Characteristics and Formation of so-called Red-Yellow Podzolic Soils in the Humid Tropics (Sarawak-Malaysia)

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Proefschrift

ter verkrijging van de graad van doctor in de Wiskunde en Natuurwetenschappen aan de Rijksuniversiteit te Utrecht, op gezag van de Rector Magnificus Prof. Dr. Sj. Groenman, volgens besluit van het College van Dekanen in het openbaar te verdedigen op 8 december 1975 des namiddags te 4.15 uur

door

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geboren op 28 maart 1929 te Middelburg

Promotores: Prof.Dr.Ir. L.J. Pons, Landbouwhogeschool, Wageningen
Prof.Dr. R.D. Schuiling

Dit proefschrift kwam in zijn volledigheid tot stand onder leiding van Prof.Dr.Ir. F.A. van Baren †

Preface

Sarawak - a geography of life

'Extensive, almost inaccessible swamps, stretching along the coast, must be passed to reach the hills which in their monotonous repetition of heights and valleys wear down the traveller, but from where the lofty mountains beyond beckon to carry on'

I dedicate this thesis to the memory of my late parents who through their efforts enabled me to receive the basic education which opened the door for my professional career, but who through their premature decease could not witness the results of their labour.

Through the instillment of the perseverance which was theirs I was able to carry on from where they had to abandon their set task.
So numerous are those to whom I owe great thanks for their assistance in furthering my education, that I would not be able to mention them all. Too many are the friends and colleagues whom I shared life with under conditions of mosquito-ridden swamps in Tropical Asia, of scouring-hot deserts in the Middle East and of thorny bushfelds in South-Africa, than that I could express to each personally my gratitude for their companionship. However, they all had their share in this travelling life of gaining knowledge where one goes.
Some mile-posts must, however, be mentioned and to maintain this metaphor I am doing this in a chronological order.

I am indebted firstly to C.L. Lameris, M.Sc. who introduced Soil Science to me in his enthusiastic lectures at the then State College for Tropical Agriculture in Deventer.
I owe much to that 'master of the field' F.H.N. Razoux-Schultz, B.Sc. who taught me to open my eyes and how to observe. I felt, Frans, that your efforts in passing your knowledge and experience on to a youngster exceeded that required from an older colleague.
My interest and knowledge on soil mineralogy find its source in W.L.P.J. Mouthaan, B.Sc. I could never ask him too much. Thank you, William, for unselfish friendship.

I am indebted to my former colleague G. Murdoch, Ph.D. who gave me much insight in handling the tool of landscape-unravelling, physiography.
To you Wouter Blokhuis, M.Sc. I owe thanks for your sense of detail of which you, perhaps unawaredly passed some on to me, and above all for your comradeship in difficult situations.

Through all this runs as a red thread the influence of Prof. Dr. F.A. van Baren. It was your encouragement, coaching and guidance, Professor, which from as late back as 1957 has lead to this goal. Without your personal interest in my work and

your assistance in the completion of my professional study after this long detour of 17 years 'gaining experience in the field' I would never have accomplished this work.
I have appreciated very much the valuable suggestions and stimulating discussions on some topics of this study with J.J. Reynders, Ph.D., L. Bal, Ph.D., F.H. Brook, M.Sc. and N. de Rooy, M.Sc.
To L.P. v. Reeuwijk, Ph.D. I am grateful for his assistance in carrying out D.T.G. analyses at the laboratories of the Dept. of Soil Science and Geology at Wageningen and to A. Breewsma, Ph.D. for carrying out some infrared absorption analyses at the laboratories of the Soil Survey Institute at Wageningen (Stiboka).

The assistance received from Mr. H.A. van Rosmalen, Mr. C. Mulder, Mr. R.G. van Schouten and Mr. A.J.N. Blees in carrying out some of the chemical and clay mineralogical analyses is gratefully acknowledged.

It is a pleasure to recall here the dedicated way in which the staff of Mdm. C.J. Meijer of which I would like to mention specifically Miss E. de Boer, conducted the tedious typing and retyping of the voluminous manuscript which greatly helped to unburden the load of work.

Many of the drawings orginally used in a former work were put at my disposal again by the Department of Agriculture, Sarawak. Alterations in these drawings and all the original diagrams were prepared by the capable hands of Miss J.M. v.d. Horst.
This work could never have been accomplished without the support of the Director of the Department of Agricultural Research of the Royal Tropical Institute, H.Ph. Huffnagel, M.Sc. on whose mandate this thesis could be completed as an official research project of the Institute.
To you Bert Muller, M.Sc. goes my gratitude for bearing with me during those years in which this study sometimes prevailed over other urgent work of which you had then to carry the burden alone.

Marie, your quiet undemanding nature provided the tranquil background support, essential for reaching this goal.

Finally, with much appreciation I would like to acknowledge the assistance of the Trustee Board of the Greshoff's Rhumphius Foundations in subsidizing the printing of this thesis.

Post Scriptum

Prof.Dr.Ir. F.A. van Baren, die mij heeft begeleid in het tot stand komen van dit proefschrift, overleed plotseling op 5 oktober 1975, toen het manuscript al ter perse was.
Het overnemen van het promotorschap door Prof.Dr.Ir. L.J. Pons en Prof.Dr. R.D. Schuiling maakte het noodzakelijk dat zij zich in zeer korte tijd de probleemstellingen moesten eigen maken.
Ik ben hun grote dank verschuldigd voor het op zich nemen van deze ondankbare taak en de wijze waarop zij mij tot steun zijn geweest.

De promovendus

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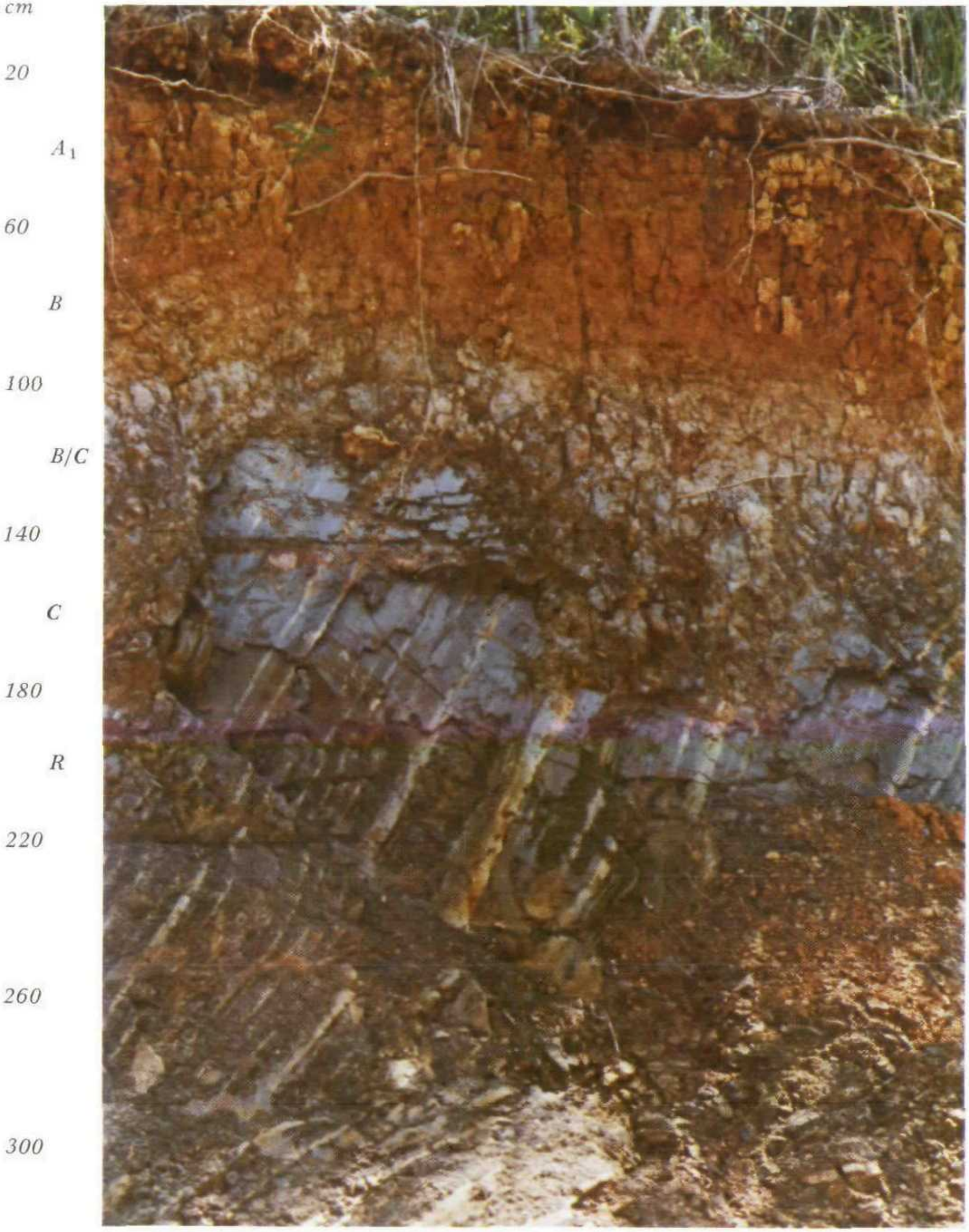

Deep exposure of Semongok series (Typic Dystropept) underlain by steeply inclined banded sandy shale and mudstone.
Note the iron-stoneline above the parent material in places. White bands in parent material are caused by chalcedonic SiO_2.

Introduction

1. Historical background

In order to acquaint the reader with the subject of this thesis some background information, specifically on historical aspects, is necessary.

The author has been engaged in regional reconnaissance soil mapping in the State of Sarawak (East-Malaysia) during the period 1960 to 1970.
Apart from covering the total of West Sarawak, some 11,200 sq. km., on a detailed reconnaissance level at a scale 1 : 100,000, selected areas were mapped and studied in more detail down to a scale of 1 : 10,000.

The results of this mapping phase were compiled and consolidated in Memoir 1, the Soils of West Sarawak (Andriesse, 1972).

These fieldstudies revealed that a wide spectrum of soils exist in the area, ranging from locally so-called Humus Podzols to Lateritic soils with all possible intergrades. During the fieldwork it became abundantly clear that type of parent material is one of the most important soil forming factors in the area responsible for the differentiation of soil types occurring over comparative short distances.

The Tropical Humus Podzols found widespread in the area on Pleistocene sediments and Tertiary sandstones (if flat-bedded) formed the subject of two papers respectively dealing with the environmental conditions and characteristics of such soils (Andriesse, 1969a), and with the development of the Podzol morphology for which a time-sequence present in a coastal ridge landscape served as an example (Andriesse, 1970). Another soil group of local importance, namely the Lowland Peats developed in coastal basins were dealt with in detail in a monograph (Andriesse, 1974).

The two major groups of soils covering the bulk of the lowlands are not further discussed in the present study, since they have been adequately covered by mentioned articles.
However, the soils occupying the upland areas, in general those areas not influenced by a groundwater table, have hitherto hardly been studied, at least as far as their genesis is concerned.

Most of the latter soils have developed on sedimentary rocks of clastic nature, shales and sandstones being dominant. Relatively smaller areas are covered by soils developed on acid intrusive and basic extrusive rocks.
In the past, genesis of soils developed over sedimentary rocks, particularly when occurring in the tropics, has received relatively little attention and the area therefore provides an excellent opportunity to gain knowledge on this subject.

Of considerable interest appeared to be the observation that most of the upland

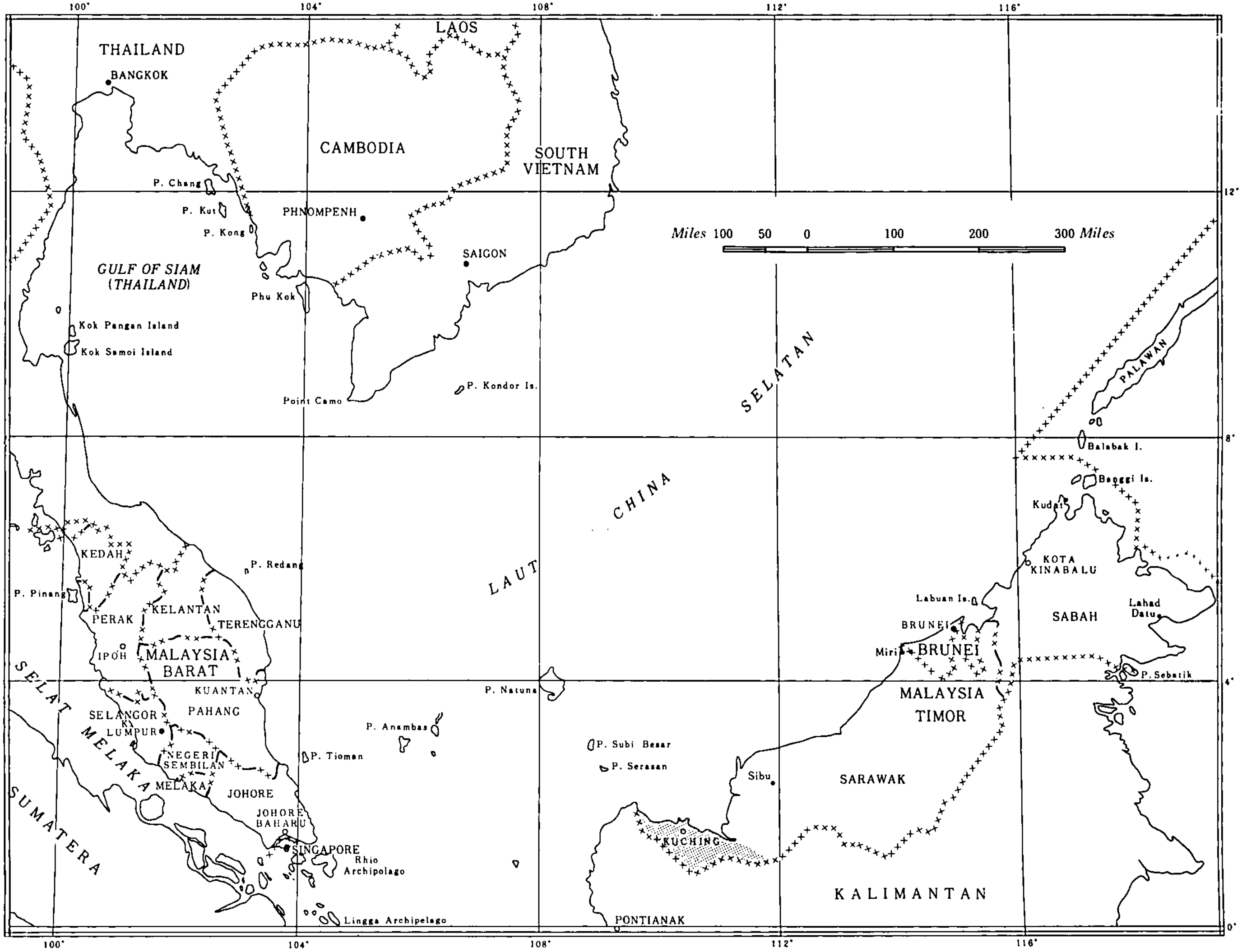

Fig. 1 *Location map*

soils showed podzolic features in their morphology and general chemical characteristics. These are most expressed in soils developed on parent materials having the highest SiO_2 content and least on parent materials with lowest SiO_2 content. A range of soils covering a spectrum from lateritic to podzolic features was thus found to be related to type of parent material.

The mentioned podzolic features have been reason why the majority of the upland soils were initially classified as Red-Yellow Podzolic soils (Soil Survey Staff, Sarawak, 1966) as has been done by others with much similar soils occurring widespread throughout South-East Asia (Dudal and Moormann, 1964). They however appear to be dissimilar from the typical Red-Yellow Podzolic Soils as occurring in the United States (McCaleb, 1959) in that they have no textural B horizon in the sence of an argillic horizon which is taken to be diagnostic for ULTISOLS (Soil Survey Staff, USDA, 1960, 1967, 1970).

The thus-stated observations made during the field investigations, and the tentative conclusions reached in that stage, provide the theme for the present thesis, which aims to bring more clarity in and more conclusive evidence for previously made assumptions and related hypotheses.

The author has been fortunate to be able to personally cover the whole of the region * by fieldsurveying. This made it possible to bring together a collection of carefully selected representative profiles which forms the basis of this study. The sites were selected with the specific purpose to bring out the major trends in soil formation and since this appeared to be mainly influenced by differences in parent material, the latter formed the basis for site selection. Because of shifting cultivation practises which may have influenced some of the inherent characteristics of the soils to be studied, another important factor playing a role in the final selection of sites was the condition that they had to be still covered by Primary Forest.

2. Definition of study area

Although this study focusses attention on a small number of representative profiles it would seem desirable that their localities should be seen in relation to the total macro environment.
Therefore, in the descriptive part of this thesis an analysis is given of the whole investigated area.

West Sarawak is the most populated, and geographically and geologically the most heterogenous part of the State of Sarawak (see Fig. 1), which politically forms part of the Federation of Malaysia.

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* *throughout the text of this thesis the word 'Region' denotes West Sarawak as indicated on Fig. 1.*

The area of interest is roughly situated between 109°35′ and 111°50′ longitude E, and between 0°50′ and 2° latitude N, and lies in the north-western region of the island Borneo.

Although the study pertains specifically to this Region, the soil types concerned occur widespread over the whole of Sarawak and are also found in the Indonesian part of Borneo, Kalimantan (Driessen, 1974).

I. Environmental Conditions

A. Climate

1. Atmospheric climate

1.1. General characteristics

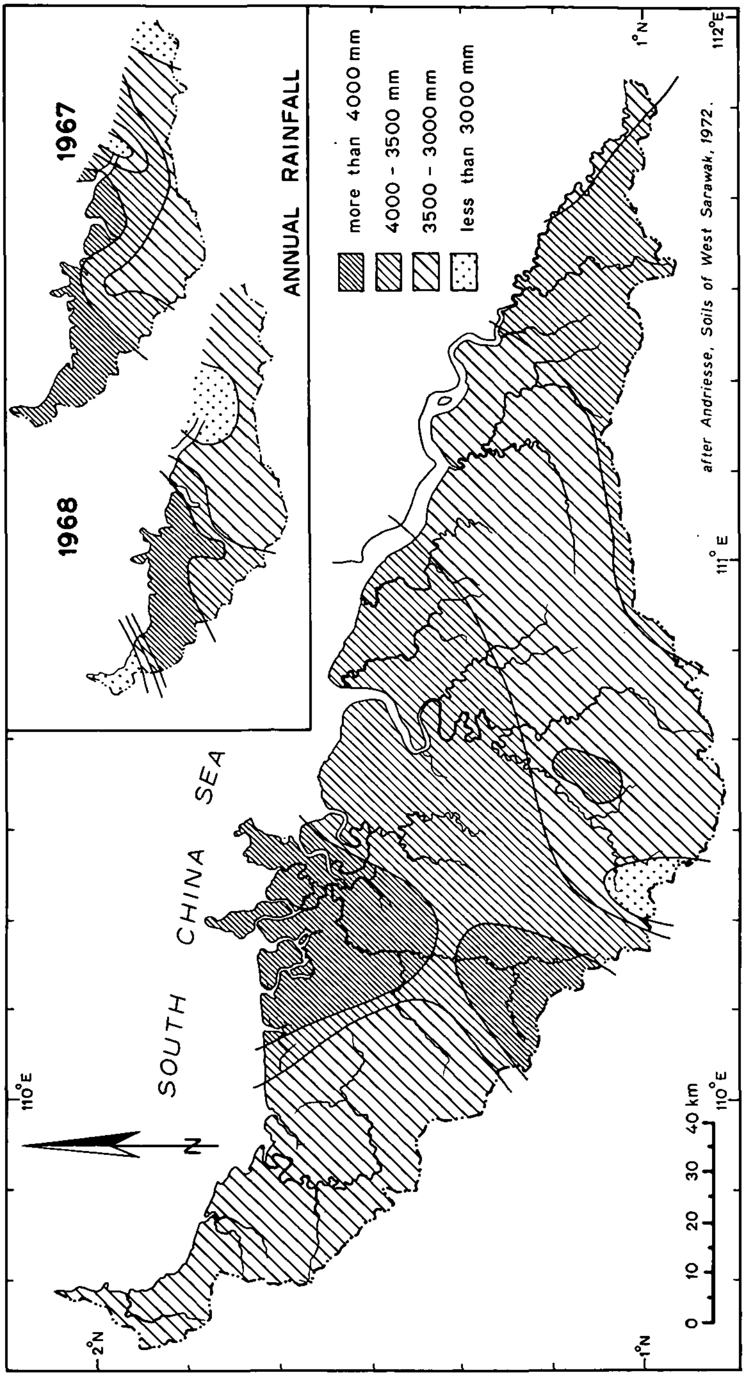
The climate of West Sarawak is characterized by heavy rainfall ranging from 3000-4500 mm annually, a relative uniform temperature ranging from an average of 25°C in the coolest month to an average of 26.5°C in the hottest month, and a high relative humidity ranging on average from 85% in the morning to 69% at noon. Seal (1958) recognizes four seasons namely the northeast monsoon from October to January to February, the mild south east monsoon from April to July/August and two shorter transitional periods of about 8 weeks each in between.

The climate in general and rainfall in particular is strongly influenced by the movements of the 'Intertropical Front', the zone of contact between air masses moved by the monsoonwinds and locally present air masses. Along this front cyclonic movements develop with a strong vertical but weak horizontal component, causing the moisture-laden air to rise, which results in condensation and precipitation. During the northeast monsoon period this Front coming from over the South China sea passes the Region. This is accompanied by heavy rainfall particularly in coastal areas. During the southeast monsoon, this Front passes once more but now coming from the south. Most rain has then already precipitated south of the mountain ranges forming the border with Indonesian Borneo, and the Front therefore causes less pronounced rainfall in Sarawak. The frequent erratic movements of the 'Intertropical Front' are decisive for the climatic variations which may occur within a given year, since rainfall and cloudiness have a strong effect on temperature and humidity. In the World Climate Classification by Köppen (1916) the climate is classified as a typical type A, Tropical Rainy Climate. The whole Region is further classified as subtype Af, indicating that there are no definite dry periods.

1.2. Rainfall

A detailed analysis of rainfall characteristics in the Region is to be found in Andriesse (1972). Only those details which are of importance for soil formation are dealt with here. The annual distribution as monthly averages is given in Table 1 for the main rainfall stations in the Region of which the locations can be found in Fig. 3. It is customary to consider hydrological data over continuous twelve-month periods in such a way that peak discharges in one season are not split up if tabulated or shown in graphs. For this reason the 'water year' in Sarawak is assumed to start in June and to end in June (see Table 1). The mean annual rainfall is shown in Fig. 2.

The monthly rainfall data makes it apparent that precipitation is significantly higher during the northeast monsoon (December-February) than during the southeast monsoon (May-October). The difference during these seasons is however greatest near the coast and diminishes with increasing distance from the sea. In an attempt to bring order in this observed phenomenon the author (1972) placed the rainfall



after Andriesse, Soils of West Sarawak, 1972.

Fig. 2 *Mean annual rainfall distribution in West Sarawak*

Table 1. Average monthly rainfall of representative rainfall stations

Location	1	2	3	4	5	6	7	8	9	10	11	12	13
Station	Kuching	S. China	Bau	Tarat	Lundu	Telok Assam	Semongok	Sematan	Simunjan	S. Bedup	Samarahan Estate	Tebakang	Simanggang
Elevation in meter	30	130	15	15	5	2	20	5	2	15	15	30	30
Number of recording years	14	31	26	14	29	9	9	8	14	6	38	8	18
July	219	216	183	191	138	194	188	171	230	175	187	201	238
August	197	230	220	179	141	161	199	141	221	249	186	180	273
Sept.	277	283	236	255	172	181	198	169	252	152	236	249	277
October	285	344	304	306	108	287	235	248	286	239	374	322	387
November	313	388	321	325	260	316	298	311	336	250	339	296	433
December	398	599	402	350	423	588	456	705	482	336	398	304	414
January	609	891	580	476	595	847	688	1056	692	321	513	405	412
February	567	679	322	406	556	693	647	766	459	358	462	310	336
March	358	445	273	327	393	530	401	435	371	351	338	251	325
April	279	307	284	292	181	178	290	231	288	193	303	277	380
May	271	300	215	240	186	159	261	114	298	258	255	219	300
June	192	204	189	153	177	162	189	108	177	171	177	148	249
Total	3965	4886	3529	3500	3160	4126	4050	4455	4092	3053	3768	3162	4024

stations into four groups as follows:

Group I -the rainfall in wettest month is less than 2 times that of the driest month.
Group II -the rainfall in wettest month is 2-3 times that of the driest month.
Group III -the rainfall in wettest month is 3 to 4 times that of the driest month.
Group IV -the rainfall in wettest month is more than 4 times that of the driest month.

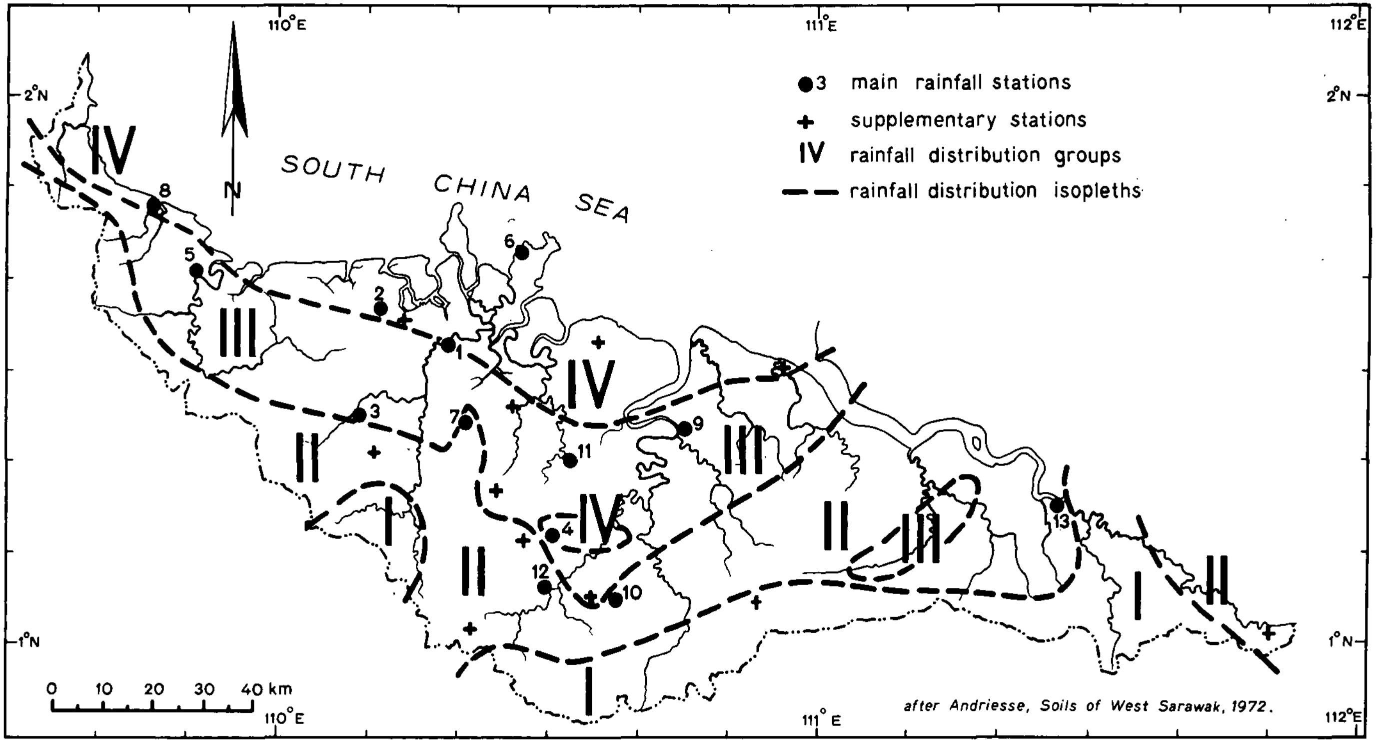
Figure 3 shows that by such a grouping 4 rainfall belts running more or less parallel to the coast can be distinguished. Local topography, however, may be responsible for minor differences within each belt.

In order to explain the effect of distance from the coast on precipitation distribution it must be recognized that 3 types of rainfall are playing a role in this.

Cyclonic rain is of dominant importance during the northeast monsoon and is most pronounced in the coastal areas. Convection rain which accompanies local thunderstorms occurs throughout the year but is generally more intensive in the interior. For this reason during the southeast monsoon the rainfall is higher in the interior than in the coastal areas causing in the former a more even spreading throughout the year. This tendency is well illustrated by the location of the four recognized rainfall belts.

Where isolated mountain massifs occur local orographic rain disturbs the general pattern. This explains the high rainfall at S. China station which is located at the slopes of a mountain massif.

Althought the mean monthly figures indicate a perhumid climate throughout the year over the whole Region, the rainfall distribution over the years shows an erratic pattern. As already mentioned this is caused by the irregular movements of the Intertropical Front. This causes not only an impredictable shifting of maximum rainfall from east to west (see isohyet maps for the years 1967 and 1968; Fig. 2) but also great variations in intensity. For instance, when the Front becomes stationary during the northeast monsoon tremendous amounts of rain are recorded for particularly coastal stations. So is the maximum recorded rainfall for a 24 hour period at Kuching station 448 mm which may account for more than 90% of the total in that month. It is therefore of importance to analyse the rainfall distribution in more detail. Andriesse (1972) studied 10-days distribution patterns for 8 representative stations for the years 1964, 1966, and 1968 separately. These years are regarded as normal, being not too wet nor too dry.
The outcome of this study indicates that in all stations studied, rain falls in about 8 to 10 rainfall peaks per year. (a peak is considered to be 50 mm more rain than in a previous decade). Very wet periods may alternate with very dry periods and this is particularly so during the northeast monsoon period depending on the movements of the Intertropical Front, as explained. A dry period of one week is then not uncommon however and even convection rain is absent near the coast. During the remainder of the year less wet periods of three days during which thunderstorms are building up alternate with wet periods of three to four days. The frequency and length of dry periods have been calculated for the main stations. The results have



after Andriesse, Soils of West Sarawak, 1972.

Fig. 3 *Rainfall distribution groups and location of rainfall stations in West Sarawak*

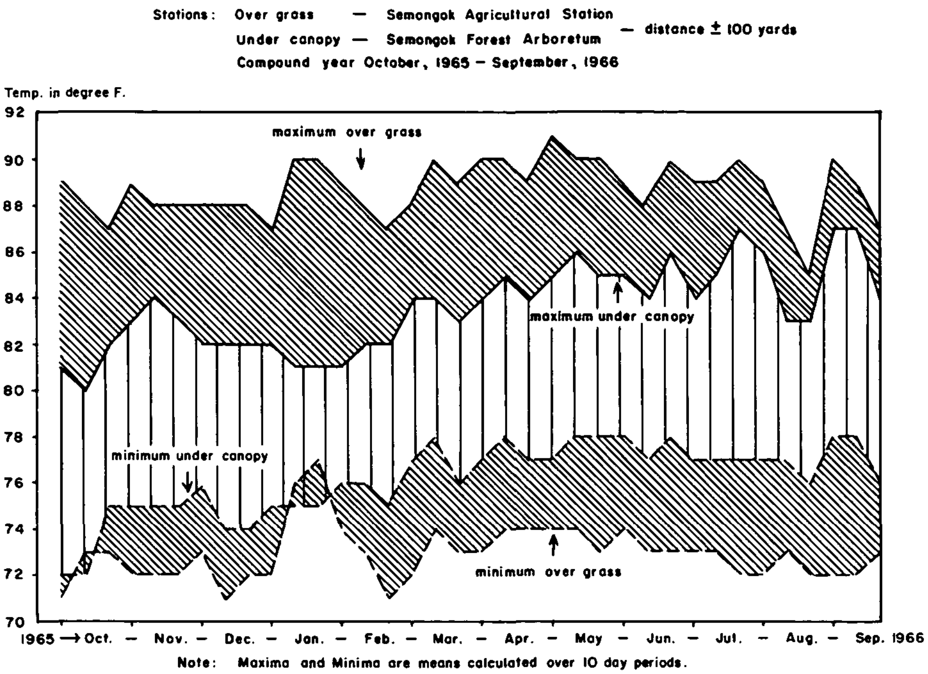


Fig. 4 *Comparison between temperature ranges over grass and under forest cover*

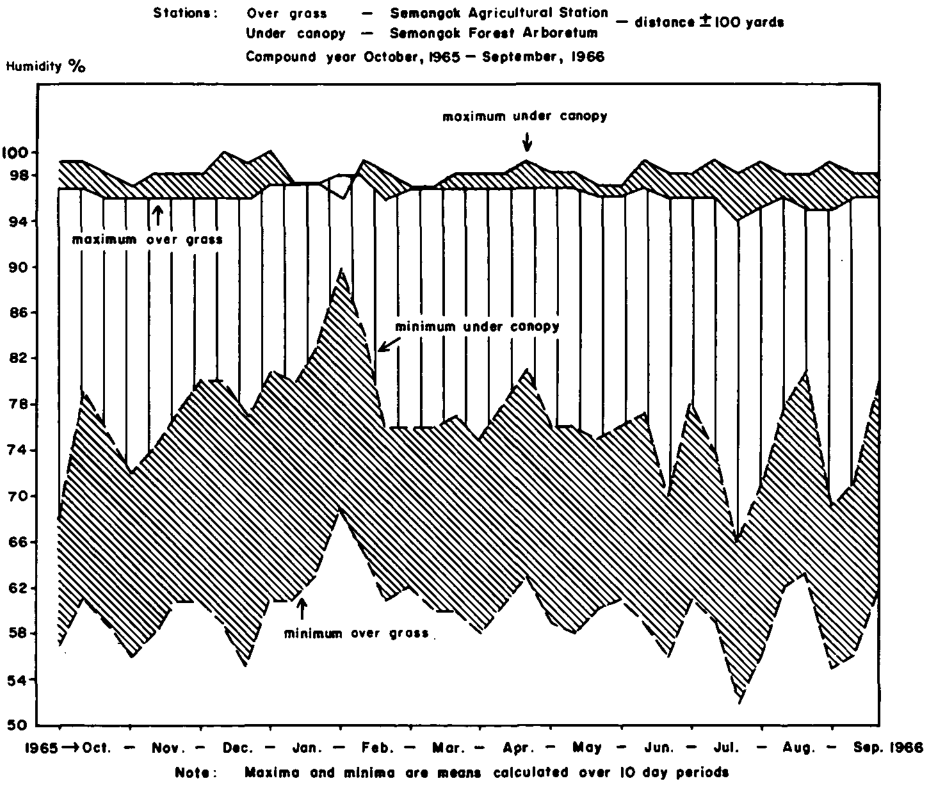


Fig. 5 *Comparison between mean humidity ranges over grass and under forest cover*

shown that drought periods lasting more than one week are more common in the east than in the remainder of the area. Dry periods of two to three days account for over 70% of the total of dry periods in the whole Region (Andriesse, 1972).

Summarizing this account on rainfall it is concluded that the total annual precipitation for all stations can vary between 3000 to 4500 mm. The belt of maximum rainfall may shift from west to east or from east to west in any given year but the general indication is that the eastern and western portions of the Region are somewhat drier than the middle portion (probably the latter is wettest because of local mountainous topography). The rain in most stations falls in stages and generally 8-10 maxima per year can be observed. Dry periods lasting longer than one week account for 7% of the total of dry periods calculated for three representative years. The difference between the seasons is greatest in the coastal belt and becomes increasingly less apparent towards the interior.

1.3. Temperature and humidity

Temperature and humidity measurements are rare for the Region. The Central Agricultural Station Semongok was chosen as being most representative for the Region, as it is not too close to the sea, sheltered from wind and its elevation is approximately 30 m. An added advantage was that close to the station a similar recording station registering temperature and humidity under a canopy of primary forest has been established so that the influence of the vegetation on both temperature and humidity could be studied, the station at Semongok being over grass. Figs. 4 and 5 show for both stations the temperature and humidity ranges for a full compound year. This year runs from Oktober 1965 to September 1966 since reliable data for both stations were only obtainable for this period. The daily maximum and minimum temperatures averaged over 10 days periods learn that the average maxima reached under a canopy are generally 3.2°C lower than over a grass vegetation (both at a height of 75 cm above groundlevel) whereas the minima under a canopy are generally 1.7°C higher than those over grass.
Vegetation therefore has a considerable influence on incoming radiation at the soil surface and fluctuations which over grass are in order of 5.5°C are strongly diminished by a forest vegetation.

The humidity ranges show a similar trend in that fluctuations are levelled off but average humidity values are higher under forest than over a grass vegetation.

Andriesse (1972) showed in a detailed study of the diurnal fluctuations of humidity and temperature that the seasonal variation which is apparent in the rainfall data is less apparent in the temperature and humidity data. The diurnal fluctuations are of much greater significance than the seasonal ones: this is particularly the case over grassland where daily fluctuations of both humidity and temperature are twice as high as those under a canopy. Seasonal variation in both temperature and humidity can therefore be ignored.
Table 2 indicates that for purposes of this study (soil formation under natural conditions) a temperature range of 32°C (absolute maximum) to 21°C (absolute minimum) can assumed to be present over most of the Region, the average temperature being 27°C. The absolute range in humidity under a canopy is 100-53%, the average is 88%.

Table 2. Diurnal temperature and humidity ranges over grass and under canopy

Temperature	**Over grass**	**Under canopy**
Highest maximum	35.0°C	32.2°C
Lowest maximum	26.6°C	24.4°C
Highest minimum	25.5°C	31.0°C
Lowest minimum	20.0°C	21.0°C
Humidity		
Highest maximum	98%	100%
Lowest maximum	93%	94%
Highest minimum	86%	98%
Lowest minimum	46%	53%
Absolute range temperature	20-35°C	21-32.2°C
Absolute range humidity	46-98%	53-100%

1.4. Evaporation

Evaporation measurements in a Class A pan with a diameter of 120 cm are available from Kuching and Simanggang Airports, respectively representative for the wettest and relatively driest parts of the Region. The monthly average values for the years 1963-1968 are given in Table 3 together with those for Bogor in Indonesia (1 year only) for comparison. It appears that the evaporation throughout the year is higher in Kuching than in Simanggang except in the month July. This is probably caused by stronger winds in Kuching (coastal area). The figures for Simanggang compare well with those of Bogor. In Table 3 a comparison is also made between the average precipitation and evaporation and if the evaporation from a free water surface is expressed as a percentage of the rainfall it appears that the evaporation is not directly related to the amount of rainfall. Thus, during the most rainy season with less sunshine hours the evaporation can be greater than in the less wet season with much more sunshine. Mohr and van Baren (1954) commenting on a similar observation for Bogor, considered that the combined effect of temperature and wind probably has as great an affect on evaporation as direct exposure to sunlight. It is hereby remarked that radiation is probably more important than sunshine, and since incoming radiation can be higher with a cloudcover than with a blue sky it would seem possible that the season with relative severe cloudiness can also be the season of greatest evaporation.

As far as the average percentage evaporation over rainfall is concerned Kuching and Simanggang are comparable but monthly variations can be noticed. For purpose of this study it can be concluded that throughout the year precipitation exceeds evaporation as measured from a free water surface (see Table 3).

2. Soil climate

In pedogenetic studies the soil climate and particularly the temperature and humidity are of more importance than the atmospheric one (Mohr et al, 1972) because biological and chemical processes operating in the soil are dependent on micro-environmental conditions.

Table 3. Evaporation and precipitation in mm

Month	Evaporation			Rainfall			E_W in % of rainfall		
	1 year Bogor (Indonesia)	mean 5 years Simanggang	mean 5 years Kuching	Bogor	mean 5 years Simanggang	mean 5 years Kuching	Bogor	Simanggang	Kuching
Jan.	141	158	164	527	403	483	27.0	39.5	34.1
Feb.	100	135	136	374	255	683	27.0	53.0	19.9
Mar.	147	137	148	189	296	336	77.8	46.4	44.2
Apr.	141	141	152	575	297	218	24.7	47.9	22.3
May	145	142	163	242	259	194	59.9	54.8	84.1
June	145	130	154	392	223	194	37.0	58.2	79.6
July	135	137	145	261	167	145	51.7	82.2	94.5
Aug.	147	136	153	272	197	204	54.0	68.8	75.0
Sept.	152	129	154	135	176	240	102.0	73.3	60.6
Oct.	151	147	150	375	294	350	24.2	50.0	42.9
Nov.	102	138	171	371	299	307	27.5	46.2	55.6
Dec.	149	142	141	242	364	443	61.5	28.9	31.8
Total	1655	1672	1831	3955	3230	3797	av.47.8%	av.54.9%	av.53.7%

Bogor (Mohr and van Baren, 1953).

2.1. Temperature

There are no soil temperature data from the Region but Wall (1966) collected such information from 2 localities in the North of Sarawak. Both recording stations were sited on a grass covered sandy soil. The records indicate that the average monthly mean soil temperatures at 30 cm depth are generally 2.7°C higher than the air temperatures is the shade. During the less wet season this may be as much as 4.2°C. The differences between the temperatures at a depth of 30 cm and 120 cm are not great, and generally are 0.8°C throughout the year. These values agree well with those reported by Mohr et al (op cit) for Jakarta, Pasaruan and Bogor in Indonesia where the soil temperatures at 110 cm exceed those of the atmospheric temperatures by respectively 3.4°C, 3.5°C and 3.33°C. Buursink (1971) reports for Sudan conditions a difference of 4.4°C whereas Siderius (1973) for Botswana arrives at a value of 4.5-4.9°C. These values are probably higher than those reported for tropical humid areas because of the arid conditions in both the Sudan and Botswana. As already suggested by both authors the theoretical value of 1°C adopted in the U.S.A. as being the difference between atmospheric and soil temperature (7th Approximation, 1960) cannot be accepted for all conditions. The available evidence would indicate that local climate can have a considerable influence on the relation soil-air temperature.

The close relationship between the values reached by Wall (1966) and those given for Java suggests that a value of 3.5°C may be assumed to be also correct for the Region, that is if the soil is not covered by dense vegetation. Mohr et al (1972) mention observations that in full shade the mean soil temperature at a depth of 30 cm is almost equivalent to that of the air. Since soil formation in Sarawak takes place under a dense cover of Primary Forest it seems justified to assume that the soil temperatures under natural conditions approximate those of the atmospheric temperatures measured under the forest canopy. For this reason an average temperature of 27°C as reigning under a canopy (see Fig. 4) can be regarded also as the normal temperature at which soil forming processes under natural conditions of the Region, take place.

2.2. Humidity

An estimate of soil humidity is in the absence of direct measurements a difficult and complex exercise. Even when this information would be available, the amount of excess water which is able to percolate through the soil can only be approximated by taking a multitude of other factors into account of which the most important are precipitation, run-off, evaporation and transpiration. These factors are again interrelated and dependent on type of vegetation, rooting depth, soil characteristics and conditions of the atmospheric climate other than precipitation. Numerous attempts have been made to calculate the excess water being available for leaching by estimating the varous losses through the vegetation either as evaporation, transpiration or evapotranspiration. Most notable attempts are those by Thornthwaite, 1948; Penman, 1948, 1949; Prescott, 1949; and Turc, 1953; but none of these appear to be valid for humid tropical areas. Papadakis (1961, 1970) introduced concepts such as the 'leaching index' in which evapotranspiration is calculated by using various atmospheric climatological data such as saturation vapour pressure and atmospheric vapour pressure, 'normal (Ln)' and 'maximum (Lm) leaching rainfall' respectively being the difference rainfall minus evapotranspiration during the humid season and the difference between two times rainfall minus evapotranspiration during the non-dry season, both in cm. In this system the humid season is considered to be the total monthly period in which rainfall is greater than evapotranspiration.

Based on data given in Table 3 and those published earlier by the author (Andriesse, 1972) it is calculated that the humid season persists throughout the year, and the climate of the Region can be classified in Papadakis' scheme as HU which indicates that all months are humid and that Ln (leaching rainfall) is more than 20% of annual potential evapotranspiration.

Another, but much older method developed by Mohr (1941) for Indonesia, still appears to be the most practical one for areas from which only scanty climatic data is available. After taking into account the results of various experiments carried out in Bogor he concluded that a value of 100 mm of average rainfall per month is a good parameter for a situation in which a surplus of water would be able to percolate through the soil, whereas any month with an average of less than 60 mm rainfall can be regarded as dry for soil formation since soils would than be able to dessicate. The interval 60-100 mm would approach the situation in which the soil does not dry out but there would be no excess water for percolation.

Schmidt and Ferguson (1951) argue that Mohr, by taking the average monthly rainfall figures as a basis for his scheme, ignores the fact that there may be periods extending over several years in which the rainfall is less than the average. They therefore adopted, what they refer to as the Q factor which indicates the average figure of the number of dry months (less than 60 mm) over a period of 10 years divided by the average figure of the number of wet months (more than 100 mm) over the same period. The Q factor then extends over a range of 0-10, and an increasing value denotes increasingly dry conditions. The Q factors were calculated for a number of main stations in the Region as shown in Table 4.

From this Table it appears that although local variations exist the Q factor is negligibly small and that even over a long period the climate in the Region can also in this classification be regarded as perhumid, thus a situation in which a surplus of rainwater available for percolating into the soil can be expected.

This is also borne out by the measurements for evaporation given in Table 3 which, although admittedly taken from a free water surface, do nevertheless indicate a great excess of rainfall over evaporation.

From the available data we may therefor assume with a high degree of certainty that throughout the year most soils in most locations will remain moist. This was also the experience in the 10 years field period during which it was observed that soils are in general in moist condition in all seasons, exceptions being the very sandy soils in which the surface horizons may desiccate to some depth during dry periods lasting a week or longer because of excessive drainage and low water storage capacity.

The small incidence of such periods is reason why for soil formation the influence of a drying-out process can be neglected.

Although soils may be moist throughout the year this does not necessarily imply that strong leaching will occur anywhere and anytime. This is dependent on soil characteristics such as texture and permeability and seasonal variation in rainfall. Sandy soils would show periodically strong flushing-out during peak rainfall where-

Table 4. Q factors according to Schmidt and Ferguson for some selected rainfall stations

	Kuching	S. China	Matang	Bau	Lundu	Simanggang
Total months less than 60 mm	4	0	2	3	3	0
Period in years	71	21	32	17	20	18
Average per year	0.056	0	0.062	0.17	0.15	0
Total months more than 100 mm	828	250	372	190	214	214
Period in years	71	21	32	17	20	18
Average per year	11.6	11.8	11.6	11.2	10.7	11.9
Q factor	0.004	0	0.005	0.02	0.014	0
Rainfall type (Schmidt and Ferguson)	A	A	A	A	A	A

as during short dry periods leaching would come to a complete standstill. Clayey soils will show a more constant, low, and less fluctuating leaching regime.

3. The influence of climate on soil formation

The precipitation can be considered as being fairly uniform throughout the Region, the variations being too small for having a direct bearing on the differentiation of soil types as existing in the Region. The climate can be classified as being perhumid, there being a surplus of precipitation throughout the year in all areas, sufficient to either maintain a constant leaching process or at least sufficient to maintain an adequate level of moisture in the soil preventing strong desiccating effects or a rise of soluble material to the surface through capillary action.

The temperature regime throughout the Region can also be considered as being uniform and is classified as Hyperthermic, more than 22°C throughout the year (Soil Survey Staff, USDA, 1967).

Therefore, in the present study concerning the genesis of upland soils in W. Sarawak, the overall direct influence of the factor 'atmospheric climate' is regarded as constant.

The 'soil climate' under a dense canopy of primary forest is considered to be fairly similar to the atmospheric climate, particularly as far as temperature is concerned. The moisture regime in soils is however influenced by local environmental factors such as topography and physical characteristics of soils such as porosity and permeability.

B. Geology and Parent Materials

1. General

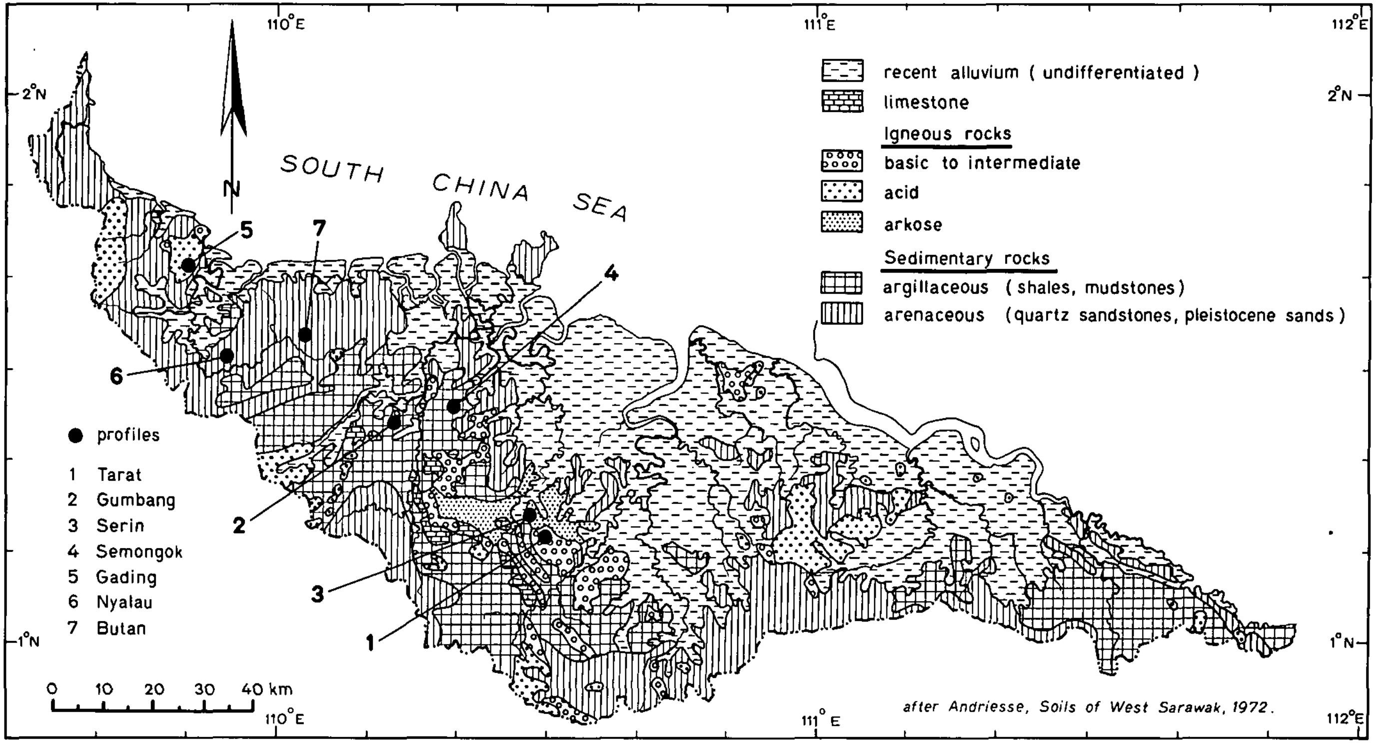
The whole Region has been geologically surveyed during the period 1949-1957 by the Geological Survey Department, Borneo Region, Malaysia; firstly on a scale 1:125,000 by Haile (1954), Wilford (1955) and Haile (1957). Subsequent more detailed surveying was carried out in selected areas by Wolfenden and Haile (1963), Wilford and Kho (1965) and Pimm (1965). A compilation of the geology of the area in its relation to soil formation has been made by the author (Andriesse, 1972). A generalized version of this compilation is included, providing background information for the present study only.

The geology of West Sarawak is complex. This part of the State forms a remnant of the old continental core which up to the Tertiary extended from the Asian mainland (Malaysian Peninsula) across the South China Sea to the centre of present Borneo (van Bemmelen, 1949). The northern boundary of this core coincides with the boundary of the study area. Situated north of this boundary is the wide expanse of the N.W. Borneo geosyncline which was gradually filled by Upper Cretaceous and Tertiary sediments and uplifted in varous stages during the Tertiary and in the Pleistocene.

The continental core consisting of granitic materials is locally covered by Triassic, Jurassic and Cretaceous sediments which in places are again overlain by Tertiary sediments of continental nature which had accumulated in localised small basins existing during that time.

Strong uplift occurred in the late Tertiary and Early Pleistocene and in places where the continental Tertiary deposits have not yet been removed by erosion and denudation they now build conspicuous mountains with typical cuesta and table mountain features.

Acid and basic igneous rocks have intruded into and have extruded through the sedimentary mantle of the core during and following the various geosynclinal periods during Triassic to Upper Tertiary times. The physical and chemical nature of these igneous rocks is varied and this together with the multitude of sedimentary rocks of varying ages and composition has resulted in a very mixed occurrence of a wide variety of rock types over comparative short distances. Most of these rock types are too local and too minor of extent to be of importance and hence they are not described in detail. Furthermore, for purposes of this study little emphasis is placed on the general geological aspects of the area but stress has been laid upon the importance of the nature and composition of the rock formations which have acted as soil parent materials. Concerning the sedimentary rocks lithology is regarded as of more importance than stratigraphy.
Whereas Fig. 6 shows the location of the major units of parent materials present in the area, Table 5 indicates their relative importance.



after Andriesse, Soils of West Sarawak, 1972.

Fig. 6 *Sketch map of Soil Parent Materials in West Sarawak*

Table 5. Type and areal extent of Soil Parent Materials in West Sarawak

Main type	Subtype	Extent in sq. km.	Percentage of Region
Igneous Rocks	Basic to intermediate igneous rocks and related metamorphic rocks	417	3.7
	Intermediate to acid igneous rocks and related metamorphic rocktypes including arkose	727	6.5
Sedimentary Rocks	Argillaceous rocks (shales, phyllites and mudstones)	2,202	19.6
	Arenaceous rocks (coarse to fine grained sandstone, conglomerates, chert. Pleistocene deposits	2,806	25
Recent (Holocene Deposits)	Riverine alluvium (fine to coarse textured)	1,175	10.4
	Marine alluvium (deltaic and estuarine deposits)	789	7
	Organic deposits (peats)	3,000	27
	Total	11,206	100

2.Igneous rocks

These comprise approximately 10% of the Region, subdivided into 3.5% basic to intermediate and 6.5% acid igneous rock types. Arkose, although actually being of sedimentary origin, has been added to acid igneous rocks because it is chemically very similar to tonalite, its lithic source (Pimm, 1965). Small stocks of basic igneous materials are found throughout the Region, and they range in composition from gabbros to andesites. Small areas of metamorphosed rocks brought together under the name greenstones occur prolifically in the extreme western area.

The largest portion of the basic to intermediate igneous rocks in the Region is located in the middle part of the Region, where they belong to the so-called Serian Volcanic Formation of Upper Triassic Age in which nonporphyritic andesites and basalts appear to be most common. Most of these were extruded beneath sealevel and have been altered through hydrothermal activity showing strong serpentinization, chloritization and sericitization. Chemical analyses of a typical rock sample, which was also used in our study, are given in Table 6 (S8220).

Acid igneous rocks vary from medium to coarse grained adamellite forming some large sills in the western part of the Region to coarse and medium grained granite and granodiorite as main stocks in the remainder of the area. There are further small occurrences of microgranodiorite, dacite, microtonalite and quartz andesite. Chemical analyses of a typical adamellite and a quartz andesite, which have both been included in the present study, are shown in Table 6 (S7285 and S1).

