MEMOIR I

THE SOILS OF WEST-SARAWAK (EAST-MALAYSIA)

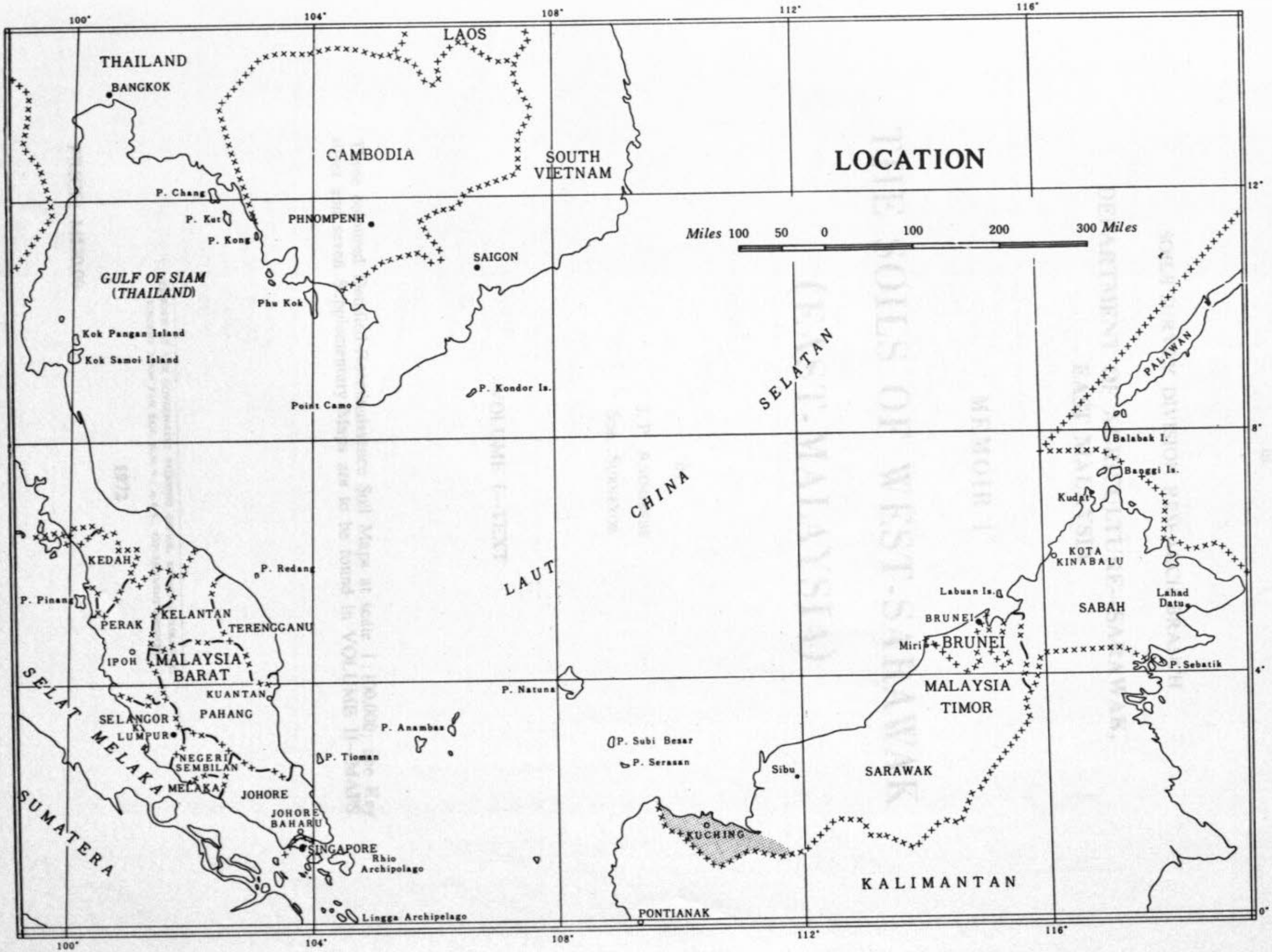
by

J. P. ANDRIESSE
SOIL SURVEYOR

VOLUME I—TEXT

THE SOILS OF WEST-SARAWAK (EAST-MALAYSIA)

A compilation of Detailed Reconnaissance soil mapping and soil research carried out in the western part of the State of Sarawak—Federation of Malaysia during the period 1960-1970.


LOCATION
Miles 100 50 0 100 200 300 Miles
THAILAND
BANGKOK
LAOS
CAMBODIA
SOUTH VIETNAM
PHNOMPENH
SAIGON
P. Chang
P. Kut
P. Kong
GULF OF SIAM (THAILAND)
Phu Kok
Kok Pangan Island
Kok Samoi Island
Point Camo
P. Kondor Is.
SELATAN
CHINA
LAUT
PALAWAN
Balabak I.
Banggi Is.
Kudat
KOTA KINABALU
SABAH
Lahad Datu
P. Sebatik
Labuan Is.
BRUNEI
Miri
MALAYSIA TIMOR
SARAWAK
Sibu
KUCHING
KALIMANTAN
PONTIANAK
P. Subi Besar
P. Serasan
P. Natuna
P. Anambas
P. Tioman
P. Redang
KEDAH
P. Pinang
PERAK
KELANTAN
TERENGGANU
IPOH
MALAYSIA BARAT
KUANTAN
PAHANG
SELANGOR
LUMPUR
NEGERI SEMBILAN
MELAKA
JOHORE
JOHORE BAHARU
SINGAPORE
Rhio Archipelago
Lingga Archipelago
SELAT MELAKA
SUMATERA
100°
104°
108°
112°
116°
12°
8°
4°
0°

SOILS SURVEY DIVISION RESEARCH BRANCH

DEPARTMENT OF AGRICULTURE—SARAWAK,
EAST MALAYSIA

MEMOIR 1

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Three coloured Detailed-Reconnaissance Soil Maps at scale 1:100,000; one Key sheet and seven Supplementary Maps are to be found in VOLUME II—MAPS.

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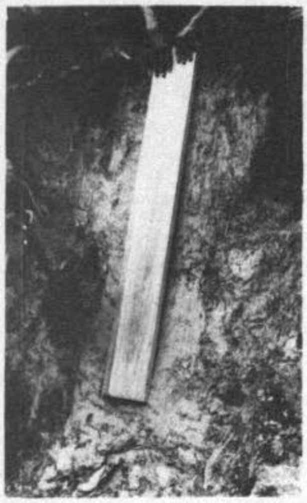
Plate I

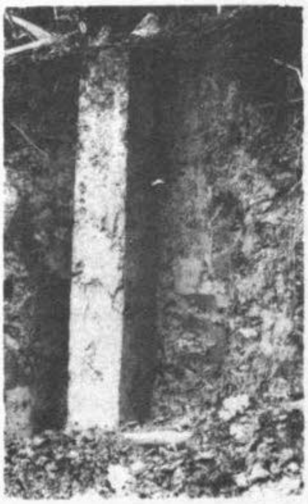
THE COLLECTION OF A SOIL MONOLITH

a
Preparation of a vertical fresh exposure at roadcutting.

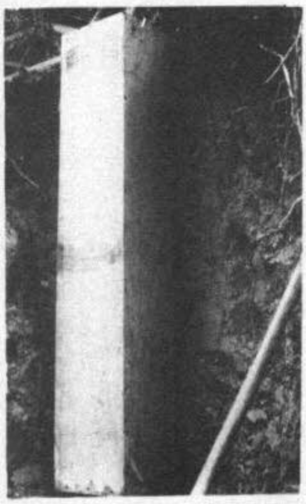


b
Measuring the required depth and the width of the soil column.

c
Digging out of the soil column.



d
Completed soil column.



e
Wooden box fitted over the soil column. The column is carefully cut loose at the back with a spade and parang and gently lowered.

f
Final preparation – the back part is sliced down to fit the box and leaves are used to fill up empty space to avoid disintegration during transport.

Part I — GENERAL INFORMATION

Chapter 1. INTRODUCTION

1. Background to the memoir

The compilation of this memoir marks the conclusion of the reconnaissance phase in soil mapping and soil research for the western part of Sarawak, a region approximately 4,300 square miles in extent.

It also coincides with the completion of a 10-year long period of soil survey work in Sarawak by the author who suggests that by consolidating the soil information collected during this period a basis may be provided for more detailed soil studies in the future.

The Soil Surveyor in general faces a difficult task when he has to transmit information of a technical nature to a wide circle of readers who in one way or another could benefit from the knowledge which he intends to make available. Among those who should be reached foremost are those directly dealing with rural development planning and specifically those concerned with agricultural extension. There are also those research workers dealing with closely allied subjects, such as Geologists, Agronomists, Foresters and not to forget those dealing with land improvement, the drainage and irrigation Engineers, who may find this information useful in their own work. It is also thought that since text books on Sarawak soil conditions are non-existent, educators would probably find useful information in this memoir for the teaching of principles of soil formation under Sarawak conditions.

In order to serve the needs of this wide spectrum of possible readers the author has attempted to split the information into a number of more or less independent chapters, each dealing with specific subjects. Because of the close relation between the subjects discussed a certain amount of repetition could not be avoided. Constant cross-reference is made to related subject matters discussed in the various chapters, so that the reader interested in those relationships will have ready access to the information required.

In order to make the discussed subjects more readily understood by those not initiated in the more scientific background of soil research, some chapters are introduced by a brief outline of the problems involved. This may have resulted in an odd mixture of popularized and basic science but the author is of the opinion that too much valuable information is being lost to those who need it mostly because research workers are generally too much inclined to stress the scientific basis of their work, thereby ignoring the practical applications of value for the more pragmatic planner.

This memoir, apart from making available soil research data, aims to indicate where specific soil knowledge is still lacking and in what field mistakes have been made in the past. It is of little use to ignore the fact that errors have been made either by too much or too little emphasis on certain subjects, or by employing a wrong approach. In this respect, the classification method adopted in Sarawak is severely critized and has therefore been treated in much detail.

By this, it is hoped that in future work either new approaches are tried out or certain aspects in soil research are refocussed to fields which hitherto received little attention.

If this memoir can contribute in some way or other to the rural development of the Region and to the betterment of its population, the author will be amply rewarded for his efforts.

2. Acknowledgements

Throughout the field surveying period the author was assisted by a great number of Agricultural and Junior Agricultural Assistants who joined the field parties for short or long periods. It is impossible to mention them all individually but an exception must be made for Agricultural Assistant, Mr Rosli bin Sahari, and mandor Mr Timothy Kinok who almost continuously either accompanied the author on field surveys or conducted surveys independently. I owe them a great debt for their technical assistance, but above that, they made the often difficult conditions bearable by their cheerful perseverance and moral support.

The survey work was greatly facilitated by the help received by Government Officers and particularly by those attached to the Department serving in the respective Districts. They provided transport or assisted in the recruiting of local labourers. To the latter, particularly those from Kampong Pichin who accompanied me for longer than 8 years, I have to extend my thanks not only for a faithful discharging of their strenuous work comprising jungle cutting, the digging of soil pits and the carrying of equipment over mountains and through swamps but also for their companionship and for teaching me the Dayak ways of life and thinking. This enabled me to feel more involved in the problems of the rural areas, giving the work more perspective. The friendly and most hospital reception extended to me by most rural people during my stays in their long-houses, and kampongs, I will never forget and has perhaps given me more than I will ever be able to repay.

For the follow-up research work, I am grateful for the co-operation received from fellow research workers in the Department, notably to the various Chemists who served in the Chemistry Division during the period. I would like to thank in particular Mr J. M. Bailey, Mr Sim Eng Shiong and Dr Mohd. Iqbal Ahmad for their stimulating interest in soil research problems and their willingness to meet the often heavy demands for soil analysis data.

I have to thank Officers in the Geological Department for helping to identify rock samples and those in the Forestry Department who assisted in problems related to natural vegetation. I am grateful to Officers in the Laboratory of Regional Soil Science of the University of Wageningen, Holland, for assistance rendered in the preparation of the mammoth-size thin sections of soils and for the micro-pedological interpretations; to the Soils Bureau of the Mineralogical and Geological Faculty of the University of Utrecht for allowing me the use of their facilities for the sand mineralogical analyses. In this respect, I owe great thanks to mineralogist Mr W. L. P. J. Mouthaan for initiating me in this work. The support of Mr H. Ph. Huffnagel, Director of the Division for Agricultural Research of the Royal Tropical Institute in Amsterdam is gratefully acknowledged, firstly for making available staff and equipment for the carrying out of analytical research and secondly for his great interest in this memoir which stimulated its completion.

The assistance received from Officers in the Department of Lands and Surveys in the photographic manipulations in the various stages of map making and the preparations of the figures for the memoir is very much appreciated. Without their consistent support, it would have been impossible to produce them in the way they are being presented.

I owe great thanks to all the drawing office staff of the Soils Division who were responsible for the ardious task of completing the original drawings and maps. In particular, I would like to extend my gratitude to the chief draughtsman Mr Lim Chia Chuang, whose technical skill is largely responsible for the high standard achieved in the final drawing and colour separation of the soil maps.

The help rendered by the Director of National Mapping in Kuala Lumpur who arranged the printing of all maps is gratefully acknowledged as is the assistance rendered by the Government Printer in Kuching who was responsible for the printing of the text in Volume I.

I am grateful to Miss Anna Yong for her untiring efforts to type and retype the various drafts of the memoir. I extend my heartfelt thanks to my colleagues Mr Lim Chin Pang and Mr Ian Baillie and to Mr Peter Eaton of the Batu Lintang Teachers' Training College for discussions and assistance in reading the drafts and for suggestions to improvement.

I finally would like to express my gratitude to my wife whose continuous moral support has been a great help to me during the long and frequent field periods and in particular during the completion stage of this memoir.

3. Definition of Area

The area which forms the subject of this memoir is shown on the location map (p.ii) and is referred to in the following text as the 'Region' or 'West Sarawak'. It is bounded in the north from Tanjong* Datu to the mouth of the Batang† Lupar by the South China Sea, the eastern boundary is formed by the true right border of the Batang Lupar to where it almost reaches the border with Kalimantan at Lubok Antu. The southern and western boundaries from Lubok Antu to Tanjong Datu are indicated by the international border with Indonesia (Kalimantan).

Administratively, it covers the Lundu, Bau, Kuching Rural, Lower and Upper Sadong Districts forming the First Division, and that part of the Simanggang and Lubok Antu Districts situated west of the Batang Lupar in the Second Division. The total area is 4,377 square miles, just over 9% of the total land area of the State of Sarawak.

These boundaries were chosen since this Region forms a geological, physiographical and climatological entity, which ensures less complexity in the descriptive parts of the memoir.

4. History of the Soil Survey of West Sarawak

No pre-war records have been found on soil survey work carried out in West Sarawak and it is assumed that no organised soil survey work was carried out in the Region until after the Second World War.

*Tanjong — headland

†Batang — river

The earliest official report on such work is from the Consulting Engineering Firm of Sir Bruce White and Partners who carried out a soil survey of the Nonok Peninsula in 1955 at the request of the Sarawak Government. The purpose was to investigate possibilities for wet rice growing in the area and the soil survey work conducted was consequently of a special and restricted nature. (Sir Bruce White, 1956). From 1954-57 the Geological Survey of the Borneo Region issued a number of memoirs on reconnaissance geological surveys in the Region in which were included brief notes on the various soil types encountered. (Haile, 1954, 1957; Wilford, 1955).

In 1955-56, Dames carried out soil studies in certain areas under 'Kerangas Forest'. This was done on the invitation of the Forest Department as part of their research work. No soil maps were prepared during this period but field notes on the soils studied are available. Much of the information collected during this period was used by Dames in the compilation of FAO Report 1512, 'Soil Research in the Economic Development of Sarawak', issued in 1962. This report also incorporates work carried out by Dames during 1958-59 in which period he was attached to the Agricultural Department as FAO Expert to organise a Soil Research Division in the Research Branch in that Department.

With the establishment of this Division in 1958 soil survey work in the modern sense could commence. The division comprised a Soils Laboratory and a Survey Section. During the early years, field work was carried out by the FAO expert in collaboration with Soil Chemist, C. D. Sutton. Much of this work was devoted to semi-detailed surveying of small areas for agricultural or settlement planning.

Dames established a number of series mainly for Podzols and Podzolic soils (these are used in the FAO report, 1962). For most surveys on which maps and reports are available (Dames, 1956, 1959a and b; Sutton, 1959a and b, 1960a and b) *ad hoc* mapping units were used and it was not until 1960 that an organised reconnaissance survey of the whole Region could be started.

The original intention was to cover the Region in a orderly manner but, frequently, urgent surveys of certain areas for road development or other purposes had to disrupt this programme and for this reason the Region was covered in a very haphazard manner, which through the years left many gaps between the numerous survey areas. Following reconnaissance surveys, semi-detailed surveys were carried out in specific areas if these were found promising for development or the Government wanted to commence development projects.

As a result many reports were issued on specific reconnaissance and semi-detailed surveys. Although in this way information could be rapidly made available to the Government, there was little time to correlate soils of one area with another, so that after a number of years a great number of soil mapping units bearing little relation to one another had been created. To remedy this, a field classification was compiled (Andriesse, 1962d), which aimed to bring some order in the chaos which could result in the mapping of the same soil units under various names in different parts of the State. By 1964 a start could be made in developing a natural taxonomic classification of Sarawak soils. Before this was completed a report on an area of approximately one quarter of West Sarawak was issued (Andriesse, 1965b). This report consolidated information, spread over a number of reports on several parts of this area, and attempted to bring order in the classification units, at least for this area. The First Approximation of the Classification of Sarawak Soils was presented to the 2nd Malaysian Soils Conference in 1966 (Sarawak Soil Survey Staff, 1966). After 1965 therefore, all soil names used in soils maps and reports are related to this classification.

By the end of 1968, the reconnaissance survey of West Sarawak was almost completed. The uncompleted parts comprised the border areas which could not be visited from the end of 1963 because of security reasons, and some parts in the Bau and Simanggang Districts for which survey requests were never made. During 1969, all these remaining areas were covered in a rapid way using broad reconnaissance methods so that the reconnaissance picture of the whole Region could be completed by the end of that year.

Taking into account that surveying in West Sarawak had to be interrupted many times for work elsewhere in the State or for subsequent resurveying of certain areas at semi-detailed level, the reconnaissance survey was completed in a comparatively short period. A total of 73 weeks was spent in the field on reconnaissance surveying. This is just short of 1½ years field work and amounts to a coverage of approximately 60 square miles per week. This could only be achieved by adopting modern methods of surveying adapted to the type of terrain and general conditions in the area. Information on the methods used can be found in the following chapter.

Chapter 2. METHODS

1. Maps and Air-Photography

Since large parts of the Region were inaccessible, particularly in the early sixties when the road system had not yet been developed to its present state, it was fortunate that topographic maps at a scale 1:50,000 were available for most of the Region. The uncontoured edition of the Directorate of Overseas Services series 34 (T 735), issued in 1957, served as a topographic base for all soil surveys until 1965 when the new contoured edition D.O.S. 434 (T 735, edition 2-GSGS) became available for the First Division. For the remainder of the area (Second Division) form lines are used in this map series to depict outstanding topographic features.

The contoured edition proved to be a great aid in soil mapping and when it became available the accuracy in delineating soil boundaries was greatly improved.

Post-war air photography by the R.A.F. from the period 1948 to 1956 was available for the whole area. The scale was mainly 1:25,000, but varied locally between 1:20,000 to 1:30,000.

In addition to these cartographic tools, use was made of Reconnaissance Geological maps of a scale 1:125,000 prepared for the Region in the period 1950-57 by the Geological Survey, Borneo Region, and the Land Use map, scale 1:250,000 (Sarawak series no. 10) issued in 1956 by the Land and Survey Department. Both types of maps have proved to be of excellent value for the interpretation of air-photographs, particularly in the early years when local experience had not yet been gained.

For some semi-detailed surveys, in particular those after 1965, use was made of the 1:10,000 scale air-photography flown and printed by the Department of Land and Survey, while 1:10,000 scale maps with 25 feet contour intervals also prepared by the Land and Survey Department were used as a topo-base. For areas where photographs and maps of that scale were not available enlarged versions of the 1:25,000 scale air photographs and the 1:50,000 scale topo-maps were employed.

Finally, the 2-GSGS edition of the T 735 series, at a scale of 1:50,000, served as a topo-base for the preparation of the 1:100,000 scale Detailed Reconnaissance Soil Map in this memoir. (Volume II) This was done by a photographic reduction process through which the 1:50,000 scale maps were reduced to 1:100,000, whereafter only the main topographic details were traced and redrafted by the Soils Division.

2. Reconnaissance Soil Surveys

The carrying out of a reconnaissance soil survey and the production of relevant maps and reports involves three stages:

(i) preparation

(ii) field work

(iii) compilation

(i) In the preparation stage, all available air-photography at a scale 1:25,000 is examined stereoscopically by employing a Toko mirror stereoscope mounted on a Casella sliding bar to allow free movement of the stereoscope over a stereo pair of photographs. The terrain seen on the air photographs is subdivided into physiographic units, while if virgin forest is still present the different vegetation types are demarcated. Geological information obtained from the geological maps is also inserted. Since in West Sarawak the relationship between soil type, landscape and geology is close, an impression on the complexity of soils to be encountered in the area under study can thus be readily obtained. By using this tentative broad soil pattern obtained through the air-photo interpretation, the position of traverses for soil examination in the field can be selected prior to the actual field work and thus considerable savings in funds, manpower and time can be realised.

(ii) The actual field work normally takes twice as long as that required for the preparation stage. Field traverses used for soil investigations have to be cut through dense secondary growth or primary jungle but use can be made of existing paths. The latter can often be made use of in the uplands populated by Land Dayaks, who maintain permanent communication paths between their settlements. A traverse (locally called 'rentis') has to start at a known point and frequently, a bend of a river or the confluence of streams is chosen as an easily recognisable point. If rentises have to be cut in upland areas where no use is made of rivers as a means of access, settlements or a crossing of two main paths can be used as known points. In dense undergrowth and dissected terrain on average a rentis of 1½ mile a day can be cut, while in easier terrain this can be over 2 miles. In these traverses, cut at a fixed bearing by using a British Army style 2 inch prismatic emersion compass, soil augerings are made at fixed intervals of 100 feet. This interval is adjusted when topographic and geological boundaries of any significance are crossed. For the augerings a Dutch Edelman auger of 4 feet length is used which, although destroying structure, enables the study of texture, colour, inclusions, wetness, rooting depths and consistency of soil horizons met in the augering. Structure in Sarawak Soils is commonly not well-developed because they are always in a moist state and therefore the drawback of not being able to describe structure is not felt as a great hindrance. Soil information obtained in the traverses is exchanged between assistants and surveyor in the camp whereafter representative sites for the collection of soil samples can be selected. Profile pits of 3 feet wide, 4 feet long and 5 feet deep are used for describing soil profiles and for the collection of soil samples. For the soil descriptions, use is made of the methods and terminology described in detail in the U.S.D.A. Soil Survey Manual (1951).

In peat areas where augers cannot be used, the depth of peat is measured by pushing a long straight sapling, cut in the forest, down into the peat. Notches cut into the sapling at intervals of 1 foot will, after the stick is pulled up, show the nature of the material which underlies the peat. Sampling of peat without special tools at a depth below the watertable has proven to be difficult.

Soil samples, weighing about four pounds each, are kept in field conditions in tied polythene bags which are again placed in linen cloth bags to prevent the loss of soil through splitting of the polythene bags during transportation from the field to the Soils Laboratory.

Rock samples are frequently collected for detailed identification and analysis by the Geological Survey.

(iii) The third stage involves the compilation of the soil maps and other relevant maps together with the soil survey report. This work is carried out at Headquarters base in Kuching, although a rough map may be compiled in the field. The soil types encountered in the traverses are depicted in colour on the traverses plotted onto the topographic maps. Final soil boundaries are drawn by employing a Hilger and Watts Sketchmaster which not only provides a stereoscopic view of one air photo pair but also enables details on air photography to be superimposed onto the topobase of a different but smaller scale. The correlation between topography, geology and vegetation seen on the air photographs and the soil types as indicated in the traverses on the topo-map can thus be readily detected and soil boundaries between traverses are drawn by inference and plotted onto the topo-base.

Reconnaissance surveys usually involve large areas and for ease of manipulation, the 1:50,000 soil maps are normally reduced photographically to a scale of 1:100,000. In addition to the soil map other supplementary maps such as advisory land-use or terrain suitability for agricultural purposes are commonly prepared for each report.

A reconnaissance survey carried out in the manner described provides information on the broad pattern of soils. Although single soil types are encountered and described in the traverses, for cartographic reasons and because of insufficient information on the boundaries, they are commonly mapped in association with other soils. From the reconnaissance survey prospective areas for agriculture development can be selected and also recommendations can be given on the alignment of roads which should tap the areas with the greatest potential.

3. Semi-Detailed Soil Surveys

Semi-detailed surveys are carried out in areas previously covered by reconnaissance surveys. Semi-detailed investigations are needed to map the soils more accurately and in more detail so that project planning before implementation can be put on a sound basis. The greater accuracy required implies that more accurate topographic maps are needed than those used for reconnaissance mapping. Therefore, maps at a scale 1:10,000 prepared by the Land and Survey Department are now normally employed. In the early sixties, when detailed topo-maps were not available, an enlargement of the 1:50,000 topo maps had to be used. This has proved to be unsatisfactory because of lack in topographic detail and scale errors caused by enlargement. If available new photography at a scale 1:10,000 is used in conjunction with the detailed topograhic maps. The same system as used for reconnaissance mapping is generally employed. There are, however, some modifications which are necessitated by the greater accuracy required in semi-detailed survey maps.

For example, the use of air photography for selecting traverse lines is restricted in semi-detailed surveying because minor soil differences are commonly not reflected by the topography or vegetation visible on air photographs. Such differences, are however important in semi-detailed mapping. Therefore, in semi-detailed work, traverses are cut at regular intervals of approximately 400 yards. Also, along the traverse soil observations are made at closer intervals, generally at every 75 feet (25 meter). Commonly, an overall density of one observation per 4-acre is achieved in semi-detailed work. This figure may vary from place to place depending on the complexity of the soil pattern.

Semi-detailed soil maps have been issued at a scale 1:10.000 to 1:25,000; the latter scale was often obtained by photographic reduction of the original soil map prepared at a scale 1:10,000.

4. Detailed Soil Surveys

Apart from surveys of experimental plots comprising small areas, detailed surveys have not been carried out by the author. In one detailed survey conducted by Scott and Bailey (1964) air photographs appeared to be even less reliable than in semi-detailed surveying and a grid of parallel rentises at intervals varying between 100 and 300 feet formed the base of the soil map. The final map issued was at a scale 1:3,960. Scott suggests that for detailed work a detailed topographic map at a scale 1:3,168 to 1:4,752 with contour intervals of 5 or 10 feet would be essential for satisfactory detailed surveying.

5. Reliability

With the employed methods the accuracy obtained in reconnaissance surveying is on average 80%, meaning that in a mapping unit depicted on a soil map 80% of the area thus embounded contains soils as indicated. Subsequent semi-detailed work after reconnaissance surveys has shown this to be generally the case but indicated that semi-detailed work is commonly essential to enable the mapping of a simple soil mapping unit comprising one family or one series only. This also depends on the complexity of soils in a given area. For instance, areas lying between the 20 feet and 200 feet level have proved to be the most complex ones as upland soils, together with old and recent alluvials may alternate over short distances without much relief contrast. Neither air photographs nor topo-maps with contour intervals of 50 feet are adequate to reveal such small differences in relief. Since reconnaissance surveys are heavily dependent on relief contrast discrepancies are most likely to occur in such areas. Greatest accuracy in reconnaissance surveying could be achieved in the lower riverine areas where the soils occur in a regular pattern. Semi-detailed methods in such areas only enable a more precise delineation of a soil boundary but the chance that in the reconnaissance soils have been overlooked in between traverse lines is less great than in upland areas.

Probably, the greatest drawback in soil surveying in West Sarawak is the inaccessibility which makes it difficult to revisit areas for a further check up. This presents even more difficulties in the remainder of Sarawak where inaccessibility is a much greater problem than in West Sarawak.

Supplementary map 1 (Volume II) shows the types of surveys which have been carried out in the area. This map may give an indication of the amount of detail achieved in soil surveying in the various parts of West Sarawak. Each embounded area has been given a code number indicating the survey area and is identical to the report number for that area. These reports together with their maps have formed the main basis for the compilation of the Detailed-Reconnaissance Soil Map in this memoir (Vol. II) and they are separately listed in the References (section b, p.266).

Supplementary map 2 (Vol. II) shows the traverse network used in the various surveys. Traverses are shown as straight full black lines, while paths and roads are indicated as wavy broken black lines. The position of soil pits from which samples were collected for analyses are also indicated. A list of laboratory reference numbers to these samples together with the types of analysis carried out has been added as an inset to this map. It should be noted that soil pits are commonly indicated by the related laboratory numbers of the samples taken from the pit. For cartographic reasons it was impossible to insert all these numbers in this map and therefore for purpose of this memoir, the pits have been renumbered. Reference numbers of soil pits used in this memoir refer therefore to those indicated on this map. Likewise, all traverses, paths and roads along which soil observations have been carried out were also given a code number so that the relevant field information from these observations lines can be readily retrieved from the archives. These code numbers have not been inserted in the map but this information if required can be obtained from the Soils Division in the Department of Agriculture.

The soil sampling pits have been evaluated on their pedological significance. Only those profiles which are regarded as being typical or representative were selected for detailed analytical studies.

Supplementary map 2 also illustrates adequately the difference in density of field observations between the various types of surveys and the type of terrain in which these surveys were conducted, e.g. a semi-detailed survey in the uplands between the 200 and 50 feet contour is based on a much greater observation density than that needed for a semi-detailed survey in the lowlands. Reconnaissance surveys over homogeneous areas show very little ground checking (peat swamps) while in areas of complex topography and geology the density of field observations is greater.

6. Compilation of the Detailed Reconnaissance Soil Map

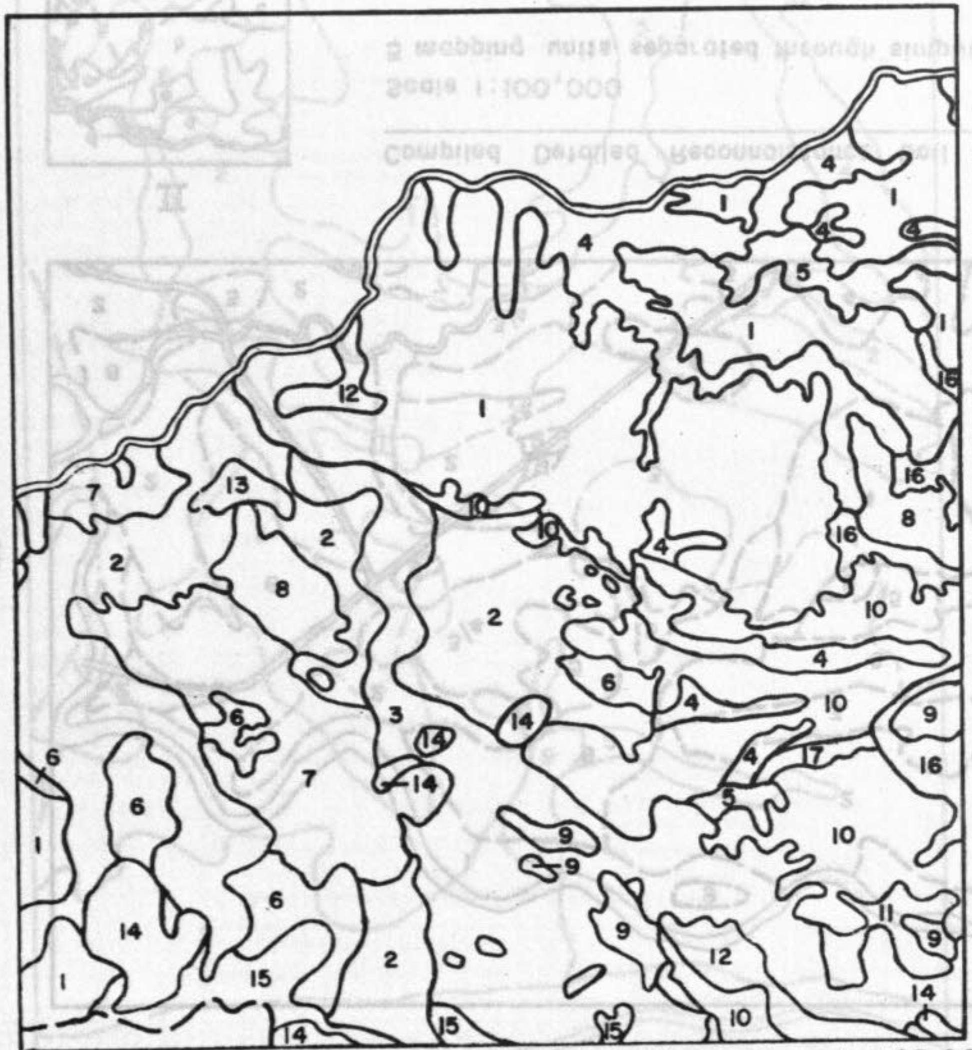
As explained in foregoing sections the basic soil information collected in West Sarawak over the last 10 years is contained in a great many soil maps of varying scale, issued at varying detail and with varying classification methods used.

The task, to collate all these data in the form of one map for the whole Region with one classification system without losing its practical value, was not an easy one. It involved much reinterpretation of mapping units employed before 1965. Also, too detailed information from semi-detailed surveys had to be scaled down in order to arrive at an acceptable cartographic homogeneity of detail throughout the region.

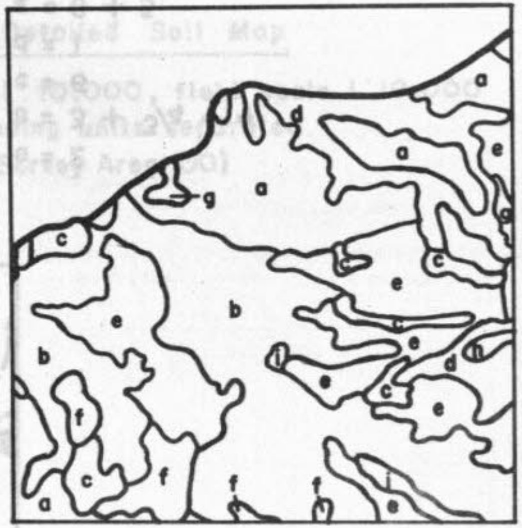
Fig. I.1 to I.3 (p.19, p.20, p.21) show how this was achieved. Reconnaissance maps at scales 1:50,000 to 100,000 did not offer much difficulty and with some reinterpretation of the mapping units the boundaries can be transferred onto the topo-base of the Detailed-Reconnaissance Map without much alteration. Semi-detailed maps with scales ranging from 1:10,000 to 1:50,000 presented greater difficulties. As can be seen in Fig. I.1, a total of 17 mapping units on a semi-detailed map at a scale 1:50,000 had to be reduced to 9. This was done either by simplification of boundaries or by amalgamating soil units of not too great diversity to form one compound unit, and by omitting small areas which could not be shown on the 1:100,000 scale map. The simplification of a 1:20,000 scale map (Fig. 1.2) resulted in 5 mapping units instead of 10, while in a 1:10,000 scale map a total of 9 mapping units was reduced to 3 (Fig. I.3).

The resulting Detailed-Reconnaissance Soil Map has been made as simple as possible but because of the great number of compound units occurring on the map, the key has become rather complex. It is therefore advisable to study the key carefully before embarking on a study of the soil map itself. For this reason, the key has been explained in detail in Chapter 12 (p.193).

