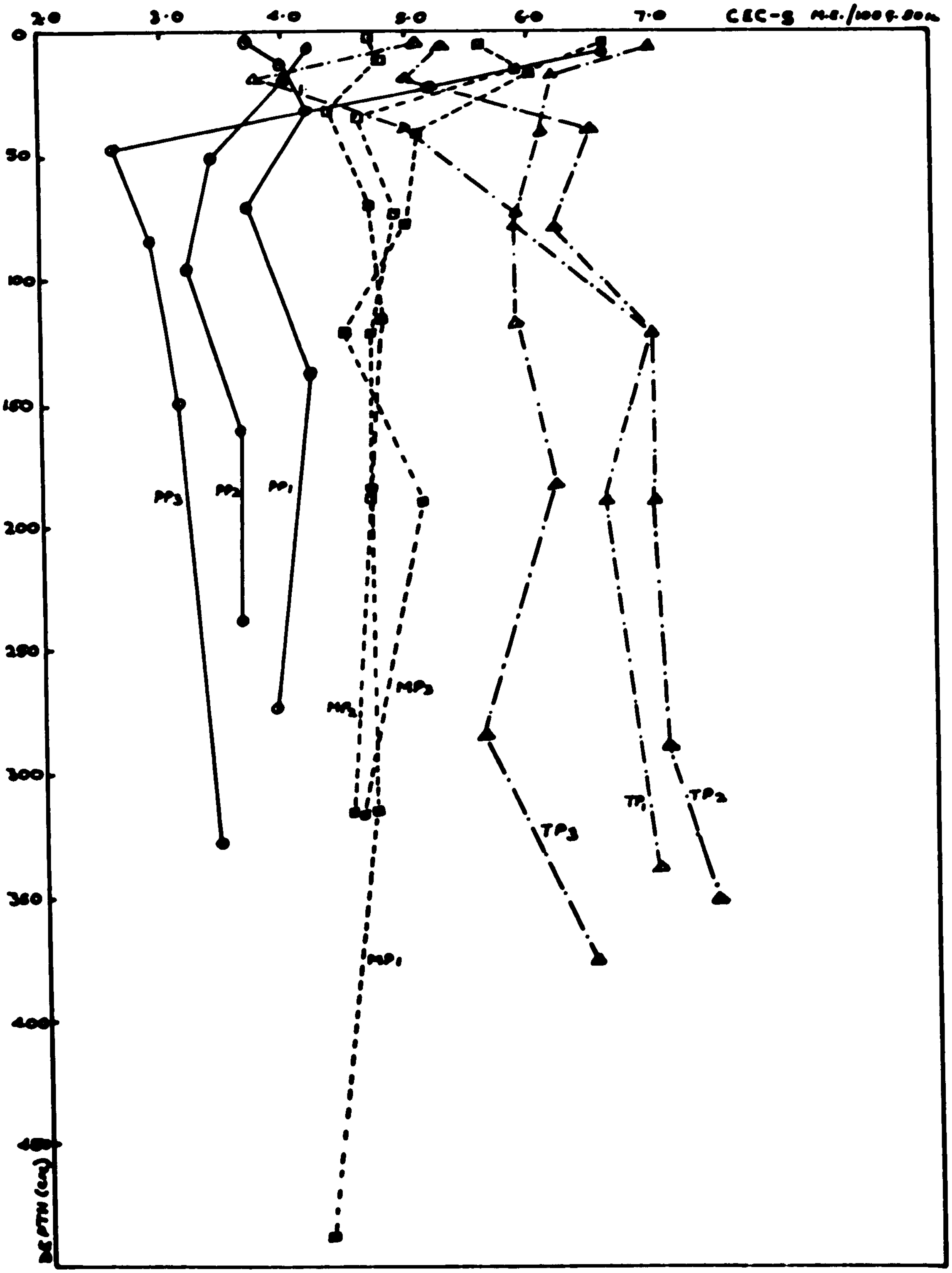


Figure 11. Depth distributions of the cation exchange capacities by summation (CEC-S) in profiles of the Gambura, Mullaittivu and Wilpattu Series.

B horizons of the Mullaittivu and Wilpattu profiles occurs for the same reasons. It is possible that the increase in this value from the middle to the lower B horizons of the Gambura soils is due to the higher fine silt contents whose clay minerals (see section on X-ray diffraction) also contribute to the calculated exchange capacities. The magnitudes of the CEC/100 g. clay in the horizons where other complicating factors are least obtrusive are in the range of 11 to 14 m.e. which is concordant with soils dominated by fairly fine-sized kaolinite and containing smaller amounts of mica and interlayered material (see sections on X-ray, d.t.a. and chemical clay mineral analyses). The differences that are apparent in the CEC values of the three soil series can be attributed to differences in clay content which follow the same order, viz. Gambura Series > Mullaittivu Series > Wilpattu Series.

Exchangeable cations, exchange acidity and base saturation

The exchangeable basic cations determined by leaching with neutral NH_4OAc (expressed as percentages of CEC-S) and the Al extracted by NH_4OAc at pH4.8 are shown in Tables A10-18 of the Appendix. Leaching with IN KCl (Chapman, 1965) failed to give titratable amounts of exchangeable Al in any of the soils.

All profiles show similar trends in the depth distribution of Ca^{++} and, since this ion is the dominant basic cation in the exchange complex, of the total exchangeable bases. The Ca values near the surface are relatively high, apparently due to recycling by plants (phytocycling) which retains the calcium ions against leaching. With depth, there is a decrease of the calcium (and total exchangeable base values) in the upper B horizons and then a gradual increase again in the lower B horizons. This is to be expected as the leaching solutions reaching the lower layers are already charged with calcium removed from the overlying material. Magnesium too shows high values in the surface horizons of all the soils probably for the same reason, viz. phytocycling. In the middle B horizons of the Gambura and Wilpattu soils, however, it shows a definite tendency to accumulate or resist leaching and maximum values are obtained at these depths. Examination of the Ca/Mg ratios indicates that calcium may be more readily displaced from exchange sites than magnesium in the middle B horizons. Potassium is present in considerably smaller amounts than Ca and Mg and it too tends to have its highest values in the surface horizons except in two profiles of the Wilpattu Series in which the B_{21} horizons have higher values. It decreases with depth into the lowermost horizons; the reasons for this will be discussed in a later section. Sodium is present only in trace quantities throughout the profile in all the soils reflecting its poor ability to compete with other ions for positions on the exchange complex. Atmospheric cyclic salt deposition resulting from the proximity of these profiles to the sea apparently provides Na in such dilute solutions that it is not able to displace the cations already present.

The inability of 1N KCl to extract titratable amounts of exchange acidity indicates that trivalent aluminium and hydrogen are insignificant components of the exchange complex (Coleman <u>et</u> <u>al</u>., 1958; Coleman <u>et</u> <u>al</u>., 1959; Lin and Coleman, 1960; Jackson, 1961; Thomas, 1961). This is in agreement with the results of Thomas (1961) who found that neutral salt solutions extract little Al in soils whose pH is greater than 5.3. NH_4OAc at pH4.8, which is known to extract a small portion of the hydroxy-Al monomer strongly adsorbed by the clays (Thomas, 1961) or present in interlayer spaces (Jackson, 1961) in addition to the exchangeable and soluble Al (Pratt and Blair, 1961), removed only meagre quantities of Al from the Red Latosols. Further, Fe ions cannot account for a significant part of the exchange acidity as measurable quantities were not extracted by 1N KCl. These considerations suggest that most of the fairly high exchange acidity of these soils can be attributed to Al - (and possibly Fe -) hydroxy compounds that are held tenaciously either on the exchange complex or in interlayer positions.

As would be expected on the basis of the above discussion of the C E C and exchangeable base distributions, the exchange acidities increase with depth from the surface to maximum values in the upper and middle B horizons (except in the case of the coarser textured Wilpattu soils in which the highest values occur at lower depths) and then decrease again. They are negatively correlated with the pH values and also with the small amounts of Al extracted by NH_4OAc at pH4.8. The latter relationship is important because it implies that this reagent extracted proportionate but small amounts of the Al-hydroxy compounds responsible for the acidity of these soils. The values of exchange acidity expressed as m.e./100 g. soil follow the same order as the clay content within profiles.

The depth functions of the base saturation percentages (Fig. 12) generally follow patterns that are similar to the Ca^{++} distributions and

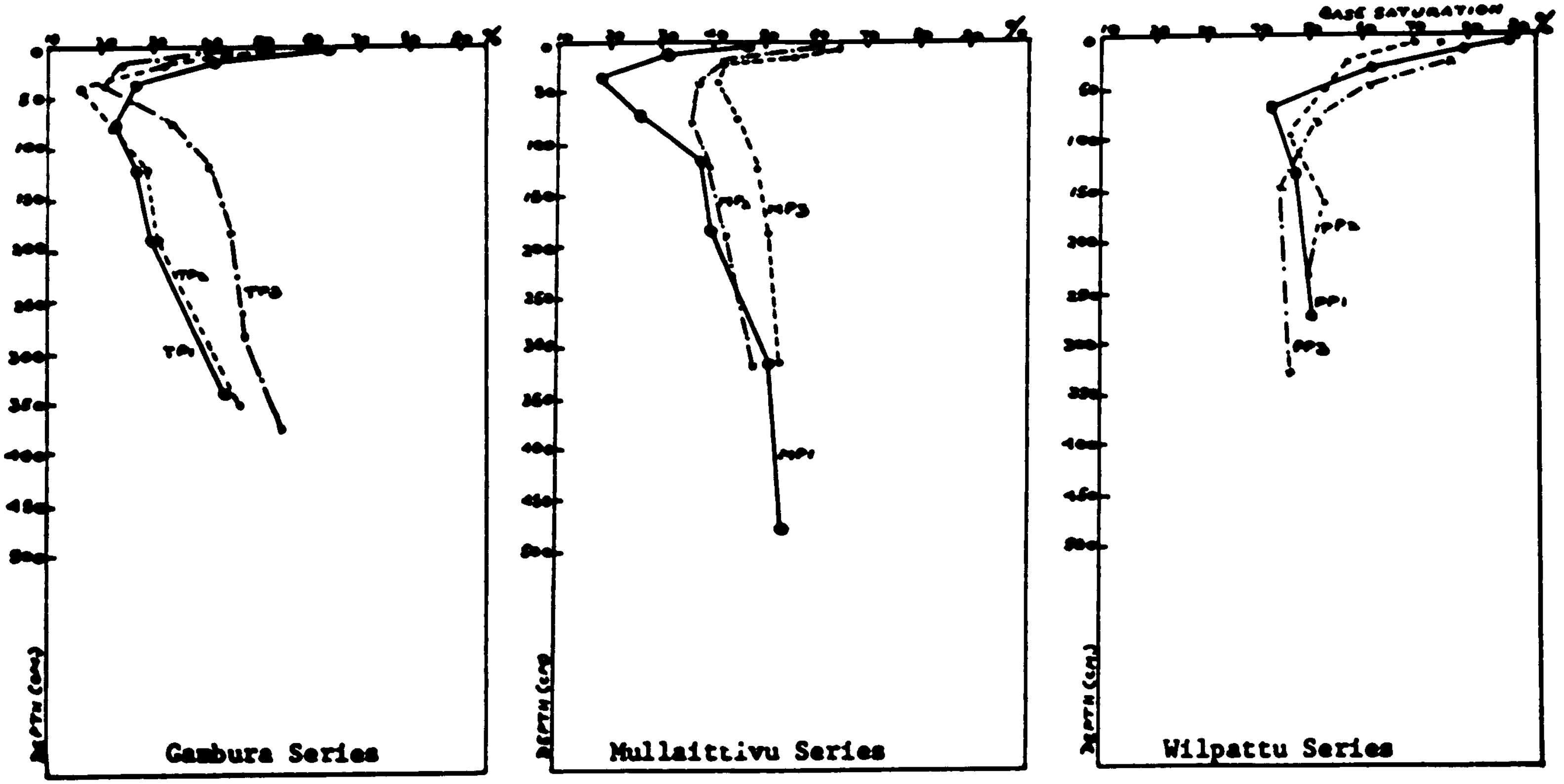


Figure 12. Variation of percent base saturation with depth in the Gambura, Mullaittivu and Wilpattu Series.

are more or less the inverse of the exchange acidity distributions. The Gambura soils tend to have the lowest values but they are not too different from those of the Mullaittivu Series. The Wilpattu soils show considerably higher base saturation percentages in the A and upper B horizons. In the lower horizons, (at a depth of about 350 cm.) all three soil series have similar values. The high values obtained for the base saturation of the upper horizons in the Wilpattu soils could conceivably result from the fact that, since these soils drain very rapidly and lose more of their water at low tensions than the Gambura and Mullaittivu soils, non-equilibrium leaching takes place and leaves the soil solution relatively more concentrated in basic cations (see also, the section on X-ray diffraction analysis).

5.40 Extractable Iron and Aluminium Oxides

Table 8. shows the percentages of iron and aluminium (expressed as oxides) extracted by Na-citrate-dithionite-bicarbonate and by acid ammonium oxalate from different horizons of the Gambura, Mullaittivu and Wilpattu Series.

The iron extracted by the dithionite treatment (Fe_2O_3d) has been widely considered to give a reasonable estimate of the pedogenic free iron oxides in soils while that extracted by the oxalate method (Fe_2O_3 o) represents the more or less amorphous forms of iron, the difference between the two being a measure of the crystalline iron oxides (Mehra and Jackson, 1960; McKeague and Day, 1966; Blume and Schwertmann, 1969; McKeague *et al*., 1971). From the extremely low values of oxalate extractable iron in the Red Latosols, it may be concluded that almost all the iron oxides in these soils are in crystalline form. Further, the small, nearly constant ratios of Fe_2O_3 o/Fe_2O_3d for all the samples suggest that even the insignificant amounts of iron oxide dissolved by the ammonium oxalate were crystalline. Similar amounts are dissolved by oxalate from standard hematite (McKeague and Day, 1966).

The depth distributions of the free iron oxide contents in the profiles of the three Red Latosol soils are illustrated in Fig. 13. They show a rapid increase in iron oxides with depth from the surface in the Gambura Series and somewhat more gradual increases in the other two series. The similarity between these distribution patterns and those of the total clay indicate that the iron oxides have participated rather passively in the general movement of colloids into the B horizons (Blume and Schwertmann, 1969). The Fe_2O_3d/clay ratios (Table 8), however,

Table 8. Extractable Iron and Aluminum of Selected Samples of < 2 mm. Soil

Profile & Horizon	Citrate-Dithionite		Amm. Oxalate		Fe_2O_3o	Fe_2O_3d	Fe_2O_3d
	$\%Fe_2O_3d^1$	$\%Al_2O_3d^1$	$\%Fe_2O_3o^3$	$\%Al_2O_3o^2$	Fe_2O_3d	Clay	c. Silt + Sand
TP_1 A_{11}	2.30	0.14	0.05	0.04	0.02	0.20	0.03
A_{12}	3.46	0.20	0.06	0.10	0.02	0.17	0.05
B_{21}	5.12	0.29	0.10	0.22	0.02	0.15	0.09
B_{22}	5.46	0.30	0.11	0.15	0.02	0.15	0.10
B_{23}	5.74	0.34	0.13	0.16	0.02	0.13	0.12
B_{24}	5.46	0.26	0.11	0.19	0.02	0.15	0.10
B_{25}	5.71	0.30	0.10	0.12	0.02	0.16	0.10
TP_2 A_{11}	2.78	0.22	0.04	0.18	0.01	0.19	0.03
B_{21}	4.32	0.22	0.09	0.21	0.02	0.16	0.06
B_{25}(u)	5.56	0.21	0.11	0.15	0.02	0.17	0.10
MP_1 A_{11}	0.92	0.16	0.04	0.19	0.04	0.11	0.01
A_{12}	1.44	0.13	0.05	0.20	0.03	0.11	0.02
B_{21}	2.02	0.20	0.04	0.23	0.02	0.09	0.03
B_{22}	2.46	0.22	ND	ND	ND	0.09	0.04
B_{23}	2.82	0.20	0.06	0.22	0.02	0.09	0.04
B_{24}	2.72	0.21	0.07	0.20	0.03	0.09	0.04
B_{25}(u)	2.96	0.23	0.07	0.26	0.02	0.09	0.05
B_{25}(l)	3.06	0.20	0.04	0.26	0.01	0.10	0.05
MP_2 A_{11}	1.09	0.10	0.03	0.31	0.03	0.11	0.01
A_{12}	1.44	0.13	0.05	0.28	0.03	0.09	0.02
B_{24}	2.70	0.17	0.08	0.47	0.03	0.08	0.04
PP_2 A_{11}	1.16	0.06	ND	ND	ND	0.15	0.01
A_{12}	1.59	0.08	0.05	0.21	0.03	0.14	0.02
B_{21}	2.14	0.08	0.05	0.23	0.02	0.13	0.03
B_{22}	2.34	0.09	0.06	0.20	0.03	0.13	0.03
B_{23}	2.84	0.11	0.08	0.32	0.03	0.11	0.04
B_{24}	2.97	0.20	0.06	0.37	0.02	0.11	0.04
PP_3 A_{11}	1.04	0.06	0.03	0.18	0.03	0.14	0.01
B_{21}	1.44	0.08	0.04	0.24	0.03	0.14	0.02
B_{24}	2.50	0.11	0.06	0.26	0.02	0.12	0.03

1. Determined in duplicate or triplicate.
2. Half the samples determined in duplicate.
3. One third of the samples determined in duplicate.

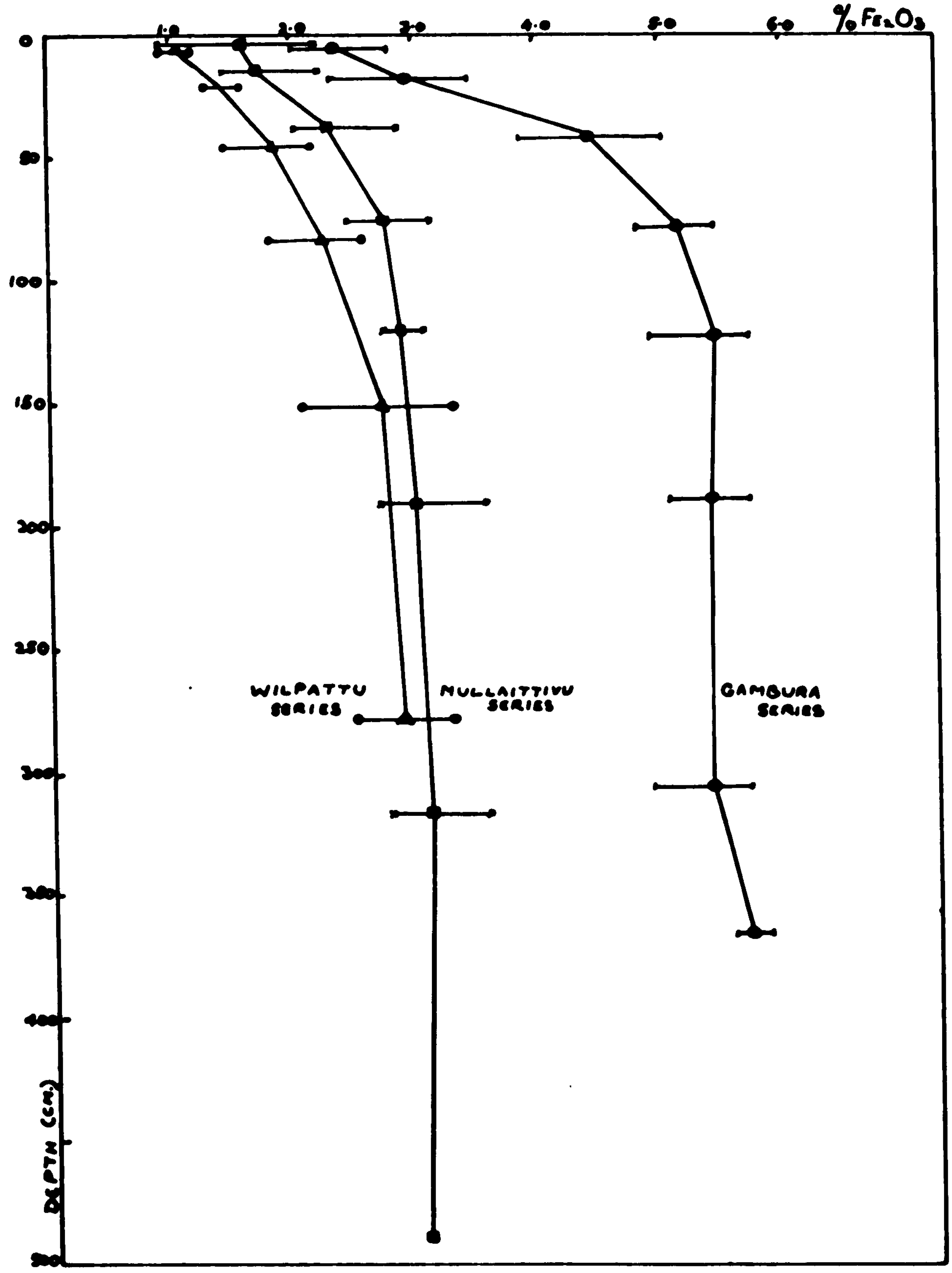


Figure 13. Mean depth distributions of Na-citrate-dithionite extractable iron oxides in the Gambura, Mullaittivu and Wilpattu Series.

have slightly higher values near the surface and lower values in the middle and lower B horizons suggesting that the migration of clay has been mildly preferred over that of the iron oxides. Examination of the Fe_2O_3d/c. Silt + sand values in the same table confirms the movement of the iron oxides (since the sand + c. silt is weathered to a fairly uniform resistant suite of minerals in all the horizons) and shows that their concentration reaches a diffuse maximum in the lower B horizons of the Gambura and Mullaittivu soils but does not reach such a maximum within the depth of sampling in the Wilpattu Series. The slight increase in iron oxides in the lowest Gambura Series horizons may be due to a minor discontinuity in the parent material or some kind of secondary accumulation, but deeper sampling and more detailed study will be required to ascertain the exact cause.

So far nothing has been said about the actual mechanism by which the iron has moved although in the above comparison with clay movement it was implied that it occurred by physical translocation of particles of iron oxide. More support for this mechanism is forthcoming from studies of the iron oxide contents in the different size fractions of the soils (Table 9.). These and the calculated particle size distributions of the iron oxides in the different horizons show a trend typical of illuviation by suspension with the finer particles increasing in the lower horizons. Soluviation or cheluviation by organic compounds should have caused a growth of the larger particles rather than forming new small ones in the lower horizons since the most effective site for precipitation is a crystal

Table 9. Percent Fe_2O_3d in Each Fraction and Calculated Particle Size Distributions of Iron Oxide of Selected Samples[1]

Profile and		% Fe_2O_3d in Fraction[1]				Approx. P.S.D. of Iron Oxides in % of Total Iron Oxides in ≤ 2 mm. Soil				
		Fine Clay	Coarse Clay	Fine Silt	Sand + c.Silt	<0.1μ	0.1-1.1μ	1.1-11.1μ	>11.1μ	$\frac{<0.1\mu}{0.1\text{-}1.1\mu}$
TP_1	A_{11}	8.6	10.3	6.9	0.2	47	37	6	10	1.3
	B_{21}	8.8	8.9	5.2	0.2	69	26	2	3	2.7
	B_{24}	10.0	8.8	4.0	0.1	66	30	3	1	2.2
MP_1	A_{11}	6.0	6.6	3.9	0.1	53	30	6	11	1.8
	B_{21}	6.0	6.6	3.9	0.1	64	28	3	5	2.3
	B_{25}(u)	6.2	6.5	4.4	0.1	58	35	4	3	1.7
PP_2	A_{11}	7.4	9.4	4.3	0.1	48	36	4	12	1.3
	B_{21}	7.7	8.1	4.5	0.1	69	23	3	5	3.0
	B_{24}	8.6	8.0	4.6	0.1	72	24	2	2	3.0

1. Dispersion by sodium saturation with NaCl and repeated washing.

of the substance to be precipitated (Fischer, 1961). Although it thus seems probable that movement in suspension is the dominant process, cheluviation does undoubtedly account for a part of the iron lost from the surface horizons. Another pathway by which iron could have been transported down the profile is by adsorption on, and subsequent movement with clay particles. When hydrous iron oxides are freshly precipitated they have iso-electric points above pH7 (Parks, 1965) and will be positively charged in soils with lower pH values. At an early stage of weathering, they may thus have adsorbed on to negatively charged clay surfaces and moved downwards with the clays. As the iron oxides aged, their iso-electric points dropped to low levels and they became negatively charged and consequently desorbed. It is conceivable that a new phase of discrete iron oxide particles could have then separated out. Although this mechanism seems highly speculative and there is no present evidence for or against it, it does explain the similarity between the clay and iron oxide distributions with depth and the close range of Fe_2O_3 d/clay values. However, even if it prevailed at an early stage, this mechanism is no longer operative as (1) the iron oxides are highly crystalline with very low iso-electric points and (2) the clay surfaces show no obvious signs of iron oxide coatings under the electron microscope.

Unless they were deposited as pre-weathered materials the iron oxides present in the lowermost horizons of each soil are a rough guide to the relative ferromagnesian silicate contents of the parent materials. In any case, the high degree of crystallinity and the virtual absence of amorphous forms in the iron oxides indicate that they have long since ceased forming and are presently not very active constituents of the soil (Gorbunov *et al.*, 1961).

While iron oxides influence numerous properties of soils like aggregation, exchange properties, phosphate fixing ability etc., the amorphous forms are far more active in this regard (Mitchell *et al.*, 1964). Being almost exclusively crystalline and present largely as discrete particles, the iron oxides of the Red Latosols are fairly inert and their most outstanding influence is on soil colour. Even relatively small percentages (1-2 percent for instance) of iron oxides present in some horizons are able to impart a strikingly deep red colour to them. Visual examination of the different size separates showed that the fine clay fraction had the most intense colours even though they did not contain much more iron oxide than the corresponding coarse clays. In this context, it is not surprising that the Wilpattu soils seem to have the highest $0.1\mu/(0.1-11)\mu$ ratios for the iron oxides in the B horizons and also the reddest hues.

The extractable aluminium did not show any consistent pattern in the Red Latosols. Citrate-dithionite extracted more free alumina than the oxalate in the Gambura samples, less than the oxalate in the Wilpattu samples and comparable amounts in one of the Mullaittivu profiles. In general, the quantities of free alumina extracted by both methods are quite low although probably sufficient to markedly influence the physical properties of these soils (Deshpande *et al.*, 1968). The aluminium oxides increase from the A to the B horizons in nearly all the profiles but show a subsequent decrease in some. It is possible that the Wilpattu soils have significantly higher proportions of amorphous aluminium oxides than the other soils as oxalate extracted much more Al_2O_3 than dithionite from the former (McKeague and Day, 1966).

5.41 X-Ray Diffraction Analysis

The coarse (2.0 - 0.2μ) and fine (<0.2μ) clay fractions of selected samples were subjected to X-ray diffraction analysis and some representative patterns are shown in Figs. 14 to 22. Table 10 summarizes the minerals present and gives a rough idea of their relative abundance in each fraction.

The analyses involved several pre-treatments of the clays. Organic matter was destroyed with hydrogen peroxide. Free iron oxides were removed by two successive Na-citrate-dithionite-bicarbonate extractions prior to the other treatments, but control samples in which they had not been removed were also used. The samples were then selectively subjected to (1) Mg - saturation and air-drying, (2) Mg - saturation and glycol solvation, (3) Mg - saturation and glycerol solvation, (4) K - saturation and air-drying and (5) K - saturation and heating to 550° C. Oriented slides were used throughout.

The diffraction patterns of all the fine clays show that they consist almost exclusively of well-crystallized kaolinite. Analysis of samples in which the iron oxides had not been removed indicated, however, that some hematite is also present. The equally low background and similar peak definition and intensities of kaolinite in the samples with and without iron oxides removed indicate that most of the iron oxides are in a crystalline state and that the effect of the Na-citrate-dithionite-bicarbonate treatments on the kaolinite diffraction peaks is negligible. As will be shown in a later section, small amounts of amorphous materials are also present in these clays.