Table 6. Chemical and normative composition of main rock types occurring in West-Sarawak

	Basalt (S 8220)	Quartz Andesite (S 1)	Arkose (S 13201)	Adamellite (S 7285)	Cretace shale
SiO_2	50.5	66.78	67.90	71.07	60.1
TiO_2	1.38	0.40	0.55	0.55	0.99
Al_2O_3	16.70	16.03	14.05	13.61	21.6
Fe_2O_3	1.22	1.25	1.63	0.62	5.36
FeO	8.35	1.99	2.65	3.29	
MnO	0.15	0.05	0.07	0.08	n.d.
MgO	5.55	1.47	1.59	1.06	1.53
CaO	8.20	4.52	1.38	2.32	<0.10
Na_2O	3.30	4.00	3.05	2.65	n.d.
K_2O	1.45	1.27	2.65	3.34	2.24
H_2O+	2.70	2.00	2.65	1.05	7.62
H_2O-	0.13	0.20	0.78	0.06	
CO_2	0.10	0.20	0.37	0.06	n.d.
P_2O_5	0.22	0.15	0.09	0.13	n.d.
ZrO_2	nil	nil	n.d.	n.d.	n.d.
S	n.d.	0.01	n.d.	n.d.	n.d.
Cl	n.d.	0.01	n.d.	n.d.	n.d.
	99.9	100.33	99.9	99.9	99.5

C.I.P.W. norm

		Basalt (S 8220)	Quartz Andesite (S 1)	Arkose (S 13201)	Adamellite (S 7285)
Quartz		-	26.7	32.76	34.40
Orthoclase		8.90	6.10	15.57	20.00
Albite		27.77	27.30	29.87	21.50
Anorthite		26.41	7.90	3.34	10.60
Corundum		-	0.60	4.59	1.60
Diopside	$CaSiO_3$	5.34	-	-	-
	$MgSiO_3$	2.80	-	-	-
	$FeSiO_3$	2.38	-	-	-
Hypersthene	$MgSiO_3$	7.10	-	-	2.40
	Mg_2SiO_4	2.80	7.4	4.00	-
	$FeSiO_3$	4.88	4.2	2.64	4.70
	Fe_2SiO_4	3.65	-	-	-
Magnetite		1.86	3.7	1.52	0.90
Ilmenite		2.74	1.50	1.06	1.10
Apatite		0.34	1.30	0.34	0,30
Calcite		0.30	1.00	0.80	0.30
Water		2.83	-	3.43	-

Ref.: S 8220-Wilford, 1965; S 1-Wilford, 1955; S 13201-Pimm, 1965;
S 7285-Wolfenden and Haile, 1965

Apart from these mainly intrusive rock types, extrusive acid rocks vary in nature from trachyte, rhyolite to dacite, acid tuff, acid breccia and lappili tuff, all of very minor importance.

The mentioned arkose of Triassic age is found in the centre of the Region covering a considerable area.

It is also included in this study and chemical analyses of a typical arkose are given in Table 6 (S13201).

3. Sedimentary rocks

Sedimentary rocks comprise approximately 45% of the Region; these include Early to Late Pleistocene clays, sand and gravels occuring on terraces.

They are subdivided into:

1. argillaceous rocks (19.6%)
2. arenaceous rocks (25%), and
3. limestone (less than 1%).

3.1. Argillaceous rock types

Common argillaceous rocks are of a carbonaceous and pyritic nature, which is indicative for a neritic depositional environment. Those of Tertiary Age also include deposits of continental origin (red mudstones). The shales, dominantly of Cretaceous Age, are commonly hard, dark grey or blue and in places contain high amounts of plant remains. Pyrite films are common along the bedding planes and cleavages of the carbonaceous shales. Phyllites are found subordinately as well as soft, dark grey mudstones. Chemical analyses for argillaceous rocks were not recorded by the Geological survey. For purposes of this study a sandy shale of Cretaceous Age was selected, the hand specimen showing the carbonic character of the commonly occurring argillaceous rocks and the pyritic films along bedding planes. The analyses given in Table 6 concern this material. The remark must however be made that the material is already partly weathered. Fresh shale exposures are extremely difficult to locate because of the generally very deep weathering crust overlying these comparatively soft and easily weatherable materials. The material analysed was taken from a deep road cutting.

3.2. Arenaceous rock types

The arenaceous rocks are commonly highly quartzitic and poorly consolidated, particularly those of Tertiary Age. The latter are dominantly of a continental nature and contain between 10 to 25% weatherable constituents comprising rock fragments and feldspars. For our study a typical sandstone bed of Tertiary Age was selected. In the absence of chemical analyses a detailed description is given of the material involved. This is a fine to medium grained moderately sorted rock, consisting of subangular grains of quartz and some feldspar, fragments of chert and shale, small flakes of muscovite, and a few grains of zircon, tourmaline and iron ore. The feldspars are slightly kaolinized or sericitized, and perthitic feldspar is more common than sodic plagioclase. Cementation is by quartz. A little interstitial sericite and chlorite is common. To this should be added that generally fine grains of carbonaceous material and plant fragments are usually present on bedding planes. Also secondary pyrite may be present and is associated with shale flakes and carbonaceous material.

3.3. Limestone

Because of the very subordinate extent of limestone, this rock type is not further discussed.

4. Recent or Holocene deposits

These cover 44.4% of the Region of which the bulk (27%) comprises organic deposits or peats which have developed in interfluvial basins. These have been described in extenso by Andriesse (1974). The remaining 17.4% can be subdivided into 7% marine deposits for the majority formed by deltaic and estuarine clays to silty clays, whereas the riverine deposits comprise mainly basin clays. Since this study is concerned only with the upland soils no further attention is given to the recent deposits.

5. The influence of geology on topography and soil formation.

Igneous rocks when occuring as comparative large stocks build conspicuous mountainous terrain. Due to differential erosion caused by variable hardness of rocktypes, minor hills or pinnacles, protruding from a landscape with subdued relief generally indicate the presence of a small sill or dyke. These are easily recognizable features on air-photographs and delineation of such areas in mapping procedures is therefore greatly facilitated. There is, however, the danger of over-emphasizing the significance of such igneous outcrops since they are often flanked by metamorphic or sedimentary rocks up to almost the summit, while only the core of the hills consist of igneous materials.

Argillaceous rocks are generally strongly folded and commonly underly strongly to moderately dissected low hilly landscapes of which the hill summits represent distinct levels (Gipfelfluhr).

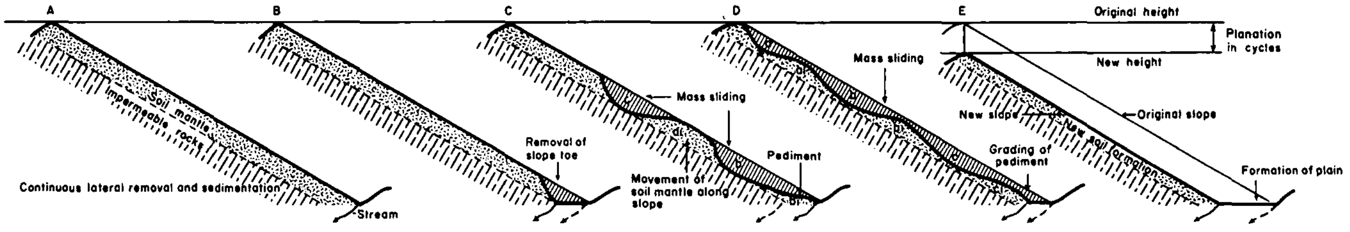
Arenaceous rocks give rise to the development of a range of topographic features. If uplifted and faulted a cuesta landscape is most often indicative for flatbedded sandstone formations. Hardness and bedding planes are further important criteria for the resulting topography after erosion. If e.g. within folded predominantly argillaceous rocks a thick bed of sandstone occurs, the latter commonly forms a prominent ridge.

Land slides and slumping appear to be the main erosional features in the Region, particularly in areas with sedimentary rocks, whereas sheet-erosion is regarded as being of subordinate importance (Andriesse, 1972).

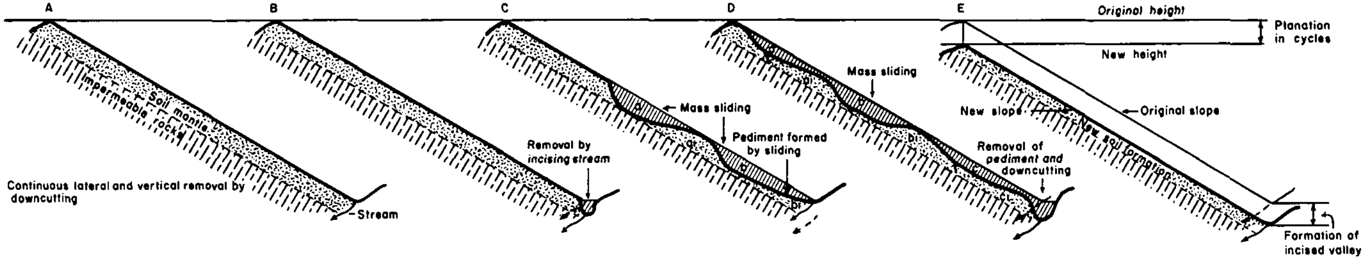
Mass movements along slopes are strongly related to the nature of the bedrock. Most hills of areas with clastic rock types, particularly shales, show a parallel slope retreat meaning that denudation of the landscape is achieved initially by lateral erosion of hills through sliding and slumping. In this process the slopes remain more or less parallel while the summits are lowered in stages. Fig. 7 illustrates such a process. Two variations are indicated.

In the first, rock-controlled meandering of a stream is undercutting the hill slope through which sliding of up-slope material is initiated. By seeking to restore the disrupted equilibrium most of the weathered mantle on the hill slopes is removed from top to toe and is locally distributed by the stream building up a valley

Fig. 7 *Parallel slope retreat through mass movement along the slope and removal at the base*



a. development of plain at local base level



b. incising stream

bottom. A new weathering and erosion cycle starts when fresh material is exposed on the hill sides. The tops of the hills are lowered at the end of each erosion cycle.

In the second variant the lateral removal of hill sides is essentially the same but the stream is incising instead of undercutting the hill slope. The incision causes a slope imbalance and initiates the sliding down of hill slope material at both sides simultaneously and the river removes all eroded material downstream.
Holmes (1965) indicates that this process is quite possible in tropical regions with exceptionally high rainfall and which have an underlying bedrock with unfavourable infiltration rate. Both conditions are found in the Region where strongly folded, steeply inclined impermeable shale beds provide slip-surfaces for the soil materials lying above them and which through high rainfall have become saturated. Mass soil movements along hill slopes, particularly on those formed by sedimentary rocks have a strong influence on the course soil development is taking. In such an environment little or none surface material is directly related to the underlying rock found in vertical section and soil depth down to the partly weathered rock mantle varies considerably.

Apart from molding the physiographic features of the Region, thereby indirectly influencing erosion and soil development, the parent material has a strong direct bearing on the chemical and physical nature of soils developing upon weathering. Inherent characteristics of soil such as texture, chemical and mineralogical composition are directly related to the parent material if the overall influence of atmospheric climate on the various parent materials is the same.

For these reasons a strong relationship between autochtonous soils and paren materials has been found to exist in the Region. This relationship will be extended upon in more detail in following sections.

C. Physiography

The Physiography of West Sarawak is described in detail by the author in a former treatise (Andriesse, 1972). The following section has been extracted from this analysis in order that the role of the landscape morphology in soil forming processes operating in the upland soils is well understood.

1. Relief

West Sarawak is characterised by a general low relief (see Fig. 8). More than 50% of the land area lies below the 30 m (100 feet) level and more than 75% is found below a level of 170 m (500 feet). The remaining 25% consists of mountainous terrain in which only a few isolated peaks reach heights of over 700 m (2000 feet). Although the overall relief is low, the area is made up of a variety of strongly contrasting relief units. A flat coastal belt comprising foodplains and basinswamps is backed by a low hilly landscape which has all the characteristics of a summit plain in which concordant hill tops range in altitude from 17 m (50 feet) near the coast to 100 m (300 feet) in the interior. From this summit plain single hills and mountains rise up as isolated monadnocks or blocks. This contrasting relief in the belt of the summit plain is caused by differential erosion due to varying hardness of the underlying rocktypes as explained in section B.5. A third belt, marking the border with Indonesia (Kalimantan) forms the most rugged terrain and lies between altitudes of 250 m (750 feet) to in places over 700 m (2000 feet). The highest elevation in the area is reached by two peaks, these being slightly over 1000 m (3000 feet) in altitude.

2. Physiographic units

To facilitate a logical analysis of the physiography, the Region has been divided into 11 main physiographic units. Apart from the differences in the terrain morphology, quite a number of other variable characteristics, such as rock types, soils, vegetation, agricultural systems and population density are closely related to these units. In fact, the mentioned characteristics are interrelated and appear to be mainly induced by geology as the prime independent factor, as explained in section B.5.

In the descriptions we restrict ourselves to the upland regions. Areas of accumulation, such as swamps, riverine and marine plains and also terraces have been omitted. Fig. 9 indicates location and distribution of the described units.

2.1. The Quop B unit (Fig. 10)

This landscape unit is characterised by a monotonous repetition of small hills ranging in height from 50 m (150 feet) near the coast to 65 m (200 feet) in the interior, with numerous small narrow valley bottoms lying at a level of about 7 m (20 feet) near the coast to about 17 m (50 feet) in the interior.

The amplitude of relief varies locally from about 45 m (135 feet) to about 25 m (75 feet). The levels of the hill summits may represent remnants of an old erosion

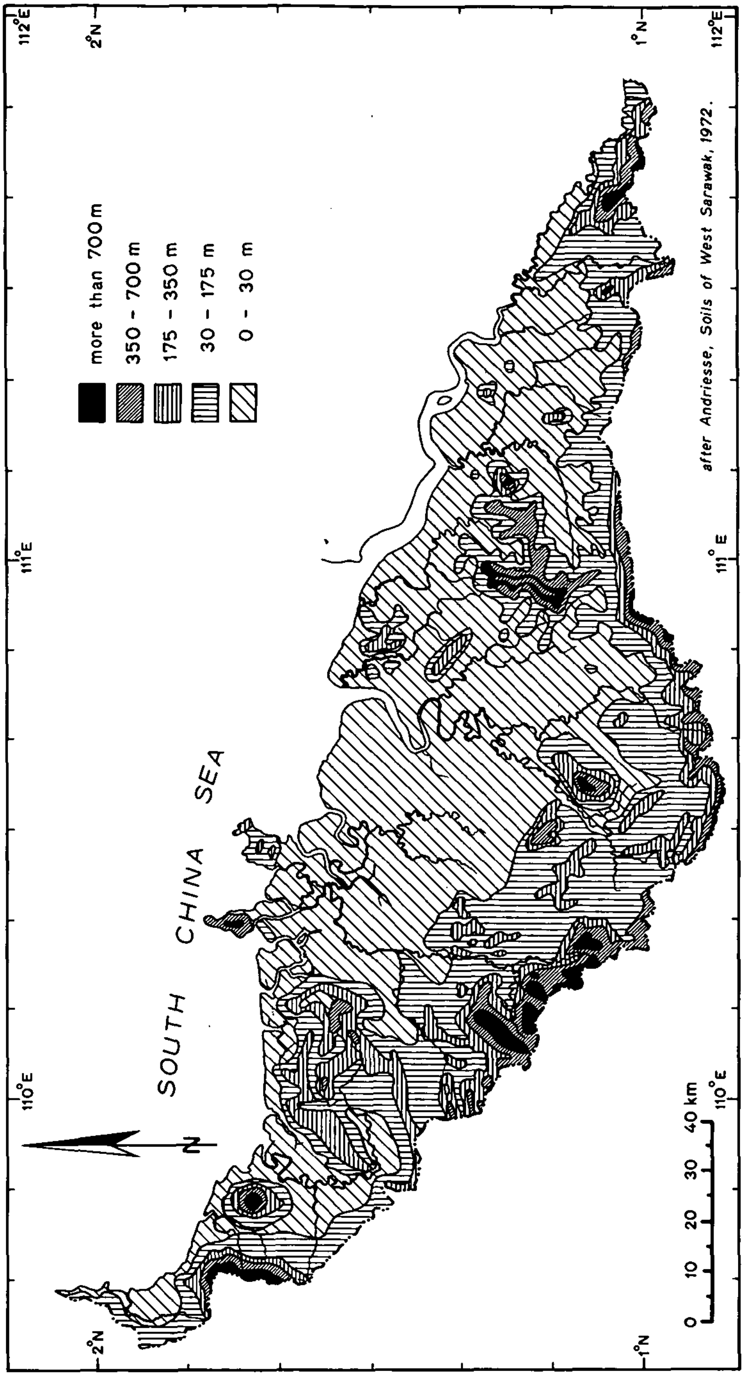
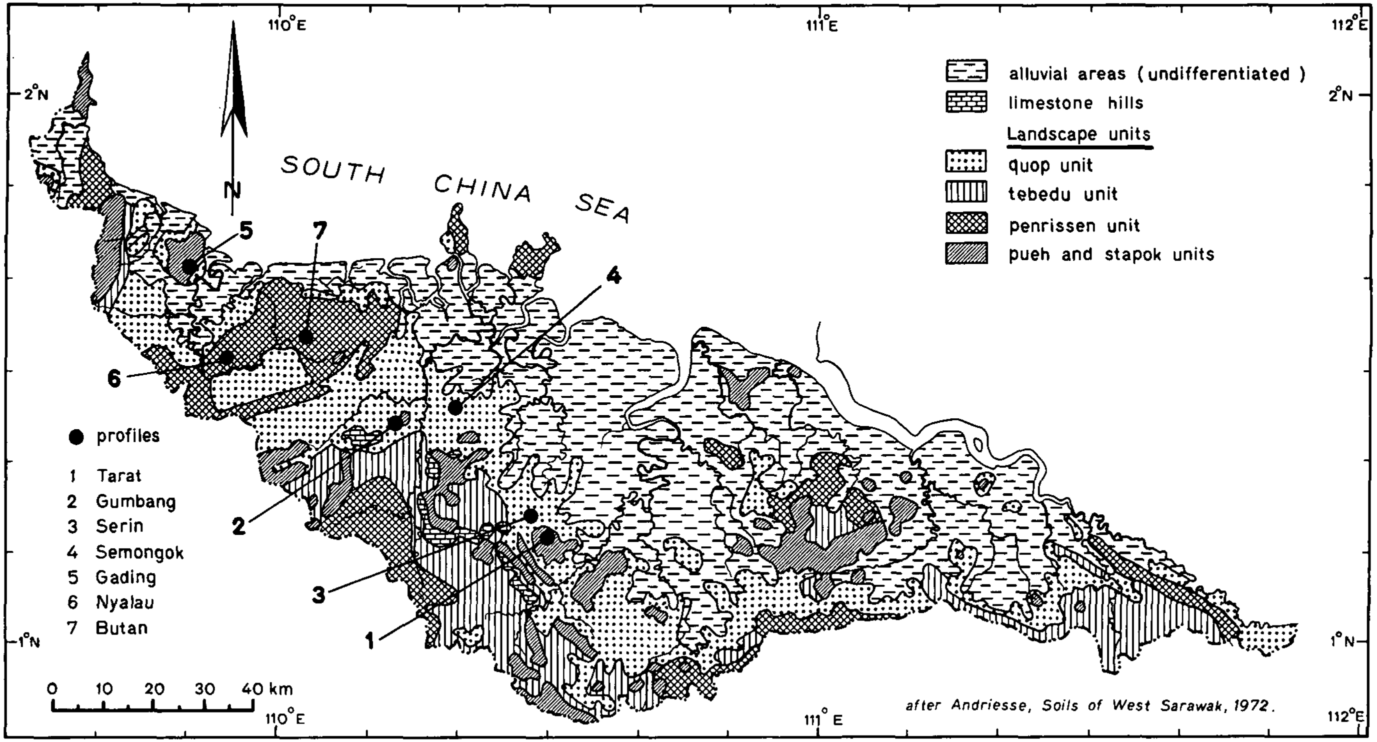


Fig. 8 *Relief map of West Sarawak*



after Andriesse, Soils of West Sarawak, 1972.

Fig. 9 *Physiography of West Sarawak*

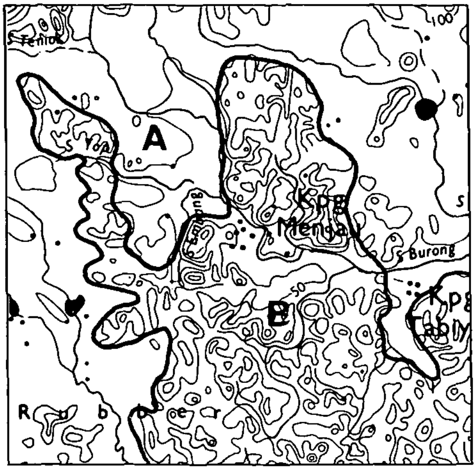


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Fig. 10 *Projected presentation of Quop B unit (contours at 50 feet interval)*

base level but since the soils on the hill tops do not differ from those of the slopes there is little direct evidence for a once existing peneplain. The almost horizontal slightly tilted level of the hill summits may have been inhereted from a surface formed by other processes than peneplanation; and/or the homogenous nature of the parent materials underlying this unit (mainly argillaceous rocks) has preserved this level upon erosion and denudation (Thornbury, 1954; Strahler, 1969). The streams in this landscape are still in the incising stage and there is little valley development unless through blockage of streams the erosion base level was raised locally so that accumulation of eroded material in valleys could take place. The slopes of the hills range from 15-35 degrees; they are often irregular due to land slips and slumps.

As explained in section B.5. these are frequently the result of the undercutting of hill slopes by meandering rivulets or brought about by incising streams. Erosion in this landscape is mainly through mass movement along slope and subsequent redistribution of hillslope material in valleybottoms (local alluvium and collovium) or the material is transported by streams. The many small streams are ephemeral and carry water only during peak rainfall periods or after local storms.

2.2. The Tebedu unit (Fig. 11)

This unit is in major characteristics quite similar to the Quop B unit, the difference being mainly in quantitative aspects. It is usually found backing the Quop B unit and is typical for most interior areas underlain by argillaceous sedimentary rocks.

The relation between Quop B and Tebedu unit is shown by Fig. 12. The concordant hill summits range in height from 70 m (200 feet) to 117 m (350 feet), the summit plain being tilted towards the coast. The valley bottoms are at the 50-70 m

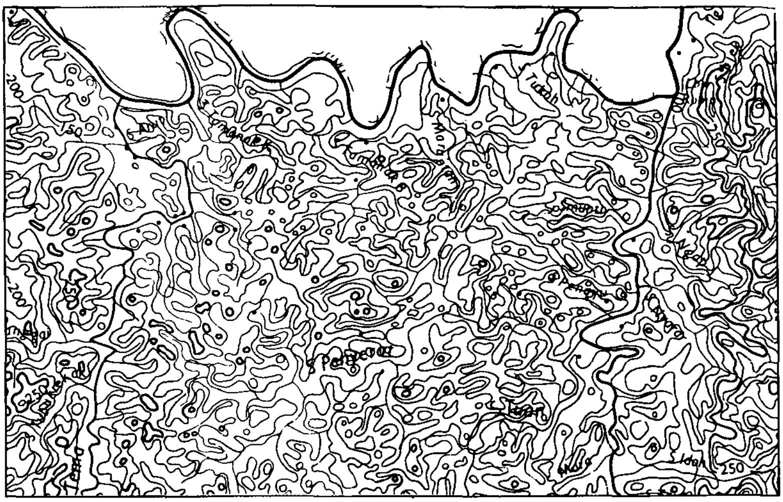

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Fig. 11 *Projected presentation of the Tebedu unit (contours at 50 feet interval)*

(150-200 feet) levels. The amplitude of relief varies therefore from 20-45 m, almost the same as that in the Quop unit but hill slopes are generally steeper and range from 25° to 35°.

Drainage and erosion aspects are the same as described for the Quop unit.

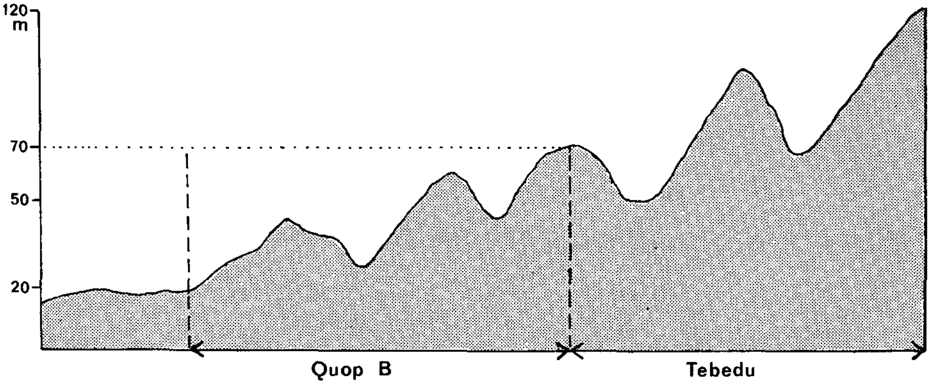

Fig. 12 *Diagrammatic cross-section of the Quop and Tebedu systems*

In many localities the Tebedu unit is separated from the Quop unit by a narrow belt of igneous rocks or limestones. Differential erosion may have caused a shift in local erosion base level sothat the downcutting process in the Tebedu unit remained static at the 50 m level while that of the Quop unit was able to continue down to the 7 m level. Fig. 13 illustrates this possibility.

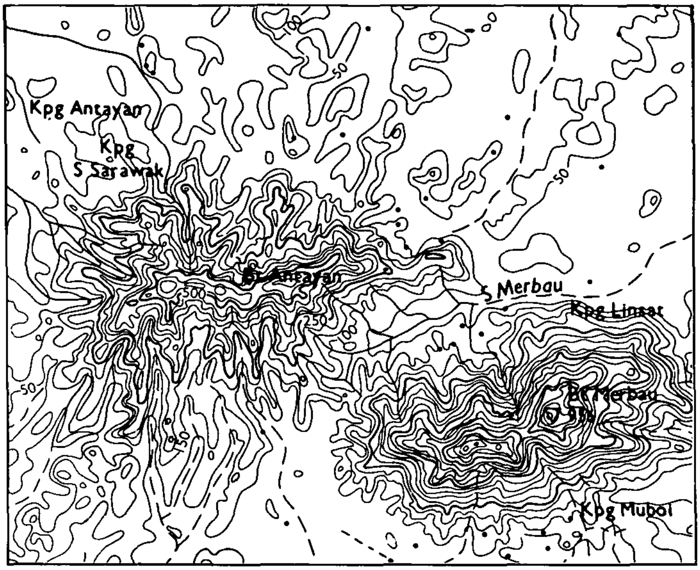

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Fig. 13 *Difference between local erosion base levels, II and IIa, in the Tebedu unit (I) as compared with base level IV in the Quop unit (III), caused by blockage of igneous massifs (Pueh unit, V)*

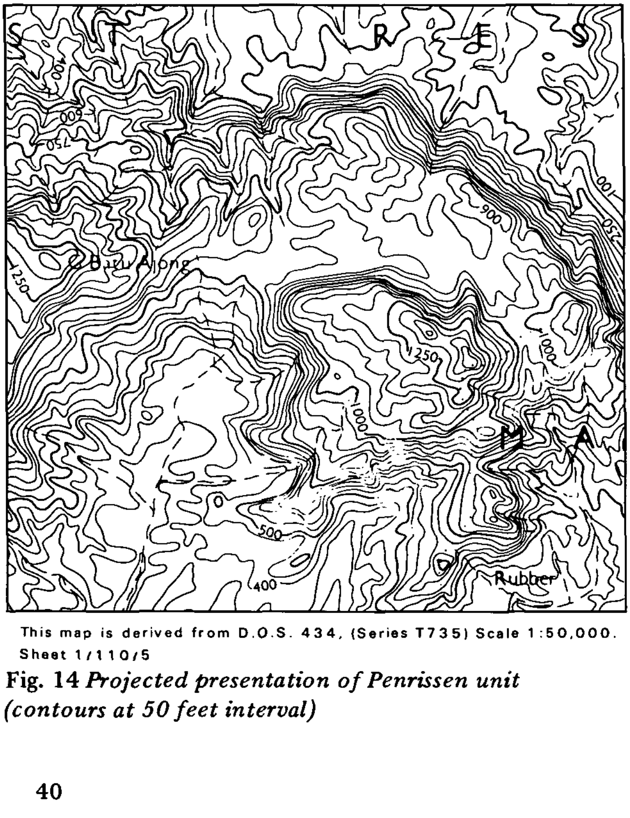

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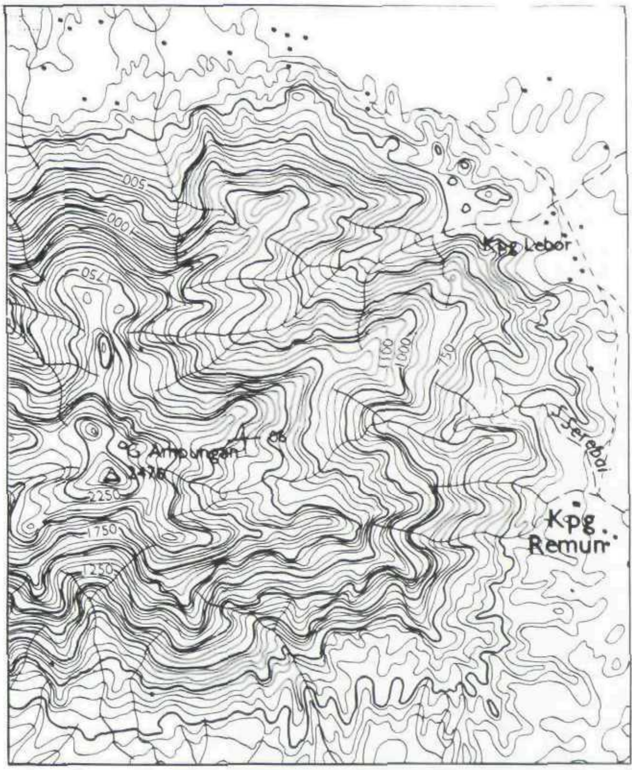
Fig. 14 *Projected presentation of Penrissen unit (contours at 50 feet interval)* variable height, but are commonly over 50 m higher than the surrounding landscape. The micro relief is usually strongly broken because of shallowness of soil and the presence of large blocks of rocks scattered over the surface, particularly at midslope and upper slope areas.

Because of its disposition erosion is severe, resulting in the development of generally shallow and skeletal soils. Mass movements of soil material through landslides are more the rule than the exception, although where coarse textured soils are found sheet erosion may also play a role. Accumulation of scree material at the footslopes is common since in general no rivers are present at the base of the hills to carry away accumulating material. The drainage pattern is strongly radial, the small streams being of ephemeral character.

2.5. The Pueh unit (Fig. 16)

The Pueh unit consists of large mountain complexes dominantly built by basic extrusive rocktypes such as the Serian Volcanic Formation (basalts and andesites) and large stocks of acid igneous rocktypes (granites, granodiorites and adamellite).



This map is derived from D O S 434, (Series T735) Scale 1 50 000
Sheet 1/110/15

Fig. 16 *Projected presentation of the Pueh unit (contours at 50 feet interval)*

2.3. The Penrissen Unit (Fig. 14)

This unit is characterized by rock controlled mountains and ridges, and by its in general high elevation above the 150 m (350 feet) level (over 1000 m in places). The rock types building this unit consist dominantly of poorly consolidated Tertiary deposits, mainly sandstones next to some mudstones. The sandstones being less prone to erosion than the mudstones usually cap typically formed cuestas, mesas, hogbacks and homoclinal ridges. These various forms are dependent on the dip and hardness of the sandstone beds. Gently dipping sandstones give rise to typical cuesta forms with long dipslopes and steep scarp slopes, whereas more steeply inclined rocks give rise to the formation of hogbacks and homoclinal ridges. This is well illustrated in Fig. 14.

The drainage pattern is complex dendritic on dipslopes but parallel on scarp slopes. Erosion is strongest on the scarps while the dipslopes are comparatively stable, particularly under Primary Forest. This is strongly reflected in the soil types formed under these conditions, mature well-developed profiles occurring dominantly on dipslopes while immature, often skeletal soils are dominant on scarp slopes.

2.4. The Stapok unit (Fig. 15)

This unit is formed by isolated, small monad-nock type hills protruding from a Quop or Tebedu landscape. The latter are underlain by argillaceous rocks while the hills of the Stapok unit are formed by a core of igneous rocks mantled by weakly metamorphosed rocks (commonly hornstone) and/or pushed up argillaceous rocks. Differential erosion due to varying hardness of rock types is thought to be responsible for the formation of Stapok-type hills. The hills are strongly sloping and of

This map is derived from D.O.S. 434 (Series T735) Sheet 1/110/14
SCALE 1:100,000

Fig. 15 *Projected presentation of the Stapok unit (contours at 50 feet interval)*

The height of these complex mountains is variable but commonly ranges from 50 m (350 feet) to 800 m (2400 feet) for the Serian Volcanic Formation, the granites and granodiorites. The adamellite, comprising two separate large stocks, gives rise to dome-shaped massifs rising from almost sealevel to in places over 1000 m (3000 feet). The terrain is commonly rugged with deep V-shaped valleys. The streams are ungraded, and waterfalls and rapids are characteristic features of their courses. Most of the load of these streams is deposited as small fan-shaped pediments at the foot of the mountains where the streams debouch onto the low hilly terrain surrounding the massifs. The drainage pattern is in general parallel with in some localities radial tendencies.

The terrain is strongly dissected, footslopes are in the range 10°-25°, but mid- and upper slope areas are commonly steeper and a considerable proportion of this land has slopes of over 35°. Erosion is therefore severe, causing a very broken micro relief of upper slope areas with rock outcrops and large boulders at the surface. Colluvial footslopes are common. Both sheet erosion and mass soil removal through landslides do occur. This terrain configuration and accompanying erosion gives rise to a very complex pattern of soil depth.

3. The influence of physiography on soil formation

It has been shown in the previous sections that the present existing relief of the terrain is predominantly influenced by geology.

In the Region studied can the climate be regarded as a constant factor exerting its influence in equal magnitude everywhere and therefore differences in physiography are mainly the result of geological phenomena and rock types. The resulting contrasts in relief, play an important role in accelerating soil forming processes by having a direct bearing on leaching rate and erosion.

In areas with no relief, run-off is virtually nil whereas an inversed relief causes ponding conditions and the resulting severe wet soil climate induces anaerobic conditions. In areas of strong relief run-off is severe, although this is again influenced by infiltration rate, but it generally promotes oxidizing conditions in upland soils because of absence of groundwater tables and ponding conditions. Where reducing conditions occur in strongly sloping areas, inherent soil and rock characteristics such as low permeability, stratification and geological structures are mainly responsible.

Apart from having a prominent bearing on the soil climate through which relief has a positive influence on rock weathering and soil formation, it also causes erosion which can be regarded as a destructing factor in profile development. Erosion constantly removes material from the soil surface and in the case of mass removal whole profiles are being disrupted, destroyed and turned-over so that soil forming processes operating within the profile are constantly changing and unable to exert their influence for prolonged periods. The result of strong soil erosion is therefore constant rejuvenation. It is realized that erosion causes removal of material in one place but sedimentation in another so that erosion can also be regarded as a soil builder. This aspect is however not relevant since the alluvial soils fall outside the scope of the present study.

For the upland conditions the general rule can be accepted that relief is mainly destructive to soil profile development because it induces rejuvenation. This does not mean that on slopes of similar magnitude this influence is of equal importance since the relationship between erosion and slope is highly dependent on the soil characteristics which vary with the nature of the parent materials.

As has been described in the section on the physiographic units, various types of erosion, which are often specific for the units and related rock types, must be taken into consideration when studying soil formation in areas of strong relief areas. The knowledge that most soils in sloping areas have strongly disrupted horizonation is reason why for soil genetic studies much caution must be exercised in selecting modal profiles. Therefore, care has been taken that the studied profiles were selected from such sites where little evidence of mass soil removal was found. In practice this would mean the upper slope area.

D. Organisms

The most important living entities playing a role in soil formation are vegetation, micro-organisms, animals and man. These are all more or less dependent on invariables such as topography and climate. Jenny (1941) introduces therefore the biotic factor, being the quality aspect of organisms, as the true independent organic variable; while he regards the quantity aspect as a dependent factor. In our specific environment of the uplands in the studied Region we can say that Man is of little importance for soil formation. The latter is studied under virgin conditions untouched by human hand and this factor is therefore not further discussed. Micro-organisms in their quantity are related to pedo-ecological characteristics such as soil climate, physical and chemical soil conditions, and little is known about the quality aspect for the Region so that also this factor will have to be omitted from the discussion.

1. Vegetation

The climatic conditions in the Region are very favourable to tree growth and the natural forest vegetation is therefore luxuriant. In the uplands two distinctive types of natural forest can be recognized.

1.1. Mixed Dipterocarp Forest

This type of forest is dominant in all upland areas where well drained conditions are the rule and extreme shallowness and/or extreme poverty of soil are absent. This results in a tendency towards replacement of the Dipterocarp Forest by Kerangas forest as described under D. 1.2. In this mixed forest Dipterocarp species dominate, but trees of other families occur also, although usually in small numbers. It has been noticed that within the general term Mixed Dipterocarp forest as occurring on the hilly terrain variations can be found e.g. on hilly, bold topography with long slopes culminating in high ridges or plateaux the composition is very mixed in accordance with topography; on very sharp ridges there is transition forest to Kerangas forest. As already explained shallowness of soil is then commonly the cause. Another subtype is found on broken hilly to mountainous terrain, mainly formed by igneous massifs (Pueh unit). Here, composition is very varied with topography, altitude and exposure and species vary with soil type, site conditions and regions.

The Mixed Dipterocarp forest contains many valuable timber species but no general indication can be given to their location, this being very much dependent on overall ecology of the site.

1.2. Kerangas Forest

Kerangas is a Dayak name given for land which cannot support hill padi and the natural forest found on such land derives its name from that connotation. Commonly, Kerangas land is characterised by sandy soils, more or less podzolized and of poor nutritional value. There are however many types and transitions within the Kerangas forest depending on local soil conditions and topography and it is therefore dangerous to refer to all vegetational cover of this nature as being an indication of bad land. It is usually found on flat to slightly sloping land but occurs also in minor areas forming steep slopes usually associated with rocky soils (see D. 1.1.).

Brunig (1969) divides Kerangas Forest into several types:

(I) One type is found on flat to almost flat topography in the lowlands. This forest type is of variable composition in which many species common for Peat Forest may occur. Emergent trees are usually Dipterocarps *(Shorea albida* Sym., *Shorea materialis* Ridl., *Shorea pachyphylla* Ridl. and *Dryobalanops* spp., the latter very local). This type also occurs on distinct plateaux with wet soil conditions and on sandy soils.

(II) Another type is located on undulating hilly terrain, often at the edges and sides of terraces or sandstone plateaux. The same species as in the former type may occur but often with stands of *Agathis borneensis* Warb. in the lowlands and *Agathis beccarrii* Warb. in the highlands above 800 m. Dipterocarp spp. are more common than in other Kerangas Types.

(III) A third type is found in hilly and mountainous terrain on dissected terraces, gently dipslopes and on exposed ridges and bouldertops. This forest type usually changes very gradually into Mixed Dipterocarp Forest.

It can be concluded that in the uplands Mixed Dipterocarp Forest and Kerangas Forest with their various transitions are forming the main natural vegetation. Differences in composition are dependent on soil type and on degree of slope.

2. Animals

Termite activity is low in Sarawak and although ants do occur in large populations they usually build their nests in rotten trees, are flanking tree trunks or are in surface horizons of soils. Soil disturbance by ants must be rated as low, although locally it does play a role in the soil forming processes in surface horizons.

Burrowing animals may enhance erosion through intense channeling in some localities. These channels act as conducting tubes for water and are widened. Large holes may form which eventually cause caving in of the surface or where they are of sufficiently large extent intitiate land slips. This process is particularly common in sandstone derived soils of steep topography.

3. The influence of organisms on soil formation

The dominant factor appears to be the vegetation. Litter production in the primary forest is high but generally very little accumulation takes place. This is particularly so for Dipterocarp Forest found on most of the hill land with reasonable fertile soils. By inference one may deduce from the absence of much surface litter that mineralization is there greater than humification. However, in the Kerangas Forest where litter production is probably not much greater than that in Dipterocarp Forest, litter accumulation does take place. In such areas there appears to be a relationship between soil type, vegetation and litter accumulation. The lighter the soil (which locally means the lower the chemical fertility) the more litter accumulates. This corresponds with an increasingly more specific vegetation. Either the litter produced is extremely resistant to mineralization and humification (it tends to stay raw for long periods) or micro-biological activity is extremely low. The many transitions existing between Dipterocarp and Kerangas Forest would make a proper study of the produced litter very interesting. The decomposition products of organic matter have a great influence on soil forming processes, the production of carbonic, humic and fulvic acids would play an important role in leaching processes, and different ratios of these acids would strongly affect soil formation.

It is therefore of importance that in studying relationships between parent material, vegetation and soils, the produced litter receives proper attention. For this reason care has been taken to include the litter in the analytical studies presented in following chapters.

Finally, a quantitative aspect of the influences of vegetation on soil formation may be its sheer weight. Baillie (1970) is of the opinion that if under Sarawak conditions the primary jungle on steep slopes reaches that stage in maturity in which the weight of the forest unbalances the equilibrium which exists between soil-mass and slope rate, land slips may be initiated and, as has been discussed, such land slips play an important role in the rejuvenation of soils.

E. Time

The effect of the factor Time on Soil Formation is impossible to quantify because of its high relativity.
The rate and nature of physico-chemical reactions taking place in rock-weathering and soil formation are next to Time dependent on the environment which influences the leaching rate, concentrations of salts in the soil water and the temperature.

Since the environmental conditions are highly variable, the factor Time cannot exert its influence in equal magnitude at all places and at all times.
Although it may be possible to date a soil by indicating the space of time which has lapsed since the soil forming process started (e.g. by benchmark dates in the case of sediments), it has little practical meaning since within that same span of time soils could in one place attain old age and in another they would remain relatively young.
This touches upon the meaning of terms such as immature, mature and senile soils (Mohr, 1944) which although probably having a connection with chemical characteristics of soils do not bear much relation to Age when measured in years or centuries.

It must therefore be contended that although Time plays a role in soil formation, its exact influence is difficult to indicate and a further extension on the philosophy of the time aspect is regarded as being rather futile.

Of practical significance is however the fact that although the landscape forms in the studied Region have juvenile characteristics (strong dissection, little valley development), the soils appear to have reached in their physico-chemical characteristics a stage which is commonly found only in highly weathered soils. No doubt, the particular parent rocks which are low in weatherable minerals play a dominant part in this, but also the severity of the climatic factor must not be discounted.

The anomaly of finding old soils (what this then may be) in a juvenile landscape is probably much more common than one is lead to believe. The 7th Approximation of the USDA Taxonomic soil classification system (Soil Survey Staff, 1960, 1967, 1970) mentions in the definition for an oxic horizon that:
'Geomorphologic evidence shows that oxic horizons are generally in soils of very old stable geomorphic surfaces, old in the sense that they are more apt to be mid-Pleistocene or earlier than late- or post Pleistocene. They are not in soils of recent surfaces with thin regolith'.
The conditions in Sarawak prove how inconsistent this definition is with reality and how careful one must be in the application of the concepts Time and Age in soil formation.

II. Field Investigations

1 General aspects of Soil Formation in the uplands of West Sarawak

The fieldinvestigations carried out during the mapping stage in the period 1960-1970 and the summary of relevant soil forming factors discussed in the previous chapter have indicated that soil genetic studies in the Region are made complicated by problems which, although possibly present in many other perhumid tropical areas with similar rock formations, are commonly ignored:

(I) The dominant rock formations are of clastic sedimentary rock origin. Although in geological surveys much emphasis is laid upon the stratigraphic aspects of such rocks, the lithology receives far less attention and the chemical and mineralogical composition is often totally omitted from the detailed studies. This is in strong contrast with the analytical detail given to rocks of igneous origin.
Even when such information is available for clastic rock types, the true parent rock of a specific soil is often difficult to indicate if the soils occur in a strongly dissected landscape with intense mass movement of weathered material.
When sedimentary rocks consist of rapid successions of thin beds of mineralogically and chemically different composition it is impossible to assess how much each type of material has contributed to the characteristics of the overlying soil. Leaching processes are difficult to study if accurate reference data (the composition of the original rock) is lacking. Igneous rocks are in all dimensions of more homogenous composition and, although overlying soils may not be directly related to the rocks found underneath, the chemical and mineralogical composition thereof is generally the same or not much dissimilar from the true parent rock. Apart from the lateral re-distribution and homogenization of material from different beds through erosion processes, other problems arise if no homogenization occurs. E.g., a bisequency in parent rock if this is formed by sedimentary strata may induce the formation of certain soil characteristics which would be absent if the material had not been stratified from the beginning.

Textural changes in the profile may be inhereted from the parent rock. Leaching of iron and precipitation thereof may have occured in the original sediments before they were consolidated. Clay minerals may have been inhereted from the parent rock, others may have formed in the soil through neoformation and transformation. All such problems are not encountered or much less so in soils derived from igneous rocks.

(II) A second problem is posed by the fact that under a humid tropical climate rock weathering is very intense. The rate of decomposition of the rock is governed by the influence of climate assisted by media such as vegetation and topography, and the hardness or weatherability of the rock. The clastic rock types are commonly more pervious to air and infiltrating water than the igneous ones and therefore chemical weathering may be able to penetrate deeply into such rocks. The amount of weatherable minerals in clastic rocks is generally much smaller than in igneous

ones, this is particularly so in the Region. This causes long preservation of rock structures. Since the clastic rocks are dominantly poorly consolidated, strongly fissured and jointed, chemical weathering is able to penetrate deep down into the rocks along these more or less vertical pathways whereas the strong stratification and lamination aids in the lateral penetration.
Processes such as oxidation and dissolution of materials and subsequent transport and accumulation take place vertically and laterally and at depth greatly beyond the normal profile level commonly studied. Horizons of accumulation which are commonly designated as B and C horizons therefore extend to great depth when clastic rock types are involved. Although the American Taxonomic soil classification system (USDA, Soil Survey Staff, 1960, 1967, 1970) does not allow accumulations of carbonates, gypsum, and iron to be present in the C horizon, they are excluded from R horizons. When following these principles it is difficult to give a correct horizon designation under the described conditions. In the field the physical characteristics of the profile are therefore taken to be indicative for a C or R horizon. Where the original rock has been largely preserved, horizons have been designated as R horizons although they may contain iron accumulations of which the source is difficult to indicate but which accumulation is largely induced by geological phenomena as stratification, fissures and joints which act as conducting channels for groundwater.

It is however extremely difficult to investigate whether the iron accumulated in R horizons is recent and thus related to present soil forming processes or whether it must be regarded as a paleopedological phenomenon in which case it is related to conditions in the landscape irrelevant to the present ones. Therefore, although restricting ourselves to characteristics of soils within a depth of 1,5 m interpretation of analytical data on movements and accumulation of soil material must take into account the fact that the profile depth studied represents only part of the full profile.

Such problems are not encountered in the profile development of soils on igneous rocks in which the weathering front proceeds more regularly. Distinct abrupt boundaries between R and C horizons are more the rule than the exception.

2. Selection of modal profiles

Based on the experience accumulated during the soil mapping stage 6 modal profiles were selected for intensive studies. These profiles represent the main soil types found in the upland of the Region.
Table 7 indicates the basis for the selection. The profiles are numbered in a sequential order of increasing SiO_2 content of the parent rock. This order will be maintained throughout the study. The exact SiO_2 content of the unweathered parent rock of the Semongok series is not known. The given value is that for partially weathered rock and its placing in the sequence is a calculated guess. The relation soil-parent material - landscape is illustrated by this table in which the last colomn indicates the soil group as classified in the local classification system to which no specific importance needs to be attached since, particularly for this study, the so-called Red-Yellow Podzolics cover a wide range of soils.

Table 7. Main characteristics of modal profiles selected for study

Nr.	Profile name	Parent rock	SiO_2 content parent rock	Landscape unit	Slope degree	Local Soil Group
1	Tarat	basalt	50.5 %	Pueh	10-20	Lateritic
2	Gumbang	quartz-andesite	66.78%	Stapok	32-45	Red-Yellow Podzolic
3	Serin	arkose	67.9 %	Tebedu	8	Red-Yellow Podzolic
4	Semongok	shale/mudstone (partially weathered)	60.1 %	Quop B	10-12	Red-Yellow Podzolic
5	Gading	adamellite	71.0 %	Pueh	10	Red-Yellow Podzolic
6	Nyalau	quartz sandstone	82.07%	Penrissen	10-14	Red-Yellow Podzolic
7	Butan	quartz sandstone	92.47%	Penrissen	8	Humus Podzol

Nr. 7 was only added to show the Podzol end member in the existing sequence from Lateritic soils to Podzols and analytical information on this profile was taken from a former study on Podzols carried out by the author (Andriesse, 1969a). This analytical information is therefore not complete as it formed no subject of further investigation in the present study.
Excepting the Tarat series which is covered by old secondary forest, all soil profiles have primary forest as natural vegetation, which is Mixed Dipterocarp Forest but for nr. 7 which is covered by Kerangas (Lowland Heath) Forest.

In order to avoid influence of erosion as much as possible the selected sites are all located just below the crest of hills or ridges. Nr. 7 is again an exception and was taken at mid-slope.
Detailed descriptions of the modal profiles are given in Appendix I, the main characteristics are given in general terms in the following section.

3. General description of selected soils

3.1. Tarat series

This series is the common soil type occurring on basic to intermediate igneous rocks, commonly with a high content of ferromagnesium minerals. As a result of lateritic weathering strong relative accumulation of free iron oxides has taken place throughout the profile, the values of free iron oxide being around 15% in all horizons. The profile has a homogenous appearance without distinct horizonation excepting the A_1 horizon which is of a darker colour than the remainder of the profile which ranges in colour from red (5YR 5/8) to red (2.5YR 5/6). The texture becomes slightly coarser with depth which for Sarawak conditions is an exception since generally the reverse situation is found. Clay content is commonly high and more than 40% in the surface horizon and slightly over 30% in the sub-horizons. Structure is well developed but very fine crumbly, consistency is friable and porosity high. No clay movement can be detected in the profile. The soils are usually deep and the C horizon is commonly found beyond a depth of 1,5 m, unless erosion has truncated the profile.

The soils are devoid of weatherable minerals, goethite, kaolinite, and gibbsite being dominant in the clay fractions while the silt and sand fractions have a high content of strongly ferruginized and altered rock fragments basically of a quartzitic nature. The pH varies between 4.5 and 5.5, CEC is less than 10 meq. in the subsoils; this is slightly higher in the surface horizons due to presence of organic matter. Base saturation is commonly low and less than 20% unless organic matter is present.

3.2. Gumbang series

This series commonly occurs on quartz andesite and tonalite. Because of the commonly strongly sloping terrain, characteristic for outcrops of these rocktypes, the soils are generally relatively shallow. Colours in the subsoil range from yellowish brown (10YR 5/4) to light yellowish brown (10YR 6/4), topsoils are darker due to organic matter content.

The soils show little or no horizonation unless the C horizon is found within a depth of 1.5 m, in which case rock debris is found to be increasing with depth. Free iron content is low as compared with the Tarat soil and is commonly below 4%. The clay content increases with depth and varies from 25% in the surface horizon to almost 40% in the lower subsoil. Structure is weakly developed when moist but is strong blocky in dried condition. The soils are slightly friable, porosity is moderate. The sand fraction does not contain much or none weatherable minerals, the clays are dominantly kaolinite with some mixed-layer minerals and gibbsite. The pH varies from 4.5 to 5.5, CEC is commonly less than 10 meq. in the subsurface horizons and slightly higher in the surface horizons. Base saturation of the subsurface horizons is lower than 20%, that of the surface horizons is higher due to influence of organic matter.

3.3. Serin series

This series is found exclusively on arkose which in chemical composition closely resembles tonalite. Also in this profile very weak or no horizonation can be found excepting the A_1 horizon. The soils range in colour from brownish yellow (10YR 6/8) to reddish yellow (7.5YR 7/8). The latter colour is commonly representative for subsoils since a gradual transition from yellow to red takes place with depth. In some locations the reddish colour is dominant in topsoils which is probably caused by truncation as a result of erosion. The soils show a gradual clay increase with depth, sandy clay loam being the dominant texture of topsoils while subsoils are characterised by a clay texture. Structure is moderately blocky in moist condition but strong blocky when dry. Consistency is massif, compact. Infiltration of surface materials washed in cracks and root channels is evidenced by colour changes.

This washed-in material is frequently mistakingly interpreted as clay-illuviation but no evidence of argillans in thin sections or an argillic horizon by texture analysis has hitherto been found. The soils are commonly deep, the C horizon normally found below a depth of 1.5 m. There are no weatherable minerals in the sand and silt fraction while the clay mineralogy is characterised by predominantly kaolinite and some gibbsite. The pH varies from 5 in the surface horizon to 5.5 in the lower subsoil. The CEC is extremely low and less than 5 meq. in all horizons excepting the surface horizons where organic matter raises the CEC to over 10 meq. Base saturation is very low and commonly below 20% in all but the surface horizon.

3.4. Semongok series

This series is found on Cretaceous shales and mudstones. It is characterized by brownish yellow to yellowish brown (10YR 6/4 to 6/8) coloured surface horizons while the subsurface horizons are usually reddish yellow (7.5YR 6/8). The C horizon is commonly somewhat lighter in colour. The soils show moderate to strong reddish yellow and grey mottling below the A or B horizon. The grey mottles increase in intensity with depth to where they merge into the grey coloured parent material. The reddish coloured mottles give way to brown and yellow and diminish in intensity with depth to where they disappear again in the C horizon. The cause of the grey mottles is still subject to speculation but there is reason to believe that the imperfectly drained condition is not the main reason for their existence. It is suggested that the persistence of the colour of the parent material to well into the B horizon, where homogenization of the soil causes their disappearance, is a more likely origin.

The soils are heavy textured with a clay content of over 50% in all horizons with a tendency of gradual increase with depth. Structure is weakly developed in moist conditions but exposures show that an angular blocky structure develops when the soils dry out. In moist condition consistency is firm to massive. The sand and silt fractions do not contain weatherable minerals, the clay fraction contains next to kaolinite, appreciable amounts of mixed-layer clays, some vermiculite and some gibbsite. The CEC is high for Sarawak upland soils and is commonly around 20 meq. with highest values in the A_1 horizon due to the organic matter content. Base saturation is however low and generally does not value more than 10%, excepting the surface horizon, where it is slightly higher. The pH is around 5 in most soils but highly acidic conditions may be encountered in the C horizon where pyritic material has oxidized and owing to formation of sulphuric acid pH may fall below 3. A layer of laterized shale flakes, broken up limonitic vein material originally present in the shale or mudstone and iron-concretized root channels is frequently present at varying depth. It usually overlies the C horizon.

3.5. Gading series

The Gading series is found on coarse textured granites, granodiorites and adamellite. The colours range from dark brown (10YR 4/3) in the surface horizon to increasingly more red colours (7.5YR 6/6 - 5YR 5/8 - 2.5YR 5/6) in the subsoil. The texture range within the profile is wide and sandy clay loams in the topsoil gradually merge into sandy and gritty clays in the lower subsoil. The clay content is from 18% in the topsoil to 28% in the subsoil.

The soils are usually quite shallow when occurring in steep terrain and only at more gentle slopes deep soils may be encountered, but still with the C horizon within a depth of 1.5 m. Structure is not well developed even in dry condition and is weak crumbly; the soils are usually friable in the surface horizons to smeary in the lower horizons and are commonly porous. Excepting the C horizon which contains some bleached biotites the soils are devoid of weatherable minerals in the sand and silt fractions. Kaolinite and gibbsite dominate the clay fraction. The pH varies between 5 and 5.5, CEC is extremely low and seldom above 4 meq. excepting in the surface horizon where it may be slightly over 10 meq. due to organic matter.