Fig. I. 1. Soil map compilation and simplification – example A (2 x reduction)



I Semi-Detailed Soil Map – scale 1:50,000, field scale 1:25,000, 17 mapping units separated. (Ref. Survey Area 44/1)

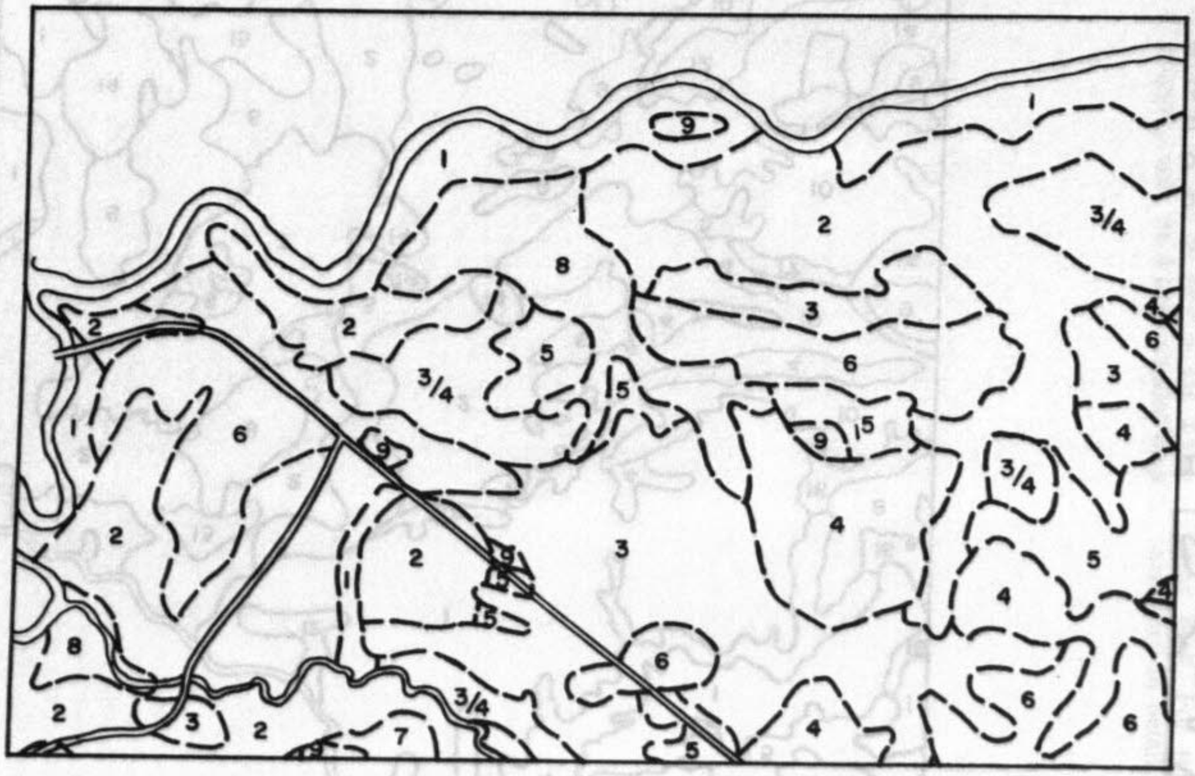


II – Compiled Detailed Reconnaissance Soil Map

Scale 1:100,000
9 mapping units separated through simplification.

a = 1 + 11
b = 2 + 3
c = (4)
d = (4) + 5 + 16 + 1)
e = 7 + 8 + (g) + 10
f = 6+2+15
g = 12
h = (9)
i = 14

Fig.I. 2. Soil map compilation and simplification — example B (5 x reduction)



I

<u>Semi-Detailed Soil Map</u>

Scale 1:20,000
Field scale 1:12,500
10 mapping units separated
(Ref. Survey Area 109)

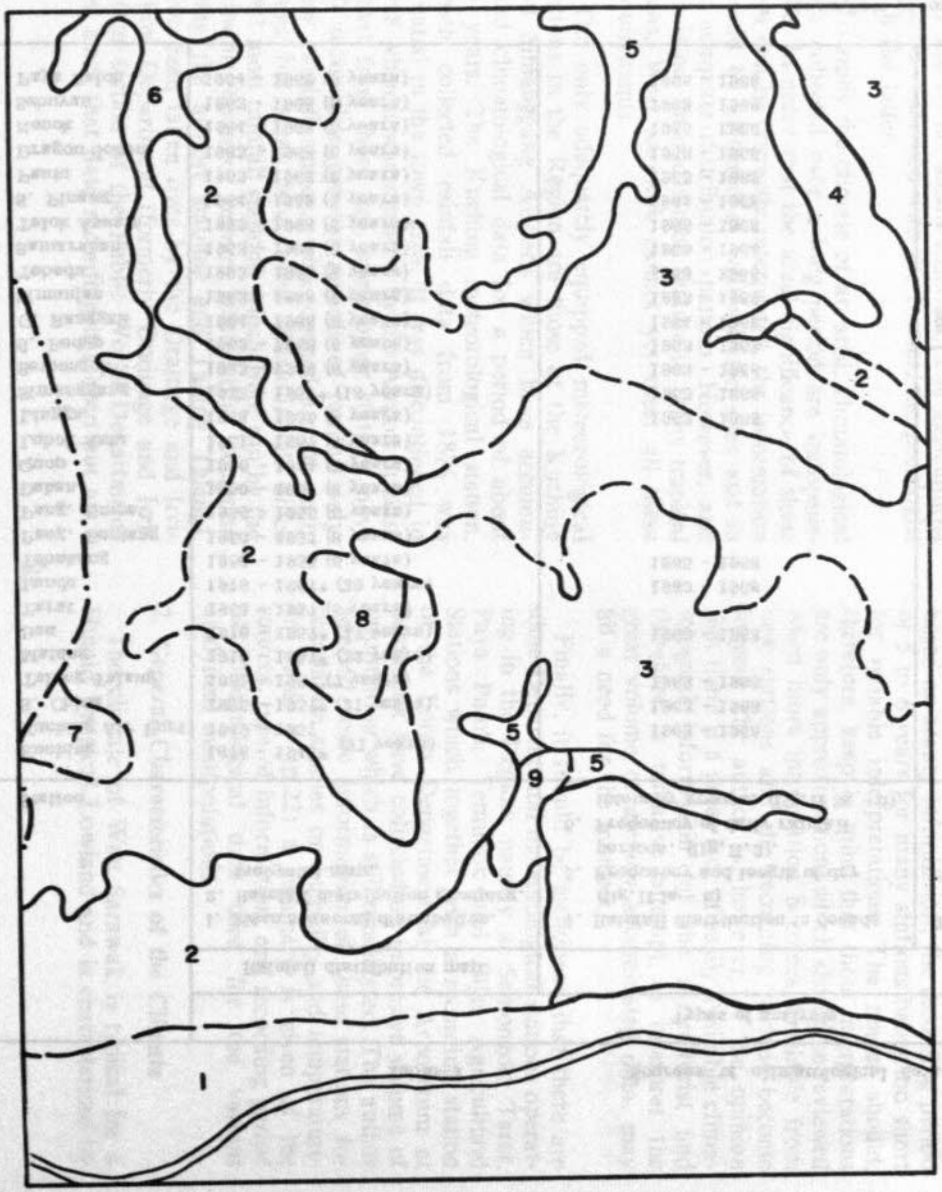
II

<u>Compiled Detailed Reconnaissance Soil Map</u>

Scale 1:100,000
5 mapping units separated through simplification.

a = 2
b = 3 + 3/4 + 4
c = 6
d = 1
e = 8 + 5

F.I. 3. Soil Map compilation and simplification — example C (10 x reduction)



I – Semi-Detailed Soil Map

Scale 1 : 10,000, field scale 1 : 10,000
9 mapping units separated
(Ref. Survey Area 100)

II – Compiled Detailed Reconnaissance Map

Scale 1:100,000
3 mapping units separated
through simplication

a = 1 + 2 + 4 + 5 + 6 + 9
b = 2 + 8
c = 3

Table 1 Sources of climatological data for West Sarawak

Station	Types of analysis: Rainfall distribution map 1. Mean seasonal distribution. 2. Rainfall distribution grouping. 3. Isohyetal map.	Types of analysis: Diagrams and histograms 4. Rainfall distribution in decads (fig. II la - h) 5. Frequency and length of dry periods. (fig. II. 2). 6. Frequency of daily rainfall intensity groups. (fig. II 3a - d).	Diagrams and histograms 7. Diurnal humidity and temperature ranges (fig. II. 4). 8. Comparison between humidity and temperature ranges over grass and under forest cover. (fig. II. 5).	Diagrams and histograms 9. Mean monthly evaporation and rainfall. (fig. II. 6).
Kuching	1876 - 1948* (71 years)			
Kuching Air Port	1949 - 1957	1963 - 1968		1963 - 1968
S. China	1925 - 1957* (21 years)	1963 - 1968		
Talang Talang	1951 - 1957 (7 years)	1963 - 1968		
Matang	1910 - 1957* (32 years)			
Bau	1916 - 1957* (17 years)	1963 - 1968		
Tarat	1950 - 1957 (8 years)			
Lundu	1916 - 1957* (20 years)	1963 - 1968		
Tebakang	1950 - 1955 (6 years)	1965 - 1968		
Pang. Bentang	1950 - 1957 (8 years)			
Pang. Empat	1950 - 1955 (6 years)			
Dahan	1950 - 1957 (8 years)			
Quop	1950 - 1954 (5 years)			
Lubok Antu	1951 - 1957 (7 years)			
Lingga	1948 - 1955 (8 years)	1963 - 1968		
Simanggang	1932 - 1957* (18 years)	1963 - 1968		
Semongok	1963 - 1968 (6 years)	1963 - 1968	1965 - 1966	1963 - 1968
S. Bedup	1963 - 1968 (6 years)	1963 - 1968		
G. Ranggau	1964 - 1968 (5 years)	1964 - 1968		
Simunjan	1963 - 1968 (6 years)	1963 - 1968		
Tebedu	1963 - 1968 (6 years)	1963 - 1968		
Samarahan	1963 - 1968 (6 years)	1963 - 1968		
Telok Assam	1963 - 1968 (6 years)	1963 - 1968		
S. Pinang	1964 - 1968 (5 years)	1964 - 1968		
Pantu	1963 - 1968 (6 years)	1963 - 1968		
Dragon School	1963 - 1968 (6 years)	1963 - 1968		
Nonok	1964 - 1968 (5 years)	1965 - 1968		
Sebuyau	1963 - 1968 (6 years)	1963 - 1968		
Paya Paloh	1964 - 1968 (5 years)	1964 - 1968		

Sources

Records prior to 1958 from Rainfall Statistics of the British Borneo Territories by Department of Civil Aviation and Meteorological Services.

Records from 1963 onwards from Hydrological Year Books 1963-1968 by Drainage and Irrigation Department.

Humidity and temperature records for Semongok Station from archives Department of Agriculture and Forestry Department (deposited at Department of Civil Aviation).

* incomplete records.

Part II — DESCRIPTION OF THE PHYSICAL ENVIRONMENT

Chapter 3. CLIMATE

1. Sources of Information

A detailed discussion of all aspects of climate serves a twofold purpose. Apart from the fact that climate is regarded as one of the important factors in soil formation, there is also hardly any agricultural activity which is not affected by climatic factors in some way.

Plant growth is intimately related to day length, temperature and humidity ranges, rainfall distribution and intensity, and the agriculturist will give due consideration to these factors. Apart from the direct relationship between soil genesis, plant growth and climate, agricultural management practises such as tillage, fertilization, pest control, water control, and erosion control can hardly be efficiently carried out if they are not adapted to the local climate.

One should make a distinction between the atmospheric climate and the soil climate because they are by no means identical. The agriculturist is more concerned with the former, the pedologist with the latter.

To study the climate of an area, climatological data collected over a long period are indispensable. In order that the areal significance of these data can be correctly interpreted, the information should be gathered at well selected sites and in an adequate distribution pattern. However, and this is not an uncommon feature in many tropical areas, West Sarawak cannot yet meet all these requirements.

The only adequately equipped meteorological stations in the Region are those of the Kuching and Simanggang Airports which have accumulated climatological data for a period of about 20 years. The Kuching meteorological station, which collected rainfall data from 1876 was situated in the town area. It was discontinued in 1948 when it was replaced by the Airport Station. Apart from these two, some other stations have left incomplete pre-war records of rainfall only. New rainfall stations were opened in the early fifties but some have been discontinued. Since 1962 most rainfall stations, which were run by the Administration or private estates (the exception being the airport stations and Talang Talang), have been taken over by the Drainage and Irrigation Department (formerly Drainage and Irrigation section of the Public Works Department) and since that date recording has been put on a new footing with a central pooling station. The latter Department has also opened up a number of new rainfall stations since 1962, and at present there is an adequate distribution of these stations in West Sarawak to allow some tentative interpretations. It should, however, be realised that the accuracy and reliability of the data for some stations leave something to be desired and the interpretation for these data needs to be viewed with some reservation.

A major step forward in making the climatological information public, was the publication of the Hydrological Yearbooks since 1962 by the Drainage and Irrigation Department. Much of the data used in this chapter has been derived from this source. The interpretation and presentation of the data in the form of diagrams, histograms and maps is, however, the responsibility of the author unless mentioned otherwise.

As already said, much of the interpretation is based on scanty information; the recording period of 5 to 6 years for many stations being too short for reliable interpretations. The reader should, therefore, keep in mind that these interpretations are only approximations which should be reviewed when more information becomes available from new stations and the recording periods become longer. The author is, however, of the opinion that there is a great lack of easily available climatological information for the agriculturist and therefore, a tentative attempt to interpret the great volume of already accumulated data, may fill a need for the moment.

Finally, it should be mentioned that there are some Departmental meteorological stations operating in the Region, namely at Semongok, Tarat, Paya Paloh, Temudok and Bijat Agricultural Stations which together with a recording station of the Forest Department at the Arboretum at Semongok have collected an impresive volume of information which is still unanalysed. The author selected some information of these stations for correlation studies on humidity and temperature. In Table 1 (p.22) a summary is given of the sources, type of information, and recording period of climatological data used for the various analytical manipulations.

2. General Characteristics of the Climate

The climate of West Sarawak is typical for a Humid Tropical Lowland and is characterised by heavy rainfall which ranges from 120-180 inches annually, a uniform temperature and a high relative humidity. Seal (1958) recognises four seasons, namely the northeast monsoon from October to January or February, the mild southeast monsoon from April to July/August and two shorter seasons of about eight weeks each, which are transitional periods between the two main monsoonal periods. The northeast monsoon brings heavy rain to the whole Region since it is exposed to the South China Sea along its full length. The northeast monsoon moves fairly uniformly across the China Sea but once it is south of latitude 5°N, its average speed decreases, and at times its boundary may become stationary or it may even temporarily retreat. The rainfall accompanying the boundary may then persist for several days and add substantially to the total rainfall (Seal, 1958). This effect will be examined in more detail under the heading 'rainfall' (p.25). The southeast monsoon is much milder, because the Region is sheltered from the mainland of Borneo by high relief in the border area with Kalimantan which induces orographic rainfall outside the Region. Nevertheless, during the southeast monsoon, the rainfall is still substantial in most of the area but locally the period is recognised as the 'dry' monsoon. It would, however, be more proper to name it the 'less wet period'.

The temperature in the whole Region is very uniform throughout the year. The mean daily minimum and maximum temperature vary between 72°F and 88°F at mean sea level, with a mean temperature over 24 hours of 78°F. At 0600 hours the mean relative humidity over the year is 98 percent and at 1400 hours 70 percent. (Seal, 1958).

3. Classification of Climate

The most widely used World Climatic Classification is that of Koppen's (1916) which classifies the whole Region as Type A, Tropical Rainy Climate. Type A is characterised by a temperature higher than 18°C (65°F) in the coldest month and the total annual precipitation expressed in millimeters exceeds 20 times the annual temperature expressed in degrees centigrade in the case of winter rains and more than 20 (t°C + 14) in the case of summer rains. The whole Region is further classified as subtype Af., which indicates that there are no definite dry periods. A dry period is defined as a period of at least one month in which there is an average precipitation of less than 60 mm. (2.4 inches).

Although widely used, the Koppen classification is prone to criticism because although the system is based on the criterion of favourability for plant life it emphasizes more the thermal rather than the moisture regimes. However, plant life is definitely related to both regimes (Subramanyam and Murthy, 1968). Thornthwaite, recognising the importance of these to plant growth devised a classification in 1948 based on the concept of Potential Evapotranspiration, and his classification is particularly of importance for agricultural purposes.

However, as Schmidt and Ferguson (1951) correctly point out, the system of Thornthwaite is determined mainly by the annual total precipitation figure since the sum total of the monthly precipitation-evaporation ratios used in the classification are calculated on the rainfall-temperature data. Since the average monthly temperature varies but little in a Tropical Lowland Climate, the sum of monthly rainfall becomes of dominant importance. In Sarawak, this value is very unreliable because of the large yearly fluctuations, hence Thornthwaite's classification cannot be adequately used at present until evaporation data become available for many more stations and the relation between measured evaporation and actual evaporation is better understood in Sarawak and in other countries of the Tropics.

Mohr (1941), devised a classification system for the Indonesian Archipelago which takes into account the average monthly totals of the rainfall. His rainfall classes are based on degrees of moisture for the various months of the year. According to Mohr, any month with 100 mm. (4 inches) of rain is considered as wet, since rainfall exceeds evaporation; any month with less than 60 mm. (2.4 inches) is regarded as dry since evaporation then exceeds rainfall, while a month with a rainfall of 60-100 mm. (2.4-4 inches) is considered as moist since rainfall and evaporation are almost in equilibrium (Mohr and van Baren, 1953).

Again, although Schmidt and Ferguson (*op. cit.*) argue that the criterion advanced by Mohr for determining the actual relation between precipitation and evaporation has given reasonably satisfactory results, the system nevertheless suffers from the same weakness inherent in the system of Thornthwaite, namely the arbitrary relation between actual and measured evaporation.

Nevertheless, Mohr's system has some advantage since it does not rely on evaporation or temperature measurements for a great number of stations. Also, the 60 mm. rainfall figure which separate the dry and moist seasons is the same as that taken by Koppen. Mohr based this figure on results of extensive experimental work and it is the nearest figure available for Tropical Lowland Climates and of relevance to West Sarawak conditions. Since no part of West Sarawak has a single month with less than 100 mm. (4 inches) of rain, the whole Region falls under Class Ia of Mohr's classification.

Schmidt and Ferguson (1951) argue that Mohr, by taking the average monthly rainfall for arriving at his classes, ignores the fact that there are periods extending over several years in which the rainfall is less than the average. This may have a bearing on crop growth and probably also on soil development although to a lesser extent. Such deviations from the mean are not revealed by Mothr's system because the amplitudes in rainfall are levelled off by averaging them. Therefore, Schmidt and Ferguson suggest to take the total number of dry months (less than 60 mm.) and the total number of wet months (more than 100 mm.) over at least a period of 10 years and take the average of these figures. They then calculate, what they call, the Q factor for a station by dividing the average number of dry months by the average number of wet months. The Q factor theoretically extends then over a range of 0-10. A small number of dry months which may occur over a period of more than 10 years is directly shown in a different Q factor and therefore small differences between stations may be more easily detected.

The author believes that Schmidt and Ferguson's modified system is a great improvement since it takes into account the great variations in rainfall which may occur over a long period and which are in Sarawak more the rule than the exception. However, for this system one requires at least an observation period of 10 years which is not available for most stations. However, an attempt has been made to calculate the Q factors for some stations which have a long recording period. They are shown in Table 2 (p.27).

Although it appears that all stations fall in the same rainfall type, the Q factor indicates that Bau and Lundu may have years with dry months, while this may also happen insignificantly in Kuching and in Matang. This system may therefore be used with advantage in future when the recording period for the new rainfall stations exceeds 10 years.

4. Rainfall

It is normal to present rainfall data as monthly averages to show the annual distribution. This is inadequate for most purposes but they are nevertheless useful to give a broad outline. Histograms for all rainfall stations with at least a recording period of 5 years are therefore shown on supplementary map 3, the Rainfall Distribution Map (Vol. II). From these histograms, it is apparent that the rainfall is significantly higher during the northeast monsoon, from December to February, and is lowest during the southeast monsoon from May to October. The difference in rainfall during these periods is greater near the coast but diminishes with increasing distance from the coast. Thus for areas near the Indonesian border, rainfall during the period from December to January is not much greater than during the period from May to October. In order to show this difference the stations were placed into four groups as follows:

Group I — stations in which the rainfall in wettest month is less than 2 times that of the driest month.

Group II — stations in which the rainfall in wettest month is 2-3 times that of the driest month.

Group III — stations in which the rainfall in wettest month is 3-4 times that of the driest month.

Group IV — stations in which the rainfall in wettest month is more than 4 times that of the driest month.

Supplementary map 3 shows this grouping and from this map it is obvious that the change in rainfall distribution is regular. Four rainfall belts running almost parallel with the coast can be recognised. Local topography, however, can create minor differences within each belt.

To explain the effect of distance from the coast on rainfall, the various types of rainfall recognised in West Sarawak should be discussed first. Local thunderstorms due to convection are rare near the coast but frequently occur in the interior due to mountainous terrain. During the northeast monsoon period, the rainfall along the coast is largely cyclonic. In the interior with diminishing cyclonic rain, the effect of convection rain during this period will offset the difference which otherwise may be noticeable. Where isolated mountain massifs occur near the coast a local orographic effect is noticeable during this period, particularly at higher altitude. This explains the high rainfall of Sungei China Station, while the rainfall of Matang Station which is 5 miles away but situated at a lower elevation is less.

The strong effect of local topography is largely responsible for an erratic rainfall distribution and great differences can occur over short distances. This can be illustrated at Tebakang and Tarat (see supplementary map 3). Tebakang lies in the rain shadow area of Bukit Sedong, while Tarat faces the sea and receives orographic rain.

During the southeast monsoon, convection rain is responsible for most precipitaion in the whole area, but this type of rain is more frequent and intensive in the interior than near the coast. Most rainstorms have already lost most of their intensity when they reach the coast and the coastal belt therefore receives lower rainfall of this nature. The small difference between the monthly rainfall throughout the year in the interior is significant for agriculture since in the interior padi may possibly be grown in seasons during which the coastal regions would suffer from water deficiency. In the interior there is, therefore, less need to reckon with seasonality as far as planting, fertilization or spraying is concerned.

The mean total annual rainfall is shown in the isohyet map (insert in supplementary map 3). As is shown in the isohyet maps for 1967 and 1968, the variability of annual rainfall is great over the years and wet years may alternate with dry years. However, it is worthwhile to note that the highest annual total normally falls in the middle of the region: one area between Matang, Kuching and the coast, the second being near the Indonesian border. The first area is receiving great amounts of rain during the northeast monsoon due to cyclonic and orographic rain, the second area, being the most mountainous part of the region, receives great amounts of rain during the whole year due to convection. The histograms of the monthly rainfall distribution for stations in these areas show this effect adequately.

There are further indications that the annual rainfall diminishes from west to east, although the most western point of the Region may receive in a certain year as much rainfall as the east in another year. It is clear that the middle portion of the Region is by far the wettest during most years, this being caused by its topography and openess to the influence of the northeast monsoon.

Hitherto, we have examined the average monthly totals which do not show adequately the great variability in rainfall which in fact exists. The rainfall does not come so evenly as these histograms suggest and for agricultural purposes short dry seasons are of significance and therefore a breakdown of the annual rainfall in 10-day periods is more useful. Therfore, in order to show such irregularities, the distribution pattern of rainfall as totals in decades was calculated for each station for 1964, 1966 and 1968 separately, as these years were regarded as more representative or typical years than other years. Eight representative stations are shown in Figs. II.1a-1h (p.28 and p.29). Two stations were chosen for each rainfall group to show the possible relation between distribution pattern and difference in intensity of rain between the wettest and driest month. However, this relation does not seem to exist. What is apparent is that in all stations, disregarding the group, peak rain comes in periods lasting several days which alternate with short periods of drier weather. A peak is considered to be more than 2 inches than in the previous decade. For most stations about 8 to 10 rainfall peaks per year can be recognised. This pattern persists throughout the year, regardless of the season. During the northeast monsoon very wet periods coincide with periods in which the boundary of the monsoon becomes static as explained in page 24. These wet periods alternate with very dry periods. A dry period of a week is not uncommon in the wet season and there is generally an absence of convection rain particularly near the coast. During the remainder of the year less wet periods of three days, during which thunderstorms are building up in increasingly unstable air, alternate with wet periods of three or four days. This is a regular feature throughout the Region but the intensity of the thunderstorms is greatest in the interior. The pattern of alternating dry and wet periods is shown underneath the rainfall distribution graphs (Fig. II.1a-h; p.28 and p.29). Of further significance is the great variability over the years in the amount of rain which falls and the periods in which it comes. As shown by Fig. II.1a-h (p.28 and p.29). for the three recording years, there is hardly a pattern observable which persists throughout the period.

Since Fig. II.1a-h (p.28 and p.29) showed that the rainfall comes in stages throughout the year, it is of agricultural interest to examine the frequency and length of dry periods. For 22 reliable stations, the total number of dry periods were counted for the period 1963-68 and these were grouped in classes ranging from 1 day to more than a week. The percentage of each class was then calculated over the total number of dry periods and illustrated in a histogram (Fig. II.2; p.31). The stations were placed in 5 groups according to the percentage of dry periods longer than one week. The subdivisions 0-2%, 2-3%,

Table 2

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	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	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

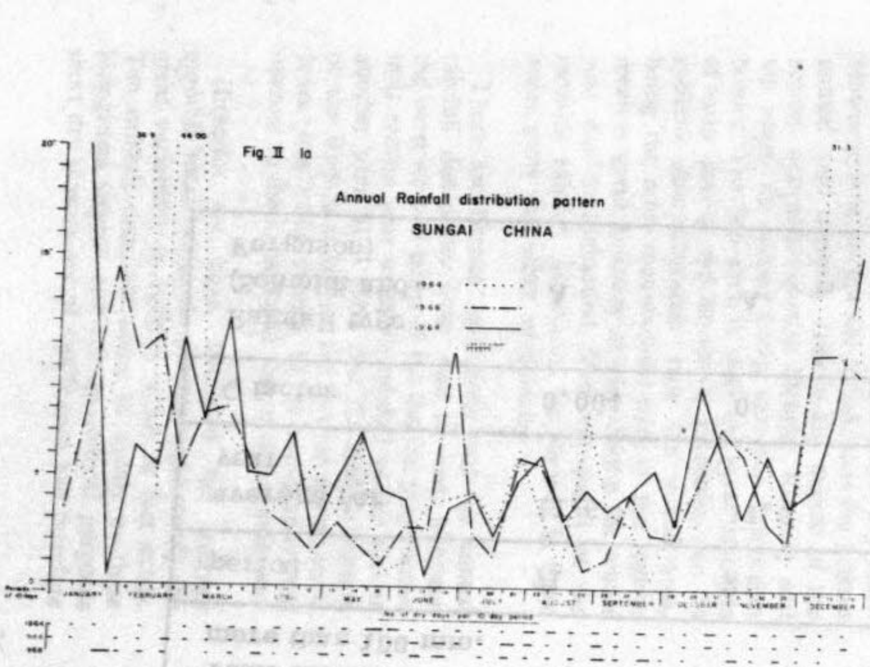


Fig. II Ia
Annual Rainfall distribution pattern
SUNGAI CHINA
1964
1966
1968
No. of dry days per 10 day period

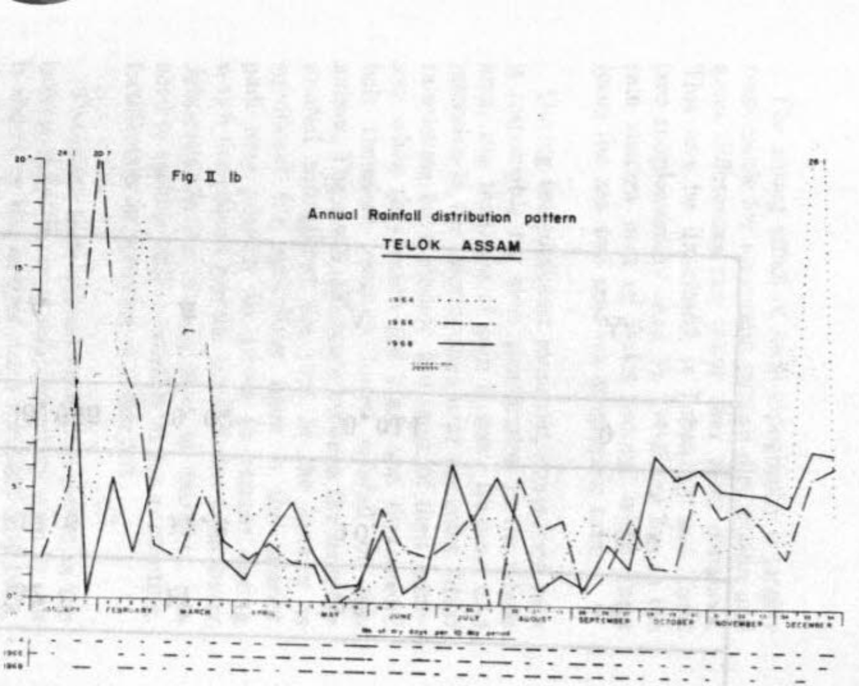


Fig. II Ib
Annual Rainfall distribution pattern
TELOK ASSAM
1964
1966
1968
No. of dry days per 10 day period

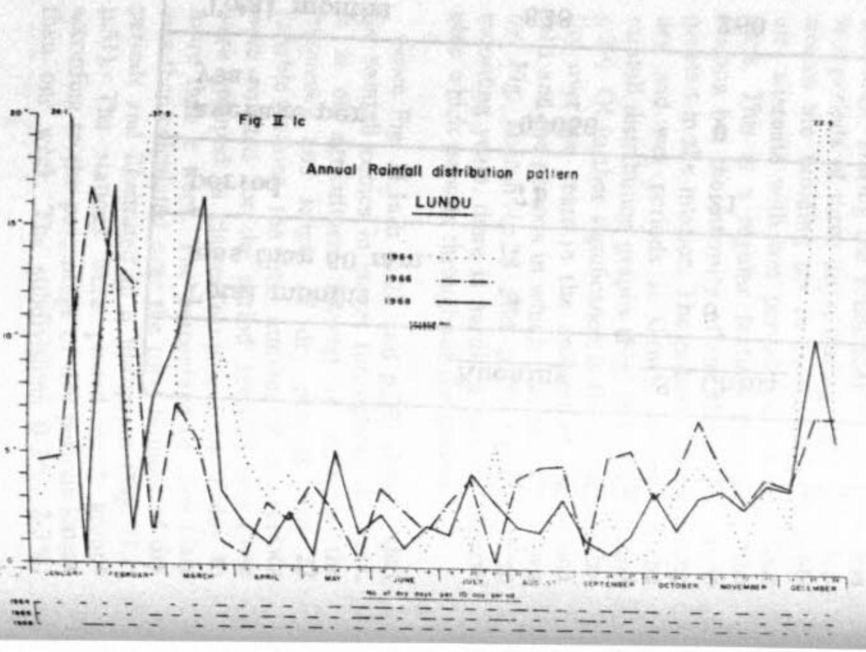


Fig. II Ic
Annual Rainfall distribution pattern
LUNDU
1964
1966
1968
No. of dry days per 10 day period

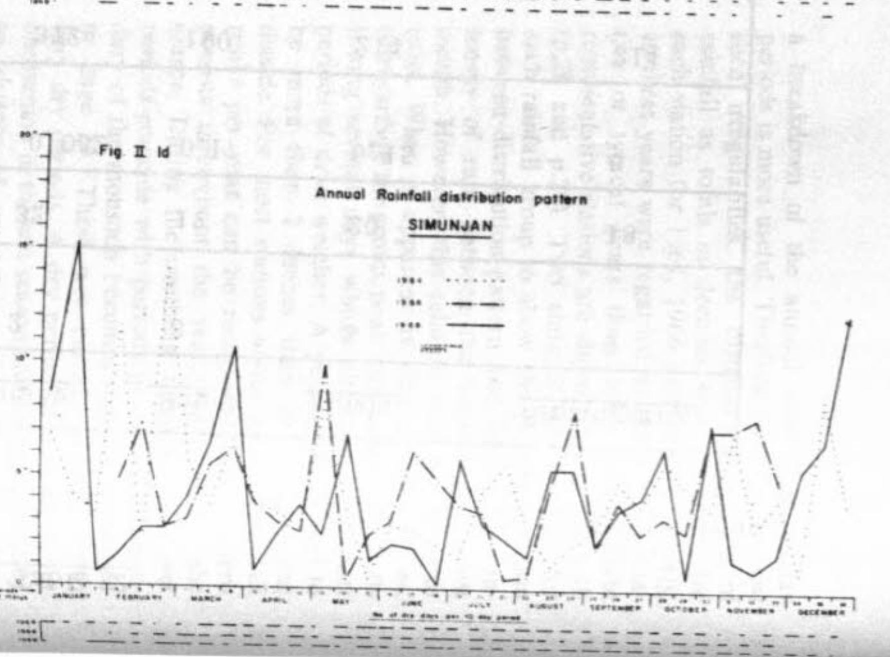


Fig. II Id
Annual Rainfall distribution pattern
SIMUNJAN
1964
1966
1968
No. of dry days per 10 day period

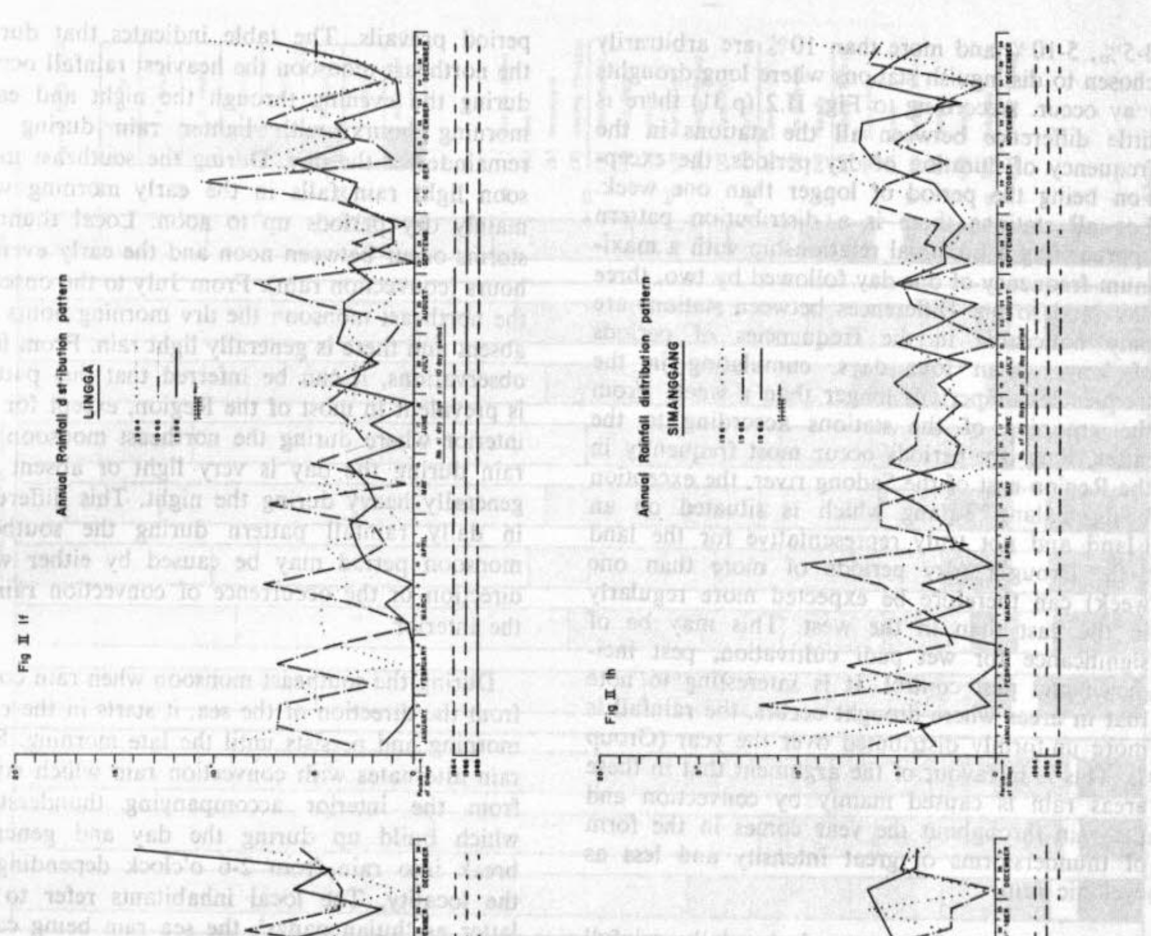


Fig II Ie
Annual Rainfall distribution pattern
SUNGAI BEDUP
Fig II If
Annual Rainfall distribution pattern
LINGGA
Fig II Ig
Annual Rainfall distribution pattern
Sg. PINANG
Fig II Ih
Annual Rainfall distribution pattern
SIMANGGANG

3-5%, 5-10% and more than 10% are arbitrarily chosen to distinguish stations where long droughts may occur. According to Fig. II.2 (p.31) there is little difference between all the stations in the frequency of duration of dry periods, the exception being the period of longer than one week. For all stations there is a distribution pattern approaching a binomial relationship with a maximum frequency of one day followed by two, three days and so on. Differences between stations are only noticeable in the frequencies of periods of longer than four days, cumulating in the frequencies of periods longer than a week. From the grouping of the stations according to the latter, long dry periods occur most frequently in the Region east of the Sadong river, the exception being Talang Talang which is situated on an island and not truly representative for the land area. Drought (dry periods of more than one week) can therefore be expected more regularly in the east than in the west. This may be of significance for wet padi cultivation, pest incidence and pest control. It is interesting to note that in areas where drought occurs, the rainfall is more uniformly distributed over the year (Group I). This is in favour of the argument that in these areas rain is caused mainly by convection and the rain throughout the year comes in the form of thunderstorms of great intensity and less as cyclonic rain.

To study the frequency of the daily rainfall intensity, which can be expected throughout the year, Fig. II.3a-3d (pp.32-35) were drawn up. The same 8 stations selected for the annual rainfall distribution patterns were taken for this analysis and were grouped together under the rainfall Groups I-IV as recognised on the Rainfall Distribution Map (supplementary map 3). From these histograms, it is apparent that the most intensive daily rainfall can be expected for all the four rainfall groups during the northeast monsoon season from December to February. However, the intensity increases from Group I-IV, days with rain over 6 inches being rare to very rare in Groups I and II. It can also be seen from these histograms that there are more rainfall days during the northeast monsoon period than during the southeast monsoon period and the number of rainfall days follows the same pattern as that of the total rainfall.