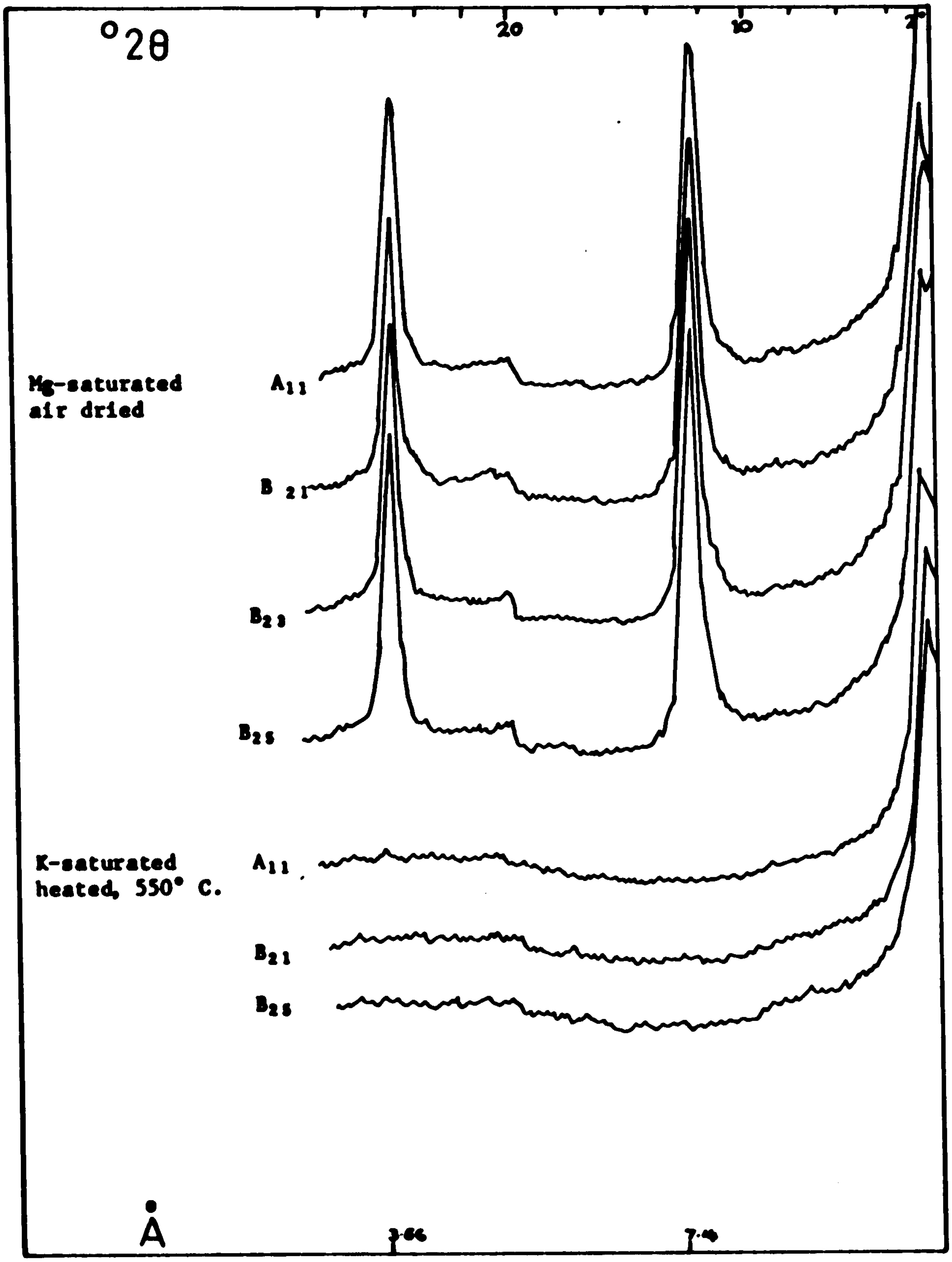


Figure 14. X-ray diffraction patterns of some fine (<0.2μ) clay samples from different horizons of Profile TP₁.

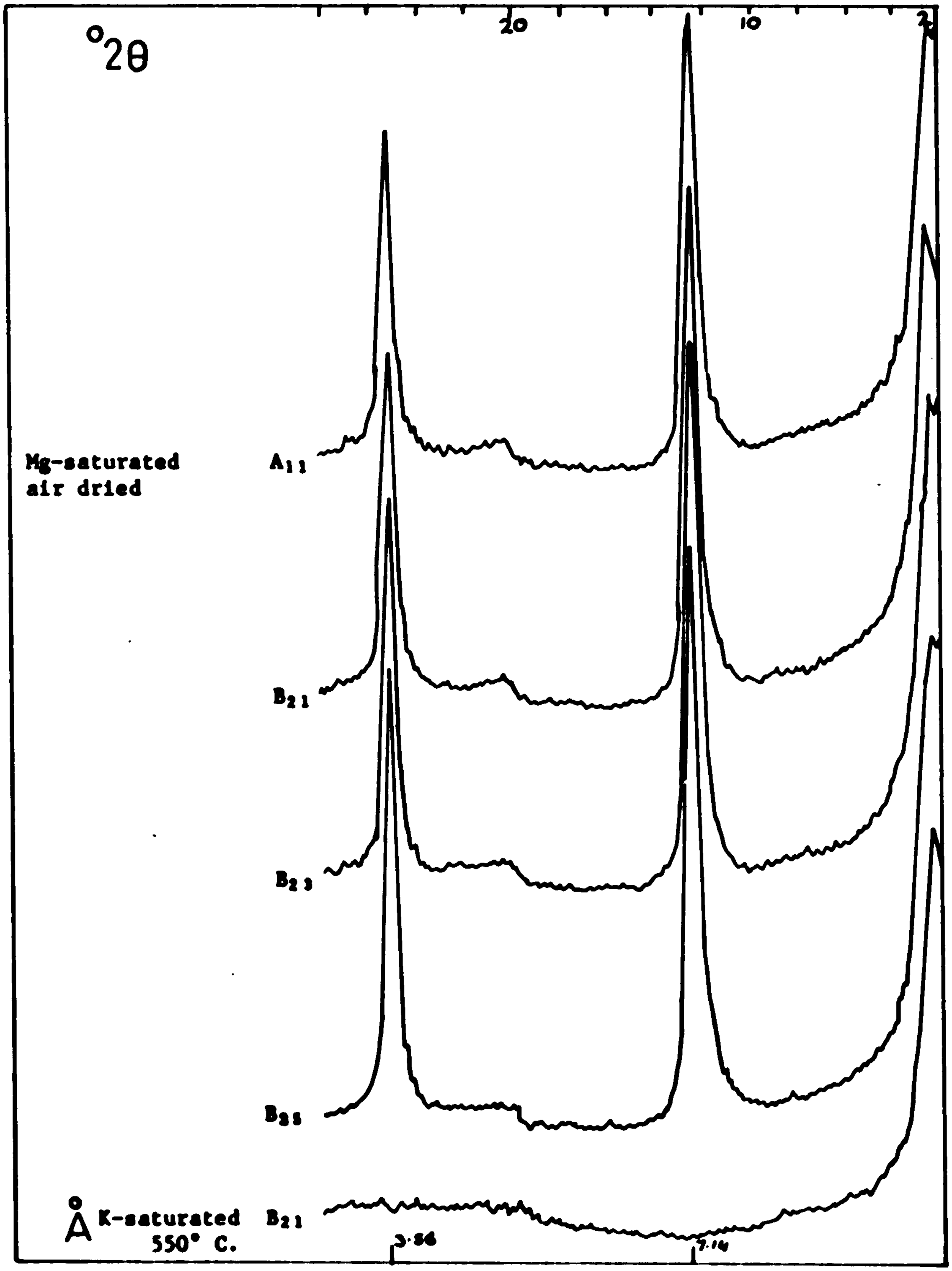


Figure 15. X-ray diffraction patterns of some fine (<0.2 μ) clay samples from different horizons of Profile MP₁.

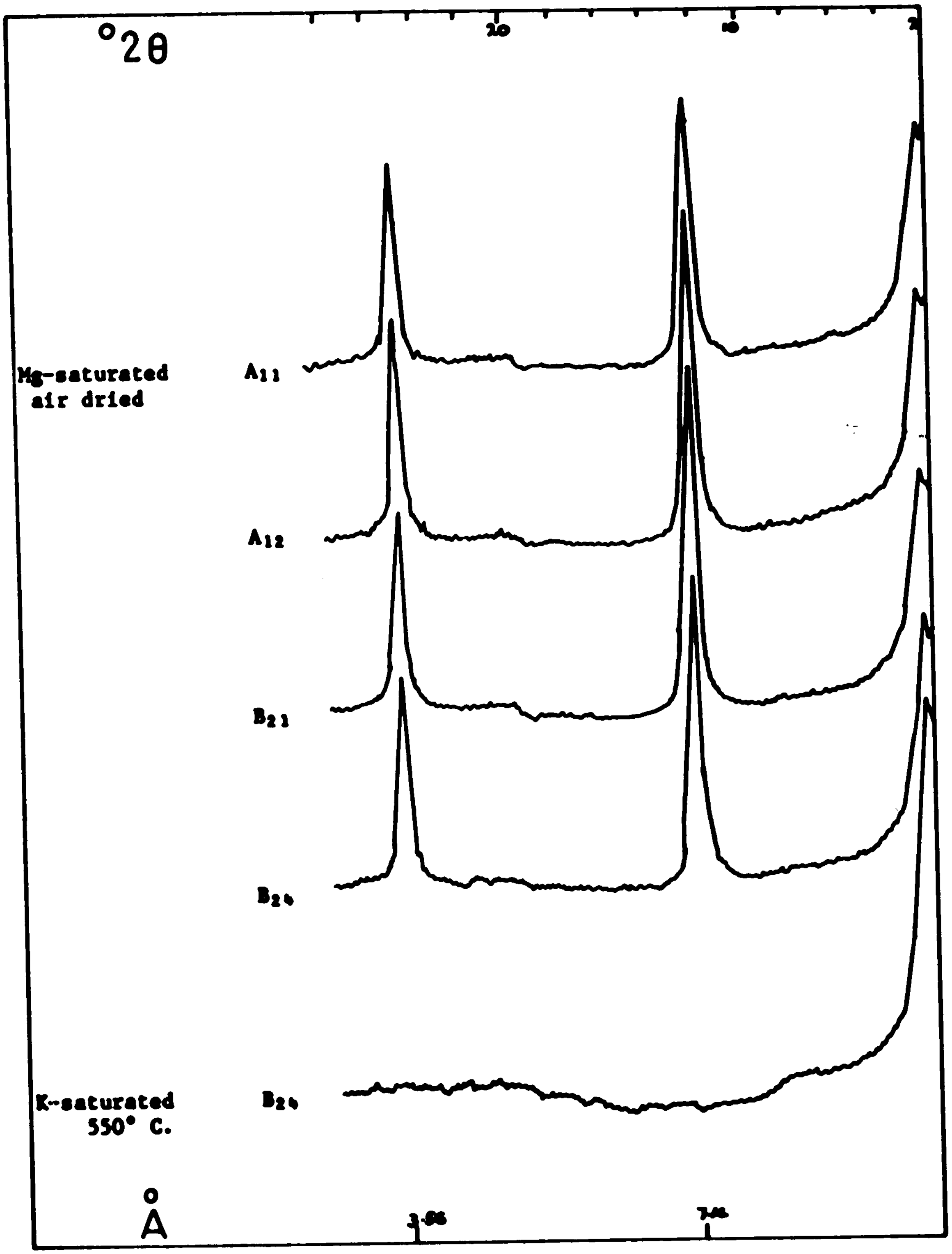


Figure 16. X-ray diffraction patterns of some fine (<0.2μ) clay samples from different horizons of Profile PP_2.

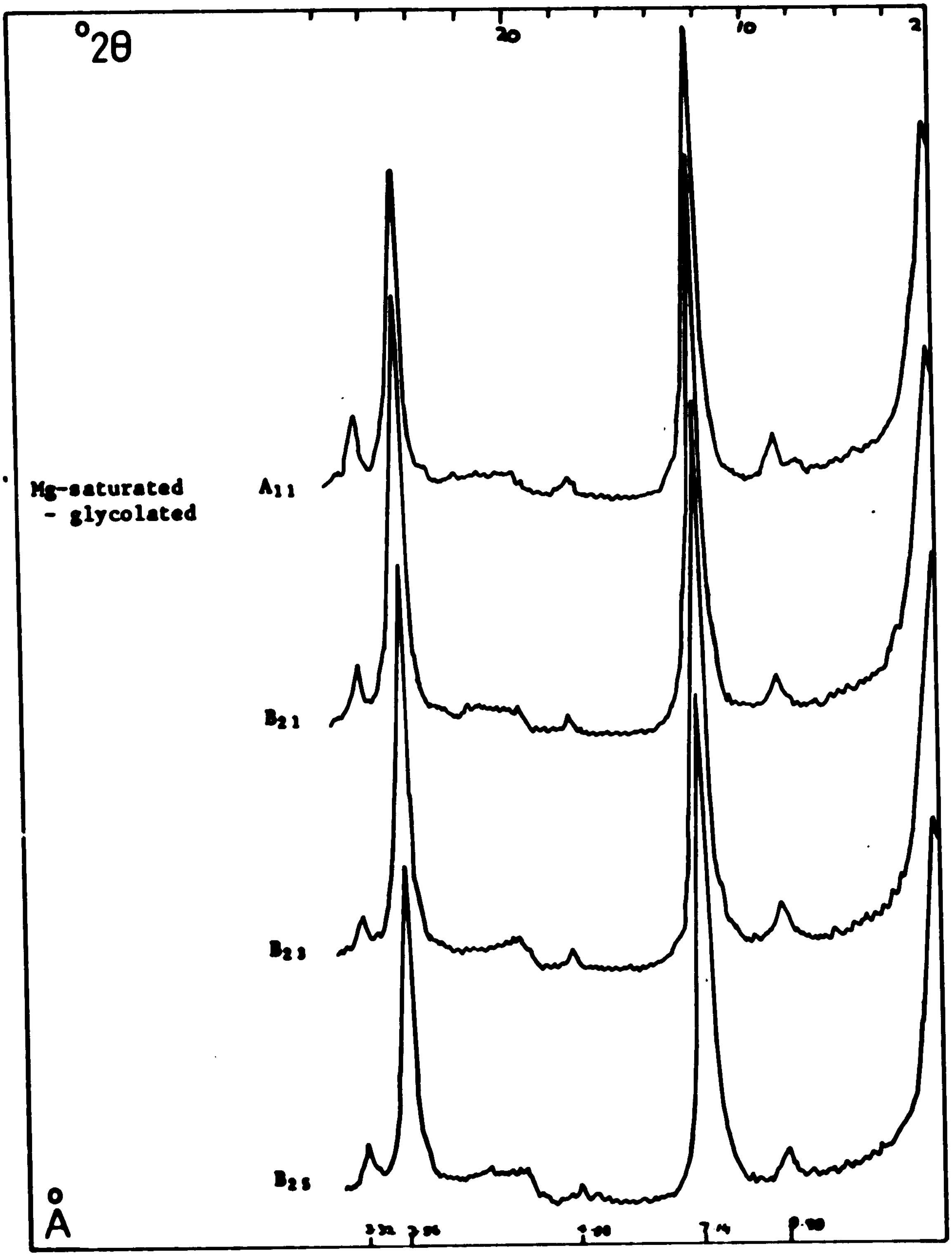


Figure 17. X-ray diffraction patterns of some coarse (2-0.2μ) fractions from different horizons of Profile TP_1 - glycolated.

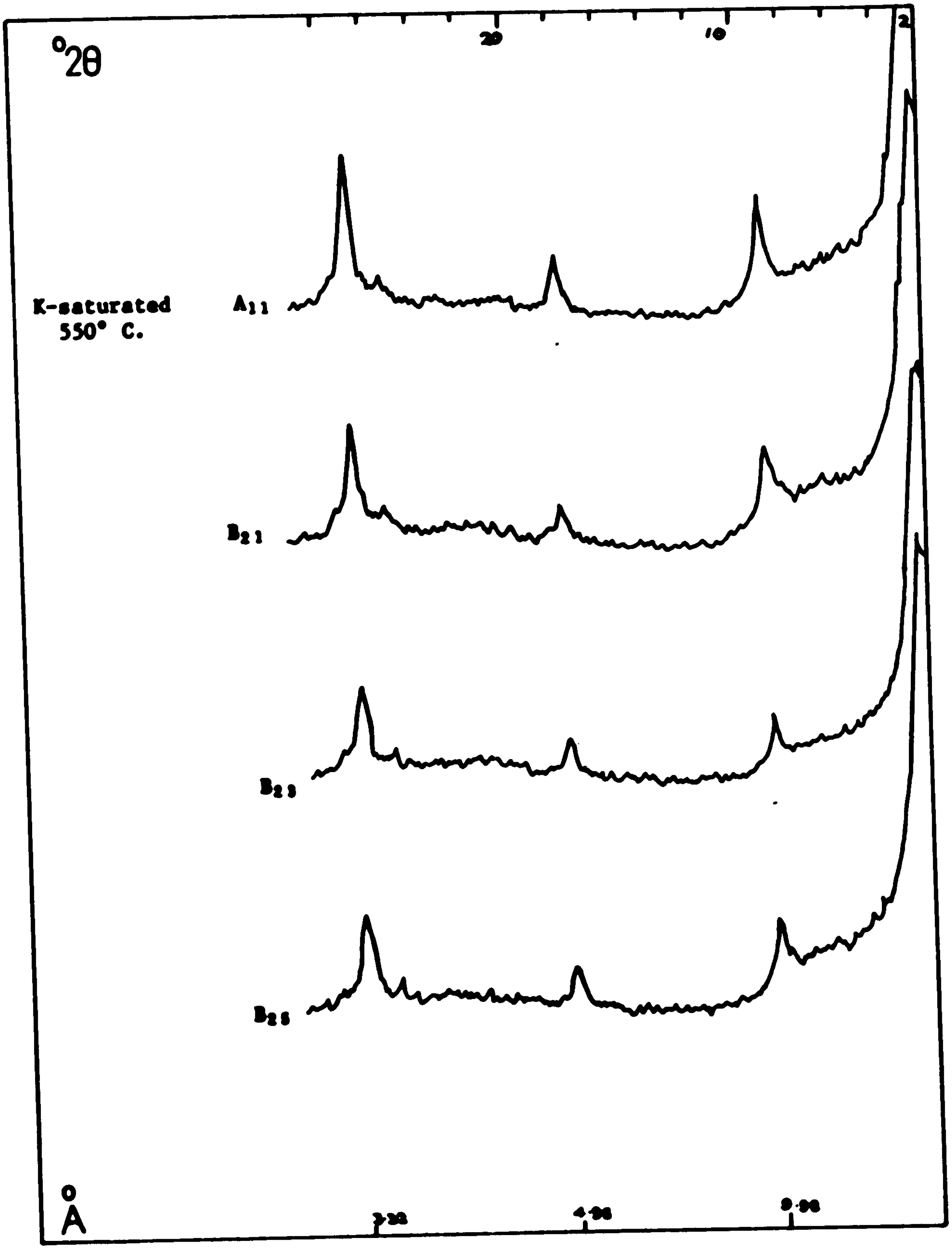


Figure 18. X-ray diffraction patterns of some coarse (2-0.2μ) fractions from different horizons of Profile TP_1 - heated.

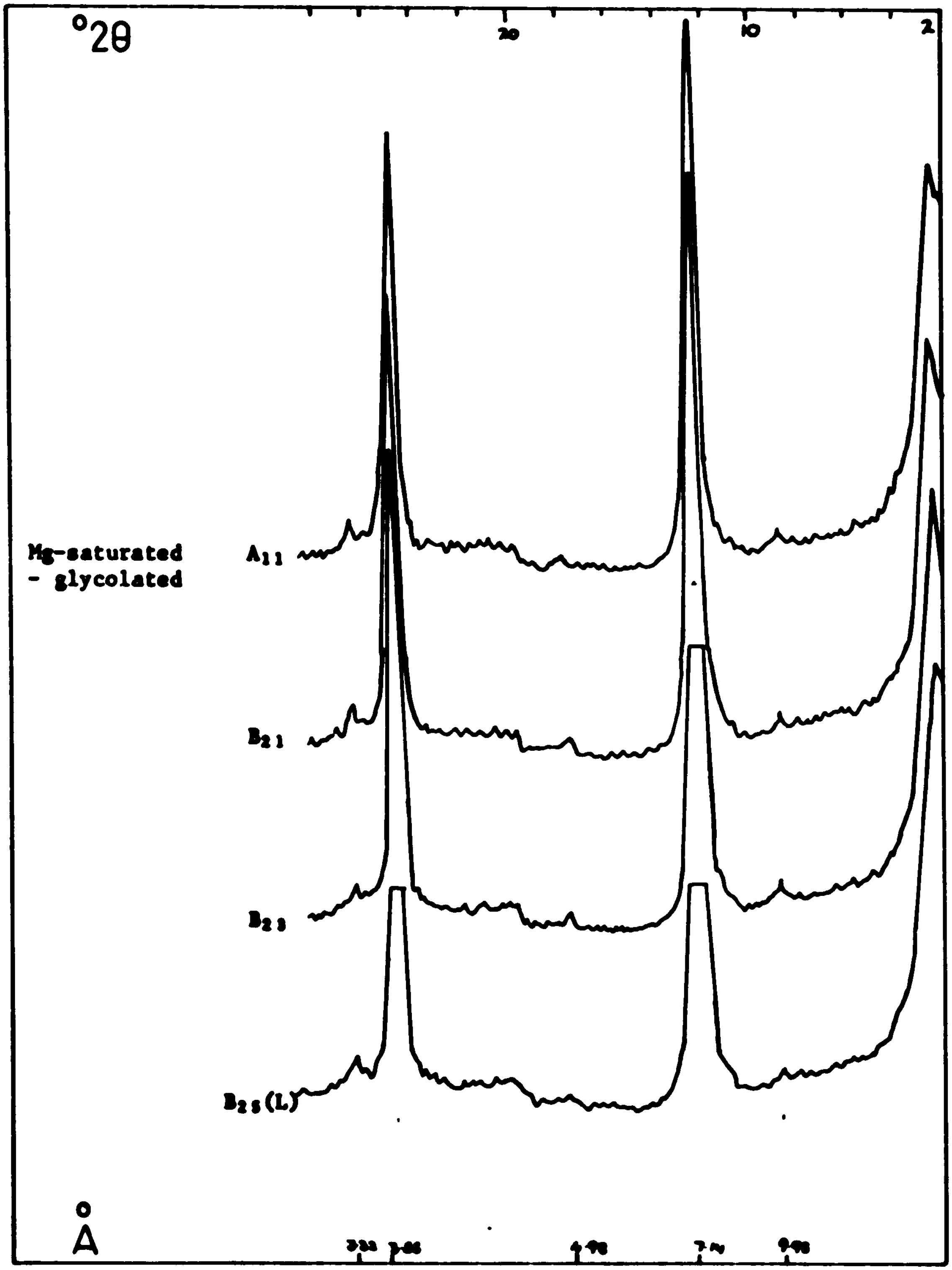


Figure 19. X-ray diffraction patterns of some coarse (2-0.2μ) samples from different horizons of profile MP_1 - glycolated.

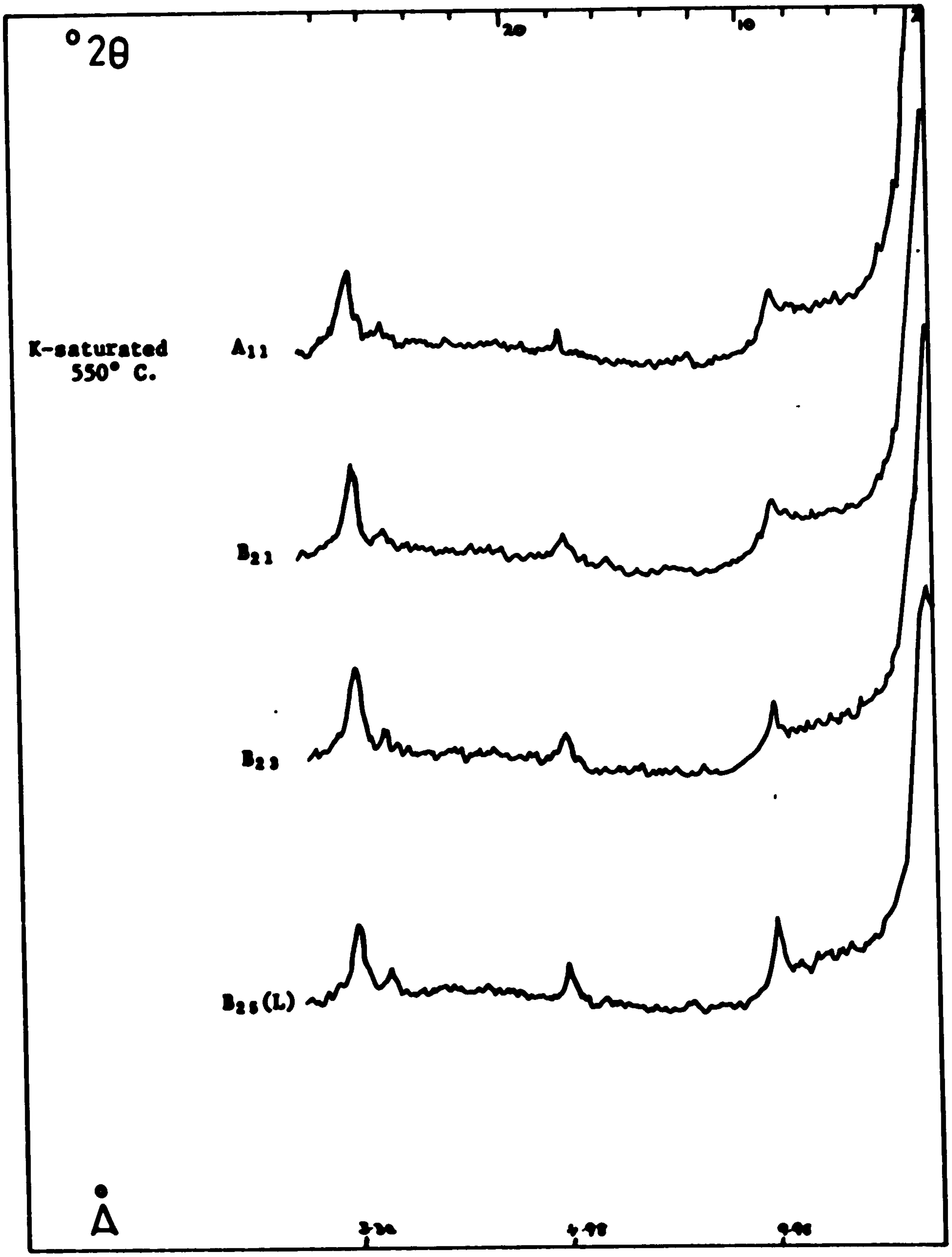


Figure 20. X-ray diffraction patterns of some coarse clay samples from different horizons of Profile MP_1 - heated.