Base saturation is likewise very low and is commonly less than 5% with the exception of the surface horizon where it is around 20%.

3.6. Nyalau series

This series is derived from medium to coarse grained quartzitic sandstones, and is based on field characteristics, very similar to the Gading series excepting the colour which is in the Nyalau yellow (10YR 7/6) to brownish yellow (10YR 6/6) at depth. The soils are commonly deep and have a very homogenous profile without apparent horizonation. The texture ranges from a sandy loam in the surface horizon to a sandy clay loam in the lower subsoil. The clay content gradually increases from about 15% in the surface horizon to 25 or 30% in the lower subsoil.

Excepting washed-in material in cracks and root channels from the surface horizon there is no evidence of argilluviation in the form of clay-skins. Structure is weakly developed and crumbly in the surface horizon, becoming more blocky with depth. The soils are friable throughout becoming more firm with depth. Porosity is high in surface horizons but diminishes with depth. There are no weatherable minerals in the sand and silt fractions, quartz being almost exclusively present. The clay fraction is dominantly kaolinite with slight traces of mixed-layer clays.

The pH ranges from 4.5 in the topsoil to 5.5 in the lower subsoil. The CEC is extremely low with values of less than 4 meq. throughout the profile excepting the surface horizon where the CEC is slightly over 10 meq. Likewise base saturation is very low and commonly below 5% but due to presence of washed-in surface material it can attain values of 20% in the subsoil.

3.7. Butan series

The Butan series is typically a Humus Podzol and shows strong horizonation with well developed histic, albic and spodic horizons. It is only found on quartzitic sandstones in gently sloping terrain. The dark reddish brown coloured (5YR 2/2) organic surface horizon lies markedly over a light grey (10YR 7/1) A_2(E) horizon which shows an abrupt boundary with the dark reddish brown (10YR 2/2) coloured B_h horizon. Below this horizon the soil is very pale brown (10YR 7/3) coloured due to dispersed organic matter with streaks of a stronger colour.

The texture ranges from a medium sand in the A_1 horizon to a sandy loam just below the B_h horizon. Below this depth textures are loamy sand to sandy loam. Strong texture contrast in the deep B horizon may occur but is then related to stratification in the parent material. The clay content varies from 5% in the topsoil to slightly over 15% in the lower subsoil.

Structure is absent in the surface horizons, the B_h horizon is weakly cemented. The horizons below the B_h are also structureless.

The sand mineralogy indicates that no weatherable minerals are present throughout the profile. The clays in the surface horizons contain dominantly quartz and some kaolinite while the B horizon clay is mainly kaolinite, with subordinately vermiculite and quartz.

The pH varies from 3 in the O horizon to slightly over 4 in the subsoil. The CEC is exceedingly low and less than 4 meq. Higher values are indicative for organic matter being present. Base saturation is around the 10%.

These general descriptions indicate that all soils studied, with the exception of the Butan profile, are characterised by a very homogenous profile showing no distinct horizonation. Of importance however, are the very gradual changes in texture, structure, colour and consistency which take place with depth and which make horizon designation in the field extremely difficult. For this reason and in order to make classification attempts meaningful, detailed mineralogical and chemical analyses are indispensable not only for detecting vertical changes in the profile but also for the lateral diversification, thus for distinguishing between soils in the selected sequence. Such analytical studies were carried out on the modal profiles and the results are discussed in the following chapters.

III. Analytical Investigations

A. The Mineral Part of the Soil

1. Texture

The USDA Taxonomix soil classification system (Soil Survey Staff, 1960, 1967, 1970) defines soil texture as the relative proportions of the various size groups of individual soil grains in a mass of soil. The term 'individual soil grains' used in this definition poses a difficulty since much room is left for various interpretations. A commonly accepted one is that with individual soil grains are meant the smallest uncompounded single units; and compound units such as grains cemented by carbonates, iron oxides and organic matter are then usually excluded. For this reason in common analytical procedures for an assessment of texture, pretreatments involving H_2O_2 and HCl for removal of these cementing agents, are included. The reason for a complete breakdown of compound units in texture analyses is not clear since the behaviour of a soil in the field is dependent on the natural composition of a soil and e.g. infiltration rate, permeability and leaching rate are related to natural grain size and porosity as existing in the field. For mineralogical studies it may be of importance that compound grains are broken down to their different basic components, but whether such grains should be broken down for assessing the particle size distribution is open to much question. Even if pretreatments with H_2O_2 and HCl are carried out it is still not understood why one discriminates between cementation by carbonates and iron oxides, and that caused by secondary silica, which is not removed in common pretreatment procedures.

The formation of compound grains is in the view of the author also part of soil forming processes and their importance should be recognized. For a study of the natural grains of a soil in fact only water should be employed and particles which are not broken down by water treatment should be regarded as naturally existing single components. On the basis of this distinction lies the observation that units which can be broken down by water are also unstable under field conditions. Extending this philosophy on natural grainsizes in soils one enters into a dialogue on what parameters should be adopted to distinguish between textural and structural units.

Compound grains may not be solid and may have porosity and behave differently in the soil than solid particles, particularly where water movement is concerned. There may be particles which are held strongly together, although in an open framework, by physical forces such as opposed electrical charges. For practical reasons the distinction between natural textural units and natural structural units can therefore best be based on water treatment. Apart from the distinction between porous and non-porous compound particles, existing as natural components in soils, new compound particles may form through air-drying which is commonly preceding the pretreatment for textural analysis.

Irreversible drying in particular is causing such new compound grains in Andosols (Muller and Schelhaas, 1972) and such grains are impossible to disperse with water. It is difficult therefore to prescribe one single treatment for a texture analysis. The soil type is of importance, while also the purpose of the analysis plays a consider-

Table 8. Granulometric analyses of main Upland Soils of West Sarawak

Method: Dispersion with 0.1 N $Na_4P_2O_7.10H_2O$ and 0.04 N Na_2CO_3 without H_2O_2 pretreatment

Soil series	Horizon	Depth in cm	coarse sand 2000-500 μm	medium sand 500-250 μm	f.s. 250-100 μm	v.f.s. 100-50 μm	silt 50-2 μm	clay less than 2 μm	water disp. clay in % of total clay	texture name U.S.D.A. system
Tarat	A_1	0 - 8	8.5	3.5	2.8	0.4	62.2	22.6	64.7	si.l.
	B_1	8 - 28	4.2	1.7	1.7	0.9	38.9	52.6	75.4	clay
	B/C	28 - 54	4.0	1.3	1.2	0.7	33.5	59.3	-	clay
	C	54 - 100+	1.3	0.6	0.6	0.3	34.8	62.4	-	clay
Gumbang	A_1	0 - 9	6.6	0.5	0.4	0.5	85.8	6.2	39.2	si.
	B_1	9 - 28	0.8	0.2	0.3	0.5	74.7	23.5	29.8	si.l.
	B_2	28 - 44	0.8	0.3	0.3	0.5	66.7	31.4	44.0	si.cl.l.
	B/C	44 - 67	0.6	0.2	0.3	0.5	62.3	36.1	8.3	si.cl.l.
	C	67 - 100+	1.5	0.4	0.4	0.4	61.4	35.9	-	si.cl.l.
Serin	A_1	0 - 10	4.4	11.2	18.4	8.7	30.5	26.8	90.3	loam
	A_2(E)	10 - 25	3.2	7.8	14.9	7.5	24.8	41.8	22.8	clay
	B_1	25 - 75	3.8	7.9	13.2	7.9	25.7	41.5	-	clay
	B_2	75 - 115	3.5	6.4	10.4	6.2	26.9	46.6	-	clay
	B/C	115 - 135+	2.6	5.9	10.0	5.9	25.1	50.5	-	clay
Semongok	A_1	0 - 9	1.1	1.0	3.1	4.7	48.2	41.9	85.7	si.clay
	B_1	9 - 29	1.4	1.0	2.7	4.1	45.1	45.7	81.5	si.clay
	B_2	29 - 68	0.8	0.8	2.4	2.6	39.4	54.0	70.2	clay
	II B_2	75 - 88	5.5	1.3	1.9	3.3	33.0	55.0	49.5	clay
	II B/C	88 - 115+	1.3	0.6	0.9	3.0	39.5	54.7	31.7	clay
Gading	A_1	2 - 7	40.6	20.4	14.7	2.4	9.4	12.5	64.7	sa.l.
	A_{12}	7 - 20	24.4	22.7	19.5	4.0	10.4	19.0	60.9	sa.l.
	B_1	20 - 50	23.6	22.9	19.9	3.3	7.2	23.1	-	sa.cl.l.
	B_{21}	70 - 100	29.3	15.7	13.7	2.3	8.9	30.1	-	sa.cl.l.
	B_{22}	100 - 120	29.3	13.4	11.1	2.2	11.5	32.5	-	sa.cl.l.
	C	120+	52.5 1)	13.8	11.1	1.6	10.0	11.0	-	sa.l.
Nyalau	A_1	0 - 9	3.5	32.8	31.8	5.0	18.9	8.0	47.6	sa.l.
	A_2(E)	9 - 30	1.5	22.2	31.0	9.1	18.8	18.5	7.6	sa.l.
	B_1	30 - 63	2.3	23.2	29.8	7.1	17.7	19.9	-	sa.l.
	B_2	63 - 110	1.9	21.5	27.4	6.6	18.1	24.5	-	sa.cl.l.
	B/C	110 - 150+	1.7	19.8	25.4	6.0	20.8	26.3	-	sa.cl.l.
Butan 2)	A_1	5 - 13	81-91		4.49		5.53	4.73	n.d.	l.sa
	A_{12}	13 - 23	83.58		8.06		4.86	4.80	n.d.	sa.
	A_2(E)	23 - 33	80.62		10.07		8.63	3.01	n.d.	sa.
	B_1h	33 - 48	70.79		7.95		11.55	8.31	n.d.	l.sa.
	B_{12}	48 - 58	64.64		6.85		9.55	15.70	n.d.	sa.l.
	B_2	58 - 84	64.13		8.28		10.48	17.20	n.d.	sa.l.
	II C	84 - 112	63.60		7.36		12.06	18.76	n.d.	sa.l.
	II R	112 - 172+	71.71		6.51		14.35	9.56	n.d.	sa.l.

1) Disintegrated rock

2) ref. Andriesse, 1972. With H_2O_2 and HCl pretreatment

able role in the choice of method. In the method employed in this study, which is primarily genetically orientated, the aim is to preserve as much as possible the original grains as existing in the soil and for this reason no pretreatment causing breakdown of compounds cemented by iron, carbonates or humates was carried out. Since irreversible drying has never been reported for the soils studied, it is assumed that no new compound particles will form upon drying out. The soils were crumbled in the field-moist stage by hand so that the large structural units could be broken down. This material was dried at 40° C and thereafter again crumbled and sieved through a 2 mm sieve. The thus-obtained fine earth was subjected to a granulometric analysis.

Table 9. The effect of H_2O_2 treatment on analysed clay content

Soil series	Horizon	Depth in cm	Percent Clay ($Na_4P_2O_9/Na_2CO_3$)	
			without H_2O_2	with H_2O_2
Tarat	A_1	0 - 8	22.6	61.3
	B_1	8 - 28	52.6	
	B/C	28 - 54	59.3	
	C	54 - 100+	62.4	
Gumbang	A_1	0 - 9	6.2	24.5
	B_1	9 - 28	23.5	
	B_2	28 - 44	31.4	
	B/C	44 - 67	36.1	
	C	67 - 100+	35.9	
Serin	A_1	0 - 10	26.8	38.8
	A_2 (E)	10 - 25	41.8	
	B_1	25 - 75	41.5	
	B_2	75 - 115	46.6	
	B/C	155 - 135	50.5	
Semongok	A_1	0 - 9	41.9	48.5
	B_1	9 - 29	45.7	
	B_2	29 - 68	54.0	
	II B_2	75 - 88	55.0	
	II B/C	88 - 115+	54.7	
Gading	A_1	2 - 7	12.5	15.7
	A_{12}	7 - 20	19.0	
	B_1	20 - 50	23.1	
	B_{21}	70 - 100	30.1	
	B_{22}	100 - 120	32.5	
Nyalau	A_1	0 - 9	8.0	11.5
	A_2 (E)	9 - 30	18.5	
	B_1	30 - 63	19.9	
	B_2	63 - 110	24.5	
	B/C	110 - 150+	26.3	

In order to test the influence of commonly used dispersing agents on clay mineralogy the fine earth was divided into 3 parts; part 1 was dispersed with Na-pyrophosphate/Na_2CO_3 part 2 with NH_4OH and part 3 with distilled water only. The complete texture analysis was only carried out on part 1 since the thus-assessed texture is closely similar to the procedure outlined in the 7th Approximation of the USDA soil classification (op cit) but in which hexametaphosphate is used instead of Na-pyrophosphate. The methods employed are described in detail in Appendix II. The results of the texture analyses are given in Table 8, which also shows the content of water dispersible clay for all soils, with the exception of the Butan series. Of considerable interest is the sudden increase in clay content which can be observed in the horizon below the A_1 horizon. Since this horizon contains most organic matter it was therefore deduced that possibly cementation of clay with organic materials may be the cause of the formation of compound grains in this horizon. For this reason new sample material of the A_1 horizons was treated with H_2O_2 and thereafter again dispersed with 0.1 N Na-pyrophosphate and 0.04 N Na_2CO_3. The resulting increase in analysed clay content is well-illustrated in Table 9. The, in general gradual clay increase with depth observable in the field and which seems to be characteristic for most Sarawak upland soils as described in section II.3, corresponds with the results obtained by the texture analyses without the use of H_2O_2. Table 9 indicates that with the use of H_2O_2 this difference in field texture may be levelled off and could even give inversed results. For instance, as indicated by Andriesse (1972) the Tarat profile generally shows in the texture analysis carried out according to conventional methods with pretreatment of HCl and H_2O_2, a general decrease in clay, while when omitting this pretreatment the reverse results are obtained. The nature of these stable compound grains which apparently can withstand the action of the dispersion agents used but which are broken down by H_2O_2 will be discussed in the following section.

The water-dispersible clay was analysed according to the method prescribed by the 7th Approximation of the USDA soil classification (USDA, 1967). To enable the use of the obtained values for distinguishing diagnostic horizons (oxic horizon) they are given in percentage of the total clay fraction. Based on the content of water dispersible clay, subsoils of the Tarat, Serin, Gading and Nyalau profiles could include an oxic horizon, which by definition should not contain more than 3% dispersible clay unless the horizon has a nett positive charge. The delta pH values given in Appendix I indicate that this is nowhere the case.

2. Mineralogical composition

2.1 Total composition of the sand fractions

The sand fractions, comprising the 2000-500, 500-250, 250-100, and 100-50 µm fractions were obtained from the texture analysis carried out without pretreatments and with Na-pyrophosphate and Na-carbonate as dispersing agent. Clay and silt fractions were syphoned-off in dispersion cylinders after which the remaining sand was separated and divided over the various fractions by wet sieving.

It is assumed that aggregates which had failed to break down or to disperse during the textural analysis can be regarded as being also stable under natural field conditions. The pretreatments with H_2O_2 and acids was dispensed with in order to preserve the actual 'field mineralogy' as much as possible. However it is possible

Table 10. Sand mineralogy – Tarat series

Horizon	A_1			B_1			B/C			C		
Fraction	1	2	3	1	2	3	1	2	3	1	2	3
Primary minerals												
Quartz	36	41	16	35	23	9	42	28	8	48	18	2
Rock fragments	-	7	4	19	18	27	25	36	43	-	15	26
Opaque (ore)	-	1	-	-	1	-	-	-	-	-	-	-
Hornblende	-	-	-	-	-	-	-	-	-	tr	-	-
Chlorite	-	-	-	-	-	-	-	-	-	1	-	-
Neoformations and alterites												
Fe-compounds/ Goethite	43	42	62	18	26	56	28	26	39	40	58	45
Misc. alterites	4	3	1	-	-	-	-	-	-	1	-	2
Yellowbr. alterites	2	1	1	14	19	8	5	8	10	9	9	25
Chalcedonic quartz with gels	14	5	10	11	10	-	-	-	-	-	-	-
Aggregates of clay minerals	-	-	-	3	3	-	-	2	-	-	-	-
Org. matter	1	-	6	-	-	-	-	-	-	-	-	-
SiO_2 (opal)	tr	-	-	tr	-	-	-	-	-	1	-	-

(1) = 100-50 μm, (2) = 250-100 μm, (3) = 500-250 μm, tr = traces.

2000-500 μm

A_1 horizon - Dom. clay aggregates (iron with clay-minerals), some quartz, gels and Fe-concr.
B/C horizon - Dom. strongly weathered rock pieces, tr. quartz, gels and Fe-concr.

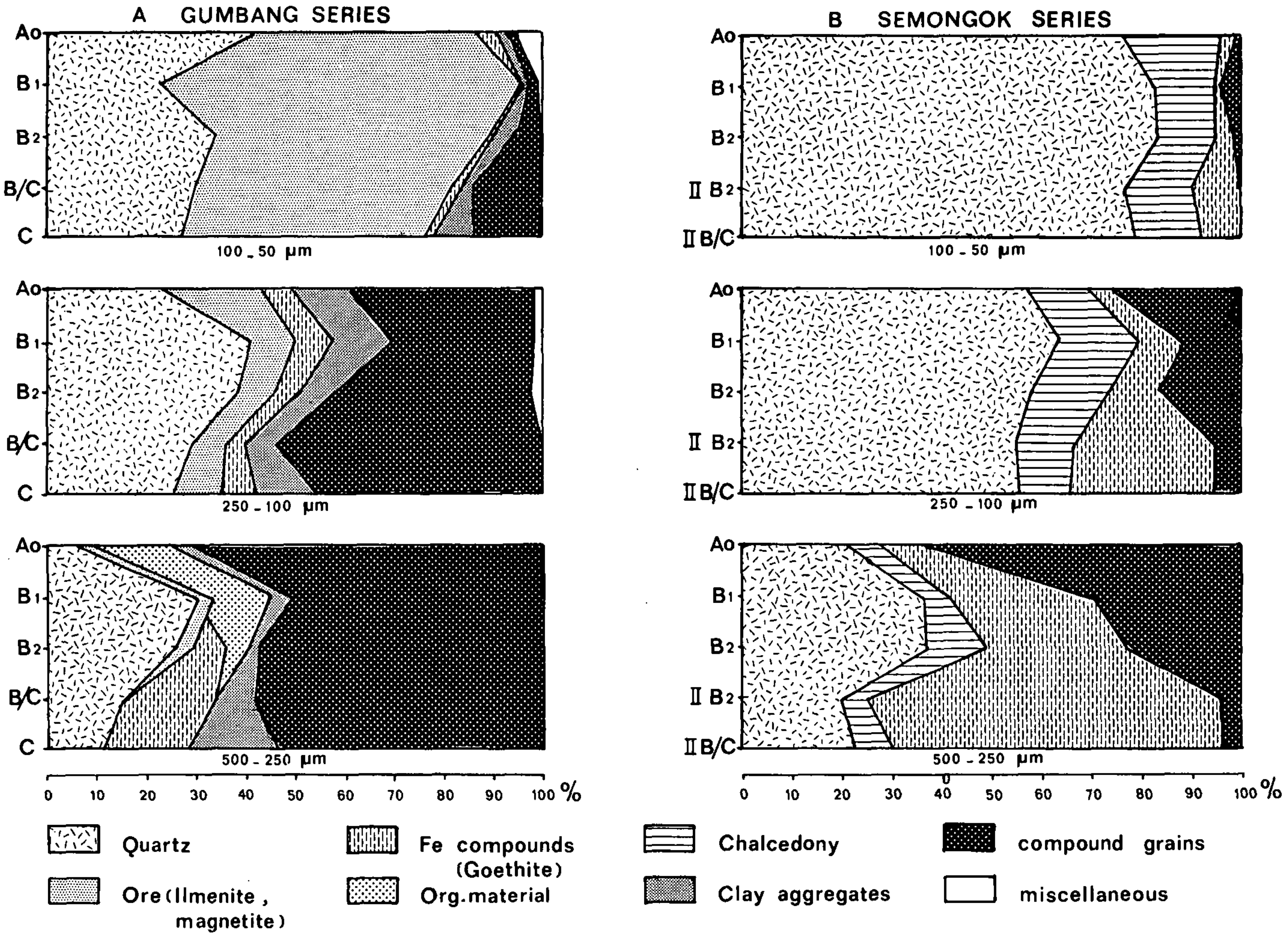


Fig. 17 *The sand mineralogy of the Gumbang series (A) en Semongok series (B)*

Table 11. Sand mineralogy - Gumbang series

Horizon	A$_1$			B$_1$			B$_2$			B/C			C		
Fraction	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Primary minerals															
Quartz	42	23	6	23	41	30	34	38	26	30	29	16	27	25	11
Ilmenite	47	20	2	73	9	3	56	8	3	52	7	-	49	10	-
Magnetite	1	2	-	1	2	1	-	3	-	-	1	1	-	-	-
Neoformations and alterites															
Goethite	4	6	-	-	7	-	1	5	7	2	3	19	2	7	17
Aggregates of clay minerals	1	-	3	2	14	4	4	7	2	2	7	8	8	22	18
Gels	2	14	8	1	2	-	5	1	1	13	-	-	14	-	-
Gels (compounds with quartz)	tr	35	64	tr	25	50	tr	38	56	tr	53	56	tr	36	54
SiO_2 (opal)	3	-	-	tr	-	-	tr	-	-	1	-	-	-	-	-
Org. matter	-	-	17	-	-	12	-	-	5						

(1) = 100-50 µm, (2) = 250-100 µm, (3) = 500-250 µm, tr = traces.

2000-500 µm

A$_1$ horizon - Dom. plant remains, some quartz and brown aggregates (organic material with less than 20 micron mineral matter, much org. SiO_2

B$_1$ horizon - Dom. quartz, yellow and brown alteration products, gels and nontronitic material from biotite?

C horizon - Dom. alteration products

that due to mechanical forces certain natural grains have broken down to some extent and that a shift from coarse to finer particle sizes has taken place.

The fractions in the sizes 500-50 μm were analysed with a polarizing microscope. The fraction 2000-500 μm could, because of its size, not be examined by a polarizing microscope employing transmitting light and this fraction was analysed qualitatively with a binocular microscope using incident light.

Fractions analysed by the polarizing microscope were studied as follows: small subsamples were placed on a glass slip in an emerging liquid having a refraction index of 1.555. A total of a 100 grains in random position were counted and determined for each fraction. According to v.d. Plas and Tobi (1965) this method would give a mean error of about 10%. However, for minerals present in a percentage of less than 15 the relative error may be over 50% and the method is therefore at its best a semi-quantitative one.

The results are presented in Tables 10 to 15 while for two profiles, namely the Gumbang and the Semongok, the results are shown is cumulative diagrams as well (Figs. 17a and b).

The composing minerals of each fraction are placed in two distinctly different groups, namely primary minerals which are relic minerals inhereted from the parent rock, and neoformations with alterites. Neoformations are minerals or mineraloids pedogenetically formed through crystallization from solutions in the soil or through alteration of existing primary minerals. The term alterites is used for either relic primary minerals which because of weathering have changed characteristics to such an extent that they have become unrecognizable or they are neoformations which have not yet attained recognizable characteristic features for specific minerals or mineraloids. Amorphous or cryptocrystalline gel-like materials generally fall within the latter group.

(I) *Tarat series*

The sand mineralogy shows strong weathering, remaining primary material is predominantly quartz and rock fragments, the latter increasing in content with depth. The quartz is strongly aggregated and anhedral. Rock fragments contain mainly quartz and iron compounds which are possibly ferruginated relic matrix material of the original rock (basalt).

The C horizon contains traces of weatherable minerals, hornblende and chlorite. Of the neoformations goethitic materials are dominant, indicating strong ferrugination. Of importance are further the yellow-brown coloured alterites which are dominantly aggregates of clay minerals possibly after biotite, hornblende and chlorite. They resemble nontronite and are probably transitional to meta-halloysite, since some individual grains display a negative uniaxial figure. Of interest is the fact that these alterites occur dominantly in the B and C horizons which may indicate that the alteration process is strongest there. The presence of chalcedonic materials and silica gels in the A_1 and B_1 horizons and absence thereof in the B/C and C horizons would indicate recrystallization of silica in the upper horizons. Of the 2000-500 μm fraction only those belonging to the A_1 and B/C horizons were examined. In the A_1 horizon this coarse sand consists mainly of clay aggregates,

Table 12. Sand mineralogy - Serin series

Horizon	A_1			A_2(E)			B_1			B_2			B/C		
Fraction	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Primary minerals															
Quartz	98	91	87	100	97	100	98	98	100	95	98	100	97	98	100
Rock fragments	-	-	-	-	-	-	-	-	-	-	-	tr	-	-	-
Biotite	-	-	-	-	-	-	-	-	-	4	1	tr	1	tr	-
Orthoclase	-	-	-	-	-	-	-	-	-	-	tr	-	-	-	-
Neoformations and alterites															
Goethite (aggr.)	tr	-	2	tr	1	-	tr	-	-	1	-	-	2	2	tr
Aggregates of clay minerals	tr	1	-	tr	-	-	-	tr	-	tr	-	-	tr	-	-
Bleached biotite	1	-	-	tr	2	-	2	-	-	tr	1	tr	tr	-	-
Yellow brown gels (altered prim. minerals, antigoritic)	1	2	5	-	-	-	-	2	tr	-	-	-	-	-	tr
Org. SiO_2 (opal)	tr	1	-	tr	-	-	tr	-	-	-	-	-	-	tr	-
Charcoal/org. matter	tr	5	6	-	-	-	-	-	-	-	-	-	-	-	-

(1) = 100-50 μm, (2) = 250-100 μm, (3) = 500-250 μm, tr = traces.

2000-500 μm

A_1 horizon - Dom. quartz, subord. charcoal, few gels.
A_2(E) horizon - Dom. quartz, few charcoal, gels and limonite.
B_1 horizon - Dom. quartz, yellow gels, few limonite.
B_2 horizon - Dom. quartz, few gels and limonite.
B/C horizon - Dom. quartz, few gels and limonite.

Table 13. Sand mineralogy - Semongok series

Horizon	A_1			B_1			B_2			II B_2			II B/C		
Fraction	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Primary minerals															
Quartz	76	57	21	82	64	36	83	58	37	77	55	19	79	56	22
Aggregated quartz (chalcedony)	20	13	7	13	16	6	12	16	11	13	11	6	13	10	8
Zircon	tr	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tourmaline	-	-	-	-	-	-	-	1	-	tr	-	-	-	-	-
Ore	-	-	-	-	-	-	-	-	-	-	-	tr	-	-	-
Muscovite	-	-	-	tr	-	-	-	-	-	-	-	-	-	-	-
Neoformations and alterites															
Goethite/Hematite	3	5	9	1	9	29	4	10	28	10	29	71	8	29	67
Compound grains	1	22	55	3	11	29	-	14	21	tr	5	4	-	5	3
SiO_2 (opal)	tr	2	1	1	-	-	1	1	-	tr	-	-	tr	-	-
Org. matter	-	1	7	-	-	-	-	-	3	-	-	-	-	-	-

(1) = 100-50 μm, (2) = 250-100 μm, (3) = 500-250 μm, tr = traces.

2000-500 μm

A_1 horizon - Dom. yellow gel-aggregates, subord. charcoal, org. matter, quartz and chalcedony.
B_1 horizon - Dom. yellow gel-aggregates, subord. Fe-concretions, quartz, chalcedony.
B_2 horizon - Dom. quartz, subord. chalcedony, goethite concr., gels.
II B_2 horizon - Dom. goethite/hematite concr.-flaky, some quartz and chalcedony.
II B/C horizon - Dom. goethite/hematite concr., some quartz and chalcedony.

possbly due to lack of dispersion; in the B/C horizon this fraction is composed mainly of undeterminable strongly weathered and ferruginized rock fragments. Strong weathering of all primary material, strong ferrugination throughout the profile and formation of secondary silica in the upper horizons characterize the sand fractions of this profile.

(II) *Gumbang series*

Quartz and ore minerals (ilmenite and magnetite) are the dominant primary minerals left in this profile. The quartz consists of two types, one much weathered and striated, the other is fresh and unweathered, displaying an euhedral habit. The ore minerals are of particular importance in the fine sand fractions.

Of the neoformations compound grains consisting of quartz and amorphous materials with meta-halloysite (as confirmed by X-ray) dominate throughout the profile. Ferrugination is most expressed in the B and B/C horizons where also aggregates of clay minerals (mainly books of kaolinite) are of importance.

This profile shows strong weathering of all primary material, there being no weatherable minerals left. The presence of two types of quartz may be significant if the euhedral forms indicate neoformation. This is open to question since they occur throughout the profile and no quantitative separation was done. Formation of kaolinite through direct alteration of primary minerals is still proceeding in the B but mainly in the C horizon. This horizon does not contain recognizable primary minerals anymore but is dominated by strongly altered materials.

(III) *Serin series*

The sand fractions of this profile are characterized by a predominance of quartz in all horizons. The quartz is strong undulose and compounded, euhedral minerals being absent. Biotite is the only primary mineral still present in very small amounts in the lower B and C horizons while also a trace of orthoclase was found in the lower B.

The neoformations and alterites are of little importance in this profile. Aggregated clay minerals are formed by books of kaolinite. The yellow-brown gels are also here mainly altered primary minerals; biotite and green hornblende can still be recognized by habit. Ferrugination is weak.

Strong weathering of all primary material is also a characteristic of this profile. Transitional material to neoformation of minerals is nearly absent which may indicate advanced maturation or a relative initial lack of moderately weatherable minerals in the parent material. Advanced maturation may therefore be the result of strong weathering of relatively easily weatherable material so that soil formation is rapid. The absence of goethite, or in general secondary free iron forms, is explained by the relative low content of iron-bearing minerals in the primary rock which is arkose of a tonalite composition.

(IV) *Semongok series*

In this profile quartz dominates the sand fractions in all horizons. The quartz is of two types, one characteristically unweathered, the other strongly pitted and

Table 14. Sand mineralogy - Gading series

Horizon	A_1			A_{12}			B_1			B_{21}			B_{22}			C		
Fraction	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Primary minerals																		
Quartz	90	95	99	96	97	99	81	96	99	84	92	100	81	94	98	56	46	49
Biotite	-	-	-	tr	-	-	1	-	-	1	2	-	1	1	-	11	15	41
Tourmaline	tr	1	1	2	-	-	2	-	-	3	1	-	1	tr	-	1	-	-
Zircon	tr	-	-	1	-	-	tr	-	-	tr	-	-	tr	-	-	-	-	-
Sphene	-	-	-	-	-	-	-	-	-	tr	-	-	-	-	-	-	-	-
sillimanite	-	-	-	tr	-	-	tr	-	-	1	-	-	-	-	-	-	-	-
Opaque (ore)	4	1	-	tr	2	-	5	1	-	5	-	-	3	1	1	3	1	-
Orthoclase	-	1	-	tr	-	-	3	-	-	-	-	-	-	tr	-	14	12	6
Rock fragments	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Neoformations and alterites																		
Weathered biotite	1	-	-	-	-	-	-	-	-	1	1	-	5	-	-	1	1	2
Bleached biotite	-	1	-	-	-	-	2	-	-	-	1	-	-	2	-	2	1	-
Gibbsite	5	2	-	1	1	1	5	2	-	5	-	-	8	2	1	11	11	-
Weathered orthoclase	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1
Clay minerals (aggr.)	-	-	-	-	-	-	-	1	1	-	2	-	1	-	-	1	11	-
Yellow-brown comp.	-	-	-	-	-	-	1	-	-	-	1	tr	-	-	-	-	-	-

(1) = 100-50 μm, (2) = 250-100 μm, (3) = 500-250 μm, tr = traces.

2000-500 μm

A_1 horizon - pred. primair quartz, some charcoal, some quartz aggregates.
A_{12} horizon - as 28, pale coloured quartz.
B_1 horizon - pred. pale yellow quartz, tr-alterites (gibbsitic) and Fe-compounds.
B_{21} horizon - pred. quartz. Some Fe-rich rock fragments, tr-alterites.
B_{22} horizon - dom. quartz. Some Fe-rich rock fragments, tr-gibbsite and opaque (ore).
C horizon - dom. quartz. Much biotite (books), gibbsitic aggregates with quartz, some weathered orthoclase.

striated. The two types may be traced back to quartz stringers and veins existing in the parent rock, shale and mudstone, and in which the quartz is geologically younger than the old quartz grains which form part of the original sediments.

Chalcedonic quartz which is also classified as inherited material is possibly also a relic from very thin secondary quartz precipitates existing between the shale laminae but a second possibility is that it has formed in the soil itself. Evidence to such a process may be found in the fact that many quartz grains show chalcedonic borders. However, such a process may also operate in the parent rock and it is therefore difficult to decide from sand mineralogy alone whether this type of silica is pedogenetic or geogenetic. There are no weatherable primary minerals left in the sand fractions throughout the profile. Secondary iron oxides are found in all, but most markedly in the B and II B horizons. The bisequent nature of this profile makes it difficult to indicate whether the accumulation of iron in the sandfractions of lower horizons is due to neoformation or whether it is caused by a sedimentary process. This will be dealt with in more detail as more evidence for either process is becoming available in following sections. Of considerable interest is the presence of compound grains which decrease in content with depth. Treatment with H_2O_2 is able to destroy them, the remaining components being quartz, and opal of silt size and traces of kaolinite with a strong component of amorphous materials (confirmed by X-ray analysis).

Since the 2000-500 μm fraction also shows a dominance of these compound grains in the upper horizons it is possible that a shift to smaller fractions has taken place due to mechanical breakdown in the texture analysis. The grain size is therefore irrelevant.

A sample of the 2000-500 μm fraction was thin-sectioned and studied under the polarizing microscope (Plate 1). This study indicates that the compound minerals are strongly rounded and that the various components are cemented together into a solid grain by presumably mainly humic material. Such compound grains were also found in the Gumbang profile but of less defined nature.

(V) *Gading series*

The Gading profile contains dominantly quartz in all sand fractions of all horizons. Quartz is relatively lowest in content in the C horizon, in which appreciable amounts of weatherable minerals namely biotite and orthoclase, are still present. The content of quartz gradually diminishes with depth while that of newly formed minerals, gibbsite, clay minerals, aggregated kaolinite after feldspar in particular, and weathered biotite increases. The quartz is typically rock-inhereted, but strongly pitted and cracked. The gibbsite is characteristically secondary formed and is cryptocrystalline. The presence of some zircon, tourmaline and sphene throughout the profile indicates the relation of this soil with ademellite parent material, while traces of sillimanite point to nearness of a high temperature-moderate pressure metamorphosed zone which is locally found at the contact of the ademellite and surrounding sedimentary rocks (Winkler, 1967). In the coarse fraction of the C horizon the biotite occurs typically as books. This profile shows little intermediate products, indicating a rapid change from primary material to soil. A transition from strongly weathered material in the surface horizon to moderately weathered materi-

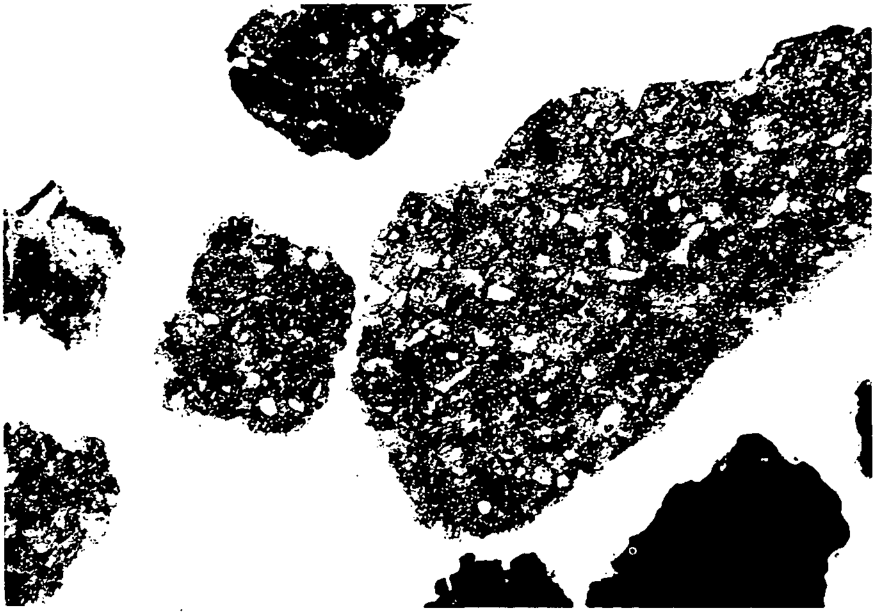


Plate 1 - *Enlarged compound grains in the 2000-500 μm fraction of the* A_1 *horizon of the Semongok series.*

al in the C horizon is however still observable. Alterites in the coarse sand fraction indicate weathering of orthoclase to kaolinite.

(VI) *Nyalau series*

Probably due to the strong quartzitic nature of the parent sandstone this profile shows an almost pure quartz composition of all fractions in all horizons. The quartz is however of two types. In the large fractions it is striated, much pitted and considerably rounded; this form is most likely related to the original sediment forming the bulk of the sandstone. The second type which is more dominant in the smaller fractions contains undulose chalcedonic SiO_2 and is probably related to the cementing agent of the sandstone. It is decidedly of secondary origin but nevertheless inhereted from the parent-rock. Some aggregated clay minerals of kaolin type are found below the A_1 horizon. Secondary forms of free iron oxide are conspicuously absent.

From the detailed analysis of the mineralogy of the sand fractions of the six series the following general conclusions can be drawn:

a. All soils in the sequence under study show strong weathering, only the B/C or C horizons contain small amounts of primary weatherable material.

b. The mineralogy of the sand fractions is strongly related to kind of parent rock. This is not so much apparent in the remaining primary minerals, which is in all cases predominantly quartz, but much more in the type of alterites

Table 15. Sand mineralogy - Nyalau series

Horizon	**A$_1$**			**A$_2$**			**B$_1$**			**B$_2$**			**B/C**		
Fraction	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Primary minerals															
Quartz	100	100	97	96	97	97	100	100	99	97	98	97	100	100	100
Zircon	tr	-	-	tr	-	-	tr	-	-	tr	-	-	tr	-	-
Tourmaline	-	-	1	tr	-	-	tr	-	-	tr	-	-	-	-	-
Biotite	-	-	-	-	-	-	-	-	-	tr	-	-	tr	-	-
Orthoclase	-	-	1	-	-	-	tr	-	-	-	-	-	-	-	-
Opaque (ore)	-	-	-	3	1	-	-	-	1	-	1	1	-	-	-
Neoformations and alterites															
Yellowbr. gels	tr	-	1	1	2	-	-	-	-	2	1	-	-	-	-
Aggregated clay minerals	-	-	-	-	-	3	tr	tr	-	1	-	2	tr	tr	-
Org. SiO$_2$ (opal)	tr	-	-	tr	-	-	tr	-	-	-	-	-	-	-	-

(1) = 100-50 μm, (2) = 250-100 μm, (3) = 500-250 μm, tr = traces.

2000-500 μm
All horizons predominantly quartz, traces of zircon and tourmaline.

and neoformations of minerals. Rocks with considerable amounts of ferromagnesium minerals give high contents of goethite in the sand fractions.

c. The type and habit of the SiO_2 minerals appear to be of considerable importance. In studies of this nature distinction must be made between primary and secondary quartz, weathered or unweathered, rock-derived or pedogenetically derived.

d. The nature of the altered materials must be carefully studied and if possible classified. Their distinction may give important clues to weathering phenomena and neoformation of secondary minerals.

e. The presence of compound grains resistent to normal dispersion methods may be typical for certain soils and their importance should be recognized in mineralogical studies.

2.2. The mineralogy of the heavy sand fraction

An analysis of the heavy sand mineralogy can provide evidence for possible foreign admixtures in soils thought to be related only to the parent material found in the profile at depth. In order to check-up this point such an analysis was carried out.
The heavy mineral fraction was separated by bromoform with a s.g. of 2.9 (Milner, 1952) from the total 250-50 μm fraction after treatment with Na-dithionite to remove the free iron oxides.

The amount of heavies was extremely small and only for the profiles with a sandy texture sufficient material could be separated for a semi-quantitative analysis as was done for the total mineralogical composition. Table 16, therefore shows only the results of the analysis for the Gading (A_1 and C horizon only), Nyalau and Butan series.

For the remaining series only some general observations can be made, with the exception of the Serin series which yielded no heavies at all.

(I) *Tarat series*

The A_1 horizon contains some rounded and subrounded zircon, and few tourmaline and rutile. Ilmenite occurs dominantly. The B_1 horizon is similar to the A_1 in this respect but no tourmaline and rutile were seen. In the lower horizons this association persists with few rutile and tourmaline.

(II) *Gumbang series*

This series yielded for all horizons almost exclusively ilmenite and magnetite with a few small zircons throughout the profile.

(III) *Serin series*

No heavy minerals were found.

(IV) *Semongok series*

Large ilmenite without leucoxene dominates the heavy mineral fraction through-

Table 16. Heavy mineral composition of the 250-50 μm fraction of some upland soils in West Sarawak

Soil series	Horizon	Depth in cm	Ratio opaque/ non-opaque	Zircon	Tourmaline	Sillimanite	Epidote	Zoizite	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Alterites	Rock fragments
Gading	A_1	2 - 7	65/35	3	81	13	-	1	-	-	-	-	1	1	-	-	-
	C	150+	44/65	-	87	12	-	-	-	-	-	-	-	1	-	-	-
Nyalau	A_1	0 - 9	51/49	41	49	-	-	-	1	4	-	5	-	-	-	-	-
	A_2(E)	9 - 30	52/48	38	31	-	-	-	2	11	3	11	-	-	1	3	-
	B_1	30 - 63	53/47	44	14	-	-	-	4	15	1	20	1	-	-	1	-
	B_2	63 - 110	35/65	45	16	-	-	-	6	11	2	15	2	-	1	2	-
	B/C	110 - 150	44/56	40	27	-	-	-	5	8	1	18	1	-	-	-	-
Butan	A_1	5 - 13	48/52	34	58	1	-	-	2	2	2	7	-	-	-	-	-
	A_{12}	13 - 23	51/49	30	48	1	-	-	1	3	3	14	-	-	-	-	-
	A_2(E)	23 - 33	45/55	39	47	-	-	-	1	2	1	10	-	-	-	-	-
	B_1h	33 - 48	57/43	43	34	-	-	-	1	5	2	15	-	-	-	-	-
	B_{12}	48 - 58	58/42	11	44	2	4	-	-	1	6	15	-	-	-	-	17
	B_2	58 - 84	35/65	11	30	3	1	-	1	1	13	21	-	-	-	-	43
	II C	84 - 112	36/64	3	30	-	1	-	-	3	13	13	-	-	-	-	37
	II R	112 - 172+	11/89	-	6	-	1	-	-	1	1	-	-	-	-	-	50

out the profile. Some tourmaline is present. In the subsoil shale fragments dominate over ilmenite, possibly more intense weathering in the surface horizon may cause this difference.

(V) *Gading series*

The A_1 horizon shows a dominance of opaque minerals over non-opaque. The opaque minerals are mainly ilmenite with some magnetite. In the weathered rock non-opaque minerals dominate over opaque. In both, A_1 and C horizons tourmaline is predominant, while sillimanite is the only other mineral of some importance. The association confirms a derivation from adamellite although the presence of sillimanite does indicate that high temperature and moderate pressure metamorphosis has occurred in the rocks at situ, or nearby.

(VI) *Nyalau series*

The ratio opaque/non-opaque is approximately 1 in the surface horizons and becomes slightly less in the lower horizons. The mineralogy of all horizons is quite consistent, zircon and tourmaline being dominant. Of interest is the considerable amount of titaniferous minerals in all horizons.

(VII) *Butan series*

The opaque/non-opaque ratio is quite similar to that of the Nyalau series, it is becoming less with increasing depth. The dominant non-opaque minerals are zircon and tourmaline. The abrupt change in the content of zircon occurring between the $B_{1}h$ and B_{12} horizons may indicate a bisequency in parent material but the difference could also be caused by a shift in grain size within the range 250-50 μm. The mineralogy of the B_2/IIC horizons is more diagnostic for a bisequency in materials. The rock fragments are dominantly shale fragments and this may indicate that a sandstone bed may gradually be replaced by a shale bed although it is also possible that the shale has totally weathered in the upper soil horizons.

Despite the fact that no complete analysis of the heavy mineral fraction of all soils could be carried out, from the results it is possible to conclude that in all soils studied no evidence could be found contrary to a truly autochtonous derivation. The mineralogical differences between some horizons can be readily explained as being either related to characteristics of parent material or to soil forming processes.

2.3. *Mineralogy of the silt fraction*

The silt fraction, 50-2 μm, was obtained from the granulometric analysis carried out without pretreatments involving the use of H_2O_2 and acids, and with Na-pyrophosphate and Na-carbonate as dispersion agents as described in detail in Appendix II.

The fractions were examined by X-ray diffraction using CoKα radiation under conditions given in Appendix II. Only for the Gading profile such an analysis was carried out on the fractions 50-20 and 20-2 μm separately since for the other profiles no separation into fine and coarse silt was made in the granulometric analysis.

Table 17 shows the results of the X-ray analysis. The presentation of these results is in accordance with the system proposed in the 7th Approximation of the USDA Soil Classification system (USDA, 1960). It should be remarked that for this semi-quantitative assessment peak heights of main reflections were used. Since crystallinity grade, particle size and conditions of analysis influence the intensities of the registered reflections (Jackson, 1956), the interpretation thereof and detected variations are of more significance for samples from one profile in which crystallinity grade and particle size will vary least than for samples from different profiles in which mentioned factors can vary considerably.

No special treatments such as heating or Mg-glycol saturation were carried out on the samples since the experience gained in the studies of the clay fractions, discussed in the following section, could be used in the interpretation of the results for the silt fraction.

(I) *Tarat series*

Moderate to large amounts of quartz are present in all horizons. The apparent quantitative differences between the various horizons as evidenced by peak intensities may be due to a shift in particle size of the quartz within the silt fraction and may have no pedogenetic significance (Brown, 1961). The goethite content in all horizons is large without apparent accumulation in one or any horizon. Probably much poorly crystallized limonitic matter is present since the main goethite reflection of 4.17 Å shows a broad peak, indicating a very small basic particle size of goethite compounded into particles of silt size. The small amounts of kaolinitic matter present show meta-halloysitic tendences; probably also antigorite is involved since a very broad plateau representing spacings from 7.1-7.35 Å exists in the diagram. The presence of such materials would confirm the findings of the mineralogical study of the sand fractions in which strongly altered primary material with transitions to compound clay minerals of halloysitic nature were also found. Gibbsite is present in small amounts throughout the profile.

(II) *Gumbang series*

Quartz predominates throughout the profile. Small amounts of montmorillonitic materials are indicated by small reflections indicating spacings of 18-18.5 Å. Such large lattice spacings, present without the use of swelling agents may indicate transitional material of micas with some interlayering of 2:1 lattice clays.
An insignificant and very broad reflection for spacings in the range 7.1-7.4 Å may indicate presence of poorly crystallized kaolinitic materials of the nature discussed for the Tarat series. Also in this profile similar transitional materials were detected in the sand mineralogy. The presence of small amounts of gibbsite probably somewhat increasing in content with depth are indicated by small, sharp reflections for spacings of 4.85 Å.

A small insignificant peak at 3.73 Å, present in the lower horizons is probably related to the 130 reflection of orthoclase, while the 220 reflections at 3.34 Å of the same intensity may be taken up by the broad base of the 3.33 Å reflection for quartz.

Table 17. Mineralogical composition of the silt fraction

Mineralogy of the silt fraction, 50-2 μm

Soil series	Horizon	Depth in cm	Q	Gibb	Goe	He	Ilm
Tarat	A_1	0 - 8	xx	x	xx	-	-
	B_1	8 - 28	xxx	x	xx	-	-
	B/C	28 - 54	xxx	x	xx	-	-
	C	54 - 100+	xx	x	xx	-	-
Gumbang	A_1	0 - 9	xxxx	tr	-	-	-
	B_1	9 - 28	xxxx	tr	-	-	-
	B_2	28 - 44	xxxx	tr	-	-	-
	B/C	44 - 67	xxxx	x	-	-	-
	C	67 - 100+	xxxx	x	-	-	-
Serin	A_1	0 - 10	xxx	tr	-	-	-
	A_2 (E)	10 - 25	xxx	tr	-	-	-
	B_1	25 - 75	xxx	tr	-	-	-
	B_2	75 - 115	xxx	tr	-	-	-
	B/C	115 - 135+	xxx	tr	-	-	-
Semongok	A_1	0 - 9	xxxx	-	-	-	-
	B_1	9 - 29	xxxx	-	-	-	-
	B_2	29 - 68	xxxx	-	-	-	-
	II B_2	75 - 88	xxxx	-	-	-	-
	II B/C	88 - 115+	xxxx	-	-	-	-
Gading¹⁾	A_1	2 - 7	xxx	x	-	-	x
	A_{12}	7 - 20	xxx	x	-	-	x
	B_1	20 - 50	xxx	x	-	-	tr
	B_{21}	70 - 100	xxx	x	-	-	tr
	B_{22}	100 - 120	xxx	x	-	-	x
	C	120+	xx	xx	-	-	tr
Nyalau	A_1	0 - 9	xxx	-	-	-	-
	A_2 (E)	9 - 30	xxx	-	-	-	-
	B_1	30 - 63	xxx	-	-	-	-
	B_2	63 - 110	xxx	-	-	-	-
	B/C	110 - 150+	xxx	-	-	-	-
Mineralogy of the silt fraction, 20-2 μm							
Gading	A_1	2 - 7	xx	xx	-	-	-
	A_{12}	7 - 20	xx	xx	-	-	-
	B_1	20 - 50	xx	xx	-	-	-
	B_{21}	70 - 100	xx	xx	-	-	-
	B_{22}	100 - 120	x	xx	-	-	-
	C	120+	x	xx	-	-	-

xxxx = predominant, xxx = large amounts, xx = moderate amounts, x = small amounts,
1) 50-20 micron fraction

Soil series	Fel	Kao	Ill/ Mica	Verm	Mont	An
Tarat	-	x	-	-	-	-
	-	x	-	-	-	-
	-	x	-	-	-	-
	-	x	-	-	-	-
Gumbang	-	tr	-	-	x	-
	-	tr	-	-	x	-
	-	tr	-	-	x	-
	tr	tr	-	-	x	-
	tr	tr	-	-	x	-
Serin	-	xx	-	tr	tr	-
	-	xx	-	x	tr	-
	-	xx	-	x	-	-
	-	xx	-	x	-	-
	-	xx	-	x	-	-
Semongok	tr	x	-	-	tr	tr
	tr	x	-	-	tr	tr
	tr	x	-	-	tr	tr
	tr	x	-	-	tr	tr
	tr	x	-	-	tr	tr
Gading1)	tr	tr	-	-	tr	-
	tr	tr	-	-	tr	-
	tr	tr	-	-	tr	-
	tr	x	-	-	tr	-
	tr	x	-	-	tr	-
	x	tr	-	tr	-	-
Nyalau	tr	tr	-	tr	x	tr
	tr	tr	-	tr	x	tr
	tr	tr	-	tr	x	tr
	tr	tr	-	tr	x	tr
	tr	tr	-	x	x	tr
Gading	tr	x	-	-	-	-
	tr	x	-	-	-	-
	tr	x	-	-	-	-
	tr	xx	-	-	-	-
	tr	xx	-	-	-	-
	x	x	xx	-	-	-

tr = traces

(III) *Serin series*

Also in this profile quartz predominates in all horizons. The kaolinite content may be relatively exaggerated because of the high grade of crystallinity which is also apparent in the clay samples of this profile. The comparative large amounts of kaolinite in the silt fraction are probably caused by the presence of much kaolinite 'books' which were also found in the sand fractions.

The presence of vermiculite is deduced from reflections indicative for 14 Å spacings. It is suggested that as is the case with the Gumbang series some interstratified micaceous materials are also present in the silt fractions.

(IV) *Semongok series*

The silt fraction of the Semongok series is also dominated by quartz. Small amounts of well-crystallized kaolinite occur, presumably also in the so-called 'book' form. Insignificant reflections in the 18-18.5 Å range may indicate presence of montmorillonite or interstratified transitions in the mica-illite-vermiculite range.

The presence of muscovite and illite in the shales forming the parent material of this soil would give reason to the development of such neoformations which are much stronger apparent in the mineralogy of the clay fractions (see following section).

Of interest are the small but sharp reflections for 3.52 Å spacings which are probably caused by presence of anatase. Small reflections indicative for 3.73,Å spacings and which are also present in the silt fraction of the Gumbang series, are most probably caused by presence of traces of orthoclase.

(V) *Gading series*

The separation of the fine silt from the coarse silt fraction appears to serve a useful purpose since, at least in this profile, the mineralogy of these fractions is decidedly different.

The coarse silt fraction is dominantly quartz with small amounts of gibbsite being present in all horizons. The gibbsite content of the weathered rock is perceptibly higher than in the above lying soil horizons. Traces of feldspar, well-crystallized kaolinite, vermiculite and montmorillonitic material are also found.

Spacings at 11-14 Å and at 18 Å were used as indications for the latter two. The fine silt fraction shows a much lower quartz content but a considerable content of gibbsite, the latter increasing gradually with depth. Kaolinite is also present, giving distinctly stronger reflections in the B horizons than in the A and C horizons. Whether this is due to better crystallinity, grain size or higher quantity of kaolinite is difficult to decide upon. The sand mineralogy indicates that weathered feldspars form compound kaolinite and presumably such altered material occurs both in the sand and silt fractions, and dominantly so in the horizons above the weathered rock. In the surface horizons the bulk masses of kaolinite may become separated, enriching the clay fraction. The fine silt fraction does not show reflections of interstratified or montmorillonitic materials but in the C horizons strong sharp reflections of mica are found.

It is suggested that the bleached biotite and biotite occurring in the weathered rock as indicated by the sand mineralogy, act as sources for the occurring interstratified and montmorillonitic materials, while the orthoclase may give rise to formation of kaolinite. Of interest is however the shift from illite/mica to kaolinite in the fine silt fractions of the C and B horizon while the coarse silt fraction shows such a shift to vermiculite and montmorillonitic materials. It is therefore quite possible that the vermiculite and montmorillonitic materials represent only a transitory stage from mica to kaolinite since the clay fractions do not show presence of 2-1 minerals anymore (see following section).

(VI) *Nyalau series*

The silt fraction shows a predominance of quartz. Also in this profile traces of orthoclase are present as is the case in the Semongok series. Traces of kaolinitic materials with halloysitic tendencies are indicated by a broad plateau of weak intensity in the 7.2-7.5 Å. The presence of small amounts of montmorillonitic material, possibly interstratified altered micas, is suspected from distinct but small reflections in the 17 to 18 Å range, and small plateau-like features in the 10 to 13.8 Å range.

2.4. Mineralogy of the clay fraction

2.4.1. General

In studies on the composition of the clay fraction of a soil it is important to realize that the method used for separating the clay from the fine earth may influence the very composition of the fraction obtained. Particularly, since previous routine investigations on the clay mineralogy of West Sarawak soils had indicated that poorly crystallized kaolinite is one of the main components in the clays of most soils and that the presence of amorphous materials can be expected in the surface horizons of some soils (Andriesse, 1972), care should be exercised not to destroy such materials by too rigorous a separation technique.