The intensity of rain per hour which was registered by the autographic rain gauge at Kuching Airport is shown in Table 3 (p.36). It is, therefore, only representative for rainfall of Group III in which cyclonic rain during the northeast monsoon period prevails. The table indicates that during the northeast monsoon the heaviest rainfall occurs during the evening through the night and early morning hours, with lighter rain during the remainder of the day. During the southeast monsoon light rain falls in the early morning with mainly dry periods up to noon. Local thunderstorms occur between noon and the early evening hours (convection rain). From July to the onset of the northeast monsoon the dry morning hours are absent and there is generally light rain. From field observations, it can be inferred that this pattern is prevalent in most of the Region, except for the interior where during the northeast monsoon the rain during the day is very light or absent but generally heavy during the night. This difference in daily rainfall pattern during the southeast monsoon period may be caused by either wind direction or the occurrence of convection rain in the interior.

During the southeast monsoon when rain comes from the direction of the sea, it starts in the early morning and persists until the late morning. Such rain alternates with convection rain which comes from the interior accompanying thunderstorm which build up during the day and generally break into rain from 2-6 o'clock depending on the locality. The local inhabitants refer to the latter as 'hujan panas', the sea rain being called 'hujan laut'.

Summarizing this account of the rainfall, it can be concluded that the total annual rainfall over the whole area varies considerably from year to year and from station to station. Rainfall of 120 inches to over 180 inches can be expected for all stations. The belt with maximum annual rainfall may shift from west to east or from east to west in various years but the general indication is that the eastern portion of the Region and the far western portion are drier than the middle part. Most rain can be expected in a wide belt running from the Sarawak River Delta to Gunung Penrissen near the Indonesian border. Local topography can bring great changes in rainfall over short distances.

Periods of drought lasting more than one week are more common in the east than in the remainder of the Region. Drought periods may occur during the wet season as well as in the less wet season. Dry periods of one to three days account for over 70% of the total of dry periods

Fig. II. 2. % Frequency of length of dry periods.

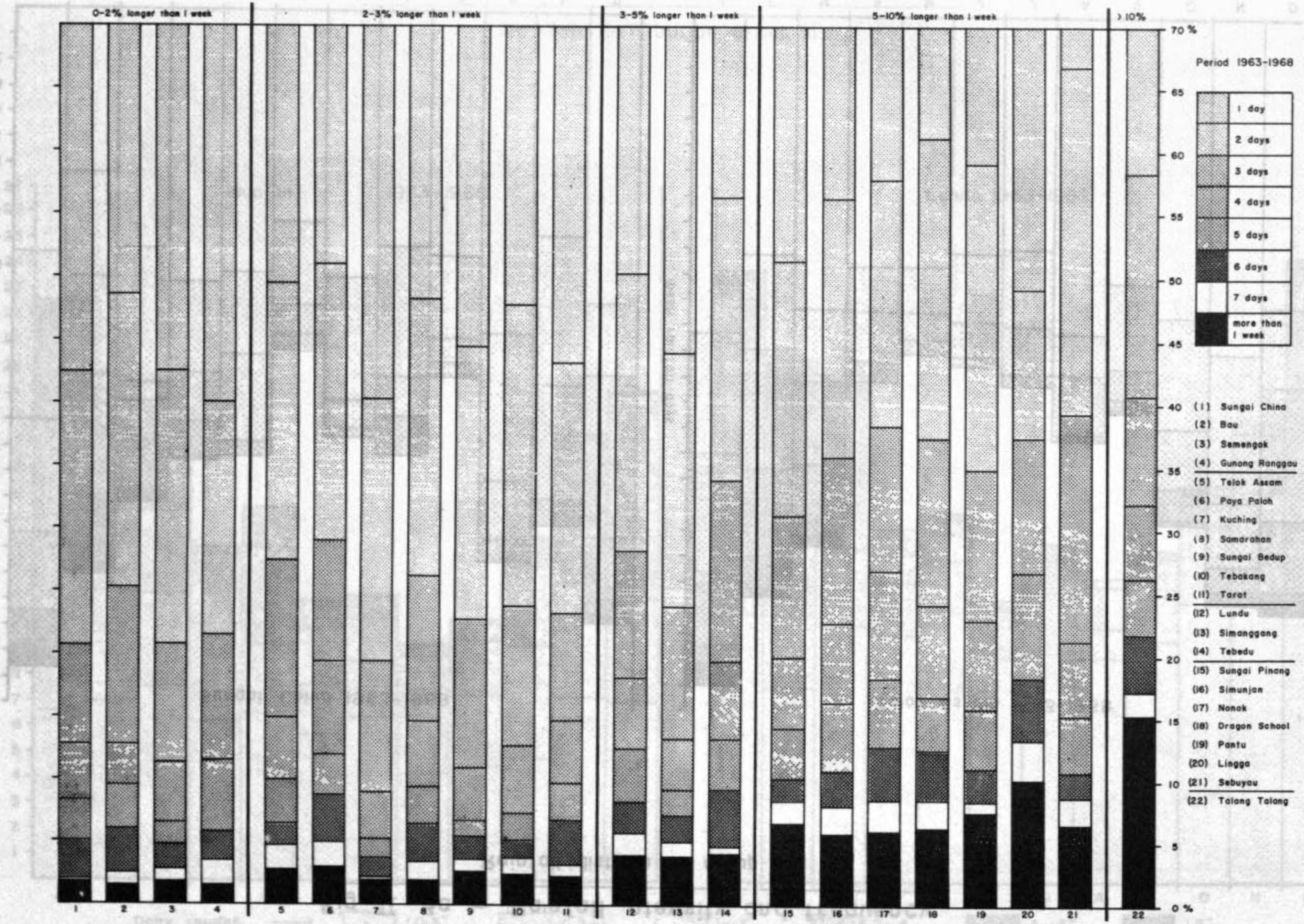


Fig. II 3a – Rainfall intensity and frequency

Rainfall distribution group IV

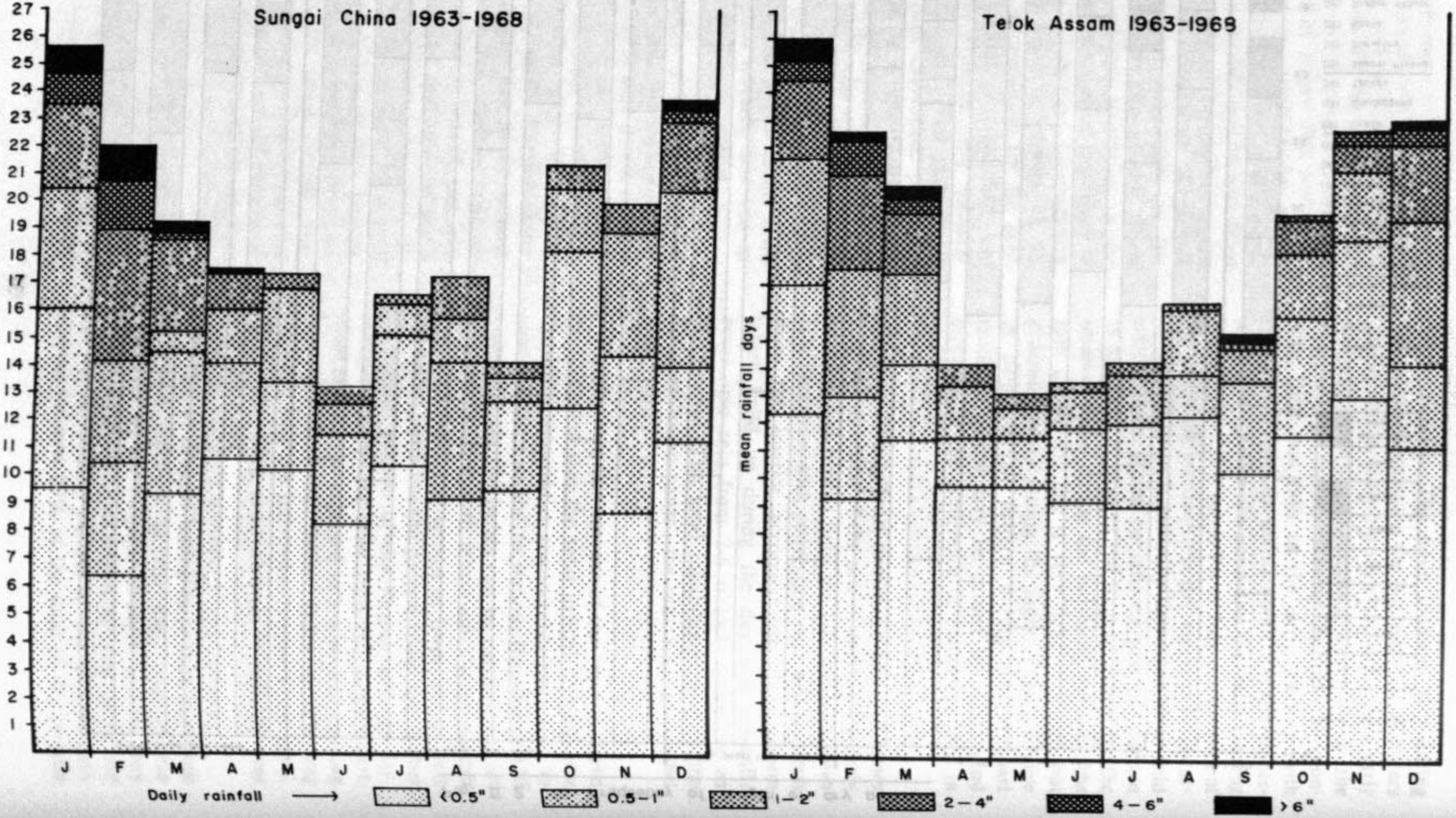


Fig. II 3b — Rainfall intensity and frequency

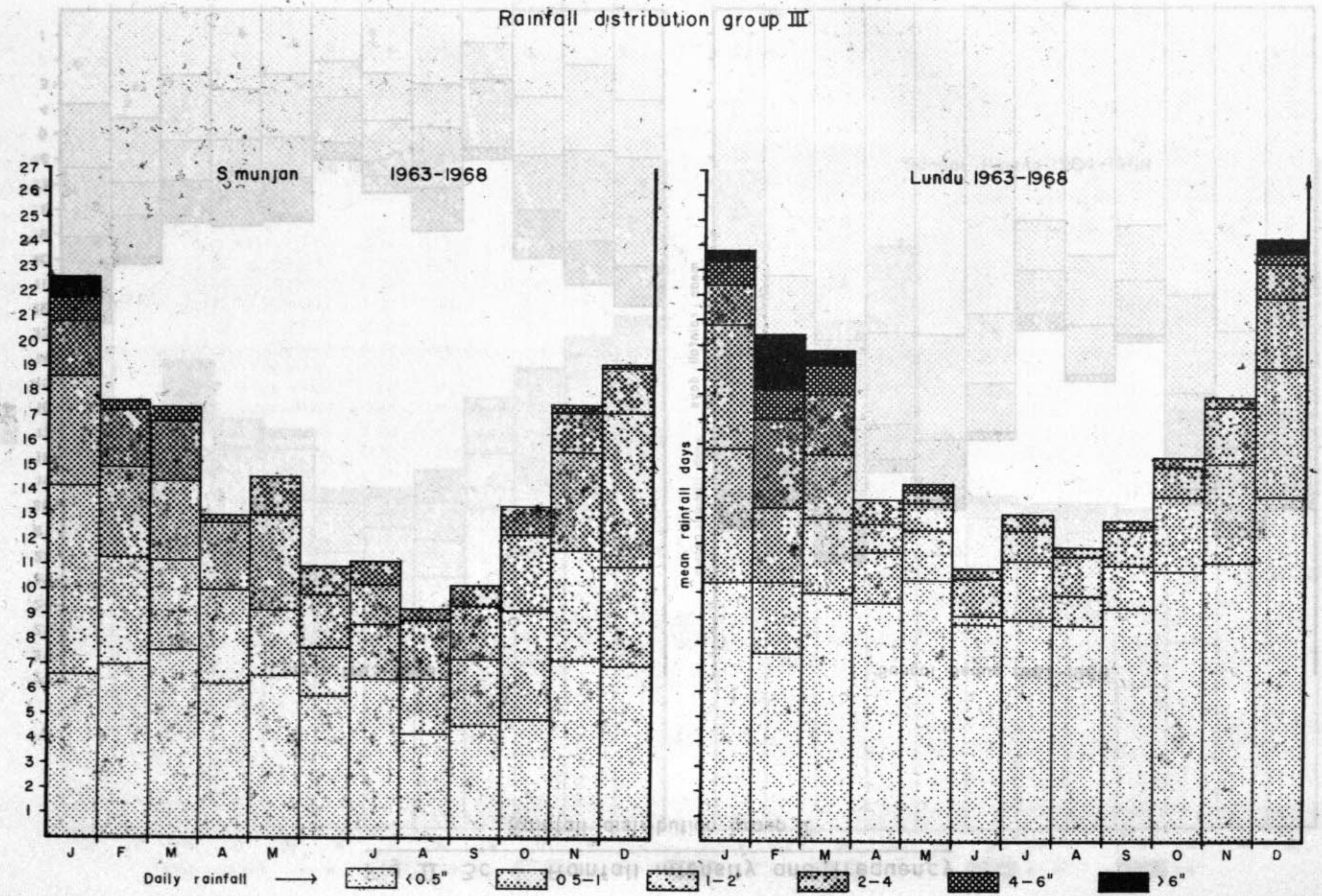


Fig. II. 3c — Rainfall intensity and frequency

Rainfall distribution group II

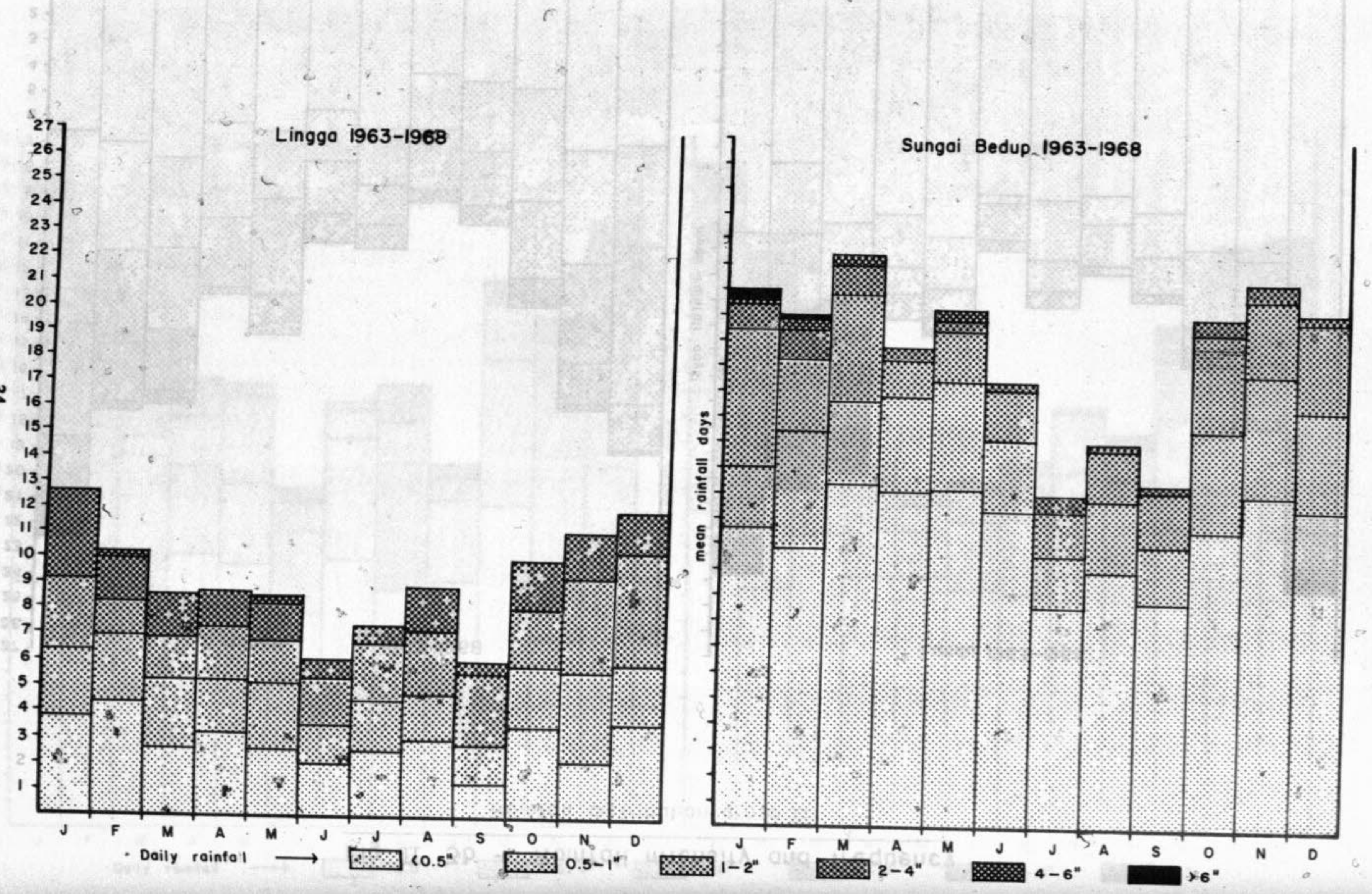


Fig. II. 3d — Rainfall intensity and frequency

Rainfall distribution group I

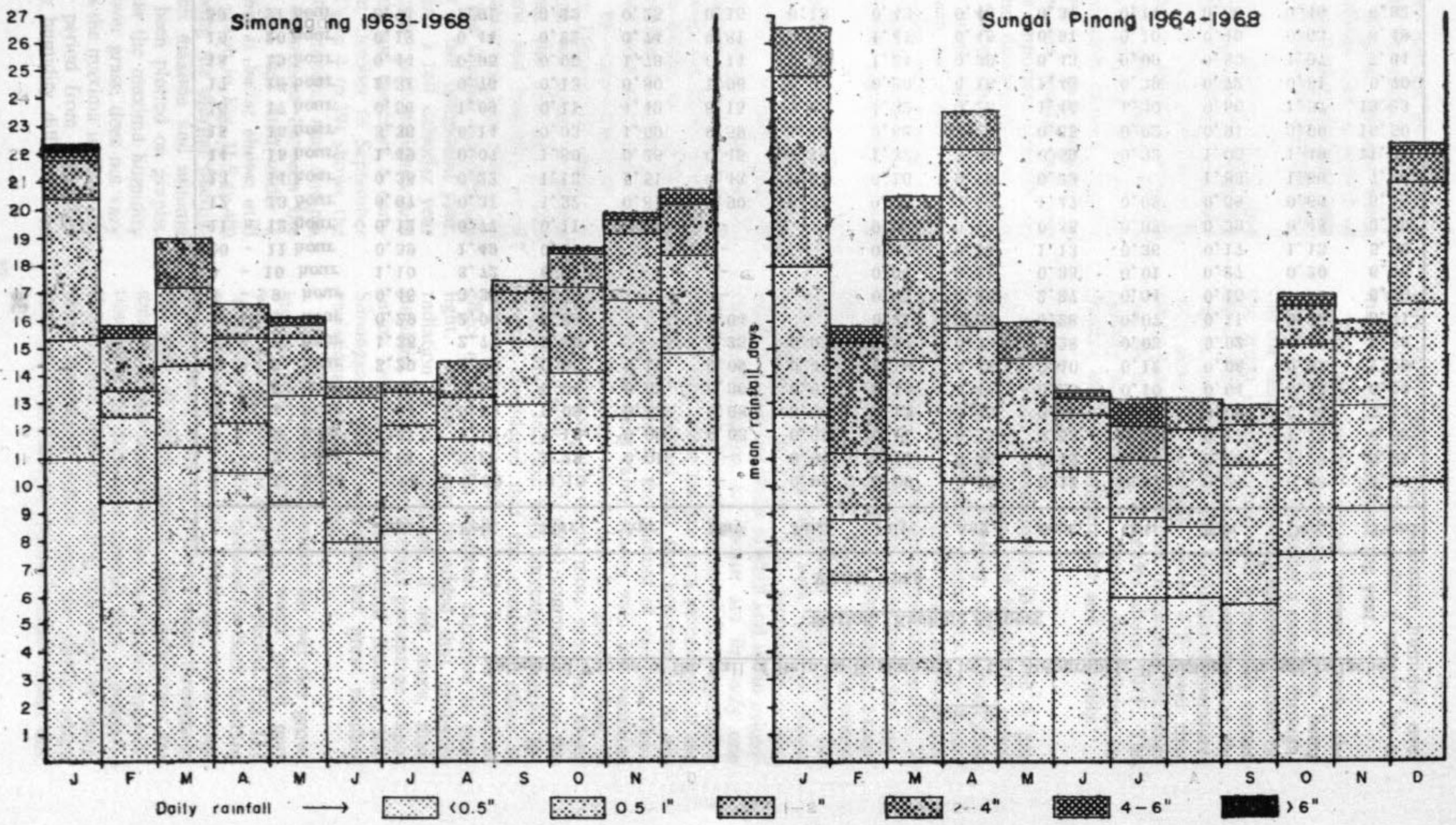


Table 3

Tabulated Values of the Fall of Rain as Registered by the Autographic Raingauge Amount in inches

Station: Kuching Airport

YEAR 1955

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
0 - 1 hour	2.23	0.59	0.10	-	-	0.08	0.09	0.35	0.12	0.87	0.24	0.68	5.35
1 - 2 hour	3.01	0.62	1.25	0.01	-	0.04	0.11	0.36	0.18	2.01	0.14	1.28	9.01
2 - 3 hour	2.61	1.18	1.15	0.06	0.03	0.03	0.11	0.25	0.53	0.73	0.13	1.22	8.03
3 - 4 hour	3.87	0.99	0.09	0.15	0.08	0.06	0.13	0.45	0.38	0.09	0.09	0.85	7.23
4 - 5 hour	3.92	0.84	0.06	0.03	0.30	0.01	0.13	0.41	0.23	0.10	0.04	0.83	6.90
5 - 6 hour	2.20	3.05	0.05	0.10	0.09	0.09	0.16	0.48	0.40	0.12	0.08	0.27	7.09
6 - 7 hour	1.35	2.77	0.26	-	0.23	0.03	0.17	0.38	0.28	0.03	0.02	0.31	5.83
7 - 8 hour	0.29	2.00	0.28	-	0.04	-	0.21	0.20	0.28	0.07	0.11	0.23	3.71
8 - 9 hour	0.46	3.36	0.30	-	-	-	0.07	0.25	2.27	0.04	0.15	-	6.90
9 - 10 hour	1.10	3.72	0.68	-	-	-	0.04	0.11	0.33	0.01	0.27	0.20	6.46
10 - 11 hour	0.39	1.49	0.10	-	-	-	0.07	0.16	1.13	0.36	0.17	1.13	5.00
11 - 12 hour	0.12	0.77	0.11	0.78	-	-	0.03	0.13	0.35	0.07	0.39	0.48	3.59
12 - 13 hour	0.07	0.31	1.32	0.81	0.90	0.01	0.02	0.15	1.47	0.08	0.38	0.66	6.18
13 - 14 hour	0.38	0.22	1.13	1.51	0.43	0.01	0.16	0.19	0.23	-	1.83	1.60	7.69
14 - 15 hour	1.49	0.07	1.80	0.28	0.45	1.76	1.32	0.09	0.59	0.32	1.05	1.49	11.52
15 - 16 hour	3.36	0.14	0.03	1.59	0.59	1.40	0.62	2.20	0.65	0.92	0.91	3.09	16.50
16 - 17 hour	0.56	1.09	0.11	4.49	0.15	0.08	1.32	0.28	1.42	1.30	0.86	1.57	13.23
17 - 18 hour	2.31	0.76	0.13	0.80	1.96	0.07	0.20	0.18	1.46	0.39	0.72	0.81	9.79
18 - 19 hour	0.44	0.95	0.05	1.78	0.14	0.26	1.24	0.39	0.43	0.09	0.80	1.07	7.64
19 - 20 hour	0.18	0.44	0.22	0.74	0.81	0.13	1.41	0.45	0.91	0.10	0.46	0.63	6.48
20 - 21 hour	2.74	1.01	0.29	0.25	0.15	0.13	0.43	0.45	0.37	0.14	0.50	0.46	6.92
21 - 22 hour	2.51	2.58	1.08	0.03	0.03	0.07	0.23	0.25	0.22	0.10	0.78	1.76	10.64
22 - 23 hour	2.62	1.35	0.10	0.54	-	0.06	0.12	0.03	0.12	0.09	0.21	0.57	5.81
23 - 24 hour	2.94	1.04	0.05	0.26	-	0.18	0.08	0.12	0.05	0.06	0.22	1.64	6.64
Total	41.15	31.34	10.74	14.21	6.38	5.50	8.47	9.12	14.40	9.09	10.55	23.19	184.14

Ref: Seal, 1958. Rainfall and Sunshine in Sarawak.

in the whole Region, dry periods of one week and over to approximately 7% of the total of dry periods for most of the Region, the east being slightly over 10% (calculated over a period of six years). However, wet years may alternate with dry years and a number of long dry periods may occur in one single year.

The rain in most stations falls in stages, and generally 8-10 rainfall maxima can be observed. The period from December to February has most rain days for all stations, this coincides also with a higher intensity of rain per rainday, although the latter diminishes from the middle of the Region to the east. The difference between the seasons, as far as total monthly rainfall, number of raindays and intensity of daily rainfall is concerned, is greatest in the coastal belt and becomes increasingly less important towards the interior. This enables the demarcation of four rainfall belts, based on the grouping of rainfall stations according to the magnitude of difference in average rainfall between the wettest and the driest month. This grouping has proved to be the only possible way to show some consistency and regularity in the rainfall distribution in the Region.

5. **Temperature and Humidity**

Temperature and humidity measurements are only taken at a few stations, notably those at Kuching and Simanggang Airports and at Semongok Agricultural Research Centre. Semongok station was chosen as being the most representative for the Region as a whole, as it is not too close to the sea, its elevation is approximately 100 feet, and it is sheltered from wind. An added advantage is that close by—approximately 100 yards away—the Forestry Department maintains a similar recording station but under a canopy of primary forest, so that the influence of the vegetation on temperature and humidity could be studied with relative accuracy. Fig. II.4 (p.38) shows for both stations the diurnal temperature and humidity ranges for a full compound year. It was not possible to find a full calendar year in which all measurements for both stations could be taken as being reliable and therefore a compound year running from October to September 1966 had to be taken. Table 4 (p.39) shows the temperature and humidity maxima and minima for both stations. The differences between the station sited over grass and that sited under a canopy are apparent. This is better shown still by the more compressed graph in Fig. II.5 (p.40) in which instead of showing the diurnal fluctuations, the calculated mean maxima and minima for 10-day periods have been plotted on graphs. These graphs indicate that the maxima humidity under both canopy and over grass, does not vary much although over grass the maxima is generally lower. During the rainy period from December to February, there is no humidity difference on very rainy days. The minimum humidity over grass is lower than that under a canopy by as much as 20% throughout the year.

The temperature shows reverse trends, the mean maximum temperature over grass being about 5·8°F higher than under a canopy throughout the year. The diminishing difference shown on the graph is not normal, and is probably caused by a defect in the recording instrument at the station under canopy. The minimum temperatures over grass are generally about 4°F lower than under canopy. The difference in temperature range due to a canopy is therefore about 10°F. The canopy has therefore a distinct normalizing influence on both temperature and humidity.

6. **Evaporation**

Evaporation measurements in a Class A pan of diameter 47·5 inches and height 10 inches are available from Kuching and Simanggang Airports. The monthly means for the years 1963-8 are given in Table 5 (p.41) together with those of Bogor in Indonesia for comparison. It appears that the evaporation throughout the year is higher in Kuching than in Simanggang except for the month of July. This is probably caused by stronger winds in Kuching. The figures for Simanggang compare well with those of Bogor in Indonesia. In Table 5 a comparison is also made between the mean rainfall and mean evaporation (the figures for Bogor are for only one year) and from the calculation of the evaporation from a free water surface 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 wet season with much more sunshine. Mohr and van Baren (1953, p.64) commenting on the evaporation increase with increasing rainfall for Bogor, considered that the combined effect of temperature and wind probably has as great an effect on evaporation as direct exposure to sunlight. To this it can be added that probably radiation is as important, if not more, than sunshine. As far as the average percentage evaporation over rainfall is concerned Kuching and Simanggang are comparable but great monthly variations can be noticed.

It is important, particularly for wet rice growing, to find out whether a water deficit may occur during the year and in what period. Fig. II.6 (p.42) shows the water balance for both Kuching and Simanggang stations. Although on average there appears to be no deficit of water throughout the year at either station when comparing the means, if one compares the maximum evaporation with the minimum rainfall then a deficit is theoretically possible. In Fig. II.6 both the maximum theoretical deficit and the deficit which may occur infrequently (mean rainfall minus abs.

Fig. II. 4 DIURNAL FLUCTUATIONS of humidity and temperature over a compound year under forest and over grass.

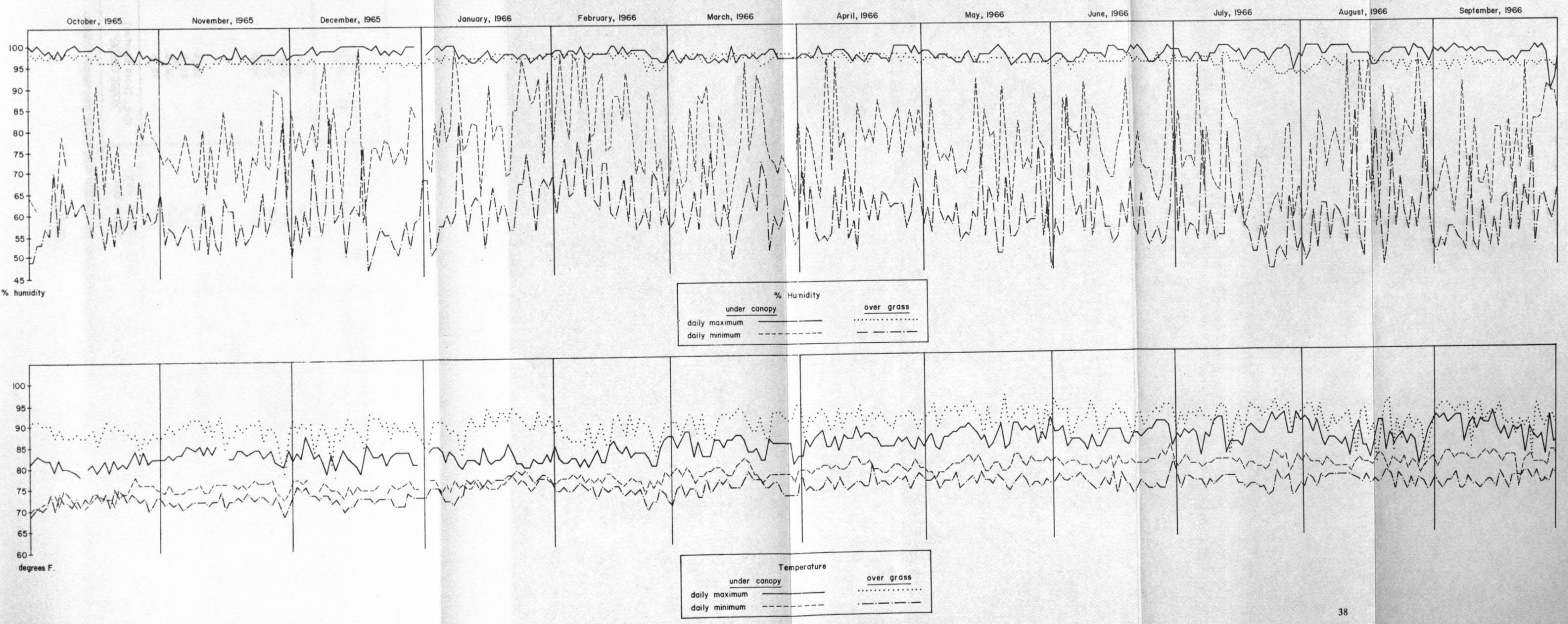


Table 4

Temperature and humidity ranges over grass and under canopy.

Temperature	over grass (2'6" from ground)	under canopy (2'6" from ground)
Highest maximum	95^oF	90^oF
Lowest maximum	80^oF	77^oF
Highest minimum	78^oF	88^oF
Lowest minimum	68^oF	70^oF
Humidity		
Highest maximum	98%	100%
Lowest maximum	93%	94%
Highest minimum	86%	98%
Lowest minimum	46%	53%
Absolute range temperature	$95 - 68^oF$	$90 - 70^oF$
Absolute range humidity	98 - 46%	100 - 53%

Table 4

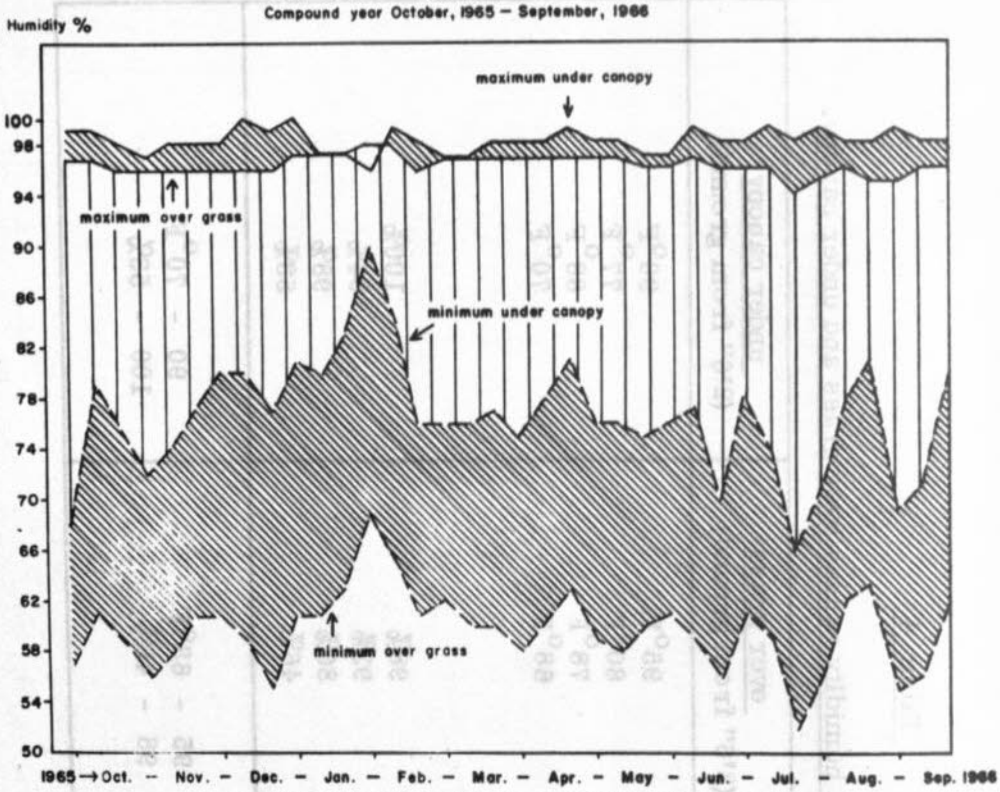
Temperature and humidity ranges over grass and under canopy.

Temperature	over grass (2'6" from ground)	under canopy (2'6" from ground)
Highest maximum	95^{o}F	90^{o}F
Lowest maximum	80^{o}F	77^{o}F
Highest minimum	78^{o}F	88^{o}F
Lowest minimum	68^{o}F	70^{o}F
Humidity		
Highest maximum	98%	100%
Lowest maximum	93%	94%
Highest minimum	86%	98%
Lowest minimum	46%	53%
Absolute range temperature	95 - 68^{o}F	90 - 70^{o}F
Absolute range humidity	98 - 46%	100 - 53%

Fig. II. 5 Comparison of mean humidity ranges over grass and under Forest cover.

Stations: Over grass — Semongok Agricultural Station; Under canopy — Semongok Forest Arboretum — distance ± 100 yards

Compound year October, 1965 — September, 1966

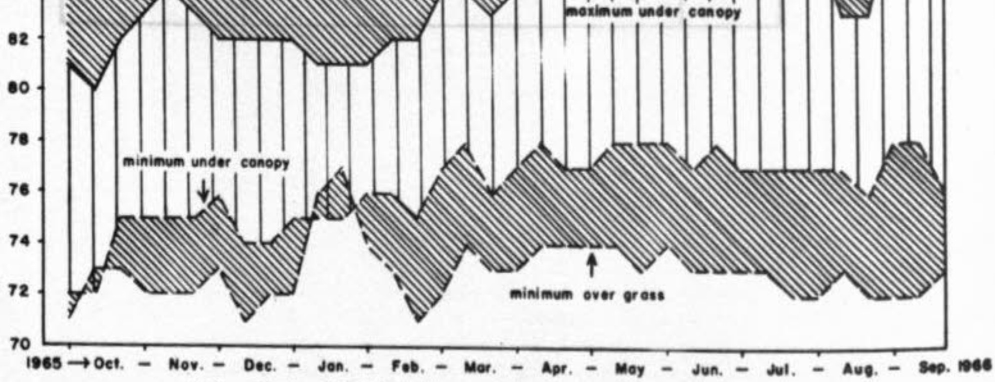


Note: Maxima and minima are means calculated over 10 day periods

Comparison of mean temperature ranges over grass and under Forest cover.