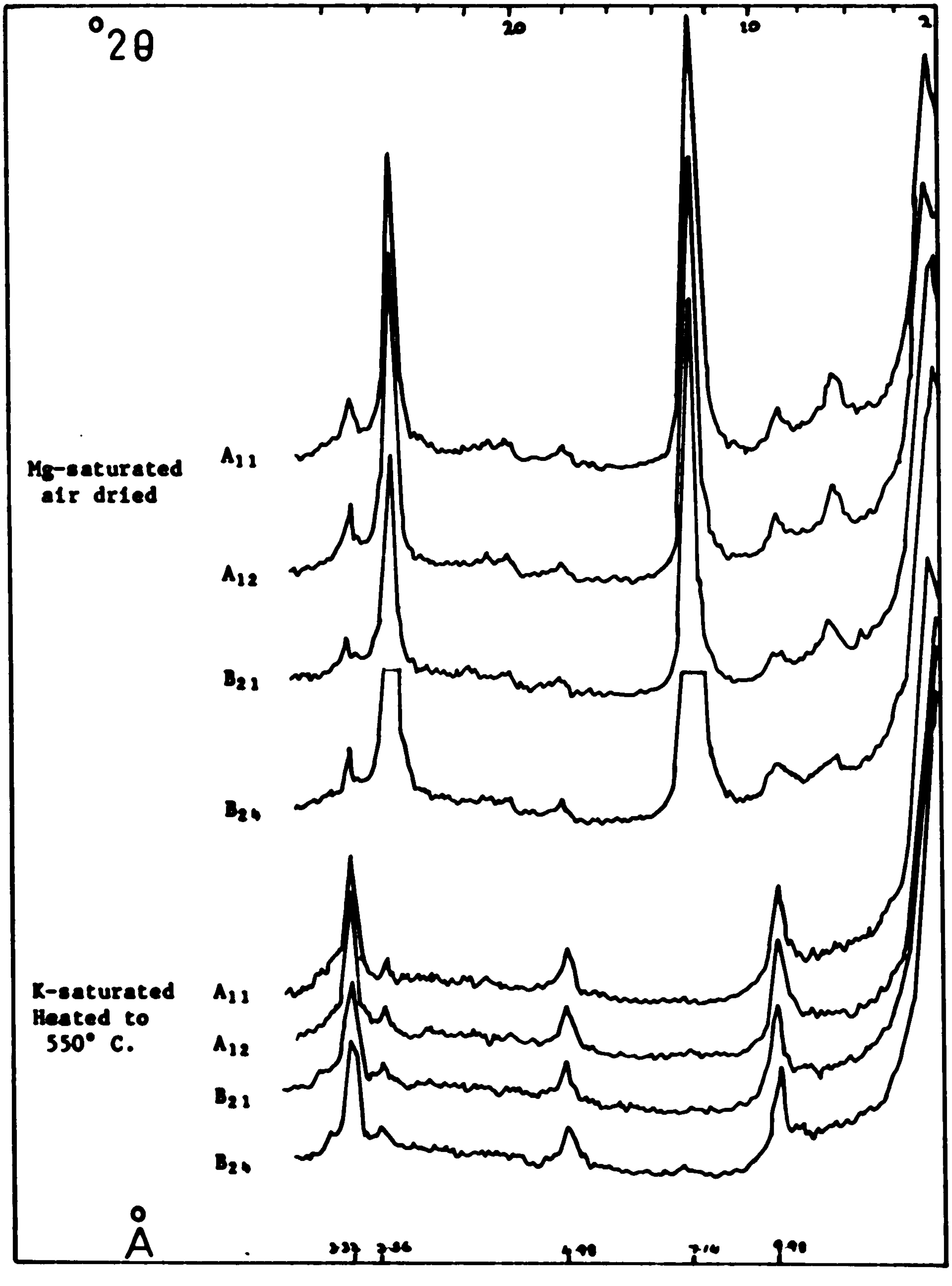


Figure 21. X-ray diffraction patterns of some coarse (2-0.2μ) clay samples from different horizons of Profile PP_2.

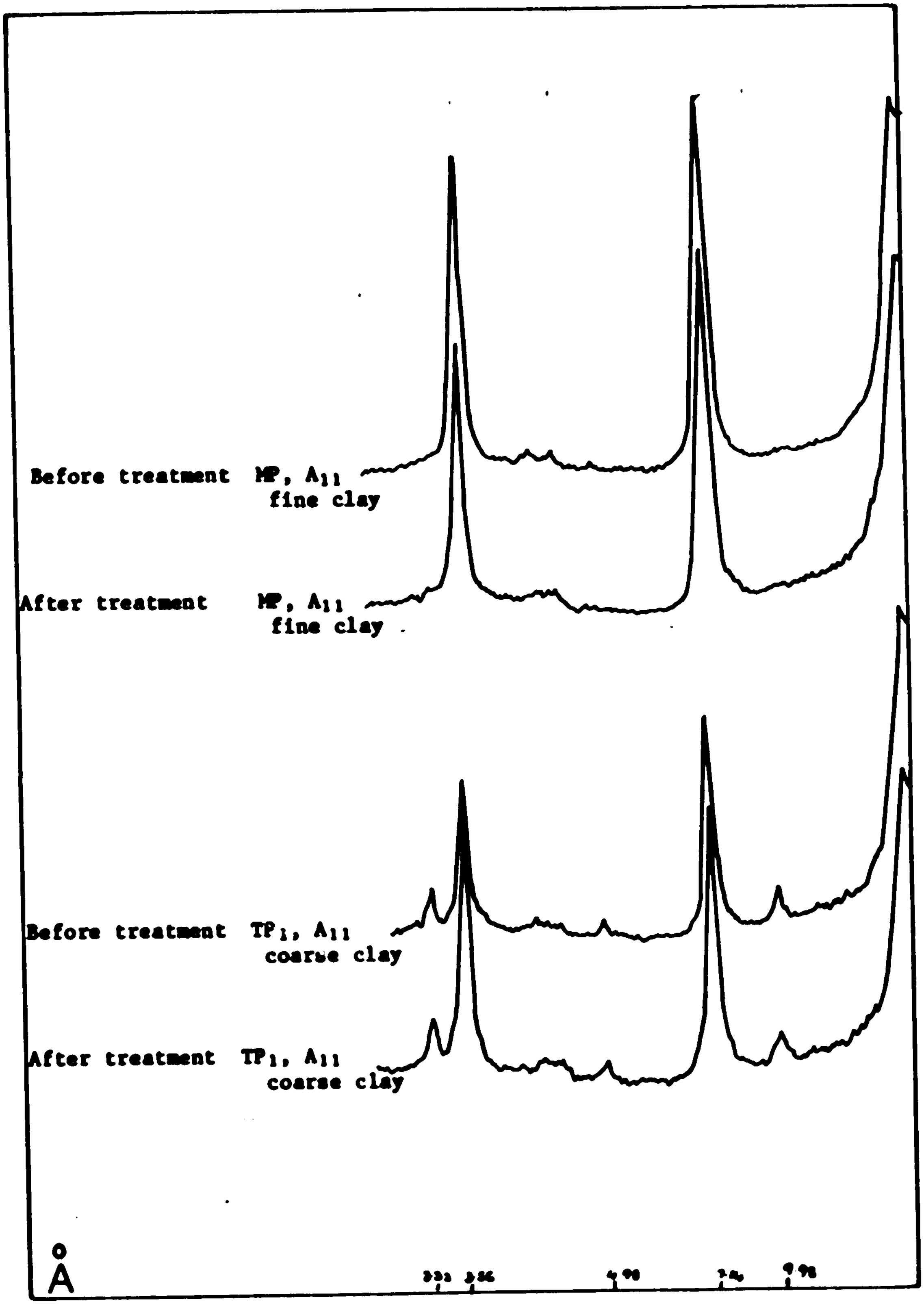


Figure 22. Effects of Na-citrate - dithionite-bicarbonate treatment on the X-ray diffraction patterns of a fine and a coarse clay.

Table 10. Mineral Estimates From X-ray Diffraction of Selected Fine and Coarse Clay Samples

Profile & Horizon		Size Fraction (µ)	Kaolinite	Mica	Vermiculite-Smectite	Mixed Layer	Anatase	Hematite
TP$_1$	A_{11}	< 0.2	+ + + +					+
		0.2-2	+ + +	+		+	Tr	+
	B_{21}	< 0.2	+ + + +					+
		0.2-2	+ + +	+		+	Tr	+
	B_{23}	< 0.2	+ + + +					+
		0.2-2	+ + +	+		+	Tr	+
MP$_1$	A_{11}	< 0.2	+ + + +					+
		0.2-2	+ + +	+		+	Tr	+
	B_{21}	< 0.2	+ + + +					+
		0.2-2	+ + +	+		+	Tr	+
	B_{23}(L)	< 0.2	+ + + +					+
		0.2-2	+ + +	+		+	Tr	+
PP$_2$	A_{11}	< 0.2	+ + + +					+
		0.2-2	+ + +	+	+	+	Tr	+
	B_{21}	< 0.2	+ + + +					+
		0.2-2	+ + +	+	+	+	Tr	+
	B_{24}	< 0.2	+ + + +					+
		0.2-2	+ + +	+	+	+	Tr	+

+ + + + = 75 - 100%
+ + + = 50 - 75%
+ + = 25 - 50%
+ = 10 - 25%
Tr. = Trace (< 10%)

The most striking feature of the X-ray patterns is the great similarity in composition of the fine clays of all three soil series. This probably reflects the inability of other clay minerals to persist in this size range under the conditions that prevailed during soil formation. There is considerable uniformity within each profile too, the only detectable change that occurs with depth being a slight intensification of the kandite peaks. This could be attributed to (a) smaller amounts of amorphous materials in the lower horizons (see section on chemical analysis of the clays) and (b) probable better crystallinity of the kaolinite with depth (see section on electron microscopy). Potassium saturation followed by heating to 550° C. caused destruction of the kaolinite peaks and confirmed the absence of any other clay mineral.

The coarse clays too are dominated by kaolinite but they also contain minor amounts of other minerals. In the Gambura and Mullaittivu Series, these are mica, mixed layer minerals, anatase and possibly some interstratified materials, the last two being present only as traces. In addition to this suite, the Wilpattu coarse clays also contain what is probably a vermiculite-smectite intergrade.

The kaolinite is well crystallized (in the X-ray sense) and generally shows a slight increase in peak intensity with depth, probably due to slight decreases in the other constituents and increasing crystallinity. The mica peaks, although relatively small, have fairly sharp apices. They also have shoulders on the low angle side suggesting that weathering is taking place to vermiculitic components and this is confirmed by intensification of the mica peaks on K - saturation.

The mica peaks show some slight attenuation and/or broadening with depth implying greater weathering in the lower horizons. The reasons for this will be discussed in the section dealing with quantitative analysis of the major constituents of the clays. The vermiculite-smectite intergrade in the Wilpattu clay was identified on the basis of (1) a 14A spacing in the Mg - saturated air-dried sample, (2) expansion to give a diffuse peak between 14.5A and 18A (max. 16A) on glycolation and 14.7 and 19.2A (max. 17A) on glycerol-solvation and (3) loss of the peak on K - saturation and heating to 550° C. The mixed layer minerals occurring in all the samples were so designated because they showed a series of small peaks between 10A and 18A which on heating to 550° C. formed a plateau with some enhancement of the 10A peak. Small peaks occurring at higher spacings than 18A are interpreted as being due to weak reflections of randomly interstratified minerals.

The occurrence of mica in the coarse but not in the fine fractions of all the soils is significant in that it implies formation by weathering rather than pedosynthesis from simpler constituents. In the Wilpattu Series, the vermiculite-smectite intergrade also occurs in the coarse clay fraction only and, like mica, shows a slight decrease with depth suggesting that it is an intermediate in the weathering of mica, since weathering differences down the profiles are slight. The mixed layer minerals are probably formed from such expanded weathering intermediates of mica, by intercalation with hydroxy alumina (and possibly hydroxy iron) interlayers. This explanation is consistent with the very low contents of free alumina and absence of gibbsite in these soils (the anti-gibbsite effect) (Jackson,1963). Feldspars are absent in the coarse clay fraction and if quartz is present, it exists only in trace amounts as it does not give a 4.26A peak. Its 3.34A peak could, if present, be obscured by the much stronger third order reflection of mica. Although only minute quantities of anatase were detected in all the samples of coarse clay, its presence could be important in inhibiting the growth of kaolinite crystals (Bundy, Johns and Murray, 1966).

The occurrence of a well defined peak at 14A representing the vermiculite-smectite intergrade only in the Wilpattu soil needs some explanation since all three soils have been formed under roughly similar climates. One possibility at least is that, since the Wilpattu soils drain much faster (at lower tensions) than the other two series and less water is held at higher tensions, not only is the leaching less efficient but the soil solution itself tends to get more concentrated as it dries out resulting in a weathering environment more concentrated in divalent cations like Ca^{++} and Mg^{++}. This, along with the resulting higher base saturation and pH of these soils, would have been conducive to the formation and preservation of 2:1 expanding layer silicates (Keller, 1964). Thus with greater amounts of vermiculite-smectite present in this soil, interlayering by the limited quantities of hydroxy alumina could still have left some expanding clays unaffected.

X-ray diffraction analysis of the fine silts showed them to be composed predominantly of quartz with minor quantities of kaolinite, mica and mixed layer material. The quartz was lowest in the lowermost horizon in the Gambura and Mullaittivu soils but showed no trend in the Wilpattu profile. Mica shows no trend in any of the soils. Small amounts of rutile, zircon, ilmenite and anatase also appear to be present,

5.42 Differential Thermal Analysis

Differential thermal analysis was carried out on selected fine and coarse clay samples with and without the removal of iron oxides by Na-citrate-dithionite-bicarbonate treatment. Some representative patterns are shown in Fig. 23.

Both fine and coarse clays revealed only kaolinite which had endothermic peaks in the region 590 - 600° C. and exothermic peaks at 950 - 975° C. The peaks were quite sharp and peak temperatures tended to increase by a few degrees with depth. Diffuse endothermic peaks in the region of 120° C. occurred for some samples and are attributed to physically adsorbed water because they were absent in samples that were stored in a $CaCl_2$ desiccator for long periods.

The slope ratios varied between 2.3 and 3.2 in the fine clays but were lower (1.8 - 2.3) in the coarse clay fractions. The occurrence of higher slope ratios with finer particle sizes has been noted by other workers (Holdridge and Vaughan, 1957), but the fairly high values in the coarse fraction are rather surprising because such high values have been attributed to poor crystallinity (Carthew, 1955). In the author's opinion, the fairly high slope ratios in the coarse clays of the Red Latosols may have resulted from one of two causes. Either the so-called coarse (2.0 - 0.2μ) clays are present predominantly in the lower end of the size-range (which would not be unexpected since the fine silt values are extremely low and the fine clay values quite high) and consequently tend to give higher slope ratios, or the high ratios could result from the characteristics of the specimen holder (Mackenzie, 1954).

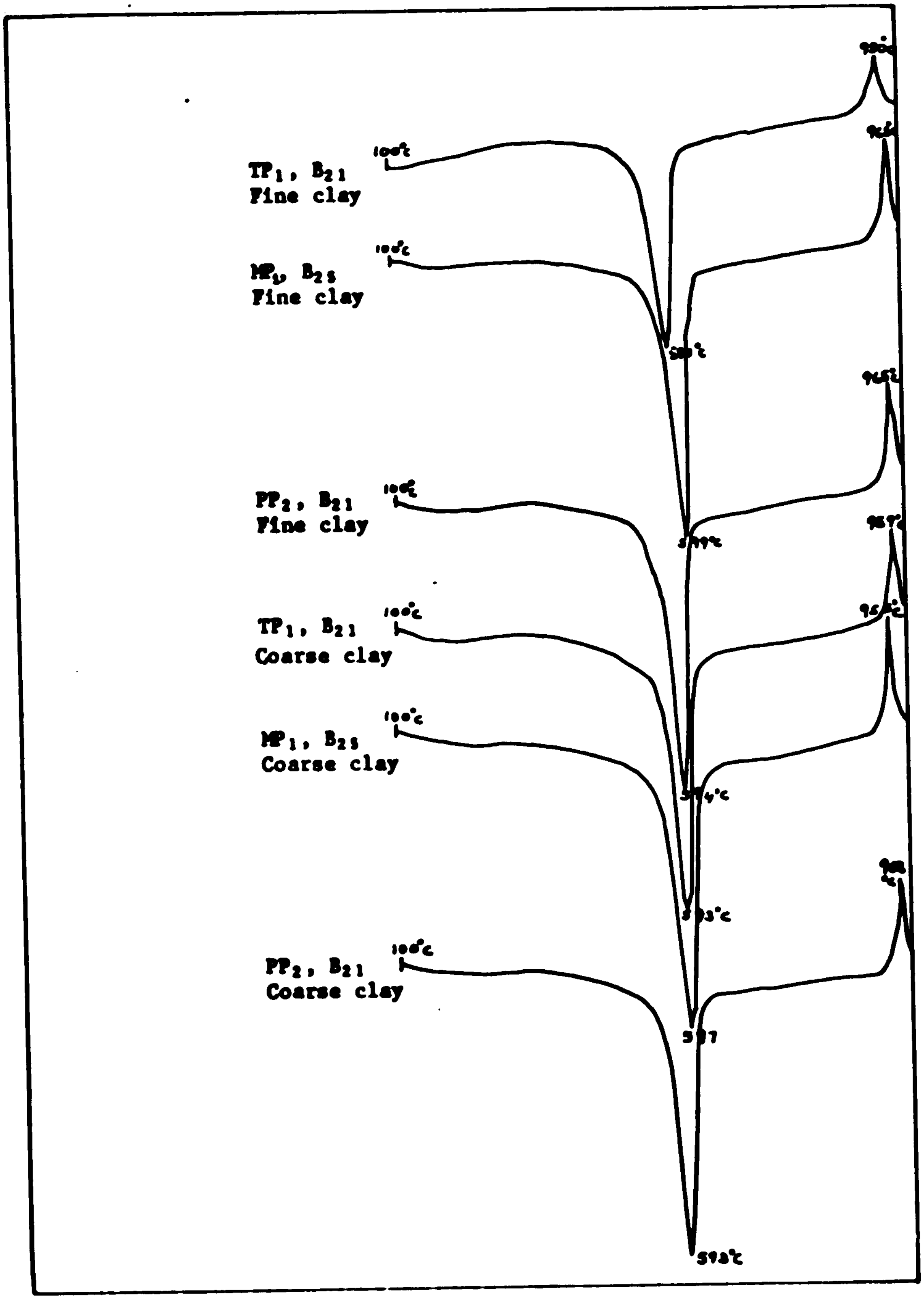


Figure 23. Differential thermal curves of some representative clays from the Gambura, Mullaittivu and Wilpattu Series.

Samples of clay from which the iron oxides had not been removed and of ground whole soil failed to give any peaks up to 500° C. suggesting that the iron is present mainly as hematite since all other free crystalline oxides of iron give characteristic differential thermal curves in this range (Mackenzie, 1957). Further, gibbsite, for which d.t.a. is very sensitive, is not present in detectable amounts.

5.43 Quantitative Chemical Analysis of the Major Constituents of Some Fine and Coarse Clay Fractions

Analysis by chemical methods served to quantify some of the information regarding the composition of the clay fractions already obtained by X-ray diffraction and differential thermal methods. These analyses were carried out on fine and coarse clays of selected samples from which the free iron oxides had previously been removed by two successive citrate-dithionite-bicarbonate treatments.

Amorphous Materials

The results of the NaOH - dissolution analysis for amorphous materials are shown in Tables 11 and 12. The percentages of amorphous materials in the fine fractions follow the order Mullaittivu Series > Wilpattu Series > Gambura Series. The higher values in the A_{11} and B_{21} horizons appear to reflect minor breakdown of clay due to the greater weathering intensities near the surface. Some eluviation of the amorphous components may have taken place from the A_{11} into the A_{12} and B_{21} horizons. The amorphous contents of the coarse clay fractions show somewhat similar trends but the Mullaittivu and Wilpattu soils have nearly equal values probably because the figures for the latter are exaggerated by the solution of a clay component (see below).

The molar SiO_2/Al_2O_3 ratios are all nearly constant and in the range 2.0 to 2.8 in the fine clay amorphous fractions suggesting that the "amorphous" component dissolved is present as sub-crystalline clay-like or clay relic materials (Jackson, 1965) rather than as free oxides or hydrous oxides. The SiO_2/Al_2O_3 values in the coarse clay amorphous fractions of the Gambura and Mullaittivu soils are close to

Table 11. NaOH - Selective Dissolution Analysis for Amorphous Materials in Fine Clay ($<0.2\mu$) Fractions of Selected Samples.

Profile and Horizon		Depth (cm.)	%SiO_2	%Al_2O_3	$\frac{SiO_2}{Al_2O_3}$[1]	% Amorphous[2]	%Fe_2O_3[3]
TP_1	A_{11}	2-10	2.8	1.8	2.6	5.1	0.6
	A_{12}	15-22	3.2	2.3	2.4	6.1	0.4
	B_{21}	30-50	2.9	1.8	2.7	5.2	0.5
	B_{23}	110-135	2.3	1.4	2.8	4.1	0.7
	B_{25}	335-345	2.4	1.5	2.7	4.3	1.3
TP_2	A_{11}	2-10	2.4	1.8	2.3	4.7	0.4
	B_{21}	30-50	2.8	2.0	2.4	5.3	0.5
	B_{25}(u)	175-205	2.6	1.7	2.6	4.8	0.9
MP_1	A_{11}	0-5	3.7	2.9	2.2	7.3	0.3
	A_{12}	8-15	3.8	2.8	2.3	7.4	0.4
	B_{21}	22-42	3.8	3.2	2.0	7.8	0.3
	B_{23}	102-128	4.2	3.1	2.3	8.1	0.3
	B_{25}(l)	485-492	3.1	2.3	2.3	6.0	0.2
MP_2	A_{11}	2-8	3.8	2.9	2.2	7.4	0.3
	A_{12}	10-20	3.7	2.7	2.3	7.1	0.3
	B_{24}	172-202	3.7	2.8	2.2	7.2	0.3
PP_2	A_{11}	2-12	2.8	2.2	2.2	5.6	0.4
	A_{12}	18-25	3.1	2.3	2.3	6.0	0.4
	B_{21}	35-65	3.9	2.7	2.4	7.3	0.3
	B_{24}	225-250	2.4	1.8	2.3	4.7	0.2
PP_3	A_{11}	0-12	2.7	2.1	2.2	5.3	0.3
	B_{21}	38-58	3.1	2.3	2.3	6.0	0.2
	B_{24}	75-95	2.7	2.1	2.2	5.3	0.3

1. Molar ratio
2. % Amorphous = $\frac{\% \; SiO_2 + \% \; Al_2O_3}{0.9}$
3. From dithionite extract of residue after NaOH dissolution.

Table 12. NaOH - Selective Dissolution Analysis for Amorphous Materials in Coarse Clay (2-0.2μ) Fractions of Selected Samples

Profile and Horizon		Depth (cm.)	%SiO_2	%Al_2O_3	$\frac{SiO_2}{Al_2O_3}$[1]	% Amorphous[2]	%Fe_2O_3[3]
TP_1	A_{11}	2-10	2.7	2.1	2.2	5.3	0.3
	A_{12}	15-22	2.8	2.3	2.1	5.7	0.4
	B_{21}	30-50	2.9	2.5	2.0	6.0	0.3
	B_{23}	110-135	2.4	2.0	2.0	4.9	0.7
	B_{25}	335-345	2.2	1.7	2.2	4.3	1.3
TP_2	A_{11}	2-10	2.0	1.8	1.9	4.2	0.4
	B_{21}	30-50	2.1	1.8	2.0	4.3	0.6
	B_{25}(u)	175-205	2.0	1.6	2.1	4.0	0.7
MP_1	A_{11}	0-5	2.3	2.0	2.0	4.8	0.3
	A_{12}	8-15	3.1	2.6	2.0	6.3	0.3
	B_{21}	22-42	3.6	2.7	2.3	7.0	0.3
	B_{23}	102-128	3.2	2.5	2.2	6.3	0.3
	B_{25}(l)	485-492	3.0	2.5	2.0	6.1	0.3
MP_2	A_{11}	2-8	2.7	2.1	2.2	5.3	0.2
	A_{12}	10-20	2.7	2.1	2.2	5.3	0.3
	B_{24}	172-202	2.7	2.6	1.8	5.8	0.3
PP_2	A_{11}	2-12	3.2	1.7	3.2	5.4	0.3
	A_{12}	18-25	3.9	2.2	3.0	6.8	0.3
	B_{21}	35-65	3.4	2.4	2.4	6.4	0.3
	B_{24}	225-250	3.4	2.3	2.5	6.3	0.2
PP_3	A_{11}	0-12	3.1	1.8	2.9	5.4	0.3
	B_{21}	38-58	3.1	1.7	3.1	5.3	0.3
	B_{24}	75-95	3.0	1.7	3.0	5.2	0.3

1. Molar ratio.
2. $\% \text{ Amorphous} = \frac{\% \; SiO_2 + \% \; Al_2O_3}{0.9}$
3. From dithionite extract of residue after NaOH dissolution.

2.0 and fractionally lower than those of most of the corresponding fine fractions. In the Wilpattu soil, however, significantly higher silica/alumina ratios are obtained presumably resulting from the solution of some smectite-like component in the dissolution procedure (Alexiades and Jackson, 1966). The free iron oxides apparently released by the dissolution treatment and determined by citrate-dithionite-bicarbonate extraction are shown as percent Fe_2O_3 in the tables. The close correspondence between these percentages in the fine clay and coarse clay fractions and the absence of any obvious relationship to the amounts of amorphous material suggest that these are merely residual free iron oxides that were not removed by the initial citrate-dithionite-bicarbonate treatments.

The residue after NaOH dissolution of the amorphous materials was subjected to X-ray diffraction analysis but the patterns were not qualitatively different from those obtained before the treatment. However, there appeared to be some slight enhancement of the kandite and mica peaks, while the vermiculite-smectite peaks in the Wilpattu samples were diminished slightly - probably reflecting the solution of the vermiculite-smectite intergrade itself. Some of these patterns are compared with the X-ray diagrams of the untreated samples in Fig. 24.

The forms in which the amorphous materials occur are difficult to establish. The presence of opaline phytoliths in some of the horizons is shown by examination of thin sections and this is undoubtedly one form in which amorphous silica occurs. Amorphous silica in soils has also been found as allophane ($Al_2O_3.2SiO_2.nH_2O$),

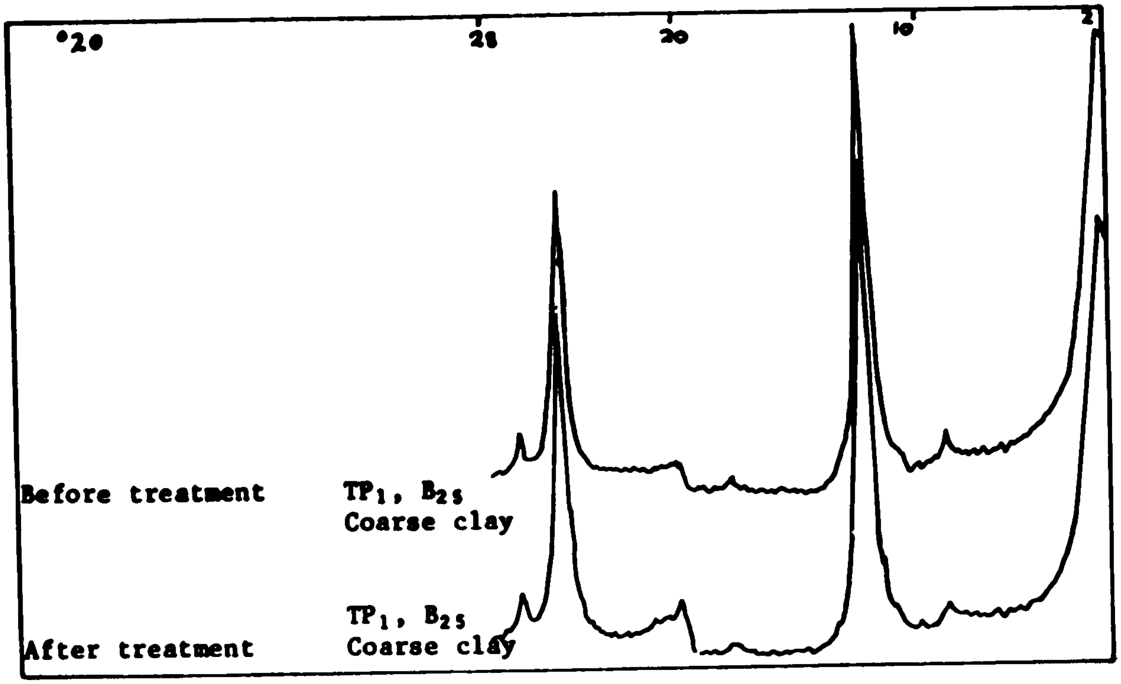


Figure 24. X-ray diffraction patterns of a coarse clay sample from Profile TP^1 before and after removal of amorphous materials by NaOH - dissolution.