The investigations on the sand and silt fractions in the present study have shown that not all clay minerals are present in clay size but that in some soils aggregates and compounds of clay minerals occur together as compound grains in the fractions of larger grain size than clay (smaller than 2 μm). The breakdown of such aggregates and the liberation of clay size material is the aim of pre-treatments and dispersion agents but these treatments might influence the chemical composition, crystallinity and possibly also the qualitative character of the obtained clay fractions. In order that a correct interpretation be made, various dispersing methods had to be tested on their influence on clay mineralogy.

Na-pyrophosphate is commonly used as a dispersing agent for both granulometric analyses and in clay separation methods. Perkins et al (1957) have shown that polyphosphates react with kaolinite decomposition products while Hashimoto et al (1969) have indicated that also gibbsite and goethite are affected. Therefore Na-pyrophosphate dispersion was tested against the use of NH_4OH, and the use of demineralized water only. The latter test involved the separation of the natural clay (water-dispersible) which could only be obtained for some samples.
The results of this particular study are to be published elsewhere (Andriesse, in prep. a) but can be summarized as follows:

a. Na-pyrophosphate/Na_2CO_3 dispersion gives consistently somewhat higher kaolinite contents in the clay fractions if kaolinite is present in the natural silt or sand fractions. The same is probably also valid for gibbsite.

Table 18. Mineralogy of the clay fraction - < 2 μm (field clay, separated with $Na_4P_2O_7/Na_2CO_3$ as dispersion agent.

Soil series	Horizon	Depth in cm	Q	Gibb	Goe	He	Fel	Kao	Verm/ Ill	An
Tarat	A_1	0 - 8	x	tr	xx	tr	-	xx	-	-
	B_1	8 - 28	x	tr	xx	tr	-	xx	-	-
	B/C	28 - 54	tr	tr	xx	tr	-	xx	-	-
	C	54 - 100+	tr	tr	xx	tr	-	xx	-	-
Gumbang	A_1	0 - 9	x	x	tr	-	-	xxxx	-	-
	B_1	9 - 28	x	x	x	-	-	xxxx	-	-
	B_2	28 - 44	x	x	x	-	-	xxxx	-	-
	B/C	44 - 67	tr	x	x	-	-	xxxx	-	-
	C	67 - 100+	tr	x	x	-	-	xxxx	-	-
Serin	A_1	0 - 10	tr	tr	x	-	-	xxxx	tr	-
	A_2	10 - 25	tr	tr	x	-	-	xxxx	x	-
	B_1	25 - 75	tr	tr	x	-	-	xxxx	x	-
	B_2	75 - 115	tr	tr	x	-	-	xxxx	x	-
	B/C	115 - 135+	tr	tr	xx	-	-	xxxx	x	-
Semongok	A_1	0 - 9	x	-	-	-	-	xx	xxx	tr
	B_1	9 - 29	x	-	tr	-	-	xx	xxx	tr
	B_2	29 - 68	x	-	tr	-	-	xx	xxx	tr
	II B_2	75 - 88	x	-	tr	-	-	xx	xxx	tr
	II B/C	88 - 115+	x	-	tr	-	-	xx	xxx	tr
Gading	A_1	2 - 7	tr	xx	x	x	-	xxx	-	-
	A_{12}	7 - 20	tr	xx	x	x	-	xxx	-	-
	B_1	20 - 50	tr	xx	x	x	-	xxx	-	-
	B_{21}	70 - 100	tr	xx	x	x	-	xxx	-	-
	B_{22}	100 - 120	tr	xx	x	x	-	xxx	-	-
	C	120+	tr	xx	x	x	tr	xxx	-	-
Nyalau	A_1	0 - 9	x	-	x	-	-	xxx	x	tr
	A_2 (E)	9 - 30	x	-	x	-	-	xxx	x	tr
	B_1	30 - 63	x	-	x	-	-	xxx	x	tr
	B_2	63 - 110	tr	-	x	-	-	xxx	x	tr
	B/C	110 - 150+	tr	-	x	-	-	xxx	x	tr
Butan	A_1	5 - 13	xxxx	-	-	-	-	x	-	x
	A_{12}	13 - 23	xxxx	-	-	-	-	xx	-	xx
	A_2 (E)	23 - 33	xxxx	-	-	-	-	xxx	-	xx
	B_1	48 - 58	xx	-	-	-	-	xxx	xx	x
	B_2	58 - 84	xx	-	-	-	-	xxx	xx	xx
	C	84 - 112	xx	-	-	-	-	xx	xx	x

xxxx - predominant, xxx - large amounts, xx - moderate amounts, x - small amounts, tr - traces.

b. Compound grains existing in the natural sand and silt fractions are partly broken down by Na-pyrophosphate/Na_2CO_3 dispersion, the different components, in this case kaolinite and quartz, being added to the clay fraction.

c. No evidence could be obtained that any of the dispersion agents used would differentially dissolve aluminium.

d. Water-dispersible clays most likely contain less amorphous materials than clays obtained by the other dispersion methods.

e. Ammonia-dispersed clays are in quantitative composition closest to the natural composition; none of the dispersion agents used appears to disperse selectively but if in the natural composition of the soil one or more clay mineral types occur specifically in sand or silt size grains, Na-pyrophosphate dispersion could cause their presence in the clay fraction.

Jackson (1965) advocates the use of 0.5 NaOH as a selective extraction method for so-called 'stable allophane' which are allegedly weathering products of kaolinite present in strongly weathered acid tropical soils. Since their presence was suspected in Sarawak soils this extraction method was also employed but in order to test the validity of the method, the effect of the treatment on the extracted material was checked by analyzing the chemical and mineralogical composition without and with treatment. All mineralogical studies on clay separates were conducted by X-ray diffraction analysis, using CoKα radiation. All X-ray analyses were carried out on non-orientated, flat powder samples. Special treatments involving Mg-glycol saturation, K-saturation and heating to 500°C to allow proper identification of 2-1 lattice clay minerals, kaolinite and chlorite, were carried out according to recommended procedures by Jackson (1956), Brown(1961), and Millot (1970).

Certain aspects of the clay mineralogy were checked by differential thermal analysis and infra-red spectrography, while on some test samples thermogravimetric analyses were carried out for a quantitative assessment of particularly gibbsite, goethite, kaolinite and vermiculite. Details of the analytical procedures are given in Appendix II.

2.4.2. Clay mineralogy of samples dispersed with Na-pyrophosphate without pretreatment.

The results of the X-ray studies are presented in table 18. Since the use of polyphosphates is recommended by the 7th Approximation of the USDA soil classification (USDA, 1960), and the study on dispersion methods did not indicate significant differences in clay mineralogy as a result of dispersion method, the X-ray analysis was carried out on the clay separates dispersed with Na-pyrophosphate/Na-carbonate.

Peak intensity and peak area of main reflections have been used for the semi-quantitative interpretation of the X-ray diffractograms. To test this interpretation on its quantitative value quantitative analyses were carried out on a number of testsamples by using D.T.A. and T.G. methods. The results of these analyses are shown in table 19.

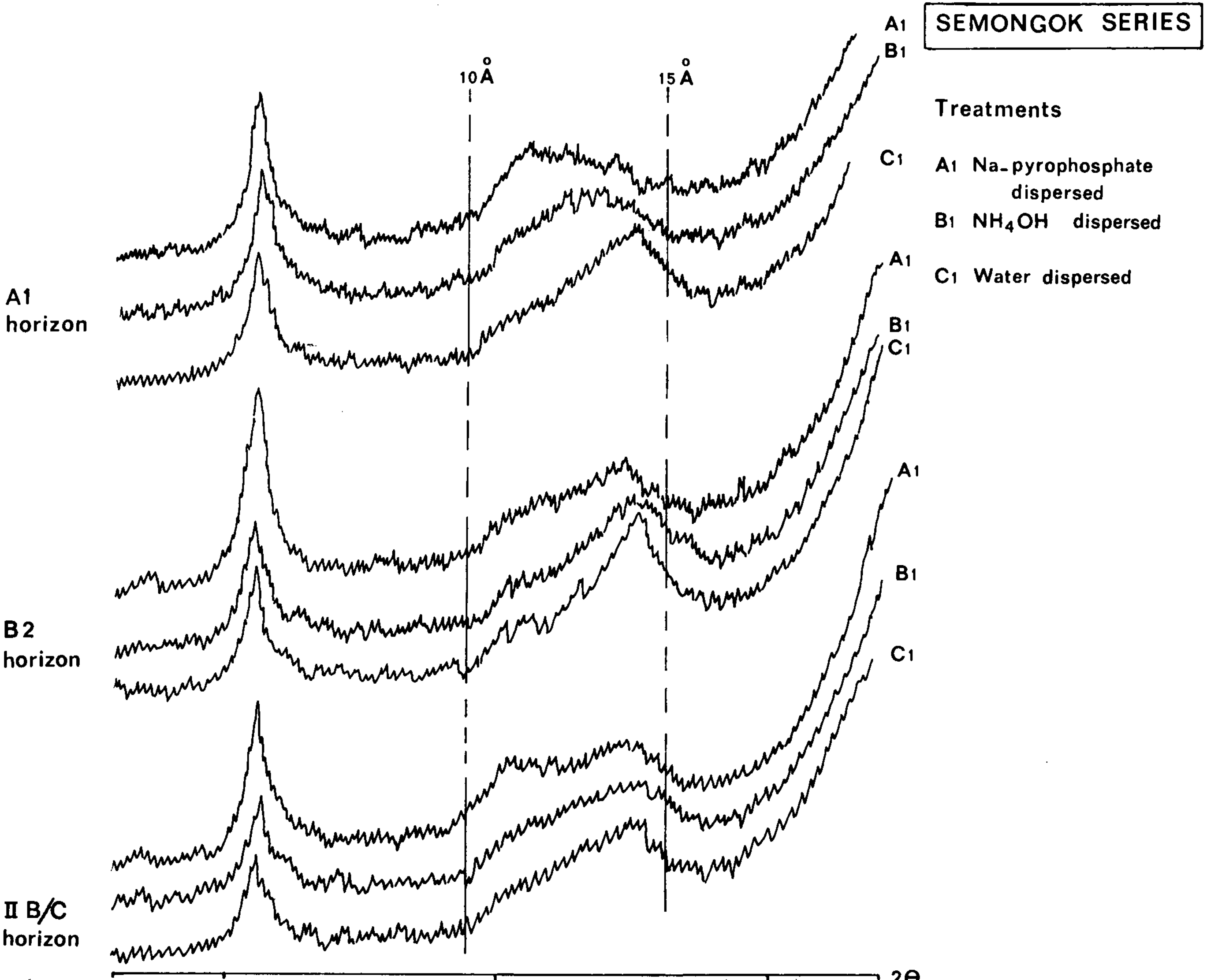


Fig. 18 The influence of dispersion agent on X-ray diffraction patterns of vermiculite and interstratified clay minerals

Table 19. Quantitative analyses of selected clay samples based on T.G. analysis.

Soil	Horizon	Gibb.	Goe.	Kaol.	Verm/Ill.	Quartz (by subtraction)
Tarat	B/C	-	50%	49%	-	1%
Gumbang	B_2	7%	16%	73%	-	4%
Serin	B_1	-	18%	65%	17%	-
Semongok	B_2	-	-	35%	60%	5%
Nyalau	B_1	-	25%	56%	18%	1%

The norms for expelled water used in the calculations were taken from Jackson (1956). A comparison of tables 18 and 19 learns that a predominant occurrence of a clay mineral means a quantity of more than 60%, large amounts about 50 to 60%, moderate amounts 30 to 50%, small amounts 5 to 30%. By using X-ray diffractograms only, there appears to be a tendency to overestimate the amount of kaolinite particularly in relation to interstratified minerals such as Verm/Ill. The content of quartz is also easily overestimated, while goethite tends to be underestimated. Probably also the latter is greatly influenced by grainsize. The following notations on particulars of the X-ray diffractograms for each soil type serve to illustrate the apparent small quantitative differences in clay mineralogy which cannot be deducted from a tabular form as used in table 18 but which are of as much genetic importance as the large quantitative differences.

(I) *Tarat series*

Poorly crystallized kaolinitic materials together with goethite make up the bulk of the samples in all horizons. Only traces of gibbsite can be detected. Quartz is present in small amounts in the A and upper B horizons but diminishes in content with depth. The character of the kaolinitic materials shows strong halloysitic tendencies suggested by the broad 001 reflections in the range 7.2-7.25 Å together with similar broad 002 reflections between 3.54 and 3.58 Å. The halloysitic character is also apparent if in the calculations for a quantitative assessment by T.G. analysis the norm for kaolinite is used for expelled water. In that case the calculated kaolinite content would be 60% making a total of 110% sample (see table 19). When using the norm for halloysite the calculated composition of the sample is more in line with reality (49% for kaolinite, 99% total sample). Of interest is further the formation of hematite from goethite when the samples are heated to 500°C which was done to distinguish possible presence of chlorite from kaolinite. This heating process caused the disappearance of the main goethite peak for 4.17 Å with a corresponding increase of the 2.68 Å reflection for hematite.

(II) *Gumbang series*

The X-ray diffractograms show an almost similar amount of moderately well-crystallized kaolinite in all horizons. The intensity of the main reflections for kaolinite however increases somewhat with depth which could mean better crystallinity grade, smaller particle size or a higher content in the lower horizons. Small amounts of gibbsite are present throughout the profile as are goethite and quartz. The main reflections of the latter minerals show a decrease in intensity with depth. For quartz this could probably indicate diminishing contents in this dimension since crystallinity grade and particle size within one profile can be assumed to be quite constant unless neoformation has taken place. For goethite both a variable content or grain size could give this effect.

(III) *Serin series*

The profile is dominated by relatively well-crystallized kaolinite. The presence of small amounts of interstratified minerals, probably transitory products in the range illite-vermiculite is shown by broad downsloping plateau-like reflections of low intensity for 10.8 and 13.6 Å spacings, the plateau reaching its highest level for 13.6 Å. Saturation with Mg-glycol does not result in shifting of the reflections to 14 Å spacings which leads to the conclusion that this material is indeed not purely vermiculite. The intensity of the plateau-like reflections increase somewhat with depth in the profile which may be due to growing content, higher crystallinity grade or greater particle size.

Gibbsite is present throughout the profile as traces, as is quartz. Goethite occurs as small amounts in all samples and intensity of reflections tends to increase with depth, which could either indicate an increase in content or in particle size.

(IV) *Semongok profile*

Vermiculite/illite interstratified minerals and vermiculite are dominant in the whole profile. The interstratified minerals cause broad plateau-like reflections for a range of 10.8-13.6 Å spacings. The intensities of these reflections increase somewhat with depth. The A_1 horizon shows a plateau-like peak sloping down from 10.8 Å to 13.6 Å while in the B_2 horizon and below the highest intensity is reached for a spacing of 13.6 Å and the lowest intensity for a spacing of 10.8 Å (see also Fig. 18). The studies on dispersion methods have indicated that this is probably caused by strong Na-adsorption, since this difference between topsoil and subsoil is not apparent when dispersion is achieved with ammonia or water.

Mg-glycol treatment causes a shift from the main reflection for 13.6 Å to one for 13.8 Å. With K-adsorption and heating to 500°C the 13.6 Å reflections shift to 10.4 Å due to partial collapsing of the lattice spaces. The 7.15 Å reflection disappears upon heating to 500°C noting presence of moderately well-crystallized kaolinite instead of chlorite. A small intense reflection of 3.52 Å spacings is probably caused by presence of anatase. Quartz is present in small amounts, while also traces of goethite could be detected.

(V) *Gading series*

Moderately well-crystallized kaolinite is dominant in all samples. The intensity of the 001 reflections is in comparison with those for the other profiles quite strong which probably points to a higher grade of crystallinity rather than difference in quantity since peak area shows little difference. This could not be confirmed by T.G. analysis since no sample material was left over for that purpose.

Gibbsite is present in moderate amounts throughout the profile. The X-ray diffractograms display an irregular distribution, namely the A_1 horizon has less gibbsite than the A_{12} horizon, while the content diminishes again in the B_{21} horizon. The highest amounts are found in the C horizon, which is also the case with the silt fraction (see section III.A.2.3.).

The high gibbsite content of the C horizon corresponds with a relatively lower kaolinite content. Feldspars are present only as traces in the C horizon. Goethite and hematite occur in small amounts throughout the profile with no apparent differences in content, while quartz is to be found as traces throughout the profile.

(VI) *Nyalau series*

Moderately well-crystallized kaolinite is dominant throughout the profile. The presence of vermiculite and/or interstratified minerals in the illite-vermiculite range is indicated by similar plateau-like peaks as found in the samples of the Semongok series. Goethite is present in small amounts throughout the profile, while quartz occurs in very small amounts throughout the profile, but its content diminishes with depth. The presence of anatase is manifest through the sharp small reflections of 3.52 Å spacings.

(VII) *Butan series*

Information on the clay mineralogy of this series was extracted from a former study (Andriesse, 1969 a) and the X-ray diffractograms were not at hand. For this reason supplementary information to that given in table 18 cannot be provided.

2.4.3. The influence of 0.5 N NaOH extraction on the mineralogy of the clay fraction and the nature of the extracted materials

'Allophane in a stable form (resistant to dilute and base solutions) occurs in fairly highly weathered Latosols and is believed to be weathering relicts of halloysite and kaolinite' (Jackson, 1956).

Since the occurrence of such stable allophane forms was suspected in Sarawak upland soils, particularly those having an endothermic reaction at 170° and 220°C, as was frequently observed in differential thermal analyses of specifically surface horizons (Andriesse, 1972), the differential solubility test for such allophanic compounds as advocated by Jackson (op cit) was used to investigate their quantity and nature.

For this purpose clays dispersed by ammonia were subjected to extraction by 0.5 N NaOH as set out in detail in Appendix II. This dispersion method was chosen because the study on dispersion methods had indicated that these clays corresponded in their composition most to the natural clay. For comparison also the water-dispersible clays in sofar present, and surface samples dispersed by Na-pyrophosphate/Na_2CO_3 were included in the study.

After extraction, the amounts of alumina and silica in solution were determined by atomic absorption spectrophotometry. The extracted clay samples were examined by X-ray diffraction using the methods given in Appendix II and the results were compared with those carried out on samples without the NaOH treatment.

Table 20 shows the amount of alumina and silica extracted by the NaOH solution for the various clay types, while for comparison the total amounts for alumina and silica in the Na-pyrophosphate/Na_2CO_3 clays are also given.

Excepting the Semongok and Nyalau series, in all other soils considerable amounts of Al_2O_3 are extracted, ranging from 30 to 50% of the total amounts present in the

Table 20. Comparison of 0.5 N NaOH extractable ('amorphous') aluminia and silica of clay fractions dispersed by various methods compared with total alumina and silica content of non-extracted clays.

Soil series	Horizon	NaOH extr. Al_2O_3%			Total Al_2O_3%	NaOH extr. SiO_2%			Total SiO_2
		A1)	B	C	A non-extr.	A	B	C	A non-extr.
Tarat	A_1	13.8	14.2	13.6	26.0	12.3	17.6	17.3	30.1
	B_1	15.4	15.3	14.6	28.0	15.0	18.7	18.4	31.5
	B/C	n.d.	16.3	n.p.	27.1	n.d.	20.1	n.p.	30.8
	C	n.d.	16.3	n.p.	28.5	n.d.	17.1	n.p.	31.9
Gumbang	A_1	14.3	13.9	14.5	29.1	19.8	14.5	16.8	40.3
	B_1	19.4	18.1	20.2	36.1	22.7	18.2	19.0	41.9
	B_2	n.d.2)	19.4	22.0	37.1	n.d.	19.8	20.6	41.7
	B/C	n.d.	17.8	20.2	37.3	n.d.	19.0	23.0	42.1
	C	n.d.	22.2	n.p.3)	38.7	n.d.	23.8	n.p.	41.5
Serin	A_1	n.d.	12.7	11.2	34.5	n.d.	13.9	11.8	40.4
	A_2(E)	n.d.	13.3	13.0	35.3	n.d.	15.7	13.9	40.1
	B_1	n.d.	13.3	n.p.	36.0	n.d.	15.0	n.p.	40.8
	B_2	n.d.	14.4	n.p.	34.2	n.d.	13.3	n.p.	38.9
	B/C	n.d.	15.7	n.p.	35.5	n.d.	13.9	n.p.	40.1
Semongok	A_1	4.72	5.2	5.1	28.2	7.0	8.0	8.0	48.4
	B_1	6.14	7.7	6.2	31.1	5.9	8.0	6.4	47.7
	B_2	n.d.	7.4	7.5	30.5	n.d.	7.5	8.8	46.6
	II B_2	n.d.	7.5	7.5	32.0	n.d.	7.5	6.4	46.6
	II B/C	n.d.	6.7	6.7	30.7	n.d.	6.4	6.4	45.3
Gading	A_1	23.61	17.95	17.95	36.5	11.76	8.56	9.62	30.9
	A_{12}	22.67	20.78	20.78	38.0	12.30	12.83	10.69	32.0
	B_1	n.d.	24.56	n.p.	38.2	n.d.	13.90	n.p.	32.4
	B_{21}	n.d.	23.61	n.p.	57.4	n.d.	14.44	n.p.	31.2
	B_{22}	n.d.	25.50	n.p.	36.5	n.d.	14.44	n.p.	31.2
	C	n.d.	26.92	n.p.	38.7	n.d.	13.90	n.p.	30.4
Nyalau	A_1	n.d.	6.0	7.8	27.0	n.d.	8.6	11.0	41.7
	A_2(E)	n.d.	9.5	n.p.	32.4	n.d.	9.9	n.p.	44.7
	B_1	n.d.	9.5	n.p.	32.9	n.d.	11.2	n.p.	44.5
	B_2	n.d.	9.7	n.p.	32.8	n.d.	11.5	n.p.	43.4
	B/C	n.d.	9.7	n.p.	33.5	n.d.	11.7	n.p.	42.9

1) A -$Na_4P_2O_7$ dispersed, B -NH_4OH dispersed, C -H_2O dispersible.

2) n.d.- not determined.

3) n.p.- not present.

clays. Silica shows a rather similar behaviour. Differences which can be observed in the extracted amounts for the 3 clay types (A, B and C) are small and not consistent in nature and are probably more related to analytical error than to compositional differences.

That such large amounts of alumina and silica are extracted by NaOH cannot be solely due to the presence of amorphous materials in such magnitude.

Changes which had occurred in the treated clay samples and which can be studied in the X-ray diffractograms are able to throw more light on this aspect.

Fig. 19 shows that in the B_1 horizon of the Tarat profile a considerable amount of the poorly crystallized kaolinite or halloysite was removed. This is illustrated by the significant decrease in the intensity of the 7.1-7.3 Å reflections. Noteworthy is that next to the 001 reflections for spacings of 7.1-7.3 Å also the 020 reflections (4.45 Å) appear to have lost intensity while the 002 reflections (3.58 Å) are comparatively least affected. The goethite and quartz peaks are enhanced in intensity probably due to a relative increase of better crystallized material in the sample.

Fig. 20 illustrates that in the B_1 horizon of the Semongok profile the intensity of the main reflections for moderately well-crystallized kaolinite (001 and 002) are improved upon NaOH treatment. This would indicate removal of poorly crystallized material. Also here the intensity of the 020 reflections which in this sample must be attributed to both kaolinite and interstratified clay minerals, shows a decrease upon NaOH treatment. Interstratified clay minerals are not much affected, the main changes being caused by a shift of the most intensive reflections to 12.2 Å which is due to Na-saturation effected by the NaOH treatment.

Fig. 21 shows that the gibbsite present in significant amounts in the B_1 horizon of the Gading profile, is totally removed by the NaOH treatment.

These X-ray studies have proven that next to poorly crystallized kaolinite which has halloysitic tendencies also gibbsite is removed. This corroborates results of studies by Wada and Tokashiki (1972) who indicate that in allophane soils in Japan halloysite and gibbsite were removed by 0.5 N NaOH.
The decrease in the 020 reflections for 4.45 Å spacings appears to contradict the suggested value of using the intensity of this peak for calculating the relative amounts of amorphous and well-crystallized clay mineral present in the sample. According to Jackson (op cit) removal of the poorly crystallized materials of 'stable allophane' would improve the intensity of this peak.

To check the influence of the differential solubility test on moderately well-crystallized kaolinite, clay material in the B_1 horizon of the Nyalau profile was examined by using a scanning electron microscope. Plates 2 and 3 indicate that the kaolinite after treatment with NaOH is conspicuously corroded at the edges and this strongly suggests that the 020 reflection is indeed affected by the treatment.
This points to the possibility that also part of the moderately well-crystallized kaolinite goes into solution through removal of the apparently already partially weathered edges. The large amounts of alumina and silica removed by the NaOH

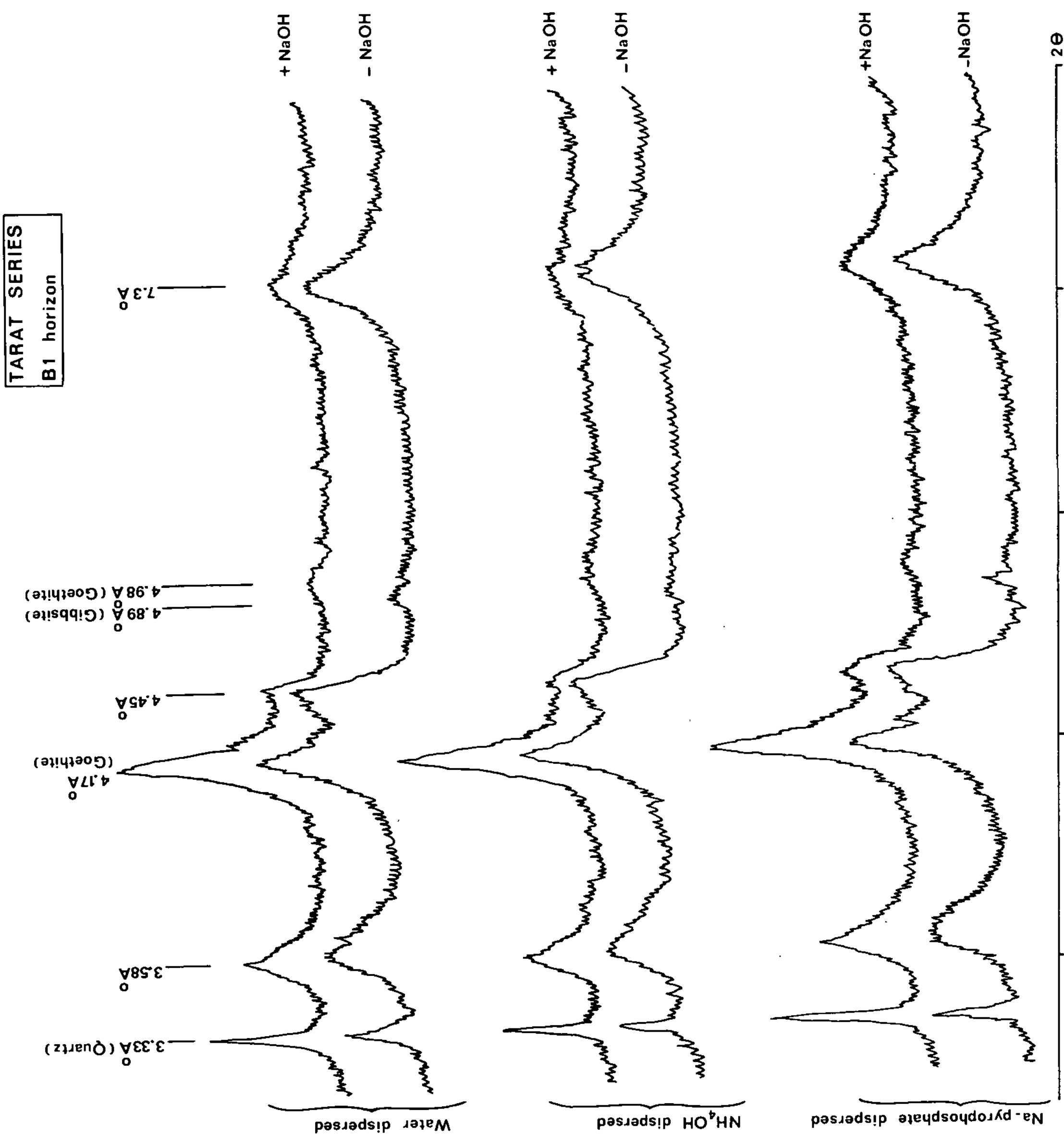


Fig. 19 *The effect of 0.5 N NaOH extraction on poorly crystallized halloysitic materials as indicated by X-ray diffraction analysis*

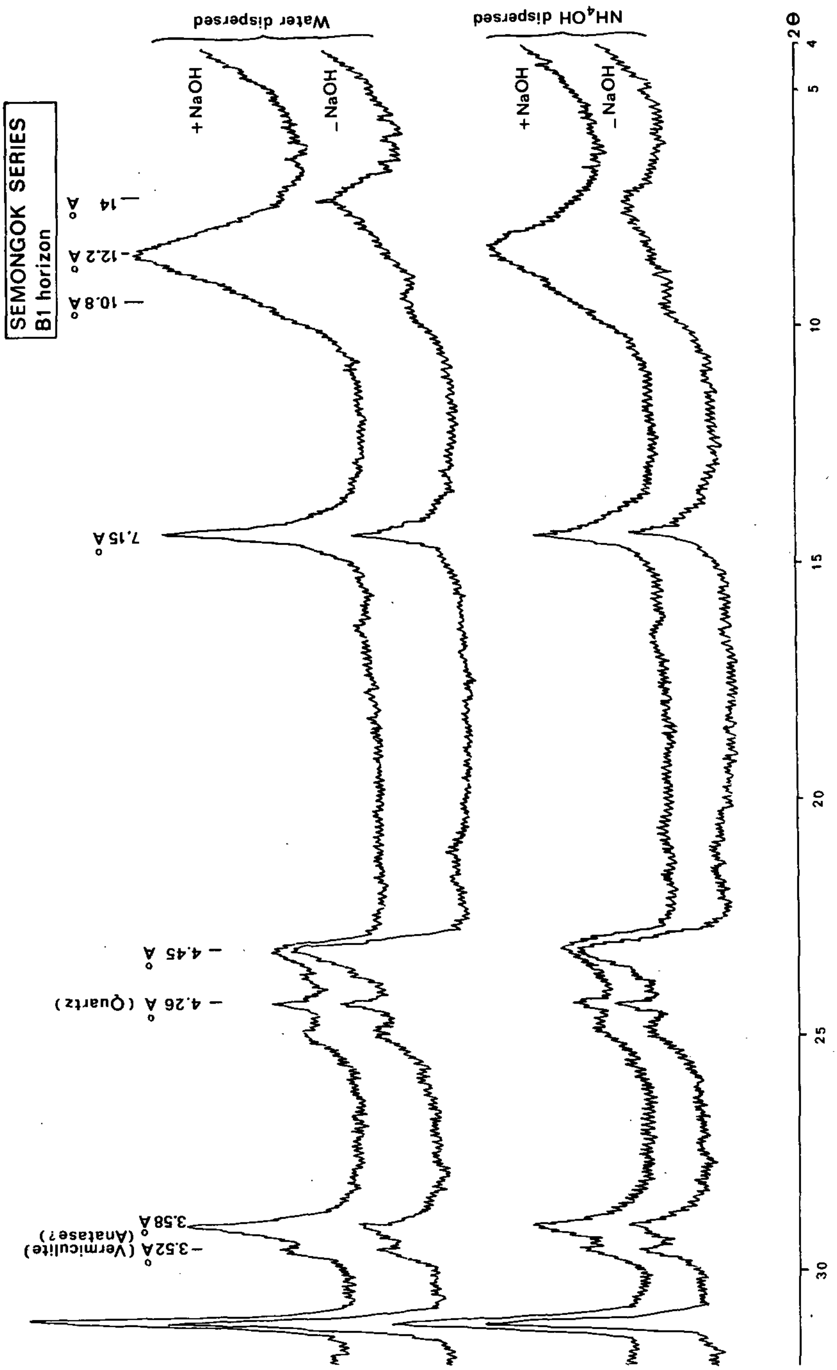


Fig. 20 *The effect of 0.5 N NaOH extraction on moderately well-crystallized kaolinite and vermiculite/interstratified clay minerals as indicated by X-ray diffraction analysis*

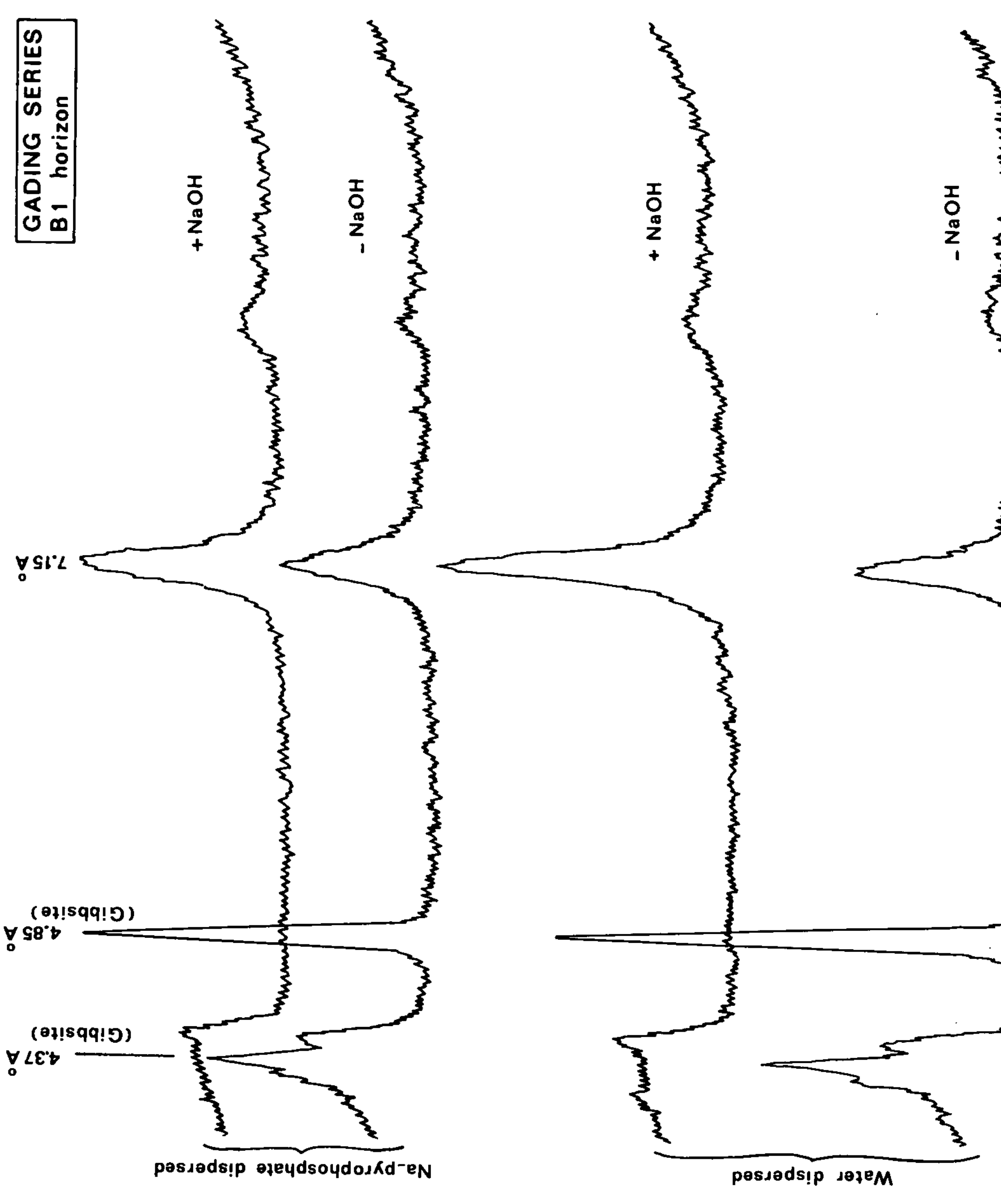


Fig. 21 *The effect of 0.5 N NaOH extraction on gibbsite as indicated by X-ray diffraction analysis*

Table 21. Comparison of SiO_2/Al_2O_3 mol. ratios for 0.5 N NaOH extracted materials and those for total clay fractions.

Soil series	Horizon	$\frac{SiO_2}{Al_2O_3}$ mol. ratios	
		0.5 N NaOH extract (NH_4OH dispersed)	Total clay (Na-pyrophosphate dispersed)
Tarat	A_1	2.11	1.97
	B_1	2.08	1.91
	B/C	2.11	1.93
	C	1.79	1.90
Gumbang	A_1	1.89	2.55
	B_1	1.71	1.97
	B_2	1.73	1.91
	B/C	1.81	1.70
	C	1.84	1.70
Serin	A_1	1.86	1.99
	A_2 (E)	2.09	1.93
	B_1	1.92	1.92
	B_2	1.57	1.93
	B/C	1.70	1.92
Semongok	A_1	2.66	2.91
	B_1	1.77	2.60
	B_2	1.71	2.59
	II B_2	1.71	2.47
	II B/C	1.89	2.51
Gading	A_1	0.81	1.43
	A_{12}	1.05	1.43
	B_1	0.92	1.44
	B_{21}	1.04	1.41
	B_{22}	0.93	1.45
	C	0.88	1.35
Nyalau	A_1	2.38	2.62
	A_2 (E)	1.83	2.34
	B_1	2.07	2.30
	B_2	2.02	2.25
	B/C	2.06	2.17

Plate 2 - *SEM photo (5000x) of clay sample from B_2 horizon (Nyalau series). Without 0.5 N NaOH treatment.*

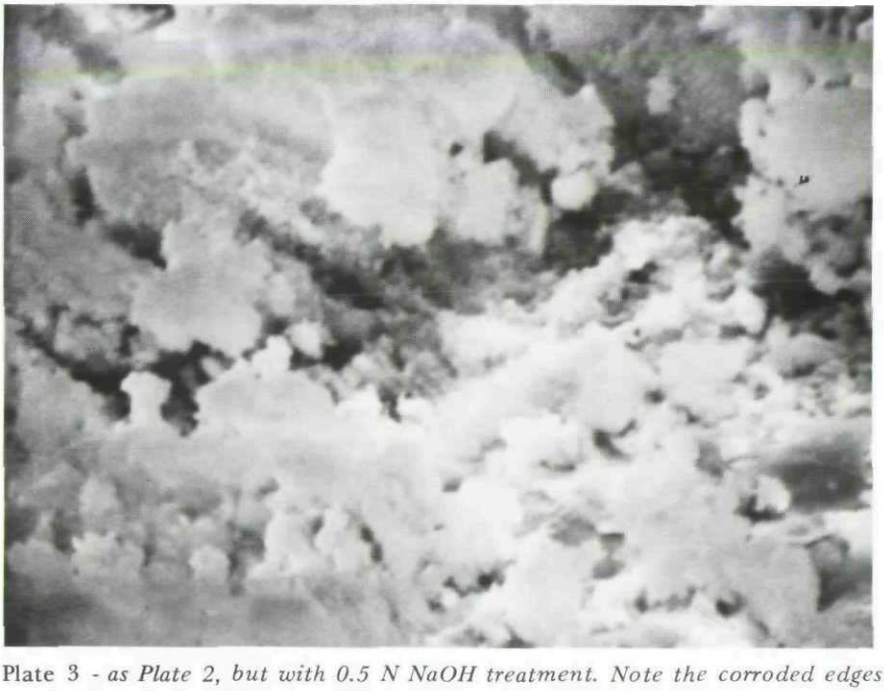


Plate 3 - *as Plate 2, but with 0.5 N NaOH treatment. Note the corroded edges of dominantly kaolinite.*

treatment can therefore be attributed to removal of halloysitic or poorly crystallized kaolinitic materials, gibbsite and partial removal of specific parts of the moderately well-crystallized kaolinite.

In summary one may conclude that the differential solubility test is difficult to use in practice if gibbsite and poorly crystallized kaolinite are present in appreciable amounts. Unless, it is the intention that also poorly crystallized kaolinite is to be regarded as 'stable allophane'.
Since it can be assumed that in the present soils the stable allophanic materials more or less adhere to the general formula of kaolinite, $Al_2Si_2O_5(OH)_4$ (Mohr et al, 1972) it may be possible to obtain an impression of the nature of the amorphous substances removed from clays not containing much gibbsite.
For this reason the molecular ratios for silica and alumina in the NaOH extracts have been calculated and these are shown in relation with those obtained for untreated clays in Table 21.

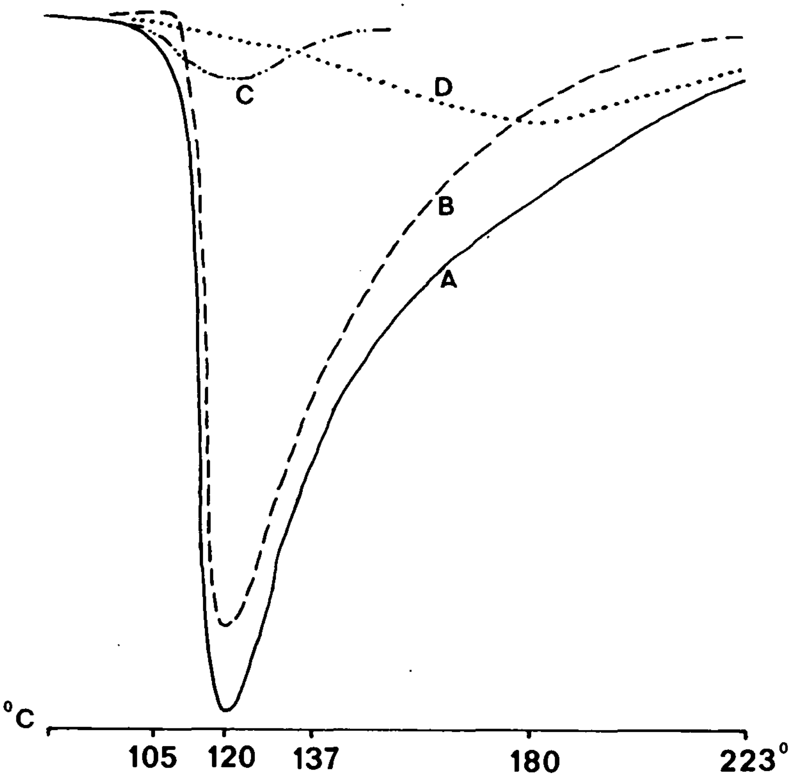
If the molecular ratio SiO_2/Al_2O_3 for kaolinite is taken to be 1.17, a deviation from this ratio in the 0.5 N NaOH extractions would then indicate whether either alumina or silica is present as discrete phases in the extracted materials.

From this table it can be concluded that for all soils, excepting the Gading in which the gibbsite content is well reflected in the low SiO_2/Al_2O_3 ratios, the relative high ratio values must be attributed to presence of more amorphous SiO_2 than amorphous Al_2O_3.
This is noteworthy so in the Semongok, Tarat and Nyalau soils but less distinctly so in the Gumbang and Serin soils but in the latter profile this could be due to presence of small amounts of gibbsite.

A differential thermal analysis is particularly useful for a study of amorphous materials in clays. Results of such analyses carried out according to procedures given in Appendix II have indicated that all soils show a large endothermic reaction in the low temperature range (110-170°C) which diminishes in intensity with depth.
However, the reason for these low temperature endothermic reactions is not immediately apparent, since they can be caused by absorbed water upon drying, allophane, silica gels and also 2-1 lattice minerals and halloysite. A detailed study was therefore done on the B_1 horizon of the Tarat profile, which is known to contain no 2-1 lattice clay minerals.

Fig. 22 illustrates that with the employment of a curve resolver the endothermic reaction can be divided up into three components, a small reaction in the 105-137°C range which is presumably caused by absorbed water on the sample upon storage, a strong reaction in the range 110-180°C which is interpreted as being caused by presence of the halloysitic materials (stable allophane?) and a weak reaction which extending over a wide temperature range from 120° to over 200°C is strongly suggestive to silica gel.
Fieldes (1955, 1966) gives an endothermic reaction at 170°C as an indication for presence of silica gel and in this sample the strongest endothermic reaction for this gel is also reached at 170°C.

By means of infra-red absorption analysis the presence of silica gel could be illustrated by a weak absorption in the range 958-960 cm^{-1} which as illustrated in Fig. 23 is indicative for silica gel. The low intensity of the absorption in this range by pure silica gel is reason why infra-red absorption analysis appears to be of little use if one deals with composite samples. The very weak absorption is easily overlooked in routine analyses.



A composite D.T.A. curve
B main component caused by adsorbed water on halloysite?
C subsidiary component „ „ „ „
D subsidiary component from 120°- 223° caused by silica gels

Fig. 22 *Components of the composite low endothermic reaction in D.T.A. of the* B_1 *horizon in Tarat profile*

From these investigations one may conclude that silica gel forms the major part of the amorphous substances present in the studied soils.

D.T.A. would indicate that generally amorphous materials decrease with depth. This cannot be proven by the NaOH extractions and calculated SiO_2/Al_2O_3 ratios of the extracts obtained, with the probable exception of topsoils.

Extracted alumina from gibbsite and kaolinite sources do influence the ratios too much to enable a valid interpretation.

3. Genetic implications of the results of the mineralogical studies

The mineralogical studies on the selected profiles have indicated that the amounts of weatherable minerals in the sand and silt fractions are exceedingly small to nil. Orthoclase, biotite and bleached biotite appear to be the only weatherable primary minerals still present as traces in the Gading, Nyalau and Serin series, the exception being the C horizon of the Gading which still contains relatively moderate amounts of these minerals. The Tarat series is the only profile in which traces of hornblende and chlorite are still present in the C horizon.

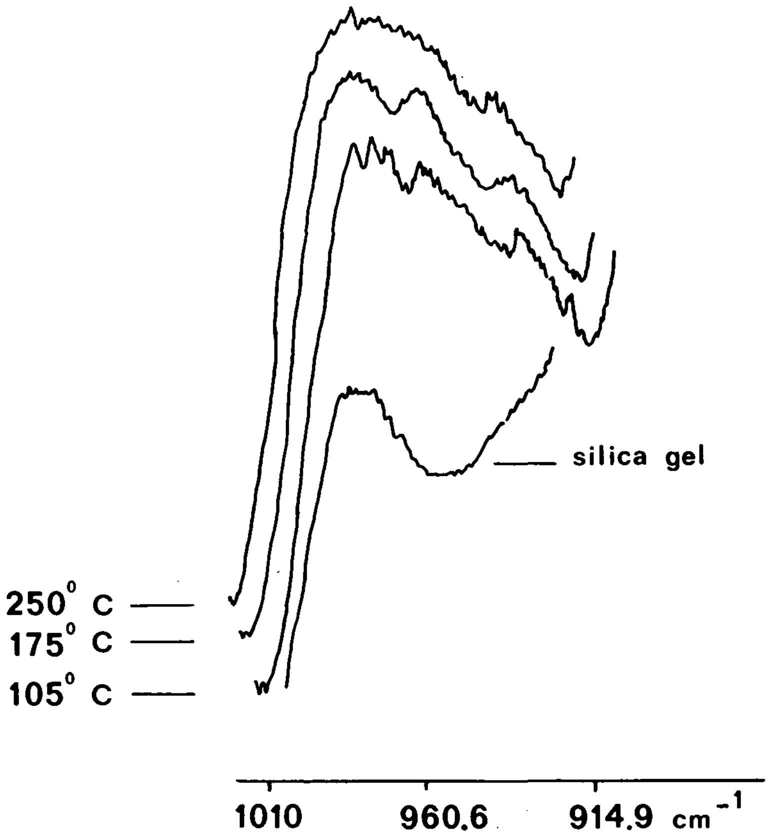


Fig. 23 *Silica gel absorption in Infrared absorption analysis of the B_1 horizon in the Tarat profile*

Quartz and ore minerals are in the Serin, Semongok, Gading and Nyalau series virtually the only rock-inhereted minerals left and they form the bulk of the sand and silt fractions. This is also the case in the Tarat and Gumbang series but in these profiles a considerable proportion of the sand and silt is formed by secondary minerals of which goethite and amorphous compounds appear to be dominant.

It is still open to question whether the quartz in the Tarat series must be considered as rock-derived since the parent rock, a basalt, would contain no primary quartz as is also indicated by the normative analyses given in Table 6.

The absence or near-absence of weatherable primary minerals in all soils gives little clue to their relative stage in weathering. It however implies that all soils are highly weathered.

The 7th Approximation of the taxonomic soils classification of the USDA (Soil Survey Staff, 1960, 1967, 1970) recognizes the fact that clay minerals form part of the weatherable material but in the criteria laid down for the presence or non-presence of a cambic horizon it restricts this to only the 2-1 lattice clays. This is probably a consequence of the reasoning that presence of 2-1 lattice clays also implies a change in other important characteristics of a soil such as cation exchange capacity, swelling and base saturation but it is essentially wrong to assume that 1-1 lattice clays are not forming a weatherable part of the soil, although they might be more stable than the 2-1 lattice clays.

Gastuche et al (1954) already indicated that weathering of small crystals of kaolinite can lead to rolling-up, similar to that of halloysite. This may be the cause for the strong halloysitic tendencies of the kaolinitic materials in the Tarat profile. Jackson (1956) also recognizes the presence of stable allophane, this being relict material of weathered kaolinitic materials. Oberlin et al (1957) showed that disordered kaolinite (fire-clays) can form through attack by sulfuric acid of a pH 2, while Millot (1970) contends that in a lateritic process in which drainage increases and the water table is lowered desilification of kaolin occurs and it is transformed into gibbsite.

However when adhering to the basic assumption of the 7th Approximation (op cit) then only in the Semongok, Nyalau and Serin series part of the clay fraction must be considered as weatherable. This is in the Semongok a considerable proportion of the soil because the clay content is high, less so in the Nyalau and least in the Serin in which the content of 2-1 lattice clays is fairly low although the clay content is high. The 2-1 lattice clays in these profiles are mainly interstratified or mixed-layer clays in which vermiculite and illite with vermiculite layers dominate. As is indicated by the 1.50 Å spacings of the 060 reflections all interstratified clays appear to be dioctahedral (Jackson, 1956) and they can be considered as degraded clay minerals in the range mica-illite-vermiculite-montmorillonite (Millot, 1970).

The absence of montmorillonite in the clays is noteworthy since it infers that the final step in this transition range is not reached. The montmorillonitic minerals indicated as being present in the silt fractions in the Semongok, Nyalau and Serin series are most probably indicative to starting interlayering in the mica-sericite minerals which could give rise to reflections for 18.5 to 19 Å spacings.

The presence of 2-1 lattice clays in the Semongok, Nyalau and Serin series is not manifest to a less advanced weathering stage than is reached by the other soils but is solely a function of the parent material. Micaceous materials are only present in the parent rocks of the Semongok, Nyalau and Serin series and the 2-1 lattice clays are therefore not neoformations from silica and alumina present in the soil solution but are transformations of the originally present micas. Most probably vermiculite is the most advanced stage in this weathering cycle and the montmorillonite stage is never reached. It is suggested that absence of magnesium may be one of the reasons why montmorillonite is not formed and that upon weathering of the vermiculite possibly neoformation of kaolinite takes place from the alumina and silica present in the soil solution. The decrease of interstratified materials towards the surface of the soil is noticeable in the intensity of the X-ray reflections and this may imply such a breakdown. The absence of 2-1 lattice clay minerals in the Tarat and Gumbang series demonstrates that for their formation in the prevailing conditions they are dependent on the nature of the parent rock. In the Gading which only contains biotite and no muscovite or sericite probably no 2-1 lattice clays are formed through transformation of biotite because this mineral is completely hydrolysed.

Excepting the kaolinitic material present in the Tarat series which shows halloysitic tendencies, all other kaolinites show a poorly to moderately well-crystallized character. They are most likely b-axis disordered as may be illustrated by the large broad peak sloping down from the 4.45 Å reflection (Brown, 1961) which, if following Millots trend of thought, would indicate degradation of kaolinite.
The 0.5 N NaOH extractions have indicated that particularly in the Tarat series much of the kaolinitic materials can be removed which would imply a very unstable character of these materials. Presumably in the Tarat series presence of halloysite does not indicate a juvenile stage in soil development but rather the reverse.

The Gading profile shows in the clay fraction a relative high content of gibbsite, the Gumbang less so, while only traces were found in the Serin and Tarat series. A comparison with the silt fractions learns that specifically in the Gading appreciable amounts of gibbsite are present in the larger fraction.

A mineralogical examination of the weathered adamellite indicates that considerable quantities of gibbsite are formed upon hydrolysis of the plagioclase and orthoclase (the former being slightly more common in the rock than the latter). The experimental studies by Wollast (1967) on the mechanism of hydrolysis of orthoclase have indicated that in the initial stages $Al(OH)_3$ is rapidly precipitated forming a protective surface on the feldspar. Berner (1971) basing his suggestions on this work contends that in an open system where silica-free water is continuously supplied, silica is constantly removed from the weathering minerals as H_4SiO_4, and gibbsite will be the end result of this feldspar weathering. At lower rates of flow, kaolinite would form because of higher H_4SiO_4 concentrations while at still lower flow rates montmorillonite would form providing that sufficient magnesium is present. The free draining environment of the Gading profile would induce such a formation of gibbsite and kaolinite.
However, the contention of Harrison (1934) is that under humid tropical conditions gibbsite would mainly form from plagioclase and in his petrografic studies he never detected gibbsite as an alteration product of orthoclase. It is therefore possible that gibbsite in the Gading is mainly formed from the plagioclase, while the orthoclase would give rise to the formation of kaolinite. If this is the case it would be reasonable to expect higher gibbsite contents in the Tarat and Gumbang profiles which parent rocks have a much higher plagioclase content while environmental conditions are similar to that of the Gading. These profiles however have a much lower content of gibbsite. This would favour the experimental results obtained by Wollast (op cit). A possible explanation may be that climatic conditions are dissimilar. Although Harrisons study (op cit) is allegedly relevant for humid tropical conditions, the area studied by him has a pronounced dry season, so that the leaching

regime must be decidedly different from that in Sarawak. Another factor playing a role is that, although the adamellite of the Gading series has the highest SiO_2 content of the three parent rocks involved (see Table 6), a large proportion of the SiO_2 is present as quartz which, as was shown by the sand mineralogy, appears to be very resistent to weathering. Therefore the basalt, although chemically being the least siliceous rock would give upon weathering the highest concentrations of H_4SiO_4 in the soil water since most silica present is easily soluble.
Such conditions would result in a relative undersaturation of silica in the soil water of the Gading through which formation of kaolinite is limited, while the relative oversaturation of $Al(OH)_3$ would result in formation of gibbsite. Such reasoning would also explain the lower gibbsite contents on the Serin and Gumbang series. Under free draining conditions therefore the nature of the parent material, and specifically whether silica is present as quartz or bound in weatherable silicates, has a confound influence on the type of secondary minerals formed upon weathering. A highly siliceous nature of a parent rock is therefore not a prerequisite for a highly siliceous nature of the soil water.

The possibility that neoformation of gibbsite could take place upon weathering of the kaolinite and that kaolinite could reform in the lower horizons after removal of the weathered components from kaolinitic materials in the surface horizons cannot be discounted. These possibilities are however strongly dependent on the solubility of the aluminium and silica and means of transport through the solum. The presence of silica gels in the amorphous materials of particularly topsoils and the absence of a relative increase of gibbsitic materials in the surface horizons would indicate a rather selective removal of $Al(OH)_3$. Since these aspects cannot be studied by mineralogy alone, a discussion on such processes is given in the chapter on the chemical studies (III.B).
Fig. 24 tries to illustrate in a diagrammatic form the various neoformations and transformations of clay minerals which based upon the mineralogical studies can be expected to play a role in the formation of the studied soils.