Stations: Over grass — Semongok Agricultural Station; Under canopy — Semongok Forest Arboretum — distance ± 100 yards

Compound year October, 1965 — September, 1966



Note: Maxima and Minima are means calculated over 10 day periods.

Table 5

Evaporation from a free surface and precipitation

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.	5.64	6.32	6.58	21.10	16.10	19.30	27.0	39.5	34.1
Feb.	4.03	5.40	5.43	14.96	10.18	27.33	27.0	53.0	19.9
Mar.	5.88	5.48	5.93	7.56	11.82	13.43	77.8	46.4	44.2
Apr.	5.64	5.64	6.10	23.00	11.88	8.73	24.7	47.9	22.3
May	5.80	5.67	6.51	9.68	10.35	7.74	59.9	54.8	84.1
June	5.80	5.20	6.17	15.68	8.94	7.75	37.0	58.2	79.6
July	5.40	5.48	5.81	10.44	6.67	5.80	51.7	82.2	94.5
Aug.	5.88	5.43	6.13	10.88	7.89	8.17	54.0	68.8	75.0
Sept.	6.08	5.17	6.15	5.40	7.05	9.59	102.0	73.3	60.6
Oct.	6.04	5.89	6.01	15.00	11.78	14.00	24.2	50.0	42.9
Nov.	4.08	5.52	6.83	14.84	11.94	12.28	27.5	46.2	55.6
Dec.	5.96	5.66	5.64	9.68	14.54	17.71	61.5	28.9	31.8
Total	67.24	66.86	73.29	168.16	129.04	151.83	av. 47.8%	av. 54.9%	av. 53.7%

Bogor for 1 year (Mohr and v. Baren, 1953).
Simanggang mean 1963 - 1968. Abs. max. 78.52 Abs. min. 58.11.
Kuching mean 1963 - 1968. Abs. max. 85.12. Abs. min. 63.17.

Fig. II. 6 EVAPORATION AND PRECIPITATION

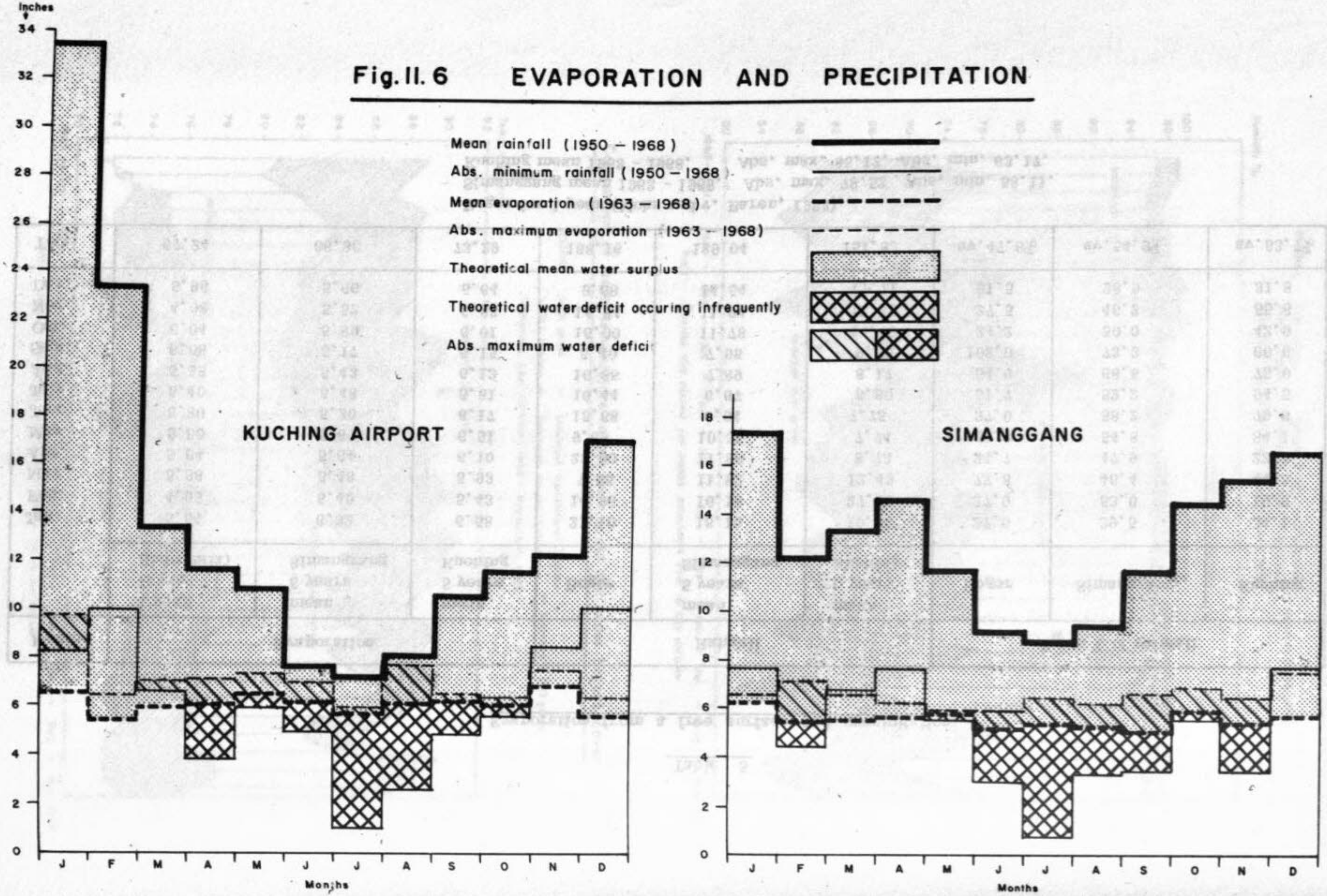


Table 6

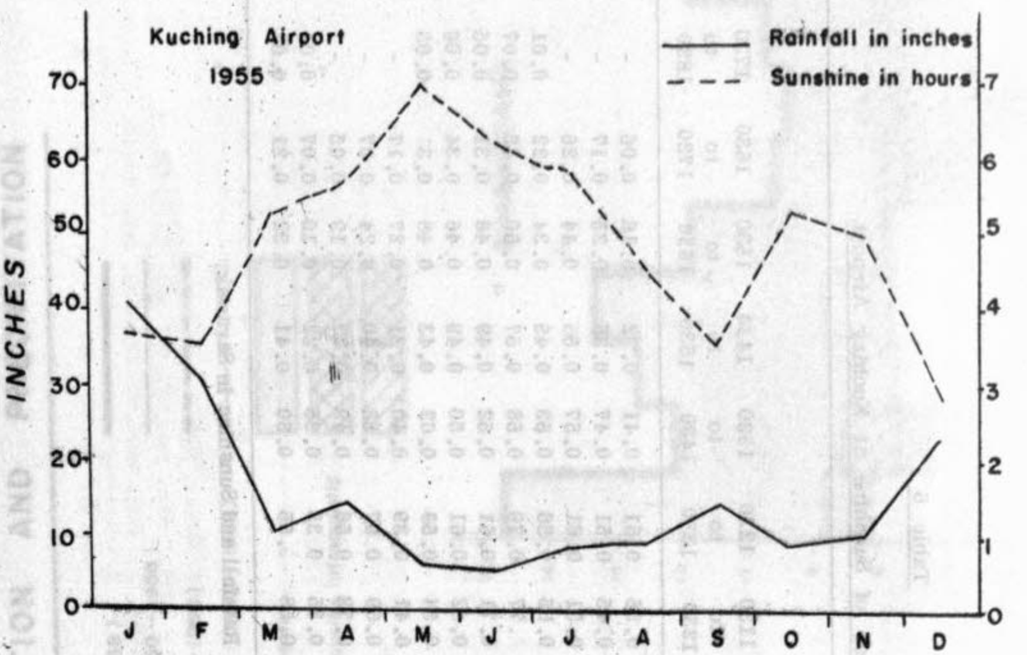
Hourly Values of Sunshine at Kuching Airport

Year 1955.	0530 to 0630	0630 to 0730	0730 to 0830	0830 to 0930	0930 to 1030	1030 to 1130	1130 to 1230	1230 to 1330	1330 to 1430	1430 to 1530	1530 to 1630	1630 to 1730	1730 to 1830	Daily mean	
January	-	0.16	0.27	0.32	0.43	0.51	0.55	0.51	0.41	0.32	0.16	0.06	-	3.71	January
February	-	0.11	0.22	0.29	0.41	0.39	0.45	0.51	0.47	0.35	0.25	0.17	-	3.60	February
March	-	0.21	0.54	0.56	0.56	0.50	0.51	0.61	0.57	0.56	0.44	0.26	-	5.31	March
April	0.01	0.27	0.59	0.75	0.71	0.67	0.65	0.56	0.53	0.45	0.34	0.22	0.01	5.77	April
May	0.05	0.40	0.61	0.71	0.74	0.84	0.77	0.70	0.58	0.57	0.50	0.45	0.07	6.98	May
June	0.02	0.33	0.54	0.66	0.77	0.75	0.71	0.61	0.52	0.49	0.46	0.31	0.05	6.24	June
July	0.01	0.34	0.55	0.55	0.64	0.66	0.62	0.61	0.50	0.49	0.46	0.34	0.06	5.84	July
August	-	0.13	0.22	0.35	0.43	0.45	0.54	0.59	0.62	0.43	0.48	0.31	0.03	4.60	August
September	-	0.11	0.31	0.37	0.40	0.42	0.41	0.39	0.40	0.31	0.27	0.17	-	3.57	September
October	-	0.17	0.50	0.63	0.70	0.69	0.69	0.67	0.58	0.40	0.24	0.07	-	5.35	October
November	0.01	0.22	0.57	0.64	0.63	0.71	0.73	0.56	0.49	0.27	0.19	0.05	-	5.06	November
December	0.01	0.13	0.23	0.30	0.36	0.35	0.35	0.35	0.35	0.22	0.10	0.07	0.01	2.83	December
Means	0.01	0.21	0.43	0.51	0.57	0.58	0.58	0.55	0.50	0.41	0.32	0.21	0.02	4.91	Mean

Ref. Seal, 1958. Rainfall and Sunshine in Sarawak.

Fig. II. 7.

Relation between Rainfall and Sunshine



maximum evaporation) are shown. There are indications for Kuching area, Rainfall Group III (see p.25), that October to March are probably the most favourable months for wet rice growing, while for Simanggang this is from December to May. The latter period may probably be the most favourable season for the whole eastern portion of the Region. These periods also coincide with the period of greatest rainfall during which excess water is a problem. These problems are discussed in detail under Chapter 4, section 5(b) (p.82). It has been indicated in section 4 of this chapter that the rainfall in belt I appears to be less variable than in belt II to IV and that probably rice cultivation can be extended outside the northeast monsoon season (p.26). The evaporation figures, however, indicate that this is probably too risky and this may illustrate that rainfall figures alone do not provide adequate information on water availability for wet rice growing. Another problem not yet been studied in Sarawak is the question whether the measured evaporation from a free water surface is representative for that of a flooded rice field. Particularly during the middle and mature stages of the rice the shading effect of rice must influence the evaporation, but this may be possibly offset by an increase in transpiration. Further, it has not been established yet what amount of water a wet rice crop needs under Sarawak conditions. This is even more so for hill rice where the rate of runoff and infiltration may be important factors. Investigations in this field are highly recommended.

7. **Sunshine**

Records of sunshine although available for Kuching, Simanggang and Semongok are not available in a published form, with the exception of Kuching Airport.

Table 6 (p.43) shows the hourly values of sunshine for Kuching station and for the same reason as given under section 4 of this chapter (p.25) this station is only representative for the belt of Group III stations and may be only indicative for the remainder of the Region. The impression received during field work is that particularly in the northeast monsoon season the interior has more sunshine than is recorded for Kuching, while this may be the case in the whole eastern region during the whole year.

Table 6, studied in combination with Fig. II.7 (p.44) indicates that the sunshine is very much related to rainfall, particularly for the first half of the year. The period July to December receives less sunshine than one would expect from the curves in the graph for the first half of the year. As shown by Table 3 (p.36) numerous light showers occur during this period, particularly during August-September, which although not adding substantially to the precipitation, effect the hours of sunshine. In this connection, it may be of interest to mention that the period July to September has been locally given the name 'little landas' since the public is under the impression that much rain is falling during this period. This is, however, not borne out by the facts. The rainfall is not higher than in any other months of the 'less wet season'. What causes this impression is that the number of rain days are greater (see also Fig. II.3a, Sungei China and Telok Assam, p.32) and because of the frequent showers and cloudiness, the sunshine hours are less.

Finally, Table 6 shows that mean sunshine hours of more than 5 per day are concentrated in the months of March to July, and in October to November, the hours 0730 to 1430 giving the highest amount of sunshine with more than 50%. Mean sunshine hours of more than 6 per day are only found in the period May and June and it is also in these months that the daily hours of 0830 to 1430 gives more than 70% sunshine.

8. **Wind**

Reliable wind information can be obtained from Kuching Airport as this station is the only one with an anometer installed. The prevailing winds, during the months October to April are northeast, and are distinctly related to the northeast monsoon, and those during the months May to September are generally south-southwest, south and south-southeast influenced by the southwest monsoon. Strong winds rarely occur; the wind velocity varies between 0-0·3 meter per second, which is considered to be calm. Wind velocities of 6-8 meters per second occur about 7 times a year. Strong gusts of wind frequently occur and commonly precede a thunderstorm. Such strong winds create heavy damage to tall trees but damage to crops seldom occurs.

9. **Cloud Conditions**

Mist and fog conditions occur generally in the early morning hours, particularly during clear nights in a dry period. This is due to the strong radiation from the earth during the night. The lowest temperatures are recorded between 4 to 6 o'clock in the early morning. The fog may persist for an hour or two in enclosed valleys but generally it is of short duration. The fog is lifted soon when the air masses are gradually warmed by the sun and this causes temporary fog conditions at higher altitudes (about 500-1,000 feet) from 8 to 9 o'clock when clouds from the moisture laden valleys are drawn up. Land above this altitude is generally shrouded in clouds during rainy weather, particularly in the northeast monsoon season. There is severe cloudiness for areas above altitudes of over 2,000 feet for a large part of the year, these areas are generally covered with clouds from 11 o'clock a.m. for the rest of the day.

Chapter 4. PHYSIOGRAPHY

1. **Relief** (see Relief Map as shown as inset in supplementary map 4, Vol. II)

West Sarawak is characterised by a general low relief; more than 50% of the Region lies below the 100 feet and more than 75% is found below a level of 500 feet. The remaining 25% consists of mountainous terrain and only a few small localities have altitudes of over 2,000 feet. Such areas comprises mainly mountain tops or ridges in the border area with Indonesia, of which the Pueh massif near Lundu, and the Bungo Range near Bau (the latter culminating in the Penrissen summit) are the highest and largest. The Pueh massif has altitudes ranging from 3,000 to just over 5,000 feet, while the Penrissen mountain ranges between 2,000 to just over 4,000 feet.

Although the overall relief is relatively low, the area is made up of a variety of strongly contrasting relief units. A flat coastal belt comprising floodplains and basin swamps is backed by a landscape which has all the characteristics of a summit plain ranging in altitude from 50 to 350 feet. From this summit plain single hills and mountains rise up as isolated blocks with elevations of over 2,000 feet. These monadnock-like hills and mountains are generally made up of igneous rocks or limestone while the summit plain is underlain by sedimentary rocks of Cretaceous Age or older. The contrasting relief in this belt of summit plains is caused by differential erosion due to the varying hardness of the rock types. A third belt, marking the border with Indonesia, forms the most rugged terrain. This latter mountainous belt is made up mainly of poorly consolidated Tertiary sandstones, mudstones and shales, which are the only sedimentary rocks in the whole area reaching altitudes of over 2,000 feet while the remainder all lie below 500 feet.

Wilford (1955, p.31; pp.92-94) indicates that Tertiary deposits originally capped all the older sediments. The latter were in Tertiary times mainly below sea level and the Tertiary sediments were deposited in small basins. After subsequent folding and faulting, which probably occurred in late-Pliocene, (Leichti, 1960, p.292) the synclinal nature of these basins was emphasised. Wilford suggests that uplifts of the whole Region took place during the Late Neogene and that the Tertiary sediments forming anticlinal areas were since then removed by erosion, thus exposing the underlying older sedimentary rocks.

Presumably the synclinal rocks were more strongly consolidated and are therefore less prone to erosion than the anticlinal ones which were largely little effected by the late-Pliocene folding and thus mainly consisted of unconsolidated Tertiary sediments.

This hypothesis assumes removal of a 1,000 to 1,5000 feet of little or non-consolidated Tertiary deposits in the anticlinal areas during post-Late Neogene periods. It would explain the contrasting topography between the areas built by the older sediments and those formed by the remnants of the Tertiary deposits, the latter forming conspicuous scarps all along their border with the older deposits and which are supposedly the relics of the old synclinal slopes which have withstood erosion better.

Thus, the contrasting relief in West Sarawak is mainly caused by differential erosion; the limestone, igneous rocks and synclinal consolidated Tertiary deposits being most resistant.

This factor has been a great aid in soil mapping since any conspicuous change in relief has invariably proved to be caused by changes in parent material and consequently soil type. Air photographs have been an invaluable tool to detect such changes.

Areas of high relief are insignificant in areal extent and thus do not restrict agriculture over the whole Region significantly. The remainder of the area, with the exception of the coastal plain and basin swamps, shows strong mesorelief caused by intensive dissection. The amplitude of relief in these summit plain areas ranges from 50 to 100 feet but slopes are generally within the 15-30 degrees range and the total extent of interstream upland area is very small. The strong mesorelief in this relatively large area affects the agricultural potential of the whole Region considerably.

The relief contrast also has a strong bearing on local rainfall and causes great variations in rainfall intensity and magnitude over short distances. This has been explained more fully in Chapter 3, section 4, (p.25).

2. **Morphological History of West Sarawak**

West Sarawak belongs to the comparatively stable continental core in which the last orogenic movement probably took place during the Late Neogene when the Region was uplifted. As indicated by Wilford (1954, p.31) the whole area was then covered by Tertiary deposits which after the uplifts came under the influence of subaerial weathering and erosion. It can, therefore, be assumed that the present geomorphic cycle began in the Late Neogene after the uplift was completed. The landscape morphology is, therefore, largely influenced by Quarternary events.

It is generally believed that the continental core, to which West Sarawak belongs, has been very stable since the Pleistocene. Haile (1957, p.100) suggests that 'apart from some minor warping the region has been very stable', while this view was also expressed by Wilford (1961, p.131), who considered that 'the continental core-part of Borneo has probably been stable for a long time'.

Leichti (1960, pp.303-321) explained the landscape features in central and northern Sarawak, Brunei and eastern Borneo by assuming post Neogene uplift *en bloc* and locally, together with warping and included West Sarawak in his description of the morphological history of Sarawak. He infers that also in West Sarawak post-Neogene uplift and warping must have played a role as he remarks on the remarkably constant height of the Batang Kayan syncline, the Klingkang Range and Bungo Range (around the 2,000 feet level) and relates them to the early-Pleistocene Peneplanation Cycle in North Borneo. These heights are, however, also found at the coast and not only in the interior (e.g. Santubong) and they are all formed by consolidated, almost horizontally bedded Tertiary sandstone formations. His hypothesis assumes uplift after peneplanation in the Pleistocene which is contradicted by Wilford and Haile (*op. cit.*). The writer believes that these flat mountain types are structurally controlled surfaces, and are not related to peneplanation. If they were caused by peneplanation, their levels should not only be confined to these rock types, and if uplift *en bloc* or warping of the magnitude suggested had taken place then the landscape would certainly be different from what it is now. Therefore, suggested relationships in morphology between North Borneo and West Sarawak must be viewed with reservation since one has to assume that in West Sarawak changes in erosion base level during the Pleistocene were mainly caused by eustatic sea levels, probably locally influenced by warping, while in that part of Borneo lying outside the continental core, uplift and warping have played a major role. This applies particularly to the period before the Holocene, the whole area having been quite stable since (Wilford, 1959, p.17).

Before embarking on a description of events which have shaped West Sarawak's landscape, a summary of Leichti's idea on the Pleistocene history of the morphology of Borneo is given below.

Leichti envisages three cycles of erosion and deposition:

I — Peneplanation cycle, probably Early Pleistocene.

II — Jerudong cycle, probably Mid-Pleistocene.

III — Alluvial cycle, subdivided into:

(a) Probably Late Pleistocene to Holocene—A cycle.

(b) Holocene to Recent.

Cycle I, the peneplanation cycle has caused the formation of a well developed peneplain of which the present height in northern Sarawak and North Borneo is 200 to 300 feet near the cost and 3,000 to 4,000 feet in the interior. The great difference in height was caused by repeated regional uplift and warping.

In West Sarawak, the highest recognisable erosion base level is formed by a summit plain ranging in height from approximately 200 feet near the coast to 350 feet in the interior. This is indicated as the Tebedu unit on the Physiographic map (supplementary map 4, Vol. II). This unit borders in the interior onto the steeply rising mountains formed by the synclinal Tertiary formations (see section I, this chapter, p.46). The levels of this summit plain correspond well with those indicating the peneplanation cycle in the coastal areas of North Borneo. It can be tentatively concluded that the development of this peneplain in West Sarawak dates back to the early Pleistocene, since uplift must be excluded for Sarawak. Except for the existence of this summit plain at the 200 to 350 feet level no other physical evidence for peneplanation has been found in West Sarawak. The summit plain is marked by absence of any terrace materials and one has to assume that either any existing old alluvium was removed through erosion and further denudation or the peneplanation had never reached a mature stage. That at one period in the Early Pleistocene the sea level was at about 200 feet above the present seems to be an established fact. Terrace alluvium up to this level has been found in many countries surrounding the South China Sea (Burton, 1962, p.20). This level correlates also with wave-cut platforms existing in the Bako-Peninsula at the 200 to 250 feet level.

The Jerudong cycle, Cycle II, of Leichti succeeded the peneplanation cycle in North Borneo by a deduced structural uplift of 150 to 300 feet in the coastal area and of probably 1,000 to 2,000 feet in the interior. This uplift caused rejuvenation of the old peneplain in North Borneo and left in the coastal areas terraces of a height varying between 20 to 120 feet but generally between 80 to 100 feet.

In West Sarawak, Leichti quotes examples of what he believes to be Jerudong terraces at a level of 90 to 120 feet near Kuching Airport and at a much lower level in the Lundu-Sematan area. However, there are reasons to believe that the Jerudong cycle is probably not present in West Sarawak, at least not in the form of terraces at the heights suggested. To explain this, it is necessary to look first at the events which followed the Jerudong cycle in North Borneo.

The Jerudong cycle was ended in North Borneo by regional uplift *en bloc* in the coastal area of about 250 feet which lead to extensive dissection.

Leichti does not state whether this uplift was caused by a change in sea level or whether it was of structural origin; from studying the landscape in West Sarawak the writer suggests that quite probably a change in sea level was involved, at least in West Sarawak. During this period the old peneplain was strongly dissected and areas near the coast were eroded to a level far below present sea level. Old river courses in the now submerged Sunda Shelf indicate the very low sea level during that period (v. Bemmelen, 1949). A subsequent rise in sea level to approximately 50 to 80 feet below the 200 to 350 feet level of the old peneplain resulted in the infilling of the formerly carved valleys by alluvium. This period is referred to as the Alluvial A Cycle.

The present topography of West Sarawak is characterised by strong topographical and soil changes at the 150 feet level. Above this level, the dissected old peneplain is devoid of old alluvial deposits, while below this level a second summit plain is found with hill tops ranging in height from 100 to 150 feet which in places are covered by a veneer of old alluvium. In the Lundu-Sematan area one finds an extensive relatively undisturbed area of terrace alluvium ranging in height from 50 to 150 feet.

This second summit plain is indicated as the Quop B unit on the Physiographic map (supplementary map 4). It is suggested that instead of belonging to the Jerudong cycle, the Kuching Airport terraces at the 90 to 120 feet level together with the 100 to 150 feet summit plain belong to the Alluvial A cycle period, during which all areas up to 150 feet above present sea level were submerged and covered by alluvial deposits under marine conditions. If the Jerudong cycle is not represented by physical evidence in West Sarawak, what could be the cause? Because of the absence of uplift in West Sarawak the Jerudong cycle deposits may originally have been deposited at lower levels than found in North Borneo and at lower levels than those of the Alluvial A cycle. In that case, they may have been buried by new deposits of the suggested marine stage during the Alluvial A cycle.

The old alluvial deposits below the 150 feet level are strongly bisequent in nature and are underlain at shallow depth by heavy clay suggesting a marine origin (they have a high Mg-content, Andriesse, 1965b, p.44) and for this reason the Quop unit has in the past been referred to as the 'old coastal plain' (Andriesse, *op. cit.* p.19).

The 150 feet level is a significant one and the great changes in landscape and soils which occur at this level over the whole Region are indicative of a probable marine transgression to that level. During this period, all previously formed valleys were filled in and a general smoothing out of the landscape occurred. Dissection in the old peneplain still continued but depositing took place at the 200 feet level and lower. Remnants of these alluvial deposits are still found at the 200 feet level along present river courses in the interior. (Near Tebedu and Pang. Tebang) and in preserved old valleys at the same level at Muara Mongkos.

It should be mentioned that no physical evidence of coastlines at the 100 to 150 feet level can be found. Also Wilford and Wall (1965, p.66) remark on this lack of evidence, which is probably caused by the fact that erosion may have removed much if it ever existed.

It is probably best to date the development of the 100 to 150 feet level as post-Early Pleistocene. It could have happened together with the Jerudong cycle during the Mid-Pleistocene but the Jerudong is then characterised by a probable marine phase in West Sarawak or it could have formed during the Alluvial Cycle A after the strong dissection which is more likely and is then of probable early-Late Pleistocene age.

When the sea level fell again in the third subcycle of the Alluvial cycle A (according to Leichti there may have been a lowering in base level of 15 to 20 feet) much of the alluvial cover was again eroded and redeposited at lower levels. At that time, probably the 20 to 50 feet terraces at the coast were formed (Lundu unit, p.64) and plains at this level developed in the Quop unit referred to earlier (Quop A unit, p.64). These terraces and old plains are probably contemporaneous with the 'Low Terrace' found at the 10 to 20 feet level in North Borneo. The development of the 'Low Terrace' in North Borneo and Brunei is assumedly dated by Leichti as Late Pleistocene to Early Holocene.*

The land area underwent further dissection and erosion during the last glacial period when the sea level was much lower than at present. The Lundu unit and Quop A unit (20 to 50 feet) were strongly dissected, particularly near the coast. Probably the rejuvenation did not reach the Tebedu unit (p.67) since the flats at the 200 feet level are relatively undissected. Large rivers formed floodplains at a level of about 10 to 20 feet above present sea level and remnants of these can still be traced e.g. at Batu Kitang Road (see Fig.II.9, p.51). Probably at that time the present day large rivers were able to extend their

*Results of C14 analysis on fossil wood, found in a Bh horizon of a Podzol formed on these terraces (±50 feet), were received subsequent to this writing. They indicate that the age of these terraces may be 25.800 years ± 2.000 years; (Kigoshi, 1970). Wilford (1959) dates the 'Low Terrrace' in Brunei as at 5.400 years, ± 200 years and the 20 to 50 feet terraces are therefore considerably older than the 'Low Terrace' which is probably contemporaneous with the Sematan unit which lies at a height of ± 14 feet above present normal high tide level, the oldest ridge in the coastal ridge system in West Sarawak. (See Sematan unit, p.59)

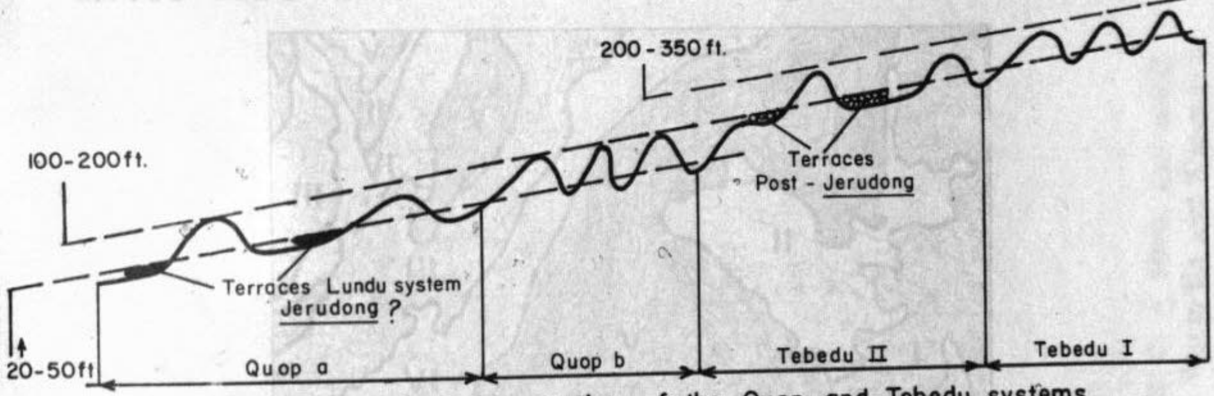
Plate 2.

View over part of the Quop A and B unit showing the 150 feet summitplain with monadnock hills of igneous intrusions (extreme right).
In background: Skyline of the Matang hogback with at the left the Singghi outlier separated from the Matang range by dissection down to 350 feet. To the left of Singghi, cuesta terrain of the Penrissen unit.

Plate 3.
Background: Skyline formed by part of the Matang hogback and Singghi mountain formed as an outlier (see also plate 2)
Foreground: Interior valley in Quop A unit. *Samarahan series* (GLEY SOILS) 7th mile Bau—Lundu road.

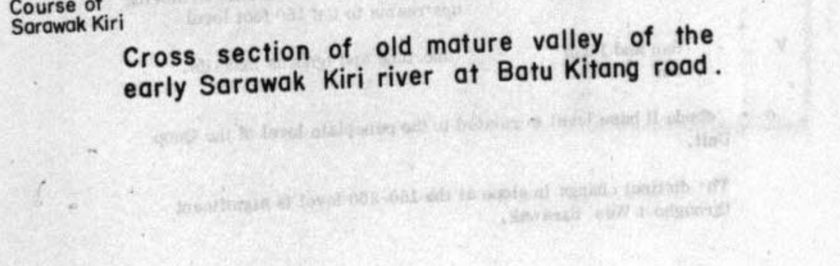
Plate 4.
Stapok unit hill (Bukit Siringgok near Bau) used for shifting cultivation. *Gumbang series* (RED-YELLOW PODZOLIC SOILS) on dacite.
Note the bouldery nature of the land.

Fig. II 8



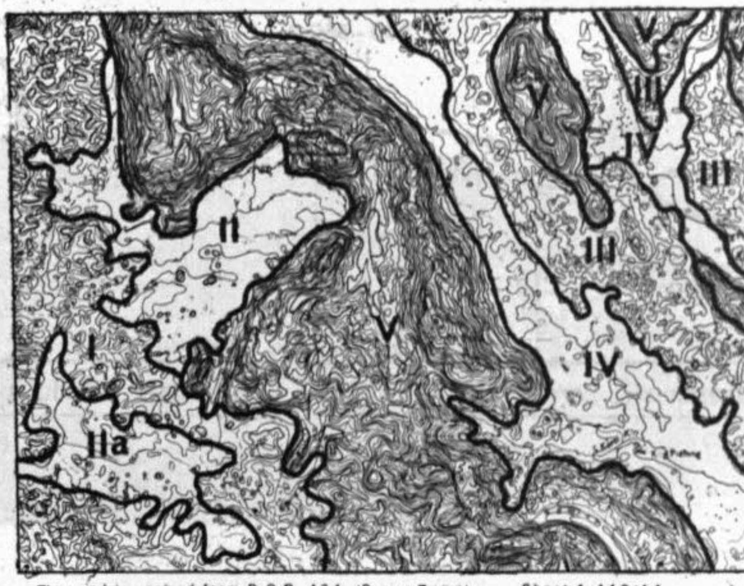
Diagrammatic cross section of the Quop and Tebedu systems

Fig. II 9



Cross section of old mature valley of the early Sarawak Kiri river at Batu Kitang road.

Rejuvenation and Degradation of Old Erosion Base Levels



This map is derived from D.O.S. 434 (Series T/3?) Sheet 1 110/14
SCALE 1:100 000

Fig. II.10

I	-	Tebedu I Unit	-	mature dissection of old peneplain level. (± 350 feet).
II	-	Tebedu II Unit	-	preserved old erosion base level. (?00 feet)
IIa	-	Tebedu II Unit	-	rejuvenation is approaching the 200 feet level.
III	-	Quop B Unit	-	mature dissection of the 200 feet level down to 100-50 feet.
IV	-	Quop A Unit	-	new base level at 50-20 feet in lower right corner with rejuvenation moving upstreams to the 150 feet level
V	-	Bau and Pueh Unit	-	limestone and igneous massifs.

Note: Tebedu II base level is related to the peneplain level of the Quop Unit.

The distinct change in slope at the 150-250 level is significant throughout West Sarawak.

Table 7

Pleistocene levels in West Sarawak in relation to those in other parts of the world.

Interglacial stages	High sea levels	Age	Height in metres (Zeuner) W.	Height in metres Sarawak
± 2 million years	Calabrian	± 2 million years	180-120	120?
Donau Gunz	Sicillian	± 1.3-1.1 million years	103-80	105-60
Mindel-Riss	Tyrrhenian	± 0.8-0.4 million years	45-32	45-30
Riss - Wurm	Monasterian	± 0.4-0.1 million years	18-7.5	15-6*
	Flandrian (dated 6000 B. P.)	(crest of last marine invasion)	2-3	3

After Zeuner, quoted by Holmes (1964, p. 714).

* This level is provisionally dated at 25,800 B. C. ± 2000, and would coincide with the pluvial period between the Wurm IIa and Wurm II b. glacial period.

Table 8

Postulated Pleistocene history of the landscape in West Sarawak

	Chronology(1)	Probable events(2)	Related feature
	Early to Mid-Pleistocene	Peneplanation. Removal of most of the a tic inal Tertiary deposits exposing underlying o r sedimentary rocks (Peneplanation cycle - Le chti).	1 Summi plain at 350- 00 feet level (Tebedu I uni)(3). 2. Absence of Tertia y posits outside the syn l nal areas. 3 Terrace emnant the interi at 300 feet in the Penrissen unit. 4 Peneplanation in Sarawak and Central Sarawak at this level (near the coast) during this period.
	Late leistocene	Probab e sea leve at the ummit plain 00 ft. ?)	Such a sea lev also suggested for Johore a d Singapore at this period Burton, 1962).
Chronology Doubtful	Mid Pleistocene	Fa in sea level Onset re uvenation of peneplain and str ng dissection. Deposition at l er levels than the ld peneplain level coinciding wi h Jerudong cycle in North Sarawak Leicht).	1. Terrace remnant at 120-5 feet and probably below (The latter may be of younger age) 2. Occurre of ektites in the terraces of this age in B unei indicate a Mid-Pleistocene age. 3. Old ma re pla remnan at 200 feet in the Tebedu un . (may also be of Late Pleistocene time).
	Early Late Ple stocene	Fall i sea level to at least 200 feet bel w present sea level This could also have happened in Pre-Jerudong time	1 Large d ive courses in the now submerged part of the Sunda shelf 2. Deep dissect on of the old peneplain and th Jerudong level to below present sea level.
	Late Pleistocene	ise n sea level to about 50 feet above the presen level Al uvial subcycle of luvial cycle A - Leichti).	1. Terraces at the 120- 0 feet level. 2. Development of a floodplain at 150 feet in the Quop ank.
	Latest Glacial period I	Fall i sea level to below resent level.	1 Strong dissection of the 150 feet floodp a n in the Quop un t.
	Fluvia period	Raise n sea level to about 50 feet a ov the present level.	1. Terraces at 50-20 feet level. 2. Terraces 50-20 feet above present floodplain level in the Tebedu unit
	Lates Glacial period II	Fall in sea level to below resent l vel.	1. Strong issection of the 50-20 feet depos ts near the coa t, leaving terrace remnants 2. Extens o of river levees following a retreating coast ine The build ng up of large interfluvial basins
	Holocene	Rise in sea level to slight y above present level (± 10 to 20 feet).	1. Formation of coastal ridge unit west of Santubong. 2. Formation of oral reefs in Sematan a ea. 3. Formation of shelf deposits and deltaic mud flats about 10 feet above present depos onal level.
	Holocene to Recent	Oscillations of sea level w th a nett fal of approximate y 20 10 feet	1 Exposed coral reefs at Sematan. 2. Formation of present day mudflats and deltai dep sits. 3. Formation of present riverine floodplains bel w th 20-10 feet level 4. Fi ling-in of the interfluvial basins and valley in the Quop nit by peat deposits

Note:- 1 The dating is tentativ ; the chronologic l order i of more s gnificance.
2. Sea level cha ges are relative and base on the assumption that the region has been tectonically stable throughout the Pleistocene.
3. The level of the old peneplain vas prob ly originall higher and has been lowere hrough denudation since its forma ion.