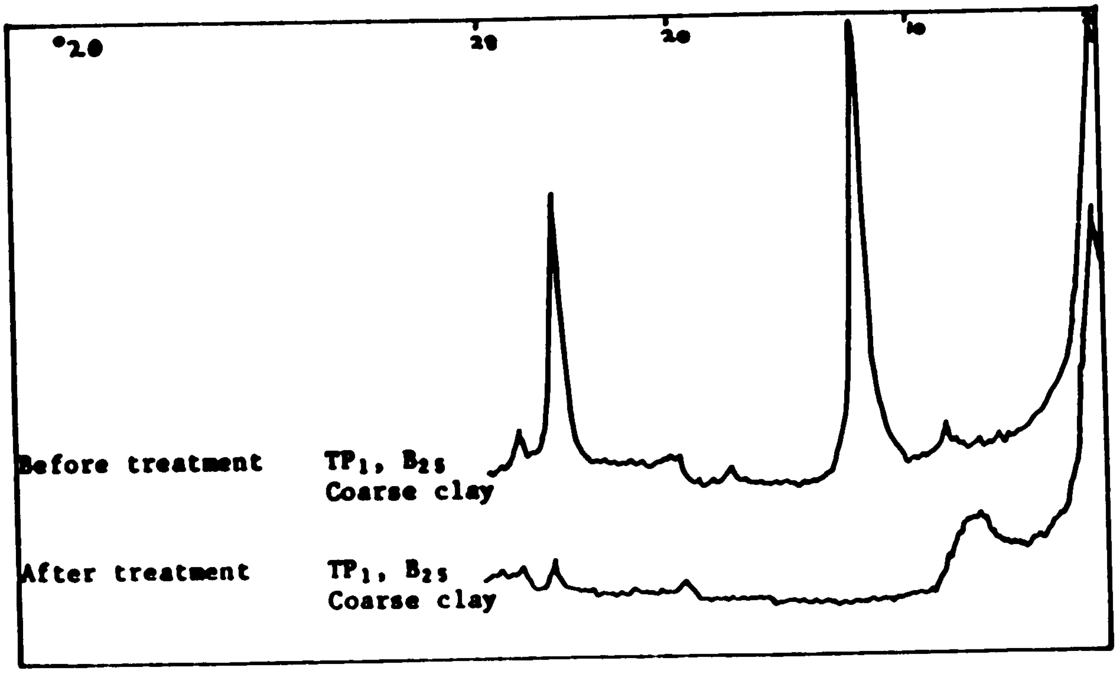


Figure 25. X-ray diffraction patterns of a coarse clay sample from Profile TP^1 before and after removal of kaolinite plus halloysite by heating and NaOH dissolution.

hisingerite ($Fe_2O_3.2SiO_2.nH_2O$), etc. (Brown, 1955) but there is no positive evidence for their existence in the Red Latosols. The occurrence of amorphous alumina in soils has not been well documented but several workers have postulated the existence of hydrous alumina (Tamura and Jackson, 1953; Fieldes, 1955; and Fridland, 1961 among others). The relative constancy of the SiO_2/Al_2O_3 ratio in the Red Latosols and its closeness to that of kaolinite (≈ 2.0) suggest that the amorphous components of these soils consist of sub-crystalline clay-like or clay relic materials formed by slight weathering of the crystalline clay. Since no gibbsite was revealed by X-ray analysis or d.t.a. it has been ignored in this discussion.

Kaolinite Plus Halloysite

X-ray diffraction analysis revealed that the crystalline portions of the fine clays consisted almost exclusively of kaolinite and consequently NaOH dissolution analysis was not carried out on this fraction. The coarse clays were heated to 550° C. and then subjected to selective NaOH dissolution to determine the kaolinite plus halloysite contents and the results are reported in Table 13. The values obtained are not very precise as duplicate ΔSiO_2 values differed considerably in many samples. However, they generally indicate that kaolinite plus halloysite constitute around 60 percent of the coarse clays. The kaolinite content of the coarse clay is, by itself, not very significant in genetic interpretations because the mineral exists in well crystallized form in a large variety of sizes in both fine and coarse clay fractions (*vide* section on electron microscopy) and fractionation may not be very accurate. Further, slight differences in the silicate mineral contents of the parent materials, translocation, and weathering of other clay minerals in the mixture could have caused minor variations in the kaolinite content. The $SiO_2:Al_2O_3$ molar ratios range between 2.0 and 2.5, which is reasonable for the kandite minerals and indicates that appreciable quantities of interlayer alumina were not dissolved (probably because of the low percentages of the mixed layer minerals).

The X-ray analysis of the residues (Fig. 25) showed that the heating and dissolution treatments had destroyed the kaolinite peak and also caused a broadening, and in some cases a complete shift of the 10A peak towards the low angle side. This was presumably the

Table 13. NaOH Dissolution for Kaolinite Plus Halloysite in the Coarse Clay (2.0-0.2μ) Fractions of Selected Samples.

Profile and Horizon		Depth (cm.)	%[1] ΔSiO_2	% ΔAl_2O_3	$\frac{\Delta SiO_2}{\Delta Al_2O_3}$[2]	%[3] Kaolinite + Halloysite
TP_1	A_{11}	2-10	27.4	22.8	2.0	58
	A_{12}	15-22	29.6	22.6	2.2	60
	B_{21}	30-50	32.0	23.8	2.3	65
	B_{23}	110-135	31.3	23.5	2.3	63
	B_{25}	335-345	29.4	23.2	2.2	61
TP_2	A_{11}	2-10	29.6	22.4	2.2	60
	B_{21}	30-50	29.6	21.8	2.3	59
	B_{25}(u)	175-205	28.6	20.2	2.4	56
MP_1	A_{11}	0-5	31.5	24.2	2.2	65
	A_{12}	8-15	32.6	24.2	2.3	66
	B_{21}	22-42	29.2	23.6	2.1	61
	B_{23}	102-128	31.4	25.3	2.1	66
	B_{25}(L)	485-492	34.6	26.0	2.3	70
MP_2	A_{11}	2-8	34.2	26.4	2.2	70
	A_{12}	10-20	28.4	22.1	2.2	58
	B_{24}	172-202	27.4	18.3	2.5	53
PP_2	A_{11}	2-12	31.4	23.8	2.2	64
	A_{12}	18-25	29.7	23.3	2.2	61
	B_{21}	35-65	29.4	23.8	2.1	62
	B_{24}	225-250	31.8	24.0	2.2	65
PP_3	A_{11}	0-12	32.1	23.1	2.4	65
	B_{21}	38-58	29.1	23.8	2.1	61
	B_{24}	75-95	29.4	25.1	2.0	63

1. Average of duplicates.
2. Molar ratios
3. % Kaolinite = 1/2 $\left[\frac{\%\Delta SiO_2}{46.5} + \frac{\%\Delta Al_2O_3}{39.5}\right]$

result of the replacement of interlayer K in the mica with the production of some vermiculite-like component. Dudas and Harward (1971) have observed similar effects in biotite after NaOH dissolution/ Na-citrate-dithionite-bicarbonate treatments without prior heating. Increase of d-spacings in biotite, muscovite and phlogopite have also been reported after replacement of interlayer potassium with sodium (Scott and Smith, 1966). The X-ray diffraction patterns also show the presence of small quantities of anatase in the residues.

Mica

Mica was not detectable by X-ray diffraction or d.t.a. in the fine clay fractions and consequently only the coarse clays were analysed for mica by HF/HCl dissolution (Table 14). The potassium mica contents were calculated on the basis of 10 percent K_2O and the sodium mica on the basis of 6.77 percent Na_2O (Alexiades and Jackson, 1966) assuming that no feldspars and high iron micas have survived in the clay fractions. (No feldspars showed up in the diffraction patterns).

The percentages of mica were slightly lower in the Mullaittivu Series than in the other two soils, probably due to a deficiency in the parent material or slightly greater weathering, or both. In all the soils there is a slight general decrease in clay-size mica with depth (but the highest values often occur in the A_{12} horizons). Somewhat similar distributions are shown by X-ray analysis. This is a reversal of the usual distribution resulting from pedogenic weathering. Similar decreases with depth have been noted in some other soils and have been attributed to mica synthesis in the upper layers due to phytocycling of potassium (Swindale and Uehara, 1966; Juang and Uehara, 1968) or to accumulation of tropospheric dust (Rex and Goldberg, 1958; Jackson, 1968; Syers et al., 1969). However, the fact that the mica occurs in the coarse clay fractions but not (in detectable amounts) in the fine clays suggests that, in the Red Latosols at least, it is rather a product of weathering than of synthesis. Further, the presence of muscovite in the coarser sand fractions of even deep subsurface horizons argues against both pedogenic synthesis and eolian or tropospheric accumulation as possible origins for the clay-size mica.

Other possible mechanisms that may account for the higher mica levels in the coarse clays of the upper horizons are (1) greater amounts of K and Na (from phytocycling and atmospheric cyclic salt deposition, respectively) supplied to these horizons, resulting in the stabilization of the mica against weathering by K and Na depletion, (2) more intense comminution of sand and silt size mica due to greater stresses in the upper horizons leading to their relative concentration in the finer fractions and (3) more effective chemical weathering conditions in the lower horizons giving rise to a relative accumulation of mica near the surface.

Cation exchange studies do show higher levels of K per 100 g. clay in the upper horizons although Na is present only in trace quantities throughout the profiles. However, it is a moot point whether the higher magnitudes of the K contents are responsible for the preservation of the mica or if they result from the weathering of higher mica contents. Greater comminution of sand and silt size mica in the surface horizons has yet to be demonstrated, although the relative stability of muscovite and its accumulation in the coarser fractions of kaolinitic clays has been noted (Bundy, Johns and Murray, 1966). The third explanation seems least likely as the feldspar contents of the fine sands, the percentages of amorphous materials and the electron micrographs of the clays all show that weathering is most severe near the surface.

The sodium clay paragonite has been reported to occur in other soils and parent materials containing muscovite (Cook and Rich, 1962).

Table 14. Percent Mica by HF/HCl Dissolution of the Coarse (2.0-0.2μ) Fraction of Selected Samples

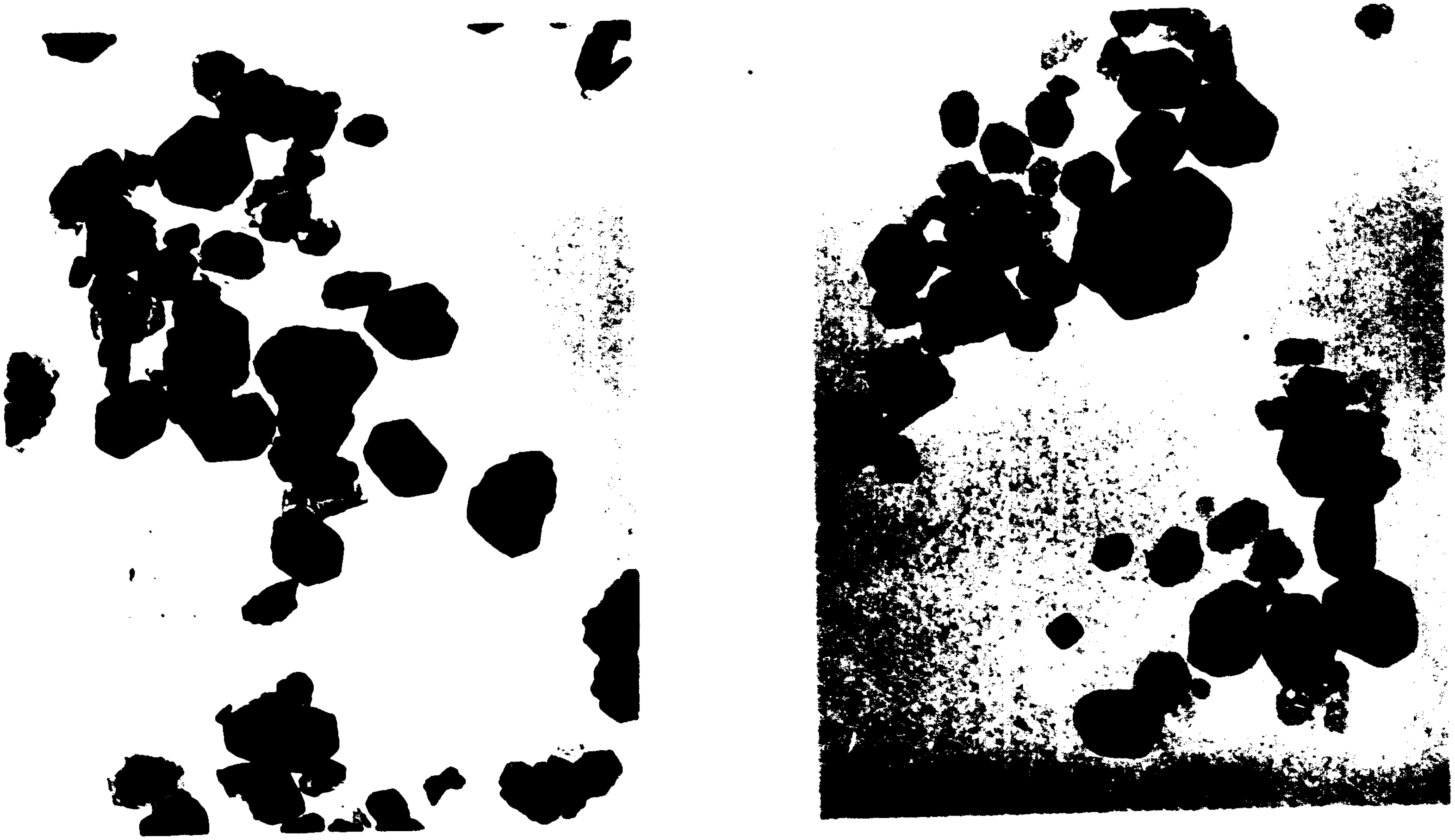
Profile and Horizon		Depth (cm.)	% K	% K Mica[1]	% Na	% Na Mica[2]	% Total Mica
TP$_1$	A_{11}	2-10	1.08	13.0	0.23	9.0	22.0
	A_{12}	15-22	1.08	13.0	0.25	10.0	23.0
	B_{21}	30-50	0.98	11.8	0.23	9.0	20.8
	B_{23}	110-135	0.90	10.9	0.19	7.5	18.4
	B_{25}	335-345	0.85	10.3	0.20	8.0	18.3
TP$_2$	A_{11}	2-10	0.90	10.9	0.20	8.0	18.9
	B_{21}	30-50	0.88	10.6	0.25	10.0	20.6
	B_{25}(u)	175-205	0.88	10.6	0.21	8.4	19.0
MP$_1$	A_{11}	0-5	0.68	8.2	0.19	7.5	15.7
	A_{12}	8-15	0.70	8.4	0.25	10.0	18.4
	B_{21}	22-42	0.62	7.5	0.19	7.5	15.0
	B_{23}	102-128	0.55	6.6	0.19	7.5	14.1
	B_{25}(L)	485-492	0.48	5.8	0.16	6.5	12.3
MP$_2$	A_{11}	2-8	0.72	8.7	0.18	7.5	16.2
	A_{12}	10-20	0.70	8.4	0.16	6.5	14.9
	B_{24}	172-202	0.62	7.5	0.16	6.5	14.0
PP$_2$	A_{11}	2-12	1.00	12.1	0.23	9.0	21.1
	A_{12}	18-25	1.02	12.3	0.20	8.0	20.3
	B_{21}	35-65	0.85	10.3	0.19	7.5	17.8
	B_{24}	225-250	0.82	9.9	0.23	9.0	18.9
PP$_3$	A_{11}	0-12	1.10	13.3	0.29	11.5	24.8
	B_{21}	38-58	1.00	12.1	0.25	10.0	22.1
	B_{24}	75-95	0.90	10.9	0.21	8.4	19.3

1. Calculated for a K content of 8.29% (10% K_2O).
2. = Paragonite - based on 5.02% Na (6.77% Na_2O).

5.44 Electron Microscopy

Selected clay samples were examined under the transmission electron microscope and representative electron micrographs of some of the features observed appear on the following pages. Pseudo-hexagonal kaolinite particles in a continuous range of sizes from <0.05μ to the upper limit of clay dominate all the samples as would be expected from the results of X-ray diffraction, differential thermal and chemical analyses of the clays. Irrespective of size they generally show good crystallinity (Plate 13b) and occasional twinning, but the surface horizon clays have some proportion of particles with weakly sub-angular outlines (Plate 10a) which probably indicates slight weathering effects since the B horizon kaolinite particles have sharper angular outlines (Plate 10b). Some mica (Plate 11a) is present in all the samples and occasional elongate tubular particles, probably halloysite or tubular kaolinite (De Souza Santos et al., 1964), are also seen (Plate 12). The Gambura Series clays contain a fluffy smectite-like material (Plate 12b). Electron opaque needles that are likely rutile crystals and cubes that may be magnetite or maghemite occur infrequently in all the samples.

Iron oxides appear to be present almost entirely as discrete particles (Plate 11a) that are removed by Na-citrate-dithionite-bicarbonite treatment (Plate 11b). No differences in the clay faces could be noted as resulting from this treatment suggesting that the iron oxides are not present as surface coatings on the clays. It may be debatable, however, whether the presence or removal of a very thin film of iron oxide would make a sufficient difference to the electron



(b) x 104,760

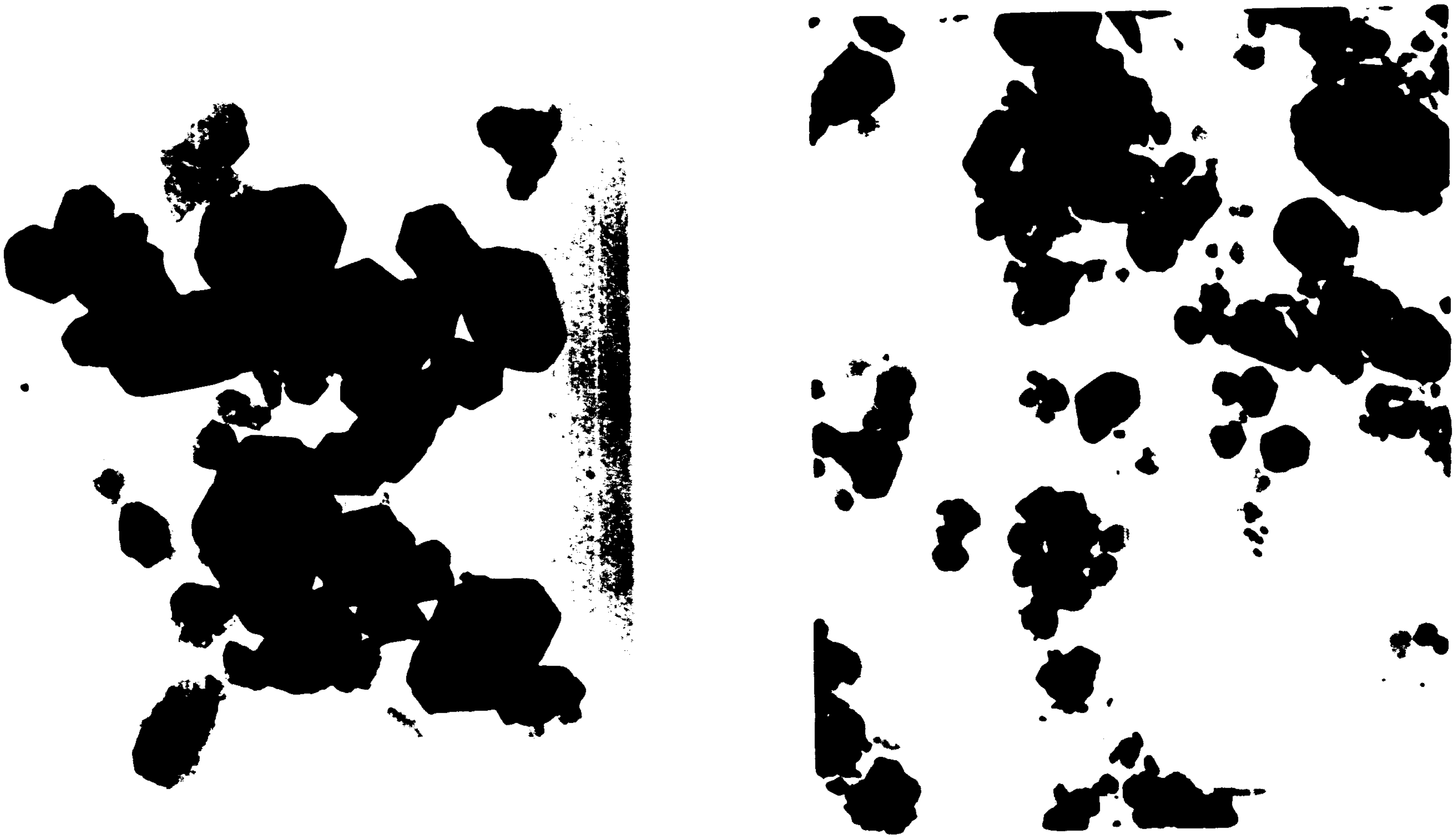
(a) x 103,200

Plate 10. Electron micrographs of clays from (a) the A_{11} and (b) the B_{23} horizons of a Gambura Series soil.

(b) x 104,760

(a) x 103,200

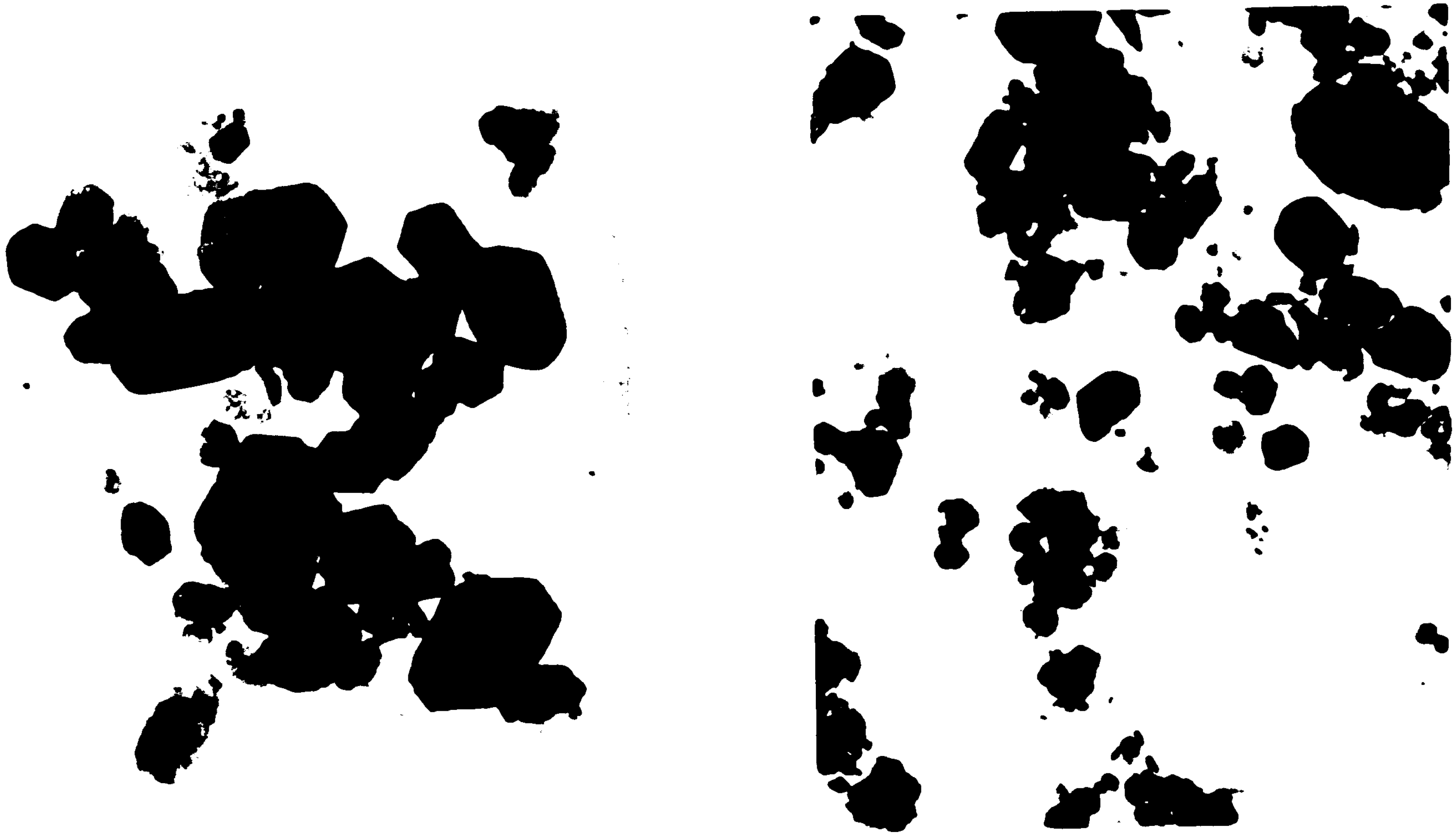
Plate 10. Electron micrographs of clays from (a) the A_{11} and (b) the B_{23} horizons of a Gambura Series soil.



(b) x 79,380

(a) x 38,250

Plate 11. Electron micrographs of a clay from the B_{25} horizon of a Gambura Series soil (a) not deferrated (b) deferrated.



(b) x 79,380

(a) x 38,250

Plate 11. Electron micrographs of a clay from the B_{25} horizon of a Gambura Series soil (a) not deferrated (b) deferrated.

(b) x 32,500

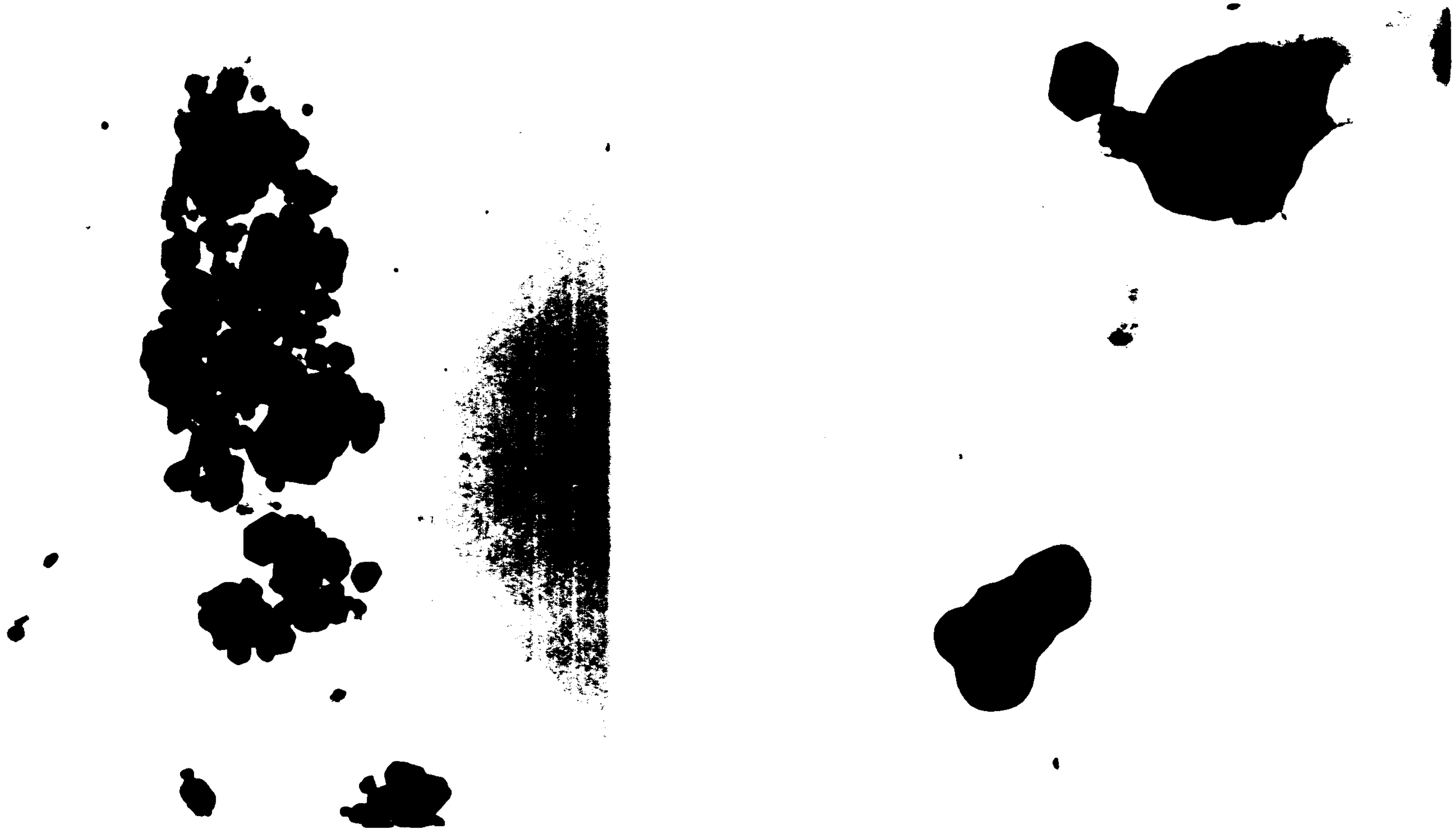
(a) x 116,400

Plate 12. Electron micrographs of clay from a Wilpattu soil showing (a) a tubular crystal (halloysite?) and (b) smectite-vermiculite intergrade.