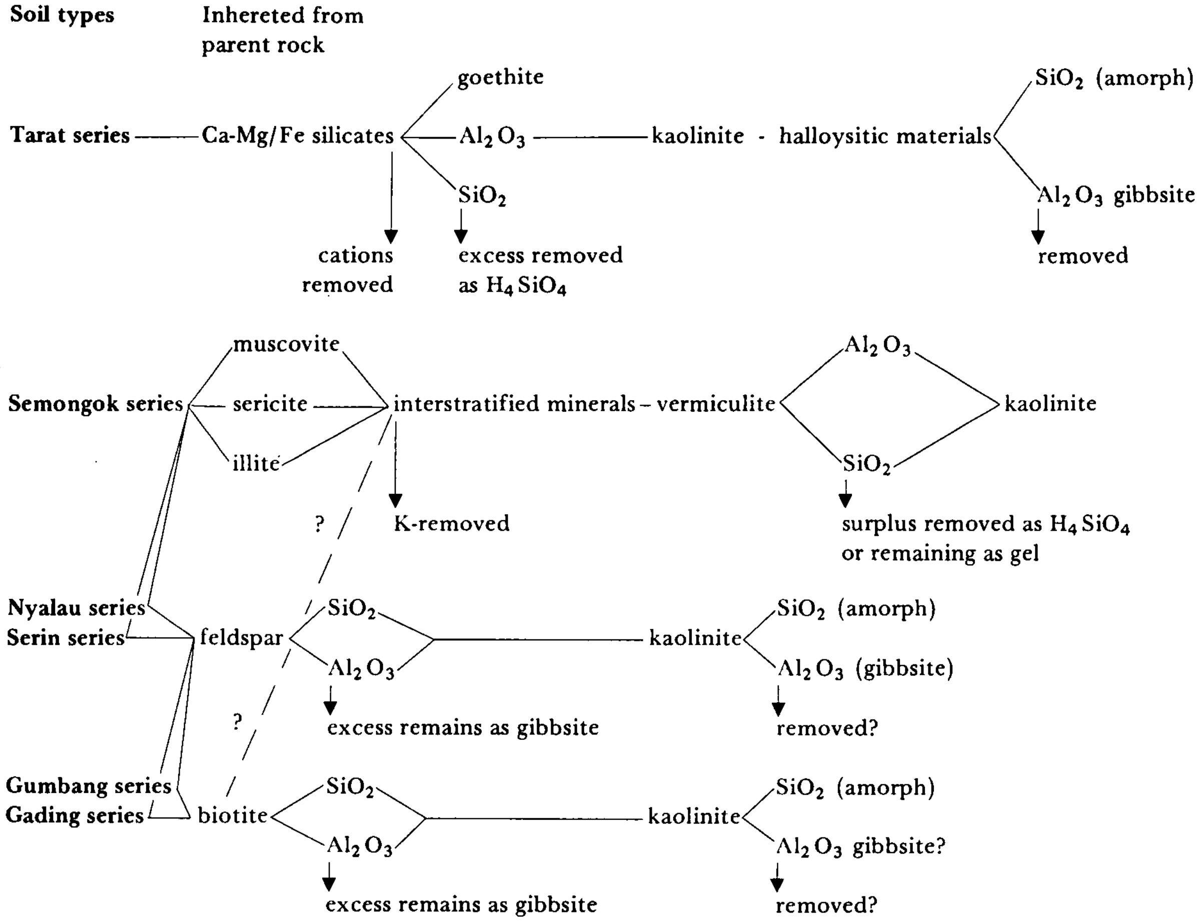


Fig. 24 *Schematic presentation of suggested transformations and neoformations of clay minerals in main upland soils of West Sarawak*

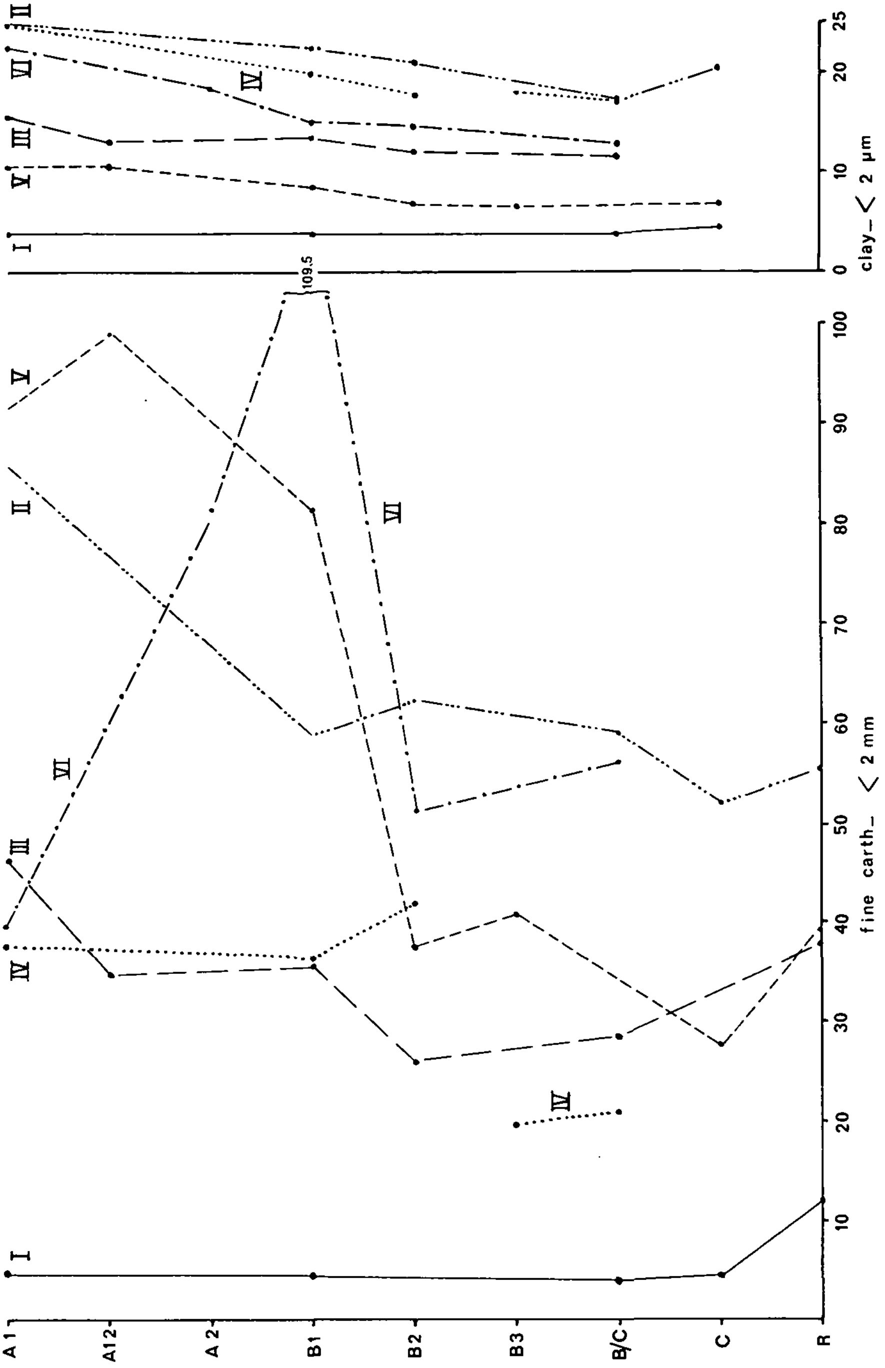


Fig. 25 *SiO_2/Fe_2O_3 molar ratios in fine earth and clay fraction of I (Tarat), II (Gumbang), III (Serin), IV (Semongok), V (Gading) and VI (Nyalau) series.*

B. The Chemical Composition

1. Introduction

The total chemical composition (macro elements only) was determined separately for the fine earth and the clay fraction. For the latter, fractions were used dispersed with Na-pyrophosphate/Na_2CO_3, without H_2O_2 treatment. The analyses were carried out by X-ray fluorescence using the standardized inert dilution method developed by Mege (1969) and Tertian and Geninasca (1971). Details of the analytical procedures are given in Appendix II. Information on the chemical composition of the Butan series was extracted from a former study (Andriesse, 1972); the total chemical analyses of this profile have been carried out by wet digestion, whereas the clay fractions had been separated by NaOH dispersion and $MgCl_2$ flocculation.

To investigate the forms and distribution of the iron and aluminium compounds, selective extractions for total free oxides, amorphous forms and organic-complexed forms for both iron and aluminium were carried out on the fine earth of all soils, excepting the Butan series. The methods used are outlined in detail in Appendix II.

In addition water-soluble silicon, aluminium and iron were determined.

2. The total chemical composition

The results of these analyses are shown for each profile in Appendix I, together with the derived molar ratios for SiO_2/Fe_2O_3, SiO_2/Al_2O_3, SiO_2/R_2O_3 and Al_2O_3/Fe_2O_3. In the following discussion the emphasis will be on these ratios since their values can give important clues to soil forming processes operating in the studied profiles.

Values for total CaO and total K_2O are extremely low and although MgO was not determined, from previous studies on these soils (Andriesse, 1972) it is known that also this oxide in no profile exceeds a content of 1%. These low figures corroborate the findings of the mineralogical studies that all soils are highly weathered and leached. The relative larger content of K_2O in the clay fractions of specifically the Semongok series and to a smaller extent of the Serin and Nyalau profiles are a direct consequence of the presence of interstratified illite/vermiculite minerals.

Although it is common usage to show diagrammatically all the silica-sesquioxide ratios profile by profile, in this study each ratio is shown separately for all profiles together in Figures 25 to 27.
This facilitates the making of comparisons between profiles in the sequence on each specific ratio.

In Fig. 25, showing the derived molar ratios for SiO_2/Fe_2O_3, it is apparent that rock weathering results in all soils for which the composition of the parent rock is known, in an initial decrease in this ratio. This is clearly illustrated by the change from R to C or B/C horizon. Therefore, weathering is characterized by an initial

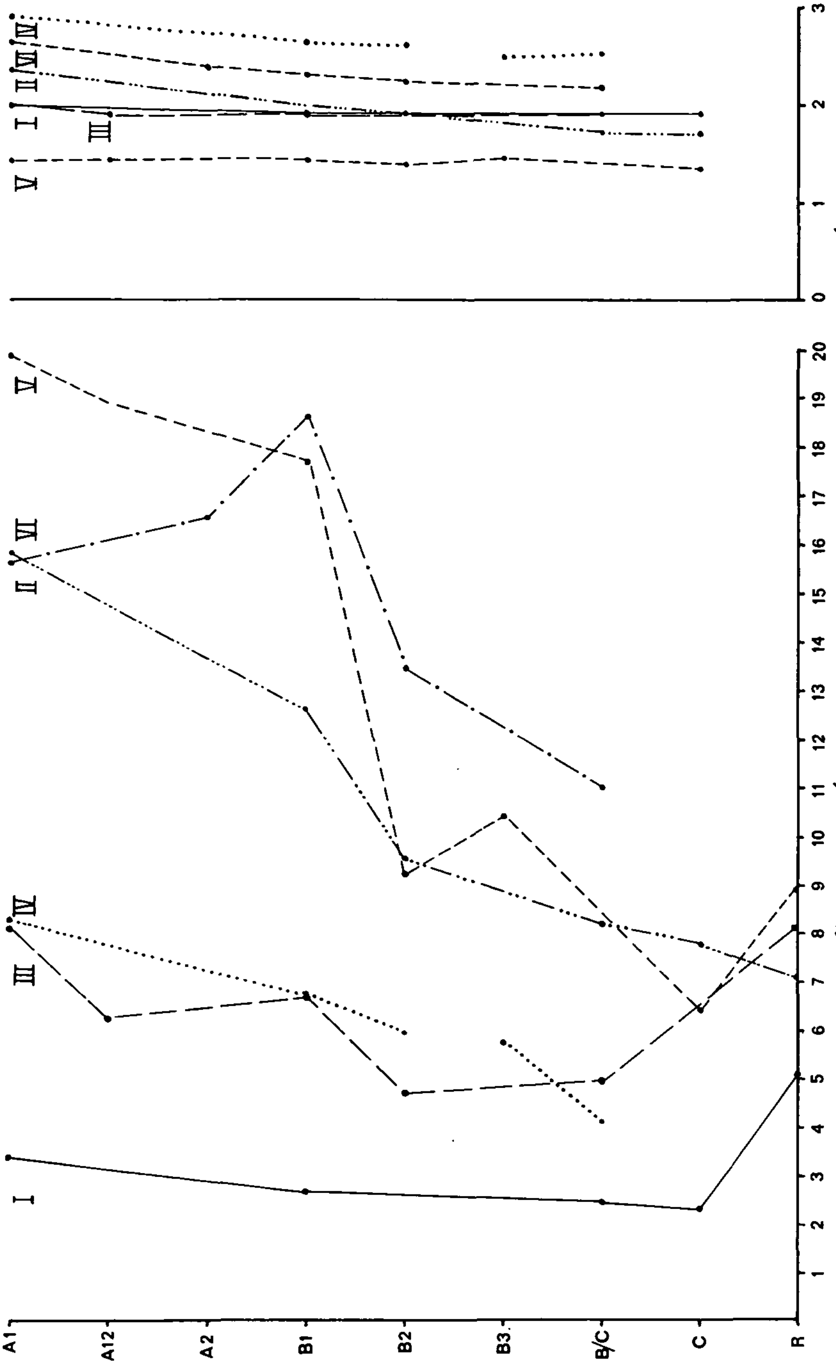


Fig. 26 *SiO_2/Al_2O_3 molar ratios in fine earth and clay fraction of I (Tarat), II (Gumbang), III (Serin), IV (Semongok), V (Gading) and VI (Nyalau) series.*

desilication process (Mohr et al, 1972). In the upper horizons the ratios increase again and this process is reversed. This increase is in some profiles very modest such as in the Tarat and Semongok profiles, in others it is very strong, such as in the Gading and Nyalau profiles. The decrease again of this ratio in the A horizon of the Nyalau, largely due to a strong increase in Fe_2O_3, is difficult to explain. Most likely iron-rich material from upslope has been deposited at the site of the Nyalau profile. However, since the ratios of the clay fraction do not show this behaviour it is assumed that this decrease is not of genetic significance.
The gradual diminishing content of Fe_2O_3 in the upper horizons of all profiles is well illustrated by the molar ratios of the clay fractions, excepting the Tarat series.

This general trend of initial desilication and thereafter a relative increase in silica appears to be most strongly present in the profiles having a more sandy texture, thus the Nyalau and the Gadang series, which are also the end members of the sequence studied. The true Podzol represented by the Butan series shows in the analyses an almost complete removal of iron (see Appendix I).

Fig. 26 showing the SiO_2/Al_2O_3 ratios, illustrates a much similar behaviour for aluminium: an initial relative increase upon rock weathering and thereafter impoverishment in the upper horizons. The abnormal distribution of alumina and silica in the upper horizon of the Nyalau profile is apparent also in this diagram and as has been indicated this is probably due to addition of foreign material in the surface horizon.
The lowering of alumina content generally observable in the surface horizons of all profiles is, as is the case with iron, strongest in the Nyalau and Gading series and comparatively least so in the Tarat series.
A comparison made between the SiO_2/Fe_2O_3 and SiO_2/Al_2O_3 ratios of the clay fractions, the most mobile part of the soil, learns that although iron and aluminium show a similar behaviour, iron is probably stronger leached or removed from the surface horizons than aluminium. This may be caused by the fact that iron is mostly present as free oxides whereas most of the aluminium is bound in the alumina-silicates, the clay minerals, which would need destruction prior to the removal of aluminium from the horizon. Also aluminium present as free alumina is less mobile than free iron oxides, as its solubility at a certain pH is not affected by possible changes in redox potentials (Segalen, 1973). Whether the apparent enrichment of sesquioxides in the C and B/C horizon is due to removal of sesquioxides from the upper horizons and subsequent accumulation in the C and B/C horizons, thus absolute enrichment, or whether the enrichment is caused by a relative increase due to an initial desilication process only, is difficult to prove. This aspect can only be properly investigated by studying the mobility of the various iron and aluminium forms present in the profile and will therefore be discussed in detail in the relevant sections (III.B.3 and 4).
Fig. 27 illustrates that the distribution of iron and aluminium in the fine earth is rather erratic. This is logical because the distribution of these elements over the various fractions is rather variable. The ratios of Al_2O_3/Fe_3O_3 for the clay fractions indicate that the iron probably moves downward preferentially over aluminium in all profiles indeed, and most strongly so in the Gading and Nyalau profiles and least in the Tarat profile. As indicated this is probably mainly caused by the difference in mobility.

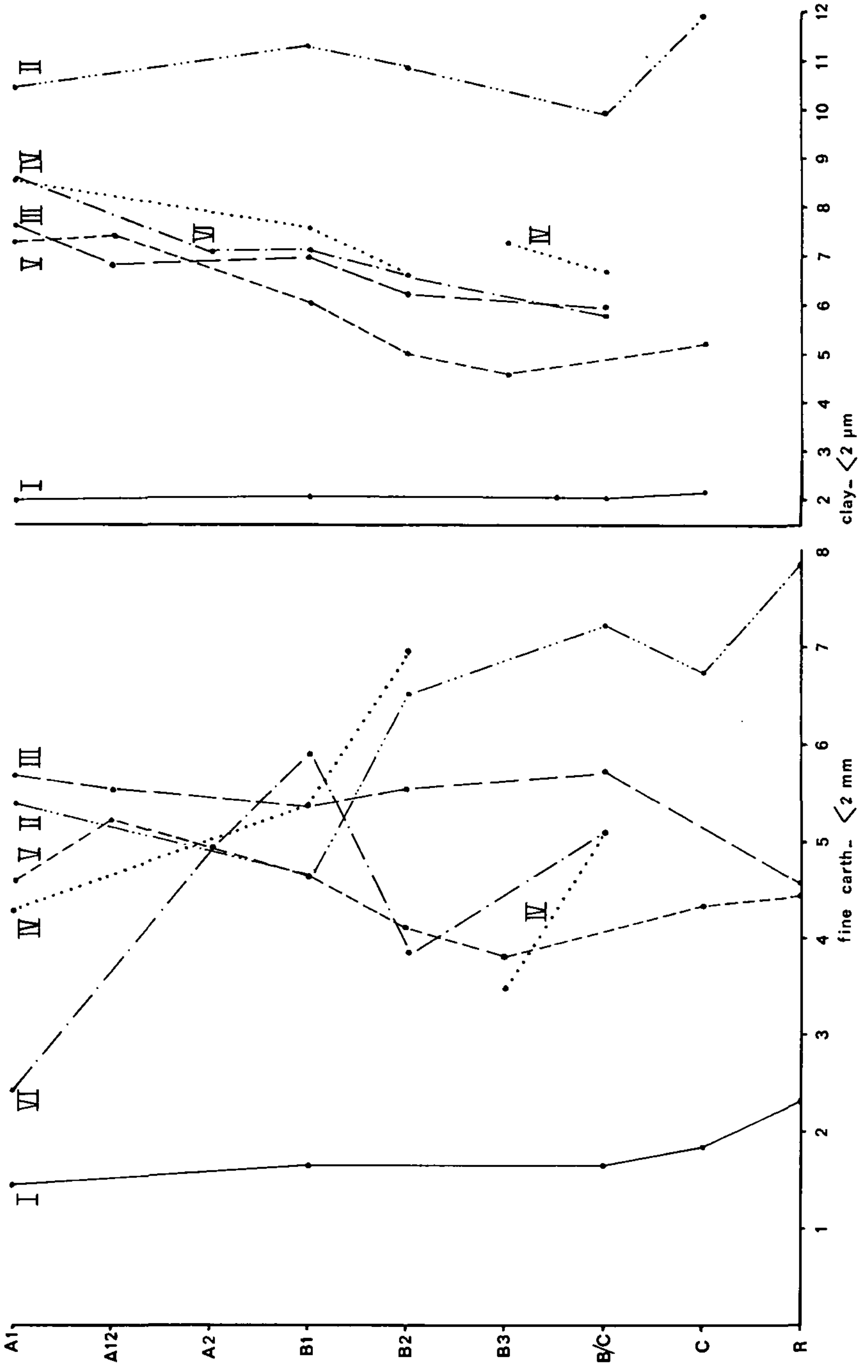


Fig. 27 *Al_2O_3/Fe_2O_3 molar ratios in fine earth and clay fraction of I (Tarat), II (Gumbang), III (Serin), IV (Semongok), V (Gading) and VI (Nyalau) series.*

Although the sequence of soils was initially put in the order of increasing SiO_2 content of the parent rocks, this order is not maintained in the SiO_2/sesquioxide ratios as illustrated in the diagrams.
This brings to the fore an important characteristic of parent materials, namely the relative proportions of SiO_2 present as quartz and that present as weatherable silicates.

The SiO_2 present in the mudstones of the Semongok series is mainly bound in clay minerals whereas in the sandstones of the Nyalau series it is mainly present as quartz or chalcedony. The mobility of the SiO_2 is therefore strongly dependent on the mineralogy of the parent rock and for this reason the chemical composition or acidity or SiO_2 content of the parent rock is not a correct parameter to classify rocks as parent materials of soils if the mode of occurrence is not included also.

The present study indicates that rocks containing a large amount of free SiO_2 in the form of quartz give rise to the formation of soils with a decidedly more coarse texture. The comparative high resistency to weathering of quartz will play an important role in the internal drainage of the soil and particularly the leaching rate, and concentrations of liberated silica, alumina and iron will be highly affected.

The pedological significance of TiO_2 distribution in soil profiles was commented upon by Joffe and Pugh (1934), by Karim (1953) in his studies on South-Australian soils and by Mohr et al (1972). Titanic oxide is allegedly more stabile than other oxides present in the soil although removal as complexed humates cannot be discounted. The distribution of TiO_2 would thus provide indications on relative losses in, or accumulations of other components, particularly SiO_2, Al_2O_3 or Fe_2O_3.
The values for TiO_2 for all profiles have been brought together in Table 22 in which the TiO_2 for both the fine earth and clay fraction has been recalculated in percentage of at 1000°C ignited material. The total chemical composition shows because of the presence of organic matter in the materials analyzed relative large losses for dispelled water, CO_2 and NO_3. The absolute values for TiO_2 are therefore affected also. Corrected values are necessary if the TiO_2 content is to be used as a reference value for judging removal or addition of other materials.

The absolute values for TiO_2 are very much a reflection of TiO_2 content of the parent rocks, these being highest for the basalt. The absolute values for TiO_2 in the clays appear to be also highly influenced by the initial grain size of titanium containing minerals.
For instance, both the quartz andesite of the Gumbang series and the adamellite of the Gading series contain 0.55 % TiO_2. TiO_2 in the quartz andesite is mainly present as ilmenite of silt and sand size as evidenced by the sand mineralogy whereas the titanium in the Gading is probably mainly present as very small rutile needles in the biotite and subordinately as larger size ilmenite. This is well reflected in the high values for TiO_2 in the clay fraction of the Gading series and the higher values in the total fine earth fraction of the Gumbang series.

The absolute values are therefore not very significant since their differences are not due to pedogenetic processes; for this we have to look for changes within the profile.

Table 22. TiO_2 contents of fine earth and clay fractions of main upland soils in West Sarawak.

Soil series	Horizon	TiO_2 in % of at 1000° C ignited material	
		fine earth <2 mm	clay <2 μm
Tarat	A_1	3.97	3.56
	B_1	3.10	3.79
	B/C	3.26	3.76
	C	3.33	3.70
	R	1.38	
Gumbang	A_2	0.90	0.35
	B_1	0.91	0.32
	B_2	0.81	0.28
	B/C	0.80	0.28
	C	0.65	0.26
	R	0.40	
Serin	A_1	0.80	1.32
	A_2 (E)	0.87	1.22
	B_1	0.80	1.26
	B_2	1.04	1.19
	B/C	0.99	1.25
	R	0.55	
Semongok	A_1	1.17	1.59
	B_1	1.27	1.62
	B_2	1.26	1.60
	II B_2	1.27	1.59
	II B/C	1.25	1.40
	R	0.99	
Gading	A_1	0.52	2.27
	A_{12}	0.46	2.23
	B_1	0.49	2.16
	B_{21}	0.80	2.04
	B_{22}	0.66	2.03
Nyalau	A_1	0.64	1.19
	A_2 (E)	0.53	1.17
	B_1	0.42	1.22
	B_2	0.55	1.16
	B/C	0.55	1.12
Butan	A_1	0.21	n.d.
	A_{12}	0.27	n.d.
	A_2 (E)	0.16	n.d.
	B_{1h}	0.42	n.d.
	B_{12}	0.31	n.d.
	B_2	0.27	n.d.
	II C	0.42	n.d.

The fine earth shows a very considerable increase in TiO_2 from R to C or B/C horizon, ranging from nearly 200% in the Gumbang, Serin and Gading series to 250% in the Tarat series. Since, as has been indicated, also iron and aluminium increase, a desilication process must be considered responsible for these large changes.

Turning now to the TiO_2 values of the clay fractions, the materials containing the most mobile components, a general decrease in TiO_2 downwards is apparent in all soils. Some profiles, the Tarat, Serin and Semongok, show again a lower content in the A_1 horizon. This gradual decrease downward the profile would indicate a general removal of other materials from the clay fractions in the surface horizon which as indicated by the SiO_2/sesquioxide ratios must be iron and aluminium, but it would also indicate that little or none accumulation in the clay fraction would take place in the lower horizons. Since, assuming that no clay illuviation takes place, accumulations of other components of clay size in lower horizons would show a correspondent decrease in TiO_2. This is nowhere the case. The decrease in TiO_2 content in some A_1 horizons may indicate that indeed TiO_2 could be removed there, possibly in an organic complexed form because this is, as indicated by Mohr et al (1972), the only likely process to stimulate dissolution of titanium.

The titanium contents of the fine earth do not follow the same trend as found in those for the clay fraction. Although the differences between the various horizons are small, the changes follow an erratic pattern, possibly due to either washed-in material of sand and silt size which was frequently observed in the soils during fieldstudies so that the titanium content of the fine earth as a whole is affected, or analytical error may be responsible. Since the analytical error does not appear to disguise the observed trend in the values obtained for the clay fraction it is most likely that transport of coarse material through rootchannels is causing this erratic distribution pattern. No significance can therefore be attached to the obtained analytical results. Ahmad and Sim (in press) do indicate that in Sarawak soils titania contents are strongly dependent on mechanical distribution of particle sizes and our findings would corroborate this.

In any case, the observation can be made that the use of titania contents of fine earth fractions in genetic studies must be viewed with reserve.

Also, Mohr et al (1972) when referring to an apparent accumulation of titanium in the lower horizons of a podzolic profile, based on chemical composition of the fine earth fraction, had difficulty in explaining this feature.

It is quite clear from these studies that the distribution of titania in the various soils is much more complicated than has hitherto been indicated and that the use of titania contents as bench mark values for probable addition or removal of other soil components cannot be satisfactory unless adequate attention is given to also particle size distribution, the fate of the clay size fraction and titania content for each fraction separately.

3. Selective iron and aluminium extractions

3.1. Introduction

During the last decade much attention has been given to the study of the nature and amounts of secondary iron and aluminium forms in soils, with the aim to relate these to soil forming processes and classification. Schwertmann (1959) revived the

well-known Tamm's method of extracting amorphous iron with ammonium-oxalate and, after modification, the method has been successfully used by Schwertmann (1964), McKeague and Day (1966) and by Blume and Schwertmann (1969) to differentiate amorphous secondary iron from total secondary or free iron as extracted by dithionite-citrate-bicarbonate. The difference between the two obtained values being the finely divided crystalline oxides.
The ratio of Fe_o (oxalate extractable) and Fe_d (dithionite extractable) has been used by Blume and Schwertmann (op cit) as a relative measure of the degree of ageing or crystallinity of free iron oxides and is therefore called the 'activity ratio', or Fe_o/Fe_d ratio. This ratio was applied with success to differentiate between main soil horizons in some soils of Germany.
It should be remarked that it has been subsequently found that the oxalate extraction appears to remove also appreciable amounts of Fe from magnetite (Baril and Bitton, 1967) and the usefulness of this ratio for soils rich in this mineral is therefore greatly diminished.

McKeague (1966) and Bascomb (1968) contributed to this new development by suggesting it necessary to make distinction between inorganic amorphous iron compounds and those of organic complexed nature since certain soils such as volcanic ash soils and some prominently mottled cambic horizons contain high amounts of amorphous inorganic Fe, while in spodic horizons the Fe is usually associated with organic matter. The oxalate extraction is unable to make distinction between the two. They tested the use of pyrophosphate extractions for organic complexed amorphous iron forms with success on a number of Canadian soils and suggested that the difference between Fe_o and Fe_p (pyrophosphate extractable) would be a good measure of amorphous inorganic Fe.

Also Bascomb (1968) found that K-pyrophosphate extracted organic iron and amorphous iron oxides, if not aged. Apparently, as a result of these findings Ball and Beaumont (1972) regard the Fe_p as the mobile fraction while they infer that the Fe_o fraction is immobile, this representing the aged hydrous oxides accumulated in situ.

In more recent investigations McKeague et al (1971) presented evidence that oxalate extractable iron is not so specifically anorganic but that it also contains part of the organic complexed iron, namely the Fe-fulvic acid complexes.

Studies by Alexandrova et al (1968) indicate that a distinction must be made between the various organo-mineral components in soils. Apparently, the humic acids and their mineral complexes are less soluble and less dispersible than the fulvic acids and their mineral complexes.

As a consequence of this Fe_p cannot be regarded as being truly representative for the mobile iron as was suggested by Ball and Beaumont (op cit)

On account of the fore-going review the various iron forms present in soils can be listed as follows:

a. silicate bound iron and compound metal oxides such as ilmenite
b. crystalline free iron oxides, mainly goethite and hematite
c. amorphous hydrous iron oxides-aged gels
d. fulvic acid complexed iron ('mobile fraction')
e. humic acid complexed iron
f. magnetite.

The listed iron forms are more or less selectively extracted from the soils as follows:

Fe_t - a,b,c,d,e,f
Fe_d - b,c,d,e, and small amounts of f
Fe_o - c,d, and partly f
Fe_p - d,e.

The observation should be made that investigations by v.d. Giessen (1966) have revealed that the difference between aged gels and the crystalline forms is in fact nothing else than crystallinity grade or crystal size. The aged gels or amorphous iron oxides appear to have a micro-crystallinity as could be shown by electron microscopy. It is therefore suggested that this difference probably also applies to the forms b. and c. in the list given above.

Although existing selective iron extractions have sofar been mainly conducted with temperate soils, the proposed chemical methods appear sufficiently realistic to investigate also the podsolic nature of the sequence of soils presently studied.

For this the fine earth fraction ($\langle$2 mm) was crushed to a particle size of less than 150 μm. Dithionite extraction was carried out according to Mehra and Jackson (1960), ammonium oxalate/oxalic acid extraction by using the method proposed by McKeague and Day (1966) and the sodium pyrophosphate extraction according to the method outlined by McKeague (1967).
Iron and aluminium in the extracts were measured by atomic absorption spectrophotometry (A.A.S.) for which a Techtron, type A.A. 4 was employed. Full particulars of the methods used can be found in Appendix II.

3.2. Results of the iron extraction

The results for the various extractable forms of iron are given in Table 23 but before discussing their implications some comments on the obtained values are necessary.
Differences between total iron (Fe_t) and dithionite extractable iron (Fe_d) are a fair measure for presence of silicatbound iron and may be used as a parameter to weathering stage (Blume and Schwertmann, 1969).
The obtained values are in general agreement with the mineralogical observations but Fe_d is considered to be too low since the difference between Fe_t and Fe_d appears to be higher than is to be expected from the mineralogy, there being hardly any primary minerals containing iron present. It is known that the extractability of Fe from goethite and hematite by dithionite is strongly dependent on particle size (McKeague et al, 1971) and despite the fact that all samples were ground to pass a 150 μm sieve there is still the possibility that this fraction is still of too large a size for complete removal of the pedogenetic iron by the method advocated by Mehra

and Jackson (1969). Tests in this laboratory have also indicated that the crucial extraction temperature of 80°C is difficult to maintain and that small deviations from this temperature result in considerable lower extracted iron.
In general, at a temperature of 77°C (the temperature used) an extraction of 75% was achieved for all profiles but the Tarat. In samples containing appreciable amounts of free iron the absolute error may therefore be large. This may well account for the unexpected large absolute differences between Fe_t and Fe_d, particularly in the Tarat series and subsoils of the Semongok series since these samples contain the highest amounts of total iron of all studied profiles and part of the iron is present in a concretionary form. The negative value for Fe_t - Fe_d in the A_{12} horizon of the Gading is probably due to an analytical error.

The Fe_d but particularly the Fe_o (oxalate extractable iron) of the Gumbang series may be influenced by the high magnetite content since both extractants remove Fe from magnetite (Baril and Bitton, 1966; Gamble and Daniels, 1972) and the sand mineralogy has indicated that this mineral is an important component in this profile.

The topsoil of the Nyalau series is probably contaminated with eroded material from upslope areas because of the anomalous high Fe_t content. This probability is also suggested by the anomalous change in the SiO_2/Fe_2O_3 and SiO_2/Al_2O_3 ratios in the topsoil of this profile (section III.B.2.).

The Fe_p (pyrophosphate extractable iron) of surface horizons appears to be generally higher than Fe_o, exceptions being the Gumbang and Tarat series. For the Gümbang this may be explained by the fact that Fe_o is high because of the high magnetite content. In the Tarat series the difference may be of genetic importance. In the Semongok and Gading series the higher Fe_p than Fe_o trend persists too well into the B horizon.

In soils studied sofar by Bascomb (1968), McKeague and co-workers (1971) and Ball and Beaumont (1972) the pyrophosphate extractable iron was always lower than the oxalate extractable iron. This is probably a characteristic of the soils used by them which were all from temperate regions. In the present soils the reverse is more rule than exception.

3.3. *Genetic implications of the results of the selective iron extractions*

Based on the results of the iron extractions given in Table 23, depth functions of the various iron forms and derived ratios were prepared. These are depicted in Figs 28a and 28b. The following observations can be made.

Fe_t - Fe_d is an indication of weathering stage of the soil unless high amounts of magnetite and ilmenite are present. In the selected soils Fe_d amounts to 75% or more of the total iron which corroborates earlier mineralogical investigations that all soils are thoroughly weathered.

Fe_d increases with depth in all profiles while the amounts of Fe_o and Fe_p decrease which indicates that degree of crystallinity of iron oxides increases with depth. This is also shown by the decreasing 'iron activity' ratios (Fe_o/Fe_d) which according to

Table 23. Extractable, exchangeable and total iron in major Sarawak Upland soils.

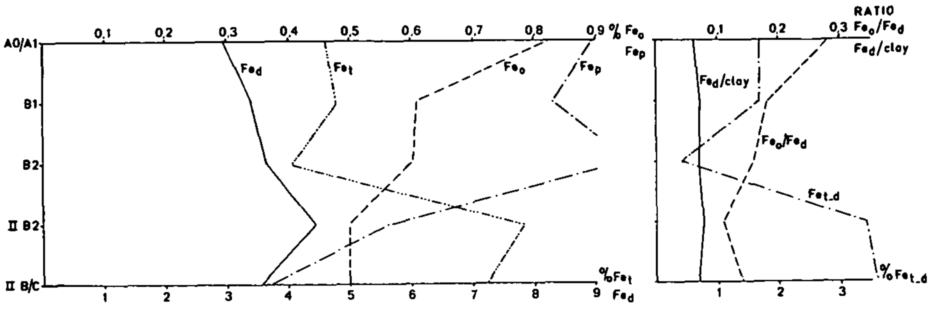
Soil series	Depth cm	Horizon	Total Fe_2O_3%	Na-dithionite %	NH_4-oxalate %	Na-pyrophosphate
Tarat	0 - 8	A_1	25.4	14.64	1.06	0.82
	8 - 28	B_1	26.1	16.65	0.66	0.54
	28 - 54	B/C	27.0	15.44	0.54	0.09
	54 - 100	C	25.2	16.02	0.34	0.02
Gumbang	0 - 9	A_1	2.7	1.37	0.61	0.47
	9 - 28	B_1	3.8	1.60	0.54	0.44
	28 - 44	B_2	3.4	2.00	0.37	0.33
	44 - 67	B/C	3.5	2.06	0.22	0.21
	67 - 100	C	3.9	2.35	0.20	0.19
Serin	0 - 10	A_1	4.4	3.60	0.37	0.59
	10 - 25	A_2(E)	5.5	4.18	0.39	0.53
	25 - 75	B_1	5.5	4.00	0.20	0.13
	75 - 115	B_2	6.9	4.86	0.11	0.04
	115 - 135	B/C	6.4	4.86	0.09	0.00
Semongok	0 - 9	A_1	5.5	2.92	0.83	0.89
	9 - 29	B_1	5.3	3.37	0.61	0.83
	29 - 68	B_2	4.4	3.66	0.60	0.96
	75 - 88	II B_2	8.7	4.46	0.50	0.56
	88 - 115	II B/C	8.0	3.55	0.50	0.37
Gading	0 - 7	A_1	2.7	2.17	0.26	0.51
	17 - 20	A_{12}	2.4	2.52	0.23	0.57
	30 - 50	B_1	2.9	2.80	0.21	0.46
	70 - 100	B_{21}	5.2	4.35	0.11	0.06
	100 - 120	B_{22}	5.3	4.98	0.10	0.03
	120+	C*	6.6	2.57	0.23	0.04
Nyalau	0 - 9	A_1	5.7	1.09	0.26	0.33
	9 - 30	A_2(E)	2.8	1.94	0.31	0.40
	30 - 63	B_1	2.1	1.83	0.20	0.23
	63 - 110	B_2	4.3	2.63	0.09	0.09
	110 - 150	B/C	3.8	2.86	0.07	0.09

* = weathered rock-discontinuity.

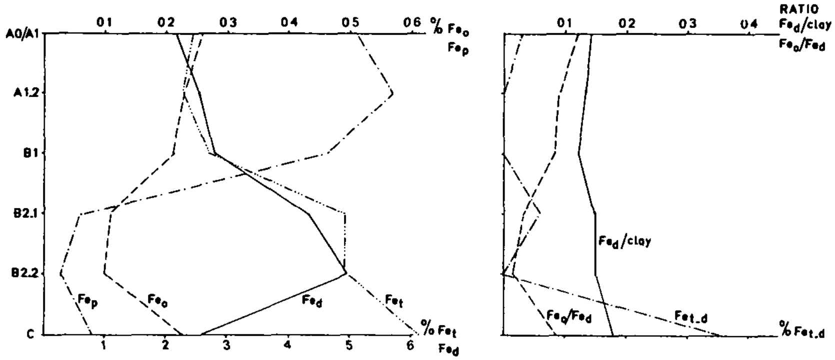
Blume and Schwertmann (1969) would indicate a high degree of ageing in subsoils and high iron activity in topsoils.

If the absolute increase in free iron in the subsoils is the result of removal of free iron from the topsoils and subsequent accumulation in the subsoil one would expect the amounts of 'aged gels' to increase with depth since the 'aged gels'

IV TYPIC DYSTROPEPT, SEMONGOK PROFILE



V PSAMMENTIC HAPLORTOX (GRANITE DERIVED), GADING PROFILE



VI PSAMMENTIC HAPLORTOX, (SANDSTONE DERIVED), NYALAU PROFILE

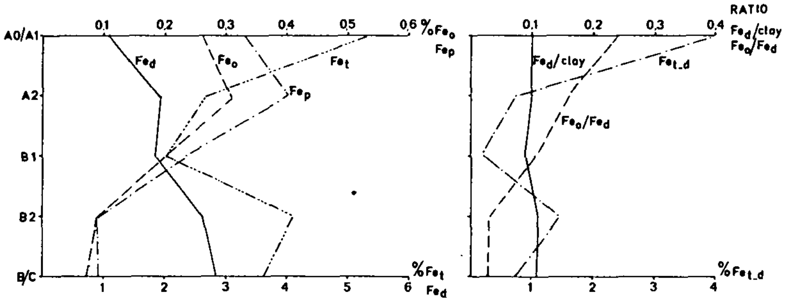
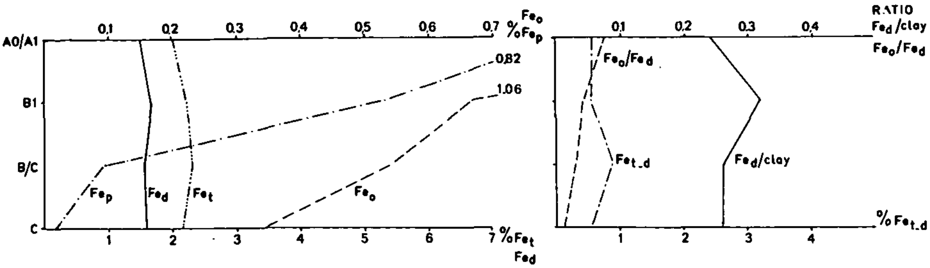
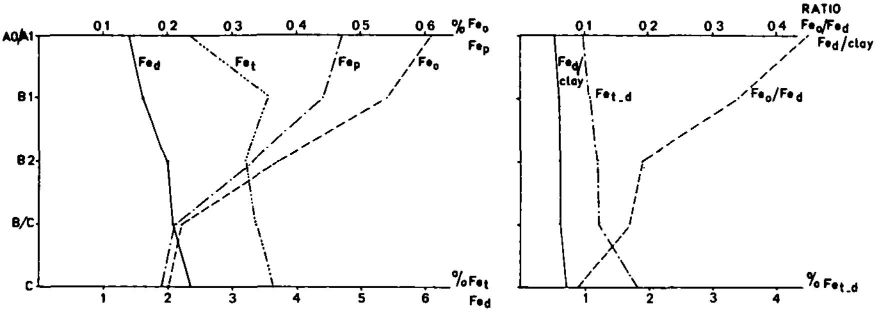


Fig. 28a *Depth functions of various iron extraction forms (Fe$_o$ - NH$_4$-oxalate, Fe$_p$ - Na-pyrophosphate, Fe$_d$ - Na-dithionite/citrate and Fe$_t$ - total) with derived functions of main upland soils in West Sarawak*

I TYPIC HAPLORTHOX, TARAT PROFILE



II OXIC DYSTROPEPT, GUMBANG PROFILE



III TROPEPTIC HAPLORTHOX, SERIN PROFILE

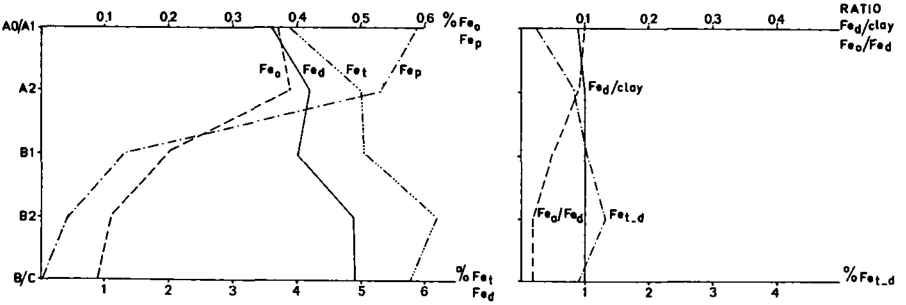


Fig. 28b *(continuation of Fig. 28a)*

represent a transitional stage from the mobile fraction removed from the surface horizons to the crystalline fraction accumulating in the subsoil.

The aged gels are extracted by oxalate, but since oxalate also extracts fulvic acid complexed iron regarded as the mobile iron, the amount of 'aged gels' is difficult to examine from Fe_o alone.

The amount of 'aged gels' can however be judged from the relationship existing between Fe_o and Fe_p. Since Fe_o represents 'aged gels' plus fulvic acid complexed iron, and Fe_p all organic complexed iron, a relation between Fe_o and Fe_p can only point to a high importance of fulvic acid complexed iron in both extractions. Figs 28a and 28b illustrate such a close relationship between Fe_o and Fe_p, and Fe_o is thus more representative for the mobile fraction than for the 'aged gels'. It is therefore suggested that the proportion of 'aged gels' must be considered as very low. However, although the diminishing content of Fe with depth may be largely a function of the fulvic acid complexed iron, it could obscure a possible increase of very low absolute value of the 'aged gels' occurring at depth. This will then be so insignificant that it cannot explain the comparative large relative difference between the crystalline iron compounds indicated as Fe_d and the amorphous compounds indicated as Fe_o. This absence or near absence of a transitory iron form (aged gels) in the subsoils is of genetic significance since it implies a very low rate or absence of a new accumulation process. Only in the Tarat and the Semongok series new accumulation may play a role since in these profiles Fe_o is larger than Fe_p so that the amount of 'aged gels' are proportionally more important.

The relative significant amounts of organic complexed iron forms (Fe_p) which are particularly present in the upper horizons suggests a high activity of the organic matter in mobilizing iron. Since it is mainly the fulvic acid part of the mineralized organic material which plays an active role in the mobilization of iron, (Oades, 1963, Segalen, 1964) the relative contents of fulvic acids in the soils would be an important pointer to the magnitude of iron removal. Fig. 28a and 28b show that the mobile iron fraction, the fulvic acid complexed iron forms, appears to decrease with depth in all soils but persists in some magnitude into the lower horizons of the Semongok series where probably also aged gels influence the Fe_o values.

The reason is not clear but there is a possibility that the imperfect drainage condition in this profile would retard the leaching-out process of the mobile fraction so that iron can accumulate. A similar process but of less magnitude may be operating in the Gumbang series.

The mobilization of iron in the surface horizons through complexing with fulvic acids would be most effective for iron present in the colloidal fraction and the relation between pedogenetic iron and clay was expressed in a diagrammatic form in Figs 28a and 28b by the Fe_d/clay ratios.

A strong relationship between clay content and free iron can be seen in the Serin, Semongok and Nyalau profiles. It may be coincidental that these profiles are also the only soils developed on sedimentary rocks but it suggests a possible relationship with the mode in which iron is found in the parent rock, which in these rocks is mainly as finely divided goethite. This would tend to accumulate in the colloidal fraction upon weathering.

From these results one may conclude that there is iron removal from the surface horizons most likely through complexing with fulvic acids, that the colloidal fraction is mainly involved and that the removal of iron does not result in a subsequent accumulation in the lower horizons. The mobilized iron is probably leached out and only under some conditions in which drainage is retarded such as is the case in the Semongok profile, possibly new accumulations in the lower horizons do occur. Presence of 'aged gels' in lower horizons of probably also the Tarat profile cannot be discounted but because of the higher values for Fe_o than Fe_p throughout the profile 'aged gels' are probably present in all horizons and not necessarily only in the lower horizons.

It is recalled that in section III.B.2. the SiO_2 sesquioxide ratios suggest that a desilication process in the C and B/C horizons followed by a deferritization process in the surface horizons is operating in all soils and that it was querried whether the desilication process would not actually mean an iron accumulation process in the C and B/C horizon subsequent to a removal from surface horizons, thus a relative accumulation of iron as opposed to an absolute accumulation. The present information would suggest that mainly a relative iron accumulation process is operating in all these horizons upon weathering and that in subsequent stages of weathering this relatively accumulated iron is gradually removed in the surface horizon through influence of organic materials. The iron is subsequently removed from the profile unless retardation in drainage would partially succeed in renewed accumulation in lower horizons. Andriesse (1970) when studying the development of the Podzol morphology in an age sequence of coastal sands in Sarawak, found that an intermediate 'red weathering' stage occurred before the full podzol morphology develops after removal of the iron.

The results of this study would also indicate that an early relative iron accumulation stage (rubefaction) is followed by a stage in which iron is mobilized and removed. The magnitude of this late stage iron mobilization may be related to the nature of the organic acids while the precipitation and accumulation of the iron lower down in the profile may be influenced by the leaching regime or possibly other factors.

3.4. Results of the aluminium extractions

Although the general contention of Schwertmann (1964), McKeague and coworkers (1971) and Ball and Beaumont (1972) is that the employed extractions are less specific for aluminium than for iron, they nevertheless have attempted to use Al_d, Al_o and Al_p as parameters for characterizing soil horizons. McKeague et al (op cit) indicated that particularly Al_p is not very specific for organic complexed aluminium as it also includes amorphous hydrated aluminium oxides and/or hydroxides. Al_o appears to be more representative for amorphous forms of aluminium than Al_d (McKeague and Day, 1966). Also Blume and Schwertmann (1969) suggest that in tropical soils containing gibbsite, Al_d must be used next to Al_o.
The results of the aluminium extractions are shown in Table 24 and are indicated as Al_d, Al_o and Al_p. Because of the less specific nature of the aluminium extracts no depth functions were prepared in a diagrammatic form as was done for the iron extractions.

A comparison of the Al_o and Al_p values with those for Fe_o and Fe_p learns that in the profiles of the Tarat, Gumbang and Gading series, the aluminium values in topsoils are lower than the corresponding values for iron, but that the reverse is true for the subsoils.

In the other profiles Al_o is throughout higher than Fe_o, but Al_p is only higher than

Table 24. Extractable aluminium in percentage by dithionite, ammonium-oxalate and sod pyrophosphate in major Sarawak Upland soils

Soil series	Depth cm	Horizon	Na-dithionite	NH_4-oxalate/oxalic	Na-pyrophosphate
Tarat	0 - 8	A_1	3.48	0.72	0.47
	8 - 28	B_1	4.23	0.81	0.42
	28 - 54	B/C	3.93	0.85	0.28
	54 - 100	C	3.48	0.21	0.23
Gumbang	0 - 9	A_1	0.76	0.42	0.36
	9 - 28	B_1	1.21	0.64	0.42
	28 - 44	B_2	1.21	0.57	0.34
	44 - 67	B/C	1.21	0.57	0.32
	67 - 100	C	1.51	0.66	0.32
Serin	0 - 10	A_1	1.97	0.49	0.45
	10 - 25	A_2 (E)	1.21	0.26	0.26
	25 - 75	B_1	0.91	0.30	0.13
	75 - 115	B_2	1.21	0.30	0.09
	115 - 135	B/C	1.21	0.30	0.09
Semongok	0 - 9	A_1	0.30	0.85	0.76
	9 - 29	B_1	0.76	0.85	0.77
	29 - 68	B_2	1.21	0.95	0.93
	75 - 88	II B_2	1.51	0.95	0.76
	88 - 115	II B/C	0.91	0.96	0.68
Gading	0 - 7	A_1	0.83	0.25	0.32
	17 - 20	A_{12}	0.91	0.15	0.34
	30 - 50	B_1	1.21	0.21	0.28
	70 - 100	B_{21}	1.36	0.11	0.11
	100 - 120	B_{22}	1.36	0.06	0.09
	120+	C*	0.83	0.25	0.19
Nyalau	0 - 9	A_1	0.15	0.42	0.38
	9 - 30	A_2 (E)	0.60	0.42	0.36
	30 - 63	B_1	0.45	0.38	0.26
	63 - 110	B_2	0.76	0.42	0.28
	110 - 150	B/C	0.60	0.34	0.26

*weathered rock-discontinuity

Fe_p in the subsoils with the exception of the Nyalau series which throughout the profile shows somewhat higher Al_p values.

From this one may deduce that the amount of hydrated aluminium oxides (gels) must in general be higher than the amounts of hydrated iron oxides, and particularly so in the subsoils. If Al_p is indeed a measure for the mobile part of the aluminium in the soil as suggested by Ball and Beaumont (op cit) than this mobility persists deep down into the profile and is there higher than for iron. Significant is however that in the Gading series in which according to the sand, silt and clay mineralogy the highest amounts of gibbsite of all soils are present in the subsoil, the amounts of both Al_p and Al_o appear to be lowest. Also the Al_d value is not significantly large. One cannot escape from the impression that the Al_d values are apart from gibbsite and amorphous forms also related to other forms of aluminium. In this connection an important observation was made by Gamble and Daniels (1972) who, when studying Al_d values in North Caroline Coastal Plain Soils involving Paleudults and Paleaquults, found that dithionite extracted appreciable amounts of silica from kaolinite and it therefore stands to reason to assume that breakdown of the kaolinite would also release aluminium oxides which are likewise extracted. In any case, it appears that Al_d is possibly not a reliable parameter for forms of pedogenetic aluminium.

The only information which can be extracted from the present investigation is that aluminium gels are present in variable amounts throughout the profile of all series. The aluminium gels, aged and fresh, are dominant over iron gels, particularly in the subsoils. This might indicate that aluminium is preferentially accumulating in the subsoil. The relative importance of Al_o over Al_p, this in contrast to Fe_o and Fe_p, may imply that the amount of organic complexed aluminium is small in comparison to organic complexed iron.
The magnitude of aluminium mobility is highest in the Semongok series which also shows most strongly an increase of aged aluminium gels with depth. This increase is not apparent in the other profiles.

3.5. Genetic implications of the results of the selective aluminium extractions

Although the extractions used are much less specific for aluminium than for iron it must be considered logical that aluminium is also mobilized from the surface horizons, as is the case with iron.
However, the proportion of aluminium gels is in the subsoils greater than that for iron. The indications are that aluminium is less mobilized in an organic complexed form than iron and it therefore probably moves also in solution or as a hydrous gel.

As a result of studies on solubility curves of silica, iron and aluminium, Pickering (1962) concludes that the migration of aluminium in ionic form in solutions with a pH below 4, and as a colloid under favourable conditions in solutions with a pH below 5, is to be expected in soils formed from weathering aluminosilicate rocks. At a pH above 5, alumina can be expected to accumulate as insoluble residues. He also concludes that in ground waters with a pH of 4 to 9 ferric iron is essentially immobile but might be transported to some extent in an organic complexed form or as a hydroxide in a colloidal suspension. Mohr et al (1972) refer to studies on the accumulation of sesquioxides by Pedro (1964) and conclude that both elements behave identically if the pH is lower than 2.2 or higher than 7.7 independent of the redox conditions of the medium. In the tract 2.2 to 7.7, the normal pH values in natural soils, the mobility of iron depends on the redox potential of the medium but only if no organic acids are present.

The present soils are in a pH range of 4.0-5.5 (topsoil to subsoil) and it is therefore well possible that because of critical pH values aluminium is mobile in the topsoils but accumulates in the subsoil, whereas iron which moves in an organic-complexed form is not affected by the pH values in the subsoil. Segalen (1972) indicates that the mobility of aluminium in a form other than an ionic one or as a chelate is difficult to conceive; thus either removal in an organic-complexed form or depolymerization of Al-hydroxides.

The source of the aluminium which is mobilized in the surface horizon must possibly be sought in the clay minerals. The clay mineralogical investigations and the total chemical composition respectively do indicate breakdown of clay minerals and impoverishment in alumina in the surface horizons. The clay mineralogical investigations do also show presence of silica gels in the surface horizons.
This evidence suggests that indeed alumina is freed upon breakdown of clay minerals and it is then removed from the clay fraction.
Another possibility is that free alumina had accumulated as gibbsite in the soils in the initial desilication process discussed in previous sections. However free alumina appears to be present only in some profiles and although the removal of this aluminium in surface horizons upon depolymerization could play a role in these profiles it is suggested that weathering of secondary clay minerals is the most likely prime source.
A differentiation of gibbsitic materials in the subsoils into gibbsite as primary residues of weathered silicates and into newly accumulated alumina compounds is probably only possible by micro-morphological studies. Since these have not been carried out this problem remains open to further research. An indication of the process actually operating may be found in the Butan series where gibbsite is found to be accumulating in the B horizon whereas a total destruction of clay mineral matter has taken place in the surface horizons. Unfortunately no specific aluminium extractions were carried out on this soil series, but because of the very low content of weatherable silicates in the parent rock (quartzitic sandstones), gibbsite, as primary residue of weathered silicates most likely plays a very insignificant role in the accumulation process.