Table 9

GENERAL CHARACTERIZATION OF THE PHYSIOGRAPHIC UNITS

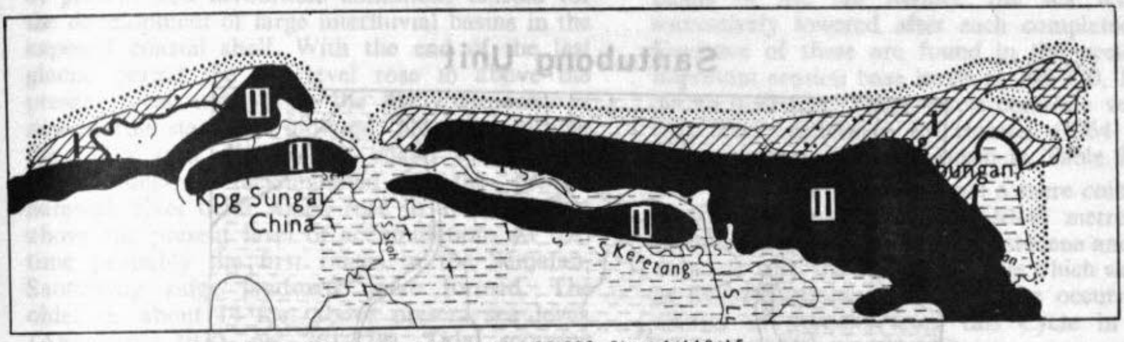
	Sematan	Santubong	Samarahan	Nonok	Quop	Lundu	Tebedu	Penrissen	Pueh/Stapok	Bau	Undup
Physiography	flat ridges	flat, marine plains	flat, riverine floodplains	flat, basin swamps	dissected hilly terrain with old valley floors	flat to undulating terrain	dissected hilly terrain	rugged terrain	rugged	rugged	dissected hilly terrain
Soils	sands, infertile	marine and estuarine clays, relatively fertile	riverine clays, relatively fertile	deep peats	upland clay soils and old sandy alluvium	sands, infertile	mainly upland clay soils	mainly sandy upland soils, infertile	upland clay soils, generally moderately fertile but shallow	no soil development	mainly upland clay soils, moderately fertile
Forest	removed	partly removed. Where existing: Mangrove/Nipah	Riperian Forest and Peat Forest if not removed	freshwater peat forest	mostly removed. Where existing: Dipterocarp Forest	Kerangas to Dipterocarp Forest in places	Dipterocarp Forest where not removed	Dipterocarp Forest to Kerangas Forest in places	Dipterocarp Forest	Limestone Forest	where existing: Dipterocarp Forest
Agriculture	coconut, some hill-rice, vegetables. Extensively used.	where existing: coconut, cocoa, off-season crops, wet rice. Extensively used.	where existing: wet rice, coconut, rubber	where existing: pineapple, wet rice, coconut.	mainly in use for shifting cultivation; rubber and pepper in places	where existing: shifting cultivation, some rubber	mainly shifting cultivation, rubber and pepper	not developed; generally under forest	where existing: pepper, shifting cultivation	none	where existing: shifting cultivation, pepper and rubber
Population	mainly Malays and Chinese	dominantly Malays and Chinese, few Ibans	mainly Malays near coast, Iban upstream	mainly Chinese. Few Malay and Iban	Chinese along main roads, Land Dayak in interior	extensively populated. Some Chinese and Land Dayak	Land Dayak	few Land Dayaks	mainly Land Dayak	none	Iban.
Erosion	none	none, coastal erosion in places	embankments may erode at places	in places where exposed at at river bank or coast	if not exposed: moderate	none	if not exposed: moderate	if exposed: severe, otherwise moderate	where exposed: moderate	chemical removal through solution	if exposed: moderate
Flooding	none	normal in wet season, severe in places	normal in wet season; severe in places	normal in wet season, severe in some places after subsidence	in places in valley bottoms: of short duration	none	none	none	none	none	none

Table 10

Areal Extent of Physiographic Units in square miles

Unit	sq. miles	
Sematan	12	
Santubong	306	
Samarahan	258	
Nonok	1018	
Quop a	564	
Quop b	483	
Lundu	241	
Tebedu	542	
Penrissen	559	
Pueh/Stapok	357	
Bau	34	
Undup	71	
Total	4445	(error in relation to soil map ± 2%)

Sematan Unit



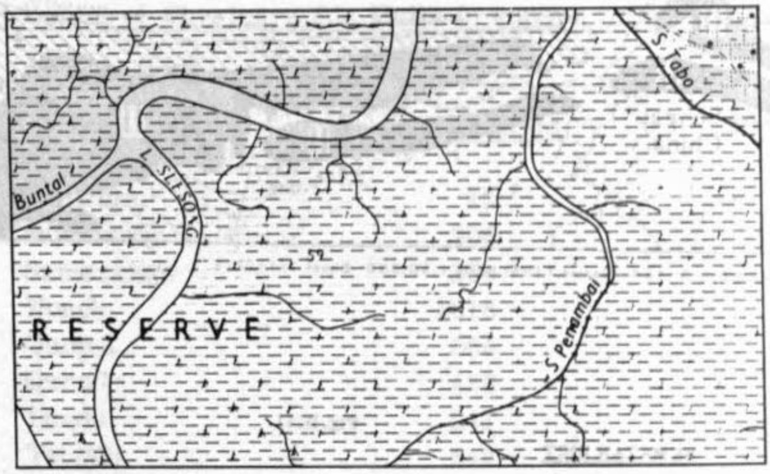
This map is derived from D.O.S. 434. (Series T735) Scale 1:50.000 Sheet 1/110/15

Fig. II.11

SEMATAN UNIT

General character	:	Generally a series of beach ridges, separated by swales and tidal creeks and generally backed by the Santubong unit or Lundu unit. Built by marine sand deposits of increasing age with distance from sea. I - youngest ridge. II - older ridge.
Levels	:	Youngest ridge 2-4 above high tide level. Older ridges are somewhat higher and in places up to 14 feet above high tide level.
Drainage	:	Tidal creeks.
Vegetation	:	Settled cultivation (coconut) and secondary growth, often lallang.

Santubong Unit



This map is derived from D.O.S. 434, (Series T735) Scale 1:50,000
Sheet 1/110/2 & 6

Fig.II.12

SANTUBONG UNIT

General character	:	Flat terrain. Micro-relief hummocky. Many 'islands' surrounded by large river branches. Generally swampy and intersected by many tidal creeks.
Levels	:	Generally 10-0 feet above mean sea level. Highest in the centre of 'island', lowest near the rim.
Drainage	:	Complex, deranged, creek pattern.
Vegetation	:	Mangrove, Nipah and Nibong.

levees much further into the coastal shelf than at present and favourable conditions existed for the development of large interfluvial basins in the exposed coastal shelf. With the end of the last glacial period the sea level rose to above the present level and during the Early Holocene a new marine stage was initiated. This affected only the areas near the present coast. Marine and deltaic deposits accumulated in the present Sarawak river delta which rose to about 10 feet above the present level of accumulation. At that time probably the first ridges in the Sematan-Santubong ridge landscape were formed. The oldest is about 14 feet above present sea level. (Andriesse, 1970, pp. 261-279). Tidal scouring greatly enlarged the new estuaries of old river channels found at the coast between Lundu and Santubong Peninsula. At that time marine deposits were probably also accumulating in the erstwhile formed interfluvial basins and Mangrove was the main vegetation. These basins were subsequently filled by peat deposits. (Anderson, 1962).

Allen (1952, p.63) reports for the Sematan area a succession of deposits in valleys showing a buried marine stage followed by a continental stage on which again a marine stage can be found. The lowest is probably related to the Alluvial Cycle A (marine stage) which continued until the last glacial period at which time deposition was under continental conditions. During the Holocene this continental stage was succeeded by a new marine one. Unfortunately, Allen does not mention the present level at the point where the boreholes were taken so that an estimation of the probable changes in erosion base levels cannot be assessed.

Since the Holocene the sea level has shown minor oscillations with a net fall of prabably 10 to 15 feet. During this period, the old mudflat and deltaic deposits were partly eroded and new deposits accumulated at a lower level (the present day deposits). A succession of ridges developed between Sematan and Santubong and peat started to accumulate in the old riverine basins and followed the retreating coastline. There is evidence that the sea level has recently risen again, at least in some parts of the area, notably between Nonok and the Lupar estuary where most of the mudflats which probably once fronted the peat swamps have been eroded. Local subsidence due to warping may also have caused this transgression of the sea in those places (Haile, 1954, pp.30-31).

This description of historical events is by no means complete. It should be realised that evidence is scanty, particularly on the dating. Probably the chronological order is in most cases correct. A doubtful case being the marine phase up to a level of 150 feet; this could have been during Mid-Pleistocene time and coinciding with the Jerudong Cycle. It could have been later.

It is of interest to note that throughout the Pleistocene with its successive stages of continental and marine conditions caused by eustatic movements of the sea mainly, the sea level was successively lowered after each completed cycle. Evidence of these are found in the presence of important erosion base levels at 200-350, 100-150, 20-50, 0-10 feet. These levels correlate very well with those published by Holmes (1964 derived from Zeuner; p.714) as shown in Table 7 (p.53).

If these correlations are not a mere coincidence then the 100-150 feet level (30-45 metre) could be firmly placed in the Mid-Pleistocene and would coincide with the Jerudong Cycle which was dated as Mid-Pleistocene because of the occurrence of tektites in deposits from this Cycle in Brunei (Wilford, 1957, pp.121-124).

Finally, Table 8 (p.54) attempts to summarise in an orderly form, the Pleistocene events which have shaped most of West Sarawak's landscape.

3. Description of Physiographic Units

To facilitate a logical description of the physiography, the Region has been divided into 11 main physiographic units of which a number were again split into subunits.

Apart from the physiographic differences, quite a number of other variable characteristics, such as geology, soils, vegetation, agricultural practices and even population are closely related to these units and this subdivision has therefore proved to be of considerable value for various other purposes, such as Advisory Land Use.

The units, therefore, may be compared with macro-ecosystems in which many environmental factors are identical in each unit. For this reason, a table with some notes on the vegetation, agriculture and population is added to the morphological descriptions (see Table 9, p.55). The relative areal importance of the units is shown in Table 10 (p.56).

(a) *The Sematan unit* (Fig. II.11, p.57)

This unit is only found west of the Santubong Peninsula and is formed by a series of low lying beach ridges which have emerged since the beginning of Holocene and which mark the coastline there. Generally, this sequence of ridges shows four stages which are best preserved in the Sematan-Pueh area. This landscape formed the subject of a special study since it forms a chronosequence in the development of the podzol morphology because increased podzolization of soils occurs with increasing distance from the coast. (Andriesse, 1970). The level of the ridge ranges from a few feet above high tide level (the most recent one) to 14 feet of the oldest ridge. The microrelief of each ridge is made up of a series of higher lying storm beaches built of sand and separated by shallow swales. The storm beaches are always dry and the watertable is low while in the swales the conditions can be wet during the wet season and the watertable is within

4 feet from the surface for most of the year. The fertility of the soils is related to the age of the deposited material and those soils nearest the present coast are the most fertile.

(b) *The Santubong unit* (Fig. II.12, p.58)

This unit is formed by deltas, tidal mudflats, and emerged coastal plains. Deltaic areas are the most extensive in this unit and are therefore described in more detail. The three main deltaic areas are found at the mouth of the Sematan river, the mouth of the Lundu-Kayan river and the mouth of the Sarawak river delta enclosed by Batang Salak in the west and Batang Samarahan in the east. Small estuarine areas are found at the mouths of Batang Sadong and Batang Lupar. All these deltas are characterised by almost flat areas which have only recently emerged and are slightly above high tide level. During spring-tide parts of the area may be flooded. The areas are intersected by large branches of the main rivers and by numerous creeks which in places tend to widen because of tidal scouring; in other places they are silted up by new deposits. The areas surrounded by these tidal outlets and river branches have in some localities a 'shield' about 10 feet above the surrounding area. These 'shields' are believed to be remnants of an older, higher lying coastal flat developed probably in Early-Holocene when the sea level was higher than at present. Most of these coastal flats were probably eroded when the erosion base level was gradually lowered during the Holocene. The present deposits are believed to be less than 6.000 years old. The soil types of the slightly elevated shield areas are more leached and are generally more silty in character than those derived from the more recent deposits which are generally clayey and saline. In this unit, high terraces of 20 to 50 feet representing remnants of an extensive terrace landscape of probably Late Pleistocene age, Alluvial Cycle A, also occur and where they are of large extent, they are shown as the *Lundu unit* (p.61).

The deltaic areas merge into each other by a former, now silted up lagoon in which some wide river branches are left as tidal outlets and which give the impression of a sunken coastline. Some of them are probably relics of estuaries or old river courses dating back to the last glacial period when the sea level was lower. Thus, Batang Sempadi may be an old course of the Lundu river, the Batang Rambungan is possibly an old course of a river draining the northern part of Sempadi Forest Reserve before this drainage was captured by what is now the Kayan river and drainage was diverted to the south. The interstream uplands between these two former drainage systems are approximately 250 feet high and the river capture may date back to the middle Pleistocene. Batang Sibu Laut and Batang Salak may be old courses of pre-Sarawak rivers. This river tends to move its main channel to the east. Within historical times the main outlet has changed from Batang Santubong to Batang Sarawak leading to Muara Tebas.

The area between Batang Samarahan and Batang Sadong, known as the Nonok Peninsula, has also been classified under this unit but has different physiographic characteristics. Nonok Peninsula is the only well-developed coastal plain in Sarawak. Probably this plain began as a mudflat fronting the coast after the last glacial period and its formation is probably contemporaneous with the slightly elevated shields in the Sarawak river delta. This mudflat was built mainly by sediments of the Samarahan and Sadong rivers which carry more fertile clay to the sea than the Sarawak river because of the occurrence of much basic igneous parent material found in the hinterland. For this reason, soils of the Nonok Peninsula are fertile by Sarawak standards. As explained in the section on the morphological history, the eastern part of the Santubong unit to the east of Batang Sadong, has been mainly eroded by the sea and the coast there is now formed by basin peats.

(c) *The Samarahan unit* (Fig. II.13, p.61)

The Samarahan unit comprises all the lower floodplains of the major rivers which are restricted to narrow belts along meandering river courses. These belts are separated from each other by commonly large basin swamps. (*Nonok unit*, p.62).

The base of these floodplains was probably formed during pre-Holocene times (last glacial period) when the sea level was lower. Broad, but lowlying levees were then built up, thus changing the interfluvial areas into basin swamps. The unit is therefore mainly made up of present river banks and low, commonly broad incipient levees. Meandering tends to remain restricted to the levee deposits only. Since, when peat, developed in the interfluvial basin swamp, is exposed through erosion at a cut-off bends of the meandering river, the river tends to move away from it. Probably the peat is comparatively more resistant to erosion than the soft clay deposited at the levees.

The river water becomes increasingly more brackish towards the sea. Brackish water tends to move upstream during the less wet period in the months April to October (Annual Report Research Branch, 1967, pp.113-115).

River banks forming part of the unit are rather inconspicuous and low, particularly near the coast. The land surface grades down almost imperceptibly from the river towards the basins where peat covers the mineral deposits with increasing thickness the further one moves away from the river. Most of the *Samarahan unit* is poorly drained and the groundwater is generally high. This is caused by the rather impermeable nature of the deposits and lack of gradient, since the

I Samarahan Unit
II Lundu Unit

This map is derived from · O.S. 434. (Series T735)
Scale 1:50.000. Sheet 1 10/15

Fig.II.13

1. SAMARAHAN UNIT

General character	:	Low lying floodplains of main river courses bordering the Nonok unit. Alluvial deposits. Relief: flat with hummocky micro-relief.
Levels	:	Generally between 20-0 feet above sea level.
Drainage pattern	:	Meandering main stream with small tributaries, nearer the coast with tidal creeks.
Vegetation	:	Mainly secondary growth (shifting cultivation - wet rice).

2. LUNDU UNIT

General character	:	Flat terraces, steep sided where bordering other units, with horizontal summits. Micro-relief hummocky with small depressions.
Levels	:	Generally between 50 and 20 feet above sea level.
Drainage	:	Undeveloped, in places deranged.
Veg ta ion	:	Kerangas forest.

Nonok Unit

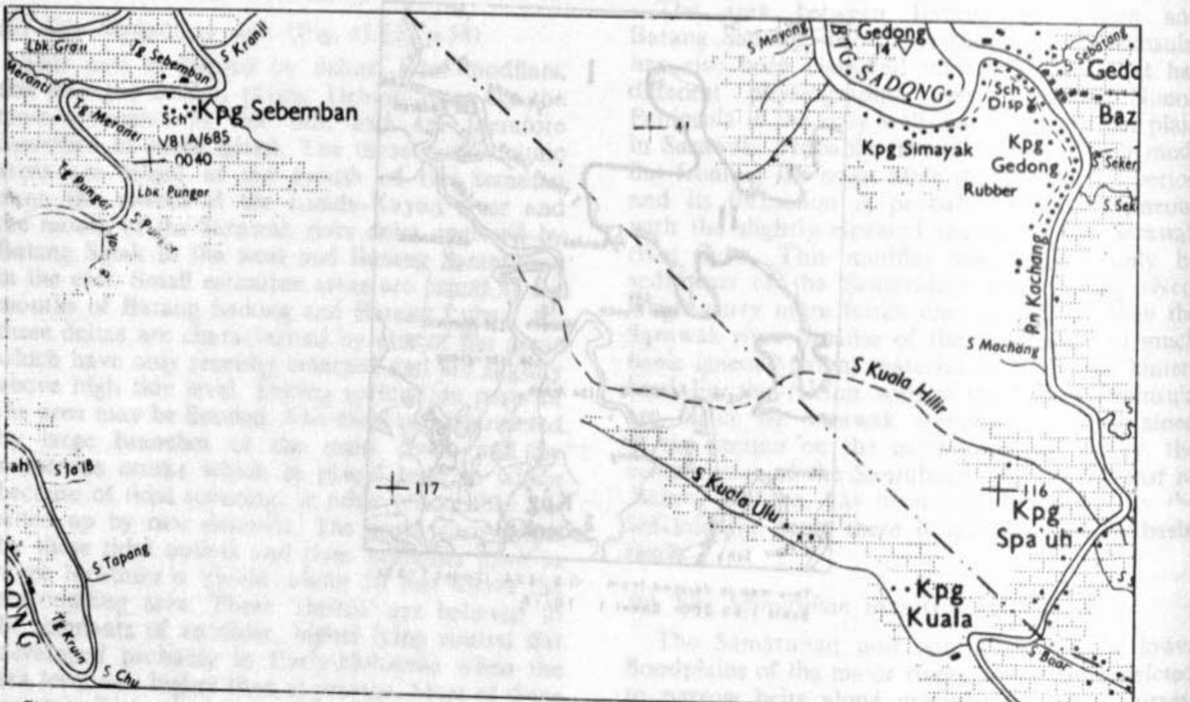


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Fig.II.14

NONOK UNIT

General character	:	Dome shaped basin swamps filled by peat deposits. Highest in centre, lowest near the bordering Samarahan unit (II). But eccentric domes may occur. Flat terrain with hummocky micro-relief and small depressions
Levels	:	Varied. Near river from local flood level (20-0 feet) to approximate 50 feet in centre.
Drainage	:	Radial.
Vegetation	:	Mainly Mixed Swamp Forest.

tidal difference in the rivers must be considered adequate to drain most of the floodplains for most of the year.

It is rather surprising to find such comparatively small floodplains in a Region where the climate and topography would tend to enhance erosion in the uplands and where deposition along a sluggishly moving river through a long stretch of lowland would normally be expected to be intense. Either the rivers carry comparatively small loads because erosion in the hinterland is not very severe or most of the eroded material is carried down to the sea. It is of interest to note that the areal extent of riverine deposits tends to decrease in the area from west to east. Thus, the Batang Samarahan shows the largest accumulation of deposits while along the Batang Lupar hardly any deposition takes place. Tidal movements in these rivers follow a similar trend, namely a weak influence in the Samarahan river to very strong tidal movements in the Batang Lupar. It is therefore suggested that little deposition takes place along rivers with a strong tidal influence, and that most material is carried down to the sea where it is deposited on the coastal shelf.

(d) *The Nonok unit* (Fig. II.14, p.62)

The *Nonok unit* comprises the largest land area in the Region and is composed of a series of large and small basin swamps situated in between the riverine floodplains, the coast and the uplands. Some small swamps in interior valleys are included. The swamps are characterised by large accumulations of peat which have developed in comparatively recent time. Wilford (1959, pp.16-20) has shown from C14 dating that at the Baram in North Sarawak the sea was at the inland margins of the peat swamps about 5,400 years ago, and that the sea has retreated since at an average rate of 30 feet per year (Anderson, 1964). This is corroborated in West Sarawak where the 'shields' in the deltaic areas and the development of the coastal ridge landscape (p 60) suggest a higher sea level around 6,000 years ago. According to Anderson the peat accumulation followed this drop in sea level but may not have occurred uniformly (in sheltered places this may have occurred more rapidly than in places exposed to sea currents).

The large basin swamps are dome-shaped. Anderson (*op. cit.*) studied peat profiles in the Central and North Sarawak peat swamps and notes that the doming is more prominent in the older peats than in the younger ones developing nearer the coast. According to Anderson, the peat also appears to be deeper inland than near the coast. There are no data from West Sarawak to substantiate this since peat depth measurements by the Soils Division usually do not extend beyond 12 feet. The convex nature of the larger peat swamps gives rise to radial drainage, resulting in an accumulation of water near the margins and a depletion at the centres, particularly during the less wet season. Flooding is, therefore, a regular natural feature only at the margins of swamps unless the peat has shrunk and the surface has subsided through artificial drainage. The watertable in peat swamps is, however, frequently near the surface being lowest at the centre. There is an intricate balance of water in these peat swamps which is easily disturbed by unplanned drainage. After drainage, areas tend to subside and flood. Without proper planning and layout, the problems created by a drainage scheme may be greater than those which it initially plans to overcome. These problems are described in detail in Chapter 13, section 2 (p.231).

That such thick peat accumulations could develop in this environment has given rise to some speculation on their formation. More details on the origin of peat accumulation are given in the chapter on Soil Genesis (p.159).

It is worth mentioning, however, that peat accumulation is found in many small valleys in upland areas. Cross-sections of these valleys reveal an almost original V-shaped form which indicates strong dissection prior to the peat accumulation. The absence of mineral materials in these peats may indicate that the present rate of erosion on the generally steep slopes is very small.

Valley peats in the Lundu area along the Kayan river and also in the Strap valley in the Lingga Subdistrict are in many places capped by a layer of mineral soil or muck. This is caused by backflooding which happens when the main river is in flood and the tributaries cannot discharge their water into the main river. This often coincides with spring tides. The backed-up water is then stagnant and sediments settle. Why this process has only been operative in comparatively recent time is not clear. A rise in sea level is theoretically possible but should have resulted in coastal erosion on a larger scale than at present. Clearing of forest upstream may be a more probable reason since this is of comparatively recent date and may have resulted in an increase in flow during the wet season. The development of sand bars at the estuary of the Lundu river may also have contributed to a raise in water level of the Kayan river and may have resulted in a temporary lowering of its discharge capacity so that flooding become more severe in the mid-course valleys.

(e) *The Quop unit* (Fig. II.15, p.65)

This unit is very complex and consists of two main parts:

Quop A: is characterised by an almost flat to gently undulating topography showing little dissection and lying between the 20 to 50 feet levels. Some isolated hills with summits ranging from 100 to 150 feet occur in this otherwise low lying terrain.

Quop B: is formed by a strongly dissected hilly terrain in which the hill tops form a summit plain at a height of 100 to 150 feet.

Both units occur in complex but the proportion of *Quop B* increases with distance from the coast.

The *Quop unit* was probably developed as follows: The 100 to 150 feet levels suggest the formation of a plain during the period when the sea level was approximately 150 feet higher than at present. During this marine stage the landscape below the 150 feet level was smoothed out by silting up of the old dissections and a cover of shelf deposits was laid over the whole area (see p.48). The area was again dissected when the sea level dropped to about the 20 feet level. This caused eros.on of the 100 to 150 feet level and consequently a removal of the alluvial veneer which was again redeposited at much lower levels, at about 20 to 50 feet above the present sea level. The 20-50 feet high areas of the *Quop A* unit must be regarded as a flood-plain which developed at this level while *Quop B* together with the rel.c hills of *Quop A* is formed by remnants of the old plain at the 100 to 150 feet level.

In *Quop A*, renewed dissection in sub-recent and recent times has caused valley development and deposition of recent alluvium below the 20 feet level, but large tracts of the old valley floor at approximately the 20-50 feet level are still present. Remnants of old alluvial deposits occupying limestone flats and found generally at the level of recent deposits, below 20 feet, are probably related to the old alluvial at the 20 to 50 feet levels. It is suggested that this alluvium was originally deposited at a higher level. The dissolution of the underlying limestone by acid groundwater has resulted in a general lowering of the ground surface level, hence this alluvium is now found below its original level of deposition.

The *Quop B* unit is strongly dissected. It comprises the more inland part of the whole *Quop unit* in which rejuvenation of the landscape by dissection was little affected by the more recent changes in base level. Little deposition takes place in this area, the down cutting process being still very active.

The *Quop unit*, particularly the *Quop A* unit is, because of its complex history, characterised by a great variation in parent materials and this accounts for the great diversity of soils occurring within this unit.

(f) *The Lundu unit* (Fig. II.13, p.61)

The *Lundu unit* comprises the larger areas of Middle to Late Pleistocene terrace deposits which are found below a level of 150 feet but mainly between the 20 to 50 feet levels. The largest extent of this unit is found in the Lundu-Sematan area where the terrace landscape is continuous, rising from a level of 20 feet near the coast to about 150 feet in the interior. This terrace landscape is situated at the foot of the Pueh massif. The strong sloping effect in this landscape, which is not present in other areas, suggests that these are coastal shelf deposits which were laid down at the foot of the mountain massif when the sea was 150 feet above the present level. At their highest level these deposits consists of a thin veneer overlying the country rock but they thicken rapidly towards the coast. The material is dominated by quartz sand, identical to the quartz found in the residual soils overlying the granites on the Pueh massif. Mineralogical analyses also confirm that these old alluvials are derived from these granites but in the subhorizons they are related to the underlying rock formations, these being mainly of metamorphosed sedimentary rocks (Andriesse, 1970, p.273). The *Lundu unit* in the Lundu-Sematan area is cut by deep valleys of streams which originate mainly in the Pueh massif and which have cut through the shelf deposits when the sea level fell below the 150 feet level in the Late Pleistocene.

The remainder of the *Lundu unit* comprises small areas of high level alluvium near Kuching Airport at the 90 to 120 feet levels, and other areas mainly at the 20 to 50 feet level near the coast. The latter are found in the *Santubong unit* (p.60) as islands surrounded by recent deltaic deposits which are deposited at the present sea level. The breaking up of this previous extensive terrace landscape near the coast into small isolated areas was caused by successive marine and continental stages which left many large river channels at this coast and which have eroded away much of the original high level deposits.

It is doubtful whether the old alluvials at Kuching Airport have developed in the same period as those at a much lower level nearer the coast. This would be the case if these old alluvials are steeply sloping shelf deposits, but at this location there is insufficient evidence to support such an assumption.

Quop A and B Units

This map is derived from D.O.S. 434. (Series T735)
Scale 1.50.000. Sheet 1/110/10

Fig. II.15

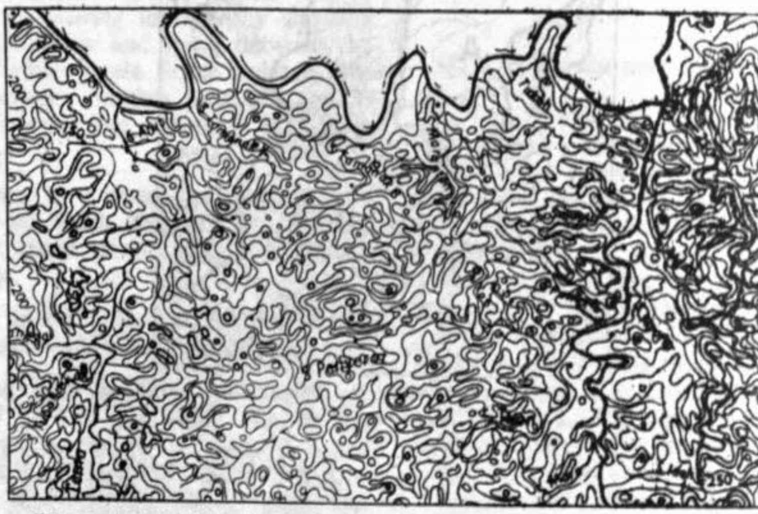
QUOP A

General character	:	Relatively undissected, gently undulating terrain with frequent terrace remnants of the Lundu unit. Small isolated hills. Mainly underlain by shales.
Levels	:	Low terrain varies between 50-20 feet above sea level. Summits of isolated hills between 150-100 feet.
Drainage pattern	:	Dendritic with rectangular tendencies.
Vegetation	:	Mainly secondary growth with some permanent cultivation.

QUOP B

General character	:	Moderately dissected terrain with generally steep slopes (15-25 degrees). Small, narrow valley bottoms. Built by shales mainly.
Levels	:	Hill summits between 150-100 feet, valley bottoms between 50-20 feet.
Drainage pattern	:	As Quop A.
Vegetation	:	Mainly secondary growth.

Tebedu Unit I



This map is derived from D.O.S. 434. (Series T735) Scale 1:50,000 Sheet 1/110/14

Fig. II. 16a

TEBEDU UNIT I

General character	:	**Moderately to strongly dissected hilly terrain.** Generally steeply sloping (20-35 degrees). V-shapes valleys with little deposition. Valleys widen towards Tebedu II unit. Built by shale mainly.
LEVELS	:	Hill summits generally between 250 and 200 feet. Locally up to 350 feet. Valley bottoms at 150-100 feet.
Drainage pattern	:	Dendritic with rectangular tendencies.
Vegetation	:	Largely secondary growth. (Shifting cultivation).

Numerous small areas of terrace alluvium originally belonging to the *Lundu unit* have been mapped together with the *Quop unit.* It was cartographically impossible to individually show all these minor areas.

(g) *The Tebedu unit* (Fig. II.16a and b, pp.66-69)

The Tebedu unit generally backs the *Lundu* and *Quop* units at the landward side and is characterised by moderately to strongly dissected terrain with slopes of 15 to over 35 degrees, but generally from 20 to 25 degrees. The hills have concordant summit heights from 200 feet near the *Quop unit* to about 350 feet in the interior.

The relationship between the *Tebedu unit* and *Quop unit* is shown in Fig. II.8 (p.51). The old erosion base level of 200 to 350 feet is believed to be of Early Pleistocene age (see under section 2, this chapter, p.46).

Since the Early Pleistocene dissection and mass wasting have worked uninterruptedly on the old peneplain and the present landscape shows evidence of a late youth to early maturation stage in the new peneplanation cycle as described by Thornbury (1954, pp.137-138). There is a minimum of interstream uplands, and most of the main streams have reached a profile of equilibrium; there are no waterfalls, and floodplains start to form along the main streams but very little deposition takes place along the great number of small tributaries, of which many are incipient streams or gullies. It is believed that full maturity has not been reached, since the main stream meander mainly in structurally controlled, incised valleys in which little deposition is yet taking place. The present erosion base level in the area is from 50 feet near the *Quop unit* to 150 feet in the interior. This means that the present base level is almost parallel to the summit plain, suggesting that throughout the Pleistocene no local uplift or warping in relation to the coastal areas has taken place.

In the *Tebedu unit* there are some large areas of flat to low undulating terrain at the 150 to 200 feet level in which old terrace deposits are found. These are indicated as the *Tebedu II subunit*. Notable areas are near Tebedu, near Tubeh and near Mongkos (see soil map, sheet 2). These areas are possibly remnants of a floodplain developed in the early Late Pleistocene when the sea level was at a suggested height of 150 feet, because its level correlates with that of the summit plain forming the *Quop B unit* (p.65).

The terrace (or floodplain) remnant near Mongkos, upstream of Sungei* Kedup, contains well indurated laterite sheets. These areas have probably escaped erosion and denudation because of river captures which left these areas isolated and unaffected by rejuvenation processes. Their location, generally behind mountain ranges, may partly explain why they have not been affected by the frequent changes in erosion base levels. The old floodplain at the 200 feet level at Tubeh is rather intriguing since it is separated by a range of limestone hills from the present erosion level situated nearby at a height of 50 feet (see Fig. II. 10, p.52).

In the *Tebedu unit* some terrace alluvium can be found near the main river courses. This alluvium is probably related to the 20-50 feet old terraces near the coast since they are found 20-50 feet above the present level of deposition.

The *Tebedu unit* is mainly underlain by shales which probably accounts for the homogeneity of this unit. Where an odd sadstone bed is present, its location is invariably indicated by a high ridge because of differential erosion.

(h) *The Penrissen unit* (Fig. II.17, p.70)

This unit is characterised by rock controlled mountains and ridges and by its generally high elevation (over 3,000 feet in places) above the 350 feet Early Pleistocene peneplain level. The rock types consist of consolidated Tertiary deposits, mainly sandstones and mudstones. The sandstones, being harder than the mudstones, usually cap the Tertiary formations, and cause the development of typical cuestas, mesas, hogbacks and homoclinal ridges all of which have in common a relative gently sloping to almost horizontal summit with either one or more steeply sloping flanks. Typical examples of mesas are Singghi mountain, formed as an outlier of the Matang cuesta complex, Penrissen mountain, Bukit† Simunjan and Bukit Lingga; the latter because of its small size is probably better classified as a butte. Hogbacks such as Bukit Santubong are generally of smaller size, but the Matang Range which stretches almost from the coast to the Indonesian border at Bukit Raya, can be considered as a long hogback, both sides having steep slopes. Cuesta's are dominant in the unit and form the large Bungo Range, and the Klingkang Range which follows the Indonesian border from Balai Ringin to the east. The dipslope of this range lies in Indonesia with the scarp forming the border. Generally, the larger units are complex, for instance the whole Penrissen-Bungo Range is composed of a cuesta forming the Bungo Range proper with several mesas forming the Penrissen mountain in the centre which is again surrounded by numerous smaller cuesta's, hogbacks and homoclinal ridges. The resulting topography is very rugged, being emphasized by the deep dissection which has taken place uninterruptedly since the Late-Tertiary when these formations were uplifted after folding. In these complexes evidence of

*Sungai — river

†Bukit — hill

old Early-Pleistocene erosion base levels can still be found. e.g. the outlier, Bukit Singghi, is separated from the Matang complex by a deep incision down to the 300 feet level. Within the Penrissen-Bunggo complex, the old floodplain of the headwaters of the Sungei Sarawak Kiri, Sungei Emban, lies at the 300 to 350 feet level. In this area the river attempts to establish an equilibrium with the present erosion base level existing at about 100 feet outside this complex. The river in this part of its course is still ungraded; the presence of hard sandstone beds causes the formation of falls and rapids which slow down the rate of dissection.

(i) *The Stapok and Pueh units* (Fig. II.18 and II.19, p.71 and p.72)

These units are formed by igneous rocks which, throughout the geological history up to the Late Tertiary period, have intruded and extruded into the sedimentary country rocks of varying ages. These igneous rocks, being more resistant to weathering than the softer sedimentary rocks, are now found as single isolated mountain massifs or as smaller monadnock type hills rising from the summit plains and mark the various erosion base levels dating back to the Early Pleistocene. *The Pueh unit* comprises larger areas formed by igneous massifs, while the *Stapok unit* is formed by numerous small monadnock type hills which are of much smaller extent than the massifs of the *Pueh unit*.

Examples of the *Pueh unit* are the Pueh and Gading massifs in the Lundu area and the Jagoi mountain range in the Bau area. These comprise granitic to granodioritic intrusions. Massifs in the Kuching-Serian Districts are formed by large intrusions of basaltic material forming the Gunong Sta-ang Range, the Sadong-Ampungan-Simuja mountains and several others towards the Indonesian border in the headwaters of the Kedup-Kayan river systems.

Bukit Buri-Bukit Lingga is another granitic massif in the east of the area.

Typical examples of the *Stapok unit* are Bukit Stapok at Batu Kawa Road, Bukit Stabar near Kuching Airport, and Bukits Antayan-Merbau near Balai Ringin shown in Fig. II.18 (p.71).

The *Pueh unit* rises from 200 feet to more than 5,000 feet in the Pueh massif but generally is between 2,000 and 3,000 feet in elevation. The terrain is rugged. In the massifs, most streams have cut V-shaped valleys into the mountain slopes; these 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 screes at the foot of the mountain where the streams debouch onto the low hilly terrain generally surrounding the massifs.

(j) *The Bau unit* (Fig. II.20, p.73)

The *Bau unit* formed the subject of an intensive study by Wilford and Wall (1965) to which the reader is referred for detailed geomorphological descriptions. In their study, Wilford and Wall combine the alluvial areas underlain by limestone with those forming the isolated, steepsided, rugged limestone hills and mountains. The alluvial areas have not been included in the *Bau unit* but are classified as part of the *Quop unit* (p.64).

The *Bau unit* is formed by limestone of mainly Cretaceous age. The limestone was exposed through erosion, the softer shale beds having eroded down to a much lower level than the hard limestone which is commonly crystalline in the Bau area. Wilford and Wall suggest that a form of peneplanation has probably caused the formation of the flat limestone areas surrounding the steep flanked hills. Removal of rock, mainly through dissolution of the limestone by acid rainwater and groundwater, takes place laterally rather than vertically, this in contrast with other rock types where denudation through vertical mass wasting is the dominant factor in the lowering of the land surface.