(b) x 32,500

(a) x 116,400

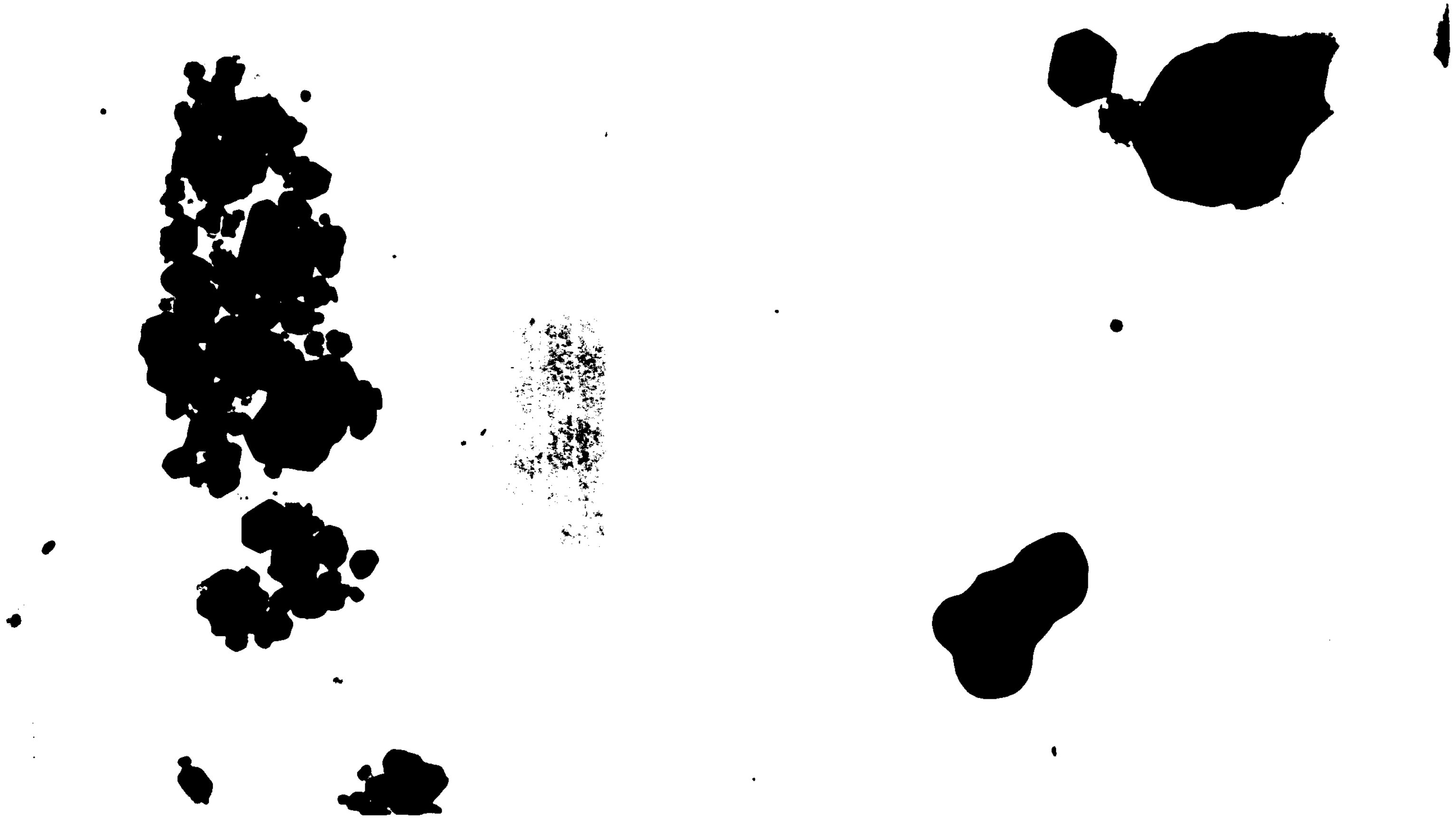
Plate 12. Electron micrographs of clay from a Wilpattu soil showing (a) a tubular crystal (halloysite?) and (b) smectite-vermiculite intergrade.



(b) x 29,250

(a) x 67,200

Plate 13. Electron micrographs showing (a) a close-up of iron oxide particles (b) a general view of a clay from a B_{24} horizon of a Wilpattu soil.



(b) x 29,250

(a) x 67,200

Plate 13. Electron micrographs showing (a) a close-up of iron oxide particles (b) a general view of a clay from a B_{24} horizon of a Wilpattu soil.

denseness of the particles as to be observable under the transmission electron microscope. The iron oxide particles have a smooth nodular appearance under high magnification (Plate 13a) but may also be present in clusters (Plate 10b). They are frequently attached to the edges of clay particles but never to the faces. From these observations it seems fairly clear that the iron oxides of the Red Latosol clay fractions are present largely as discrete particles rather than as coatings on the clay surfaces. Similar observations were made by Greenland _et al._, (1968) on the iron oxides of other tropical red soils.

It is interesting to note, in passing, that the generally high degree of morphological crystallinity of the kaolinite in the Red Latosols is reflected by the X-ray diffraction patterns, which relationship has been noted by other workers (Murray and Lyons, 1956) but to which exceptions occur (Robertson _et al._, 1954).

Many of the electron micrographs show a large number of irregular light patches or scars on the surfaces of the kaolinite particles. These are almost certainly voids formed by exposure to electron beam radiation because Chute and Armitage (1968) were able to produce almost identical effects in kaolinite particles by a few minutes exposure to a high intensity electron beam. They attributed these voids or pits to "high pressure gas accumulation resulting from thermal dehydroxylation of the crystals", since loss of crystallinity was shown by selected area electron diffraction patterns taken before and after irradiation. No voids appeared if the kaolinite crystals were heated to 550° C. or more before electron microscope examination.

The rims or halos that are also seen around the crystals of kaolinite in some photographs were postulated by these workers to be due to diffusion of hydroxyls to the crystal edges where they chemically combine with hydrocarbon vapours present in the microscope column.

5.45 X-Radiography

The technique of X-radiography is sensitive to even minor differences in density of the constituent grains of a deposit as well as to their packing (Calvert and Veevers, 1962; Hamblin, 1962). Examination of relatively large sections (10 to 14 cm. vertically) of the B_{25} horizons of the Red Latosols failed to reveal any signs of stratification (Plate 14 shows the X-radiograph of one such section). Since faunal and root activity are presently, and probably have been in the past, of minor occurrence at these depths (>300 cm.) it seems likely that the original deposit itself was of an extremely uniform nature.

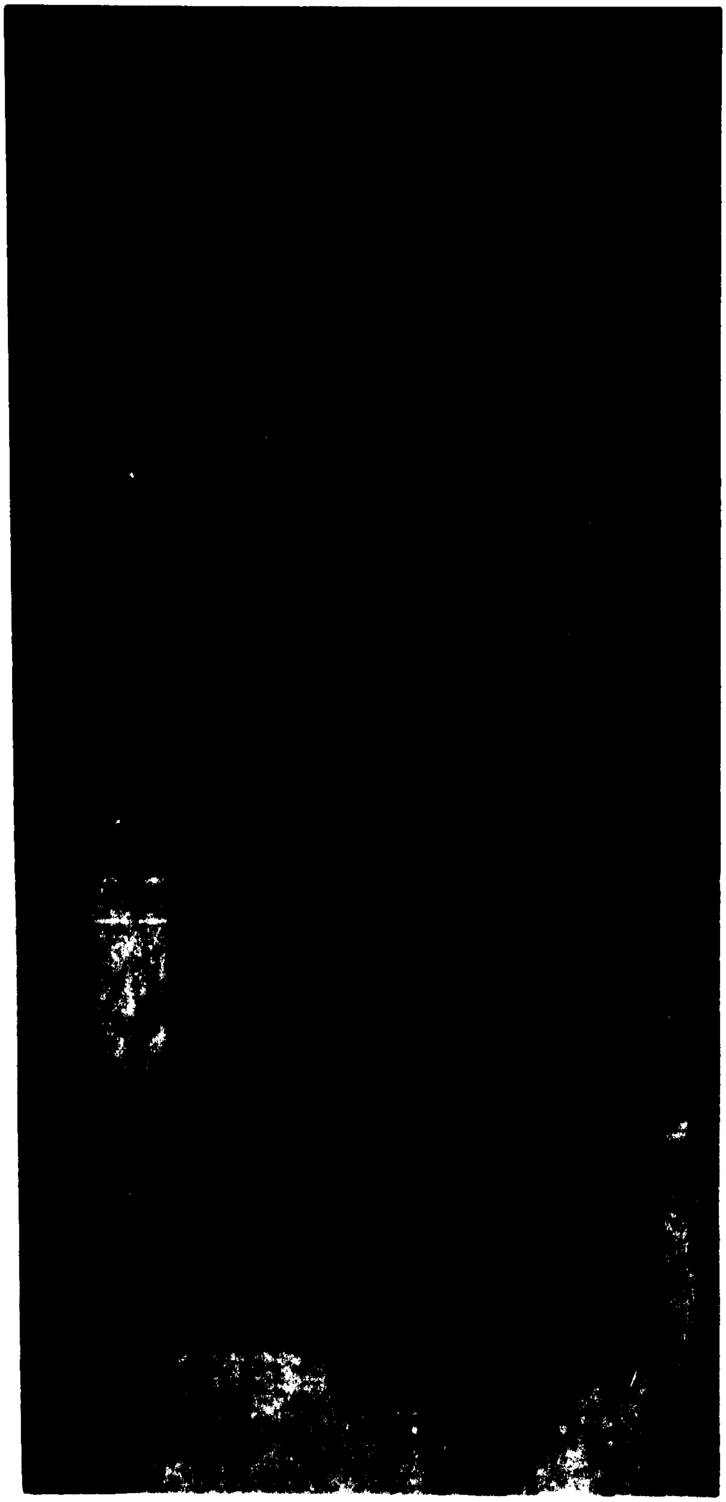
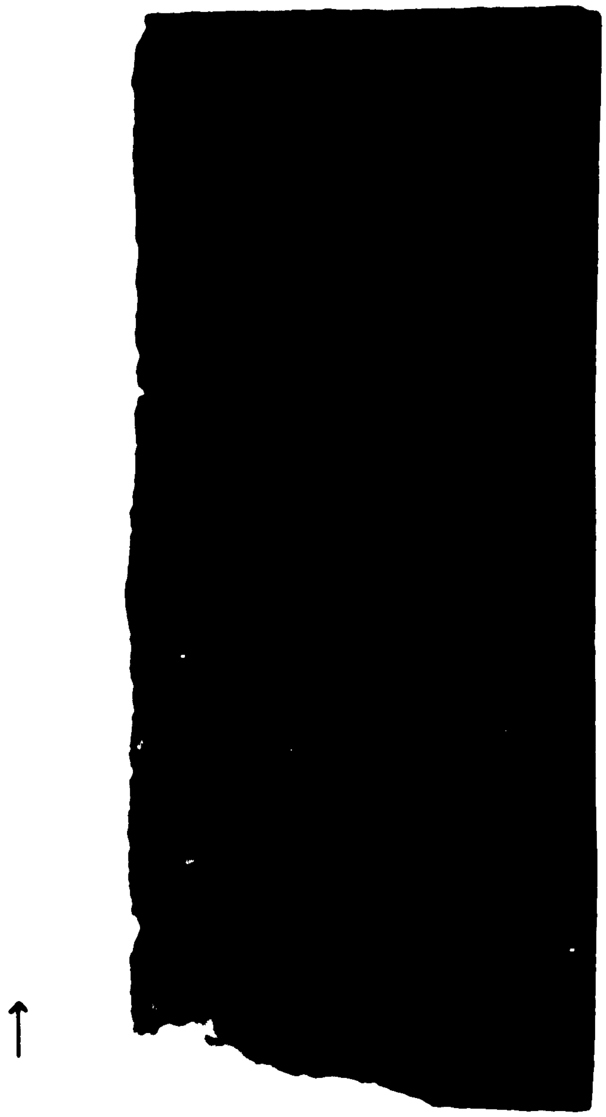


PLATE 14 X-RADIOGRAPH OF A SOIL CLOD FROM THE B_{25} HORIZON OF A GAMBURA SERIES PROFILE

[illegible]



6. GENESIS AND CLASSIFICATION OF THE RED LATOSOLS

6.1 Introduction

The concept of genesis used in this study is that outlined by Simonson (1959) in which soils are regarded as open systems deriving their properties from the operation of essentially four kinds of processes, viz. additions, removals, transfers and transformations. These processes may act in complementary or opposing directions to give a particular soil its unique characteristics and horizon sequence. Commonly, studies of the processes that have been responsible for soil formation are carried out with reference to the underlying relatively unaltered material which is assumed or proved to be similar to the parent material of the soil. In the case of the Red Latosols of Ceylon, however, no vestiges of such unaltered materials remain and reliance has to be placed on the knowledge that has accumulated regarding the effects of soil forming processes on profile characteristics themselves. By detailed observations of the physical, chemical, mineralogical and micromorphological features of the soil, it is possible to infer the processes that have been at work and even reconstruct, to some extent, the nature of the parent materials.

Attempts to relate the soil forming processes to the environmental factors (the state factors of Jenny, 1961) pose a similar problem. Many soils, particularly in unglaciated areas, have developed to their present state under more than one set of environmental conditions. But here again, the soils themselves, often provide important clues in regard to past climates, vegetation, etc. To the extent that such clues have not been obliterated or greatly modified by more recent or present environments, information already available from studies of the relationship between monogenetic soils and the state factors may be utilized to deduce some of the environmental conditions that prevailed during the formation of older soils like the Red Latosols.

In the following paragraphs the parent materials and the main soil forming processes that were instrumental in producing the present characteristics of the Red Latosols are described and an attempt is made to deduce some aspects of the environment(s) of soil formation. Variations among the three soil series of this sub-group are discussed with particular reference to differences in lithology of the parent materials, and the soils are classified.

6.2 The Parent Materials

Geomorphic evidence cited earlier (Section 2.13) indicates that the parent materials of both the Red Latosols and the Red Earth Formation were beach-dune-ridge deposits. The general lack of stratification in regard to particle size and mineralogy as shown by particle size distribution studies, mineralogical analysis of the fine sands and X-radiography suggest that these deposits were not pre-weathered. This conclusion is further reinforced by the existence of mineral grains obviously weathering or weathered in place (seen in thin sections) and from the very slightly higher contents of feldspar at lower depths in the fine sands - an <u>in situ</u> weathering effect. The absence of surface erosional features probably indicates that the parent materials (and the Red Latosols themselves) had very good internal drainage and high infiltration rates, which is consistent with a beach sand type of deposit.

The parent materials of the Red Latosols were not only quite uniform with depth but also had only small lateral variations locally, as demonstrated by the particle size distributions of the $>50\mu$ fractions and the mineralogical analysis of the fine sands. Regionally, however, important differences in the parent materials may be noted which are reflected in the different soil series. Although the original mineralogy of the Red Earth deposit cannot be determined with any degree of certainty, the clay and iron oxide percentages provide rough indications of the relative amounts of total weatherable silicate minerals and ferromagnesian silicate minerals, respectively, that were present initially in the three soil series of the Red Latosols since, in a leaching environment, the weathering of such minerals result in the products shown by the schematic equations

felsic minerals ⟶ clay + quartz[1] + soluble products ↓
SiO_2, Mg^{++}, Ca^{++} etc.
(which tend to get leached out)

mafic minerals ⟶ clay + non-quartz resistant minerals
+ iron oxides + soluble products. ↓

---

1. and other resistant minerals.

These transformations have essentially gone to completion in the Red Latosols. Free aluminium oxides are present only in insignificant amounts in these soils and have not been considered. Of course, redistributions of clay and iron oxides have to be taken into account but, considering the profiles as wholes, the following conclusions may be arrived at:-

1. the contents of easily weatherable alumino-silicate minerals in the parent materials followed the order Gambura > Mullaittivu > Wilpattu and the contents of quartz + other resistant minerals followed the reverse order;

2. while the same sequence, viz. Gambura > Mullaittivu > Wilpattu, is apparent for the amounts of ferromagnesian silicate minerals, the difference between the Mullaittivu and Wilpattu parent materials would have been slight in this respect. Also, the ratio of ferromagnesian silicate to total weatherable silicate minerals as deduced from the values of free iron oxides/clay show the order Gambura > Wilpattu > Mullaittivu.

6.3 Processes of Soil Formation

The characteristics of these Red Latosols are determined to a large extent by advanced chemical weathering as indicated by the near-absence of feldspars and ferromagnesian silicates, low silt/clay ratios and clay fractions that are dominated by kaolinite and iron oxides. This is in accord with the high infiltration and inferred high percolation rates of these soils which would have aided in the rapid removal of the soluble products of weathering (Sherman and Alexander, 1959; Keller, 1964). However, adequate amounts and intensities of rainfall to leach the soil (such as are provided by the present climate) would also have been required for advanced weathering to reach such depths that a weathering sequence from lower to upper horizons is nearly absent. The stable landscape may also have been important in providing sufficient time for weathering to reach this stage.

The kaolinite present in the Red Latosols is well crystallized (showing very slight weathering of the crystals only in the surface horizons) as evidenced by the results of electron microscopy. This, and the near-absence of free Al oxides, indicate that the mineral is quite stable under the existing conditions (and has been stable since it formed) and is undergoing further weathering only very slowly. Also, since little addition to the kaolinite content is taking place through weathering, it is possible to assign the Red Latosols to the kaolin stage of weathering of Jackson and Sherman (1953) which is characterized by a maximum in the kaolinite content as a function of weathering. The absence of gibbsite and extremely small contents of extractable (free) alumina are significant because these are typical products of weathering in warm humid situations either directly from primary minerals (Harrison, 1934) or via kaolinite (Sherman, 1952). It implies that climates much wetter or more continuously moist than those of the present have not prevailed for any significant periods of time in the Red Latosol region in Ceylon since soil formation began. This point will be elaborated on later in this section.

Hematite was the only detectable free iron oxide although maghemite may also be present especially in the surface horizons (Oades, 1963). Since Fe ions have to be removed from the reaction medium for kaolinite to form (Keller, 1964) it is likely that hydrated iron oxide separated out at a very early stage in weathering. Subsequent aging under the influence of the hot dry seasons could have resulted in ionic environments that favoured the formation of hematite. Although in the initial stages the iron oxides may have existed as hydrated coatings on the clay surfaces, they are now largely present as discrete particles as shown by the particle size distribution studies and electron microscopy. The intense reddish colours of the soils are related to their iron oxide contents and possibly to the state of subdivision of the iron oxide particles.

The small amounts of mica and mixed layer clays occurring in these soils and the smectite-vermiculite intergrade in the Wilpattu soils are present in the coarse (0.2 - 2μ) clay fractions but not in the fine ($< 0.2\mu$) clays, thus ruling out pedosunthesis from simpler constituents as a mode of origin for these clay minerals. Rather, they seem to be intermediates in the weathering of coarser (muscovite) mica or feldspar or both. The slight decrease in mica content with depth could be the result of higher potassium levels maintained near the surface by phytocycling. Mixed layer minerals, which are present in very small amounts, have probably formed by an "anti - gibbsite effect" (Jackson, 1962) which involves Al-hydroxy interlayering of mica-vermiculate-smectite intergrades formed by weathering of mica.

Qualitative weathering differences between the three soil series of the Red Latosol sub-group are minimal indicating that if any major climatic changes did occur, they probably affected the whole area fairly uniformly. The occurrence of the vermiculite-smectite intergrade only in the Wilpattu Series could conceivably result from the fact that these soils drain much faster (at lower tensions) than the other two series and less water is held at higher tensions. Consequently, not only is the leaching less efficient (with less time to equilibrate) but also, the soil solution itself tends to get more concentrated in cations like Ca and Mg as the soils dry out, thus providing an environment conducive to the formation and preservation of 2:1 expanding layer silicates (Keller, 1964). The higher base saturations of the Wilpattu soils support this contention.

Quantitative differences in the weathering products are caused primarily by variations in the initial mineralogy of the parent deposit which have determined the amounts of clay and iron oxide that occur in each soil. The fractionally lower mica contents of the Mullaittivu Series could have resulted from more intense weathering induced by the slightly higher precipitation in this region but, since the base saturation percentages are comparable with those of the Gambura Series, are more likely due to the lower contents of mica in the parent materials themselves.

Clay migration, like the weathering processes discussed above, is another important process that has contributed to the present characteristics of the Red Latosols. Unlike the weathering processes, however, it has resulted in increased horizon differentiation. The fine clay/coarse clay ratios definitely indicate that clay has moved down the profile (since the parent materials were quite uniform) as brought out in sub-section 5.35. The occurrence of void argillans in the B horizons tend to support this conclusion. The depth of movement and spread of illuviated clay are greatest in the coarsest textured Wilpattu soils and least in the finest textured Gambura Series, which is to be expected. Most of the clay that has moved is kaolinite as this is the only detectable clay mineral in the fine ($<0.2\mu$) fraction. Some coarse clay too has probably moved but the lower contents near the surface may equally well have resulted from comminution to finer sizes which show greater mobility. Destruction of the clays of the A horizons cannot account for an appreciable part of the difference in clay content between the A and B horizons as electron microscopy shows that the weathering of kaolinite particles in the surface layer is very slight and gibbsite (or other free Al-oxide) was not detected in the surface (or any other) horizon.

The mechanism of clay movement is probably simple peptization and transport in suspension by percolating rainwater. Determination of the water dispersibility of the clays shows that this method of movement is probably still viable as appreciable amounts of clay were suspended by this treatment in the A horizon of the Gambura Series and the A, upper B and middle B horizons of the other two soils. Resilication of gibbsite cannot be postulated as a pathway for the downward movement of kaolinite as there is no source of silica for such resilication to take place in the B horizons without depleting the A horizons.

Free iron oxides too have been subject to downward movement probably as discrete particles (vide sub-section 5.40), though the movement of clay seems to have been slightly preferred leading to higher Fe_2O_3/clay ratios in the surface horizons.

Leaching of the Red Latosols has not only resulted in the redistribution of clay and iron oxides with attendant changes in other soil characteristics like bulk density, water physical properties, cation exchange capacity, etc., but has also caused changes in the cation suites of clays in the different horizons. Most of the basic cations released by weathering have probably been leached out of the soils (to the depths of sampling at least) and the rest have been redistributed within the profiles. While the surface horizons resist leaching to a certain extent because of the effects of vegetation, the upper B horizons are being depleted of bases and acquiring acid characteristics. This process has, however, not been acting long enough to weather the clay minerals in these horizons to any appreciable extent. The lower B horizons are still fairly well supplied with bases. Calcium and magnesium have apparently been differentially leached with the latter having maxima at higher depths. Potassium has been leached out to a large extent in the lower parts of the profiles, but phyto-cycling has apparently caused its retention to some extent in the A and upper B horizons. Sodium exists only as trace quantities in all the soils having been almost completely removed by the leaching process. Horizons which have been depleted of a considerable part of their bases have acquired acid properties resulting from the strong adsorption of hydroxy aluminium ions (sub-section 5.39).

Rapid mineralization of organic matter in the Red Latosols is indicated by the low carbon and nitrogen contents and narrow C/N ratios. Nevertheless, even these small amounts of organic matter have influenced the properties of these soils in several important respects. The slightly browner and/or darker colours and somewhat better structures of the A (as compared to the B) horizons of most of these soils are, at least in part, due to their organic matter contents. Organic matter was also probably responsible for peptizing some of the clay and iron oxides that have migrated downwards. It undoubtedly contributes to the cation exchange capacities of the surface horizons and is part of a cycle by which nutrient cations are retained against leaching by plant uptake, thus giving rise to higher base saturation values in these horizons. The fractionally higher organic matter contents of the Mullaittivu Series as compared to the other two soils apparently result from the slightly greater precipitation and vegetative growth in that region.

Although the processes discussed above, have helped to a greater or lesser degree in the formation of different soil horizons, the outstanding feature of the Red Latosols is the weakness of their horizon differentiation. There are several likely reasons for this. First, the intense weathering to great depths has prevented the development of a clear cut weathering sequence from the lower to the upper horizons. Secondly, a strong colouration or staining by iron oxides has tended to camouflage (at least visually) the limited differences that have arisen as a result of the soil forming processes. Thirdly, termite activity has probably been instrumental in reversing, to some extent, the tendency towards horizon differentiation in the upper horizons by soil mixing. Other fauna and tree-throw are likely to have aided this process. Fourthly, rapid rates of water movement through the soil have resulted in a greater spread of eluviation-illuviation and leaching effects. For example, the illuvial clay is spread out over a considerable depth, and the B horizons consequently show only weak illuvial characteristics and do not meet the requirements of an argillic horizon. Fifthly, rapid mineralization of organic matter has prevented the formation of strong, distinctive A_1 horizons. Finally, phytocycling has retarded the leaching of cations, and hence the weathering of clays in the surface horizons.

6.4 Factors of Soil Formation

The soil forming or state factors which are considered in this section are those outlined by Jenny (1941), viz. parent materials, climate, biotic factors, topography and the time over which soil formation has taken place. These have already been dealt with in a general way in the section dealing with the envivironments of the Red Latosols, but the following discussion pertains more specifically to the manner in which the state factors have influenced soil development. Further, since changes in some of the state factors may have taken place during the period over which the Red Latosols acquired their present characteristics, an attempt is made to use geomorphic data and the pedologic record to deduce the nature of the environments that are likely to have prevailed during this period.

The Red Latosols are described in earlier sections as having developed on the Red Earth Formation, but this is true only in a restricted sense as the weathering of the Red Earth would have occurred simultaneously with the development of the Red Latosols. The parent materials of the Red Latosols (and the Red Earth) were, as already indicated, beach-dune-ridge deposits laid down at some time during the Quaternary. To recapitulate the evidence cited earlier for the beach origin of these parent materials, the areal shape of the deposit and its occurrence as a narrow belt along the coast interrupted only by transverse streams suggest a near shore or littoral origin. The invariable outcropping of the basal ferruginous gravel (which overlaps the sands, sandstones and organic reef type sediments of the Moongil Aru Formation) as a relatively narrow band at the inland boundary of the Red Earth Formation appears to rule out wind-blown and fluvial origins ascribed to the deposit earlier (Wayland, 1919; Joachim, 1935; Moormann and Panabokke, 1961). Also, the occurrence of the Red Earth in undiminished thicknesses even in areas where streams disappear underground into underlying karstic limestone, argues against fulvial deposition. No evidence has also been found of any buried vegetation or soils which are features often present underneath extensive eolian or fluvial deposits.

The most important positive evidence for beach deposition, however, comes from observations of the landforms on the Red Earth Formation and their comparison with the beaches of today. Cooray (1967, 1968) was not only able to observe sililarities between the two, for example the diversion of drainage on the inland side of Red Earth ridges which resemble closely the diversions behind barrier bars of present beaches, but was also definitely able to recognize a raised beach on the Red Earth. The writer's own observations of similar features and his examination of a beach to Red Earth-like material weathering sequence in the Hambantota area, tend to confirm these findings.

The nature of the parent materials has been dealt with in a sub-section at the beginning of this chapter in which evidence was cited to show that they were relatively unweathered, highly permeable materials consisting of varying amounts of quartz, alumino-silicates and ferromagnesian silicates with no obvious stratification. Differences in the relative amounts of alumino silicates and ferromagnesian silicates in the three major regions of deposition are considered responsible for the different clay and iron oxide contents of the three soil series developed on this deposit.

The climates of soil formation in all but the most recently formed soils could have undergone major changes at some time, thus giving rise to polygenetic features. While such changes may have taken place during the development of the Red Latosols, they are mostly indeterminable. The absence of gibbsite or significant amounts of free aluminium oxide in these soils, however, precludes the occurrence of climates much wetter than the present one at <u>any</u> stage in their development. Numerous workers (for example, Knecht, 1945; Utescher, 1948; Sherman, 1952; Gordon and Tracey; 1952; Jackson and Sherman, 1953; Maignen, 1966) have found that free aluminium oxides (and in particular gibbsite) are formed under more or less continuously humid and usually warm conditions where the supply of silica is limited. Kalpage <u>et</u> <u>al</u>. (1963), in their study of the mineralogy of three great soil groups of Ceylon, found that only in the soil from the wet zone (annual average rainfall, 3,250 mm.; annual average temperature, 27° C.) was gibbsite present. Sherman (1952) was actually able to demonstrate a sequence of decreasing kaolinite and increasing gibbsite from dry to continuously wet areas with high rainfall. He also found that the peak of kaolinization occurred in the Low Humic Latosols which have developed under an annual rainfall of 875 to 1,125 mm. (<u>ibid</u>.). Maignen (1966) estimates that conditions for gibbsite formation occur in well-drained situations only when the annual precipitation is at least 1,200 mm. in tropical environments.