4. Water-soluble aluminium, iron and silicon

In order to obtain an impression on the relative amounts of easily mobilized compounds in all horizons of each soil type, the water-soluble aluminium, iron and silicon contents were determined in the at 40°C dried fine earth. The method is described in Appendix II.

The obtained values are given in Table 25.
It is logical to assume that the drying-out of the samples may have affected the contents of easily soluble material since materials may have entered into a less soluble form and most likely the values given here are not more than indications.

Table 25 shows that in general more water-soluble iron is present than water-soluble aluminium. This situation is reversed in the topsoils in which water-soluble aluminium is higher than water-soluble iron, the exception being the topsoil of the Nyalau series which throughout this study has given anomalous contents for iron

Table 25. Water-soluble aluminium, iron and silicon in at 40° C dried fine earth of major upland soils in West Sarawak

Soil series	**Horizon**		in ppm	
		Al	Fe	Si
Tarat	A_1	0.40	0.00	38.4
	B_1	tr*	4.15	12.7
	B/C	tr	2.07	6.2
	C	tr	2.07	5.0
Gumbang	A_1	3.60	2.05	21.9
	B_1	2.30	1.51	14.0
	B_2	0.25	0.25	14.0
	B/C	0.25	0.51	14.0
	C	0.25	0.25	15.0
Serin	A_1	20.20	8.17	16.5
	A_2 (E)	4.30	4.06	12.7
	B_1	0.50	2.53	9.6
	B_2	0.00	0.25	6.0
	B/C	tr	2.03	4.8
Semongok	A_1	11.50	10.44	18.8
	B_1	2.33	3.11	15.6
	B_2	1.30	3.11	13.0
	II B_2	0.26	0.52	11.0
	II B/C	0.26	1.04	10.4
Gading	A_1	5.00	7.00	0.18
	A_{12}	tr	tr	0.15
	B_1	tr	tr	0.15
	B_{21}	tr	tr	tr
	B_{22}	tr	tr	tr
	C	tr	tr	0.18
Nyalau	A_1	11.44	43.23	17.5
	A_{12}	4.55	6.07	14.4
	B_1	0.25	2.01	12.8
	B_2	tr	3.04	12.2
	B/C	tr	0.51	10.7

*traces - smaller than 0.25 for aluminium and iron.

forms, and the topsoil of the Gading series in which the small difference may be caused by analytical error.

Studies on the relative solubility of aluminium and iron which were reviewed by Oades (1963) and Segalen (1964, 1973) have shown that ferrous iron is soluble below a pH of 7.8 whereas ferric iron is only soluble below a pH of 3.4. The redox potential therefore plays an important role in the solubility of iron and in reducing conditions iron may be easily mobilized in the ferrous form. Apart from the mobilization in the ionic form, iron can be easily mobilized in the presence of organic matter through the formation of chelates. In this process the fulvic acid part of the humified organic matter plays an important role since these are easily soluble in water, whereas the humic acid part is not (Alexandrova et al, 1968). As a third possibility iron can be mobilized in the sol form in the presence of organic matter which then acts as a protective colloid.

In the present soils mobility of iron in the ionic form is remote since the pH is above 3.4 in all horizons, and movement in the ferrous form must be discounted because most soils are well drained. Only in the Semongok series, which is imperfectly drained, the redox potential may in periods of excessive rainfall drop significantly sothat iron could be mobilized in the ferrous form. The possibility that reducing conditions develop in all topsoils in time of excessive wetness cannot be totally discounted.

The mobility of aluminium appears to be little affected by the redox potential, and mobility is essentially only possible in the ionic form below a pH of 4.5, thus in a somewhat less acid environment than is needed for the mobilization of iron in the ferric form.

As is the case with iron, also aluminium can be mobilized by the chelating activity of the organic acids in which the fulvic acids play the dominant role.
On account of above considerations the values for water soluble-iron in Table 25 most probably represent mainly the organic-complexed iron forms since any water-soluble iron in the ferrous form would have entered into the insoluble ferric form upon drying. The values for water-soluble aluminium could next to that bound in the organo-mineral compounds represent partly the mobile aluminium in the ionic form in horizons with a pH of less than 4.5. Probably because of the latter cause is the water-soluble aluminium in topsoils higher than the water-soluble iron, with mentioned exceptions.

The diminishing values with depth for both iron and aluminium corresponds well with the trend found in the pyrophosphate extractable iron and aluminium (see Table 23) which are parameters for the organic-complexed forms and a strong relation between the water soluble forms and the organic matter must therefore be suspected.

A possible absolute accumulation in the subsoils of removed aluminium from the topsoils but the absence of any evidence of absolute accumulation of iron has been commented upon in section III.B.3.

The persistence of water-soluble iron even after drying at 40°C in the subsoils and of water-soluble aluminium but of lower magnitude than iron would indicate that indeed organic-complexed iron remains soluble in the soil and is in that form removed from the profile whereas aluminium which is partly mobile in the ionic form becomes insoluble at depth because of the lower acidity in the subsoils. Nevertheless, part of the aluminium may also be removed from the profile in the organic-complexed form.

The values for water-soluble silicon appear to be considerably higher than those for water-soluble aluminium and iron, the exception being the Gading profile. As is the case with the aluminium and iron, more soluble silicon is present in the topsoils than in the subsoils.

Demolon (1952) gives an average value of 12 ppm silicon for riverwater, 40.0-28.5 ppm for water from granitic sources and 61 ppm for water originating from sandstone areas. Scheffer and Schachtschabel (1970) indicate that normal soil water contains 2-30 ppm of silicon but infer that values higher than 16 ppm are abnormal and only occur in specific soils such as recent volcanic ash soils in Japan and in stagnant groundwater. Extremely high values of soluble silicon for recent volcanic ash soils are also reported by Mohr (1944).
It must therefore be contended that the values for water-soluble silicon in the present non-volcanic soils are on the high side and particularly so in the topsoils. Scheffer and Schachtschabel (op cit) state that this latter observation is a common fact and relate this to the presence of bio-opal in the topsoils. However, the mineralogy of the soils under study do not indicate presence of such material and the cause must be sought elsewhere.

Water-soluble silicon is related to various sources, silicic acid, amorphous silica and quartz. The solubility of silicic acid is low, saturation concentration being 56-66 ppm but solubility increases with increasing temperature and is only pH dependent below a pH of 2 and above a Ph of 8 (Scheffer and Schachtschabel, 1970). They indicate that the low solubility of silicic acids may be explained by the strong adsorption of sesquioxides being present.
The solubility of silicon gel, amorphous silica, is higher and according to Pickering (1964) is in the natural pH range of 4 to 9 a thousand fold that of alumina. Berner (1971) gives a saturation concentration of 100-140 ppm.
The solubility of quartz is very low, and dependent on grain size is in the range 1.4-3.3 ppm at 25°C (Scheffer and Schachtschabel, 1970).

The mineralogy of the soils under study indicates presence of silica gels in most soils and particularly so in the surface horizons of which that of the Tarat series must be specifically mentioned. Considering the above, the comparative high values for water-soluble silicon given in Table 25 are most likely mainly related to the presence of silica gel. The low values for the Gading series are explained by the fact that this soil, already from the initial stages of weathering, was considerably undersaturated with silica which has caused precipitation of much gibbsite. This aspect was already commented upon earlier in the section on clay mineralogy and is also revealed by the very low SiO_2/Al_2O_3 ratios in the 0.5 NaOH extracts given in Table 21.

The presence of silica gels throughout the profile but their gradual increase in the surface horizons, thus upon proceeding weathering indicates a low mobility of released silica, probably caused by the relative high concentrations of silicon in the soil water. The concentration of silica gel in the topsoils is not caused by accumulation of bio-opal thus through an organic cycle but it likely illustrates the increasing weathering of clay silicates. Such a process is also suggested in the diagram shown in Fig. 24, which is based on the clay mineralogical studies.

Although amorphous SiO_2 may be more soluble than alumina in the pH range of the present soils, as indicated by Pickering (op cit), it is suggested that comparatively more alumina is removed from the topsoils upon weathering of clay minerals mainly because of the activity of the organic matter. Possibly both silica and alumina are removed from the soil but the absolute accumulation of SiO_2 is a result of the difference in degree and nature of removal of these oxides.

5. Reaction and exchange characteristics

5.1. Introduction

Highly weathered soils of the humid tropics exhibit peculiar electrochemical properties which differ markedly from those shown by soils of the temperate regions. They often give marked differences in CEC values at different pH and show phosphate fixation while variations can exist in the delta pH values, sometimes in the negative.

It can in general be stated that soils of the temperate regions are characterized by surfaces bearing a constant surface charge which does not change markedly with pH, while soils of the humid tropics are characterized by surfaces having a constant surface potential which is solely determined by the potential determining ions H+ and OH− (v. Ray and Peech, 1972). This may be explained by the fact that soils of the humid tropics, particularly highly weathered ones, contain large amounts of iron and aluminium oxides which presence has a pro~~con~~found influence on the nett charge of a soil since they are either positively charged below their I.E.P. (iso-electric point) or negatively charged above their I.E.P., whereas organic matter and clay minerals usually remain negatively charged over the natural pH range of 3-9. Mainly for the latter reason and the fact that sesquioxides play a relative small role in soils of temperate regions, remain the CEC values of such soils relatively stable independent on the pH at which the measurements are taken.

The magnitude of the charges of the sesquioxides, either positive or negative are much influenced by the nature in which they occur in the soil. Hsu and Bates (1964) show that in increasingly larger polymers of e.g. aluminium, the charge decreases, while the I.E.P. is increased (v. Schuylenborgh and Sänger, 1949).
Differences in measured CEC at varying pH can, apart from the presence of these free oxides, be the result of the blocking of exchange sites present in clay minerals through coatings on the soil clays by the positively charged iron and alunimium oxides (Sumner, 1963; Greenland and Oades, 1968) and also, in the case of 2-1 lattice clays being present, through interlayering by Al-oxides with the formation of so-called chloritized vermiculite (de Villiers and Jackson, 1967a, 1967b).

A study of the exchange characteristics of the soils under study may therefore be able to give some clues on the nature of the sesquioxides and the interstratified clay minerals which were found to be present. Soil structure and related soil erosion is also strongly related to electro-chemical properties (Fuerstenau, 1969).

For these reasons the following properties were determined: pH-H_2O and pH-KCl were measured in a 1:2.5 water extract; cation exchange capacity, unbuffered and buffered at pH 8.2 using $BaCl_2$/TEA, was determined for the fine earth; exchangeable cations were analysed using $BaCl_2$ 0.6 N for percolation; phosphate fixation capacity was measured by the Metson method. Particulars of the procedures employed are given in Appendix II.

The results of the analyses are given in Table 26.

5.2. Reaction

All soils are highly acid with the exception of the Tarat series which is moderately acid. pH-H_2O generally shows a gradual increase with depth which, because the values for exchangeable cations show a strong decrease with depth, is most probably caused by the decrease in organic acids. Values for pH-KCl show the same trend. If values for pH-KCl are considered indicative for anion exchange capacity than this appears to be highest in the Gading and the Tarat series in which the difference between pH-H_2O and pH-KCl are also smallest, particularly in the subsoil.

This observation correlates well with the clay mineralogy of these soils; the Gading having a relative high content of aluminium hydroxides (gibbsite) while the Tarat is characterized by a high content of iron oxides (goethite). In both these profiles the content of sesquioxides does also increase with depth.

In none of the profiles however is the total positive charge higher than the negative charge since the delta pH values are all positive.

5.3. Cation exchange properties

The pH dependent charge appears to be considerable in all soils, the CEC at pH 8.2 being in all soils higher than the CEC at the pH of the soil. There are however differences in magnitude between the profiles which justify a more detailed discussion.

In the Tarat series the pH dependent charge is almost double that of the pH independent charge. This is in this profile mainly caused by the high goethite content of the clay fraction (see also Tables 18 and 19). Sumner (1963) indicates that goethite is positively charged below a pH of 8. According to Parks (1965) the I.E.P. of well crystallized anhydrous species of $Fe(OH)_3$ in equilibrium with polymeric species varies from 2 to 9.

The large increase in CEC at pH 8.2 is therefore most likely caused by a surpassing of the I.E.P. at which goethite becomes negatively charged. The small amounts of gibbsite also present in this profile probably play a role also, the I.E.P. of this mineral probably being around 6 (v. Schuylenborgh and Sänger, 1949).

The unbuffered CEC of around 8 corresponds with the mineralogical composition of the clay fraction, halloysite normally having a CEC of 5 to 10. The higher values in the A_1 and B_1 horizons are caused by presence of organic matter and probably

Table 26. Reaction, exchangeable bases and CEC at pH of soil compared with CEC at pH 8.2 (pH dependent charge) of major upland soils of West Sarawak

Soil Series	Horizon	pH H_2O	pH KCl	CEC unbuf. f.e.	CEC unbuf. clay	CEC pH 8.2 f.e.
Tarat	A_1	5.0	4.5	20.2	89.4	38.6
	B_1	5.0	4.2	5.44	13.4	19.7
	B/C	5.3	4.8	4.50	7.6	15.0
	C	5.3	5.0	5.06	8.1	13.3
Gumbang	A_1	4.6	3.9	14.2	229.0	29.3
	B_1	4.4	3.8	4.43	18.8	11.4
	B_2	4.6	3.8	4.06	12.9	9.59
	B/C	4.7	3.8	4.06	11.3	9.24
	C	4.6	3.8	4.44	12.4	9.05
Serin	A_1	3.4	3.3	6.30	22.7	20.0
	A_2(E)	4.1	3.6	2.77	6.6	9.22
	B_1	4.4	3.7	2.77	6.6	6.27
	B_2	4.6	3.9	2.75	5.9	5.53
Semongok	A_1	3.7	2.9	25.03	60.0	45.15
	B_1	4.3	3.5	18.11	39.6	27.46
	B_2	4.4	3.6	16.73	31.0	24.71
	II B_2	4.6	3.6	16.64	30.3	23.74
	II B/C	4.7	3.6	19.14	35.0	25.24
Gading	A_1	4.9	3.9	3.78	30.24	10.52
	A_{12}	4.2	4.0	2.63	13.8	6.02
	B_1	4.7	4.3	0.93	3.1	3.66
	B_{21}	4.8	4.4	0.69	2.3	3.01
	B_{22}	4.9	4.6	0.58	1.7	3.09
	C	n.d.	n.d.	1.01	10.0	3.44
Nyalau	A_1	4.1	3.5	8.21	102.0	20.00
	A_2(E)	4.0	3.7	3.33	18.5	7.51
	B_1	4.4	3.7	3.10	15.5	5.67
	B_2	4.4	3.6	4.31	17.6	6.87
	B/C	4.4	3.6	4.61	17.5	6.91
Butan	A_1	3.3	n.d.	n.d.	n.d.	6.40
	A_{12}	4.2	n.d.	n.d.	n.d.	3.00
	A_2(E)	4.7	n.d.	n.d.	n.d.	0.50
	B_1h	3.6	n.d.	n.d.	n.d.	4.70
	B_{12}	3.9	n.d.	n.d.	n.d.	7.50
	B_2	4.3	n.d.	n.d.	n.d.	1.00
	II C	4.3	n.d.	n.d.	n.d.	0.50

Soil Series	meq. 100 gram fine earth - pH of soil						Base saturation Ca-Mg-K-Na
	Ca	Mg	K	Na	Al	Sum	
Tarat	7.3	3.00	0.69	0.18	0.62	21.79	100
	2.45	1.10	0.37	0.11	1.25	5.28	74
	1.93	0.68	0.27	0.11	0.29	3.28	66
	1.55	1.82	0.14	0.15	0.16	3.82	72
Gumbang	9.37	2.41	0.60	0.17	2.22	14.77	88
	1.27	0.71	0.10	0.20	3.74	6.02	52
	0.89	0.46	0.04	0.15	3.74	5.28	38
	0.76	0.33	0.03	0.13	4.03	5.28	31
	0.64	0.21	0.03	0.17	4.19	5.24	24
Serin	0.46	0.42	0.38	0.15	5.41	7.48	24
	0.33	0.06	0.04	0.13	3.58	4.14	20
	0.38	0.06	0.04	0.28	2.59	3.35	27
	0.13	0.04	0.03	0.13	2.61	2.94	12
Semongok	0.15	0.32	0.30	0.09	20.97	24.36	3.5
	0.01	0.11	0.19	-	16.54	17.18	6
	-	0.04	0.23	-	16.56	16.96	2
	0.06	0.06	0.23	0.09	14.95	15.44	3
	0.06	0.06	0.34	-	17.14	17.60	3
Gading	0.26	0.27	0.10	0.04	2.56	3.28	18
	0.06	0.04	0.02	-	1.37	1.49	5
	0.04	0.02	-	-	0.58	0.64	7
	0.04	0.02	-	-	0.42	0.48	9
	0.06	0.02	-	-	0.31	0.37	14
	0.06	0.02	0.06	-	0.31	0.43	14
Nyalau	0.26	0.59	0.23	-	5.50	7.39	13
	0.14	0.04	0.05	-	3.29	3.60	7
	0.16	0.04	0.06	0.04	2.89	3.22	10
	0.01	-	0.04	-	3.73	3.78	1
	0.04	-	0.05	-	3.80	3.85	1
Butan	0.42	0.02	0.17	0.30	0.61	1.73	15
	0.30	0.01	0.05	0.33	0.15	0.94	23
	0.42	0.02	0.05	0.33	0.11	0.90	100
	0.19	0.02	0.06	0.36	3.82	4.45	13
	0.12	0.02	0.06	0.37	4.55	1.10	8
	0.19	0.02	0.06	0.33	2.41	1.01	60
	0.19	0.01	0.06	0.33	2.55	3.14	100

of some allophanic materials which may have a CEC as high as 100 (Scheffer and Schachtschabel, 1970).

The Gumbang series shows rather similar cation exchange characteristics, but the mineralogy of the clay fraction (see Table 18) indicates that the role of gibbsite in causing a high pH dependable charge, is much larger than in the Tarat, whereas that of goethite is very small.
The unbuffered CEC values for the clay are larger than expected, kaolinite being the dominant mineral, but they are still within the range 3-15 given for kaolinite (Scheffer and Schachtschabel, 1970).

The Serin series has very low unbuffered CEC values, which remain low even when CEC is determined at pH 8.2. The clay mineralogy which shows presence of small amounts of interstratified mineral gives reason for expecting higher CEC values. It is suggested that in this profile, in which goethite is present in small amounts in the clay fraction, negatively charged exchange sites may be blocked by the goethite, as was suggested by Sumner (1963) and Greenland and Oades (1968). The higher values for the A_1 horizon are due to organic matter being present.

The Semongok series has relative high values for unbuffered CEC which, as can be seen from Table 18, is caused by the relative high content of interstratified clays in the clay fraction. The content of pure vermiculite is probably not great, otherwise the CEC would be much higher, vermiculite having a CEC of 100-200 meq/100 g clay (Scheffer and Schachtschabel, op cit). The relative small difference between unbuffered and buffered CEC indicates a low influence of sesquioxides which is confirmed by Table 18 showing an almost absence of these materials in the clay fraction.

The Gading profile has exceptionally low unbuffered CEC values, approaching to zero and also the CEC at pH 8.2 is extremely low and much lower than is to be expected from the clay mineralogy which shows a dominance of kaolinite (see Table 18). However gibbsite is present in moderate amounts, and goethite in small amounts. It is very likely that much of the negatively charged sites of the kaolinite are blocked by positively charged $Fe(OH)_3$ coatings as was also suggested for the Gumbang series. It is further suggested that probably also gibbsite which at a pH of around 5 should be positively charged, plays a role in this blocking effect. However, the small pH dependable charges present in all horizons of this profile point to a low influence of the sesquioxides in deciding the CEC. If polymers of aluminium hydroxide are playing a role one would expect much higher CEC values at a pH of 8.2. Probably due to a high polymerization of the aluminium hydroxides the exchange capacity has become very low and therefore the measured CEC's are mainly related to kaolinite which because of its high crystallinity in this profile also has a relative low exchange capacity.

The CEC values of the Nyalau series are also very low but this is caused by the coarse texture. The unbuffered CEC of the clay confirms the clay composition which as shown in Table 18 is mainly kaolinite with some interstratified minerals. Probably also here is the pH dependable charge mainly caused by the influence of goethite, gibbsite being absent.

For the Butan series CEC was only determined at a pH of 7.0. Values for this CEC are very much a reflection of the clay mineralogy as shown in Table 18. The low values for the topsoil and the B_h horizon indicate that the organic matter present in these horizons does have a low exchange capacity, at least considerably lower than that present in the other soil series. Whether this is related to the C/N ratio (see Table 28) is worth further investigation.

It can be concluded that the cation exchange characteristics largely confirm the findings of the study on the clay mineralogy. The role of free iron compounds in deciding CEC values is most important in the Tarat series and in general appears to be of more influence than the presence of free aluminium compounds. The low influence of the latter may be the result of a high polymerization grade. The remark must however be made that a possible influence of gels cannot be discounted but their existence is not shown by the X-ray data given in Table 18. There are no reasons to expect the presence of much chloritized vermiculite in the soils containing interstratified or mixed-layer clays. It is however contended that a possible presence of small amounts of such materials could better be determined by more specific methods involving CEC determinations before and after treatment with probably 0.5 N NaOH as suggested by de Villiers and Jackson (1967b). Presence of organic matter is the most influential factor in determining the level of cation exchange capacity of these soils.

5.4. Exchangeable cations and base saturation

Table 26 illustrates the extreme poverty in bivalent cations. It also illustrates the importance of the organic matter in preserving a certain level of the bivalent cations in the topsoils. Of considerable interest is the decreasing content in exchangeable calcium and magnesium in the sequence of the studied soils based on the silica content of the parent rocks. This may indicate that the chemical composition of the parent rock is indeed influencing that of the organic matter formed, and that this is maintained even when the soil has reached a highly advanced weathering stage. The dominant exchangeable cation is aluminium which is a reflection of the advanced leaching stage accompanied by increasing acidity. Although the absolute values in the Semongok appear to be extremely high, a comparison with the CEC learns that in all soils the relative contribution of aluminium in the total exchangeable bases is about the same with the exception of the Tarat; the high values for the Semongok series are therefore not an exception.

Base saturation is in general low which indicates the high leaching rate in Ca, Mg, K and Na. Also in the base saturation values is the sequential order in which the soil series were placed maintained. This is most likely also a reflection of the stabilizing influence of the organic matter referred to earlier. In all profiles, with the exception of the Butan series, is the base saturation highest in the topsoils. This is caused mainly by the higher Ca and Mg level of humus bound cations.

5.5. Phosphate retention (see Table 27)

The phosphate retention capacity of a soil is related to the anion exchange capacity of a soil and the ability of sesquioxides to fix phosphates through the formation of complex salts. Because of the extreme low calcium level in the studied soils the role of calcium can be ruled out (Taylor et al, 1964).

Table 27. Phosphate retention capacity in selected horizons of major upland soils of West Sarawak

Soil series	**Horizon**	**% absorbed P in 100 g of dried fine earth**
Tarat	A_1	54.9
	B_1	61.0
	B/C	70.3
Gumbang	A_1	29.9
	B_1	36.3
Serin	A_1	34.7
	A_2 (E)	35.5
	B	38.4
Semongok	A_1	68.6
	B_1	70.3
	II B_2	74.7
Gading	A_1	15.3
	A_{12}	19.4
	B_{21}	22.7
Nyalau	A_1	25.0
	A_2 (E)	34.7
	B_2	35.1

In all the soils the P-retention increases with depth and this may be explained by the fact that the content of sesquioxides also increases with depth, and particularly so the iron oxides. The low values for the Gading series are in part caused by the coarse texture. The high values in the Tarat series are probably a reflection of the high content of goethite throughout the profile.

Highest values were obtained for the Semongok series in which the role of the crystalline sesquioxides, however, must be considered as very low. This was also brought to the fore by the CEC characteristics discussed in section 5.3. of this chapter. In this profile therefore other causes must play a role. The high values for exchangeable aluminium in this series make it very likely that the phosphate is partly retained through aluminium released from exchange sites.

Bailey (1967) found in experiments with this soil type that the CEC was increased upon phosphate fertilizing. This points to a process of liberation of exchange sites through fixation of aluminium by the added phosphate. It is possible that further release of aluminium through hydrolyses of the clay minerals may play a role but the analytical information is insufficient to substantiate this. Noteworthy is however that in this profile with its high content of interstratified minerals and its low content of crystalline iron oxides, aluminium which does not appear to occur as gibbsite in significant amounts is playing a crucial role in phosphate fixation.

Reference may be made to section B.3.4. in which the various aluminium extrac-

tions are discussed and in which presence of aluminium gels were suspected in all soils, but particularly in the Semongok series. Presence of such gels is not revealed by Table 18 in which only the composition of the crystalline part of the clays is shown.
Table 24 in which the different forms of aluminium are presented may therefore be more indicative to the role of aluminium in phosphate fixation. Velez and Blue (1971) found that phosphorus sorption in a tropical soil from Costa Rica was as much related to amorphous aluminium forms extracted by oxalate than to crystalline forms extracted by citrate-dithionite-bicarbonate (CDB), whereas in a temperate soil this was mainly due to crystalline aluminium forms. The amorphous forms increased by liming which was explained by the release of Al ions from organic matter (chelates) and from exchange sites. A possible similar mechanism may be operating in the soils under study and the oxalate extractable aluminium as shown in Table 24 may therefore be more indicative to phosphate adsorption than the clay mineral composition as shown by Table 18. Table 24 would also correlate with the low P-retention values observed for the Gading series and the high values for the Tarat series.

These findings would further be in accordance with results obtained by Udo and Uzu (1972) who found in a study on 10 Nigerian acid soils that the citrate-dithionite and the oxalate extractable oxides were of equal significance but that the role of aluminium was more important than that of iron.

C. The Organic Part of the Soil

1. Introduction

The factor 'Organic matter' plays an important role in soil formation; reference is made to section I.D. in which this factor has been discussed in general terms. Although it is realized that living organisms, such as bacteria and fungi play an important part in chemical reactions taking place in the soil, in this study the main emphasis has been on the dead organic debris since it has been shown that upon decomposition and transformation of this material compounds are formed which are able to fix sesquioxides as chelates and mobilize them under conditions in which they otherwise would be stable.
Studies by Bloomfield (1953a, b and c; 1954a, b and c; 1955 and 1956), by Schnitzer (1957, 1959) and by Martin and Reeves (1957a and b) have made it abundantly clear that particularly the low molecular fraction of the humus acids, namely the fulvic acids, is particularly active in mobilizing aluminium and iron in soils, this process being most strongly operating in podzolic soils and Podzols.

Also v. Schuylenborgh and co-workers (1955, 1957, 1958, 1959, 1961), paid much attention to the role of organic matter in the formation of tropical soils, and in particular to the relation of parent material and the nature of the organic matter formed after mineralization or humification.

Therefore, in order to study the relative magnitude of the mobilizing activity of the organic matter, the content of humic and fulvic acids was determined next to percentage carbon and nitrogen. Humic and fulvic acids were analyzed according to the ORSTOM method, % C was determined by Walkley-Black and % N by the micro-Kjeldahl method. The particulars of the followed methods are given in Appendix II.

For profiles in which an O horizon is present, however weakly developed, sampled material was subjected to the same chemical analyses as carried out on the mineral soils; total chemical composition, however, was determined after ashing. Results of the analyses of the organic matter present in the mineral horizons are shown in Table 28, those for the O horizons in Table 29.

2. The organic matter in the mineral horizons

The C/N ratios of the A_1 horizons range from 9.6 in the Tarat series to 27 in the Butan series and show a gradual increase in the sequential order of the studied soils. There is therefore a relation between C/N ratio and acidity of parent material. A similar increase was found by Tan and v. Schuylenborgh (1961) in a sequence of zonal soils on acid volcanic material but located at increasing altitude, ranging from Yellow Podzolic Soils in the lowlands to Podzols in the highlands of Sumatera (Indonesia) and in which the C/N quotient showed a range from 10.9 to 22.3. Whereas in the present study the correlation is based on acidity of parent material, the climate being constant, in Sumatera this appears to be caused by altitude (climate), the parent material being constant. This would need further clarification. Nye and Greenland (1960) conclude from a review on the C/N ratio of many soils in the tropics that its value is a rough guide to the mineralization of the humus; high values indicating less mineralization and more humification. Schuylenborgh and co-workers (op cit) reason that in soils with a high base status and well-drained conditions the organic matter decomposes completely, sothat the soil forming agent is carbonic acid, whereas in soils on acid parent materials the organic matter is less rapidly mineralized resulting in the formation of organic acids. Hardon (1936) found a strong correlation between pH and C/N ratio for well-drained topsoils in South-Sumatera, presumably also as a result of the base status.

In section III.B a positive relation was found between pH-H_2O, exchangeable bases, base saturation and the acidity of the soil parent material as indicated by the sequential order of the studied soils. This relationship appears to be also existent now in the C/N ratios of the topsoils. This would confirm Hardons finding that C/N ratio is related to pH, and the statement made by v. Schuylenborgh and co-workers that mineralization of organic matter is more rapid in soils with a higher base status developed on basic rocks, appears to be valid also for the present soils. However, apart from the base status, mineralization is also influenced by humidity and temperature (Mohr et al, 1972) and this apparently plays the dominant role in the altitude sequence of soils reported by Tan and v. Schuylenborgh (op cit).
In the Sarawak soils the climate must be considered a constant factor and therefore the rate of mineralization is solely influenced by the base status of the organic matter. The apparent decrease in the rate of mineralization which is observable from the 1st to 7th member of the soil sequence would mean an increase in humification and according to Schnitzer (1967) who studied this aspect on 24 Canadian soils, this should also mean an increase in fulvic acid content since these are formed from humic acids through oxidative degradation.

Table 28 showing humic and fulvic acid contents indicate that this is in general also true for the tropical soils being studied, at least for the subsoils. Surface horizons can contain more humic than fulvic acids but this may be caused by a difference in oxidation stage of the humified organic matter since the surface horizons contain organic litter in all stages of decomposition, but probably more significant is the fact that the fulvic fraction is water-soluble and therefore easily leached out.
Of importance is that in all soils the humic/fulvic acid ratios are generally below 1 and in subsoils dominantly below 0.5 which indicates a dominance of fulvic over humic acids.
There appears to be no relationship of any consequence between the humic/fulvic acid ratios and the acidity of the parent material and therefore the surmise initially made in this study (see Introductory Chapter) that in all soils formed on basic parent material less fulvic acids will be formed upon decomposition of organic matter than in soils developed on acid parent materials appears to be partially wrong. At least, the present evidence is inconclusive since the data obtained on contents of humic and fulvic acids may be influenced by the oxidation stage of the organic matter. What can be concluded is, that in soils on increasingly more acid parent materials humification appears to dominate over mineralization (see C/N ratios) and that therefore, when following the train of thoughts propounded by v. Schuylenborgh and co-workers (op cit) carbonic acids are becoming of less impor-

Table 28. C/N ratios, humic and fulvic acid contents of mineral horizons of main upland soils in West Sarawak

Soil series	Horizon	% dry fine earth			in $^0/_{00}$ C of dry fine earth			Humic/ fulvic acid ratio
		C	N	C/N ratio	Humic acid	Fulvic acid	Total	
Tarat	A_1	4.61	0.48	9.6	6.9	8.2	15.1	0.84
	B_1	1.40	0.18	7.8	2.0	11.2	13.2	0.18
	B/C	0.93	0.10	9.3	2.7	7.8	10.5	0.35
	C	0.44	0.05	8.8	2.0	5.2	7.2	0.39
Gumbang	A_1	5.51	0.45	12.2	10.4	8.0	18.4	1.30
	B_1	1.02	0.11	9.3	2.0	5.3	7.3	0.37
	B_2	0.62	0.06	10.3	2.0	3.6	5.6	0.56
	B/C	0.43	0.05	8.6	1.2	3.3	4.5	0.36
	C	0.39	0.04	9.8	1.7	2.5	4.2	0.68
Serin	A_1	2.52	0.25	10.1	5.4	9.7	15.1	0.56
	A_2 (E)	0.76	0.09	8.9	1.4	5.3	6.8	0.26
	B_1	0.51	0.08	10.2	1.8	2.6	4.4	0.47
	B_2	0.37	0.03	12.3	1.6	1.5	3.1	1.06
	B/C	0.15	0.02	7.5	2.9	-	2.9	-
Semongok	A_1	3.18	0.27	11.7	12.1	7.2	19.3	1.70
	B_1	0.86	0.11	7.8	2.4	4.8	7.2	0.50
	B_2	0.57	0.08	7.1	2.1	3.3	5.4	0.64
	II B_2	0.36	0.06	6.0	2.7	1.8	4.5	1.50
	II B/C	0.26	0.09	2.9	1.4	2.8	4.2	0.50
Gading	A_1	1.69	0.13	13.2	3.8	5.5	9.3	0.69
	A_{12}	0.63	0.09	7.2	1.0	4.6	5.6	0.22
	B_1	0.27	0.03	8.0	0.5	3.1	3.6	0.14
	B_{21}	0.22	0.02	10.0	0.7	4.0	4.7	0.18
	B_{22}	0.21	0.03	7.6	0.3	1.8	2.1	0.17
Nyalau	A_1	4.23	0.25	16.9	9.5	7.1	16.6	1.34
	A_2 (E)	0.54	0.08	6.8	1.2	2.9	4.1	0.41
	B_1	0.19	0.03	6.3	0.7	1.5	2.2	0.47
	B_2	0.19	0.02	9.5	0.5	1.6	2.1	0.31
	B/C	0.09	0.03	3.0	0.7	1.6	2.3	0.43
Butan	A_1	4.78	0.16	27.0	n.d.*	n.d.		
	A_{12}	0.46	0.02	23,0	n.d.	n.d.		
	A_2 (E)	0.14	0.004	35.0	n.d.	n.d.		
	B_{1h}	4.52	0.08	90.0	n.d.	n.d.		
	B_{12}	2.64	0.006	440.0	n.d.	n.d.		
	B_2	0.57	0.01	57.0	n.d.	n.d.		
	II C	0.18	0.003	60.0	n.d.	n.d.		

* = not determined

tance in soil forming processes, whereas the humus acids (humic and fulvic acids together) become proportionally more influential.

It can further be concluded that because of the formation of more humus acids than carbonic acids the activity of the organic matter in complexing iron and aluminium increases with the acidity of the parent materials. The absolute values found for humic and fulvic acids in subsoils are probably partly influenced by presence of decayed roots, e.g. the Tarat has higher amounts in the subsoils than any other soil, because it is well-rooted, whereas the Nyalau has the lowest amounts because it has no root development at lower depth.
Therefore the dominance of fulvic over humic acids or the reverse is locally influenced in the subsoil by the oxidation rate and decomposition stage of these roots and since this is not a constant factor in the selected soils, observed differences are not of pedogenetic consequence.

Of much importance is however the fact that as a rule the fulvic acids are considerably dominant over humic acids and therefore the process of mobilization and removal of iron and aluminium must be very active.

3. The organic matter of the organic horizon

Table 29 indicates that as a consequence of the lower stage in decomposition the C/N ratios of the O horizons are in general higher than those of the A_1 horizons (see Table 28).

As is the case with the organic matter in the mineral horizons, also in the O horizons a correlation exists between pH-H_2O and the C/N ratio. The pH decreases in the soil sequence while the C/N increases, the Nyalau series being an exception. As can be learned from the total chemical analyses of the ash, pH is much related to calcium content.

It is further noteworthy that the humic/fulvic acid ratios are by far exceeding those found for the mineral horizons. The trend of decreasing ratios with depth generally existent in the mineral horizons therefore starts already in the O horizon. It is suggested that the type of organic matter, leaves, branches or roots may affect the ratio while also the oxidation stage exerts its influence. Nevertheless, although the O horizons contain more humic than fulvic acids, the stage for the chelating process and mobilization of iron and aluminium is already set by the composition of the relatively fresh organic matter.

The TiO_2 values for the ash are too high for organic matter and suggest that the material of the O horizon is not purely organic. Also the low loss on ignition at 700°C points to presence of mineral matter. This is most likely clay material which is contaminating the organic matter of the O horizon owing to run-off. Even upon prolonged suspension this clay could not be separated from the organic materials. For this reason the total chemical composition of the ash is not truly representative for the organic matter deposited on the soils.

When comparing the SiO_2, Al_2O_3 and Fe_2O_3 values of the ash with that of the clay fraction of the A horizon (see Table 30), it is obviously that due to the organic

Table 29. Chemical composition of O horizons of main upland soils in West Sarawak

Soil series	**Horizon**	pH-H_2O	**% dry fine earth**			**in $^0/_{00}$ C of dry fine earth**			
			C	N	C/N ratio	Humic acids	Fulvic acids	Total	**Humic/fulvic acid ratio**
Gumbang	0	5.7	14.7	0.97	15.2	6.5	8.2	14.7	0.79
Serin	0	3.8	16.3	1.07	15.2	18.7	7.3	26.0	2.56
Semongok	0	3.3	17.8	1.31	13.6	44.3	5.9	50.2	7.50
Nyalau	0	4.4	16.5	1.09	15.1	25.6	11.8	37.4	2.16
Butan	0	3.0	25.82	1.62	24.0	n.d.*	n.d.	n.d.	n.d.

Soil series	**Horizon**	**Loss on ignition** 700° C	**Total chemical analyses in % of ash ****						**Loss on ignition** 1000° C
			Fe_2O_3	Al_2O_3	SiO_2	TiO_2	CaO	K_2O	
Gumbang	0	29.3	3.07	8.65	79.50	0.76	3.68	0.04	2.05
Serin	0	40.5	6.15	19.10	69.20	0.81	0.43	0.24	5.07
Semongok	0	54.7	3.00	14.80	75.60	0.92	0.17	0.42	2.94
Nyalau	0	49.2	2.97	10.40	79.10	0.57	0.60	0.63	1.57
Butan ***	0	n.d.	0.20	0.00	60.77	0.08	0.11	n.d.	n.d.

* = not determined

** = ignited at 700° C to remove organic matter

*** = on dry matter basis

Table 30. SiO_2, Al_2O_3 and Fe_2O_3 content of O horizons in comparison with those of the A_1 horizon (clay fraction)

Soil series	Horizon	SiO_2	Al_2O_3	Fe_2O_3
Gumbang	O	79.50	8.65	3.07
	A_1	40.30	29.10	4.38
Serin	O	69.20	19.10	6.15
	A_1	40.40	34.50	7.08
Semongok	O	75.60	14.80	3.00
	A_1	48.40	28.20	5.21
Nyalau	O	79.10	10.40	2.97
	A_1	41.70	27.00	4.92

matter accumulation silica is added to the surface horizons. Variations existing in the absolute amounts are probably influenced by mineral matter present in the samples of the O horizon and no significance can be attached to them.

IV Synthesis

1. Introduction

Part IV of this thesis aims to combine the results of the field and laboratory investigations presented and discussed in a systematic way in Parts I, II and III.

Various conceptions on soil forming processes operating in the soils under discussion have been proposed or suggested, based often on evidence of one or more characteristics revealed by the particular analytical results being dealt with in the relevant section.

These conclusions need to be organized in order that their interrelationships, if existing, can be shown and that a coherent conception of the soil forming processes operating in the soils can be developed in its proper dimensions.

The study presented here started off with a preconcepted idea that the upland soils in West Sarawak formed a range of soils covering a spectrum from lateritic to podzolic features dependent on type of parent rock from which the soils were derived and it was tentatively suggested that the upland soils under the reigning perhumid climate moved through an initial laterization stage towards a podzolic stage upon maturation, the recognizable features thereof being most expressed and most readily developed in the silica-rich soils (see INTRODUCTION).

Much of the reasoning around the pedogenetic processes operating in the soils centres on the terms podzolization and laterization and it is therefore proper to review the generally accepted concepts for these terms before applying these to local conditions.

2. Podzolic and Lateritic processes

Scheffer and Schachtschabel (1970) base their definition of the podzolization process on a review on this subject by Muir (1961) and state that the term means a transportation of the aluminium and iron down the profile together with organic materials and that the process is mostly related to the occurrence of particular plant associations and a very low pH. The downward transportation of organic materials concern mainly low molecular compounds of little changed parts of the fresh organic debris and water-soluble low molecular 'Huminstoffe' (approximately the same as stable humus; Jacks, 1955) leached from the raw humus. These compounds contain organic substances able to complex aluminium and iron, the latter mainly after reduction in the ferrous form, and to transport these elements through the soil. However, colloidal transport cannot be completely discounted and if occurring, is regarded as a continuation of clay illuviation. Since aluminium and iron compounds released by weathering are of small particle size, it is suggested that e.g. polyphenols act as protective colloids for their downward transport.

Precipitation of transported materials is, particularly in the initial stages of podzolization, caused by the higher pH in the subsoil; secondly by an increase in redox potential sothat the organic complexes are able to oxidize. The increase of microbiological activity accompanying the pH increase may also influence the mineralization of the organic complexes and the liberation of the aluminium and iron. Thirdly, drying-out of the subsoil can help to stabilize the organic complexed compounds. Podzolization results in the end in strong horizonation with well-developed A_2 (E), B_h and or B_s (sesquioxides) horizons.

Laterization as reviewed by Sivarasingham et al (1962), Pedro (1964), Magnien (1966), Schellmann (1967) and Sys (1967) as quoted by Scheffer and Schachtschabel (1970) is defined as a chemical process characterised by a strong leaching of silica acid and bases but a relatively much weaker leaching of aluminium and iron, sothat the latter become relatively enriched in the solum (ferralitization process). In places an absolute enrichment in aluminium and iron can take place through precipitation of aluminium and iron eluviated elsewhere. Goethite is the dominant iron oxide and gibbsite the dominant aluminium hydroxide occurring whereas kaolinite and halloysite are the main clay silicates forming in this process. Quartz remains stabile but is also removed in prolonged laterization, whereas in some cases neoformation of quartz may take place.

In the description of a podzolization process Scheffer and Schachtschabel (op cit) do not specifically define the term clay illuviation although elsewhere they infer that it is a process in which both clay particles and weathering products of clays destroyed in the topsoil, are transported downwards and are accumulating in the subsurface horizons.
However the terms 'lessivierung' and 'illimerisation' are specifically used for clay removal in the dispersed form while breakdown of clay and removal of weathering products are excluded. This distinction is also made by French authors who consider 'lessivage' a process in which organic matter is rapidly mineralized but insufficiently humified sothat ligands are formed to mobilize iron, and clay particles can be dispersed (Duchaufour, 1951, 1959, 1970). Also 'lessivage' is defined as the process of migration and deposition of unaltered clay-size particles in the soil profile (CPCS, 1967; van den Broek and van der Marel, 1968 as quoted by de Boer, 1972).

These authors regard 'podzolization' to include breakdown of the clay silicates and removal of the aluminium. Also, the Russian view is one of making distinction between the processes of illimerization in which unaltered clay minerals are involved and podzolization in which breakdown of clay minerals is concerned (Fridland, 1958; Corbunov, 1961; Gradusov and Dyazdevich, 1961). Stobbe and Wright (1959) prefer to view the illimerization process as an initiation process to podzolization.
Mohr et al (1972), in contrast to Mohr (1944) and Mohr and van Baren (1953) in which podzolization and laterization are still regarded as pedogenetic processes very much as has been indicated by Scheffer and Schachtschabel (op cit), consider the two processes as compound ones and prefer to define and discuss the various sub-processes individually since one or more sub-processes may be operating in both podzolization and laterization.

They recognize in podzolization:

a. *a deferritization process* - the formation of organic substances capable of complexing sesquioxides (especially iron) and leaching of the ensuing complexes if the latter are soluble.

b. *a ferritization process* - the accumulation of sesquioxides in the subsurface horizons.

These processes can also be termed cheluviation and would then include the destruction of clay silicates, after a proposal by Swindale and Jackson (1956), and chilluviation.

c. *an argeluviation process* - the purely mechanical removal of unaltered clay from the surface horizon.

d. *an argilluviation process* - the accumulation of clay into the sub-surface horizons.

e. *an organic precipitation process* - the final stage in podzol formation.

Laterization is then mainly characterized by:

a. *a desilication process* - as opposed to deferritization in the podzolization process and indicating both actual and relative accumulation of iron, aluminium and in some cases quartz.

b. *a plinthitization process* - the development of the ability of plinthite to harden upon drying.

Plinthite is the highly weathered mixture of sesquioxides, clay and quartz and various other materials which can be present in the sesquioxide accumulation horizon which when hard in natural condition is called laterite.

From the given reviews it can be concluded that:

(I) The formation of ligands (organic compounds which form complexes with iron and aluminium) and their downward transport resulting in the impoverishment of the surface horizon in iron and aluminium, the breakdown of silicate clays and removal of particularly aluminium, and their subsequent accumulation in subsurface horizons, are generally regarded as essential processes characteristic for podzolization.

(II) The downward movement of unaltered clays by dispersion - thus a mechanical process - and their subsequent accumulation in subsurface horizons is generally regarded as a distinctly separate process, although some authors indicate that possibly this process preceeds podzolization per se (Stobbe and Wright, op cit) while others tend to include it as part of the full podzolization process (Mohr et al, 1972).

(III) Laterization is essentially a desilication process in which iron and aluminium is enriched relatively and/or absolutely but the formation of plinthite is not essential for a soil to be classified as laterized.

3. Soil forming processes operating in the Sarawak Upland Soils

To facilitate a logical discussion of results of the analytical studies the soils had been placed in a sequential order based on SiO_2 content of the parent rock or parent material. This sequence was chosen on account of field observation indicating that with increasing acidity of the parent material podzolic features, such as formation of O, A_2 (E), B_s and B_h horizons become increasingly more apparent and therefore the assumption was made that the intensity of the podzolization process would be related to the amount of fulvic acids produced upon decomposition of the organic matter.

In order not to mix up the issues with too much detail the above stated conception, and with that the sequential order of the studied soils, will be put aside initially.
In this discussion attention will firstly be focussed on the whole group of soils and an attempt will be made to analyse the quality aspect or the nature of the processes operating in all soils. Thereafter we will turn to the quantity aspect or magnitude of these processes in which the soil sequence existing in this group will again be brought to the fore.

The mineralogical evidence clearly shows that all soils are strongly weathered, there being nono or hardly any weatherable minerals left. One would be tempted to try establish some weathering order in the range of soils studied, based on clay mineralogy. However the available field and laboratory data has made it undeniable that the presence of 2-1 minerals are not of relevance to indicate weathering stage or mode of soil formation as may be the case in a monsoonal climate or in topographic basins under which conditions bases and silica may locally accumulate to give rise to neoformation of such clay minerals.

In Sarawak the occurrence of 1-1 or 2-1 lattice clays is solely related to type of weatherable minerals in the parent materials. For this reason, the Semongok or Nyalau series can, because of presence of 2-1 lattice clays, not be considered as being less weathered than e.g. the Tarat series, nor can it be used as an indication to a different soil forming process. With the exception of the Butan series which has developed on a stable dipslope all series have formed in a relative young landscape characterized by strong dissection and steep slopes. In fact, the very selection of the profiles aimed at collecting samples only from soils with identical site characteristics excepting the parent material.
Therefore, based on field and mineralogical evidence it can be stated that all studied soils with the mentioned exception have more or less been exposed to weathering for the same length of time. The variation in visual and intrinsic properties of the developed soil profiles is therefore not so much related to the duration of processes acting upon the soil but rather to the nature thereof (quality and quantity aspect). The chemical composition has indicated that in all soils desilication occurs upon initial weathering of the rock or parent material (transition R to C and B/C horizons) and according to the discussed review on laterization this must be regarded as essentially a part of such a process. In the early stages of rock weathering and soil

formation the base status of the percolating solution is still high and as shown by van Schuylenborgh and co-workers (see section III.C.2), carbonic acid is then the dominant agent in weathering processes. During this stage silicium and, to a less degree, aluminium are soluble, the reaction of the soil being slightly acid and iron and aluminium are able to accumulate relatively to silicium. Since this process appears to be active in all soils it is suggested that in the early stages of soil formation sufficient bases are present for maintaining a weakly acid reaction.

With proceeding weathering under the prevailing perhumid climate leaching will cause a lowering of the base status. The ensuing impoverishment of the organic matter in bases will retard the mineralization process and humification becomes dominant. The formed humus acids will then start to replace the role of the carbonic acids and humic and fulvic acids will become increasingly more active in chelating iron and aluminium. Sufficient lowering of the pH would also influence the mobility of the free iron and aluminium which can then be moved in the soluble form.
The production of fulvic acids in the surface horizons and the related decrease in pH is mainly responsible for the process of iron and aluminium removal which, as evidenced by the analytical data, occurs in all soils studied. Next to the mobilization and removal of these materials from the surface horizons sufficient proof could be accumulated for a process of intensive breakdown of all silicate materials in the clay fraction and removal of particularly the released aluminium but with accumulation of relatively more silicium in the form of gels, thus causing a relative enrichment of silicium in the upper horizons. The chemical composition of the soils illustrate that such a deferritization process is active in all soils. This is, based on the given review, to be regarded as part of a podzolization process which however should also include precipitation and accumulation of removed materials in the lower horizons.

Evidence of any significance for such an accumulation process could not be found in the studied soils. Although the possibility exists that some iron oxides may absolutely enrich the subsurface horizons in the Tarat and Semongok series, this is of low magnitude. The accumulation of some aluminium, however, is more likely and this could be explained by the fact that iron moves predominantly in the chelated form whereas aluminium could also move in an ionic form but would precipitate again in the subsoil because of specific pH ranges not affecting the mobility of iron.

For this reason in none of the soils studied a B_S, however weakly developed, could be found neither by visual observation nor in the analytical data. All soils show a gradual increase in iron with depth without a subsequent decrease indicative for a horizon of absolute accumulation.

'Where has all the iron gone?' laments Mohr in discussing upland soils from Borneo in his work on Soils of Equatorial Regions (1941) and this is also the question now. Why is it that the chelated iron is not accumulating in subsurface horizons due to breakdown of the ligands through oxidation or bacterial activity or by simply a concentrating process due to bad drainage conditions.
Here lies the crucial factor which distinguishes the studied soils from true iron podzols.

In looking for a possible explanation reference is made to section II.1 where it is pointed out that the chemical profile meaning the horizons of eluviation and illuviation greatly extend beyond the normal profile depth studied and that illuviated materials can be found in the permeable rock strata along beddingplanes and in cracks and joints of sedimentary rocks. Thick sheets of limonite have formed in vertical and lateral pathways in otherwise impermeable shales; they are formed at places of abrupt textural changes in sedimentary rocks where coarse sandstones intersect mudstones (see plate 4).

Plate 4 - *Deep exposure of steeply inclined abrupt sandstone (at left)-mudstone (at right) transition. A limonite sheet has formed at a depth of approximately 15 m at the interface.*

The suggestion is therefore made that the chelated iron is able to move down with the percolating groundwater to great depth and is thus removed laterally and vertically from the profile in which it was originally formed to places where the ligands are broken down. Such geo-genetic iron is therefore of pedo-genetic origin.

Relicts of such 'fossil' iron are actually forming an apparent B_s in the Semongok series. This is in fact a stoneline of broken up fragments of referred to iron sheets but the presence of this stoneline may give rise to some renewed precipitation of iron moved down as chelates and the analytical data indicates that this may indeed be the case.

A study of all iron accumulation forms found in Sarawak soils has been taken in hand (Andriesse, in prep.b) and field evidence sofar collected has indicated that precipitation of iron at great depth in the little altered rock is a common feature in all sedimentary rocks underlying the upland soils of Sarawak. The removal of iron in the chelated form from soils formed on igneous rocks and its subsequent precipitation elsewhere would involve studies on movements and chemical composition of ground- and surface waters.

Since all igneous rocks are surrounded by sedimentary rocks it is likely that in some cases a connection may exist between precipitated iron in the sedimentary rocks and removed iron from soils on igneous rocks. There is presently unsufficient data to substantiate this.

The author has indicated earlier in his study on the environment of Podzols in Sarawak (Andriesse, 1969a) that accumulation horizons are only found within the normal profile depth of 1.5 m when an abrupt textural change occurs or with the presence of a high watertable. In none of the soils studied such conditions are fullfilled, the only exception being the Butan series which has a well-developed B_h horizon.

Abrupt textural changes reported from elsewhere are often the result of the development of an argillic horizon (argilluviation). No field nor analytical evidence could be found for the existence of an argillic horizon in the studied soils; the textural change in the Butan could be caused by an already existing one in the sedimentary rocks and it is not of pedogenetic origin.

Field evidence for a purely mechanical removal of unaltered clay from the surface horizon and its subsequent accumulation at depth is not of any consequence in the studied soils. Field studies illustrate that some illuviation takes place through mechanical infiltration along root channels and cracks but the perhumid climate apparently does not allow the soils to dry out sufficiently for the development of sufficient pathways for clay to be removed in suspension through the soil. Even when clay is dispersed in the surface horizon, it is probably more removed through washing-out by run-off water on the generally steeply sloping terrain than through a washing-in process. Next to climate, terrain configuration must be considered an important factor in the development of argillic horizons.

A high water table is not conceivable in the upland soil region with its strongly dissected terrain but it may have occurred in the past in some localities near valleys, and as indicated by the author (Andriesse, 1972) hardened plinthite or laterite can be found there in the Tarat and the Semongok series (see plates 5 and 6). Such soils are anomalous for the area but their existence does indicate the nature of the conditions that leads to accumulations of iron and aluminium oxides.

From the above it can be concluded that the podzolization process in the upland soils amounts under well drained conditions to only a deferritization process as defined by Mohr et al (1972), without being accompanied or succeeded by an argeluviation, argilluviation and/or an organic precipitation process.

A ferritization process is however present if we take into account the deep chemical

B horizons extending far beyond the normal depth at which soil profiles are studied. Thus a normal podzolization process but without preceeding chilluviation is operating in all soils. It may further be concluded that the absence of chilluviation and non-presence of a high water table are reason why a normal horizonation which can be expected from an iron podzol is not found. Intense weathering and leaching which causes a low pH even in the lower subsoil is another reason why precipitation of sesquioxides is of relative small significance. This factor may be of paramount importance in soils under a different climate.

The differentiation of upland soils into series with decidingly different properties is caused by the quantitative aspect of the soil forming processes as discussed, and an analysis thereof will be given in the following section.

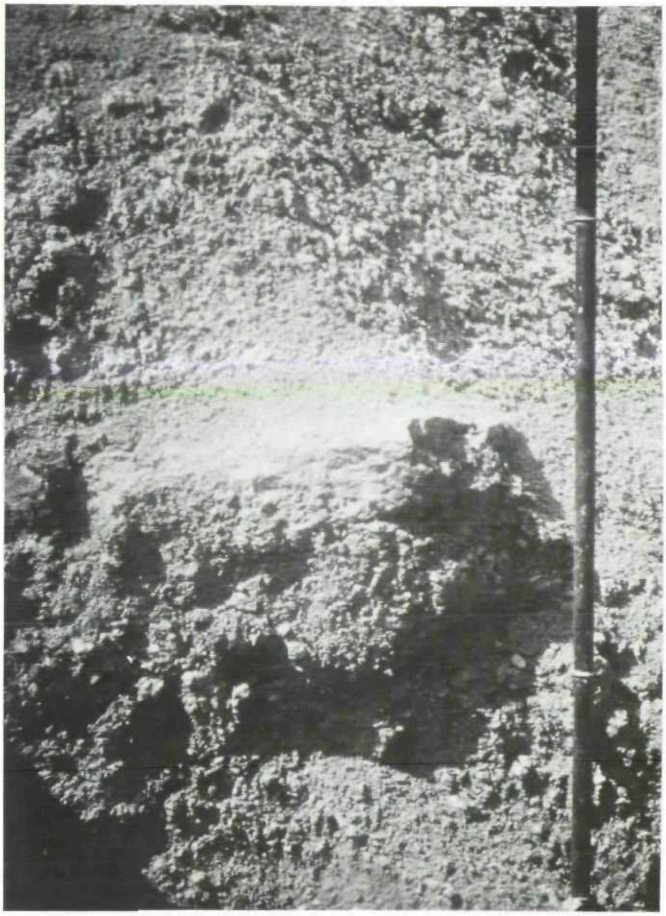


Plate 5 - *Hardened plinthite in Tarat series at a depth of approximately 3 m, caused by a now fossil groundwater level.*

4. Causes for the differentiation in Sarawak Upland Soils

The sequence of soils selected for this study covers a range of soils classified as Lateritic (Tarat series), Red-Yellow Podzolic (Gumbang, Serin, Semongok, Gading and Nyalau series) and as a Podzol (Butan series). It has been shown that all soils in this sequence are subjected to the same soil forming processes. How then can the different horizonation and variable chemical properties be explained?