The almost vertical bedding of the strongly folded sediments in the Bau region has certainly helped to emphasize this striking difference in erodibility. The hills and mountains display typical karst features in drainage and microrelief. Pinnacles, pot holes and caves occur in abundance on and in these steep mountains, while surface streams are almost absent.

(k) *The Undup unit*

The *Undup unit* is found mainly in the extreme east of the Region and is formed by the catchment area of the Undup River. The *Undup unit* is exclusive as it cannot be easily correlated with the other units. It comprises a hilly to mountainous terrain at levels varying from 350 to over 2,000 feet and formed mainly by shales. The unit does not show the normal peneplain levels found in most of the area, neither is the contrasting topography caused by differential erosion. The hilly to mountainous terrain is strongly dissected but there is a wide valley plain formed by the River Undup within which the river is at present meandering and incising to lower levels. No levels for this former floodplain are known but it probably lies between the 50 to 100 feet level which may indicate that the river was probably graded and at equilibrium during the Mid to early Late Pleistocene.

Tebedu Unit II

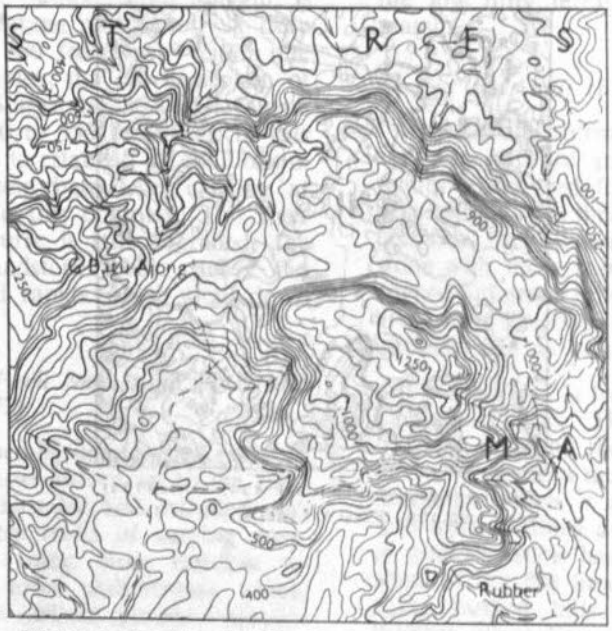
This map is derived from D.O.S. 434, (Series T735)
Scale 1:50,000. Sheet 1/110/14

Fig. II. 16b

TEBEDU UNIT II

General character	:	Comparable to Quop 'A' unit but highest levels in Quop 'A' correspond with lowest in Tebedu II. Old terrace remnants (not belonging to Lundu unit) present.
Levels	:	Valley bottoms between 150 and 100 feet. Hill summits between 250 and 150 feet.
Drainage pattern	:	As Tebedu I.
Vegetation	:	Secondary growth and settled cultivation. (rubber and pepper).

Penrissen Unit



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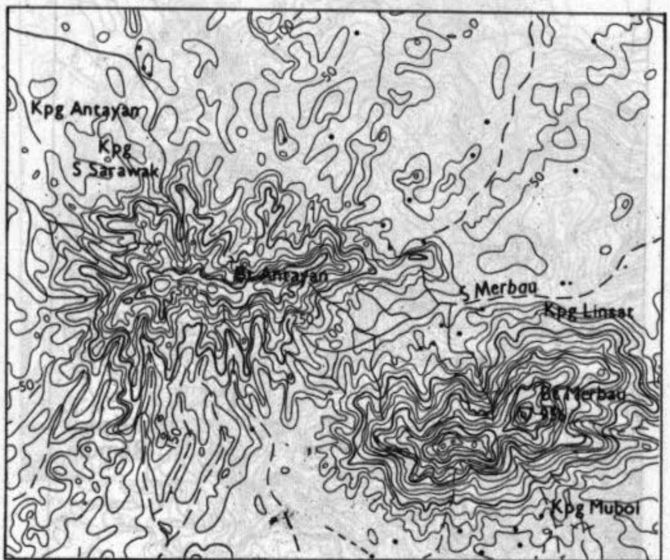
Sheet 1/110/5

Fig.II.17

PENRISSEN UNIT

General character	:	Cuesta terrain with Mesa-type outliers, hogbacks and homoclinal ridges. Gentle dipslopes alternating with steep scarpslopes. Built by tertiary sandstone.
Levels	:	Varying from 150 feet to over 2,000 feet.
Drainage pattern	:	Complex. Parallel on scarpslopes, dendritic at dipslopes.
Vegetation	:	Mainly Primary Forest. On dipslopes 'Kerangas' forest, on scarpslopes Dipterocarp forest.

Stapok Unit



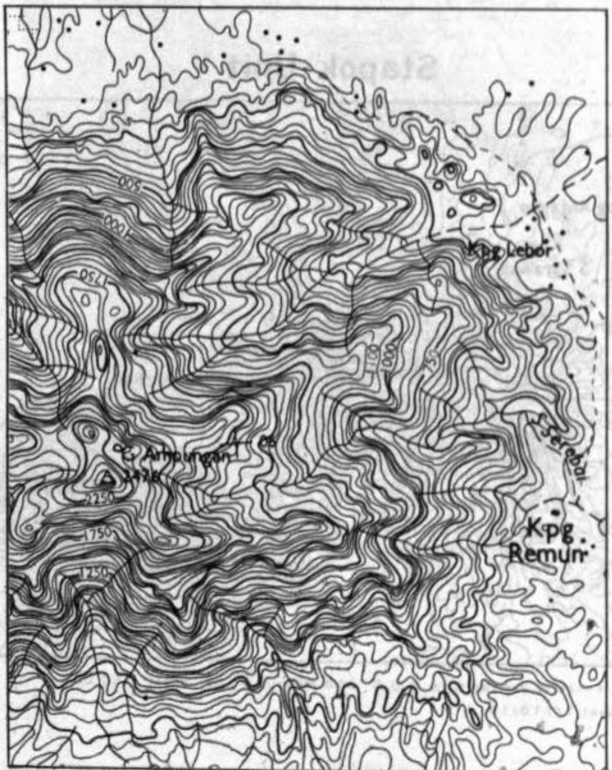
This map is derived from D.O.S. 434 '(Series T735 Scale 1:50 000.
Sheet 1/110/15

Fig II.18

STAPOK UNIT

General character	:	Monadnock type hills w th steep slopes; built of igneous rocks mainly. Surrounded generally by Quop or Tebedu units.
Levels	:	Varying. Hill summits of ± 500, 800 and 1,000 feet are most common. Generally a break in slope between 250 to 150 feet.
Drainage	:	Radial.
Vegetation	:	Secondary growth and Primary Forest. (Dipterocarp).

Pueh Unit



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

Fig. II.19

PUEH UNIT

General character	:	Steeply sloping mountainous terrain, built of igneous rocks mainly.
Levels	:	Varying, but height of summits generally at ± 1,000, 2,400 and 3,000 feet. Generally a break in slope at levels 250 to 150 feet.
Drainage pattern	:	Parallel with radial tendencies in some localities.
Vegetation	:	Mainly Primary Forest. (Dipterocarp) On basalts largely secondary growth. (shifting cultivation).

Bau Unit

This map is derived from D.O.S. 434, (Series T735)
Scale 1:50,000. Sheet 1/110/9

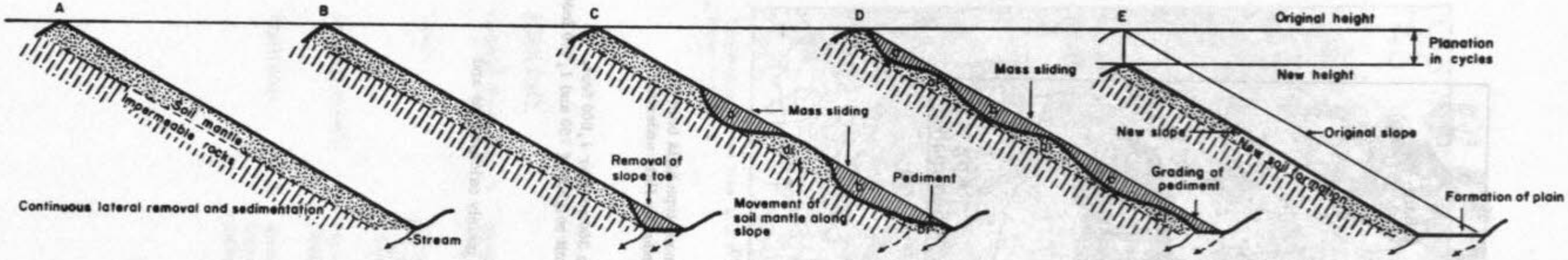
Fig.II.20

BAU UNIT

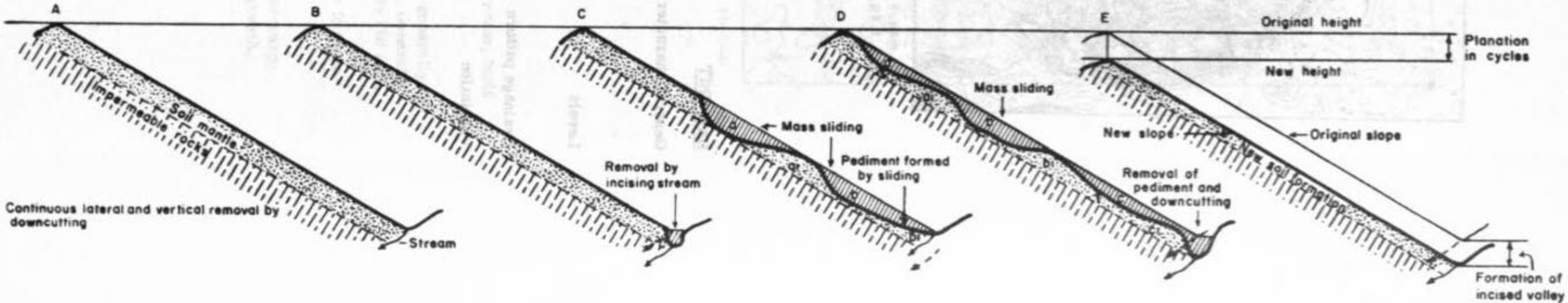
General character	:	Steep sided monadnock type hills built by limestone, surrounded by flats underlain by limestone.
Levels	:	Height varies from 350 to over 1,000 feet. Common are summit heights of 750 and 1,000 feet.
Drainage pattern	:	Karst unit.
Vegetation	:	Primary Forest - mainly calciphylous and calcifugal.

Fig.II. 21

I. Parallel Slope Retreat through Mass-Sliding and Removal by Stream at Local Base Level



2. Parallel Slope Retreat through Mass-Sliding and Removal by Incising Stream



There is ample evidence in this unit to suggest a rejuvenation of the landscape since the Mid-Pleistocene. Many rapids have formed in the once graded Undup plain and the river has cut down into its own deposits to at least 20 feet. Only in the upstream areas is the river almost at the same level with its banks. Haile (1954, p.100) suggests that the Batang Lupar valley has been slightly down-warped relative to the adjacent areas in the north and south, and this may partly explain this rejuvenation. Another cause may be the existence of hard sandstone beds in the predominantly shale country which may have built up barriers lower downstream (e.g. the Temudok Range). These barriers may have prevented rejuvenation of the middle course of the Undup which became graded and a floodplain was formed until this barrier had been sufficiently downgraded to allow rejuvenation to proceed stream-upward. Other evidence is provided by a strong suggestion of a river capture after the downgrading of the Temudok Range. The pre-Undup course probably discharged into the present Entulang river flowing to the west and south of Bukit Temudok.

4. Erosion and Deposition

Erosion is discussed under the heading Physiography, since although the Climate, and particularly rainfall, may be considered the most effective agent in causing erosion, directly and indirectly, the landscape on which erosive forces are active has a great bearing on the effectiveness of these forces. The underlying rock formations may also have a great influence on the way erosion is modifying the landscape. This is particularly the case in West Sarawak where the interplay of rainfall and rock formations are largely responsible for the shaping of the present landscape. In West Sarawak the three most important forms of erosion are surface erosion, riverine erosion and coastal erosion. Other types of erosion which may occur elsewhere in Sarawak are of no significnce in the Region.

(a) Surface Erosion

By surface erosion is meant the downslope movement of soil and associated bedrock. This may be effected by what is called soil-creep involving slow displacement of soil particles along slopes under control of gravity, and landslides involving mass movements of soil along slopes. Solifluction, earth and mudflows are also processes of downslope erosion but are considered to be of little importance in West Sarawak.

All these surface erosion processes are controlled by gravity and therefore operate on sloping land, their intensity increasing with increasing steepness of the land.

The percolation rate and the amount of surface runoff depend on the porosity of the soil and the permeability of the underlying bedrock. A high percolation rate leaves little as runoff. When the soil reaches its highest water absorption rate or saturation point then the excess water will form runoff. However, excess rainwater reaching the ground is in its turn related to the vegetative cover which through evaporation, absorption and adsorption may retain a considerable amount of the total rainfall and with small showers very little rainfall may reach the ground.

In other countries, the direct impact of a heavy shower on a dry soil causes structural breakdown and sealing of the surface soil so that most water reaching the soil will be carried away as runoff water. However, most West Sarawak upland soils are covered with a dense vegetation which prevents direct impact of the rain on the soil surface.

With a high rate of run-off sheet erosion and gully erosion are among the most destructive forces causing denudation and dissection of a landscape. Because of the very dense forest cover in West Sarawak and the presence of a thin humus layer such forms of erosion are here of very little importance. Some observations on the amount of surface erosion were made in hill padi farms and pepper farms where soil is deprived of a forest cover for some time. In a hill padi farm on a slope of about 25 degrees sheet erosion appeared to be negligible. This is probably due to the cover of weeds and rice plants on the land surface so that any displacement of soil is halted by the closely spaced stems of this vegetative cover. In pepper farms which are almost bare, sheet erosion and gully erosion may be more severe, depending on the slope and soil type. Observations in pepper farms on a Tarat Family soil of the Lateritic Group with a slope of about 20 degrees, showed that within a 5-year period very little soil was removed because of the comparatively stable aggregates of these Lateritic soils. However, some sheet erosion was evident.

These observations are corroborated by erosion studies in the Philippines where under almost similar conditions the soil losses in a shifting cultivation cycle are considered to be very low. (pers. comm. McTaggart, 1969)

There are other significant indications that sheet erosion caused by run-off in Sarawak under the present conditions is not considered to be severe. Narrow inland valleys which are covered by deep peat deposits accumulated during the last 5,000 years or so, and which are surrounded by steeply sloping hills do not have any appreciable amount of mineral matter in the peat. There are also no mineral layers in the peat or topping it. One may, therefore, conclude that there has been very little soil removal by sheet erosion during the time the peat was formed.

Also, West Sarawak rivers appear to contain little sediment as compared with rivers in regions with another type of climate and vegetation.

One may ask: If sheet-wash cannot have caused the strong dissection observed in most of the uplands of West Sarawak, what process is then involved?

There are two possibilities, namely surface creep or landslides and land slumping. Holmes (1965, p.501) states that surface creep is the dominant process in surface erosion in conditions where a thick soil cover is effectively protected by vegetation. This process favours a slope retreat with declining angle. As can be observed in West Sarawak most slopes are showing a parallel retreat which means that denudation of the landscape is caused by lateral removal of hills in which the slopes are kept parallel while the summits remain for a long period at their original height which is lowered in stages. A slope retreat with declining angle shows a rapid but continuing lowering of the summit while the slopes become increasingly more gentle. Little or no surface creep therefore appears to be involved. Holmes further indicates that this is quite possible in tropical regions with exceptional high rainfall and which have an underlying bedrock with an unfavourable infiltration rate. Such conditions are particularly prevalent in West Sarawak where impermeable shale and hard igneous rocks lower the infiltration rate considerably. By inference one may therefore conclude that landslides and slumps are probably the dominant processes responsible for surface erosion. This is also borne out by the facts. In hill padi areas where the cover is removed, slumping is very much in evidence. This can also be seen clearly on air photographs of areas with a dense forest cover where the numerous landslides and slumps are observable as small white streaks. These slumps occur in series and as many as 5 can be counted from the bottom to the summit of a hill. Fig. II.21 (p.74) illustrates how such slumps develop and what the resulting landscape looks like. Most slumps are controlled by bedding or cleavage planes of sedimentary rocks such as shales of which the dip may vary from 15 degrees to almost vertical.

At times of heavy rainfall the soil mass overlying the strongly weathered shale becomes saturated with water, the saturation process being enhanced by the vegetative cover and humus so that the topsoils are not sealed-off. This saturated soil mass slides down over the slippery surface of the impermeable weathered shale. The rate of slump is governed by the degree of slope so that on gentle slopes masses may be replaced over short distances while on steep slopes this may be much greater and the slump may attain the magnitude of a landslide. Baillie (pers. comm., 1970) suggests that the weight of the vegetative cover may also contribute to this. The slump leaves at the upper slope margin a steeply inclined surface which accelerates further slumping of the upper slope areas. At the lower end of the slump the slopes are levelled off. Slumps reaching the bottom of the slope are eroded away by small streams if they are present there, until these bottom ends are sufficiently steepened again to cause further slumping down and the whole process of slumping from bottom to summit is repeated. Throughout this process the slopes remain parallel during their retreat, but in each cycle the summit is lowered. The magnitude of dissection is maintained until the summits have reached local erosion base level. This may explain the homogenous dissection in most shale country in which, although the amplitude of relief may vary from 20 to 350 feet the degree of slope remains very constant.

Although slumping of slopes may occur mainly during periods of high rainfall, the removal of material at the bottom slope is a constant process. This process also explains why very little sediment is found in the peat valleys described earlier, because the bulk of the material is moved by a small stream present at a foot slope. Where a stream is absent a sort of pediment is formed at the foot hill until a meandering stream reaches this pediment and removes it. The slumping process may be interrupted if the pediment is not removed, since stability of the slope is then temporarily maintained.

Footslopes may be steep when they are bordered by a stream, but gentle if they are bordered by a pediment. The middle slopes may be broken by the numerous slumps. Small springs developed along impervious layers may contribute to the formation of gullies and are often responsible for the headward development of rivers into a ridge.

The erosion process just described is operative in most shale country, or in areas where sandstone and shale are interbedded if the cleavage or bedding planes of those rocks are strongly dipping. In areas where these are absent, however, slumps do not occur to such an extent as has been described although some sagging is noticeable on steep slopes. Areas with more or less horizontally bedded rock formations show cuesta features and sheet-wash or surface erosion predominates along the gentle dipslope while landslides occur at the strongly sloping scarp. Mass removal takes place mainly at the scarps, and therefore dipslope soils tend to be much more developed than those found at scarp slopes.

Plate 5.
Hills in the Quop A unit showing parallel slope retreat due to slipping and sliding of soil masses.

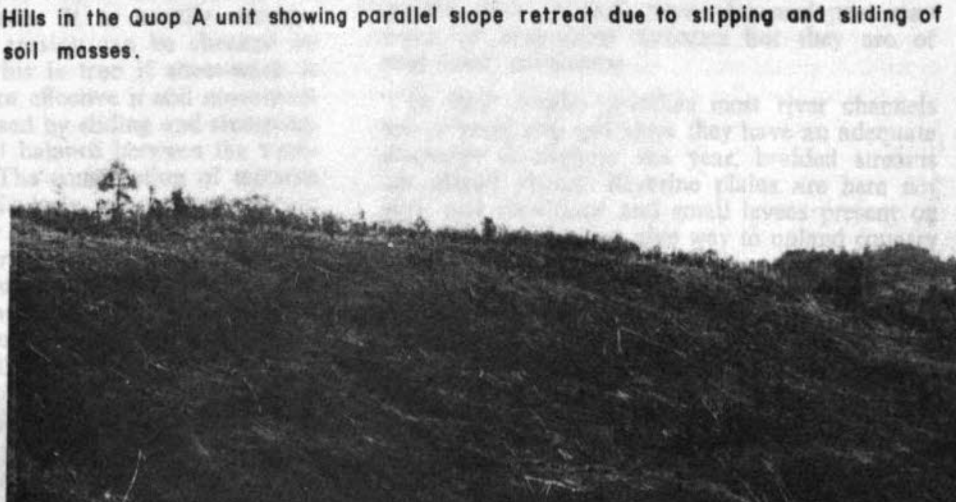


Plate 6.
Close view of slips developing on a steep slope.

Plate 7

Hill padi farm showing formotion of gullies and landslips. Tertiary sandstone. Tebedu I unit (200 – 350 feet summit plain). Nyalau family (RED-YELLOW PODZOLIC SOILS). 8½ miles Bau–Lundu road.

Plate 8

Typical hay-stack hills formed by limestone in the Bau area. Meluan Family (SKELETAL SOILS).

Surface erosion on the igneous rocks shows almost similar features as those found in shale country. The soil masses when saturated with water slide down over a slip-plane provided by the hard and impenetrable igneous rocks. Since the igneous rocks weather slowly compared with the generally soft shale, denudation is taking place at a lower pace than on the shale country. For this reason, the many monadnock type hills of the *Stapok unit* (p.71) have developed. It may be asumed that both the igneous and sedimentary rocks were probably at much the same height but the former are now protruding from the present landscape. (See Fig. II.22, p.83).

In West Sarawak, sheet wash erosion is probably most evident in the *Pueh unit* which is composed of high, steeply sloping granitic massifs on which sandy soils have developed. Despite the dense vegetation cover, the light textured soils with poorly developed structure are more easily washed on steep slopes. The same can be said for the rugged part of the *Penrissen unit* built by poorly consolidated sandstones.

The observation that surface erosion in the largest part of the uplands is dominantly caused by slumping, sliding and removal of soil-rock debris at the lower slope by river channels, has agricultural significance. It is usually recommended that surface erosion can be checked by terracing. However, this is true if sheet-wash is concerned, but it is not effective if soil movement down the slope is caused by sliding and slumping. There exists a natural balance between the topography and climate. The construction of terraces on steep slopes, particularly where the soils are shallow, may enhance sliding and slumping rather than curb them. If agriculture on steep slopes has to be practised it would probable be best not to interfere with this natural balance, but to plant perennial crops without terracing. If clean cultivation without much soil cover is practised, terraces would then be necessary to prevent the formation of gullies and sheet erosion. As a rule, such clean cultivation should not be practised on steep slopes. It is often argued whether perennial cultivation should be allowed on steep slopes in shale country or not. Detailed field examinations indicate that as long as the natural slope balance is not disturbed and where the cover can be quickly restored, there is very little reason why this form of cultivation should not be practised on shale country. The drawbacks will be mainly of an economic and physical nature.

(b) Riverine Erosion

Although riverine erosion shows many aspects, in this section the discussion is restricted to only those of dominant importance in West Sarawak as far as soil development is concerned.

Most rivers in their lower stretches meander in their own deposits (p.60). The meandering rivers erode the outer bends which are frequently undercut and which may cave in at times of high floods. Deposition takes place at the inner bends which are extended into the river channels. In this way riverine deposits are removed on one side while new material is deposited on the other. This process continues until the outer bend has reached the deep peat deposits developed in the interfluvial basins. As the peat is more stable than the soft riverine deposits, it is able to resist the river encroachment and the river subsequently alters its course with renewed deposition taking place at the former outer bend and erosion at the former inner bend. During this process these bends are probably migrating towards the coast but vertical erosion (deepening of the stream channel) is thought to be minimal since most rivers are tidal in these stretches and have already reached local base level. It is suggested that in this process little new sediment is added and that much of the eroded sediment is redeposited slightly lower downstream. Floods which may recur every year in the wet season may deposit fresh material on the levees on both banks of the river and where the river channel has reached the peat of the interfluvial basin mineral soil may be deposited on this peat. In such areas clay and peat may occur as alternating horizons but they are of very local occurrence.

In their middle stretches most river channels are of small size and since they have an adequate discharge throughout the year, braided streams are almost absent. Riverine plains are here not very well developed and small levees present on both sides of the river give way to upland country at short distances from the river. Although the river may still meander, this is in most cases controlled by bedrock exposed at the river bends. Lateral erosion of river banks takes place mainly during the wet season when the river is at its bank full discharge capacity.

In the upper stream areas where most rivers still show signs of meandering, rivers are still ungraded and continue to incise. Very little deposition takes place in these areas and the process is one of continuous down cutting and removal while the channels are widened side ways through lateral erosion of country rock.

Summarizing, the different parts of the drainage basins show the following types of riverine erosion:

(i) In the lower stretches: lateral erosion of river banks and levees, and deposition take place simultaneously and continuously. Vertical erosion does not take place, the rivers are graded in this part of their courses.

(ii) In the middle stretches: lateral erosion of river banks takes place during times of high floods. During such periods some deposition may also occur. Vertical erosion of river beds through a downgrading process is not important.

(iii) In the upper stretches: vertical erosion causes deeper incision of the river channel and lateral erosion widens the river bed. No deposition takes places and levees are almost absent.

These three parts are well illustrated by the distribution of soils as depicted on the soil maps.

(c) **Coastal Erosion**

Coastal erosion is much in evidence between the estuaries of the Batang Sadong and of the Batang Lupar. Large tracts of coastal land between the mouth of the Batang Lupar to Muara* Sampun in the Nonok Peninsula have been eroded as evidenced by the exposure of deep peat along this part of the coast. Air photographs taken in 1947 and 1963 reveal that rapid erosion is taking place at this part of the coast (Andriesse, 1964b). This erosion is probably caused by an interplay of strong currents and tidal movements. West of Sungai Sampun in the Nonok Peninsula, erosion is giving way to accretion which is much in evidence for the remainder of the coast line up to Tanjong Datu. Between Santubong and Tanjong Datu the coast is mainly formed by coastal sand ridges (p.59) which in some places show accretion while in other places they are being eroded. Along this coastal stretch, tidal currents at the mouths of many rivers have a strong influence on the local sedimentation process. Sand banks built up rapidly, particularly at the estuaries of the Lundu and Sematan rivers, and the resulting change in coastal currents may locally influence erosion and accretion. The overall impression is, however, that the coastline from Tanjong Datu to Nonok is quite stable but from Nonok to the Batang Lupar, it is subjected to active marine erosion. Local subsidence of this area as a possible contributory factor to marine erosion in this coastal stretch cannot be ruled out.

5. Drainage and Flooding

(a) **Drainage**

The Region comprises the drainage basins of Sungei Samunsam, Sungei Sematan, Batang Kayan, Batang Sarawak, Batang Samarahan, Batang Sadong and the western half of the Batang Lupar.

*Muara — river mouth

Most drainage basins can be subdivided into three parts, namely:

(i) The lower parts which are characterised by large interfluvial basins and incipient levees which grade into deltaic or estuarine flats.

(ii) The middle parts which are characterised by a great number of small interior valleys converging to the main river, and uplands mainly below the 200 feet level.

(iii) The upper parts which consist dominantly of generally strongly dissected or rugged uplands above a level of 200 feet.

Since drainage patterns are shown and defined in Fig. II.11 to 20 (pp.57, 58, 61, 62, 65, 66, 69, 70, 71, 72, 73) no more attentions will be given to these.

(i) Most rivers in these parts are graded and flow sluggishly for most of the year. The rivers are wide-channeled probably as a result of the scouring effect of strong tidal currents and are tidal up to their middle courses. Large tributaries are comparatively few; these drain sections of the middle and upper parts of the basins. Smaller tributaries draining the interfluvial peat basins occur in multitude.

(ii) River courses in the middle part of the drainage basins are narrow, and deep with steep banks occurring at outer beds of meanders. A great many tributaries of tertiary importance occur in this part of the drainage basin. Many of them flow through narrow interior valleys which are flanked by steeply sloping hills drained by many ephemeral streams ending in gullies. These are frequently fed by small artesian wells.

(iii) The upper part of the drainage basins have narrow, deeply incised rivers with shallow water during the dryer part of the year. Braiding may occur in some places. Embankments are not very well developed, steeply sloping hills rising up straight from the river beds. The streams are ungraded unless a bed of hard rock crosses the river so that downgrading of part of the upper stream area to the level of this bed has occurred. Small waterfalls, rapids and cascades may occur in the upper stream areas. The tributaries are many but small. They are formed by gully-like streams carrying water in some magnitude only after rain and then for short periods. Many of them are fed by artesian wells which maintain a small trickle of water during the dry periods.

Plate 9

Typical ungraded mountain stream in basic igneous massif used for domestic water supply by local inhabitants.

Plate 10

Lateral erosion of riverbanks during floods in the wet season in the middle reaches of main rivercourses.
The Sarawak Kanan river opposite Siniawan bazaar.

The uplands of the middle and upper parts of the basins are supplied with a well-developed drainage system, so that in these areas drainage is rapidly effected. The alluvial areas in the middle part of the drainage basins frequently lack adequate drainage, particularly during the wet season.

This is mainly caused by the disparity in gradient. The upper parts of the drainage basins are largely still ungraded and drainage is rapidly effected. The middle and lower parts are more or less graded and receive too much water in too short a time. This situation is aggravated by the tidal influence in the lower reaches of the river courses in which during high tide periods drainage may stop altogether.

(b) **Flooding**

Flooding in West Sarawak occurs irregularly but mainly during the northeast monsoon period from December to February. Outside this period some flush flooding may occur in upper catchment areas due to local thunderstorms of high intensity but they are of short duration and have a localised effect. Although in such 'bandjir' like floods erosion of river banks may occur, damage to crops, livestock or property is never severe. Floods during the northeast monsoon are of two kinds:

(i) If part of the main river catchment receives continuous rainfall over a prolonged periods, flush flooding of interior valleys in that part of the catchment area may occur. Since the main stream does not reach its bank-full discharge capacity such flood waters can be carried away within relatively short time, depending on the rainfall in the affected area. The effect of this short but intensive flooding may create much damage to crops. Particularly wet rice land in the interior is prone to this kind of flood, and a total loss of the crop may occur. However, little can be done to minimise this type of flooding since it is caused by a combination of climatic and topographic factors. One can no doubt improve the natural drainage capacity by deepening small river channels and clearing them of woody debris, but this is an expensive undertaking and must be repeated regularly since the channels silt up rapidly. Moreover, the many small bends in the small rivers which would need straightening will form again unless concrete embankments are erected. Fortunately, these floods occur infrequently and not necessarily always affect the same area.

(ii) The second type of flooding which is more serious is caused by continuous and prolonged heavy rain over the whole catchment area of a main river so that the main river reaches its bank-full discharge capacity. Since most rivers have little gradient from their middle reaches to their estuaries and the tidal influence extends far upstream, the flood waters are backed up and some drainage is only effected during periods of low tide. This situation of back flooding is aggravated when it coincides with king tide. Backing up of flood waters means in fact a raising of the local base level in the secondary and tertiary stream areas and impedes drainage even in the upper parts of a catchment area. If the rain still continues when this situation is reached, then severe flooding can occur in all the main and minor valleys. This 'backflooding' may recur several times in one wet season but it may be absent for several years. This is caused by the irregularity in rainfall which has been discussed under 'Climate' in Chapter 3 (p.25). Catchment areas which are most affected are those of the Lundu-Kayan river, the Batang Sarawak Kanan, the Batang Samarahan and the Batang Sadong.

Severe backflooding affecting the major drainage areas are difficult to remedy and the costs required to stop the floods would not be justified. Reforestation of some upland areas may help, but it appears that even in densely forested areas this type of flooding can be as severe as in areas under shifting cultivation. In the interior valleys, the hazard of backflooding is a serious limitation to crop growth. It prevents the growing of perennial crops sensitive to floods lasting more than 3 days, and while many of these valleys are suited to wet rice growing, this irregular and impredictable flooding makes this cultivation risky.

Backflooding, however, has its beneficial effect in that it enriches the top soils of the affected valleys with fresh sediments. This may be one of the reasons why wet rice can be grown continuously in these areas without fertilizers and with relatively good results.

Fig. II 22
Differential denudation caused by hardness of rocks.

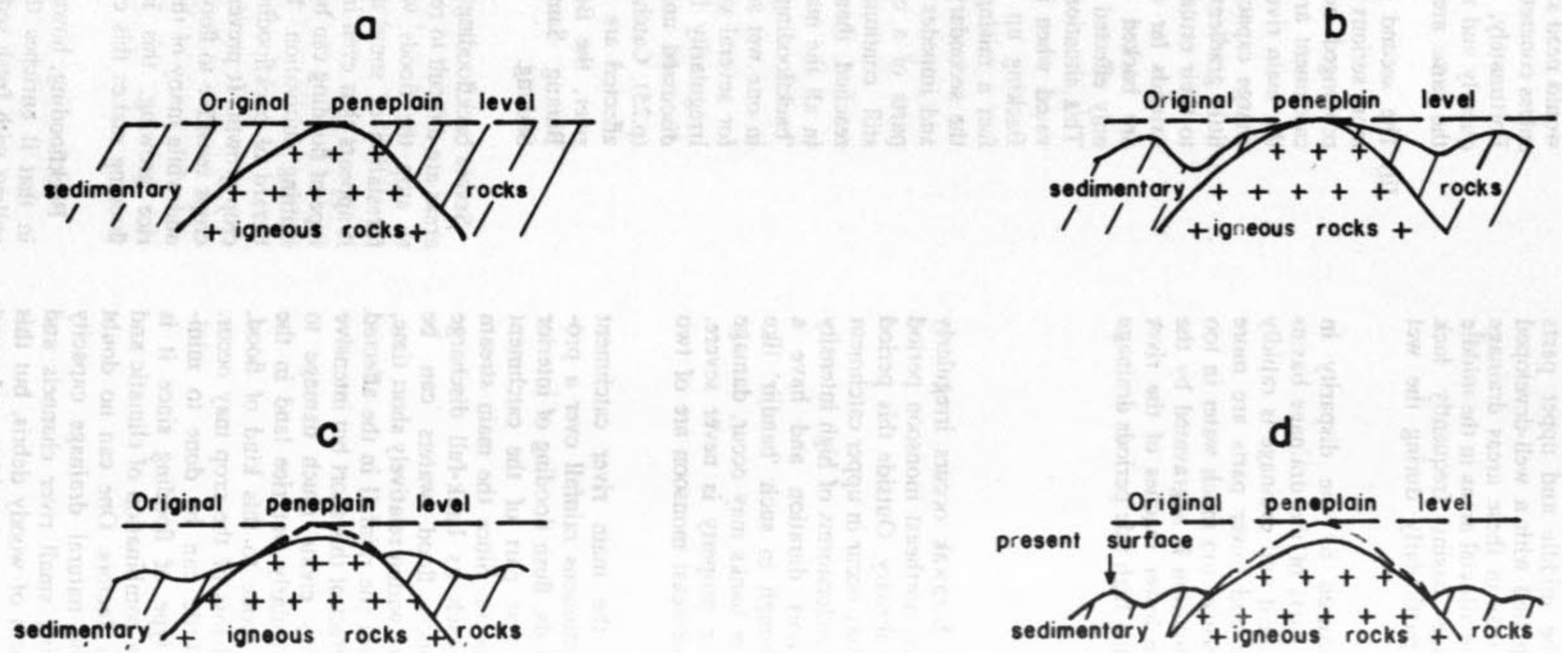


Table 11

Type and areal extent of Soil Parent Materials in West Sarawak

MAIN TYPE	Subtype	extent in sq. miles	Percentage of Region	
IGNEOUS ROCKS	Basic to intermediate igneous rocks and related metamorphic rocks	163	3.7	10.2
	Intermediate to acid igneous rocks and related metamorphic rocktypes including arkose	284	6.5	
SEDIMENTARY ROCKS	Argillaceous rocks (shales, phyllites and mudstones)	860	19.6	45.5
	Arenaceous rocks (coarse to fine grained sandstone, conglomerates, chert. Pleistocene deposits.	1096	25	
	Limestone	35	0.8	
	Riverine alluvium (fine to coarse textured)	459	10.4	
RECENT DEPOSITS	Marine alluvium (including deltaic and estuarine deposits)	308	7	44.4
	Organic deposits (peats)	1172	27	
	TOTAL	4377	100	100

Table 12: Composition and Norm of Gabbro, Adamellite, and Microtonalite

Rock Type	Gabbro	Adame te	amellite
Specimen Number	S6820	S28	S7285
Locality	Bukit Gebon	near Tan ong tu	Mile $1\frac{1}{2}$ u Se ayan Road
SiO_2	49.58	68 80	1.07
TiO_2	0.30	0 58	0.55
Al_2O_3	18.88	14.81	13 61
Fe_2O_3	0.8	0.56	0.62
FeO	4 9	4.03	3.29
MnO	0.12	0.08	0.08
MgO	8 9	1.41	1.06
CaO	14 0	2.32	2 32
Na_2O	2 0	1.96	2.64
K_2O	0.1	3.4	3 34
H_2O+	0 61	1.58	1 05
H_2O-	0.	0 23	06
CO_2	n.d	Nil	06
P_2O_5	Nil	0 13	0 13
ZrO_2	n.d	Nil	0.02
F	n.d	trac	n.d.
BaO	n.d.	trac	n.d.
S	n.d.	0.0	n.d.
Cl	n.d.	.05	n.d.
Less O=F+Cl+S	-	0.02	-
Total	99.97	100.04	99.90

C.I.P.W. NORM

Quartz	-	34.9	34.4
Orthoclase	0.6	20.6	20.0
Albite	17.8	16.2	21 5
Anorthite	41.7	10.6	10.6
Corundum	-	3.9	1 6
Diopside ($CaSiO_3$	12.1	-	-
Diopside ($MgSiO_3$	8.0	-	-
Diopside ($FeSiO_3$	3.2	-	-
Hypersthene ($MgSiO_3$	4.1	3 5	2.4
Hypersthene $FeSiO_3$	1.6	6.1	4 7
Olivine (Mg_2SiO_4	6.0	-	-
Olivine (Fe_2SiO_4	2.6	-	-
Magnetite	1.2	0 9	0.9
Ilmenite	0.6	1.1	1.1
Apatite	-	0.3	0.3
Halite	-	0.1	-
Total	99.5	98.2	97.5

Analysts: W.A. Tooke, Geological Su ey Depart ent, Federation of Malaya (S28); Mineral Resources Division (S6820 and S7285).