Since the Red Latosols of Ceylon now have, and throughout their formation probably possessed, somewhat excessive or excessive drainage, the non-formation of gibbsite (or appreciable amounts of other free aluminium oxides) is positive evidence against the prevalance of a much wetter or more continuously moist climate than that existing today. This is further substantiated by the absence of any segregation of iron and aluminium oxides into zones or mottles in any part of the soil (Stephens, 1965). In fact, there is no feature of these soils that is incongruent with the existing climate provided the rapid infiltration and percolation rates that exist, and have existed in the past, are taken into account. Thus, the study of a well-drained soil in Ceylon developed _in situ_. on parent materials derived largely from coarse-grained charnockite rocks under a climate comparable to that of the Red Latosols (Panabokke, 1958), showed that kaolinite was the dominant clay mineral with some mica and hematite also present. However, weatherable primary minerals are still present in this soil indicating that, unlike in the Red Latosols, the weathering reactions have not gone to near-completion. On the other hand, weatherable minerals are almost absent in some Low Humic Latosols of Hawaii, which are developed on basic crystalline rocks and andesitic ash or their erosional materials (Sherman and Alexander, 1959) under a climate that is similar to that of the Red Latosols of Ceylon. These Hawaiian soils closely resemble the Red Latosols, and like the latter, have high infiltration and percolation rates which probably carried the weathering reactions almost to completion. It therefore appears that rapid removal of the soluble weathering products, due to high infiltration and percolation rates, and possibly a longer period of soil formation are implicated in the advanced weathering of the Red Latosols, in which most of the weatherable mineral reserve has disappeared, rather than a past wet climate. The existence in the past of more arid climates than the present one cannot be ruled out, however, but no traces of greater aridity remain.

Relating the present climate to processes of soil formation in the Red Latosols we see that the precipitation during the wet season is sufficient to rapidly leach the soil to great depths which, considering the high temperatures, is consistent with the advanced weathering of nearly all the primary weatherable minerals to clay fractions dominated by kaolinite and iron oxides, the leaching out of most of the cations released by weathering, the redistribution of clay and iron oxides and the considerable horizon spread of these soils. The high temperatures and long dry season could account for the rapid mineralization and non-accumulation of organic matter, the provision of ionic environments conducive to the transformation of free iron oxides to hematite and the inhibition of weathering of silicate minerals to simpler products (e.g. gibbsite) due to concentration of soil solutions. It is thus seen that, not only is a past wet climate quite unlikely in view of the near-absence of free aluminium oxides or gibbsite, but that it is not even necessary to invoke climatic changes to explain the present characteristics of the Red Latosols.

The vegetation under which the Red Latosols formed may have changed with time due to possible arider climates in the past or to successions that followed the original colonization of the beach deposits by plants, but such changes would have affected the entire area more or less uniformly. The present vegetation, which is directly responsible for the organic matter contents of these soils and indirectly for properties influenced by organic matter, tends to hold cations in the surface horizons against leaching to lower depths by phytocycling. The vegetation also contributes in some degree to soil mixing.

The chief organisms active in the Red Latosols are probably micro-organisms and termites. Little is known about the microbiology of these soils, but micro-organisms are probably responsible for the rapid mineralization of organic matter and possibly for the development of weak structure in the A horizons. Termites are important mainly in soil mixing either directly by transport of soil particles or indirectly by the filling of termite passages by material from upper horizons. Their activities are generally confined to the upper metre or two of the soil (but may occasionally penetrate to lower depths) and have yet to be studied in the Red Latosols. Preliminary analysis of a termite mound and the adjacent soil in this study suggest, however, that the materials used in the construction of the mounds have similar amounts of sand, silt and clay to the B_{22} horizon, but fractionation of the sand shows a tendency to discriminate against the coarser fractions. More detailed field and laboratory studies are needed, however, before any conclusion is drawn regarding the ways in which termites influence soil development. No accumulations of lime similar to those reported to occur elsewhere (Thorp, 1949) were noted in the mounds examined.

The topography has been important in the formation of the Red Latosols only in so far as the low gentle slopes have prevented observable erosion or mass wasting. The lowest parts of the slopes are occupied by Yellow Latosols and unclassified soils with poor drainage but the areal extents of these two drainage members is very limited.

The period over which soil formation has taken place is difficult to assess. Evidence obtained by Wayland (1919) from what he believed to be the implements of Paleolithic and Neolithic man occurring in the underlying gravels led him to assign the Red Earth Formation to the Pleistocene on the assumption that the Red Earth and basal gravels were contemporaneously deposited. Relation to sea-level changes accompanying the major glacial epochs is risky as this region is known to have been tectonically unstable in the past, (Hanreck and Sirimanne, 1968). Soil development has practically reached a steady state so that inferences regarding age cannot be drawn from the degree of this development. The fact that no major wet phases have occurred since soil formation began, however, lends itself to a "not much older than" type of indirect correlation with the admittedly incomplete evidence of climatic changes gathered from fossils (Deraniyagala, 1958). If the evidence presented by Deraniyagala (ibid.) for the wet Ratnapura phase (corresponding to the Würm glaciation) is applicable to north and north-west Ceylon, the Red Latosols have to be assigned to a period that post-dates this phase. The author, however, prefers to await more definitive evidence from radiometric dating before reaching a conclusion on the age of these soils.

6.5 Classification

The Red Latosols of Ceylon are a sub-group of the Red-Yellow Latosol great soil group in the presently used Ceylonese soil classification. Analytical data obtained by the Land Use Division (unpublished data, 1960-66) and in the course of the present study suggest that the criteria for the base saturation percentages may have to be revised upwards and the methods of exchange analysis now used may have to be changed. In terms of the classification used by the Soil Conservation Service of the United States (Soil Survey Staff, Soil Conservation Service, U.S.D.A., 1970) which is currently employed in Ceylon for purposes of international soil correlation, the Ceylon Red Latosols belong to the Ustox sub-order. The Mullaittivu soils satisfy the requirements of the Eutrustox but the surface horizons of the Gambura and Wilpattu soils are not dark enough or do not show a sufficient chroma difference with the oxic horizons to enter this great group.

The Red Latosols of Ceylon are also similar to the Red Earths of Australia, the Kaolinitic Red Latosols of Brazil and occupy an intermediate position between the Ferrallitic and Ferruginous Tropical (Fersiallitic) soils of Africa.

7. SUMMARY AND CONCLUSIONS

The results of this study show that the Red Latosols of Ceylon are very deep, somewhat excessively drained, dark red to dark reddish brown, slightly acid soils with weak horizon differentiation. Soil structures are weak in the surface horizons and nearly absent at lower depths. Primary weatherable minerals are almost absent and the sand and silt fractions consist largely of quartz and other resistant minerals like magnetite, ilmenite, zircon and rutile. The clay fractions are dominated by well-crystallized kaolinite and hematite but also contain small amounts of mica, mixed layer minerals and, in the Wilpattu Series, a vermiculite-smectite intergrade. The cation exchange capacities which vary considerably with the pH at which they are determined, are generally low. Base saturation percentages are low in the upper B horizons and somewhat higher in the A and lower B horizons, with the Wilpattu Series having slightly higher values. Calcium, magnesium and hydroxy-Al (and possibly hydroxy-Fe) are the predominant cations on the exchange complex but not necessarily in that order of abundance. Differences among the three soil series that constitute the Red Latosol sub-group are manifested mainly in the clay and iron oxide contents and the properties they influence.

The results of the geomorphic and genetic studies showed that the Red Latosols are developed on more or less unweathered Quaternary beach deposits which were uniform with depth and laterally within each soil series but differed considerably, on a regional level, between series. The main pedogenic processes that have been active in the formation of the Red Latosols are (1) uniform deep weathering caused by high temperatures, seasonally high rainfall and rapid infiltration and percolation rates, (2) transformation of iron oxides to hematite, (3) translocation of clay and iron oxides probably by peptization and movement in suspension, (4) leaching of bases partly out of the soil and partly to lower depths and consequent base depletion of the upper B horizons, (5) phytocycling of nutrient cations and consequent resistance to leaching in the surface horizons, (6) rapid mineralization of organic matter and (7) interaction of the small amounts of organic matter present in the surface horizon to produce minor differences in colour, structure and cation exchange properties. The weak horizon differentiation in these soils results principally from uniform weathering to great depths, the spread of illuvial materials over considerable vertical distances and to a lesser extent soil mixing by termites, other fauna and vegetation. The differences among the soil series have resulted, in large measure, from variations in the mineralogy of the parent deposits, in agreement with the initial hypothesis on which the sampling was based.

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APPENDIX

Table A1. Soil Profile Descriptions

Profile No: TP1

Classification: Gambura Series, Red Latosol Sub-group

Location: 21 1/4 M.P. on Mankulam-Vellankulam Rd. (Lat. 9° 18-8'N
Long. 80° 9.75')

Elevation: 9m. above m.s.l.

Landform: Gently undulating coastal plain

Slope: 0.5° Position on slope: Mid-slope

Land Use: Low dry mixed evergreen and deciduous forest with some shrub.
Species: Weera, Kon, Karolla, Ehela (local names)

Surface cover: Nellu (local name) and some leaf litter

Climate: Dry zone (see climatic data for Mannar)

Drainage: Somewhat excessively drained

Parent material: Beach-dune-ridge deposit (Quaternary) now part of
Red Earth Formation

Surface features: Occasional termite mound. No signs of erosion.

Moisture conditions in profile: Dry throughout

Date of description: 4th July, 1969

Macromorphology

Horizon	Depth (cm)	Sample Depth (cm)	Description
A11	0-12	2-10	Dark reddish brown (2.5YR 3/4) (dry and moist); sandy loam; weak sub-angular blocky; soft, very friable; common fine, few medium and coarse discontinuous tubular random inped pores; termite passages; occasional vertical cracks; many fine and few medium roots; clear smooth boundary.
A12	12-25	15-22	Dark red (2.5YR 3/6) (dry) and dark reddish brown (2.5YR 3/4) (moist); sandy clay loam; very weak coarse sub-angular blocky; slightly hard, very friable; few fine and medium and occ. coarse tubular random inped pores; occ. vertical cracks; termite passage fillings; many fine common medium and few large roots; clear smooth boundary.

Profile No: TP1 continued

Horizon	Depth (cm)	Sample Depth (cm)	Description
B21	25-55	30-50	Dark red (2.5YR 3/6) (dry) and dark reddish brown (2.5YR 3/4) (moist); sandy clay; very weak coarse subangular blocky to structureless, massive; slightly hard, slightly firm; common very fine, few fine and occ. medium and coarse tubular random inped pores; termite passage fillings; occ. vertical cracks extend from above horizons; many fine, common medium and few large, roots; diffuse smooth boundary.
B22	55-100	65-90	Dark red (2.5YR 3/6) (dry) and dark red to dark reddish brown (2.5YR 3/5) (moist); sandy clay; very weak coarse sub-angular blocky to structureless, massive; soft and very friable; common fine and medium and occ. coarse tubular random inped pores; occ. termite passages and fillings; many fine, few medium and large, roots; occ. vertical cracks, termite nests; diffuse smooth boundary.
B23	100-145	110-135	Dark red (2.5YR 3/6) (dry) and dark reddish brown (2.5YR 3/4) (moist); sandy clay; very weak coarse subangular blocky to structureless, massive; soft to slightly hard and very friable; few fine medium and coarse tubular random inped pores; occ. termite fillings; common fine, few medium and large, roots; occ. termite nests and vertical cracks; diffuse smooth boundary.
B24	145-235	175-205	Dark red (2.5YR 3/6) (dry) and dark reddish brown (2.5YR 3/4) (moist); sandy clay; very weak coarse subangular blocky to structureless, massive; slightly hard and friable; common fine and medium and few coarse tubular random inped pores; termite passages and fillings; vertical cracks; common fine and medium, few large roots; diffuse smooth boundary.

Profile No: TP1 continued

Horizon	Depth (cm)	Sample Depth (cm)	Description
B25	235-345+	335-345	Dark red (2.5YR 3/6) (dry) and dark reddish brown (2.5YR 3/4) (moist); clay; very weak coarse sub-angular blocky to structureless, massive; slightly hard and friable; common fine and medium tubular random inped pores; occ. termite passages, fillings and nests; vertical cracks; common fine and medium, few large roots.

Micromorphology

Horizon	Depth (cm)	Description
A11	6	Inundulic intertextic and porphyroskelic fabric with interconnected ortho vughs and channels. Plasma strongly stained with organic matter and iron oxides. Very weak grain cutans at high magnification. Phytoliths.
A12	18	Weak skel-vo-insepic inundulic intertextic and porphyroskelic fabric with irregular vughs. Microstructural units slightly larger than above. Phytoliths. Weak embedded grain and vugh argillans.
B21		Not sectioned
B22		Not sectioned
B23	122	Skel-vo-insepic mixed agglomeroplasmic and porphyroskelic fabric. Irregular ortho vughs and few narrow simple skew planes. Embedded grain and occasional skew plane argillans. Some weak vugh argillans seen at high magnification. The plasma is much redder and more translucent than in surface horizons. Grains weathering in place.
B24	190	Fabric similar to above but skew planes are scarce. Some charcoal fragments.
B25	340	Inundulic porphyroskelic and agglomero plasmic fabric. Acicular and irregular ortho vughs. Very thin discontinuous, slightly separated embedded grain argillans. Iron oxide staining quite strong.

Profile No: TP2

Classification: Gambura Series, Red Latosol Sub-group

Location: Near 21 1/2 M.P. on Mankulam-Vellankulam Road (Lat. 9° 18-8'N, Long. 80° 9.5')

Elevation: 9m. above m.s.l.

Landform: Gently undulating coastal plain

Slope: 0.5-0.75° Position on slope: Mid slope

Land Use: Low, dry mixed evergreen and deciduous forest with shrubs.

Species: Wira, Kon, Karolla, Keppitiya, Ehela (local names)

Surface cover: Nellu (local name) and leaf litter

Climate: Dry zone (see climatic data for Mannar)

Drainage: Somewhat excessively drained

Parent material: Beach-dune-ridge (Quaternary) deposits, now part of Red Earth Formation.

Surface features: Occasional termite mound. No signs of erosion

Moisture conditions in profile: Dry throughout

Date of description: 5th July, 1969

Macromorphology

Horizon	Depth (cm)	Sample Depth (cm)	Description
All	0-10	2-10	Dark reddish brown to dark red (2.5YR 3/5) (dry) and dark reddish brown (2.5YR 3/4) (moist); sandy clay loam; weak medium sub-angular blocky; soft to slightly hard and very friable; common fine, few medium and occ. coarse tubular random inped pores; some earthworm casts; termite passages; occ. vertical cracks; many fine, common medium and few large roots; clear smooth boundary.

Profile No: TP2 continued

Horizon	Depth (cm)	Sample Depth (cm)	Description
A12	10-25	12-22	Dark red (2.5YR 3/6) (dry) and dark reddish brown (2.5YR 3/4) (moist); sandy clay loam (finer than above); very weak medium sub-angular blocky; slightly hard and friable; common fine and medium and occ. coarse tubular random inped pores; termite passages and fillings; occ. vertical cracks; many fine, common medium and few large roots; clear smooth boundary.
B21	25-55	30-50	Dark red (2.5YR 3/6) (dry) and dark reddish brown (2.5YR 3/4) (moist); sandy clay; very weak coarse sub-angular blocky to structureless, massive; slightly hard and friable; many very fine, common fine and medium and occ. coarse tubular random inped pores; occ. vertical cracks; root hole and termite passage fillings; many fine, medium and large roots; diffuse smooth boundary.
B22	55-100	65-90	Dark red (2.5YR 3/6) (dry) and dark reddish brown (2.5YR 3/4) (moist); sandy clay; very weak coarse subangular blocky to structureless, massive; soft to slightly hard and very friable; many very fine, common fine and medium and occ. coarse tubular random inped pores; termite nests; root channel fillings; occasional fragments of charcoal; some vertical cracks; many fine, few medium and large, roots; diffuse smooth boundary.
B23	100-145	110-135	Dark red (2.5YR 3/6) (dry) and dark reddish brown (2.5YR 3/4) (moist); sandy clay; very weak coarse subangular blocky to structureless, massive; slightly hard and friable; common fine and medium tubular random inped pores; rare vertical cracks; termite passage fillings and nests; root channel fillings; common fine, few medium and large roots; diffuse smooth boundary.

Profile No: TP2 continued

Horizon	Depth (cm)	Sample Depth (cm)	Description
B24	145-235	175-205	Dark red (2.5YR 3/6) (dry) and dark reddish brown (2.5YR 3/4) (moist); sandy clay; structureless, massive; slightly hard and friable; many very fine and fine and rare coarse tubular random inped pores; occ. termite channel fillings and nests; common fine, few medium and large roots; diffuse smooth boundary.
B25	235-360	275-305 (upper) 345-360 (lower)	Dark red (2.5YR 3/6) (dry) and dark reddish brown (2.5YR 3/4) (moist); sandy clay loam to sandy clay; structureless, massive; hard and friable; sand grains somewhat coarser than above; very fine and fine and rare coarse tubular random inped pores; small nodules of clayey material; fragments of charcoal; occ. termite nest and passage fillings; root channel fillings; few fine and medium roots.

Micromorphology

Horizon	Depth (cm)	Description
A11	6	Skel-insepic inundulic porphyroskelic and intertextic fabric with interconnected ortho vughs. Embedded grain and some free grain argillans. Porphyroskelic parts consist of smaller grains than intertextic parts. Plasma stained strongly by iron oxides and organic matter.
A12	17	Intertextic and agglomeroplasmic areas with skel-insepic inundulic plasmic fabric. Interconnected ortho vughs and channels. Free grain and embedded grain argillans. Organic remains. Phytoliths. Organic matter/iron oxide staining quite strong.
B21	40	Vo-skel-insepic inundulic agglomeroplasmic fabric with intertextic areas. Irregular vughs and channels. Organic remains. Embedded grain and weak vugh argillans. Grains weathering in place.
B22, B23		Not sectioned

Profile No: TP2 continued

Horizon	Depth (cm)	Description
B24	190	Vo-skel-insepic inundulic mixed porphyroskelic and agglomeroplasmic fabric. Irregular ortho and meta vughs. Skew planes and channels. Embedded grain and vugh argillans. Phytoliths. Mineral grains weathering *in situ*.
B25	290	Vo-skel-insepic inundulic porphyroskelic with smaller areas of agglomeroplasmic fabric. Irregular meta vughs and skew planes. Embedded grain and thin vugh argillans. Larger skeletal grains arranged in somewhat linear patterns. Occasional fine sesquioxide nodule. Mineral grains weathering in place.

Profile No: TP3

Classification: Gambura Series, Red Latosol Sub-group

Location: 21 3/4 M.P. on Mankulam-Vellankulam Rd. (Lat. 9° 18-8'N,
Long. 80° 9.25'E)

Elevation: About 9m. above m.s.l.

Landform: Gently undulating coastal plain

Slope: 1/2° Position on slope: Mid-slope

Land Use: Low, dry mixed evergreen and deciduous forest with some shrubs.
Species: Milla, Wal-dehi, Buruta, Kon, Karolla, Kuratiya
(local names)

Surface cover: Thick cover of Nellu (local name) and leaf litter

Climate: Dry zone (see climatic data for Mannar)

Drainage: Somewhat excessively drained

Parent material: Quaternary beach-dune-ridge deposit now part of
Red Earth Formation

Surface features: Occasional termite mound. No signs of erosion

Moisture conditions in profile: Dry throughout

Date of description: 6th July, 1969

Macromorphology

Horizon	Depth (cm)	Sample Depth (cm)	Description
All	0-10	2-8	Dark red (2.5YR 3/6) (dry) and dark reddish brown (2.5YR 3/4) (moist); sandy loam; weak medium sub-angular blocky; soft and very friable; few fine, medium and coarse tubular random inped pores; some earthworm casts; occ. vertical cracks; termite passage fillings; many fine, common medium and large roots; clear smooth boundary.

Profile No: TP3 continued

Horizon	Depth (cm)	Sample Depth (cm)	Description
A12	10-28	12-25	Dark red (2.5YR 3/6) (dry) and dark reddish brown (2.5YR 3/4) (moist); sandy loam; very weak medium sub-angular blocky; slightly hard and friable; common very fine, fine and medium and occ. coarse tubular random inped pores; root and termite channel fillings; occasional vertical cracks; many fine and medium, few large, roots; clear smooth boundary.
B21	28-50	32-45	Dark red (2.5YR 3/6) (dry) and dark reddish brown (2.5YR 3/4) (moist); sandy clay loam; very weak coarse sub-angular blocky to structureless, massive; slightly hard and friable; many very fine, common fine, medium and coarse tubular random inped pores; a few vertical cracks; occ. termite nest; root and termite channel fillings; many fine, few medium and large, roots; gradual smooth boundary.
B22	50-95	60-85	Dark red (2.5YR 3/6) (dry) and dark reddish brown (2.5YR 3/4) (moist); sandy clay; very weak coarse sub-angular blocky to structureless, massive; hard and slightly firm; common very fine and fine and rare coarse tubular random inped pores; vertical cracks; occ. termite nest; root and termite channel fillings; common fine, few medium and large roots; diffuse smooth boundary.
B23	95-140	105-130	Dark red (2.5YR 3/6) (dry) and dark reddish brown (2.5YR 3/4) (moist); sandy clay; very weak coarse subangular blocky to structureless, massive; hard and slightly firm; common very fine and fine, few medium tubular discontinuous random inped pores; root and termite channel fillings; vertical cracks; common fine, few medium and large roots; diffuse smooth boundary.

Profile No: TP3 continued

Horizon	Depth (cm)	Sample Depth (cm)	Description
B24	140-230	165-200	Dark red (2.5YR 3/6) (dry) and dark reddish brown (2.5YR 3/4) (moist); sandy clay; structureless, massive; slightly hard and friable; common very fine and fine, few medium and rare coarse tubular random inped pores; occ. termite nest; few medium and large roots; diffuse smooth boundary.
B25	230-385+	260-310 (upper) 370-385 (lower)	Dark reddish brown (2.5YR 3/4) (dry and moist); sandy clay; structureless, massive; slightly hard and friable; common very fine and fine, few medium tubular discontinuous random inped pores; occ. vertical cracks; few fine, medium and large roots.

Micromorphology

Horizon	Depth (cm)	Description
A11	5	Inundulic intertextic fabric with islands of porphyroskelic material. Interconnected vughs and channels. Free grain and embedded grain argillans visible at high magnifications. Organic remains. Phytoliths. Iron oxide/organic matter soil nodules.
A12	18	Weak vo-skel-insepic inundulic agglomeroplasmic and intertextic fabric with interconnected vughs. Embedded grain and weak vugh argillans. Organic remains. Phytoliths.
B21	39	Vo-skel-insepic inundulic porphyroskelic fabric with intertextic areas. Irregular ortho and meta vughs in the intertextic areas. Embedded grain and vugh argillans. Phytoliths. Organic remains.
B22	72	Skel-vo-insepic porphyroskelic fabric with areas of agglomeroplasmic material. Irregular ortho vughs and narrow skew planes. Embedded grain, vugh and skew plane argillans. Incipient soil nodules. Charcoal fragments. Organic remains *in situ*. weathering of mineral grains.

Profile No: TP3 continued

Horizon	Depth (cm)	Description
B23	118	Vo-skel-insepic inundulic porphyroskelic and agglomeroplasmic fabric. Irregular ortho and meta and interconnected vughs (the latter in the agglomeroplasmic areas) skew planes and channels. Weak embedded grain and vugh argillans. Charcoal fragments. In situ. weathering of mineral grains.
B24	182	Vo-skel-insepic inundulic porphyroskelic fabric with patches which are agglomeroplasmic and intertextic. Irregular ortho and meta vughs and channels. Also some areas of interconnected vughs. Weak embedded grain and vugh argillans. Larger skeletal grains associated with looser fabric. In situ weathering of mineral grains.
B25	285	Skel-insepic inundulic porphyroskelic fabric with patches of agglomeroplasmic fabric. Irregular ortho and meta vughs and skew planes. Embedded grain argillans. Occasional iron oxide rich nodules.

Profile No: MP1

Classification: Mullaittivu Series, Red Latosol Sub-group

Location: 23 1/4 M.P. on Mankulam-Mullaittivu Road

Elevation: 20m. above m.s.l.

Landform: Gently undulating coastal plain

Slope: 1/2° Position on slope: Mid-slope

Land Use: Medium dry mixed evergreen and deciduous forest with lower shrub storey. Species: Milla, Burutha, Welan, Wewarana, Korakaha, Bolpana, Kuratiya, Tharana (local names)

Surface cover: Leaf litter

Climate: Dry zone (see climatic data for Mullaittivu)

Drainage: Somewhat excessively drained

Parent material: Quaternary beach-dune-ridge deposit

Surface features: Occasional termite mound. No signs of erosion

Moisture conditions in profile: Dry throughout

Date of description: 11th July, 1969.

Macromorphology

Horizon	Depth (cm)	Sample Depth (cm)	Description
All	0-5	0-5	Dark reddish brown (5YR 3/3) and reddish brown (5YR 5/3) (dry); reddish brown (5YR 4/4) (moist); loamy sand; very weak coarse crumb; loose; earthworm casts and termite passages; many fine medium and large roots; abrupt wavy boundary.

Profile No: MP1 continued

Horizon	Depth (cm)	Sample Depth (cm)	Description
A12	5-18	8-15	Yellowish red to red (5YR to 2.5YR 4/6) (dry) and reddish brown (5YR 5/3) (moist); sandy loam; weak medium sub-angular blocky; soft and friable; common fine, few medium and occ. coarse tubular random inped pores; occ. earthworm casts; few small fragments of charcoal; many fine, common medium and few large roots; termite and root hole fillings; occ. termite nest; some earthworm casts; few vertical cracks; clear smooth boundary.
B21	18-48	22-42	Red (2.5YR 4/6) (dry) and dark red (2.5YR 3/6) (moist); very weak coarse sub-angular blocky to structureless, massive; slightly hard and friable; common very fine and fine, few medium and occ. coarse tubular random inped pores; termite and root channel fillings; some fragments of charcoal; termite nests; few vertical cracks; common fine, few medium and large roots; gradual smooth boundary.
B22	48-92	57-82	Red (2.5YR 4/6) (dry) and dark red (2.5YR 3/6) (moist); sandy clay loam; very weak coarse sub-angular blocky to structureless, massive; slightly hard and friable; common very fine, few fine and occ. coarse tubular random inped pores; largely termite passages; few termite nests; termite and root channel fillings; occ. fragments of charcoal; vertical cracks; common fine, few medium and large, roots; diffuse smooth boundary.
B23	92-138	102-128	Red (2.5YR 4/6) (dry) and dark red (2.5YR 3/6) (moist); sandy clay loam to sandy clay; very weak coarse subangular blocky to structureless, massive; slightly hard and friable; common very fine, occ. fine and medium and coarse tubular random inped pores; some termite and root channel fillings; termite nest; rare cracks; common fine, few medium and large roots; diffuse smooth boundary.

Profile No: MP1 continued

Horizon	Depth (cm)	Sample Depth (cm)	Description
B24	138-228	170-200	Red (2.5YR 4/6) (dry) and dark red (2.5YR 3/6) (moist); sandy clay; structureless, massive; soft to slightly hard and friable; common very fine, few fine,occasional medium and rare coarse tubular random inped pores; mostly termite passages; termite passage and root fillings (rare); fragments of charcoal; rare cracks; few fine and medium roots; diffuse smooth boundary.
B25	228-455	300-330 (upper) 485-492 (lower)	Red (2.5YR 4/6) (dry) and dark red (2.5YR 3/6) (moist); sandy clay; structureless, massive; slightly hard and friable; common very fine, few fine and occ. medium and rare coarse tubular random inped pores, rare termite nests and passages; root fillings; very few fine and medium roots. The proportion of quartz gravel and very coarse sand increases in the lower part of this horizon.

Micromorphology

Horizon	Depth (cm)	Description
A11	3	Isotic intertextic and agglomeroplasmic fabric with irregular and interconnected vughs. Channels. Normal soil nodule. Phytoliths. Organic remains.
A12	12	Undulic agglomeroplasmic and intertextic fabric. Irregular ortho vughs, interconnected vughs and channels. Very thin discontinuous embedded grain and vugh argillans visible under high magnification. Phytoliths. Organic remains.
B21	32	Inundulic porphyroskelic and intertextic fabric with irregular ortho vughs and interconnected vughs. Channels. Very thin discontinuous embedded grain and vugh argillans. Phytoliths. Organic remains. Less organic staining than above.