The mineralogical and chemical data of the soils show that the formation of fulvic acids, the magnitude of iron and aluminium mobility and clay breakdown is not necessarily increasing with the order of soils in the sequence. The Tarat series, although showing by visual observation least podzolization shows perhaps the formation of most fulvic acids and the strongest clay breakdown.

Plate 6 - *Honeycomb hardened plinthite in Semongok series at a depth of approximately 5 m, caused by a now fossil groundwater level.*

It is therefore not the magnitude of the processes which differs in the soils but as has already been surmised initially, the material which is acted upon is dissimilar, chemically and mineralogically.

The original content of iron and aluminium in the parent rock sets a limit to the amount which can accumulate through the initial desilication process, particularly since in this process only a relative accumulation is involved. For this reason in the Tarat series developed on basic igneous rocks, values of 25% for total iron can be attained, whereas those for the other series can range only from 8 to 2%.

A removal through the chelating activity of say 2% in the surface horizon would in materials originally poor in iron cause a considerable bleaching and development of an albic or A_2 horizon. The removal of the same amount of iron from the surface horizon of the Tarat would not give any discolouration effect. The existing relation between iron content of parent material and soil horizonation can thus be explained; the Tarat having the highest Fe_2O_3 values in parent material and soil, shows no horizonation at all whereas the Butan series at the other end of the sequence has the most strongly developed horizonation, followed by the Nyalau, the others being intermediate.

A second factor having a profound influence on horizonation is the leaching rate. Soils with coarse texture are more easily leached than clay soils and the same is true for soils with an open structure as opposed to soils which are densely structured.

As far as texture is concerned the Butan, Nyalau and Gading can be considered soils with a high leaching rate because of coarse texture, whereas the Tarat may have a high leaching rate because of its open structure. The soil texture developing upon rock weathering and soil formation is much related to type of parent material. Rocks with a high content of weatherable minerals give rise to soils with a high clay content, rocks with a high content of quartz such as granites and sandstones give rise to coarse textures. Therefore in the given soil sequence the leaching rate can be almost directly brought into relation with the quartz content of the parent rock, the exception being the Tarat series, in which owing to the high content of free iron oxides the structure has remained very open.

From the above it can be concluded that the combined effect of the original iron content and the differences in leaching rate each being related to the parent material is the main reason for the ensuing variations in horizonation developing in the soils under study.
Increased podzolization in the sequence is therefore not the result of an increase in magnitude of the processes but rather the impact of the processes is increasingly more strongly apparent due to decreasing iron content and increase of leaching rate.

The cation content of the parent materials does initially play a role in soil formation because the transition – mineralization to humification of organic matter – is slower in soils on parent materials with a high base content but is not able to prevent podzolization in the end. Nevertheless, a high content in bases may slow down the process.

The frequently observed gradual clay increase with depth apparent in many tropical soils of humid regions (Brugière and Marius, 1966; Marius and Misset, 1968 as quoted by de Boer, 1972) is also present in the sequence studied.

The removal of clay from the A horizon with no correlative accumulation at lower depth, called 'appauvrissement' by de Boer (op cit), needs explanation.
From the present study it can be concluded that in Sarawak soils four factors are involved:

1. Clay is constantly broken down through weathering owing to the aggressive humus acids, and individual components, Al_2O_3 and SiO_2, are respectively removed and remain in situ. Possibly the SiO_2 initially deposited as gel in the surface horizons but also at lower depth, is partly recrystallized as chalcedony and ends up in the silt or sand fraction.

2. Iron originally present in the clay fraction is removed through chelating by organic acids. Free aluminium possibly present as gibbsite in this fraction is mobilized likewise but could also go into solution at a sufficient low pH. The Fe_d/clay ratios reported in Figs. 28a and 28b illustrate a close relation between total iron and clay content.

3. Surface-wash through dispersion and removal by run-off water is likely to occur. De Boer (op cit) indicates that bioturbation through which constantly fresh material is supplied to the immediate surface would also play an active part in this process.

4. Granulation, the formation of pseudo-sand through cementing of clay and silt particles by organic matter and possibly gels (SiO_2 and possibly some iron) is active in surface soils. This would cause a shift from fine to coarse particles mainly apparent in the field texture and laboratory texture if determined without the use of H_2O_2. The pseudo-sand grains appear to be largely destroyed by H_2O_2 treatment.

5. Conclusion

The consequence of the nature of the soil forming processes which are found to operate in the upland soils is that ultimately no soil can escape podzolization, providing a sufficient leaching rate is maintained and alteration of the landscape is not rejuvenating the profile in time.
With podzolization is then meant the destruction of all clay material in the surface horizon, the removal of sesquioxides and the development of an albic horizon. The accumulation at lower depth of sesquioxides or organic matter must be regarded as a separate process which occurs only within normal profile depth if certain conditions are present. Argilluviation may likewise be a process related only to local environment. This 'deferralitization' process as we propose to call it may cause also a differentiation into three zones, a relatively enriched silica zone in the surface (1), an absolutely enriched aluminium zone below (2) and an absolutely enriched iron zone (3) at still greater depth. Zones (2) and (3) are then the result of small differences in pH range, but are not necessarily located in the top 1.5 m of the profile.

In temperate climates 'deferralitization' starts early in soil formation due to specific vegetation types induced by severe climatic conditions and the strong humification of the acid organic matter formed. This also causes strong pH differences between surface and subsurface horizons which help to create conditions for the development of sesquioxide accumulation horizons at shallow depth. Also, because there is no initial desilication stage, less aluminium and iron need to be removed for causing a bleached A_2 (E) horizon.

In warm humid climates the profile is allowed to pass through a full desilication stage until the pH has dropped sufficiently through the leaching of most bases to allow humification to play its role. Initial content of iron and bases, and intensity of the desilication process retard the process. During its full coarse of soil development or rather complete destruction of mineral matter with possible exception of minerals strongly resistent to weathering, the profile is constantly exposed to changing environmental factors which cause deviations or retardations from the set course, such as the development of an argillic horizon, plinthite and laterite. Landscape configuration could introduce accumulations of bases and oxides through influx from other sources and leaching is then not allowed to exert its effect again on the profile until the landscape has changed. The ultimate soil, if it exists, is found on very old landscapes but since these revert again to dissected ones, recycling of that soil material is the consequence of attaining old age. Quite possibly most of the quartzitic sands of the Tertiairy sedimentary rocks in Sarawak in which only zircon, tourmaline and titaniferous minerals are present, may be relict material of soils gone through a weathering process as indicated. The present soil formation on such materials represents then only recycling stages in which 'deferralitization' is occurring at a more rapid pace than in the initial cycle.
The presence of Humus Podzols formed on the deposits of eroded soils of this new cycle of upland soils (Andriesse, 1969a) would indicate that in the third cycle full deferralitization is even more rapidly attained than in the second one.

Therefore, the purpose of the study of soil formation is to pinpoint at which stage in what cycle the soil is at the present moment, and to find out what conditions have caused retardation and deviation from the path leading to the one ultimate end, which is total destruction if material is not assimilated earlier by metamorphosis subsequent to sedimentation.

6. Classification

In Table 31 the 7 studied soils are classified at the Great Soil Group level in chronological order according to respectively a tentative scheme by Dames for Sarawak soils (1962), a classification of South-East Asian soils (Dudal and Moormann, 1964), the 1st official Soil Classification Scheme by Soil Survey Staff of Sarawak (1966) and the FAO/UNESCO legend of the World Soil Map (Dudal, 1968).

As illustrated by this table much confusion exists on the terminology Latosol, Red-Yellow Podzolic and Lateritic.

The basic definition for Red-Yellow Podzolic soils is derived from the former US Soil Classification System by Thorp and Smith (1949) and reads: 'A group of well-developed, well-drained acid soils having thin organic (A_0) and organic mineral (A_1) horizons over a light colored bleached (A_2) horizon, over a red, yellowish-red, or yellow and more clayey (B) horizon. Parent materials are all more or less siliceous. Coarse reticulate streaks or mottles of red, yellow, brown and light grey are characteristic of deep horizons of Red-Yellow Podzolic soils where parent materials are thick'.

Table 31. Classification of major upland soils in West Sarawak according to local and regional schemes and the FAO/UNESCO soil legend

Soil series	**Dames** (Sarawak) 1962	**Dudal and Moormann** (S.E. Asia) 1964	**Soil Survey Staff** (Sarawak) 1966	**FAO/UNESCO** (World) 1968
Tarat	Yellow Latosol	Reddish-Brown Latosol	Lateritic Soil	Helvic Ferralsol
Gumbang	Yellow Latosol	Red-Yellow Latosol	Red-Yellow Podzolic	Ochric Ferralsol
Serin	Red-Yellow Podzolic	Red-Yellow Latosol	Red-Yellow Podzolic	Ochric Ferralsol
Semongok	Red-Yellow Podzolic	no equivalent	Red-Yellow Podzolic	Ochric Cambisol
Gading	Yellow Latosol	Red-Yellow Latosol	Red-Yellow Podzolic	Ochric Ferralsol
Nyalau	Red-Yellow Podzolic	Red-Yellow Latosol	Red-Yellow Podzolic	Ochric Ferralsol
Butan	Humus Podzol	Podzol	Podzol	Humic Podzol

In the same system the term latosol is not well-defined but appears to be reserved for soils formally called lateritic having no podzolic morphology but which are chemically rather similar to the Red-Yellow Podzolics.

Although the referred to 1949 US classification does not specifically mention the necessity for Red-Yellow Podzolic soils to have a horizon of clay illuviation, the original soils from which the name is derived and occurring in the south-eastern United States do have a B_t horizon (McCaleb, 1959) and much of the confusion which has arisen on the name Red-Yellow Podzolic roots in this fact.

Dames (1962) although recognizing the podzolic morphology of many of the upland soils of Sarawak (the bleached A_2) assumed the existence of a B_t or he strictly adhered to the original definition which only refers to a higher clay content in the B but in which a subsequent decrease is not mentioned. For this reason all soils having no bleached A_2(E) are according to this scheme classed as latosolic and all others with a bleached A_2(E) horizon as Red-Yellow Podzolics, excepting the Humus Podzol which classification is based on the well-developed O, A_2(E) and B_h horizons.

Dudal and Moormann (op cit) explicitly mention that the Red-Yellow Podzolic

soils should have a B_t horizon but recognize the fact that not in all soils an A_2 horizon need be present. The emphasis has therefore shifted from the podzolic horizonation to clay illuviation. For this reason no soils in Sarawak can be placed in this scheme as Red-Yellow Podzolics and they have become Latosols.
Since Latosols must be well-drained and well-structured, many of the upland soils of West Sarawak are not well-placed in this group because structure is usually not well developed but this may be an effect of the perhumid climate. The Semongok series has a silica/sesquioxide ratio of the clay fraction over 2 while also the CEC of the clay is over 20 meq./100 g. Because these defined parameters for Latosols are surpassed and no other soil groups with the properties of the Semongok is distinguished, this series cannot be classified in this scheme.

The Soil Survey Staff of Sarawak (op cit) has attempted to bring existing nomenclature in line with diagnostic features as recognized and defined by the 7th Approximation of the USDA Taxonomic soil classification system (Soil Survey Staff, USDA, 1960, 1967, 1970). In their official classification scheme are the Red-Yellow Podzolics defined as soils having an argillic horizon. At that time (1966) the assumption that a B_t was indeed present in most soils still persisted and a B_t was taken to be synonymous for an argillic horizon.

It is in fact the Legend for the World Soil Map in which the soils can be most satisfactory placed since it is not tied to so many detailed diagnostic properties as is the case with the 7th Approximation of the USDA system referred to.
An adoption of the latter system in Sarawak has hitherto given rise to serious problems. The rigid adherence of this classification to defined criteria and the adoptation of certain parameters for analytical values based on standardized analytical methods provides on the one hand a firm unbiassed basis for classification, on the other hand in the absence of such information the system cannot be adopted overnight.
The existence of an argillic horizon which was thought to be present based on field evidence, could not be proven by textural analyses nor by micro-morphological studies on thin sections sofar carried out (Andriesse, 1972). For this reason the Order of Ultisols is non-existent in the major upland soils, at least, former studies and the present one give no indication of their presence and evidence from elsewhere would show the illogic of expecting their occurrence in Sarawak since they are usually found in quite old landscapes with a climate having strong seasonal characteristics.

What about the presence or non-presence of an oxic or cambic horizon diagnostic respectively for Oxisols and Inceptisols? The distinction of these horizons is based on differences in base exchange capacity, amount of weatherable minerals present, water-dispersable clays and other criteria. It appears that for the Sarawak Upland Soils threshold values for the adopted parameters are more rule than exception and slight variations may bring one and the same soil series in either the Inceptisols or Oxisols depending on the analytical method used.
Therefore routine analyses which are commonly not identical to those advocated by the 7th Approximation can frequently not be used and this necessitates the need for specific analytical data. An added difficulty which has been given very little attention in this classification system is, that it bypasses the fact that the full

horizonation of well-developed soils exceeds in tropical regions by far the 1.5 m profile depth which is being classified.
The results of this study have also indicated that illuviated horizons can be expected to occur at great depth. It is realized that the 7th Approximation is not a genetic system, but the criteria adopted for a differentiation into Orders and for a choice of diagnostic horizons imply that it is however strongly influenced by genetic considerations. A classification according to the 7th Approximation is therefore difficult and does not reveal much of the genetic relationship which exists.

The Tarat series can without problems be placed in the Order of Oxisols since it contains a well-developed oxic horizon. Soil climate brings the series in the suborder of Orthox. Because of the CEC of the clay being more than 1 meq./100 g in the subsoil, absence of gibbsite sheets or gravel size aggregates, and the base saturation being less than 35% and carbon being less than 1% in all horizons, the profile is classed as a Haplorthox. It has further all the characteristics for an appropriate placing in the subgroup of Typic Haplorthox.

The Gumbang series contains only a few weatherable minerals and the subsoil would qualify for an oxic horizon were it not for the high content of water-dispersible clays which is anomalous for an oxic horizon. Also the CEC of the clay is only marginally representative for an oxic horizon considering the fact that it has been determined at the pH of the soil. Also base saturation is higher than usual for an oxic horizon. Apparently the soil is very much an intergrade and since the general impression is that the subhorizon is more a cambic than an oxic one the soil has been put in the Order of Inceptisols. Because of the soil climate and low base saturation it is placed in the great group of Dystropepts, whereas the low CEC is reason for classifying the profile as an Oxic Dystropept.

The Serin series has an oxic horizon. Although it contains some 2-1 lattice clay minerals its content in the subsoil is insufficient to qualify for a cambic horizon. Also the CEC is too low. For similar reasons as given for the Tarat series is the Gumbang placed in the great group of Haplorthox but because of its better developed structure in the dry state it is classified in the subgroup of Tropeptic Haplorthox.

The Semongok series does not contain an oxic horizon. This is clearly illustrated by too high a content of 2-1 lattice clay minerals, high CEC, high water-dispersible clay content throughout the profile and well-developed structure when dry. The presence of a stoneline containing weathered shale pieces and concretionary iron is also contrary to the qualification of a horizon to be oxic.
Base saturation, however, is exceedingly low and more diagnostic for an oxic horizon than a cambic one. Here is again an example of the frequently referred to transitional nature of the characteristics of the upland soils. It is suggested that the anomalous nature of the subsurface horizons is caused mainly by the parent materials containing a considerable content of 2-1 lattice clays in themselves but having apart from some micas no weatherable minerals. The high content of the mixed-layer clays is therefore the only cause for the presence of a cambic horizon and for placing this series into the Order of Inceptisols. On account of soil climate the Semongok is put into the great group of Dystropepts and, because it has all the

characteristics of this subgroup, into the subgroup of Typic Dystropepts. The mottled appearance of the subsoil which may at first sight be related to aquatic conditions shows at closer study to be more connected with a change-over from grey-coloured parent material to yellow-coloured homogenized soil material and has therefore not been taken as being diagnostic for an Aquept.

The subsoil of the Gading series has all the properties of a well-developed oxic horizon: no water-dispersible clay, weakly developed structure, CEC of clay lower than 16 meq./100 g, virtually no weatherable minerals and low base saturation. This series is therefore appropriately classified as an Oxisol. For the same reasons as given for the Tarat series the soil belongs to the great group of Haplorthox. The texture is transitional between a Typic and a Psammentic Haplorthox, but because of its strong textural contrast with the commonly occurring local Typic Haplorthox, the soil would be most properly placed in the Psammentic subgroup.

The Nyalau series, has, as is the case with the Semongok series, a moderate content of mixed-layer clays but the CEC of the clay is barely above the higher limit of that of an oxic horizon. It however contains no water-dispersible clays, no weatherable minerals excepting a moderate content of mixed-layer clays, has a low base saturation and weakly developed structure. The subsoil would therefore qualify more for an oxic than a cambic horizon, the content of 2-1 lattice clays being responsible for the CEC of the clay being somewhat higher than the allowable limit. For reasons as given for the Gading series this soil is also classified as a Psammentic Haplorthox. In fact, the only difference between the Gading and Nyalau at this level of classification is the higher sesquioxide content of the former.

There is no difficulty to place the Butan series into the Order of Spodosols, a well-developed albic and spodic horizon being present. It is periodically saturated with water but has no characteristics associated with wetness because of the almost complete lack in iron and manganese. Therefore the profile can be classed in the suborder of Humods instead of Aquods. The climate places this soil into the great group of Tropohumods and since it has all the characteristics typical for that group it is finally classified as a Typic Tropohumod.

Some final remarks conclude this subject.
One of the aims of the present study was to comply with the frequently made request by the compilators of the U.S. Taxonomic soil classification system (Soil Survey Staff, 1960, 1967, 1970) for more detailed studies on specifically tropical soils sothat the system could be tested on its value for Tropical regions.
The results of the study have shown that indeed such studies are of great necessity and prove that conditions in tropical soils can be such that only after radical changes in this now too rigid framework all tropical soils can be satisfactory accommodated.
The present parameters laid down for e.g. cambic and oxic horizons lead to a separation at the order level of practically almost identical soils. This example is in the Tropics by no means an anomaly and forfeits the purpose of classifying soils. The system also bypasses the fact that an albic horizon can be present without the concurrent presence of a spodic horizon within the normally studied profile depth.

Summary

As a follow-up of 10 year intensive field studies in West Sarawak, a sequence of carefully selected upland soils has been subjected to a thorough analytical study in order to unravel the genetic relationship between its members, but specifically to find analytical evidence for the qualitative and quantitative aspects of the dominant influence of parent material on soil differentiation within the sequence.

This sequence consists of seven soils: one locally so-called Lateritic Soil, five Red-Yellow Podzolic Soils and one Humus Podzol.
They are placed in the order of increasing SiO_2 content of the parent rock or parent material, these being: a basalt, quartz andesite, arkose, shale, adamellite (biotite granite) and quartz sandstones.

In part I of the study an evaluation is given of the soil forming factors. The climate is typical for a tropical humid lowland and, under a cover of dense primary tropical rainforest, it allows a surplus of precipitation to leach the soil continuously, or at least keeps it moist throughout the year. For pedo-genetic purposes the local climate can be regarded as a constant factor.
The terrain is moderately to strongly dissected, but the modal profiles have all been selected from places where mass movement of soil along slopes, the most active form of erosion in the Region, has not disturbed the profile horizonation.
The field investigations dealt with in part II indicate that this is in general only the case near the crest of hills.

In part III the results of the analytical studies are discussed. Although the landscape has juvenile characteristics, the sand and silt mineralogy show that all soils are highly weathered, there being hardly any weatherable minerals left in the soils studied.
The clay mineralogy shows variations in composition for the seven soils, due to differences in parent material: basalt gives rise to poorly crystallized kaolinite with halloysitic tendencies, sedimentary rocks give admixtures of 2-1 lattice clay minerals or they are dominant, particularly in the case of shale. This can be related to presence of micas in the parent rocks.

Other parent materials give mainly moderately well-crystallized kaolinite while only the soil on adamellite contains also a fair amount of gibbsite.

Instability of the kaolinitic clay minerals was proven by 0.5 N NaOH extraction. The presence of silica gels particularly in surface horizons which could be illustrated by DTA and Infrared absorption analysis, and the absence of amorph and crystalline aluminium oxides form evidence that in these horizons a process of clay breakdown, followed by removal of the aluminium, is active.
The chemical composition of the soils shows that upon rock weathering an initial desilication process takes place in all soils. This consequent accumulation of iron

and aluminium in the B- and B/C horizons is succeeded by a removal again of the same components in the surface horizons. The TiO_2 content of the clay fractions provide also evidence that such a process is operating in all soils.

The results of the selective iron and aluminium extractions corroborate these findings but do also indicate that iron is mainly mobilized in the organic complexed form but without subsequent precipitation and accumulation in the B horizon, while aluminium appears to be also partly mobilized in the ionic form and is able to precipitate in the B horizon as a result of critical pH differences between top and subsoils.
The values obtained for water-soluble silicon, iron and aluminium would also point in a similar direction.

A fractionation of the organic part of the soils showed that in all soils fulvic acids are dominant over humic acids, this being particularly so in the subsoils.
The dominant role of fulvic acids in the removal of iron from these profiles is extensively treated in an analysis of podzolic and laterization processes given in part IV of this study. As a result of this analysis, it can be stated that in all soils studied podzolic processes, or at least those processes playing a role in the development of the podzol morphology are dominant.
These processes are locally characterized by breakdown of clay mineral matter in and removal of sesquioxides from, the surface horizons, absence or near-absence of absolute iron accumulations, but presence of some aluminium accumulation in the B horizon. However, no evidence for clay leaching could be found.

It is concluded that under the prevailing environmental conditions the chemical and mineralogical composition of the parent material has a dominant influence on the soil texture and thereby controls the leaching rate. This composition also decides the magnitude of the sesquioxide concentrations in the C and B/C horizons formed upon the initial desilication process. Furthermore, in soils developed on cation-rich parent rocks the formation of fulvic acids takes place only upon prolonged leaching.

The presence or absence of an albic horizon, as a result of iron leaching, is therefore strongly related to the nature of the parent material and its formation becomes first apparent in the soils developed on parent rocks with the highest quartz content which commonly combine coarse texture with a low cation and low iron content.

Although clay breakdown and iron leaching appear to occur also in the soils over basalt, an albic horizon has not (yet) formed because of the very high iron content of the solum due to the initial desilication process.
Absolute iron accumulation horizons commonly found at shallow depth in podzolic soils in temperate regions locally develop only under specific conditions and are mainly found at great depth in cracks and joints of sedimentary rocks, probably as a result of breakdown of the chelated iron compounds moved down vertically and laterally through path-ways of percolating groundwater.
Based on the results of this study the hypothesis is propounded that removal of all iron and aluminium from surface horizons (deferralitization) is the ultimate fate of all soils, providing that the leaching rate can be maintained and the landscape does

not change to such an extent that the process of continuous leaching is replaced by some other process.

A critical analysis of the classification problems of the Red-Yellow Podzolic soils in general and those of the studied Region in particular closes the subject. An attempt to classify the soils according to the USDA Taxonomic system meets difficulties of a structural nature, e.g. in the classification framework no recognition is given to the fact that an albic horizon can be present without the concurrent formation of an illuviation horizon within the adopted profile depth limits.

Samenvatting

In aansluiting op een tien jaar durende periode van intensieve veldstudies in West Sarawak werd een sequentie van zorgvuldig uitgezochte heuvelgronden onderworpen aan een diepgaand onderzoek, dat tot doel had de genetische samenhang van de bodemtypen binnen de sequentie uiteen te zetten. In het bijzonder was deze studie gericht op het verkrijgen van analytisch bewijsmateriaal met het doel de kwalitatieve en kwantitatieve aspekten van de dominante invloed van moedermateriaal op de bodemdifferentiatie te belichten.

Deze sequentie van zeven bodemseries bestaat volgens de lokale klassificatie uit: één 'Lateritic Soil', vijf 'Red-Yellow Podzolic Soils' en een 'Humus Podzol'. Zij werden gerangschikt volgens een toenemend SiO_2 gehalte van het moedermateriaal, te weten: bazalt, kwarts-andesiet, arkose, schalie, adamelliet (biotiet graniet) en kwarts-zandsteen.

In het eerste deel van deze studie wordt een evaluatie gegeven van de bodemvormende faktoren. Het gebied heeft een tropisch regenklimaat en een daarmee samenhangend bosbestand van tropisch laagland regenwoud, waardoor gedurende het gehele jaar een overmaat van neerslag beschikbaar is voor het onderhouden van een konstante uitloging van de bodems, in ieder geval voldoende om uitdroging tegen te gaan.
Geconcludeerd wordt dat het lokale klimaat, bodemgenetisch gezien, als een konstante faktor kan worden beschouwd.
Het terrein is zeer geaccidenteerd, maar met het oog op de betrouwbaarheid van de aanwezige horizonatie werden alle bestudeerde profielen zo geselecteerd, dat de invloed van massa-beweging langs de hellingen kon worden uitgesloten.
De veldstudies, nader uitgewerkt in deel twee, wijzen namelijk uit dat ongestoorde profielen alleen dicht bij de heuveltoppen kunnen worden aangetroffen.
Het derde gedeelte behandelt de resultaten van het analytisch onderzoek. Alhoewel het landschap de indruk vestigt van geringe ouderdom te zijn, blijkt echter uit de mineralogie van de zand- en stoffracties, dat alle gronden sterk doorverweerd zijn. Het kleimineralogisch onderzoek toont aan dat variaties aanwezig zijn in de mineralogische samenstelling van de zeven gronden. Dit is terug te voeren tot verschillen in moeder-materiaal: de bazalt bodem bevat slecht gekristallizeerd kaoliniet met sterk halloysiet-achtige eigenschappen, en de gronden op klastische afzettingsgesteenten, met name de schalies, vertonen naast kaoliniet een sterke bijmenging tot dominante aanwezigheid van 2-1 rooster kleimineralen.
De vorming van de laatste componenten kan worden verklaard uit het voorkomen van mica-bestanddelen in de sedimentaire gesteenten. De gronden op andere moedermaterialen hebben in hoofdzaak matig goed gekristallizeerd kaoliniet als hoofdbestanddeel, terwijl slechts in de graniet bodem een belangrijke hoeveelheid gibbsiet wordt aangetroffen.

Een behandeling met 0.5 N NaOH toonde aan dat de aanwezige kaolinitische materialen, met name die in de bazalt bodem, zeer onstabiel zijn.
De aanwezigheid van siliciumgelen, vooral in de bovengronden, die door DTA en Infra-rood absorptieanalyse kan worden geillustreerd, en de afwezigheid van amorfe en kristallijne aluminiumoxiden zijn aanwijzingen dat in de bovengronden afbraak van kleimineralen, gevolgd door een selectieve verwijdering van de aluminium bestanddelen heeft plaatsgevonden.

De totaal chemische samenstelling laat zien dat in alle profielen bij het verweringsproces in eerste instantie silicium wordt uitgespoeld, zodat een relatieve aanrijking van ijzer en aluminium in de C- en B/C-horizonten optreedt. Dit proces wordt gevolgd door één van ijzer en aluminium verarming in de bovenste horizonten, hetgeen ook duidelijk blijkt uit het verloop van de TiO_2-waarden van de kleifracties in het profiel.
Deze verarming aan sesquioxiden wordt eveneens aangetoond door middel van selectieve ijzer- en aluminiumextracties die er tevens op wijzen dat ijzer in hoofdzaak in beweging wordt gebracht in de organisch-complexe vorm.
Deze ijzer-chelaten worden uitgespoeld uit de A-horizonten, maar blijken niet uit te vlokken in de B-horizonten.
Aluminium daarentegen, wordt, naast verwijdering in de organisch-complexe vorm, ook uitgespoeld in de ion-vorm en kan door de kritische pH verschillen tussen boven- en ondergronden wel uitvlokken in bepaalde profielen.

De resultaten van de water-oplosbare silicium-ijzer- en aluminium-bepalingen wijzen in eenzelfde richting.

Een fraktionatie van de organische stof in deze gronden levert het bewijs dat fulvozuren dominant aanwezig zijn boven huminezuren; dit is speciaal het geval in de ondergronden.

In het vierde gedeelte, dat min of meer een synthese vormt van de veld- en analytische studies wordt de dominante rol van de fulvozuren in het uitlogingsproces van ijzer uitvoerig belicht. Uit een analyse van de beschikbare literatuur over podzolizatie- en laterizatie-processen blijkt dat bij de vorming van alle gronden in de bestudeerde sequentie het podzolizatie-proces centraal staat.
Dit proces is lokaal gekenmerkt door afbraak van kleimineralen en verwijdering van de sesquioxiden in de bovengronden, enige accumulatie van aluminium in de B-horizonten en afwezigheid of zeer geringe aanwezigheid van ijzeraccumulaties in deze horizont. Klei-inspoeling echter kon in geen van de gronden worden aangetoond.

Geconcludeerd wordt, dat onder de gegeven omstandigheden de chemische en mineralogische samenstelling van het moedermateriaal de belangrijkste faktor vormt bij het bepalen van de textuur van de bodem en daardoor een grote invloed heeft op de uitlogingssnelheid.
Daarnaast is deze samenstelling ook van invloed op de absolute grootte van de sesquioxide-accumulatie in de B- en B/C-horizonten gedurende de initiële bodemvorming. Ook worden in gronden op moedermaterialen die rijk zijn aan basen slechts na voortdurende uitloging fulvozuren gevormd.

Derhalve wordt het al of niet aanwezig zijn van een 'albic horizon', als een gevolg van ontijzering, in hoofdzaak bepaald door het moedermateriaal. De sterkste ontwikkeling vindt plaats op gronden gevormd in materiaal met het hoogste kwartsgehalte, wat in de praktijk gepaard blijkt te gaan met een zeer laag initieel ijzergehalte.

Alhoewel klei-afbraak en in mindere mate ontijzering ook plaats vindt in de bazalt bodem is het hoge gehalte aan initieel geaccumuleerd ijzer in de B- en B/C-horizonten er de oorzaak van dat visuele kenmerken van ontijzering (nog) ontbreken.

Het proces van ijzeraanraking binnen normale profiel diepte dat in podzolen van gematigde streken een normaal verschijnsel is, blijkt in het bestudeerde gebied alleen op te treden onder specifieke omstandigheden, en wel op zeer grote diepte in scheuren en spleten van afzettingsgesteenten.
Laterale en verticale afvoer van organisch-complex gebonden ijzerverbindingen kan door middel van grondwater plaats vinden tot op zeer grote diepte alwaar de omstandigheden gunstig blijken te zijn voor afbraak en het ijzer kan precipiteren en accumuleren.

Gebaseerd op de resultaten van deze studie wordt de stelling geponeerd, dat het eindstadium van iedere bodem gekenmerkt wordt door een totale verarming aan ijzer en aluminium (deferralitization), voorop gesteld dat aan de voorwaarde van onafgebroken uitloging wordt voldaan en het landschap geen ingrijpende veranderingen ondergaat gedurende dit proces.

Deze studie wordt afgesloten met een kritische analyse van de klassificatie problemen betreffende de Red-Yellow Podzolic Soils in het algemeen en die van het bestudeerde gebied in het bijzonder. De genese van de lokale Red-Yellow Podzolic Soils blijkt af te wijken van het concept zoals geformuleerd in de Verenigde Staten.

Een poging de bestudeerde gronden te plaatsen in het nieuwe Amerikaanse Taxonomische systeem van bodemklassificatie stuit op problemen van structurele aard, zoals het niet onderkennen van het feit dat een 'albic horizon' zich kan ontwikkelen zonder de gelijktijdige formatie van een illuviatie horizont binnen de gestelde dieptelimiet.

Appendix I

Soil Profile Descriptions and Analytical Information

Note: Descriptions follow guidelines suggested by FAO (1966); horizon designations those proposed by FAO/UNESCO (1974).

1. Tarat series

Local Soil Group: Lateritic soil.
Family: Tarat.
Series: Tarat.
7th Approximation: Typic Haplorthox.
Location: Gunong Sedong-Serian District.
Latitude: 1°12′ N.
Longitude: 110°29′ E.
Site: Upper slope of steep ridge (approx. 25-30°).
Parent material: Weathered strongly altered basalt.
Vegetation: Very old secondary forest resembling Primary Forest. Undergrowth mainly ferns.
Rainfall: Mean annual rainfall 3500 mm without any month with less than 100 mm.
Altitude: 150 m.

O Thin layer of very irregular thickness of decomposed and fresh leaf material; thoroughly rooted; abrupt boundary to

A_1 0-8 cm: brown (10YR/3), moist, loam; strong crumbly to fine subangular blocky; friable; many, fine roots; clear, smooth boundary to

B_1 8-28 cm: yellowish red (5YR5/8), moist, clay loam; weak, fine subangular blocky to weak crumbly; friable; many, medium and fine roots; some infiltration from surface material into cracks; few pieces of strongly weathered rock; gradual, wavy boundary to

B/C 28-54 cm: reddish yellow (5YR6/8), moist, clay loam; structureless, massive; slightly firm; few decomposed medium roots; increasingly more pieces of strongly weathered rock coloured black (5YR2/1), weak red (10YR4/3) and light olive brown (2.5Y5/4); diffuse, wavy boundary to

C 54-100 cm: reddish yellow (5YR6/8), moist, clay loam to clay; accumulation of large, strongly weathered rock pieces of stone size coloured black, red and greenish grey; structureless, massive; firm.

Note: upon drying strong, crumb structure develops in A_1 *horizon and strong, subangular blocky structure in the B, B/C and C horizons.*

Laboratory data Tarat series

		Particle size distribution in μm % dry fine earth							
		Sand				Silt	Clay		
Depth in cm	Horizon	2000-500	500-250	250-100	100-50	50-2	<2	waterdisp. clay	Laborarory texture
0 - 8	A_1	8.5	3.5	2.8	0.4	62.2	22.6	20.14	silt loam
8 - 28	B_1	4.2	1.7	1.7	0.9	38.9	52.6	39.65	clay
28 - 54	B/C	4.0	1.3	1.2	0.7	33.5	59.3	-	clay
54 - 100+	C	1.3	0.6	0.6	0.3	34.8	62.4	-	clay

	pH 1:5		Exchangeable cations in meq/100 g fine earth								
Horizon	H_2O	KCl	Ca	Mg	K	Na	Al	Sum	CEC (unbuf.)	CEC (pH 8.2)	Base sat. %
A_1	5.6	4.5	17.3	3.00	0.69	0.18	0.62	21.79	20.2	38.6	100
B_1	5.0	4.2	2.45	1.10	0.37	0.11	1.25	5.28	5.44	19.7	74
B/C	5.3	4.8	1.93	0.68	0.27	0.11	0.29	3.28	4.50	15.0	66
C	5.3	5.0	1.55	1.82	0.14	0.15	0.16	3.82	5.06	13.3	72

	% dry fine earth			$^{0}/_{00}$ of C		
Horizon	C	N	C/N ratio	Humic acid	Fulvic acid	Humic/Fulvic acid ratio
A_1	4.61	0.48	9.6	6.9	8.2	0.84
B_1	1.40	0.18	7.8	2.0	11.2	0.18
B/C	0.93	0.10	9.3	2.7	7.8	0.35
C	0.44	0.05	8.8	2.0	5.2	0.39

	elemental composition of fine earth in %								Molar ratios			
Horizon	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	K_2O	Loss on ignition	Sum	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
A_1	36.7	20.1	18.7	3.10	0.52	0.17	21.9	101.2	4.85	3.33	1.97	1.46
B_1	36.5	22.0	23.3	2.61	<0.10	0.10	15.7	100.3	4.41	2.66	1.66	1.66
B/C	34.7	23.1	24.0	2.78	<0.10	0.25	14.7	99.6	3.99	2.45	1.52	1.63
C	34.8	21.6	25.3	2.86	<0.10	0.18	14.3	99.1	4.28	2.34	1.51	1.83

	elemental composition of clay fraction in %							Molar ratios			
Horizon	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	K_2O	Loss on ignition	Sum	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
A_1	30.1	20.2	26.0	2.83	0.19	20.6	99.9	3.96	1.97	1.31	2.01
B_1	31.5	21.4	28.0	3.14	0.15	17.1	101.3	3.91	1.91	1.28	2.05
B/C	30.8	20.9	27.1	3.14	0.45	16.5	98.9	3.92	1.93	1.29	2.03
C	31.9	20.7	28.5	3.14	0.14	15.1	99.4	4.10	1.90	1.30	2.16

	mineralogy of the silt fraction									
Horizon	Q	Gibb	Goe	He	Ilm	Fel	Kao	Verm	Mont	An
A_1	xx	x	xx	-	-	-	x	-	-	-
B_1	xxx	x	xx	-	-	-	x	-	-	-
B/C	xxx	x	xx	-	-	-	x	-	-	-
C	xx	x	xx	-	-	-	x	-	-	-

	mineralogy of the clay fraction						
Horizon	Q	Gibb	Goe	He	Fel	Kao	Verm/Ill	An
A_1	x	tr	xx	tr	-	xx	-	-
B_1	x	tr	xx	tr	-	xx	-	-
B/C	tr	tr	xx	tr	-	xx	-	-
C	tr	tr	xx	tr	-	xx	-	-

2. Gumbang series

Local Soil Group: Red-Yellow Podzolic.
Family: Abok.
Series: Gumbang.
7th Approximation: Oxic Dystropept.
Location: Gunung Serambu-Bau District.
Latitude: 1°25′ N.
Longitude: 110°13′ E.

Site: Upper slope of very steep ridge (approx. 32-45°).
Parent material: Weathered quartz andesite.
Vegetation: Primary Mixed Dipterocarp forest.
Rainfall: Mean annual rainfall 3240 mm without any month with less than 100 mm.
Altitude: 400 m.

O 5-0 cm: Dominantly decayed branches and leaf litter; abrupt boundary to

A_1 0-9 cm: dark brown (10YR4/3), moist, loam; very fine, subangular blocky; single structure elements: firm, mass: friable; many, coarse to medium roots; earth worm activity; clear, smooth boundary to

B_1 9-28 cm: yellowish brown (10YR5/4), moist, clay loam; few weathered rock pieces; weak, medium subangular blocky; firm; many, coarse roots; diffuse wavy boundary to

B_2 28-44 cm: light yellowish brown (10YR6/4), moist, clay; structureless, massive in profile, fine crumb to very fine subangular blocky in hand; mass: weak friable, single elements: firm; many, medium to fine roots; accumulation of few to many weathered rock pieces of stone size; diffuse, wavy boundary to

B/C 44-67 cm: as B_2 horizon but with many weathered rock pieces of stone size; very firm; few, fine roots; diffuse, wavy boundary to

C 67/100 cm: light yellowish brown (10YR6/4), moist, clay; many weathered to fresh stones and boulders; structureless, massive; slightly firm; few, fine roots.

Note: on site many individual rounded large rock boulders, partly buried. Colluvial influence.

Laboratory data Gumbang series

		Particle size distribution in μm % dry fine earth							
		Sand				Silt	Clay	waterdisp.	Laboratory texture
Depth in cm	Horizon	2000-500	500-250	250-100	100-50	50-2	< 2	clay	
0 - 9	A_1	6.6	0.5	0.4	0.5	85.8	6.2	2.43	silt
9 - 28	B_1	0.8	0.2	0.3	0.5	74.7	23.5	7.01	silt loam
28 - 44	B_2	0.8	0.3	0.3	0.5	66.7	31.4	13.81	silty clay loam
44 - 67	B/C	0.6	0.2	0.3	0.5	62.3	36.1	3.01	silty clay loam
67 - 100	C	1.5	0.4	0.4	0.4	61.4	35.9	-	silty clay loam

	pH 1:5		Exchangeable cations in meq/100 g fine earth								
Horizon	H_2O	KCl	Ca	Mg	K	Na	Al	Sum	CEC (unbuf.)	CEC (pH 8.2)	Base sat. %
A_1	4.6	3.9	9.37	2.41	0.60	0.17	2.22	14.77	14.2	29.3	88
B_1	4.4	3.8	1.27	0.71	0.10	0.20	3.74	6.02	4.43	11.4	52
B_2	4.6	3.8	0.89	0.46	0.04	0.15	3.74	5.28	4.06	9.59	38
B/C	4.7	3.8	0.76	0.33	0.03	0.13	4.03	5.28	4.06	9.24	31
C	4.6	3.8	0.64	0.21	0.03	0.17	4.19	5.24	4.44	9.05	24

	% dry fine earth			‰ of C		
Horizon	C	N	C/N ratio	Humic acid	Fulvic acid	Humic/Fulvic acid ratio
A_1	5.51	0.45	12.2	10.4	8.0	1.30
B_1	1.02	0.11	9.3	2.0	5.3	0.37
B_2	0.62	0.06	10.3	2.0	3.6	0.56
B/C	0.43	0.05	8.6	1.2	3.3	0.36
C	0.39	0.04	9.8	1.7	2.5	0.68

	elemental composition of fine earth in %								Molar ratios			
Horizon	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	K_2O	Loss on ignition	Sum	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
A_1	7.46	2.32	7.96	0.76	0.28	0.17	15.6	101.7	15.6	15.9	13.4	5.38
B_1	78.1	3.54	10.5	0.84	< 0.10	< 0.10	7.47	100.7	58.5	12.6	10.4	4.64
B_2	74.7	3.19	13.3	0.75	< 0.10	0.25	7.52	99.8	62.2	9.54	8.27	6.52
B/C	72.4	3.26	15.0	0.74	< 0.10	< 0.10	7.58	99.2	59.1	8.20	7.20	7.21
C	71.5	3.63	15.6	0.60	< 0.10	0.14	8.02	99.6	52.4	7.78	6.77	6.74

	elemental composition of clay fraction in %							Molar ratios			
Horizon	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	K_2O	Loss on ignition	Sum	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
A_1	40.3	4.38	29.1	0.26	< 0.10	26.5	100.6	24.5	2.35	2.15	10.4
B_1	41.9	5.01	36.1	0.26	< 0.10	17.6	101.0	22.2	1.97	1.81	11.3
B_2	41.7	5.37	37.1	0.23	< 0.10	17.6	102.1	20.7	1.91	1.75	10.8
B/C	42.1	5.88	37.3	0.23	< 0.10	16.7	102.3	16.9	1.70	1.54	9.9
C	41.5	5.09	38.7	0.22	< 0.10	16.3	101.9	20.2	1.70	1.57	11.9

	mineralogy of the silt fraction									
Horizon	Q	Gibb	Goe	He	Ilm	Fel	Kao	Verm	Mont	An
A_1	xxxx	tr	-	-	-	-	tr	-	x	-
B_1	xxxx	tr	-	-	-	-	tr	-	x	-
B_2	xxxx	tr	-	-	-	-	tr	-	x	-
B/C	xxxx	x	-	-	-	tr	tr	-	x	-
C	xxxx	x	-	-	-	tr	tr	-	x	-

	mineralogy of the clay fraction							
Horizon	Q	Gibb	Goe	He	Fel	Kao	Verm/Ill	An
A_1	x	x	tr	-	-	xxxx	-	-
B_1	x	x	x	-	-	xxxx	-	-
B_2	x	x	x	-	-	xxxx	-	-
B/C	tr	x	x	-	-	xxxx	-	-
C	tr	x	x	-	-	xxxx	-	-

3. Serin series

Local Soil Group: Red-Yellow Podzolic.
Family: Abok.
Series: Serin.
7th Approximation: Tropeptic Haplorthox.
Location: Panchur Forest Reserve-Serian District.
Latitude: 1°16′ N.
Longitude: 110°27′ E.
Site: Moderately sloping hilly terrain. Upper slope area (8°).
Parent material: Weathered arkose.
Vegetation: Primary Mixed Dipterocarp forest.
Rainfall: Mean annual rainfall 3400 mm without any month of less than 100 mm.
Altitude: 100 m.

O 2-0 cm: Decomposed leaf litter and branches; many fine to very fine roots; abrupt, smooth boundary to

A_1 0-10 cm: yellowish brown (10YR5/4), moist, sandy clay loam; strong, fine crumbly; friable; many, medium to coarse roots; distinct, smooth boundary to

A_2 (E) 10-25 cm: brownish yellow (10YR6/8), moist, clay loam; structureless, massive, in hand: weak subangular blocky; firm; few, fine, decomposed roots; material from above washed in cracks; diffuse, wavy boundary to

B_1 25-75 cm: brownish yellow (10YR6/8), moist, clay; structureless, massive, angular blocky in hand; firm; common, fine, decayed roots; washed-in material along cracks and in rootchannels; diffuse, broken boundary to

B_2 75-115 cm: reddish yellow (7.5YR7/8), moist, clay with medium, common, distinct, pale yellowish mottles; strong, subangular blocky; firm; few, strongly weathered, faint red coloured arkose; few, fine, decayed roots; diffuse, broken boundary to

B/C 115-135 cm: reddish yellow (7.5YR7/8), moist, clay with increasingly fine, common, pale yellow mottles; strong blocky;
very firm; with depth increasingly more pinkish red strongly weathered arkose.

Laboratory data Serin series

		Particle size distribution in µm % dry fine earth							
		Sand				Silt	Clay		
Depth in cm	Horizon	2000-500	500-250	250-100	100-50	50-2	< 2	waterdisp. clay	Laboratory texture
0 - 10	A_1	4.4	11.2	18.4	8.7	30.5	26.8	16.88	loam
10 - 25	A_2 (E)	3.2	7.8	14.9	7.5	24.8	41.8	9.00	clay
25 - 75	B_1	3.8	7.9	13.2	7.9	25.7	41.5	-	clay
75 - 115	B_2	3.5	6.4	10.4	6.2	26.9	46.6	-	clay
115 - 135+	B/C	2.6	5.9	10.0	5.9	25.1	50.5	-	clay

	pH 1:5		Exchangeable cations in meq/100 g fine earth								
Horizon	H_2O	KCl	Ca	Mg	K	Na	Al	Sum	CEC (unbuf.)	CEC (pH 8.2)	Base sat. %
A_1	3.4	3.3	0.46	0.42	0.38	0.15	5.41	7.48	6.30	20.0	24
A_2(E)	4.1	3.6	0.33	0.06	0.04	0.63	3.58	4.14	2.77	9.22	20
B_1	4.4	3.7	0.38	0.06	0.04	0.28	2.59	3.35	2.77	6.27	27
B_2	4.6	3.9	0.13	0.04	0.03	0.13	2.61	2.94	2.75	5.53	12
B/C	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

	% dry fine earth			$^0/_{00}$ of C		
Horizon	C	N	C/N ratio	Humic acid	Fulvic acid	Humic/Fulvic acid ratio
A_1	2.52	0.25	10.1	5.4	0.7	0.56
A_2(E)	0.76	0.09	8.9	1.4	5.3	0.26
B_1	0.51	0.08	10.2	1.8	2.6	0.47
B_2	0.37	0.03	12.3	1.6	1.5	1.06
B/C	0.15	0.02	7.5	2.9	n.d.	n.d.

	elemental composition of fine earth in %								Molar ratios			
Horizon	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	K_2O	Loss on ignition	Sum	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
A_1	66.6	3.84	13.9	0.70	<0.10	0.12	13.0	98.3	46.2	8.14	6.92	5.68
A_2(E)	65.2	5.00	17.7	0.79	<0.10	0.19	9.10	98.1	34.7	6.25	5.30	5.55
B_1	67.6	5.05	17.3	0.73	<0.10	<0.10	8.71	99.6	35.6	6.64	5.60	5.36
B_2	60.5	6.19	21.9	0.94	<0.10	<0.10	9.72	99.5	26.0	4.69	3.97	5.54
B/C	62.0	5.80	21.2	0.90	<0.10	<0.10	9.29	99.4	28.4	4.96	4.22	5.73

	elemental composition of clay fraction in %							Molar ratios			
Horizon	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	K_2O	Loss on ignition	Sum	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
A_1	40.4	7.08	34.5	1.07	0.20	18.8	12.1	15.2	1.99	1.76	7.63
A_2(E)	40.1	8.11	35.3	1.03	0.10	15.7	100.3	13.1	1.93	1.68	6.81
B_1	40.8	8.07	36.0	1.06	0.13	15.8	101.8	13.4	1.92	1.68	6.99
B_2	38.9	8.63	34.2	1.01	0.09	15.3	98.1	12.0	1.93	1.66	6.21
B/C	40.1	9.28	35.5	1.07	0.11	14.9	101.0	11.5	1.92	1.64	5.99

	mineralogy of the silt fraction									
Horizon	Q	Gibb	Goe	He	Ilm	Fel	Kao	Verm	Mont	An
A_1	xxx	tr	-	-	-	-	xx	tr	tr	-
A_2(E)	xxx	tr	-	-	-	-	xx	x	tr	-
B_1	xxx	tr	-	-	-	-	xx	x	-	-
B_2	xxx	tr	-	-	-	-	xx	x	-	-
B/C	xxx	tr	-	-	-	-	xx	x	-	-

	mineralogy of the clay fraction							
Horizon	Q	Gibb	Goe	He	Fel	Kao	Verm/Ill	An
A_1	tr	tr	x	-	-	xxxx	tr	-
A_2(E)	tr	tr	x	-	-	xxxx	x	-
B_1	tr	tr	x	-	-	xxxx	x	-
B_2	tr	tr	x	-	-	xxxx	x	-
B/C	tr	tr	xx	-	-	xxxx	x	-

4. Semongok series

Local Soil Group: Red-Yellow Podzolic.
Family: Merit.
Series: Semongok.
7th Approximation: Typic Dystropept.
Location: Semongok Forest Reserve-Kuching District.
Latitude: 1°23′ N.
Longitude: 110°19′ E.
Site: Moderately sloping hilly terrain. Almost top upper slope area (10°).
Parent material: Weathered shales and mudstones.
Vegetation: Primary Mixed Dipterocarp forest.
Rainfall: Mean annual rainfall 4100 mm without any month of less than 100 mm.
Altitude: 70 m.

O 4-0 cm: Decomposed leaf litter, branches and roots; common, fine and very fine roots; abrupt, smooth boundary to

A_1 0-9 cm: yellowish brown (10YR5/4), moist, clay loam; strong, fine crumbly; friable; many, fine roots; earth worm activity; clear, smooth boundary to

B_1 9-29 cm: reddish yellow (7.5YR6/6), moist, clay loam; distinct, grey gleying along root channels; weak, fine subangular blocky, slightly firm; common, medium and fine roots; diffuse, smooth boundary to

B_2 29-68 cm: reddish yellow (7.5YR6/8), moist, clay with common, distinct, fine, yellow (2.5Y7/0) mottles; weak, angular blocky structure, slightly firm; few, medium and fine roots; some washed-in material along cracks and root channels; diffuse, broken boundary to

IIB_S 68-75 cm: iron stoneline consisting of many irregular to flat iron concretions (hard iron coated shale fragments); some orientation noticeable; embedded in reddish yellow (7.5YR6/8), moist, clay; abrupt, smooth boundary to

IIB_2 75-88 cm: reddish yellow (5YR6/8), moist, clay with distinct, common, fine, red (2.5YR6/6) and light grey (10YR7/2) mottles; strong, angular blocky; very firm; diffuse, broken boundary to

IIB/C 88-115 cm: light grey (10YR7/2), moist, clay with many, distinct, medium, reddish yellow (5YR6/8) and common, medium, prominent red (2.5YR5/6) mottles (variegated); strong, angular blocky; very firm; few, soft, iron-coated weathered shale pieces.

Laboratory data Semongok series

		Particle size distribution in μm % dry fine earth							
		Sand				Silt	Clay		
Depth in cm	Horizon	2000-500	500-250	250-100	100-50	50-2	<2	waterdisp. clay	Laboratory texture
0 - 9	A_1	1.1	1.0	3.1	4.7	48.2	41.9	25.20	silty clay
9 - 29	B_1	1.4	1.0	2.7	4.1	45.1	45.7	37.24	silty clay
29 - 68	B_2	0.8	0.8	2.4	2.6	39.4	54.0	37.89	clay
75 - 88	II B_2	5.5	1.3	1.9	3.3	33.0	55.0	27.21	clay
88 - 115+	II B/C	1.3	0.6	0.9	3.0	39.5	54.7	17.35	clay

	pH 1:5		Exchangeable cations in meq/100 g fine earth								
Horizon	H_2O	KCl	Ca	Mg	K	Na	Al	Sum	CEC (unbuf.)	CEC (pH 8.2)	Base sat. %
A_1	3.7	2.9	0.15	0.32	0.30	0.09	20.97	24.36	25.03	45.15	3.5
B_1	4.3	3.5	0.01	0.11	0.19	-	16.54	17.18	18.11	27.46	6
B_2	4.4	3.6	-	0.04	0.23	-	16.56	16.96	16.73	24.71	2
II B_2	4.6	3.6	0.06	0.06	0.23	0.09	14.95	15.44	16.64	23.74	3
II B/C	4.7	3.6	0.06	0.06	0.34	-	17.14	17.60	19.14	25.24	3

	% dry fine earth			$^0/_{00}$ of C		
Horizon	C	N	C/N ratio	Humic acid	Fulvic acid	Humic/Fulvic acid ratio
A_1	3.18	0.27	11.7	12.1	7.2	1.70
B_1	0.86	0.11	7.8	2.4	4.8	0.50
B_2	0.57	0.08	7.1	2.1	3.3	0.64
II B_2	0.56	0.06	6.0	2.7	1.8	1.50
II B/C	0.26	0.09	2.9	1.4	2.8	0.50

	elemental composition of fine earth in %								Molar ratios			
Horizon	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	K_2O	Loss on ignition	Sum	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
A_1	65.1	4.62	13.4	0.99	<0.10	0.68	15.3	100.2	37.5	8.25	6.76	4.55
B_1	65.3	4.78	16.5	1.14	<0.10	0.57	10.3	98.7	36.3	6.72	5.67	5.40
B_2	63.6	4.05	18.1	1.15	<0.10	0.65	8.7	96.4	41.7	5.97	5.22	6.98
II B_2	58.8	7.85	17.4	1.14	<0.10	0.70	10.0	96.0	19.9	5.74	4.46	3.47
II B/C	56.2	7.21	23.4	1.13	<0.10	1.24	9.49	98.8	20.7	4.08	3.41	5.07

	elemental composition of clay fraction in %							Molar ratios			
Horizon	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	K_2O	Loss on ignition	Sum	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
A_1	48.4	5.21	28.2	1.36	1.02	14.7	98.9	24.7	2.91	2.61	8.48
B_1	47.7	6.45	31.1	1.42	0.99	12.5	100.2	19.6	2.60	2.30	7.54
B_2	46.6	7.08	30.5	1.41	0.96	11.8	98.4	17.5	2.59	2.36	6.75
II B_2	46.6	6.87	32.0	1.41	1.19	11.4	99.5	18.0	2.47	2.17	7.29
II B/C	45.3	7.18	30.7	1.23	1.91	12.2	98.5	16.8	2.51	2.18	6.70

	mineralogy of the silt fraction									
Horizon	Q	Gibb	Goe	He	Ilm	Fel	Kao	Verm	Mont	An
A_1	xxxx	-	-	-	-	tr	x	-	tr	tr
B_1	xxxx	-	-	-	-	tr	x	-	tr	tr
B_2	xxxx	-	-	-	-	tr	x	-	tr	tr
II B_2	xxxx	-	-	-	-	tr	x	-	tr	tr
II B/C	xxxx	-	-	-	-	tr	x	-	tr	tr

	mineralogy of the clay fraction							
Horizon	Q	Gibb	Goe	He	Fel	Kao	Verm/Ill	An
A_1	x	-	-	-	-	xx	xxx	tr
B_1	x	-	tr	-	-	xx	xxx	tr
B_2	x	-	tr	-	-	xx	xxx	tr
II B_2	x	-	tr	-	-	xx	xxx	tr
II B/C	x	-	tr	-	-	xx	xxx	tr

5. Gading series

Local Soil Group: Red-Yellow Podzolic.
Family: Abok.
Series: Gading.
7th Approximation: Typic Haplorthox (psammentic subgroup).
Location: Near Sekambul-Lundu District.
Latitude: 1°41′ N.
Longitude: 109°35′ E.
Site: Strongly dissected foothills, near crest of ridge (15°).
Parent material: Weathered adamellite.
Vegetation: Primary Mixed Dipterocarp forest.
Rainfall: Mean annual rainfall 3290 mm without any month of less than 100 mm.
Altitude: 50 m.