Ref: Wolfen and Haile, 1963, p.83.

n.d. - not determined

Table 13: Compositions and Norms of Serian Volcanic Formation Andesitic and Basaltic Lavas

Rock type		Andesites				Basalts	
Specimen number		S227	S8220	S11294	S11295	S11576	S11601
Locality		Mile $27\frac{3}{4}$, Simanggang Road	Sungai Baki near Bunga	North of Gunong Selabor	North of Gunong Selabor	Sungai Idi near Mapu	Sungai Paku near Mapu
SiO_2		54.1	50.5	51.6	55.8	50.9	53.4
Al_2O_3		14.8	16.7	13.8	13.0	16.6	15.9
Fe_2O_3		4.20	1.22	3.20	2.05	2.20	1.50
FeO		2.50	8.35	6.60	9.90	6.30	6.45
MgO		5.00	5.55	6.40	2.70	6.40	5.75
CaO		7.60	8.20	8.55	5.15	9.80	9.55
Na_2O		3.25	3.30	2.40	3.95	2.75	2.41
K_2O		1.25	1.45	2.30	1.13	0.82	0.98
H_2O^-		2.85	0.13	0.50	0.24	0.18	0.19
H_2O^+		2.15	2.70	2.20	2.75	2.40	2.17
CO_2		0.08	0.10	0.14	0.24	0.21	0.36
TiO_2		1.44	1.38	1.76	2.30	0.95	0.87
P_2O_5		0.66	0.22	2.26	0.40	0.18	0.13
MnO		0.07	0.15	-	0.21	0.18	0.15
S		0.04	-	-	-	-	-
Total		99.99	99.9	99.8	99.8	99.9	99.8
				C.I.P.W. NORM			
Quartz		11.22	-	3.36	10.80	1.44	6.48
Orthoclase		7.23	8.90	13.34	6.67	5.00	6.12
Albite		27.25	27.77	20.44	33.54	23.58	20.44
Anorthite		22.24	26.41	20.02	14.18	30.30	29.47
Diopside	($CaSiO_3$	4.64	5.34	8.35	3.02	6.73	6.26
	($MgSiO_3$	12.50	2.80	5.50	1.00	4.20	3.60
	$FeSiO_3$	-	2.38	2.24	2.11	2.11	2.38
Hypersthene	($MgSiO_3$	-	7.10	10.50	5.70	11.80	10.80
	($FeSiO_3$	-	4.88	4.36	10.96	6.34	7.13
Hypersthene	(Mg_2SiO_4	-	2.80	-	-	-	-
	(Fe_2SiO_4	-	3.65	-	-	-	-
Magnetite		3.94	1.86	4.46	4.64	3.25	2.09
Ilmenite		2.74	2.74	3.34	4.41	1.82	1.67
Haematite		1.44	-	-	-	-	-
Apatite		1.68	0.34	0.67	1.01	0.34	0.34
Calcite		1.00	0.20	0.30	0.60	0.50	0.80
Water		5.00	2.83	2.70	2.99	2.58	2.36
Total		100.88	100.00	99.76	100.01	99.99	99.94

Analyses by Australian Mineral Development Laboratories

Ref: Wilford, 1965, p. 37.

Table 14: Composition and Norm of Rocks from the Semabang Member of the Serian Volcanic Formation

Rock Type	Rhyolite tuff	Dacite
Specimen number	S11897	S11810
Locality	Gunong Ramungan	Mujat
SiO_2	75.78	63.74
TiO_2	0.37	1.95
Al_2O_3	11.83	13.35
Fe_2O_3	1.19	0.70
FeO	2.59	5.90
MnO	0.35	0.37
MgO	1.19	1.88
CaO	nil	3.47
Na_2O	0.32	5.22
K_2O	3.54	2.21
H_2O+	2.39	1.10
H_2O-	0.13	0.24
CO_2	0.11	nil
P_2O_5	0.13	0.32
Total	99.92	100.45

C.I.P.W. Norm

		Rhyolite tuff	Dacite
Quartz		56.0	13.90
Orthoclase		20.9	13.10
Albite		2.7	44.10
Anorthite		-	6.30
Corundum		7.5	nil
Diopside	($CaSiO_3$	-	3.70
	($MgSiO_3$	-	1.40
	($FeSiO_3$	-	2.30
Hypersthene	($MgSiO_3$	3.0	3.30
	(FeSiO	3.8	5.40
Magnetite		1.7	1.00
Ilmenite		0.7	3.70
Apatite		0.1	0.80
Phosphorus pentoxide		-	-
Water + carbon dioxide		2.63	-
Water		-	1.34
Total		99.93	100.34

Analysis by: A.W. Dye Pty Ltd. Australia

Ref: Pimm, 1965, p.56.

Table 15: Analyses of Arkose from the Serin Arkose Member of the Sadong Formation

Specimen Number	S13131	S13201
Locality	Sungai Sebengkong	Sungai Tarat
SiO_2	64.1	67.9
TiO_2	0.52	0.55
Al_2O_3	14.1	14.5
Fe_2O_3	0.55	1.63
FeO	3.60	2.65
MnO	0.06	0.07
MgO	1.74	1.59
CaO	5.00	1.38
Na_2O	3.55	3.05
K_2O	2.45	2.65
H_2O+	2.15	2.65
H_2O-	0.20	0.78
CO_2	1.67	0.37
P_2O_5	0.13	0.09
Total	99.8	99.9

C.I.P.W. Norm

Quartz	23.50	32.76
Orthoclase	14.46	15.57
Albite	29.87	29.87
Anorthite	13.34	3.34
Corundum	0.71	4.59
Hypersthene ($MgSiO_3$	4.30	4.00
($FeSiO_3$	5.41	2.64
Magnetite	0.70	1.52
Ilmenite	0.91	1.06
Apatite	0.34	0.34
Calcite	3.80	0.80
Water	2.35	3.43
Total	99.65	99.92

Analysts: Australian Mineral Development Laboratories

Ref: Pimm, 1965, p. 39.

Chapter 5. GEOLOGY AND PARENT MATERIALS

1. Sources of Information

The whole Region was geologically surveyed in the period 1949-57 by the Geological Survey Department, British Territories in Borneo (now Geological Survey, Borneo Region, Malaysia). Reconnaissance information on the geology of the Region was compiled by Haile (1954), Wilford (1955) and Haile (1957). Geological surveys at a semi-detailed level were subsequently carried out in the western portion of the Region. This information was published by Wolfenden and Haile (1963), Wilford and Kho (1965), and Pimm (1965). The former surveys were published at a scale 1:125,000 while the latter were based on the 1:50,000 scale topographic series (T735). More detailed investigations on the mining area in Bau were published by Wolfenden (1965) and Pimm (1967) but these are pedologically of less interest.

Information in this section has been largely obtained from referred to sources and no further reference will be made to these unless this will be necesary in specific cases.

The geology of West Sarawak is complex. Although many rock types occur, most are too local and minor in significance for the Region as a whole and hence they cannot all be described in detail. For purposes of the memoir, the geology of the area has been simplified, and the rock formations have been evaluated on their pedological significance. This has resulted in the compilation of supplementary map 5 (Vol. II), which shows the geology of the Region in terms of parent material of soils. Table 11 (p.84) shows the relative importance of the various rock types as soil parent materials in the Region.

2. Igneous Rocks

Igneous rocks comprise approximately 10.2% of the Region; basic to intermediate igneous rock types form 3.7%, while the more acid igneous rock types to which have been added arkose and metamorphic rock types of similar chemical composition, comprise 6.5% of the Region. Examples of the composition of the most common igneous rock types of pedological significance are given in Tables 12-15 (pp.85, 86, 87, 88).

(a) Basic Igneous Rocks

Basic igneous rocks are found in small areas in the Lundu-Sematan area where they are composed of pyroxene andesite lava (at Sematan) on which bauxite has formed, basic lava and tuffite within the Serabang Formation occurring near Tanjong Datu, gabbro and hybridised gabbro (Table 12, p.85) at Bukit Gedong (west of Gading mountain) and in an area north and northeast of Bukit Gading. Included are a series of metamorphosed basic igneous rocks comprising amphibolite, pyroxenite, peridotite, greenstones and associated rocks. The latter occur as small outcrops and are not shown on the map. Basic igneous rocks in the Kuching Rural Upper and Lower Sadong Districts (middle portion of the Region) belong mainly to the Serian Volcanic Formation of Upper Triassic age in which non-porphyritic andesite (Table 13, p.86) appears to be the most common rock type. Most of these rock types were probably extruded beneath the sea and have been altered in varying degree through hydrothermal activity.

In some places these volcanic rock types are interbedded with Triassic sediments of the Sadong Formation. In the extreme east of the Region a small outcrop of basalt, basalt agglomerate and associated rocks are found. These rocks were probably formed subaerially and are porphyritic in nature.

Basic rock types mapped near the coast between Kuala Lupar and Kuala Sadong comprise silicified volcanic rock types. Wolfenden (1963, p.4) indicates that they are probably of cretaceous age. They have been named the Sebangan Hornstone Formation (Haile, 1954, p.21).

The basic to intermediate rocks and associated metamorphosed rock types have in common a high ferro-magnesium content and this has given rise to the development of soils belonging to the LATERITIC SOIL GROUP which is found exclusively on these rock types. Difference in chemical and textural composition are responsible for the differentiation of soils within this group.

(b) Acid Igneous Rocks

Acid igneous rocks in the Lundu area consist mainly of medium to coarse-grained biotite adamellite (Table 12, p.85) and associated rocks of Upper-Cretaceous age, while those in the Bau area consist of a larger stock of coarse to medium-grained granodiorite of pre-Cretaceous age forming the Jagoi and Kisam ranges, and a series of small outcrops of microgranodiorite, dacite, microtonalite and quartz andesite of Tertiary age.

The acid igneous rocks in the Kuching Rural and Upper Sadong Districts are composed of the more acid members of the Serian Volcanic Formation, namely the Semabang Trachyte Member comprising trachyte, rhyolite to dacite, acid-tuff, acid-breccia and lappili-tuff (Table 14, p.87) and a large area of arkose which although being a sandstone is chemically and mineralogically too much of a granitic nature to include it in the sedimentary rock types. The arkose (Table 15, p.88) is named the Serin Arkose Member of the Sadong Formation and is composed of fine-grained rock types of a composition which indicates a tonalitic source. (Pimm, 1965, p.38). It is almost exclusively found west of Serian.

Acid igneous rocks occurring in the east of the Region in the headwaters of the Strap river consist of a large area of coase grained pre-Tertiary granite and a large area of younger granite and granodioritic stocks with varying texture. Tertiary granite with normal texture forms Bukit Buri while porphyritic microgranites and microgranodiorites form some small isolated hills. The large outcrop forming Bukit Lesong, near Lingga, is formed by microgranite which is particularly low in ferro-magnesium minerals, while other granitic stocks in the area may be more like the adamellite found near Lundu. A great number of associated acid igneous rocks forming dikes and sills in sedimentary rocks are found all over the Region. These cannot be shown on supplementary map 5 but their occurrence is illustrated by the pattern of soil distribution as shown on the soil maps.

The soil types derived from coarse-textured acid igneous rocks show relationships with soils formed on sandstones, while those soils derived from fine-textured igneous rock types often show similarities with soils derived from argillaceous rocks. The total iron content of the acid igneous rocks has a bearing on the iron content of related soil types. This iron content is intermediate between that found in soils derived from basic igneous rocks types and that in soils derived from sedimentary rock types. In places, it is only this characteristic which enables differentiation of soils from acid igneous rocks and soils of sedimentary rocks origin although transitions to both, soils on basic igneous rocks and sedimentary rocks occur. A notable exception is the microgranite forming Bukit Lesong which is almost devoid of iron so that very pale coloured soils are found there. Soils on coarse-grained granites inherit a coarse sandy clay to sandy clay loam texture in which coarse sand grains are found in a clay matrix, the sand grains being composed of residual quartz of the granite while the clays are secondary minerals formed after feldspars and ferro-magnesium minerals occurring in the granite.

Igneous rocks build a conspicuously mountainous landscape and any minor hill or pinnacle protruding from a landscape with subdued relief may indicate the presence of a small sill or dike. These are easily recognisable features on air-photographs and delineation of such areas is therefore greatly facilitated. There is, however, a danger of over-emphasizing the significance of such igneous outcrops. The plug-like intrusions are often flanked by metamorphic rock types which are chemically more related to the original sedimentary rocks. Because of their hardness they form together with the igneous core, which may be only outcropping in places conspicuous monadnock-like hills.

3. Sedimentary Rocks

Sedimentary rocks comprise approximately 45% of the Region; these include Pleistocene clays, sands and gravels occurring on terraces. Pedologically, there is little difference between poorly consolidated Tertiary sandstone and gravels and those deposited during the Pleistocene, the difference being mainly that the latter are always horizontally bedded because they have not been affected by folding.

The sedimentary rocks are subdivided into: (a) argillaceous rocks comprising phyllites, shales and mudstones; (b) arenaceous rocks composing coarse- to fine-grained sandstones, conglomerates, and Pleistocene deposits which for the majority are coarse to medium textured, and (c) limestone. Arenaceous rocks occupy about 25% of the Region, argillaceous rocks about 20% and less than 1% is limestone. Arenaceous and argillaceous rocks commonly occur as a composite lithologic unit. Only the dominance of one over the other is shown on supplementary map 5.

(a) Argillaceous Rocks

Argillaceous rocks are most extensive in the Lundu District. The reason why they are not shown as such on supplementary map 5 is that they usually underly sandy Pleistocene deposits so that the area as a whole is mapped as being arenaceous. In the western part of the Lundu District, west of Batang Kayan, they are mapped as the Serabang Formation, probably of Jurassic-Cretaceous age, while in the eastern part, the lowest stratigraphic members of the Tertiary Plateau Sandstone Formation occur. South to the Batang Kayan in the eastern part of the Lundu District argillaceous rocks belong to the upper stratigraphic members of the Plateau Sandstone Formation.

The Serabang Formation consists mainly of shale, slaty shale, slate and pelitic hornfels which have been affected by slight dynamic metamorphism followed, near igneous intrusions, by thermal metamorphism. They outcrop mainly in valley-sides where overlying Pleistocene deposits have eroded but near the Indonesian border south of Sungei Pasir these sediments are absent and the Formation is extensively found in a low hilly landscape.

The argillaceous rocks in the lowest stratigraphic members of the Plateau Sandstone Formation consist of thinly bedded, laminated, grey and dark grey, carbonaceous silty shale with thin siltstone. The upper members consist of shale and greenish-grey and greyish-red mudstones.

The argillaceous members of the Plateau Sandtone Formation are either very gently dipping or horizontally bedded and this results in a low undulating monotonous landscape.

Argillaceous rocks of Cretaceous age and belonging to the Padawan Formation are predominant in the Bau District. Shale is the most common rock type; it is hard dark grey or blue and in places it contains high amounts of plant remains and finely divided carbonaceous matter. Films of iron pyrite are common along the bedding planes and cleavages of the carbonaceous shale. Grey mudstone and calcareous shale occur locally. The shale is in most places strongly folded and builds strongly dissected hilly terrain varying between 50 to 350 feet.

In the areas surrounding Kuching town, argillaceous rocks are largely overlain by old alluvium. They outcrop in places along and to east of the Kuching-Serian road. The rocks comprise phyllite and shale and they are probably of the same age and nature as those found in the Lundu District (Jurassic-Cretaceous). Southward up to the Indonesian border argillaceous rocks are of the same Formation as that described for the Bau District and give rise to the formation of similar terrain as found in the Bau area.

Argillaceous rocks in the western section of the Upper Sadong District also belong to the Padawan Formation described for the Bau District. In the east they are of Upper Triassic age and belong to the Sadong Formation in which the argillaceous rocks comprise shale and silty shale. The shale is bluish-grey to black and carbonaceous. Some moderately hard, bluish-black, graphitic shale, commonly sheared and slicken-sided occurs in places. The shales are generally folded and build strongly dissected terrain.

Finally, argillaceous rocks in the east of the Region belong mainly to the Upper and Lower Kantu beds of Tertiary age. The upper Kantu beds are probably of continental origin and are composed of greyish-red, micaceous mudstones and greenish-grey mudstones. They outcrop in localised areas. The lower Kantu beds probably are of estuarine origin and contain grey, dark-grey and olive-grey shale, graphitic shale and claystone.

It should be remarked that the greyish-red mudstones in the upper Kantu beds show much similarity with mudstones of the same colour in the younger Tertiary Plateau Sandstone Formation of continental origin described for the Lundu District. Soils derived on these mudstones show also many similarities (see *Stom series,* p.170).

A small area of Upper Cretaceous to Lower Tertiary shales is found just west of the Batang Lupar between Lubok Antu and Engkilili.

As has already been remarked most argillaceous rocks are strongly folded and build a strongly dissected hilly landscape. In contrast, mudstone tends to underly a much more gently sloping hilly terrain.

Shales in general give rise to much the same soil formation. The soils show many colour variations from white-yellow to almost red which is largely dependent on the original iron content of the argillaceous rocks and the form in which it is present. Carbonaceous shales nearly devoid of iron give upon weathering almost white coloured soils. Apart from chemical differences between the shale, the hardness appears to play a role in the differentiation of soil depth which is related to erosion and resulting topography. Textures of soils derived from shales mainly range from clay loam to clay but admixtures of beds of arenaceous rocks within the dominant argillaceous parent material may influence this.

(b) **Arenaceous Rocks**

Arenaceous rocks in the Lundu District west of the Batang Kayan comprise greywacke sandstones, detrital conglomerates and cherts, all of the Serabang Formation (Jurassic-Cretaceous). The greywackes show considerable variation in degree of sorting, amount of feldspar, and degree of thermal metamorphism. Greywackes from the Tanjong Datu area and near the Pueh and Gading adamellites are thermally metamorphosed. The conglomeratic rocks of the Serabang Formation are commonly composed of greywacke conglomerates. Lenses of white to red cherts are common. Most of these are recrystallised to some degree, commonly as a result of thermal metamorphism. As is the case with the argillaceous members of the Serabang Formation large areas of these rocks types have been covered by coarse-grained Pleistocene deposits and the described rock types are therefore of only local importance where they outcrop in valleys or in foothills. Their largest extent is between Sungei Pasir and the Indonesian border where they occur at a level higher than 150 feet.

East of the Kayan river in the Lundu District a large area of arenaceous rock types is formed by the Plateau Sandstone Formation which is also present in an area north of the Pueh Range in the Samunsam basin. The former area comprises thick successions of massive, current-bedded sandstone together with thin beds and lenses of conglomerate with minor interbedded shale. The sandstones contain between 10 and 25% of weatherable constituents comprising igneous rock fragments and feldspar. The conglomerates are mostly pebbles of sedimentary rock origin with a small admixture of pebbles from igneous rock sources. In the area north of Pueh the sandstones have a greater range in composition and also contain arkosic sandstones.

The Santubong and Bako Peninsulas are also mainly formed by arenaceous rocks of the Plateau Sandstone Formation. In the Kuching Rural District occur further arenaceous rocks formed by the chert and feldspatic grit members of the Sejingkat Formation of probable Jurassic to Cretaceous age. The chert is much the same as found in the Lundu area while the grit is commonly coarse-grained, grey, well-bedded and usually cut by quartz veins. Much of these rock formations is overlain by coarse-grained Pleistocene deposits and a distinction between the latter and the feldspatic grit if only exposed in a soil pit, is difficult to make. The remainder of the arenaceous rocks in the Kuching Rural District forms the large Penrissen region which is composed of members in the Plateau Sandstone Formation described for the Lundu area.

In the Upper Sadong District the arenaceous rocks comprise the coarse textured members of the Sadong Formation and are formed by medium to coarse-grained sandstone with at least 50% of detrital vein and metamorphic quartz. The typical sandstone is pale to medium grey, speckled white and dark grey. In places it is soft and easily weathered while in other places it is recrystallised and hard. Conglomerates occur as lenses in the sandstone and are composed of at least 50% of detrital, vein and metamorphic quartz and chert. Other fragments include acid igneous rock materials, sandstone and shale.

Arenaceous rocks in the Lower Sadong District comprise sandstones of the Plateau Sandstone Formation (near the Indonesian border and near Simunjan), while some other parts are formed by the arenaceous members of the Sadong Formation.

In the Second Division, the Plateau Sandstone occurs again dominantly in the arenaceous parent materials with the exception of the Marup Range near the Batang Lupar which is composed of the Basal Sandstone in the Kantu beds of Early Tertiary age. They are almost vertically bedded and are composed of yellowish-white, porous, crumbly sandstone, much similar to those of the Plateau Sandstone Formation.

The arenaceous rocks are for the majority highly quartzitic in nature and give rise to poor soils. Hardness and bedding planes are important criteria for the resulting topography after erosion. The Plateau Sandstone Formation gives rise to a cuesta landscape with long dipslopes if the beds are nearly horizontal. Much similar sandstone, but vertically bedded, builds the steeply rising Marup range in the east. This range is a typical example of a hogback.

An indication of the locations where coarse-grained Pleistocene deposits have been mapped as arenaceous rocks can be obtained from the Physiographic map, supplementary map 4, in which the areas are shown in black (*Lundu unit*). They comprise beds of coarse to medium grained sand, pebbles and some clay. They are highly quartzitic, even more so than the average sandstone in the area and are probably mainly derived from the Plateau Sandstone Formation. An exception is the Lundu area where most of the Pleistocene deposits are composed of quartz grit and sand derived from adamellite.

(c) Limestone

Limestone, which forms 0.8% of the whole Region is only of local importance in the Bau, Kuching Rural and Upper Sadong Districts. It is there mainly formed by the Bau Limestone Formation which was probably accumulated in a shallow clear water marine environment during the Cretaceous. The limestones are almost pure, and devoid of sand grains and other terrigenous debris. ('The bulk is pure, consisting of 98 to 99% $CaCO_3$ and less than 2% combined magnesia and insoluble residue', Wilford, 1955, pp.216-217). In the Bau area, they are highly calcitic and locally metamorphosed resulting in mineralization in acid intrusive veins. The limestone builds a typical karst topography with high steep hills resembling haystacks surrounded by limestone flats. Although limestone areas are of academic interest, and often significant because of their association with economic minerals, pedologically they are of very little importance because very little soil development has taken place on them. Where soils are present they are mainly formed in detrital material derived from other sources, although the proximity of the highly calcareous environment has influenced the characteristics of these soils. (Wilford and Wall, 1965)

4. Recent Deposits

Recent deposits form nearly 45% of the Region. However, 27% of it comprises deep peat. Because of their large areal extent, they are agriculturally highly significant. In particular, the riverine and marine mineral deposits which, although occurring in relative small amounts, are of high agricultural potential.

(a) Riverine Deposits

Riverine deposits forming 7% of the Region are mainly composed of clay deposits, smaller upper stream areas have medium to coarse-grained deposits. The riverine deposits are mineralogically and chemically very varied depending on the source material. The deposits near basic igneous intrusions may be highly ferruginous and are fine-textured while those near the Plateau Sandstones are highly quarzitic and coarse-textured. Such local differences become less distinct in deposits of the lower riverine areas where the materials are chemically and texturally homogenized by addition from other sources mainly through tributaries. Since most of these materials have derived from partially or totally weathered parent rock sources, weatherable mineral contents are low. Exceptions are the recent alluvials found near igneous rock sources. All recent deposits are relatively chemically richer than related upland soils.

(b) Marine Deposits

Marine deposits comprise firstly coarse-grained material building sand ridges and beaches between Tanjong Datu and the Santubong Peninsula. These have mainly derived from the Pueh adamellite with admixtures coming from rocks in the Serabang and Plateau Sandstone Formations; secondly, the marine deposits comprise deltaic and estuarine clays and silty clays which in places are highly organic because of incorporation of plant debris from mangrove and nipah vegetation during deposition. They are generally chemically and texturally fairly homogeneous, the depositional environment being the same for most of the area, while the sea has chemically homogenized much of the materials brought down by the rivers. The deposits are poor by world standards and do not contain much weatherable minerals. This can be expected since the lithology of the hinterland is composed mainly of quartzitic sedimentary rock types. Nevertheless, they are relatively fertile for Sarawak soils, mainly because of potassium and magnesium enrichment by the marine environment. They are low in calcium which is probably caused by the fact that the muddy environment is not suited to a rich calcareous micro-fauna.

(c) Organic Deposits

The organic deposits form the largest single area of parent materials found in the Region. Their formation has been discussed in detail under the *Nonok unit* (p.63). Since their chemical, morphological and agricultural characteristics are dealt with under **Anderson Family** (p.188) it suffices to say that, with relatively poor sedimentary material underlying the peats, the organic deposits which are chemically related to these deposits, cannot be expected to be fertile.

Chapter 6. VEGETATION AND LAND USE

1. Sources of Information

The general outline of the land use and vegetation is shown on supplementary map 6 (Vol. II) which is based on the Land Use Map series No. 22, First Edition (1968) prepared by the Land and Survey Department. For cartographic reasons, the units shown on the original map had to be simplified so that the respective areas could be shown on a scale 1:500.000. Certain types of primary forests were combined into one unit, while units referring to specific crop use were combined into two major units, namely: land used for permanent agriculture, and land used for shifting cultivation. For purposes of this memoir such a differentiation is considered to be adequate.

For more detailed information the reader is, therefore, referred to the original source issued at a scale 1:250,000.

The relative importance of the various land use units shown on Map 6 is illustrated in Table 16 (p.94). The acreages shown are those derived from planimetric measurements of the Sarawak Land-Use Map, issued by the Land and Survey Department in 1966. These measurements were calculated by district and it was necessary to remeasure those parts of the Simanggang and Lubok Antu Districts falling within the Region. A small discrepancy exists between figures obtained by measurements done by the Soil Survey Division, and those obtained by the Land and Survey Department. This is because all measurements obtained by the Soil Survey Divi-

Table 16 Approximate area extent of simplified land use units by District (in sq. miles)

Land used for Agriculture or other purposes	Lundu	Bau	Kuching	Upper Sadong	Lower Sadong	Simanggang	Lubok Antu
Permanent used land for agriculture or settlement.	31.1	92.4	299.8	98.8	81.2	106.4	10.6
Shifting cultivation used for hill and swamp padi infrequently, in association with various stages of secondary growth.	153.3	148.0	204.5	379.7	76.3	346.9	69.8
Total	184.4	240.4	504.3	478.5	157.5	453.3	80.4
Land Under Primary Forest							
Swamp forest of different types	8.2	-	99.6	125.0	380.2	387.5	10.0
Hill Forest and Riverine Forest (mainly Dipterocarp Forest)	216.0	79.5	107.5	180.1	64.9	64.7	5.6
'Kerangas' Forest	234.4	20.2	32.1	5.3	13.1	12.2	-
Mangrove and Nipah Forest	45.4	-	153.4	-	2.9	-	-
Total	504.0	99.7	392.6	310.4	461.1	464.4	15.6
Total land area calculated from Land Use Map (1:250,000)	688.4	340.1	896.9	788.9	618.6	917.7	96.0
Total land use calculated from Soil Map (1:100,000)	678.8	330.2	926.5	781.4	659.7	900.3	98.6
Error over soil Map	+1.5%	+3%	-3.2%	+0.9%	-6.2%*	+1.9%	-2.7%

* This discrepancy is unexplanable. The area calculated from the Soil Map agrees with the total area calculated from the 1:50,000 scale topographic map (series T735)

sion are based on the more accurate grid-point system (Dmitriyev, 1965), while those obtained by the Land and Survey Department are based on the 1:250,000 scale maps planimetric measurements.

2. Land Used for Permanent Agriculture and Settlements

This land-use unit comprises roughly 720 square miles or 16½% of the Region and is made up of Town and Mining Land and Land permanently used for agriculture. The total acreage of the Town and Mining land is relatively small compared with land used for permanent agriculture and can be ignored. Land, permanently used for agriculture comprises land used for horticulture (mainly minor areas of fruit trees), rubber, pepper, coconut, and wet padi, if permanently used.

Land used for permanent agriculture occurs concentrated in Mixed Zone areas, mainly because these areas are largely populated by Chinese who employ intensive farming methods and who attempt to make optimum use of the land space available to them (Chapter 8, section 4, p.107 and section 6, p.112). Permanent agriculture is furthermore found in the Native Area Land (Chapter 8, section 6, p.112) along the coast and at the fringes of lower riverine areas. Small areas of permanent agriculture are found scattered within the Interior Land (Chapter 8, section 6, p.112) mainly used by the Iban and Land Dayaks and in some small rubber estates in the Bau District. As can be seen from Table 16 (p.94), the total area used for permanent agriculture is small in relation to the total land available for agriculture.

The location of permanent agriculture bears very little relation to general soil conditions and is much more dependent on the population group which owns it than on any other factors. The only significant relation between location and permanent agriculture is to be found in the choice of crops. Coconut is planted mainly along the coast on the sandy ridges, on marine and deltaic clays found in the riverine deltas, and along the lower stretches of river courses. In the latter areas is also concentrated land used for wet padi cultivation, although the land permanently used for this crop is but small. In the upland areas, rubber and pepper are the main crops. The former is dominant in area but the latter, because of its high income per surface unit, is economically of much greater importance. Particularly recent years have seen a great expansion in pepper growing in the Dayak populated areas. It is of interest to note that much of the old rubber owned by the Iban and Land Dayaks and occurring in the interior land is located on inferior soils. These are often found in the vicinity of Dayak longhouses or kampongs where the land was found to be inferior for padi planting, either because of overfarming in the past or because of natural soil conditions. In the Iban areas where the settlements are commonly located on small flattish terrace sites near a river, kerangas soils often dominate near these settlements. Apart from the fact that the tapping of rubber necessitated planting near settlements, this soil type, though unsuitable for padi planting, appeared to the Dayak in the old days the best way of using this type of land. Therefore, a large area of old rubber is now found on soils unsuitable for this crop. Pepper, which is a much more sensitive crop to soil conditions is in the Land Dayak areas frequently planted on the best soils they have, although this is very much dependent on individual ownership and initiative. In the Mixed Zone areas, pepper is often planted on a variety of soil types since the Chinese owners, who are in need of land, were able to improve on the soil conditions and could therefore, particularly in years when the price of pepper was high, obtain a good income.

Coconut planting is largely an occupation engaged by Malays in the coastal area. In the past this was done at a subsistence level without much maintenance. At present the cultivation is intensified and there is much expansion of this crop into lands under mangrove and nipah which after amelioration can be used for coconut. The most intensively planted areas are found in the Nonok Peninsula where both Malays and Chinese show a great interest in this crop. Further expansion takes place on the levees and margins of peat swamps along the major river courses which are mainly populated by Malays and Ibans.

Wet padi is seldom grown on a permanent basis. Since the Land Use Map was prepared from air photographs, it was difficult to differentiate between wet padi land permanently used, and wet padi land used in rotation. Therefore, all wet padi grown at the time when the photographs were taken, was indicated as permanent wet padi land. However, the bulk of this land is still under shifting cultivation although the rotation period is short (varying from 2 to 4 years).

The change over from a mangrove-nipah vegetation to wet padi and coconut cultivation involves amelioration measures which greatly affect the natural soil conditions. The same is true for the margins of peat swamp used for the same crops. These changes are discussed in detail in Chapter 13 (p.228).

Since with a few mentioned exceptions permanent agriculture has brought very little change to the overall soil conditions the subject is not further dealt with.

3. **Shifting Cultivation**

As can be seen on supplementary map 6 and from Table 16 (p.94), large tracts of land are being used for shifting cultivation. This type of agriculture is based on the natural soil fertility and on its rejuvenation potential. The latter is tapped by allowing a cropping period to be followed by a fallow cycle in which the forest regenerates. It is, therefore, closely related to natural soil conditions. Because this cultivation method has been practised for centuries over large areas the natural environment has been greatly influenced.

Shifting cultivation in Sarawak is not known under a simple local term such as the *taungya system* in Burma, the *chena system* in Ceylon or the *caingin system* in the Philippines. It is probably best described by the word *'berumai* or *berumûh system*', umai being the Iban word for a hill padi farm while umûh or umoh is generally used by the Land Dayaks for the same.

The system involves the felling of initially primary forest which is then left to dry for a short period of two to three months, whereafter it is burnt. After the burn the padi seed is dibbled in by men, using pointed poles while the women who follow after throw 3 to 4 seeds in each hole. Frequently, maize or jobstears are planted in between, normally in places where ash has accumulated. Weeding is done once, about two months after the sowing. The rice is harvested after approximately 7 months and the field is subsequently either left to fallow for the forest to regenerate or is used again for rice in the following year. If reused, either the young regrowth is again cut and burned a couple of months after the harvest and again planted with rice, or the field is planted up with tapioca already during the first season and left for about a year to mature, whereafter the roots are collected for consumption or for pig fodder. Rarely is the land used for a third season. The land is left fallow for the forest to regenerate until a forest has reached a stage in maturity at which a new cycle can be initiated by felling, burning and planting. When the land was covered with primary forest, the subsequent growth after one rice crop may be vigorous but the regeneration process is much slower and less healthy if the land was covered with secondary forest or is used for longer than one season. Not only the regeneration process decelerates but also the vegetation degenerates, in that more and more weeds and noxious shrubs start to invade the land. The regeneration process has come to almost a complete stop if the land is overfarmed and the soils are degraded. In that condition the soil is too exhausted of nutrients to support another type of vegetation than that characteristically found in overfarmed areas, lallang (*Imperata cylindrica*), almost pure stands of somah (*Ploiarium alterniolium*), resam (coarse ferns), kemunting (*Melastoma malabathricum*) and other weeds and shrubs of less importance.

Land in use for shifting cultivation therefore comprises land showing all stages of regrowth, healthy old secondary forest of 20 to 30 years old, young secondary forest, ranging from 10 to 20 years old, very young secondary forest (temudak) from 3 to 10 years old and 'jeramei', from 1 to 3 years old. The age of the regenerating forest is relative and much dependent on the original fertility of the soil and land use in the past. Overfarmed land, carrying a 'jeramei' vegetation in which the undergrowth is still dominant, may have this type of vegetation for years.

Although there are local differences in land use, such as cropping for one season or three seasons, this is mainly caused by local conditions such as non-availability of much other suitable land. Freeman (1955, p.130) rightly points out that cultivation of two or three years in succession should be condemned since it gives rise to serious soil degradation. However, the author cannot agree with Freeman's statement that if 'virgin rain forest is felled, fired and farmed for one season only, and then allowed to recuperate and thereafter the resulting secondary jungle is brought into cultivation at sufficiently rare intervals (12-15 years), and never more than one season, the land may be utilized virtually indefinitely without serious degradation taking place'.

This would only be possible if the soils had large supplies of nutrients to sustain many vegetative cycles but the analyses of Sarawak soils have borne out the fact that this is not the case. Most of the nutrients are stored in the topsoil and in the vegetation. They move in a continuous cycle formed by soil-vegetation-litter-humus and very little is contributed to this supply by the soil itself unless deep rooting trees are able to bring up nutrients from the subsoil and enrich the topsoil. Although some nutrients such as potassium seem to be in adequate supply in the soils, phosphate and nitrogen which are indispensable for the vegetation are almost exclusively tied up in the humus and vegetation. Therefore, in each cycle, some of these nutrients are lost and particularly when two growing seasons are used most of the nitrogen and phosphate present is removed by the crop or lost by oxidation and leaching. A study, conducted by the author in the Undup area, and aimed at investigating the nutritional changes in topsoils under shifting cultivation during a 1-15 years period, revealed that only the nitrogen and available phosphate contents changed markedly, while no correlation could be found between the fallow period and other nutrients*

*It is the intention to publish the results of this study at a later date and elsewhere.

The contention that providing certain conditions are upheld, shifting cultivation would not result in degradation of the land, cannot be supported since although the degradation would certainly be slowed down it would happen eventually, depending on the original supply of nutrients in the soil which is related to the soil type.

There is another reason why the 15 years cycle advocated by Freeman cannot be supported by the author. Freeman states (1955, p.134) that in a 15 years cycle with a use of 60% of the land, roughly 5 bilik families (on average about 25 persons) per square mile would find adequate land for their needs. Studies in the Upper Sadong District (Andriesse, 1964a) indicate that in that area, even allowing for the land not used for agriculture such a population density had not been reached in areas used for shifting cultivation, although overfarming was much in evidence. The *Tebedu unit*, which is roughly for 60% suitable for agriculture and more or less for 80% in use for shifting cultivation, may in general be referred to as an example. The population density in this unit never reaches a figure of 25 per square mile in the Land Dayak areas and still most of the vegetation on this land shows now inadequate regeneration.