Profile No: MP1 continued

Horizon	Depth (cm)	Description
B22	70	Inundulic porphyroskelic fabric with small areas of intertextic fabric. Ortho and meta irregular vughs and areas of interconnected vughs. Skew planes, channels. Very thin, embedded grain and vugh argillans. Organic remains.
B23	115	Weak skel-vo-insepic inundulic porphyroskelic fabric with agglomeroplasmic areas. Irregular meta vughs, channels and skew planes. Thin discontinuous embedded grain and void argillans.
B24	185	Weak vo-skel-insepic inundulic porphyroskelic fabric with slightly elongated ortho and meta vughs. Skew planes. Weak discontinuous embedded grain and vugh argillans. Grains weathering in place.
B25	315	Skel-insepic agglomeroplasmic and porphyroskelic fabric with irregular ortho vughs and interconnected vughs. Skew planes. Embedded grain and weak vugh argillans. Fine sesquioxide nodules.

Profile No: MP2

Classification: Mullaittivu Series, Red Latosol Sub-group

Location: 21 1/2 M.P. on Mankulam-Mullaittivu Road

Elevation: 54m. above m.s.l.

Landform: Gently undulating coastal plain

Slope: 3/4° Position on slope: Mid-slope

Land Use: Medium to tall dry mixed evergreen and deciduous forest with lower shrub storey. Tree species: Welan, Kuma, Palu, Burutha, Milla, Bolpana, Ulkenda, Tharana, Kuratiya, Korakaha (local names)

Surface cover: Leaf litter

Climate: Dry zone (see climatic data for Mullaittivu)

Drainage: Somewhat excessively drained

Parent material: Quaternary beach-dune-ridge deposit

Surface features: Occasional termite mound. No erosion

Moisture condition in profile: Dry throughout

Date of description: 13th July, 1969

Macromorphology

Horizon	Depth (cm)	Sample Depth (cm)	Description
All	0-8	2-8	Reddish brown (5YR 4/3) (dry) and dark reddish brown (5YR 3/3) (moist); loamy sand; very weak medium crumb; soft and loose to very friable; common very fine and fine tubular and interstitial random inped pores; earthworm casts; termite and root holes; many fine and medium and few large roots; occ. vertical cracks; abrupt smooth boundary.

Profile No: MP2 continued

Horizon	Depth (cm)	Sample Depth (cm)	Description
A12	8-22	10-20	Reddish brown (5YR 4/3) (dry) and dark reddish brown (5YR 3/3) (moist); sandy loam; weak medium sub-angular blocky; slightly hard and friable; many very fine and fine common medium and occ. coarse tubular random inped pores; occ. fragments of charcoal; termite passage and root channel fillings; occ. vertical cracks; few earthworm casts; occ. termite nests; many fine, common medium and few large roots; clear smooth boundary.
B21	22-52	28-48	Dark red (2.5YR 3/6) (dry) and dark reddish brown (2.5YR 3/4) (moist); sandy clay loam; very weak coarse sub-angular blocky to structureless, massive; hard and friable to slightly firm; many very fine and fine, common medium and occ. coarse tubular random inped pores; vertical cracks; occ. termite nests, passages and passage fillings; some root channel fillings; many fine, common medium and few large roots; gradual smooth boundary.
B22	52-98	62-85	Dark red to red (2.5YR 3.5/6) (dry) and dark red (2.5YR 3/6) (moist); sandy clay loam; very weak coarse sub-angular blocky to structureless, massive; slightly hard and friable; common very fine, fine and medium and occ. coarse tubular random inped pores; termite passages, passage fillings and nests; root channel fillings; occ. vertical cracks; common fine, few medium and large roots; diffuse smooth boundary.
B23	98-142	108-135	Red (2.5YR 4/6) (dry) and dark red (2.5YR 3/6) (moist); sandy clay loam to sandy clay; very weak coarse sub-angular blocky to structureless, massive; slightly hard and friable; common very fine, fine and medium and occ. coarse tubular random inped pores; occ. termite nests, passages and passage fillings;

Profile No: MP2 continued

Horizon	Depth (cm)	Sample Depth (cm)	Description
			occ. fragments of charcoal; few vertical cracks; common fine, few medium and large roots; diffuse smooth boundary.
B24	142-232	172-202	Red (2.5YR 4/6) (dry) and dark red (2.5YR 3/6) (moist); sandy clay; structureless, massive; slightly hard and friable; common very fine and fine, few medium and occ. coarse tubular random inped pores; larger pores are mostly termite passages; termite passage and root channel fillings; occ. vertical cracks; common fine, few medium and large roots; diffuse smooth boundary.
B25	232-335	300-330	Red (2.5YR 4/6) and dark red (2.5YR 3/6) (moist); sandy clay; structureless, massive; slightly hard and friable; occ. gravel; sand is coarser than above; common very fine and fine, few medium and occ. coarse tubular random inped pores; rare termite nests, termite passages and root channel fillings; few fine, medium and large roots.

Micromorphology

Horizon	Depth (cm)	Description
A11	5	Isotic to undulic intertextic fabric with small islands of agglomeroplasmic fabric. Interconnected and irregular vughs. Weak embedded grain and free grain argillans. Organic remains. Phytoliths.
A12	15	Undulic intertextic fabric with islands of porphyroskelic material. Irregular and interconnected vughs. Weak embedded grain argillans. Organic remains. Phytoliths. Soil nodules.
B21	38	Skel-vo-insepic inundulic porphyroskelic fabric with intertextic areas. Irregular ortho and meta vughs and channels. Vugh and embedded grain argillans. Organic remains. Phytoliths. Plasma more translucent and redder than above.

Profile No: MP2 continued

Horizon	Depth (cm)	Description
B22	74	Vo-skel-insepic porphyroskelic and intertextic compound fabric. Irregular and acicular vughs. Channels. Skew planes. Vugh and embedded grain argillans. Grains weathering in place.
B23	121	Vo-skel-insepic agglomeroplasmic fabric with areas of intertextic and porphyroskelic material. Irregular and interconnected vughs. Embedded grain and vugh argillans. *In situ* weathering of grains.
B24	187	Vo-skel-insepic porphyroskelic fabric with agglomeroplasmic areas, the latter chiefly associated with larger skeletal grains. Irregular ortho vughs, channels and skew planes. Embedded grain and void cutans. Occasional soil nodules. *In situ* weathering of grains.
B25	315	Vo-skel-insepic porphyroskelic fabric with agglomeroplasmic areas. Irregular ortho vughs. Interconnected vughs, channels and skew planes. Embedded grain cutans and some weak vugh and channel argillans. Grains weathering in place.

Profile No: MP3

Classification: Mullaittivu Series, Red Latosol Sub-group

Location: 8 1/8 M.P. on Mullaittivu-Nedunkerni Road

Elevation: 60m. above m.s.l.

Landform: Gently undulating coastal plain

Slope: 1° Position on slope: Upper mid-slope

Land Use: Medium to tall dry mixed evergreen and deciduous forest with a lower shrub storey. Tree species: Kuma, Wewarana, Wira, Welan, Buruta, Tharana, Ulkenda, Bolpana, Waldehi (local names)

Surface cover: Leaf litter

Climate: Dry zone (see climatic data for Mullàittivu)

Drainage: Somewhat excessively drained

Parent material: Quaternary beach-dune-ridge deposit

Surface features: Occasional termite mound; no signs of erosion

Moisture conditions in profile: Dry throughout

Date of description: 14th July, 1969

Macromorphology

Horizon	Depth (cm)	Sample Depth (cm)	Description
A11	0-8	2-8	Reddish brown (5YR to 2.5YR 4/4) (dry) and dark reddish brown (5YR to 2.5YR 3/4) (moist); loamy sand; weak medium crumb; loose to soft and loose to very friable; many very fine and fine, common medium and occ. coarse tubular and interstitial random inped and exped pores; coarse pores are mainly termite passages; occ. vertical cracks; some earthworm casts; many fine and medium, few large roots; abrupt smooth boundary.

Profile No: MP3 continued

Horizon	Depth (cm)	Sample Depth (cm)	Description
A12	8-25	10-22	Reddish brown (2.5YR 4/4) (dry) and dark reddish brown (2.5YR 3/4) (moist); sandy clay loam; weak medium sub-angular blocky; soft and very friable; common very fine, few fine and occ. medium and coarse tubular random inped pores; common fragments of charcoal; root holes and termite passage fillings; occ. vertical cracks; many fine, common medium and few large roots; gradual smooth boundary.
B21	25-55	30-50	Red (2.5YR 4/6) (dry) and dark red (2.5YR 3/6) (moist); sandy clay loam, finer than above; very weak coarse sub-angular blocky to structureless, massive; many very fine and fine, common medium and occ. coarse tubular random inped pores; rare small pellets of soil; occ. termite nest; termite passage and root channel fillings; occ. vertical cracks; occ. fragments of charcoal; many fine, common medium and few large roots; diffuse smooth boundary.
B22	55-100	65-90	Red (2.5YR 4/6) (dry) and dark red (2.5YR 3/6) (moist); sandy clay loam to sandy clay; very weak coarse sub-angular blocky to structureless, massive; slightly hard and friable; common very fine, fine and medium and occ. coarse tubular random inped pores; occ. vertical cracks, fragments of charcoal and termite nests; root hole and termite passage fillings; many fine, common medium and few large roots; diffuse smooth boundary.
B23	100-145	110-135	Red (2.5YR 4/6) (dry) and dark red 2.5YR 3/6) (moist); sandy clay; very weak coarse sub-angular blocky to structureless, massive; slightly hard and friable; common very fine and fine, few medium and occ. coarse tubular random inped pores; occ. termite nests and termite passage and root channel fillings; occ. fragments of charcoal, vertical cracks; common fine, few medium and large roots; diffuse smooth boundary.

Profile No: MP3 continued

Horizon	Depth (cm)	Sample Depth (cm)	Description
B24	145-235	175-205	Red (2.5YR 4/6) (dry) and dark red (2.5YR 3/6) (moist); sandy clay; very weak coarse sub-angular blocky to structureless, massive; slightly hard and friable; common very fine and fine, occ. medium tubular random inped pores; occ. vertical cracks; rare termite nests, passages and root channel fillings; common fine and few medium and large roots; diffuse smooth boundary.
B25	235-368+	300-338	Red (2.5YR 4/6) (dry) and dark red (2.5YR 3/6) (moist); sandy clay; very weak coarse sub-angular blocky to structureless, massive; slightly hard to hard and friable to firm; common very fine and fine, occ. medium tubular random inped pores; occ. vertical cracks extend halfway through this horizon; few medium and large roots.

Micromorphology

Horizon	Depth (cm)	Description
A11	5	Isotic to undulic intertextic fabric with small porphyroskelic islands. Interconnected vughs and channels and chambers. Occasional free grain cutans. Organic remains. Phytoliths.
A12	16	Isotic to undulic intertextic fabric with small porphyroskelic and agglomeroplasmic areas. Irregular ortho and few meta vughs. Channels. Weak embedded grain cutans. Phytoliths. Organic remains. Less organic staining than above.
B21	40	Inundulic mixed porphyroskelic, agglomeroplasmic and intertextic fabric. Interconnected vughs and irregular ortho and meta vughs. Channels. Embedded grain and weak vugh argillans. Phytoliths. Organic remains. Matrix more translucent than above.

Profile No: MP3 continued

Horizon	Depth (cm)	Description
B22	77	Weak skel-vo-insepic inundulic agglomeroplasmic and porphyroskelic fabric. Irregular and interconnected vughs and some partially filled channels. Skew planes. Embedded grain and void cutans. Phytoliths. Grains weathering in place.
B23	122	Skel-vo-insepic inundulic agglomeroplasmic fabric with areas of porphyroskelic fabric. Irregular meta and ortho vughs and some areas of interconnected vughs. Channels, some partially filled. Embedded grain, plane and void cutans. Phytoliths. Grains weathering in place.
B24	190	Skel-vo-insepic agglomeroplasmic fabric with porphyroskelic areas. Irregular and acicular ortho and meta vughs. Skew planes. Channels. Embedded grain, vugh and plane cutans. Grains weathering *in situ*.
B25	319	Inundulic porphyroskelic fabric. Irregular and acicular vughs, both ortho and meta types. Many skew planes. Very weak grain and vugh cutans.

Profile No: PP1

Classification: Wilpattu Series, Red Latosol Sub-group

Location: One mile N. of 4th M.P. on Anuradhapura-Puttalam Road

Elevation: About 15m. above m.s.l.

Landform: Gently undulating coastal plain

Slope: 1/2° Position on slope: Upper mid

Land Use: Medium dry mixed evergreen and deciduous forest with lower shrub storey. Species: Wira, Welan, Bora-damana, Bulupitiya, Ulkenda, Bolpana, Korakaha, Kuratiya (local names).

Surface cover: Leaf litter

Climate: Dry zone (see climatic data for Puttalam)

Drainage: Somewhat excessively drained to excessively drained

Parent material: Quaternary beach-dune-ridge deposit

Surface features: Occasional termite mound. No evidence of erosion

Moisture conditions in the profile: Dry throughout

Date of description: 2nd August, 1969

Macromorphology

Horizon	Depth (cm)	Sampling Depth (cm)	Description
All	0-8	0-8	Dark red (2.5YR 3/6) (dry) and dark reddish brown (2.5YR 3/4) (moist); sand; very weak medium subangular blocky to structureless, single grain; loose; common very fine, fine and medium tubular and vescicular inped pores; some earthworm casts and termite passages; occ. vertical cracks; many fine and medium, common large roots; clear smooth boundary.

Profile No: PP1 continued

Horizon	Depth (cm)	Sample Depth (cm)	Description
A12	8-18	10-15	Dusky red (10R 3/4) (dry) and dusky red (10R 3/3) (moist); sand; weak coarse sub-angular blocky; soft and very friable; many very fine and fine and few medium and coarse vescicular inped pores; occ. vertical cracks; occ. earthworm casts and termite nests; many fine and medium, common large, roots; clear smooth boundary.
B21	18-48	22-42	Dusky red (10R 3/4) (dry) and dusky red (10R 3/3) (moist); sandy loam; very weak coarse sub-angular blocky to structureless, massive; soft to slightly hard and very friable; many very fine and fine vescicular random inped pores; occ. vertical cracks; root hole and termite passage fillings and nests; many fine, common medium and few large roots; gradual smooth boundary.
B22	48-92	60-82	Dusky red (10R 3/4) (dry) and dusky red (10R 3/3) (moist); sandy loam, finer than above; slightly hard and very friable; many very fine and fine and occ. medium and coarse vescicular inped pores; occ. fragments of charcoal and termite nests with fillings; many fine, few medium and large roots; diffuse smooth boundary.
B23	92-182	125-150	Dusky red (10R 3/4) (dry) and dusky red (10R 3/3) (moist); sandy clay loam; structurelesss massive; hard and friable; some pores as above; occ. vertical cracks with fillings from above; few fine, medium and large roots; diffuse smooth boundary.

Profile No: PP1 continued

Horizon	Depth (cm)	Sample Depth (cm)	Description
B24	182-315	250-300	Dusky red (10R 3/4) (dry) and dusky red (10R 3/3) (moist); sandy clay loam; structureless, massive; hard and friable; same pores as above; occ. vertical cracks; few fine medium and large roots.

Micromorphology

Horizon	Depth (cm)	Description
A11	4	Granular fabric with very small intertextic areas. Strongly interconnected vughs. Chambers and channels. Free grain argillans. Sesquioxidic soil nodules. Organic remains. Phytoliths. Mineral particles weathering in situ.
A12	12	Isotic granular to intertextic fabric. Strongly interconnected vughs. Free grain cutans. Organic remains. Phytoliths.
B21	32	Vo-skel-insepic inundulic intertextic fabric with areas which are granular. Interconnected vughs. Free grain and vugh cutans. Organic remains. Phytoliths.
B22	71	Skel-vo-insepic intertextic fabric with interconnected vughs. Free grain, embedded grain and vugh cutans. Organic remains. Phytoliths. Mineral grain decomposing in place.
B23		Not sectioned
B24	275	Skel-vo-mosepic porphyroskelic and intertextic fabric. Irregular vughs. Interconnected vughs in the intertextic areas. Embedded grain and vugh argillans. Organic remains.

Profile No: PP2

Classification: Wilpattu Series, Red Latosol Sub-group

Location: 4th M.P. on Anuradhapura-Puttalam Road

Elevation: About 12m. above m.s.l.

Landform: Gently undulating coastal plain

Slope: 45' Position on slope: Upper mid

Land Use: Medium dry mixed evergreen and deciduous forest with lower shrub storey. Species: Burutha, Wira, Kohomba, Welan, Galwelan, Bolpana, Kuratiya, Keppitiya, Korakaha (local names)

Surface cover: Thin patchy cover of Cytococcum Trigonum and leaf litter

Climate: Dry zone (see climatic data for Puttalam)

Drainage: Somewhat excessively drained to excessively drained

Parent material: Quaternary beach-dune-ridge deposit

Surface features: Occasional termite mound. No evidence of erosion

Moisture conditions in the profile: Dry throughout

Date of description: 1st August, 1969

Macromorphology

Horizon	Depth (cm)	Sample Depth (cm)	Description
All	0-15	2-12	Dark red (2.5YR 3/6) (dry) and dark reddish brown (2.5YR 3/4) (moist); sand; very weak medium sub-angular blocky; loose to soft and loose to very friable; many very fine, common fine, few medium and coarse tubular and interstitial inped pores; termite passages, earthworm casts; many fine and medium, common large roots; clear smooth boundary.

Profile No: PP2 continued

Horizon	Depth (cm)	Sample Depth (cm)	Description
A12	15-28	18-25	Dark red (2.5YR 3/6) (dry) and dark reddish brown (2.5YR 3/4) (moist); loamy sand; weak medium subangular blocky; soft and very friable; many very fine, common fine and occ. coarse tubular and interstitial inped pores; occ. termite passages, vertical cracks termite nests; termite passage and root channel fillings; many fine and medium, common large roots; clear smooth boundary.
B21	28-72	35-65	Dusky red (10R 3/4) (dry) and dusky red (10R 3/3) (moist); sandy loam to sandy clay loam; very weak coarse sub-angular blocky to structureless, massive; soft to slightly hard and very friable; same pores as above; some termite passages, passage fillings and nests; occ. vertical cracks; fragments of charcoal; many fine, common medium and few large roots; gradual smooth boundary.
B22	72-118	82-110	Dark red (2.5YR 3/6) (dry) and dark reddish brown (2.5YR 3/4) (moist); sandy clay loam; very weak coarse sub-angular blocky to structurelesss, massive; slightly hard and very friable; same pores as above; occ. termite passages, nests and passage fillings; occ. vertical cracks; common fine and medium and few large roots; diffuse smooth boundary.
B23	118-208	150-175	Dark red (2.5YR 3/6) (dry) and dark reddish brown (2.5YR 3/4) (moist); sandy clay loam; structureless, massive; hard and slightly firm; many fine, common medium and occ. coarse tubular and interstitial random pores; termite passages and passage fillings; few termite nests; occ. vertical cracks; common fine and medium and few large roots; diffuse smooth boundary.

Profile No: PP2 continued

Horizon	Depth (cm)	Sample Depth (cm)	Description
B24	208-265+	225-250	Dusky red (10R 3/4) (dry) and dusky red (10R 3/3) (moist); sandy clay loam; structureless, massive; hard to very hard and firm; many fine, common medium and occ. coarse tubular and interstitial random inped pores; rare termite passages and nests; very occ. vertical cracks; few fine and medium roots.

Micromorphology

Horizon	Depth (cm)	Description
A11	7	Isotic granular to intertextic fabric with small porphyroskelic islands. Strongly interconnected vughs. Weak free-grain cutans. Organic remains. Phytoliths. Sesquioxidic soil nodules.
A12	22	Skel-insepic inundulic intertextic fabric with some granular areas. Interconnected vughs. Channels. Free grain argillans. Phytoliths. Organic remains. Skeletal grain decomposing *in situ*.
B21	50	Skel-vo-insepic inundulic intertextic fabric with more plasma than above and porphyroskelic islands. Interconnected vughs. Free grain and vugh argillans. Phytoliths. Matrix more translucent than above.
B22	96	Vo-skel-insepic intertextic fabric with small islands of porphyroskelic material. Interconnected vughs, channels. Free grain and void argillans. Phytoliths.
B23	162	Vo-skel-insepic porphyroskelic and intertextic fabric. Irregular and acicular vughs and interconnected vughs in the intertextic areas. Channels. Embedded grain and weak vugh argillans.
B24	237	Weak vo-skel-insepic inundulic porphyroskelic and intertextic fabric with irregular vughs. Some interconnected vughs. Embedded grain, free grain and weak vugh argillans.

Profile No: PP3

Classification: Wilpattu Series, Red Latosol Sub-group

Location: 1/4 mile on Kaladi Road from 4 M.P. on Anuradhapura-Puttalam Road

Elevation: About 10m. above m.s.l.

Landform: Gently undulating coastal plain

Slope: 1° 55' Position on slope: Upper mid

Land Use: Medium dry mixed evergreen and deciduous forest with lower shrub storey. Species: Wira, Welan, Kohomba, Galwelan, Mora, Gadumba, Bolpana, Tharana, Kuratiya, Korakaha (local names)

Surface cover: Leaf litter

Climate: Dry zone (see climatic data for Puttalam)

Drainage: Somewhat excessively drained to excessively drained

Parent material: Quaternary beach-dune-ridge deposit

Surface features: Occasional termite mound. No evidence of erosion

Moisture conditions in profile: Dry throughout

Date of description: 3rd August, 1969

Macromorphology

Horizon	Depth (cm)	Sample Depth (cm)	Description
All	0-12	0-12	Reddish brown (2.5YR 4/4) (dry) and dark reddish brown (2.5YR 3/4) (moist); sand to loamy sand; weak medium sub-angular blocky to structureless, single grain; loose; common medium and coarse, tubular and interstitial random inped pores; some earthworm casts; many fine, medium and large roots; clear smooth boundary.

Profile No: PP3 continued

Horizon	Depth (cm)	Sample Depth (cm)	Description
A12	12-32	15-30	Dark red (2.5YR 3/6) (dry) and dark reddish brown (2.5YR 3/4) (moist); loamy sand; weak coarse subangular blocky; loose to soft and very friable; common very fine and fine and occ. medium and coarse vescicular tubular and interstitial inped pores; termite passages and passage fillings and occ. termite nest; occ. vertical cracks; many fine and medium, common large, roots; gradual smooth boundary.
B21	32-62	38-58	Weak red (10R 4/4) (dry and moist); loamy sand to sandy loam; very weak coarse sub-angular blocky to structureless, massive; soft and very friable; many very fine and fine and occ. medium and coarse tubular and vescicular inped pores; occ. vertical cracks; root hole and termite passage fillings; occ. termite nests; many fine, common medium and large roots; gradual smooth boundary.
B22	62-108	75-95	Weak red (10R 4/4) (dry and moist); sandy loam; very weak coarse sub-angular blocky to structureless, massive; soft and very friable; same pores as above; occ. termite passages, nests and passage fillings; few root hole fillings; occ. fragments of charcoal; common fine, few medium and large roots; diffuse smooth boundary.
B23	108-198	125-175	Dark red (10R 3/6) (dry) and dusky red (10R 3/4) (moist); sandy clay loam; structureless, massive; soft and very friable; same pores as above; occ. vertical cracks; rare termite nests; few fine, medium and large roots; diffuse smooth boundary.

Profile No: PP3 continued

Horizon	Depth (cm)	Sample Depth (cm)	Description
B24	198-375+	312-350	Dark red (10R 3/6) (dry and moist); sandy clay loam; structureless, massive; hard and slightly moist; same pores as above; rare termite nests; occ. root channel filling and vertical cracks.

Micromorphology

Horizon	Depth (cm)	Description
A11	6	Isotic granular to intextic fabric with small islands of porphyroskelic fabric. Strongly interconnected vughs. Weak free grain argillans. Phytoliths. Plant remains.
A12	22	As above but the s-matrix is undulic and slightly more translucent. Also the intertextic character is greater than above.
B21	48	As above
B22	85	Vo-skel-insepic inundulic intertextic fabric with areas that are granular to intertextic. Interconnected vughs. Channels. Grain and weak vugh argillans. Phytoliths.
B23	150	Vo-skel-insepic inundulic intertextic fabric with small porphyroskelic areas. Interconnected and irregular vughs. Grain and vugh argillans.
B24	331	Vo-skel-insepic intertextic fabric with agglomeroplasmic areas. Interconnected and irregular vughs. Grain and weak vugh argillans.