O 0-2 cm: Decomposed litter; many, fine roots with some medium sandy loam; crumbly; friable; abrupt, smooth boundary to

A_1 2-7 cm: brown (10YR4/3) dry, sandy loam; common, medium, faint, dark-brown (10YR3/2) mottles; weak, fine, subangular blocky; friable to loose; common, fine, continuous pores; many, fine roots; gradual, smooth boundary to

A_{12} 7-20 cm: strong brown (7.5YR5/8, 10YR5/8) slightly moist, medium sandy loam; weak, fine subangular blocky; friable to loose, many, fine roots; common, fine, continuous pores; gradual, smooth boundary to

B_1 20-50 cm: strong brown (7.5YR5/8) slightly moist, medium sandy clay loam; weak, fine subangular blocky; very friable; few, fine roots; common, fine, continuous pores; diffuse, smooth boundary to

B_{21} 50-100 cm: reddish yellow (7.5YR7/8) slightly moist, sandy clay loam; weak, fine crumbly; very friable; few, fine roots; common, fine, continuous pores; diffuse, smooth boundary to

B_{22} 100-120 cm: reddish yellow (7.5 YR7/8) slightly moist, sandy clay loam to sandy clay; coarse sand mixed with clay (granitic texture); few, fine, red pieces of strongly weathered parent material; weak, fine crumbly; friable; few, fine roots; common, fine, continuous pores; diffuse, broken boundary to

C 120+ cm: as B_{22} mixed with large rounded boulders of fresh and weathered adamellite and a highly metamorphosed rocktype.

Laboratory data Gading series

		Particle size distribution in μm % dry fine earth							
		Sand				Silt	Clay	waterdisp.	Laboratory texture
Depth in cm	Horizon	2000-500	500-250	250-100	100-50	50-2	<2	clay	
2 - 7	A$_1$	40.6	20.4	14.7	2.4	9.4	12.5	8.09	sandy loam
7 - 20	A$_{12}$	24.4	22.7	19.5	4.0	10.4	19.0	11.57	sandy loam
20 - 50	B$_1$	23.6	22.9	19.9	3.3	7.2	23.1	-	sandy clay loam
70 - 100	B$_{21}$	29.3	15.7	13.7	2.3	8.9	30.1	-	sandy clay loam
100 - 120	B$_{22}$	29.3	13.4	11.1	2.2	11.5	32.5	-	sandy clay loam
120+	C	52.5	13.8	11.1	1.6	10.0	11.0		sandy loam

	pH 1:5		Exchangeable cations in meq/100 g fine earth								
Horizon	H_2O	KCl	*Ca*	*Mg*	K	*Na*	Al	*Sum*	CEC (unbuf.)	CEC (pH 8.2)	Base sat. %
A$_1$	4.95	3.9	0.26	0.27	0.10	0.04	2.56	3.28	3.78	10.52	18
A$_{12}$	4.25	4.0	0.06	0.04	0.02	-	1.57	1.49	2.63	6.02	5
B$_1$	4.70	4.3	0.04	0.02	-	-	0.58	0.64	0.93	3.66	7
B$_{21}$	4.85	4.4	0.04	0.02	-	-	0.42	0.48	0.69	3.01	9
B$_{22}$	4.95	4.6	0.06	0.02	-	-	0.31	0.37	0.58	3.09	14
C	n.d.	n.d.	0.06	0.02	0.06	-	0.31	0.43	1.01	3.44	14

	% dry fine earth			$^0/_{00}$ of C		
Horizon	C	N	C/N ratio	Humic acid	Fulvic acid	Humic/Fulvic acid ratio
A$_1$	1.69	0.13	13.2	3.8	5.5	0.69
A$_{12}$	0.63	0.09	7.2	1.0	4.6	0.22
B$_1$	0.27	0.03	8.0	0.5	3.1	0.14
B$_{21}$	0.22	0.02	10.0	0.7	4.0	0.18
B$_{22}$	0.21	0.03	7.6	0.3	1.8	0.17
C	-	-	-	n.d.	n.d.	-

	elemental composition of fine earth in %								Molar ratios			
Horizon	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	K_2O	Loss on ignition	Sum	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
A$_1$	82.2	2.46	7.03	0.48	<0.10	<0.10	8.90	101.3	91.33	19.86	16.31	4.6
A$_{12}$	82.8	2.27	7.44	0.44	<0.10	<0.10	5.20	98.4	98.57	18.90	15.86	5.21
B$_1$	82.7	2.73	7.97	0.47	<0.10	<0.10	5.40	99.5	81.17	17.69	14.53	4.59
B$_{21}$	70.2	4.93	13.00	0.75	<0.10	<0.10	6.62	95.7	37.74	9.21	7.40	4.09
B$_{22}$	73.3	4.94	11.90	0.62	<0.10	<0.10	6.32	97.3	40.66	10.43	8.24	3.77
C	63.0	6.11	16.70	0.87	0.23	1.58	7.27	95.8	27.63	6.40	5.19	4.32

	elemental composition of clay fraction in %							Molar ratios			
Horizon	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	K_2O	Loss on ignition	Sum	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
A$_1$	30.9	7.78	36.50	1.69	0.13	25.2	102.5	10.5	1.43	1.26	7.34
A$_{12}$	32.0	8.00	38.00	1.75	0.16	21.5	101.4	10.6	1.43	1.26	7.43
B$_1$	32.4	9.89	38.2	1.75	0.11	19.0	101.4	8.69	1.44	1.23	6.05
B$_{21}$	31.2	11.70	37.40	1.67	0.43	18.1	100.5	7.08	1.41	1.18	5.01
B$_{22}$	31.2	12.50	36.50	1.65	0.09	18.9	100.8	6.61	1.45	1.19	4.57
C	30.4	11.60	38.70	1.55	0.41	19.5	101.2	6.95	1.33	1.12	5.22

	mineralogy of the silt fraction									
Horizon	Q	Gibb	Goe	He	Ilm	Fel	Kao	Verm	Mont	An
A$_1$	xxx	x	-	-	x	tr	tr	-	tr	-
A$_{12}$	xxx	x	-	-	x	tr	tr	-	tr	-
B$_1$	xxx	x	-	-	tr	tr	tr	-	tr	-
B$_{21}$	xxx	x	-	-	tr	tr	x	-	tr	-
B$_{22}$	xxx	x	-	-	x	tr	x	-	tr	-
C	xx	xx	-	-	tr	x	tr	tr	-	-

	mineralogy of the clay fraction							
Horizon	Q	Gibb	Goe	He	Fel	Kao	Verm/Ill	An
A$_1$	tr	xx	x	x	-	xxx	-	-
A$_{12}$	tr	xx	x	x	-	xxx	-	-
B$_1$	tr	xx	x	x	-	xxx	-	-
B$_{21}$	tr	xx	x	x	-	xxx	-	-
B$_{22}$	tr	xx	x	x	-	xxx	-	-
C	tr	xx	x	x	tr	xxx	-	-

6. Nyalau series

Local Soil Group: Red-Yellow Podzolic.
Family: Nyalau.
Series: Nyalau.
7th Approximation: Psammentic Haplorthox.
Location: 24 th mile Bau/Lundu Rd-Lundu District.
Latitude: 1°33′ N.
Longitude: 109°54′ E.
Site: Strongly dissected hilly terrain with cuesta features. Dipslope, upper slope area (15°).
Parent material: Weathered quartzitic sandstone.
Vegetation: Primary Mixed Dipterocarp forest (poor).
Rainfall: Mean annual rainfall 3290 mm without any month of less than 100 mm.
Altitude: 150 m.

O	2-0 cm: Partly decomposed litter of leaves, twigs and branches; many, fine and very fine roots; abrupt, smooth boundary to
A_1	0-9 cm: dark brown (10YR4/3), moist, fine sandy loam; weak, fine crumbly; loose; common, fine, continuous pores; many, fine to medium roots, few, large roots; earthworm activity; clear, smooth boundary to
A_2(E)	9-30 cm: brownish yellow (10YR6/6), moist, fine sandy clay loam; weak, fine subangular blocky; firm; common, fine, continuous pores; few, coarse roots; many, fine to medium roots; diffuse, wavy boundary to
B_1	30-63 cm: reddish yellow (7.5YR7/8), moist, fine sandy clay loam; weak, fine subangular blocky; firm; common, fine continuous pores; few, fine roots; distinct presence of washed-in material along cracks and old root channels; diffuse, wavy boundary to
B_2	63-110 cm: reddish yellow (7.5YR7/8), moist, fine sandy clay loam; common, fine, distinct, red (2.5YR5/6) mottles; few, large, white blotches; strong, fine subangular blocky; very firm; few, medium decomposed roots; gradual, wavy boundary to
B/C	110-150 cm: reddish yellow (7.5YR7/8), moist, fine sandy clay; common, fine, distinct, red and pale yellow mottles; strong, medium subangular blocky; very firm; few, fine, white, strongly weathered pieces of sandstone.

Laboratory data Nyalau series

		Particle size distribution in µm % dry fine earth							
		Sand				Silt	Clay	waterdisp. clay	Laboratory texture
Depth in cm	Horizon	2000-500	500-250	250-100	100-50	50-2	< 2		
0 - 9	A_1	3.5	32.8	31.8	5.0	18.9	8	3.81	sandy loam
9 - 30	A_2(E)	1.5	22.2	31.0	9.1	18.8	18.5	1.40	sandy loam
30 - 63	B_1	2.3	23.2	29.8	7.1	17.7	19.9	-	sandy loam
63 - 110	B_2	1.9	21.5	27.4	6.6	18.1	24.5	-	sandy clay loam
110 - 150+	B/C	1.7	19.8	25.4	6.0	20.8	26.3	-	sandy clay loam

	pH 1:5		Exchangeable cations in meq/100 g fine earth								
Horizon	H_2O	KCl	Ca	Mg	K	Na	Al	Sum	CEC (unbuf.)	CEC (pH 8.2)	Base sat. %
A_1	4.1	3.5	0.26	0.59	0.23	0.00	5.50	7.39	8.21	20.00	13
A_2(E)	4.0	3.7	0.14	0.04	0.05	0.00	3.29	3.60	3.33	7.51	7
B_1	4.4	3.7	0.16	0.04	0.06	0.04	2.89	3.22	3.10	5.67	10
B_2	4.4	3.6	0.01	0.00	0.04	0.00	3.73	3.78	4.31	6.87	1
B/C	4.4	3.6	0.00	0.00	0.05	0.00	3.80	3.85	4.61	6.91	1

	% dry fine earth			‰ of C		
Horizon	C	N	C/N ratio	Humic acid	Fulvic acid	Humic/Fulvic acid ratio
A_1	4.23	0.25	16.9	9.5	7.1	1.34
A_2(E)	0.54	0.08	6.8	1.2	2.9	0.41
B_1	0.19	0.03	6.3	0.7	1.5	0.47
B_2	0.19	0.02	9.5	0.5	1.6	0.31
B/C	0.09	0.03	3.0	0.7	1.6	0.43

	elemental composition of fine earth in %								Molar ratios			
Horizon	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	K_2O	Loss on ignition	Sum	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
A_1	74.7	5.30	8.14	0.59	< 0.10	0.84	7.53	97.2	37.4	15.6	11.0	2.40
A_2(E)	81.8	2.66	8.44	0.50	< 0.10	0.29	5.00	98.3	81.5	16.5	13.7	4.94
B_1	82.9	2.01	7.55	0.40	< 0.10	0.26	3.96	97.1	109.5	18.6	15.9	5.89
B_2	78.7	4.08	9.99	0.46	< 0.10	0.31	4.62	98.3	51.4	13.4	10.6	3.84
B/C	76.2	3.62	11.80	0.53	< 0.10	0.57	4.28	97.1	55.9	11.0	9.19	5.08

	elemental composition of clay fraction in %							Molar ratios			
Horizon	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	K_2O	Loss on ignition	Sum	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
A_1	41.7	4.92	27.0	0.89	0.94	25.5	100.9	22.5	2.62	2.35	8.59
A_2(E)	44.7	6.51	32.9	1.00	1.05	14.3	100.0	18.3	2.34	2.08	7.80
B_1	44.5	7.72	32.9	1.05	0.82	13.7	100.7	15.3	2.30	2.00	6.67
B_2	43.4	7.86	32.8	1.01	0.84	12.9	98.8	14.7	2.25	1.95	6.53
B/C	42.9	9.00	33.5	0.98	1.13	12.8	100.3	12.7	2.17	1.85	5.84

	mineralogy of the silt fraction									
Horizon	Q	Gibb	Goe	He	Ilm	Fel	Kao	Verm	Mont	An
A_1	xxx	-	-	-	-	tr	tr	tr	x	tr
A_2(E)	xxx	-	-	-	-	tr	tr	tr	x	tr
B_1	xxx	-	-	-	-	tr	tr	tr	x	tr
B_2	xxx	-	-	-	-	tr	tr	tr	x	tr
B/C	xxx	-	-	-	-	tr	tr	x	x	tr

	mineralogy of the clay fraction							
Horizon	Q	Gibb	Goe	He	Fel	Kao	Verm/Ill	An
A_1	x	-	x	-	-	xxx	x	tr
A_2(E)	x	-	x	-	-	xxx	x	tr
B_1	x	-	x	-	-	xxx	x	tr
B_2	tr	-	x	-	-	xxx	x	tr
B/C	tr	-	x	-	-	xxx	x	tr

7. Butan series

Local Soil Group: Podzol.
Family: Silantek.
Series: Butan.
7th Approximation: Typic Tropohumod.
Location: Path Stinggang to S. Punguh-Lundu District.
Latitude: 1°34′ N.
Longitude: 110°1′ E.
Site: Moderately dissected hilly terrain with cuesta features. Middle slope area of dipslope (8°).
Parent material: Weathered quartzitic sandstone.
Vegetation: Primary 'Kerangas' forest.
Rainfall: Mean annual rainfall approx. 3250 mm without any month of less than 100 mm.
Altitude: 120 m.

O 0-5 cm: Dark reddish Brown (5YR2/2), slightly moist, decomposed organic matter with few sand grains; many, fine roots; few, coarse roots; abrupt, smooth boundary to

A_1 5-13 cm: dark reddish brown (5YR3/2), moist, sand; moderate, fine crumbly; weak friable; transparent sand grains; abrupt wavy boundary to

A_{12} 13-23 cm: reddish grey (5YR5/2), moist, medium sand; staining by humus; structureless, single grain; loose; few, fine roots; clear, wavy boundary to

A_2 (E) 23-33 cm: light grey (10YR7/1), moist, medium sand; many, medium, faint, light grey and common, medium, faint, reddish grey mottles; structureless, single grain; firm; veins filled with humic materials run through this horizon without apparent direction; abrupt, smooth boundary to

$B_{1}h$ 33-48 cm: dark reddish brown (5YR2/2), moist, loamy sand; weakly cemented; few, fine roots at boundary with A_2; abrupt, irregular boundary to

B_{12} 48-58 cm: light yellowish brown (10YR6/4), slightly wet, fine sandy loam, weak, fine platy with humus accumulation between structure elements; many, coarse decomposed roots; pockets of dark reddish brown coloured (organic) cemented material; clear, smooth boundary to

B_2 58-84 cm: very pale brown (10YR7/3), slightly wet, loamy sand to sandy loam; structureless, massive; very firm; many rootchannels filled in with organic materials, also present along fractureplanes of dried out clods; clear, smooth boundary to

IIC 84-112 cm: pale yellow (2.5YR8/4), wet, sandy clay; brownish yellow (10YR6/6) mottling, in some places as lateral bands, otherwise mainly along root channels; sticky and plastic; some quartz pebbles at 112 cm.

*Laboratory data Butan series**

		Particle size distribution in μm % dry fine earth					
		Sand		Silt	Clay	water disp.	Laboratory
Depth in cm	Horizon	2000-500	500-50	50-2	< 2	clay	texture
5 - 13	A_1	81.91	4.49	5.53	4.73	n.d.	Loamy sand
13 - 23	A_{12}	83.58	8.06	4.86	4.80	n.d.	sand
23 - 33	A_2(E)	80.62	10.07	8.63	3.01	n.d.	sand
33 - 48	B_1h	70.79	7.95	11.55	8.31	n.d.	loamy sand
48 - 58	B_{12}	64.64	6.85	9.55	15.70	n.d.	sandy loam
58 - 84	B_2	64.13	8.28	10.48	17.20	n.d.	sandy loam
84 - 112	II C	63.60	7.36	12.06	18.76	n.d.	sandy loam

	pH 1:5		Exchangeable cations in meq/100 g fine earth							
Horizon	H_2O	KCl	Ca	Mg	K	Na	Al	Sum	CEC (pH 7.0)	Base sat. %
A_1	3.3	n.d.	0.42	0.02	0.17	0.39	0.61	1.73	6.40	15
A_{12}	4.2	n.d.	0.30	0.01	0.05	0.33	0.15	0.94	3.00	23
A_2(E)	4.7	n.d.	0.42	0.02	0.05	0.53	0.11	0.90	0.50	100
B_1h	3.6	n.d.	0.19	0.02	0.06	0.36	3.82	4.45	4.70	13
B_{12}	3.9	n.d.	0.12	0.02	0.06	0.57	4.53	1.10	7.50	8
B_2	4.3	n.d.	0.19	0.02	0.06	0.53	2.41	1.01	1.00	60
II C	4.3	n.d.	0.19	0.01	0.06	0.33	2.55	3.14	0.50	100

	elemental composition of fine earth in %								Molar ratios			
Horizon	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	K_2O	Loss on ignition	Sum	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
A_1	92.77	0.20	0.26	0.21	0.17	n.d.	n.d.	-	11.85	6.16	55.0	1.9
A_{12}	97.25	0.10	0	0.27	0.15	n.d.	n.d.	-	27.00	-	27.0	-
A_2(E)	92.73	0.60	0	0.16	0.09	n.d.	n.d.	-	4.08	-	4.1	-
B_1h	94.42	0.60	2.65	0.42	0.13	n.d.	n.d.	-	4.13	60.4	52.9	6.8
B_{12}	83.83	0.80	5.56	0.31	0.09	n.d.	n.d.	-	2.80	25.7	23.5	10.9
B_2	88.15	1.20	7.15	0.27	0.11	n.d.	n.d.	-	1.96	21.0	18.9	9.3
II C	85.57	2.10	7.95	0.42	0.24	n.d.	n.d.	-	1.09	18.4	15.7	5.9

	mineralogy of the clay fraction							
Horizon	Q	Gibb	Goe	He	Fel	Kao	Verm/Ill	An
A_1	xxxx	-	-	-	-	x	-	x
A_{12}	xxxx	-	-	-	-	xx	-	xx
A_2(E)	xxxx	-	-	-	-	xxx	-	xx
B_1h	xx	-	-	-	-	xxx	xx	x
B_{12}	xx	-	-	-	-	xxx	-	xx
B_2	xx	-	-	-	-	xx	xx	x

*after Andriesse (1972)

Appendix II

Analytical Methods

1. Granulometric analysis

Soil samples were dried at 40°C, thereafter crushed by a pestle and sieved through a 2 mm sieve. The material passing through the sieve was kept as fine earth for analysis. 20 mg of fine earth was thoroughly mixed with 10 ml of dispersion agent consisting of a solution of 0.1 M sodium-pyrophosphate and 0.04 M sodium carbonate. The thus-created paste was washed out with distilled water and wet-sieved through a 50 micron sieve into a 1000 ml cylinder which was subsequently filled with demineralized water to the 1 litre mark. Thereafter the suspension was thoroughly stirred. The fractions 0-50, 0-20 and 0-2 μm were separated and determined by the pipette method and the weight percentage of the fractions 2-20 and 20-50 μm was indirectly obtained by calculation.
The fractions 2000-500, 500-250, 250-100 and 100-50 μm were obtained directly by sieving, drying and weighing the material remaining on the 50 μm sieve. The weight of each fraction was corrected for moisture content and expressed as percentage of fine earth at 105°C.

H_2O_2 pre-treatment carried out on surface horizon samples was done prior to adding the dispersion agent and consisted of adding to the 20 mg of fine earth a mixture of 25 ml distilled water and 25 ml H_2O_2 (30% p.a.). If, after the reaction had been completed, organic matter was still present, another 25 ml of H_2O_2 was added until complete oxidation was achieved. The granulometric analysis proceeded then as indicated.

2. Clay separation

Clay samples for mineralogical and chemical studies were obtained by the following methods:

a. Na-pyrophosphate dispersible clay

The procedure as outlined for the granulometric analysis was followed and the suspended clay was syphoned-off after 20 hours to a depth of 23 cm, whereafter the cylinder was again topped up to the 1 litre mark. This procedure was repeated several times until after 20 hours of settling the water column down to 23 cm had become clear. The clay was separated by centrifuging, dried at 40°C and stored in glass containers.

b. NH_4OH dispersible clay

20 g of fine earth was placed in a 1 litre cylinder filled with demineralized water. After stirring, 5 ml of concentrated ammonia was added which was repeated if little or no dispersion took place even after prolonged agitation.
The clay in suspension was removed and separated as indicated for Na-pyrophosphate dispersible clay. However, acetic acid was added prior to centrifuging to achieve flocculation.

c. Water-dispersible clay

Water-dispersible clay was measured quantitatively according to the procedure outlined in the supplement to 7th Approximation of the USDA taxonomic soil classification system (Soil Survey Staff, USDA, 1967). The separation of water-dispersible clay for further study was done in the same manner as indicated for the pyrophosphate and ammonia dispersed clays but flocculation was done with 1N $MgCl_2$.

3. X-ray Diffraction Analysis

The analyses were carried out with a Philips diffraction set PW 1049 with a power of 1.6 KW, employing CoKα radiation. The diffractograms were made with a pen recorder. Use was made of standard Philips aluminium sample holders which were filled from the back with silt or powdered clay previously dried at 40°C. The front part of the sample holders were covered with a glass slide fastened with cellotape which was removed after filling and placement of the back-plate. This method ensures a low degree of preferred orientation of clay minerals.

The conditions for the analyses were:

High voltage: 42
Current: 36 mA
Filter: Fe
Divergence slit: 1°
Receiving slit: 0.3 mm
Scatter slit: 1°
Detector: Proportional counter
Scanning speed: 2°/min.
Full scale: 4×10^3
Time constant: 1 sec.

4. Differential Thermal Analysis

Use was made of home-made ovens with platinum sample holders with Pt/Rh thermo-couples centred in the sample. Heating was done at a rate of 8.33°C/min from room temperature to 1000°C in a N_2 atmosphere regulated with a flow meter at 500 ml N_2/min. Amplification and recording of the thermal reactions was achieved by using a BD 5 Micrograph and a BA 5 Channel selector from Kipp and Sons.

5. Differential Thermogravic Analysis

For the analysis a Dupont 990 assembly was employed. 16 mg of sample material dried at 40°C was heated in air to a maximum of 500°C at a rate of 20°C/min. Vertical scale on the recording paper was 0.5 g/inch.

6. 0.5 N NaOH extraction

This extraction was carried out according to the method described by Jackson (1956, 1965) with the following amendments. In the colorimetric determination of silica ascorbic acid was used instead of amino-naphtol-sulfonic acid. The determination of alumina in the extract was done by means of a Techtron atomic absorption spectrophotometer, type A.A.4.

7. Total chemical analysis by X-ray Fluorescence

The samples were analyses by a method which can best be characterized by the term 'method of inert standardized dilution' as proposed by Mege (1969). Principally the same method was more elaborately described by Tertian (1971, 1972) under the name 'method of double measurement or method of double dilution'. The concentration of the elements is calculated by the formula:

$$C_o = D_f . I_f . \frac{K_s . I_1 . I_2}{I_1 - I_2}$$

in which

C_o = concentration of the element in the undiluted ovendry material
D_f = dilution correction factor (for differences in the dilution)
I_f = intensity correction factor (for drift in the signal)
K_s = a constant for the apparatus and the determined element which can be calculated from measurements on standards in different solutions
I_1 = peak minus background intensity in the first dilution (1:5)
I_2 = peak minus background intensity in the second dilution (1:15)

In addition a blank correction for the lighter elements in lower concentrations can be applied.

Samples were prepared for analysis by weighing two portions of the oven dry material (0.6 and 0.2 g) in a platinum 5% gold crucible. These portions were both fused with 3 g $Li_2B_4O_7$ at 1150°C. After cooling two glass discs from the same sample but with different dilution ratios (1:5 and 1:15) were thus obtained. An estimation of the loss of ignition from the sample was made by weighing the discs in the crucible.

The concentrations of the oxides for the elements Fe, Al, Si, Ti, K and Ca were determined with a Philips X-ray spectrometer PW 1540/15 using a PW 1011/00 1.6 KW generator, a PW 1355/10 discriminator and a PW 2168/21 Cr tube of 2 KW. For the measurements a built-in flow-proportional counter was employed.

The conditions for the analysis were:

element	2 θ position		crystal	KV	mA	collimator	vacuum
	peak	background					
Fe	57.5	55.5	LiF	30	16	fine	–
Al	145.1	141.0	PE	50	30	coarse	+
Si	109.2	106.0	PE	50	30	coarse	+
Ti	86.1	84.0	LiF	50	30	fine	–
K	50.7	48.5	PE	50	30	fine	+
Ca	113.1	111.0	LiF	50	30	fine	+

Pre-set time of measurement was chosen to obtain in peak position at least 10.000 counts within a minimum of 10 and a maximum of 100 seconds. Countings were repeated for control of possible unacceptable irreproducability or signal drift. Background intensity was measured in the same time as peak intensity.

8. Infra-red Absorption Analysis

Approx. 1 mg of sample material was mixed with 300 mg KBr in an agate mortar. Pellets were made in vacuum by a hydraulic press. Diagrams were taken after drying the pellets at 105° for 2 hours and cooling to room temperature. Use was made of a Grubb Parsons spectromaster model MK2E2. This is a double beam I.R. spectrophotometer for wave lengths 0.6 to 25 μm (16600 to 400 cm^{-1}), equipped with a KBr prism and two gratings for respectively 0.6 to 5 μm and 5 to 25 μm. Scanning speed for these wave lengths was respectively 1 μm in 8 min. and 1 μm in 2 min. Paper speed was 20 mm/min. Resolving power is 1 to 3 cm^{-1}, accuracy of the wave length scale varies (approx. 0.5 cm^{-1} at 10 μm).

9. Selective extractions for iron and aluminium

Fine earth was crushed to a particle size of less than 150 micron. On this material, Na-dithionite bicarbonate/citrate extraction was carried out according to Mehra and Jackson (1960), NH_4-oxalate/oxalic acid extraction by using the method proposed by McKeague and Day (1966) and Na-pyrophosphate extraction according to the method outlined by McKeague (1967). Iron and aluminium in the extracts were measured by a Techtron, type A.A.4 atomic absorption spectrophotometer. Preliminary tests (Massaro, 1973) indicated that:

a. addition of lanthanum to the solutions is necessary and that for avoiding precipitation of La with NH_4-oxalate and with Na-pyrophosphate, the lanthanum solution should be prepared in 1.2 N HCl. Measurements in the NH_4-oxalate extract were done within 2 hours after addition of the La-solution, whereas those in the pyrophosphate extracts had to be carried out before organic matter started to flocculate as a result of addition of the lanthanum.

b. Interference of foreign ions and components in the soil extract upon addition of lanthanum were not observed. Also, organic matter present in the pyrophosphate extract did not affect the measurements of Fe and Al.

c. Al appears to give lower values in the pyrophosphate extracts if centrifuging is done at 35,000 instead of 15,000 g, Fe values appear to be little affected. For this reason 27,500 g was used.

10. Water soluble salts

The fine earth was shaken with demineralized water (soil-water ratio 1:5) for two hours and extract obtained by filtration. Silicon was measured with the colorimeter, iron and aluminium by atomic absorption spectrophotometry as indicated under 9.

11. Reaction

Fine earth was shaken for two hours with distilled water or 1N KCl in a 1:5 soil-water ratio or 1N KCl mixture. Measurements were done in the suspension with a pH meter with glass electrode.

12. Exchangeable cations and cation exchange capacity

Cation exchange capacity, unbuffered and at a pH of 8.2, and the exchangeable cations were determined according to a method outlined by Rosmalen (1974).
This method has been developed specifically for soils containing amorphous materi-

als with high pH dependent charges and is based on saturating the sample with the reference cation barium from an unbuffered $BaCl_2$ solution; washing-out with a diluted solution of the same salt; percolating with NH_4NO_3; and determination of the reference cation in the desorbed solution. This procedure is repeated at pH 8.2. The amount of chloride in the final percolate is used for correcting the values of barium to calculate the unbuffered CEC and the CEC at pH 8.2.

13. Phosphate retention

P-retention was measured in the fine earth according to Metson (1956) using KH_2PO_4. The shaking period was 24 hours.

14. Organic materials

For a calculation of the C/N ratio nitrogen was determined by the micro-Kjeldahl method and carbon according to the procedure known as the Walkley-Black method.

The humic and fulvic acids were determined by the so-called ORSTOM method which is based on extraction of the total humus by 0.1 M Na-pyrophosphate and separation of the humic and fulvic acid fractions by adding H_2SO_4 to the extract which causes the humic acids to precipitate.

Total C in the pyrophosphate extract was determined according to the Allison method. Oxidation with $K_2Cr_2O_7$ which is used in the ORSTOM method did not give reliable results owing to the destruction of $K_2Cr_2O_7$ itself because heating could not be properly controlled. The humic acids were determined by dissolving the removed organic materials which had precipitated after addition of H_2SO_4, with 0.1 N NaOH, whereafter the carbon content of this fraction was analysed by again the Allison method.

The fulvic acid fraction was calculated by taking the difference between carbon content of total extracted humus and carbon content of the humic acid fraction.

References

M.I. Ahmad, E.S. Sim (in press) Titanium content of some Sarawak Soils. *Proc. Symp. 'The Fertility and Chemistry of Tropical Soils', Kuala Lumpur, 1973.*

L.N. Alexandrova, T.Th. Arshavkay, E.M. Dorfman, M.F. Lyuzin, O.V. Yurlova (1968) Humus acids and their organo-mineral derivates in soil. *Int. Congr. Soil Sci. Trans. 9th. Adelaide; 3:143-151.*

Andriesse, J.P. (1969a) A study of the environment and characteristics of Tropical Podzols in Sarawak (East-Malaysia). *Geoderma, 2:201-227.*

– (1969b) The influence of the nature of parent rock on soil formation under similar atmospheric climates. *Proc. UNESCO Symp. on Tropical Weathering, Bandung; UNESCO Natural Resources Research XI: 95-110, Paris.*

– (1970) The development of the Podzol morphology in the Tropical Lowlands of Sarawak (East-Malaysia). *Geoderma, 3: 261-279.*

– (1972) *The Soils of West Sarawak (East-Malaysia), Memoir 1.* Govt. Printer, Kuching, Sarawak.

– (1974) Tropical Lowland Peats in South-East Asia. *Communication 63: Royal Trop. Inst., Amsterdam.*

– (in prep. a) The influence of dispersion method on the mineralogical and chemical composition of the separated clays.

– (in prep. b) Morphological, mineralogical and chemical characteristics of hardened iron and aluminium accumulations in Sarawak soils.

Bailey, J.M. (1967) Chemical changes in a Sarawak soil after fertilization and crop growth. *Plant and Soil, 27, 1: 33-50.*

Baillie, I.C. (1970) Pers. Comm. Forest Department, Sarawak.

D.F. Ball, P. Beaumont (1972) Vertical distribution of extractable iron and aluminium in soil profiles from a Brown-Earth-Peaty Podzol Association. *J. Soil Sci. 23: 298-308*

R. Baril, G. Bitton (1967) Anomalous values of free iron in some Quebec soils containing magnetite. *Can. J. Soil Sci. 47: 261.*

Bascomb, C.L. (1968) Distribution of pyrophosphate extractable iron and organic carbon in soils of various groups. *J. Soil Sci. 19: 251-268.*

Bemmelen, R.W. van (1949) *The Geology of Indonesia.* Staatsdrukkerij, the Hague.

Berner, R.A. (1971) *Principles of chemical sedimentology.* McGraw-Hill, New York.

Bloomfield, C. (1953a) Sesquioxide immobilization and clay movement in podzolized soils. *Nature, 172: 958.*

– (1953b) A study of podzolization I: The mobilization of iron and aluminium by Scots pine needles. *J. Soil Sci. 4: 5-16.*

– (1953c) A study of podzolization II: The mobilization of iron and aluminium by the leaves and bark of *Agathis australis (Kauri). J. Soil Sci. 4: 17-23.*

– (1954a) A Study of podzolization III: The mobilization of iron and aluminium by rimu *(Dacryidium cupressinum). J. Soil Sci. 5: 39-45.*

– (1954b) A study of podzolization IV: The mobilization of iron and aluminium by picked and fallen larch needles. *J. Soil Sci. 5: 46-49.*

– (1954c) A study of podzolization V: The mobilization of iron and aluminium by aspen and oak leaves. *J. Soil Sci. 5: 50-56.*

– (1955) A study of podzolization VI: The immobilization of iron and aluminium. *J. Soil Sci. 6: 248-292.*

– (1956) The experimental production of podzolization. *Int. Congr. Soil Sci. Trans. 6th. Paris; Rapp. E: 21-23.*

H.P. Blume, V. Schwertmann (1969) Genetic evaluation of profile distribution of aluminium, iron and manganese oxides. *Soil Sci. Soc. Am. Proc. 33: 438-444.*

Boer, M.W.H. de (1972) *Landforms and Soils in eastern Surinam (South America)* Ph.D. Thesis, Agr. Univ. Wageningen. Pudoc, Wageningen.

J.M.M. van den Broek, H.W. van der Marel (1968) Weathering, clay migration and podzolization in a hydromorphic loess soil. *Geoderma, 2: 121-150.*

Brown, G. (1961) *The X-ray identification and crystal structures of clay minerals.* Mineralogical Society, London.

J.M. Brugière, C. Marius (1966) In: *Boer, M.W.H. de (1972)* Reconnaissance des sols de long du Maroni et de la Crique Grand Inini. *ORSTOM, Cayenne (unpublished report).*

Brunig, E.F. (1969) The classification of Forest Types in Sarawak. *The Malay Forester, 32, 2: 143-179.*

Buursink, J. (1971) *Soils of Central Sudan.* Ph.D. Thesis, State Univ. Utrecht, the Netherlands.

CPCS (1967) In: *Boer, M.W.H. de (1972).* Classification des sols. ENSA, Grignon.

Dames, T.W.G. (1962) Soil Research in the economic development of Sarawak. *EPTA report no. 1512, FAO, Rome.*

Demolon, A. (1952) *Dynamique du sol.* Dunod, Paris.

Driessen, P.M. (1974) Pers. comm. Soil Research Institute, Bogor, Indonesia.

Duchaufour, Ph. (1951) Lessivage et podzolization. *Rev. Forest. France, 3, 10: 647-652.*

– (1959) *La dynamique du Sol forestier et climat atlantique.* Les Presses Universitaires, Laval, Canada.

– (1970) *Précis de Pedologie.* Masson, Paris.

Dudal, R. (1968) Definition of Soil Units for the Soil Map of the World. *World Soil Resources Report no. 33, FAO, Rome.*

R. Dudal, F.R. Moormann (1964) Major soils of Southeast Asia. *J. Trop. Geog. 18: 54-80.*

FAO (1966) *Guidelines for soil profile description.* Rome.

FAO/UNESCO (1974) *Soil Map of the World. Vol I, Legend (advance copy).* UNESCO, Paris.

Fieldes, M. (1955) Allophane and related mineral colloids. *N.Z. J. Sci. Techn. Section B, 37: 336-350.*

– (1966) The nature of allophane in soils. *N.Z. J. of Sci. 9: 599-607.*

Fridland, F.M. (1958) Podzolization and illimerization. *Soviet Soil Sci. 1: 24-32.*

Fuerstenau, B.W. (1969) Interfacial processes in mineral water systems. *Int. Congr. of pure and applied Chem. Trans. 12th. Sydney: 135 164.*

E.E. Gamble, R.B. Daniels (1972) Iron and silica in water, acid ammonium oxalate, and dithionite extracts of some North Caroline Coastal Plain Soils. *Soil Sci. Soc. Am. Proc. 36: 939-943.*

M.C. Gastuche, J. Delvigne, J.J. Fripiat (1954) Altération chimique des kaolinites. *Int. Congr. Soil Sci. Trans. 5th. Leopoldville; 2: 439-449.*

Giessen, A.A. van de (1966) Hydratatie en hydrolyse, II: De hydrolyse van oplossingen van Fe(III) nitraat. *Chemisch Weekblad, 62: 305.*

Gorbunov, N.I. (1961) Movements of colloidal and clay particles in soils (problems of leaching and podzolization). *Soviet Soil Sci. 7: 712-724.*

B.P. Gradusov, G.S. Dyardevich (1961) Chemical and mineralogical composition of clay fractions in strongly podzolic soils in connection with element migration. *Soviet Soil Sci. 7: 749-756.*

D.J. Greenland, J.M. Oades (1968) Iron hydroxides and clay surfaces. *Int. Congr. Soil Sci. Trans. 9th. Adelaide; 1: 657.*

Haile, N.S. (1954) *The Geology and Mineral Resources of the Strap and Sadong Valleys, Memoir 1.* Geol. Survey Dept. Kuching, Sarawak.

– (1957) *The Geology and Mineral Resources of the Lupar and Saribas Valleys, West Sarawak, Memoir 7.* Geol. Survey Dept. Kuching, Sarawak.

Harrison, T.B. (1934) *The Katamorphism of Igneous Rocks under Humid Tropical Conditions.* CAB publication, Rothamsted, Harpenden.

I. Hasimoto, J.D. Hughes, O.D. Philen (1969) Reaction of tri-ammonium hydrophosphate with soils and soil minerals. *Soil Sci. Soc. Am. Proc. 33: 404-405.*

Holmes, A. (1964) *Principles of Physical Geology.* Thomas Nelson and Sons, Ltd., London.

P.H. Hsu, T.F. Bates (1964) Adsorption of phosphate by aluminium and iron soils. *Soil Sci. Soc. Am. Proc. 28: 474-478.*

I.S.S.S. (1967) *Proposal for uniform system of Soils Horizon designations.* (First draft, September, 1967). Bulletin no. 31.

Jacks, G.V. (1955) *Multilingual vocabulary of Soil Science.* FAO, Rome.

Jackson, M.L. (1956) *Soil Chemical Analysis. Advanced Course.* Pub. by the author, Dept. of Soils, Univ. Wis., Madison, USA.

– (1965) In: *Agronomy no. 9: 578-601.* Am. Soc. of Agron. Inc., Madison, USA. Free oxides, hydroxides and amorphous aluminosilicates.

Jenny, H. (1941) *Factors of Soil Formation.* McGraw-Hill, New York.

J.S. Joffe, A.J. Pugh (1934) Soil profile studies, VI: Distribution of titanium in soils, with special reference to Podzols. *Soil Sci. 38: 245-258.*

Karim, A. (1953) The pedological significance of titanium. *J. Soil Sci. 4, 1: 56-58.*

Massaro, P. (1973) Investigations into the measurement of iron and aluminium by A.A.S. in soil extracts of dithionite, ammonium oxalate/oxalic acid and pyrophosphate. *Internal report AO 24-B05. Trop. Inst., Amsterdam.*

Maignien, R. (1966) In: *F. Scheffer and P. Schachtschabel (1970) Nat. Resource. Res. Bd. 4, UNESCO, Paris.*

C. Marius, A. Misset (1968) In: *Boer, M.W.H. de (1972).* Reconnaissance pédologique de la Guyne francaise méridionale. ORSTOM, Cayenne (unpublished report).

A.E. Martin, R. Reeves (1957a) Chemical studies of podzolic illuvial horizons, I: The extraction of organic matter by organic chelating reagents. *J. Soil Sci. 8: 268-278.*

– (1957b) Chemical studies of podzolic illuvial horizons, II: The use of acetylacetone as an extractant of translocated organic matter. *J. Soil Sci. 8: 279-286.*

McCaleb, S.B. (1959) The genesis of the Red-Yellow Podzolic Soils. *Soil Sci. Soc. Am. Proc. 23: 164-168.*

McKeague, J.H. Day (1966) Dithionite and oxalate extractable Fe and Al as aids in differentiating various classes of soils. *Can. J. Soil Sci. 46: 13-22.*

J.A. McKeague, J.E. Brydon, N.M. Miles (1966) Differentiation of forms of extractable iron and aluminium in soils. *Soil Sci. Soc. Am. Proc. 35: 33-38.*

J.A. McKeague, M.G. Cline (1963) Silica in soils. *Advances Agron. 15: 339-396.*

Mege, R.V. (1969) A standardized inert dilution method in X-ray fluorescence analysis. *Anal. Chem. 41, 42.*

O.P. Mehra, M.L. Jackson (1960) Iron oxide removal from soils and clays by a dithionite-citrate system buffered with sodium bicarbonate. *Clays, Clay minerals, 7: 317-327.*

Metson, A.T. (1956) Methods of chemical analysis for soil survey samples. *N.Z. Soil Bureau Bulletin 12.*

Millot, G. (1970) *Geology of clays.* Springer Verlag, New York.

Milner, H.B. (1952) *Sedimentary petrography.* Murby, London.

Mohr, E.J.C. (1944) *Soils of Equatorial Regions.* Edwards, Ann Arbor, Michigan.

E.J.C. Mohr, F.A. v. Baren (1954) *Tropical Soils, 2nd edition.* v. Hoeve, the Hague.

E.J.C. Mohr, F.A. v. Baren, J. v. Schuylenborgh (1972) *Tropical Soils, 3rd edition.* Mouton-v. Hoeve, the Hague.

Muir, A. (1961) In: *F. Scheffer, P. Schachtschabel (1970). Advances Agron. 13, 1.*

Muller, A. (1969) Volcanic ash-derived soils. *Trop. Abstr. 24, 6: 353-358.*

A. Muller, R.M. Schelhaas (in press) Influence of drying on moisture characteristics of some volcanic ash derived soils. *Proc. 2nd Panel on Volcanic Ash Soils, Pasto, Colombia, 1972.*

Oades, J.M. (1963) The nature and distribution of iron compounds in soils. *Soils and Fertilizers, 26, 2: 69-79.*

Oberlin, A. (1957) Alteration des cristaux de kaolinite; détermination par microdiffraction electronique de la structure des produits altérés. *C.R. Acad. Sci. Fr. 244: 1658-1661.*

Papadakis, J. (1961) *Climatic tables for the world.* Av. Cordoba, 4564, Buenos Aires.

– (1970) *Climates of the World, their classification, differences and geographic distribution.* Ed. by the author, Av. Cordoba, 4564, Buenos Aires.

Pedro, G. (1964) In: *F. Scheffer, P. Schachtschabel (1970) Ann. Agron. 15, 85: 243.*

Penman, H.L. (1948) Natural evaporation from open water, bare soil, and grass. *Proc. Roy. Soc. 193a: 120-145.*

A.T. Perkins, R.D. Dragsdorf, M.S. Bhangoo (1957) Reaction between phosphates and kaolinite decomposition products. *Soil Sci. Soc. Am. Proc. 21: 154-157.*

Pickering, R.J. (1962) Some leaching experiments on three quartz-free silicate rocks and their contribution to an understanding of laterization. *Econ. Geol. 57: 1185-1206.*

Pimm, A.C. (1965) *Report 3, Serian Area, West Sarawak, Malaysia.* Geological Survey, Borneo Region, Malaysia.

Pedro, G. (1964) Premier résultats sur la génèse des laterites par voie expérimentale. *Int. Geol. Congr. Rep.: 108-111.*

L. v.d. Plas, A.C. Tobi (1965) A chart for judging the reliability of point counting results. *Am. J. of Sci. 263: 87-90.*

J.A. Prescott, M. Peech (1949) A climatic index for the leaching factor in soil formation. *J. Soil Sci. 1: 9-19.*

B. v. Ray, M. Peech (1972) Electrochemical properties of some Oxisols and Alfisols of the Tropics. *Soil Sci. Am. Proc. 36: 587-593.*

Rosmalen, H.A. v. (1974) Determination of exchangeable cations and cation exchange capacity (CEC) of recent volcanic ash soils and acid tropical soils containing amorphous materials. *Turrialba, 24, 3: 274-279.*

F. Scheffer, P. Schachtschabel (1970) *Lehrbuch der Bodemkunde.* Ferdinand Enke Verlag, Stuttgart.

Schellmann, W. (1964) In: *F. Scheffer and P. Schachtschabel (1970). Geol. Jb. 81: 645.*

F.H. Schmidt, J.H.A. Ferguson (1952) Rainfall types based on wet and dry period ratios for Indonesia with Western New-Guinea. *Verh. Kement. Perhub. Djaw. Meteorol. dan Geofis, nr. 42.*

Schnitzer, M. (1957) Mobilization of iron in podzol soils by aqueous leaf extracts. *Chem. Ind. 49: 1594.*

– (1959) Interaction of iron with rainfall leachates. *J. Soil Sci. 10: 300-308.*

– (1967) Humic-fulvic acid relationships in organic soils and humification of the organic matter in these soils. *Can. J. Soil Sci. 47.*

J. v. Schuylenborgh (1957) Investigations on the classification and genesis of soils derived from andesitic tuffs under humid tropical conditions. *Neth. J. Agr. Sci. 5: 195-210.*

– (1958) On the genesis and classification of soils derived from andesitic tuffs under humid tropical conditions. *Neth. J. Agr. Sci. 6: 99-123.*

J. v. Schuylenborgh, F.F.F.E. v. Rummelen (1955) The genesis and classification of Mountain soils developed on tuffs in Indonesia. *Neth. J. Agr. Sci. 3: 192.*

J. v. Schuylenborgh, A.M.H. Sänger (1949) The electrokinetic behaviour of iron and aluminium hydroxides and oxides. *Rech. Trav. Chem. 68.*

Schwertmann, V. (1959) Die fraktionierte Extraktion der freien Eisenoxide in Boden, ihre Mineralogischen Formen und ihre Entstehungsweisen. *Z. Pflanzenarnähr. Düng. Bodenkunde, 84: 194-204.*

– (1964) Differenzierung der Eisenoxide der Bodens durch Extraktion mit NH_4. Oxalat Lösung. *Z. Pflanzenernähr. Düng. Bodenkunde, 105: 194-202.*

V. Schwertmann, W.R. Fisher, H. Papendorf (1968) The influence of organic compounds on the formation of iron oxides. *Int. Congr. Soil Sci. Trans. 9th. Adelaide; 1: 645-655.*

Seal, J. (1958) Rainfall and Sunshine in Sarawak. *Sar. Museum J. VIII, 11 (new series): 500-544.*

Segalen, P. (1964) Le fer dans les sols. *ORSTOM publ. nr. 4, Paris.*

– (1973) L'Aluminium dans les sols. *ORSTOM publ. nr. 22, Paris.*

Siderius, W. (1973) *Soil Transitions in Central East Botswana (Africa)* Ph.D. Thesis, University of Utrecht, the Netherlands.

S. Sivarajashingham, L.T. Alexander, J.G. Cady, M.G. Cline (1962) In: *F. Scheffer and P. Schachtschabel (1970). Adv. Agron. 14: 1.*

Soil Surey Staff, Sarawak (1966) A classification of Sarawak soils. *Technical paper nr. 2. Res. Branch, Dept. of Agr. Sarawak (Malaysia).*

Soil Survey Staff, USDA (1951) Soil Survey Manual, *Handbook nr. 18.*

– (1960) *Soil Classification. A Comprehensive system (7th Approximation)*

– (1967) *Supplement to Soil Classification system (7th Approximation)*

– (1970) *Selected chapters from the unedited text of the Soil Taxonomy.*

P.C. Stobbe, J.R. Wright (1959) Modern concepts of the genesis of podzols. *Soil Sci. Soc. Am. Proc. 23: 161-164.*

Strahler, A.N. (1968) *Physical Geography.* Wiley and Sons, Inc., New York.

Sumner, M.E. (1963) Effects of iron oxides on positive and negative charges in clays and soils. *Clay Miner. Bull. 5: 218-226.*

Tan Kim Hong, J. v. Schuylenborgh (1959) On the classification and genesis of soils derived from andesitic volcanic material under a monsoon climate. *Neth. J. Agr. Sci. 7: 1.*

– (1961a) Classification and genesis of soils over acid volcanic material. *Neth. J. Agr. Sci. 9: 41-54.*

– (1961b) On the organic matter in tropical soils. *Neth. J. Agr. Sci. 9: 174-180.*

A.W. Taylor, E.L. Gurney, E.C. Moreno (1964) Precipitation of phosphate from calcium phosphate solutions by iron oxides and aluminium hydroxide. *Soil Sci. Soc. Am. Proc. 28: 49-52.*

Tertian, R. (1971) Quantitative X-ray fluorescence analysis using solid solution specimens. A theoretical study of the influence of the quality of primary radiation. *Spectrochim. Act. 26b: 71.*

– (1972) X-ray fluorescence analysis of liquid and solid solution specimens. A theoretical account of the double concentration method and its performances. *Spectrochim. Act. 27b: 159.*

R. Tertian, R. Geninasca (1972) Analyse des Roches par une méthode de fluorescence X comportant une correction précise pour d'effet interélément. *X-ray Spectrometry, 1: 83.*

Thornbury, W.D. (1954) *Principles of Geomorphology.* Wiley and Son, Inc., New York.

Thornwaite, C.W. (1948) An approach towards a rational classification of climate. *Geogr. Review, 38: 55-94.*

J. Thorp, G.D. Smith (1949) Higher categories of soil classification: Order, suborder, and great soil groups. *Soil Sci. 67: 117-126.*

Turc, L. (1953) The soil water balance: Interrelations of rainfall, evaporation and run-off. *African Soils, III: 139-172.*

E.J. Udo, F.O. Uzu (1972) Characteristics of phosphorus adsorption by some Nigerian soils. *Soil Sci. Soc. Am. Proc. 36: 879-883.*

J. Velez, W.G. Blue (1971) Effect of lime on extractable iron and aluminium, and phosphorus sorption in a Tropical and a Temperate soil. *Soil and Crop Sci. Soc. Florida Proc. 31: 169-173.*

J.M. de Villiers, M.L. Jackson (1967a) Cation exchange capacity variations with pH in soil clays. *Soil Sci. Soc. Am. Proc. 31: 473-476.*

– (1967b) Aluminous chlorite origin of pH dependent cation exchange capacity variations. *Soil Sci. Soc. Am. Proc. 31: 614-619.*

K. Wada, Tokashihi, Y. (1972) Selective dissolution and difference in infrared spectroscopy in quantitative mineralogical analyses of volcanic ash soil clays. *Geoderma, 7, 3/4: 199-213.*

Wall, J.R.D. (1966) *The Bekenu, Niah-Suai area, Sarawak (Malaysia).* Ph.D. Thesis, Reading University, England.

R.M. Weaver, J.K. Syers, M.L. Jackson (1968) Determination of silica in citrate-bicarbonate-dithionate extracts of soils.*sSoil Sci. Soc. Am. Proc. 32: 497-501.*

Wilford, G.E. (1955) *The Geology and Mineral Resources of the Kuching-Lundu area, West Sarawak, Memoir 3.* Geological Survey Dept., British Territories in Borneo (now Malaysia).

G.E. Wilford, C.H. Kho (1965) *Report 2, Penrissen area, West Sarawak, Malaysia.* Geological Survey, Borneo Region, Malaysia.

Winkler, H.G.F. (1967) *Petrogenesis of metamorphic rocks, revised 2nd Ed.* Springer Verlag, New York.

E.B. Wolfenden, N.S. Haile (1963) *Report 1, Sematan and Lundu area, West Sarawak.* Geological Survey Dept. British Territories in Borneo (now Malaysia).

Wollast, R. (1967) Kinetics of the alteration of K-feldspar in buffered solutions at low temperature. *Geochim. et Cosmochim. Acta, 31: 635-648.*

Curriculum Vitae

De auteur werd in 1929 te Middelburg geboren en behaalde in 1948 het H.B.S.-b diploma aan het Chr. Lyceum Zandvliet te Den Haag. Na het vervullen van zijn dienstplicht vervolgde hij zijn studie aan de toenmalige Rijks Hogere School voor Tropische Landbouw te Deventer, waar hij in 1953 het einddiploma behaalde.

Na een verblijf van drie jaar in Nederlands Nieuw Guinea als bodemkarteerder bij het Bodemkundig Bureau van de dienst Landbouw en Visserij, was hij in de jaren 1957 en 1958 werkzaam als bodemkundige voor de Consulting Engineers firm Sir Alexander Gibb and Partners, waarvoor hij een karteringsopdracht vervulde voor irrigatiedoeleinden in de Kaspische Zeevlakte in Iran. Daarna werd hij aangetrokken als Soil Surveyor voor de High Commission Territory Swaziland, alwaar hij karteringswerkzaamheden verrichtte voor irrigatieprojekten en farmplanning.

In 1960 volgde overplaatsing naar de Britse Crown Colony Sarawak. In 1961 nam hij de algehele leiding op zich van de regionale bodemkartering welke functie hij vervulde tot 1970. In die periode legde hij zich speciaal toe op de bestudering van de genese van tropische Podzolen en podzolische gronden. De resultaten van deze studies werden vastgelegd in een aantal artikelen. In 1970 werd hij verbonden aan het Koninklijk Instituut voor de Tropen te Amsterdam, waar hij in 1972 de leiding op zich nam van de nieuwe opgerichte sectie Mineralogie en Bodemgenetische Research, binnen de onderafdeling Bodemkundig Onderzoek.

In de periode 1970-1972 legde hij de laatste hand aan een memoir welke over de gronden van West Sarawak handelt en verscheen er een monografie over Tropische Laagland Venen in Z.O. Azië.

In de jaren 1971-1974 voltooide hij zijn studie in de geologie aan de Rijksuniversiteit te Utrecht, waar hij zich specialiseerde in de bodemkunde.

Het onderzoek, dat leidde tot dit proefschrift en dat reeds was aangevangen tijdens zijn verblijf in Sarawak, werd afgesloten gedurende zijn verbintenis met het Koninklijk Instituut voor de Tropen.

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