Table A2. Particle Size Distributions In Profiles of the Gambura Series[1] - Free Iron Oxides Not Removed

Profile	Horizon	Sample Depth (cm.)	Gravel (>2mm.)	Sand 2.0-.05 mm.	Silt .05-.002 mm.	Clay <2μ
TP_1	A_{11}	2-10	Tr	79	6	15
	A_{12}	15-22	Tr	69	5	26
	B_{21}	30-50	Tr	54	5	41
	B_{22}	65-90	Tr	51	4	45
	B_{23}	110-135	Tr	45	4	51
	B_{24}	175-205	Tr	50	3	47
	B_{25}(u)	335-345	1	43	7	49
TP_2	A_{11}	2-10	Tr	73	6	21
	A_{12}	12-22	Tr	70	5	25
	B_{21}	30-50	Tr	58	4	38
	B_{22}	65-90	Tr	53	3	44
	B_{23}	110-135	Tr	47	3	50
	B_{24}	175-205	Tr	48	2	50
	B_{25}(u)	275-305	Tr	47	4	49
	B_{25}(L)	345-360	2	44	5	49
TP_3	A_{11}	2-8	Tr	82	3	15
	A_{12}	12-25	Tr	80	3	17
	B_{21}	32-45	Tr	66	3	31
	B_{22}	60-85	Tr	56	3	41
	B_{23}	105-130	Tr	55	4	41
	B_{24}	165-200	Tr	54	5	41
	B_{25}(u)	260-310	Tr	55	5	40
	B_{25}(L)	370-385	1	50	6	43

1. Recoveries of 98-102 percent. Values adjusted to 100 percent.
2. Tr = Trace (<0.5 percent).

Table A3. Particle Size Distributions in Profiles of the Mullaittivu Series[1] - Free Oxides Not Removed

Profile	Horizon	Sample Depth (cm.)	Gravel >2mm.	Sand 2.0-0.5 mm.	Silt 0.05-0.002 mm.	Clay <2μ
MP_1	A_{11}	0-5	Tr[2]	85	4	11
	A_{12}	8-15	Tr	80	4	16
	B_{21}	22-42	Tr	70	4	26
	B_{22}	57-82	Tr	65	2	33
	B_{23}	102-128	Tr	61	4	35
	B_{24}	170-200	Tr	60	4	36
	B_{25}(u)	300-330	2	55	5	38
	B_{25}(L)	485-492	7	53	5	35
MP_2	A_{11}	2-8	Tr	85	4	11
	A_{12}	10-20	Tr	80	4	16
	B_{21}	28-48	Tr	71	4	25
	B_{22}	62-85	Tr	62	4	34
	B_{23}	108-135	Tr	60	5	35
	B_{24}	172-202	Tr	60	4	36
	B_{25}	300-330	1	56	4	39
MP_3	A_{11}	2-8	Tr	85	3	12
	A_{12}	10-22	Tr	75	4	21
	B_{21}	30-50	Tr	65	5	30
	B_{22}	65-90	Tr	60	5	35
	B_{23}	110-135	Tr	59	1	40
	B_{24}	175-205	Tr	56	4	40
	B_{25}	300-338	2	55	6	37

1. Recoveries of 98-102 percent. Values adjusted to 100 percent.
2. Tr = Trace (<0.5 percent).

Table A4. Particle Size Distributions in Profiles of the Wilpattu Series[1] - Free Oxides Not Removed

Profile	Horizon	Sample Depth	Gravel >2mm.	Sand 2.0-0.5 mm.	Silt 0.05-0.002 mm.	Clay <2μ
PP_1	A_{11}	0-8	Tr[2]	92	2	6
	A_{12}	10-15	Tr	90	3	7
	B_{21}	22-42	Tr	83	3	14
	B_{22}	60-82	Tr	73	3	19
	B_{23}	125-150	Tr	68	6	26
	B_{24}	250-300	Tr	69	4	27
PP_2	A_{11}	2-12	Tr	90	2	8
	A_{12}	18-25	Tr	86	2	12
	B_{21}	35-65	Tr	78	2	20
	B_{22}	82-110	Tr	76	3	21
	B_{23}	150-175	Tr	71	2	27
	B_{24}	225-250	Tr	68	2	30
PP_3	A_{11}	0-12	Tr	89	2	9
	A_{12}	15-30	Tr	86	2	12
	B_{21}	38-58	Tr	84	2	14
	B_{22}	75-95	Tr	81	1	18
	B_{23}	125-175	Tr	74	3	23
	B_{24}	312-350	Tr	73	1	26

1. Recoveries of 98-102 percent. Values adjusted to 100 percent.
2. Tr = Trace (<0.5 percent).

Table A5. Means and Ranges of P.S.D.A. Results - Free Iron Oxides Not Removed

Series	Horizon	Means			Ranges		
		Sand	Silt	Clay	Sand	Silt	Clay
Gambura	A_{11}	78	5	17	73-82	3-6	15-21
	A_{12}	73	4	23	69-80	3-5	17-26
	B_{21}	59	4	37	54-66	3-5	31-41
	B_{22}	53	4	43	51-56	3-4	41-45
	B_{23}	49	4	47	45-55	3-4	41-51
	B_{24}	51	3	46	48-54	2-5	41-50
	B_{25}(u)	48	5	46	43-55	4-7	40-49
	B_{25}(L)	47	6	46	45-51	5-6	43-49
Mullaittivu							
	A_{11}	85	4	11	85-85	3-4	11-12
	A_{12}	78	4	18	75-80	4-4	16-21
	B_{21}	69	4	27	65-71	4-5	25-30
	B_{22}	62	4	34	60-65	2-5	33-35
	B_{23}	60	3	37	59-61	1-5	36-40
	B_{24}	59	5	36	56-60	4-7	33-40
	B_{25}(u)	55	5	38	56-57	4-6	38-39
	B_{25}(L)	53	5	35	--	--	--
Wilpattu	A_{11}	90	2	8	89-92	2-2	6-9
	A_{12}	87	2	11	86-90	2-3	7-12
	B_{21}	82	2	16	78-84	2-3	14-20
	B_{22}	78	2	20	76-81	1-3	18-21
	B_{23}	71	4	25	68-74	2-6	23-27
	B_{24}	70	2	28	68-73	1-4	26-30

Table A6. Particle Size Distribution of Selected Samples After Removal of Free Iron Oxides[1] - Percentages[2] Based On <2mm. Soil After Removal of Oxides

Profile and Series	Horizon	Sampling Depth (cm.)	Sand 2-0.05	Coarse Silt 50-20 µ	Fine Silt 20-2 µ	Total Silt 50-2 µ	Coarse Clay 2-0.2 µ	Fine Clay <0.2 µ	Total Clay <2 µ
TP$_1$ (Gambura Series)	A_{11}	2-10	83.0	2.4	2.8	5.2	4.5	7.3	11.8
	A_{12}	15-22	73.9	2.3	2.5	4.8	6.1	15.2	21.3
	B_{21}	30-50	59.0	2.1	1.7	3.8	9.3	27.9	37.2
	B_{22}	65-90	55.5	2.1	1.9	4.0	11.2	29.3	40.5
	B_{23}	110-135	49.4	1.9	2.2	4.1	13.2	33.3	46.5
	B_{24}	175-205	54.9	1.9	3.7	5.6	13.8	25.7	39.5
	B_{25}	335-345	48.3	4.2	8.2	12.4	15.4	23.9	39.3
TP$_2$ (Gambura Series)	A_{11}	2-10	78.7	1.7	3.8	5.5	7.7	8.1	15.8
	B_{21}	30-50	66.4	1.8	2.0	3.8	3.8	9.9	19.9
	B_{25}(u)	275-305	52.5	3.4	7.8	11.2	15.2	21.1	36.3
MP$_1$ (Mullai-ttivu Series)	A_{11}	0-5	87.8	2.0	1.3	3.3	4.2	4.7	8.9
	A_{12}	8-15	83.3	2.2	1.5	3.7	5.7	7.3	13.0
	B_{21}	22-42	72.8	2.3	1.5	3.8	9.2	14.2	23.4
	B_{22}	57-82	67.6	2.2	1.9	4.1	10.2	18.1	28.3
	B_{23}	102-128	63.8	1.9	1.7	3.6	11.8	20.8	32.6
	B_{24}	170-200	64.0	2.0	1.5	3.5	12.5	20.0	32.5
	B_{25}(u)	300-330	60.9	2.2	2.7	4.9	14.1	20.1	34.2
	B_{25}(L)	485-492	61.5	2.6	2.9	5.5	13.0	20.0	33.0
MP$_2$ (Mullai-ttivu Series)	A_{11}	2-8	86.5	1.2	1.9	3.1	5.0	5.4	10.4
	A_{12}	10-20	80.9	2.1	1.6	3.7	6.9	8.5	15.4
	B_{24}	172-202	61.7	2.1	1.9	4.0	13.7	20.6	34.3
PP$_2$ (Wilpattu Series)	A_{11}	2-12	90.8	0.7	0.7	1.4	3.9	3.9	7.8
	A_{12}	18-25	86.8	0.9	0.8	1.7	5.3	6.2	11.5
	B_{21}	35-65	81.5	0.8	1.3	2.1	7.2	9.2	16.4
	B_{22}	82-110	79.7	1.0	1.1	2.1	7.8	10.4	18.2
	B_{23}	150-175	73.3	1.0	1.1	2.1	10.5	14.1	24.6
	B_{24}	225-250	71.5	1.0	1.1	2.1	11.3	15.1	26.4
PP$_3$ (Wilpattu Series)	A_{11}	0-12	91.0	0.6	1.0	1.6	3.1	4.3	7.4
	B_{21}	38-58	87.3	0.8	1.3	2.1	4.8	5.8	10.6
	B_{24}	312-350	75.7	0.9	1.2	2.1	9.6	12.6	22.2
Termite Mound Sample			69.1	2.0	1.6	3.6	10.0	17.3	27.3

1. By Two Na-Citrate-Dithionite-Bicarbonate Extractions.
2. Two thirds of the samples were determined in duplicate.

Table A7. Particle Size Distribution of Selected Samples After Removal of Free Iron Oxides[1]- Percentages[2] Based On < 2mm. Soil Before Removal of Oxides

Profile and Series	Horizon	Sand 0.05 > mm.	Coarse Silt 50-20µ	Fine Silt 20-2µ	Total Silt 50-2µ	Coarse Clay 2-0.2µ	Fine Clay <0.2µ	Total Clay <2µ	Oxides by Difference
TP_1 (Gambura Series)	A_{11}	80.2	2.3	2.7	5.0	4.3	7.1	11.4	3.4
	A_{12}	70.0	2.2	2.4	4.6	5.8	14.4	20.2	5.2
	B_{21}	55.1	2.0	1.6	3.6	8.7	26.0	34.7	6.6
	B_{22}	51.6	1.9	1.8	3.7	10.4	27.2	37.6	7.1
	B_{23}	45.6	1.8	2.0	3.8	12.2	30.8	43.0	7.6
	B_{24}	51.3	1.8	3.4	5.2	12.9	24.0	36.9	6.6
	B_{25}	44.9	3.9	7.6	11.5	14.3	22.2	36.5	7.1
TP_2 (Gambura Series)	A_{11}	75.0	1.6	3.6	5.2	7.3	7.7	15.0	4.8
	B_{21}	61.9	1.7	1.8	3.5	9.2	18.6	27.8	6.8
	B_{25}(u)	47.7	3.1	7.1	10.2	13.8	19.2	33.0	9.1
MP_1 (Mullaitt-ivu Series)	A_{11}	85.9	1.9	1.3	3.2	4.1	4.6	8.7	2.2
	A_{12}	81.3	2.1	1.5	3.6	5.6	7.1	12.7	2.4
	B_{21}	70.4	2.2	1.5	3.7	8.9	13.7	22.6	3.3
	B_{22}	65.4	2.1	1.8	3.9	9.8	17.6	27.4	3.3
	B_{23}	61.4	1.8	1.6	3.4	11.4	20.0	31.4	3.8
	B_{24}	61.8	1.9	1.4	3.3	12.1	19.3	31.4	3.5
	B_{25}(u)	58.3	2.1	2.6	4.7	13.5	19.2	32.7	4.3
	B_{25}(L)	59.3	2.5	2.8	5.3	12.5	19.3	31.8	3.6
MP_2 (Mullaitt-ivu Series)	A_{11}	86.0	1.2	1.9	3.1	5.0	5.3	10.3	0.6
	A_{12}	79.9	2.1	1.6	3.7	6.8	8.4	15.2	1.2
	B_{24}	59.6	2.0	1.8	3.8	13.2	19.9	33.1	3.5
PP_2 (Wilpattu Series)	A_{11}	89.5	0.7	0.7	1.4	3.8	3.8	7.6	1.5
	A_{12}	84.9	0.9	0.8	1.7	5.2	6.1	11.3	2.1
	B_{21}	79.2	0.8	1.2	2.0	7.0	8.9	15.9	2.9
	B_{22}	77.3	1.0	1.0	2.0	7.6	10.1	17.7	3.0
	B_{23}	71.3	1.0	1.1	2.1	10.2	13.7	23.9	2.7
	B_{24}	69.8	1.0	1.1	2.1	11.0	14.7	25.7	2.4
PP_3 (Wilpattu Series)	A_{11}	89.2	0.6	1.0	1.6	3.0	4.2	7.2	2.0
	B_{21}	84.7	0.8	1.3	2.1	4.7	5.6	10.3	2.9
	B_{24}	72.8	0.9	1.1	2.0	9.2	12.1	21.3	3.9

1. By two NaCitrate-Dithionite-Bicarbonate Extractions.
2. Two thirds of the samples were determined in duplicate.

Table A8. **Water Dispersible Clay**

Profile	Horizon	Sample Depth (cm.)	Water Dispersible Clay (%)
TP_1	A_{11}	2-10	9.6
	A_{12}	15-22	18.7
	B_{21}	30-50	0.9
	B_{22}	65-90	0.3
MP_1	A_{11}	0-5	5.6
	A_{12}	8-15	7.7
	B_{21}	22-42	15.5
	B_{22}	57-82	16.3
	B_{23}	102-128	24.3
	B_{24}	170-200	2.9
	B_{25}	300-330	1.3
PP_2	A_{11}	2-12	4.4
	A_{12}	18-25	7.7
	B_{21}	35-65	16.0
	B_{24}	82-110	0.2

Table A9. Average Percentages of Voids, Plasma and Skeleton in Horizons of the Gambura, Mullaittivu and Wilpattu Series

Series & Horizon		Average[1]			Range	
	Voids	Plasma	Skeleton	Voids	Plasma	Skeleton
Gambura A_{11}	31	24	45	26-34	17-29	40-49
A_{12}	20	36	44	19-21	28-40	41-51
[3]B_{21}	22	45	33	18-26	44-45	31-38
[2]B_{22}	12	56	32	-	-	-
[3]B_{23}	16	55	29	16-17	51-59	25-32
B_{24}	14	51	35	8-18	46-61	31-37
B_{25}	12	56	36	8-14	52-60	31-44
Mullai-ttivu A_{11}	31	20	49	27-41	22-23	36-51
A_{12}	24	24	52	24-24	22-27	49-54
B_{21}	18	40	42	16-21	39-40	39-44
B_{22}	19	40	41	16-23	38-42	39-42
B_{23}	19	43	38	16-21	42-45	34-42
B_{24}	17	48	35	15-20	43-57	28-41
B_{25}	16	49	35	14-18	47-49	35-37
Wilpattu A_{11}	41	11	48	42-44	8-13	43-49
A_{12}	34	15	51	30-39	12-17	49-53
B_{21}	31	23	46	28-32	19-29	43-49
B_{22}	28	27	45	21-34	25-32	41-47
B_{23}	18	35	47	17-18	32-39	44-50
B_{24}	19	34	47	18-22	32-34	44-48

1. Four hundred counts per section were made on 3 sections per horizon unless otherwise indicated. A magnification of x2.5 x 12.5 was used throughout.
2. Only 2 sections used.
3. Only 1 section used.

Table A10. Chemical Properties of Profile TP_1 of the Gambura Series

Horizon and Sample Depth (cm.)		A_{11} 2-10	A_{12} 15-22	B_{21} 30-50	B_{22} 65-90	B_{23} 110-135	B_{24} 175-205	B_{25} 335-345
Carbon[1] %		0.62	0.38	0.27	0.18	0.18	0.11	0.12
Nitrogen[1] %		0.12	0.10	ND[8]	ND	ND	ND	ND
C/N		5.2	3.8	ND	ND	ND	ND	ND
pH 1:1 in water		6.6	5.7	5.1	5.3	5.4	5.5	5.7
pH 1:2 in 0.01 M$CaCl_2$		6.0	5.1	4.3	4.2	4.3	4.4	5.0
Exch. Cations[2]	Ca	37.7	18.0	10.8	9.7	10.0	18.2	32.9
	Mg	20.8	18.0	9.2	8.1	12.9	7.6	7.1
	K	5.7	6.0	6.2	4.8	4.3	4.5	2.9
	Na	Tr[9]	Tr	Tr	Tr	Tr	Tr	1.4
Exch. Acidity[2]		35.8	58.0	73.8	77.4	72.8	69.7	55.7
CEC-7[3] m.e./100 g. soil		2.9	2.6	3.2	3.3	3.9	3.6	4.2
CEC-S[4] m.e./100 g. soil		5.3	5.0	6.5	6.2	7.0	6.6	7.0
CEC-S[5] m.e./100 g. clay		35.3	19.5	15.6	13.8	13.9	14.0	14.2
Base Sat.[6] %		64	42	26	23	27	30	44
Extr. Al[7] m.e./100 g. soil		Tr	0.02	0.06	0.08	0.03	0.03	0.02

1. Oven dry basis
2. Percent of CEC-S
3. By neutral NH_4OAc
4. Exch. cations + exch. acidity
5. Calculated
6. Σ Exch. basic cations x 100/CEC-S
7. With NH_4OAc at pH 4.8
8. Not determined
9. Trace (< 1%)
10. One in three samples duplicated for exchange analysis. All pHs in duplicate

Table A11. Chemical Properties of Profile TP_2 of the Gambura Series

Horizon and Sample Depth (cm.)		A_{11} 2-10	A_{12} 12-22	B_{21} 30-50	B_{22} 65-90	B_{23} 110-135	B_{24} 175-205	B_{25}(u) 275-305	B_{25}(L) 345-360
Carbon[1] %		0.91	0.70	0.23	ND[8]	ND	ND	0.12	ND
Nitrogen[1] %		0.13	0.11	ND	ND	ND	ND	ND	ND
C/N		7.0	6.4	ND	ND	ND	ND	ND	ND
pH 1:1 in water		6.2	5.5	5.0	5.2	5.5	5.2	5.4	5.5
pH 1:2 in 0.01 M $CaCl_2$		5.8	4.8	4.3	4.3	4.4	4.4	4.7	4.9
Exch. cations[2]	Ca	35.7	17.7	6.6	3.4	14.3	18.6	26.8	32.0
	Mg	12.9	11.3	6.6	15.3	11.4	10.0	11.3	10.7
	K	4.3	3.2	3.3	3.4	2.9	2.9	2.8	2.7
	Na	Tr[9]	Tr	Tr	Tr	Tr	Tr	Tr	1.3
Exch. acidity[2]		47.1	67.8	83.5	77.9	71.4	68.5	59.1	53.3
CEC-7[3] m.e./100 g. soil		3.8	3.2	3.0	3.4	4.2	3.9	4.3	4.5
CEC-S[4] m.e./100 g. soil		7.0	6.2	6.1	5.9	7.0	7.0	7.1	7.5
CEC-S[5] m.e./100 g. clay		33.4	24.7	15.9	13.5	13.9	14.0	14.6	15.0
Base sat.[6] %		53	32	16	22	29	31	41	47
Extr. Al[7] m.e./100 g. soil		0.02	ND	0.09	ND	ND	ND	0.02	ND

1 to 10 - See footnotes to Table A10.

Table A12. Chemical Properties of Profile TP_3 of the Gambura Series

Horizon and Sample Depth (cm.)		A_{11} 2-8	A_{12} 12-25	B_{21} 32-45	B_{22} 60-85	B_{23} 105-130	B_{24} 165-200	B_{25}(u) 260-310	B_{25}(L) 370-385
Carbon[1] %		0.68	0.36	ND[8]	ND	ND	ND	ND	ND
Nitrogen[1] %		0.13	0.07	ND	ND	ND	ND	ND	ND
C/N		5.2	5.1	ND	ND	ND	ND	ND	ND
pH 1:1 in water		5.9	5.2	5.1	5.2	5.4	5.6	5.8	5.7
pH 1:2 in 0.01 M $CaCl_2$		5.2	4.4	4.2	4.3	4.5	4.8	5.3	5.3
Exch. cations[2]	Ca	31.4	15.8	10.0	15.3	25.4	32.3	37.5	42.4
	Mg	7.8	5.3	6.0	15.3	11.9	9.7	8.9	9.1
	K	5.9	2.6	4.0	3.4	3.4	3.2	1.8	1.5
	Na	Tr[9]	Tr	Tr	Tr	Tr	Tr	Tr	1.5
Exch. acidity[2]		54.9	76.3	80.0	66.0	59.3	54.8	51.8	45.5
CEC-7[3] m.e./100 g. soil		2.6	1.7	2.7	3.5	3.7	4.0	3.6	4.3
CEC-S[4] m.e./100 g. soil		5.1	3.8	5.0	5.9	5.9	6.2	5.6	6.6
CEC-S[5] m.e./100 g. clay		33.9	24.4	16.4	14.4	14.2	15.3	14.2	15.4
Base sat.[6] %		45	24	20	34	41	45	48	55
Extr. Al[7] m.e./100 g. soil		ND	ND	ND	ND	ND	ND	ND	ND

1 to 9 - See footnotes to Table A10.

Table A13. Chemical Properties of Profile MP$_1$ of the Mullaittivu Series

Horizon and Sample Depth (cm.)		A_{11} 0-5	A_{12} 8-15	B_{21} 22-42	B_{22} 57-82	B_{23} 102-128	B_{24} 170-200	B_{25}(u) 300-330	B_{25}(L) 485-492
Carbon[1] %		0.84	0.68	0.48	0.27	0.24	0.15	0.12	0.07
Nitrogen[1] %		0.12	0.11	ND[8].	ND	ND	ND	ND	ND
C/N		7.0	6.2	ND	ND	ND	ND	ND	ND
pH 1:1 in water		6.1	5.8	5.3	5.4	5.5	5.6	5.6	5.7
pH 1:2 in 0.01 M $CaCl_2$		5.6	5.0	4.4	4.6	4.9	5.2	5.5	5.3
Exch. Cations[2]	Ca	34.0	20.8	11.4	14.9	29.2	31.9	40.4	41.9
	Mg	8.5	6.3	4.5	8.5	8.3	8.5	10.6	11.6
	K	4.3	4.2	2.3	2.1	Tr	Tr	Tr	Tr
	Na	Tr[9]	Tr	Tr	Tr	Tr	Tr	Tr	Tr
Exch. acidity[2]		53.2	68.7	81.8	74.5	62.5	59.6	49.0	46.5
CEC-7[3] m.e./100 g. soil		2.4	2.3	2.2	2.6	2.8	2.7	3.0	2.8
CEC-S[4] m.e./100 g. soil		4.7	4.8	4.4	4.7	4.8	4.7	4.7	4.3
CEC-S[5] m.e./100 g. clay		42.2	29.9	16.9	14.1	14.0	13.4	12.2	12.7
Base Sat.[6] %		47	31	18	26	38	40	51	53
Extr. Al[7] m.e./100 g. soil		0.02	0.03	0.09	0.03	0.02	0.02	0.02	0.01

1 to 10 - See footnotes to Table A10.

Table A14. Chemical Properties of Profile MP_2 of the Mullaittivu Series

Horizon and Sample Depth (cm.)		A_{11} 2-8	A_{12} 10-20	B_{21} 28-48	B_{22} 62-85	B_{23} 108-135	B_{24} 172-202	B_{25} 300-330
Carbon[1] %		1.28	0.95	ND[8]	ND	ND	0.17	ND
Nitrogen[1] %		0.16	0.14	ND	ND	ND	ND	ND
C/N		8.0	6.8	ND	ND	ND	ND	ND
pH 1:1 in water		6.4	6.4	6.4	6.3	6.4	6.5	6.4
pH 1:2 in 0.01 M $CaCl_2$		6.0	5.8	5.5	5.6	5.8	5.8	5.9
Exch. cations[2]	Ca	48.5	38.9	28.3	30.6	34.0	36.2	37.8
	Mg	12.1	11.9	8.7	10.2	10.6	10.6	13.3
	K	4.6	5.1	4.3	4.1	4.3	4.3	2.2
	Na	Tr[9]	Tr	Tr	Tr	Tr	Tr	Tr
Exch. acidity[2]		34.8	44.1	58.7	55.1	51.1	48.9	46.7
CEC-7[3] m.e./100 g. soil		3.8	3.3	2.5	2.9	2.7	2.8	2.8
CEC-S[4] m.e./100 g. soil		6.6	5.9	4.6	4.9	4.7	4.7	4.5
CEC-S[5] m.e./100 g. clay		60.5	36.8	19.1	14.4	13.3	13.0	11.5
Base sat.[6] %		65	56	41	45	49	51	53
Extr. Al[7] m.e./100 g. soil		0.01	0.02	ND	ND	ND	0.02	ND

1 to 10 - See footnotes to Table A10.

Table A15. **Chemical Properties of Profile MP_3 of the Mullaittivu Series**

Horizon and Sample Depth (cm.)		A_{11} 2-8	A_{12} 10-22	B_{21} 30-50	B_{22} 65-90	B_{23} 110-135	B_{24} 175-205	B_{25} 300-330
Carbon[1] %		0.91	0.78	ND[8]	ND	ND	ND	ND
Nitrogen[1] %		0.15	0.13	ND	ND	ND	ND	ND
C/N		6.1	6.0	ND	ND	ND	ND	ND
pH 1:1 in water		6.5	6.1	6.1	5.6	5.6	5.6	5.7
pH 1:2 in 0.01 M $CaCl_2$		6.0	5.3	5.3	4.6	4.9	4.8	5.1
Exch. cations[2]	Ca	46.4	30.0	23.5	24.0	28.9	37.2	39.1
	Mg	10.7	8.3	9.8	10.0	8.9	5.9	8.7
	K	3.6	3.3	3.9	2.0	2.2	Tr	Tr
	Na	Tr[9]	Tr	Tr	Tr	Tr	Tr	Tr
Exch. acidity[2]		39.3	58.4	62.8	64.0	60.0	56.9	52.2
CEC-7[3] m.e./100 g. soil		3.2	3.1	2.7	2.8	2.7	3.1	2.8
CEC-S[4] m.e./100 g. soil		5.6	6.0	5.1	5.0	4.5	5.1	4.6
CEC-S[5] m.e./100 g. clay		46.4	28.8	17.0	14.0	12.3	12.9	12.4
Base sat.[6] %		61	42	37	36	40	43	48
Extr. Al[7] m.e./100 g. soil		ND	ND	ND	ND	ND	ND	ND

1 to 10 - See footnotes to Table A10.

Table A16. Chemical Properties of Profile PP_1 of the Wilpattu Series

Horizon and Sample Depth (cm.)		A_{11} 0-8	A_{12} 10-15	B_{21} 22-42	B_{22} 60-82	B_{23} 125-150	B_{24} 250-300
Carbon^1 %		0.55	0.56	ND^8	ND	ND	ND
Nitrogen^1 %		0.08	0.08	ND	ND	ND	ND
C/N		6.9	7.0	ND	ND	ND	ND
pH 1:1 in water		6.8	6.8	6.4	5.5	5.6	5.8
pH 1:2 in 0.01 M $CaCl_2$		6.3	6.2	5.7	4.8	4.7	5.2
Exch. cations^2	Ca	62.2	53.0	35.7	27.0	40.5	35.9
	Mg	21.6	22.0	21.4	13.5	7.1	15.4
	K	5.4	5.0	4.8	2.7	Tr	Tr
	Na	Tr^9	Tr	Tr	Tr	Tr	Tr
Exch. acidity^2		10.8	20.0	38.1	56.8	52.4	48.7
CEC-7^3 m.e./100 g. soil		2.4	2.6	2.5	2.2	2.7	2.2
CEC-S^4 m.e./100 g. soil		3.7	4.0	4.2	3.7	4.2	3.9
CEC-S^5 m.e./100 g. clay		61.5	57.1	30.1	19.5	16.2	14.3
Base sat.^{6} %		89	80	62	43	48	51
Extr. Al^7 m.e./100 g. soil		ND	ND	ND	ND	ND	ND

1 to 10 - See footnotes to Table A10

Table A17. Chemical Properties of Profile PP_2 of the Wilpattu Series

Horizon and Sample Depth (cm.)		A_{11} 2-12	A_{12} 18-25	B_{21} 35-65	B_{22} 82-110	B_{23} 150-175	B_{24} 225-250
Carbon[1] %		0.62	0.49	0.16	0.14	0.11	0.08
Nitrogen[1] %		0.09	0.08	ND[8]	ND	ND	ND
C/N		6.9	6.1	ND	ND	ND	ND
pH 1:1 in water		6.3	6.3	6.2	5.9	6.0	5.9
pH 1:2 in 0.01 M $CaCl_2$		5.9	5.5	5.4	5.2	5.5	5.5
Exch. Cations[2]	Ca	57.1	42.5	35.3	31.3	33.3	38.9
	Mg	11.9	12.5	11.8	12.5	16.7	8.3
	K	2.4	2.5	5.9	3.1	2.8	2.8
	Na	Tr[9]	Tr	Tr	Tr	Tr	Tr
Exch. acidity[2]		28.6	42.5	47.0	53.1	47.2	50.0
CEC-7[3] m.e./100 g. soil		2.6	2.3	2.2	1.7	2.1	2.2
CEC-S[4] m.e./100 g. soil		4.2	4.0	3.4	3.2	3.6	3.6
CEC-S[5] m.e./100 g. clay		54.6	33.3	16.7	15.1	13.0	12.0
Base sat.[6] %		71	58	53	47	53	50
Extr. Al[7] m.e./100 g. soil		0.01	0.01	0.02	0.02	0.02	0.02

1 to 10 - See footnotes to Table A10.

Table A18. Chemical Properties of Profile PP_3 of the Wilpattu Series

Horizon and Sample Depth (cm.)		A_{11} 0-12	A_{12} 15-30	B_{21} 38-58	B_{22} 75-95	B_{23} 125-175	B_{24} 312-350
Carbon[1] %		0.86	0.78	0.92	ND[8]	ND	0.07
Nitrogen[1] %		0.11	0.09	ND	ND	ND	ND
C/N		7.8	8.7	ND	ND	ND	ND
pH 1:1 in water		6.6	6.7	6.7	6.0	5.7	5.6
pH 1:2 in 0.01 M $CaCl_2$		6.1	6.1	6.0	5.3	5.1	5.1
Exch. cations[2]	Ca	60.6	51.9	38.5	27.6	29.0	32.4
	Mg	12.1	11.5	11.5	13.8	9.7	11.8
	K	3.0	3.8	11.5	10.3	6.5	2.9
	Na	Tr[9]	Tr	Tr	Tr	Tr	Tr
Exch. acidity[2]		24.3	32.8	38.5	48.3	54.8	52.9
CEC-7[3] m.e./100 g. soil		4.3	3.0	1.3	1.6	1.4	1.7
CEC-S[4] m.e./100 g. soil		6.6	5.2	2.6	2.9	3.1	3.4
CEC-S[5] m.e./100 g. clay		72.6	43.8	18.9	16.2	13.2	13.6
Base sat.[6] %		76	73	62	52	45	47
Extr. Al[7] m.e./100 g. soil		Tr	ND	0.01	ND	ND	0.01

1 to 10 - See footnotes to Table A10.

Table . A19 **Means and Ranges of Citrate-Dithionite Extractable Iron**

Series	Horizon							
	A_{11}	A_{12}	B_{21}	B_{22}	B_{23}	B_{24}	B_{2s}(u)	B_{2s}(L)
Gambura								
Mean	2.37	2.95	4.44	5.17	5.47	5.43	5.41	5.74
Range	2.02-2.78	2.30-3.46	3.88-5.12	4.82-5.46	4.92-5.74	5.10-5.74	4.96-5.71	5.60-5.88
Mullaittivu								
Mean	1.58	1.71	2.31	2.77	2.88	3.00	3.12	3.06
Range	0.92-2.72	1.44-2.25	2.02-2.88	2.46-3.16	2.74-3.08	2.70-3.58	2.80-3.60	--
Wilpattu								
Mean	1.05	1.40	1.86	2.24	2.74	2.92	--	--
Range	0.94-1.16	1.30-1.59	1.44-2.14	1.80-2.58	2.08-3.30	2.50-3.30	--	--