The possibility that in the past this land carried many more people must be ruled out and the author's view is that in these areas the land had already been subjected to too many cropping cycles to make an adequate regeneration possible. This is aggravated by the fact that the vegetation in each new cycle will require a longer period to reach maturing. Overfarming was probably caused by felling and burning of forest which had not reached sufficient maturity although it probably could have been older than 15 years. Also, declining yields caused by burning of immature forest may result in enlarging the farming area to recoupe the losses and therefore more than four acres may be required per family. (Four acres being the acreage normally required).

Although a sufficient time-space between cropping on the same land would result in better regeneration, the original condition is never restored and the vegetation will deteriorate after each cycle. Probably, the only soils on which adequate regeneration may take place for many cycles, are those which are constantly rejuvinated by erosion. Such soils occur on steep slopes and are generally shallow. Particularly on the basic igneous rocks in the Kuching Rural and Upper Sadong Districts such soils appear to have a great recuperation power. Degradation of land, therefore, is not only the result of wrong cultivation methods but is also influenced by the natural fertility of the soil.

In relation to this, it is of interest to note that the rotation cycles in wet padi areas are much shorter and frequently as short as 3 years. Some areas are used every year without effect on crop yields. Soil analyses do not show much difference in nutrient reserve between the low land soils and related upland soils. The nutrient level in the former appears to remain quite constant, even although a crop is grown without using fertilizers. This is probably caused by an enrichment of nutrients from the flood water bringing new sediments to the surface of the land during the flooding period. Also, the particular environment of wet padi fields may enhance the fixation of nitrogen from the atmosphere and may make phosphate available from sources which in the upland soils must be regarded as being permanently unavailable (see Chapter 14, p.235).

Iban areas generally have a higher proportion of degraded soils than areas occupied by Land Dayaks. Where this is not caused by a difference in the inherently natural fertility it is probably due to wrong cultivation methods. Notable areas are those along the Serian-Simanggang Road from the 80th mile up to Simanggang. The soils there were originally not less fertile than much similar soils in the Land Dayaks areas but as pointed out by Freeman (1955, pp.111-114) too many cropping seasons may have accelerated the degrading process. The causes are difficult to find. This may be over-population in the past, It is known that many Iban have moved out of this area during the 19th century (Pringler, 1970). It could also have been caused by frequent absenteeism of the male population who in the past went on raids so that the remaining womenfolk had to use young regrowth for farming. It would be of interest to study this in detail although the matter is now only of purely academic interest.

The influence of shifting cultivation on the fertility of the soils has been adequately illustrated but what is its effect on erosion and the physical conditions of the soil. As explained in Chapter 4, section 4a, (p.75), sheet wash is normally absent in most of the uplands of West Sarawak and even in hill padi farms this seems to be negligible. Freeman (1955, p.126) corroborates this by his own observations made in the Balleh area of the Third Division.

The effect on the physical condition of the soil is, however, more serious if more than one crop is successively grown on the same type of land. The small amount of humus normally present in the topsoil of Sarawak soils is totally destroyed by burning and thereafter by oxidation through exposure. Particularly sandy soils are much affected, and in such old padi farm, commonly a thin cover of white sand covers the normally dark coloured top horizon if this is exposed for some time. The surface horizon of clay soils tends to dry out, hardens and loses its friability. This enhances run-off, not necessarily sheet wash. Much of the nutrients derived from the burn may be washed away through this increased run-off. For this reason, one commonly finds a better stand of the rice in hollows and at the bottom of slopes than elsewhere on a hill slope.

Loss of humus and a breakdown of the structure are characteristics of degraded topsoils. The decline in fertility and physical characteristics go hand in hand. Although with fertilizers one might be able to remedy to first mentioned deficiency, the physical conditions are more difficult to improve. It has been noted that on gently sloping degraded clay soils commonly somah (*Ploiarium alterniolium*) dominates the vegetation. This specific vegetation is probably caused by the inferior structure of the soil which causes wet conditions through a declining infiltration rate. Surplus rainwater cannot run-off adequately on this gently sloping land and causes semi-aquatic conditions which can be compared with the conditions found in Podzols with a hard humus pan.

4. **Primary Forest**

Shifting cultivation practises has caused a rapid areal decline of natural primeval vegetation over most of the Region. The areas still under virgin forest mainly comprises land which is either too difficult to cultivate because of bad topography, inferior soils and swampy conditions, or the spread of population was halted before these areas were touched.

For these reasons, most of the primary forest left in the Region is found on mountainous terrain, in the fresh water peat swamps or in the tidal swamps of the deltaic areas. Primary forest areas with good soils are small and are mainly found in the Lundu District.

The total area still under Primary Forest comprises 2,248 square miles or about 50% of the total land area. For purposes of this memoir, the forest is subdivided into four main types, namely:

(a) Freshwater Swamp Forest

(b) Hill Forest and Riverine Forest

(c) 'Kerangas' Forest

(d) Tidal Swamp Forest (mangrove and nipah)

The relative areal importance of these types is shown in Table 16 (p.94).

(a) **Freshwater Swamp Forest**

This vegetation consists of varying types which have been classified by Brunig (1969, pp.151-161). Only those of importance in the area are described here.

(i) Mixed Peat Swamp Forest comprising Ramin (*Gonostylus bancanus*)–Jongkong Forest, occurring on perfectly flat lands, not under the influence of tidal water and mostly in large delta's or in broad belts along the coast. Further Terentang-Pulai (*Campnosperma-Alstonia*) Peat Swamp Forest occurs at the fringes of basin swamps towards beach forest or sometimes towards small rivers. Meranti (*Shorea spp.*)—Pulai (*Alstonia spp.*) Forest occurs at the edges of extensive swamps while the Mixed Peat Swamp proper occurs normally towards the centre of basin peats.

(ii) *Shorea albida* Peat Swamp Forest occurs only in some larger peat swamps, notably those in the Lupar-Sadong-Samarahan basins, but always in the centres. In the Region, only one subtype is usually found, namely the 'padang paya', a heterogeneous community in which *Dactylocladus stenostachys, Cratoxylon glaucum, Combreto carpus rotundatus* and *Litsea palustrus,* dominate. This is a distinct forest type which can be easily differentiated from the Mixed Peat Swamp Forest on air photographs, since it is characterised by a dense, rather uniform dark-grey canopy while the Mixed Swamp Forest proper is usually indicated by an irregular canopy of mixed tones.

Most Freshwater Peat Forest is found on deep peat, though at the fringes of basins it may occur on rather shallow peat. Areas with shallow peat, however, have normally already been taken up by the population for farming. Particularly the Ramin-Jongkong Mixed Peat Swamp Forest may be of great commercial value, but the density of valuable species may vary. The same is true for the Meranti-Pulai Mixed Peat Swamp Forest.

The *Shorea albida* Peat Swamp Forest usually indicates locations where peat accumulations are deepest. It is still not known why the vegetation is different on these locations, which comprise usually the tops of the dome-shaped peat basins. It may be caused by an advanced leaching process since in every vegetation cycle more and more nutrients are lost so that the top layers of the deepest peat accumulations are poorest in nutrients. More information is needed on this subject. Drainage may be another factor playing a role.

(b) **Hill Forest and Riverine Forest**

On supplementary map 6, the typical Riparian Forest occurring on levees not formed by peat has been shown in combination with the Hill Forest. These fringe areas are too small to be shown separately and they are of little importance for the Region as a whole; although locally they may supply some valuable timber species. Brunig (1969, pp.161-168) classifies Kerangas Forest under Dryland Forest, the equivalent for Hill Forest used in this section, but since the Kerangas Forest is typical for certain soil conditions, for purposes of this memoir, it is justified to treat it as a separate unit.

The remaining Hill Forest shown on supplementary map 6 consists therefore of Mixed Dipterocarp Forest subdivided by Brunig (*op. cit.*) into:

(i) A forest in flat to low undulating terrain with no distinct topographic features visible on air photographs, and with varied species depending on soil type and terrain and,

(ii) A forest on undulating to low hilly terrain. In the latter the composition is also varied depending on terrain and soils. In both subtypes transitions to Kerangas Forest are found on more sandy parent materials.

(iii) Mixed Dipterocarp Forest on hilly, bold topography with long slopes culminating in high ridges or plateaux. This forest is very mixed in composition in accordance with topography. On very sharp ridges there is a tendency towards replacement by Kerangas Forest or dense scrub forest.

(iv) A subtype is found on broken hilly to mountainous terrain, which are mainly areas formed by igneous massifs. Here, the composition is very varied with topography, altitude and exposure and species vary with soil type, site conditions and regions. Locally, transitions to Kerangas and Montane Forest Types exists. This subtype occurs notably on the crests of ridges built by granites in the Pueh-Gading massifs. Such areas are because of its vegetation often wrongly interpreted as Podzol areas. However, this specific subtype of Hill Forest resembling Kerangas Forest is associated with a rocky surface soil. The Mixed Dipterocarp Forest contains many valuable timber species but no general indication can be given to their locations, this being very much dependent on site conditions which vary from place to place with topography, soils and parent material.

(v) Riverine or Riparian Forest occurs on river banks and frequently in wide, flat valleys filled in by mineral deposits in places covered with very shallow organic deposits. On dry river banks one can differentiate a Riverine Forest in which Belian (*Eusideroxylon zwageri*) and Engkabang (*Shorea spp.*) are conspicuous. On the flat floodplains near rivers and often just behind the dry river banks (Empran soils), the riverine forest approaches the composition of Mixed Fresh Water Swamp Forest.

(vi) One type of hill forest not mentioned yet is that found on the Limestone hills in the Bau, Kuching Rural and Upper Sadong Districts (Bau Physiographic unit). It is of a very specific nature and varies extremely widely in physiognomy and composition.

(c) **Kerangas Forest**

Kerangas is a name used by the Dayaks for land which cannot support hill padi and the natural forest on it derives its name from that usage. 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 which depend on local soil conditions and topography and therefore it is dangerous to refer to all Kerangas Forest as being an indication of bad land. It is, however, commonly found on flat to gently sloping topography but occurs in minor areas forming steep slopes usually associated with rocky soils.

Brunig (1969, pp.165-167) divides Kerangas Forest into several types:

(i) One type is found on flat to almost flat topography in the lowlands and commonly referred to as Kerangas or Kerapah. This forest type is of variable composition in which many species common for Peat Forest may occur. Generally, the soils are poor and sandy, and frequently waterlogged in places because of humus pans found in the subsoil. Emergent trees are usually Dipterocarps, (*Shorea albida, Shorea materialis, Shorea Dryobalanops* very local, but in quite a number in the Lundu-Sematan area, and *Shorea pachyphylla*). In mountainous terrain this type occurs frequently on distinct plateaux.

(ii) Another type is found in undulating to low 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* in the lowlands and

Agathis beccarii in the highlands above 2,500 feet. Dipterocarp spp. are more common than in other Kerangas Types.

(iii) A third type is found in hilly and mountainous terrain on dissected terraces, gentle dipslopes and on exposed ridges and boulder tops. On sharp ridges the forest is ecologically and floristically rather different from the forest on the slopes but this is rather indistinct on air photographs. Crown sizes of the main canopy indicates soil fertility. This forest type usually changes very gradually into Mixed Dipterocarp Forest.

The Kerangas Forest Types are of great pedological interest since they frequently show up markedly on air photographs indicating a change in environment. This may be caused by drainage or fertility. Although there are many transitions between Mixed Dipterocarp Forest, Kerangas Forest and Peat Forest, one can generally say that in this range Mixed Dipterocarp Forest usually indicates the best soil conditions, Kerangas Forest the worst, with true Humus Podzols as the extreme, while Peat Forests indicate a poor swampy environment. It is remarkable that Kerangas Forest occurs both on the most mature soils in the areas, the Podzols, and on the most juvenile ones, namely those formed by rock debris on high mountain crests built commonly by sandstone formation and granites. This proves the adaptability of the species in this forest type to a great range in conditions.

(d) **Tidal Swamp Forest—Mangrove and Nipah**

This forest type is found mainly in deltaic and estuarine areas where the local environment is usually characterised by constant sedimentation in brackish to salt water. Several belts can be recognised.

(i) Exposed tidal mudflats along the shore and along large rivers frequently have a vegetation of Pedada (*Sonneratia spp.*). On river banks, often Nipah (*Nipah fruticans*) together with Api-Api (*Avicennia* spp.) are found, or Bakau (*Rhizophora spp.*) with Nyireh (*Xylocarpus spp.*).

(ii) More inland, away from the tidal rivers one may find Nyireh together with *Bruguirea spp.* as a Mixed Mangrove Forest.

(iii) In more sheltered areas where the influence of saltwater becomes less the Nipah palm normally becomes dominant, while at still higher locations the Nibong palm (*Oncosperma filamentosa*) may become dominant.

The tidal swamp forest is indicative of saltwater conditions in a varying degree and the species found in them are quite indicative to salt levels prevailing at their sites. A change over from strongly to weakly saline condition is marked by the sequence mangrove species—*Nipah fruticans—Oncosperma filamentosa.*

Finally, one type of forest occurring only locally in the Sematan-Tanjong Datu area has not yet been mentioned, namely Beach Forest. Most areas formerly covered by this forest have been cleared for coconut.

This forest occurs on recent sand beaches with Ru Laut (*Casuarina equisetifolia*) as the dominant species. On lowlying sandy beaches and swamp flats behind the beach a mixed beach forest may be found. Nibong (*Oncosperma horrida*) may occur on unconsolidated sand.

Part III — DESCRIPTION OF SOCIO-ECONOMIC ASPECTS OF THE ENVIRONMENT

Chapter 7. INFRASTRUCTURE

1. Administration

Administrative boundaries are shown on supplementary map 2 (Vol. II)

This memoir covers five administrative districts in full, while two districts are only partially covered. The five administrative districts fully covered by this memoir comprise the Lundu District, the Bau District, the Kuching Rural District and the Upper and Lower Sadong Districts. The latter were formerly known under the names Serian and Sadong Districts.

Two districts only partially covered are the Simanggang District of which only the western part falls within the Region and the Lubok Antu District of which only a small part is covered in the extreme southeast corner of the Region.

The Simanggang District is subdivided into three subdistricts of which the Sebuyau and Simanggang Subdistricts are only partly covered by the memoir, while the Lingga Subdistrict is completely covered. Finally, the Lubok Antu District is subdivided into the Engkilili Subdistrict and the Lubok Antu Subdistrict both of which falling partly within the Region.

All districts are headed by a District Officer who resides in the District Administrative Centre, which commonly gives the name to the District. Exceptions are Upper Sadong District and the Lower Sadong District which have as their respective administrative centres Serian and Simunjan. Subdistricts are normally headed by a Sarawak Administrative Officer who resides in the place giving its name to the subdistrict.

Until recently, Government Up-Rriver Agents and Native Officers could be found in remote areas but with the improvement of communications since Malaysia these are for the majority now replaced by travelling Sarawak Administrative Officers who regularly visit the remote areas but who reside in the District or Subdistrict headquarters.

At the local level, the various communities have elected headmen who are called Tuai Rumah in the areas populated by Iban, Kepala Kampong in the Malay and Land Dayak areas while the Kapitan China plays a similar role in Chinese communities. Above the level of Kepala Kampong one finds the Penghulu in the Iban areas and the Orang Kaya Pemancha in the Land Dayak areas. These are each heading a group of villages which are closely related through communal ties. Finally, each native group or subtribe may be headed by a Temonggong or Pengarah (the latter name is only used in the Land Dayak areas), who work closely with the administration at district level. While local headmen are commonly elected by the local villagers with the approval of the Government, O.K.P's, Penghulu's and Pengarah's are appointed by the Government and can therefore in this sense be regarded as government officials. The Kepala Kampong in Malay areas can frequently be put at equal level to that of a Penghulu or Pengarah since they are heading a larger number of people than a Tuai Rumah or Kepala Kampong of respectively Iban or Land Dayak longhouses or Kampongs.

Various districts combinedly form a division which is headed by a Resident. The Lundu, Bau, Kuching Rural and Upper and Lower Sadong Districts form the First Division in Sarawak of which Kuching is its administrative centre. Kuching is also the State Capital. The remainder of the Region falls within the Second Division of which Simanggang is the administrative centre.

At local Government level, the Region is subdivided into Municipalities (Kuching only) with an elected Municipal Council which is administratively independent, and District Council areas with an elected District Council in which the District Officer is representing the Government as advisor. The District Council areas can be regarded as enlarged municipal areas.

2. Communications and Marketing

The administrative outline given in foregoing section is necessary for a full understanding of the patterns of communication-lines, settlements, marketing and resulting agricultural development.

In the past when communications were mainly maintained by either sea or river transport, district and subdistrict centres could be regarded as virtual capitals of small regions from which action emanated and to which the interest of the local population converged. These headquarters were commonly situated at the lower course of a main river, just downstream of the last main tributary. This enabled quick communication by sea with the State Capital Kuching and communication by river with all the people living in the river basin. The watersheds between main drainage basins are therefore commonly forming administrative boundaries. These watersheds frequently indicate also boundaries between subtribes and at local level watersheds of tributaries normally form boundaries of kampong areas. In the past, apart from ease of administration, the location of administrative centres were also selected with a view to pacification of the upriver areas. Administrative centres therefore became converging points of communication lines, these being streams in the lowlands, while in the upriver areas they were until recently formed by permanent communication tracks, particularly in Land Dayak areas. Marketing, therefore, concentrated in these centres and for this reason large bazaars (rows of shophouses) were erected. These bazaars supplied the upriver areas with necessary goods often in exchange for agricultural and jungle produce. Although barter trading is now replaced by exchange of money, with the historically established ties between trader and supplier and the ensuing credit facilities barter-trading is still much in evidence.

Apart from these main bazaars, small bazaars were frequently founded at a main confluence of rivers while a local shopkeeper in the upriver areas, frequently living in a location where the river is just navigable in wet periods, played his role as local dealer.

The construction of roads throughout the Region in the period 1958-70 has thoroughly changed this situation. Trunk roads were built across country to link administrative centres and they replaced long established water routes by shorter land routes. Feeder roads, which can be compared with tributaries of a main stream (the trunk road), were constructed to enable quick access to formerly remote interior areas. The cutting of watershed boundaries by a trunk road is making it often easier now for upriver people to visit a bazaar of a neighbouring district than the one found in their own district centre. Such is the case in some parts of the upper Simunjan riverine basin in the Lower Sadong District and in some upper parts of the Kayan river basin in the Lundu District. The former area has now easier access to Serian than to Simunjan while the latter area is more conveniently served by Bau instead of Lundu.

Apart from the fact that these new communication lines have established easy and quick access to remote areas the traditional settlement patterns and agricultural activities have also been greatly influenced, particularly in the upriver areas. While in the past most people lived along streams, they now tend to concentrate along roads. Traditional agriculture in upriver areas consisted mainly of shifting cultivation and the collecting of jungle produce with the cultivation of some rubber. Part of these areas are now in easy reach of markets and have become therefore attractive to the establishment of more lucrative crops such as pepper. The much needed fertilizers for this crop can now be much easier transported to the gardens and at less expense than before.

The small bazaars located at the confluence of main tributaries have become less important since they are now often bypassed by roads which maintain direct communications with administrative centres and bazaars. Although the latter are still the main marketing places for their respective areas, their importance has been influenced by the new roads. The spheres of attraction have in some cases become smaller while for other centres they have been enlarged. Serian is a good example for the latter, while Lundu may serve as an example of the former, Bau having captured part of its trade. Also the function of the local shopkeepers and small bazaars has become smaller because of more direct dealings with the main bazaars.

The upper riverine areas are in the main now served with a good communication network. The upper Kedup (Upper Sadong-Kayan area) and some other areas in the Bau and Lundu Districts still suffer from long communication lines. The lower riverine areas and particularly those of the Samarahan, Sadong and Lupar rivers are still devoid of road communications and there the traditional transport by water is still the main means of communications.

It stands to reason to assume that the trend of more and more concentrated permanent agriculture along the road communication lines will continue. The Kuching-Serian road serves as an historical example. This road was built in the thirties and populated by Chinese from the Bau area which could not find further employ in the dwindling mining industry. This has caused a ribbon development which was undoubtedly influenced by the allocation of land to the Chinese settlers only along this road, and the ribbon development is therefore not exactly a natural one. However, the completion of the Bau-Lundu road and the Serian-Balai Ringin road has now given cause to the same type of development and this being not influenced by extraneous causes may serve as a better example of natural development.

The upriver areas are still served by many footpaths built by the local population in the past and now improved as gotong-royong paths. They still serve as local communication lines between kampongs and as access lines to motorable roads. The Iban who, even in remote up-country, did not rely very much on land routes and who preferred to wait for rain to take their boats downriver (this is contrast with the Land Dayaks who traditionally preferred to move by land), are now more and more establishing land routes, although for the transporting of goods they still make much use of the rivers.

In conclusion, the location of roads and administrative centres has resulted in the development of intensive agriculture mainly along roads and around these centres, this often regardless of soil suitability. Land-use in these areas is therefore more influenced by economic factors such as ease of communication and transport than to productivity of soils. Commonly along the roads, the best soils are used for permanent agriculture, but only if land availability is not a problem. This factor is becoming less important where economic factors start to weigh more heavily such as in the immediate surroundings of large markets like Kuching, where soil suitability is overruled by other economic considerations.

CHAPTER 8. POPULATION AND LAND SETTLEMENT

1. Sources of Information

The Region is by Sarawak standards well-populated, about 30% of Sarawak's rural population is living in an area of about 9% of the total land surface of the State.

Table 17 (p.108) shows the total population by race in the various districts, while Table 18 (p.109) shows the approximate population density.

The figures in Tables 17 and 18 are obtained from the 1960 Sarawak Census (Jones, 1962) and do not hold good for the present situation. They are therefore only of indicative value, but adequately show the relative importance of each racial group in the various districts which probably has changed very little over the years. Since no separate figures were available for those parts of the Simanggang and Lubok Antu Districts falling within the Region, the figures for Simanggang as stated by Jones were reduced by half, and those for Lubok Antu by four-fifths. The latter figures are therefore of very indicative value only.

The notes on the history of settlement are mainly based on information received from the local inhabitants while on surveying. They throw an interesting light on the movements of people and related land use in the past and present, but it is well realised that the information is neither complete nor probably completely true. The author is well aware of these fallacies but nevertheless is of the opinion that a little information of this kind is better than none at all. It is hoped that by this, interest is created in this subject which has been very much ignored in the past, particularly as far as the Land Dayaks are concerned, and that more comprehensive studies carried out by more competent workers may follow this one in future.

2. The Iban (36,700 people)

The Ibans are found in most parts of the Second Division falling within the Region and in the Lower Sadong District. They have also settled along the lower stretches of rivers in the Kuching Rural and Lundu Districts. Traditionally, the Iban (Sea Dayak) use water transport and this is the reason why they are found concentrated along major streams and in areas along the coast. The various groups of Ibans found in the Region originate mainly from the middle part of the Batang Lupar river basin between Lubok Antu and Engkilili. (Pringler, 1970). From these areas people moved up the small streams to the watershed with the Undup area which was thereafter settled. Little or none is known about the original people living there, if any. Pringler (1970) indicates that they may be Bukitans who were non-agriculturists. Quite possible the Undup was populated by Iban moving from the Engkilili area and by Iban moving upstream along the Undup river. The Iban which are traditonally hill-padi planters using shifting cultivation methods, required large areas of primary forest to satisfy their needs. Primary forest was usually cut down at a rate of about 4 acres per family per year and planted up with hill padi. The 'umah' was abandoned after one or two crops because of declining yields and encroachment of weeds and a new area of primary jungle was felled (see Chapter 6, p.97). When the area of primary forest left became too small for the community one either had to return to the old areas covered with secondary jungle or to look for virgin areas. In the old days, the last course was frequently taken. Iban moved down the Lupar river and upstream of the Strap river until this was populated up to the Indonesian border and the watersheds with the Lower Sadong river. The same type of migration took place in the Sebuyau river basin and along the coast.

In the areas just described there are four main groups of Iban which refer to themselves as Batang Ai (the Lubok Antu area), Undup (in the Undup area itself and along the Batang Lupar downstream of Engkilili to the Undup river), Balau (further downstream Simanggang along the Batang Lupar and in the drainage basin of the

Batang Strap) and Sebuyau (along the lower reaches of the Batang Lupar, along the coast and in the Sebuyau drainage basin. This differentiation seems to be already of long standing and is probably not affected by moving of people from one area to another. Generally people moving from one territory to another retain their original kinship name at least for some considerable time. Some recent movements of Undup people into the Balau area has taken place but people still refer to themselves as Undup Iban (ref. Kampong Kranggas); older settlements in the Lundu area are still referred to as Sebuyau people.

The Lower Sadong District was populated probably starting from the estuary of the Sadong river stream upward, so that the coastal areas were first settled followed by the Simunjan Kiri and Simunjan Kanan basins. A very old settlement called Tapang Lebat (Balau people) in the upstream area of the Batang Krangan forms the mother-settlement of many longhouses in the area such as Pinang, Sabal Kruin and Abok, which are all Balau people. It is therefore possible that in the past Balau people moved across the watershed from the Strap basin into the upper areas of the Sadong basin and initially settled in Tapang Lebat a long distance away from their original area. Thereafter, they spread out again. It is here where Sebuyau and Balau people met up, the former moving upstreams along the Sadong river while the latter were moving downstream. From the Lower Sadong area and the Nonok Peninsula Sebuyau people have migrated to the Kuching and Lundu areas. The Sebuyau people although Iban in language and culture have adopted many ways which are not akin to the Iban. This may be due to a long separation from the main group or closer contact with other population group living near the coast. Example: they have practised wet padi farming longer than any other group of Iban people.

During the last decennia Iban movements have virtually stopped and are now strictly controlled. During the late fifties, a group of Batang Ai people were allowed to settle in the middle Kayan area of the Lundu District (ref. Kampong Sebandi). Another group from Kanowit settled quite recently at Batu Gong at the Samarahan river. Because of restricted movements, the Iban population is more and more reverting to re-using land used for shifting cultivation in the past and to the growing of permanent crops. It is of interest to note that although e.g. the Undup area was quite probably densely populated in the past, the land appears to be less overfarmed than in more recently settled areas. This is not related to differences in natural soil fertility but it is probably caused by the fact that in the past when the primary jungle was consumed much of the population moved out again to new areas, so that the remaining people were but few. The remaining small population had sufficient secondary forest left to maintain long rotation cycles for adequate regeneration of forest. In the newly settled areas where the struggle for land was much severe, particularly after the migrations were curbed by the Government the length of the rotation cycles declined in a much shorter period than in the older abandoned areas. Therefore, the presence of overfarmed land in a certain area does not necessarily imply that the areas have been occupied for a long period. It probably only indicates that the land use was too intensive during the period the land was used.

3. **The Land Dayaks** (57,043 people)

Land Dayaks form the majority of the native races in the Bau and Upper Sadong Districts. Most of the upper riverine areas in these districts, including the Lundu and Kuching Rural Districts are populated by them. They are probably the oldest established group in the Region and appear to be related to Dayak tribes found as far away as Sabah while there is also a linguistic connection with the Melanaus, another old established group in the coastal areas of the Third and Fourth Divisions.

The Land Dayaks in the area can be differentiated into many tribes and subtribes of which the main differences are of a linguistic nature. There are many local differences in *adat**, style of housing, clothing and in tools but they are minor if compared with the large Iban group.

It is, nevertheless, surprising to note how great the linguistic differences between the various groups can become, so that even the most basic names for water and food are totally different in the various languages. How such a tremendous change in word choice can come about is shown by the following example: The word 'ramin' for house is almost invariably used by the many Land Dayak tribes; even in Sabah and in the Melanau areas this word is known. In the Jagoi area in Bau the word 'bori' is used for a farm-hut but 'ramin' for a house in the village. At present the younger population uses almost exclusively the word 'bori' for all houses, also for those in the village and the word 'ramin' is becoming outmoded.

In the Upper Sadong area we find one main group, namely the Bukar-Sadong Dayaks which can be subdivided into the Kayan (no connection with the Kayans in the 3rd Division) and Kedup subtribes which have small dialectial differences in their language but also in *adat*. Both subtribes seem to originate from across the Indonesian border where still many people of the same group

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***Adat — custom**

are living. They probably split up when arriving in Sarawak and one stream moved down into the Kayan river basin, while the other settled in the Kedup river basin. Information on the movements of the Kayan subgroup were collected during soil surveys. These movements are shown in Fig. III.1 (p.110) which is incomplete and serves only as an illustration.

Kujong Sain is probably the oldest settlement in the area. From this mother-kampong sprouted Temung, Tebedu, Taub and Gahat. From Taub, people moved to Pichin which in its turn became the mother kampong of Tebakang and Krusin. Tebakang again is the mother kampong of the latest split-off, namely Kampong Sebemban found downstream of Serian.

One can, therefore, speak of mother kampongs of the First, Second, Third and Fourth generation, although probably at least four human generations or a 100 years had passed before a new split-off occurred. Wallace (1869) reports in his journey along the Sadong river which took place in 1855-56 that he came across Tebakang as being the first Land Dayak village going upstream from Serian. This kampong is therefore at least 120 years old; he also refers to Borotoi (probably Retoh) and Budw (probably Tebedu). He makes mentioning of Menyerry at the top of the mountain in the source area of the Kayan river. Remnants of Menyerry are still there (Tembawang-fruit trees), but the old kampong has disappeared.

It is of interest to note that all the movements depicted in Fig. III.1 (p.110) indicate a direction towards the coast and downstream. This is contrary to the general belief that the Land Dayak were in the past probably coastal people (the bended parang is often used as an example of a relic tool used to hollow out the interior of sago trees) but the facts point out that they probably never reached the coast but were halted by other people there. The bended parang is explained by them as facilitating cutting and weeding on steep slopes. Quite certainly they had at one stage to withdraw inland or their movements were halted because of raiding Ibans moving upriver but in the Sadong area a reversed movement never took place to the extent that one is led to believe. The location pattern of mother villages indicates that movements involved comparative long distances and the spreading out was not regularly. New settlements would be founded quite far away from the old ones leaving enough land in between, which was taken up at a later stage by a new group or it was gradually consumed by people spreading from the mother villages. A rough estimation is that the area has been settled probably for at least 600 years or so. The Land Dayaks quite definitely have in their language a Javanese influence. There is also a Hinduistic trend in their religious beliefs and it stands to reason to assume that they are influenced by the Javanese during the Modjopait era (around 1,200 A.C.) when still living in the Kapuas region of Kalimantan. It is regrettable that the Land Dayaks are a group on which little historical studies have been made. Their history probably reaches back further into the past than that of the Iban but for this reason it may be more difficult to reconstruct.

It can be learned from the available facts that the Sedong Dayaks are very much tied to their specific area, in which they were confined for a long time. That they were able to support themselves in such a comparative small area is partly due to the fact that the soils there are of relative high fertility for Sarawak standards; probably their restricted number has played a role as well. Quite definitely the forest regeneration is not as bad as in many places populated by the Iban, but this could also be related to different farming methods.

The latest movements coincided with the Japanese occupation during which settling in the primary forest area between the Kedup river and the Krang river was allowed. Since this area is partly still under primary forest (Balai Ringin Forest Reserve) one would think that in the past nobody lived there, it being a type of nomansland between the Iban in the east and the Land Dayaks to the west.

Land Dayaks movements in the Kuching Rural and Bau Districts followed very much the same pattern. In the Kuching Rural District and in the triangle Penrissen Road-Kuching-Serian Road from 7th mile to the 21st mile, one finds a variety of subtribes which are referred to as the Quop people. One can made further distinction between the Simpok people (a very small subtribe living almost exclusively at Simpok), the Bra-ang people who have their mother village in Bra-ang Wah on the mountain of that name and which have spread along the Padawan Road and to the east to where they meet the Bukar tribe east of Sira and Subang. The Karuh people live along the Sarawak Kiri and at the end of the Penrissen Road. They are related to the Sennah people living more upstream of the Sarawak Kiri up to the watershed with the Sadong drainage basin. These tribes and subtribes have all come down from the Penrissen-Bungo area (so they say) and each subtribe probably is related to one mother village which was founded in the early days. These mother villages are remote from each other and people from these villages did not spread out very far. Land settlement must, therefore, have started from small nuclei at relative long distances which have expanded until the territory of neighbouring villages was reached.

The Bau area shows a similar settlement pattern. Also here the stories relate to the Kalimantan border area, Penrissen-Bungoh massif, as the original homeland of the local Dayaks. They probably came down along the Sarawak Kanan. A very old mother village is Tembawang Sauh to which most of the Jagoi-Singghi people are in some way related. The villages on Bukits Singghi and Jagoi were founded due to recurring Iban raids. When this stopped in the middle of the 19th century, people started to spread out as shown in Fig. III.2 (p.110). This has been qu te a recent development and it is amazing to see how rapid this process was; no doubt the population increased was accelerated by better medical care, and the curbing of Iban raids. The Jagoi tribe moved not in to the Lundu District until the Japanese occupation (Selampit). In this area further expansion was halted by the Government policy not to allow more movements into primary forest areas.

The Lundu District is populated by Selakau Dayaks of which the Biawak and Pueh subtribes are the most important ones. They have come in from Kalimantan in quite recent times; old Pueh Selakau's can still recall the day. This is probably the reason why a large area of primary jungle still exists in the Lundu District.

There are a few other minor tribes living in the Region, such as the Lara Dayaks at Kandai, the Gumbang people at Gumbang, and the Melikin in the Balai Ringin area. The latter appear to be related to the Iban and originally owned much land in the Nonok Peninsula (as the story goes).

All Dayak tribes have in common that they are fervent hill padi planters. The system employed has been discussed in Chapter 6 (p.97,. Of interest is to note that they have their own soil classification system which is totally geared to the cultivation of padi. Much emphasis is placed on the blackness of the topsoil and the location of the land. So is a footslope area (Tanah lebak) characterised by a dark topsoil and classified as a number one soil for hill padi. A sandy soil on a flat area is called 'kerangas', undoubtedly the least suitable for padi. The Land Dayaks generally work their hill padi farms more intensively than the Iban. Their burnings are better, and much small debris is gathered and piled for repeated burns. No doubt the non-availability of large areas of primary forest for the last generations has influenced this use.

4. The Chinese (100,241 people)

The Chinese form the largest population group in the Region but in the upper riverine areas they are in the minority. By introducing new crops and good farming methods, they greatly contribute to the agricultural development in the areas where they have settled. Other races which in the past supplied much of the farm labour in Chinese areas, have gained a lot of valuable agricultural experience through these contacts.

Most Chinese settlements are in some way related to the mining industry which flourished in the Bau area in the 19th century. Although Chinese business and tradesmen have lived in the Region probably for centuries their numbers were greatly increased when gold, silver and mercury were found in the Bau area. Originally, they came down in large numbers from the Sambas area in Kalimantan to work as coolies in the Bau mines (Lee, 1970). Their descendants settled first in the Bau District and were engaged in agriculture if not working in the mines. Land was obtained by direct purchase from the local Dayaks or by arrangements through intermarriages. The Krokong-Bau-Buso-Sinawan-Batu Kitang area is almost entirely inhabited by Chinese who concentrated in this Mixed Zone Area created by the Government so that they could freely purchase land. When a large number of mines were closed down the Chinese left the Bau area in great numbers and settled along the Kuching-Serian Road and in the Nonok Peninsula where also Mixed Zone Areas were created. This areas received a great influx of Chinese farmers during the thirties. Apart from the large Chinese communities found around Kuching Town, along the Kuching-Serian Road in the Bau area, and in the Nonok Peninsula, small concentrations are found near Engkilili (also connected with mining activities in the past at the Marup Range), in the Pantu area along the Batang Strap, at Tebedu in the upstream area of the Sadong-Kayan river where Chinese in the past were engaged in gold mining and in search for diamonds, and in the Lundu District around the Gading massif.

These Chinese settlements are all farming communities which have been and are of great economic importance for the Region as a whole. In the past, the bulk of the farming produce came from these areas. The creation of Mixed Zone Land in which most of the Chinese farmers have settled has resulted in a concentration of areas with intensive land use. Such a land use pattern does not reflect soil suitability but is only the result of extraneous factors. The Mixed Zone Areas therefore are exemplary of what can be done with even the less suitable soil types, given sufficient capital and know-how.

The exchange of know-how between the Chinese and other races, particularly the Land Dayaks who for a long period, have lived in close contact with them, is slowly changing the agriculture pattern in some Land Dayak areas. This is a natural process which takes a long time to mature but the influence is certainly much in evidence by the large areas of pepper now planted up by former farm labourers in their own areas.

The Chinese are masters in adapting themselves to unsuitable conditions and are able to grow pepper on wet swampy land, if this happens to

Table 17

Total Rural Population of the Region by District and Community

Census District	All Communities	European	Malay	Melanau	Sea Dayak	Land Dayak	Other Indigenous	Chinese	Others
Lundu	13,408	23	4,242	7	2,014	4,035	51	3,009	27
Bau	23,119	4	1,510	1	185	13,057	-	8,196	166
Kuching Rural	98,877	149	35,934	165	4,970	16,151	49	39,433	2,026
Upper Sadong	37,378	23	2,870	14	4,293	23,102	17	6,627	432
Lower Sadong	24,593	1	12,672	15	7,658	76	-	3,311	860
First Division	197,375	200	57,228	202	19,120	56,421	117	60,576	3,511
Simanggang	20,194	27	3,597	6	13,935	26	1	2,569	32
Lubok Antu	3,225	1	33	-	2,811	2	1	375	2
Second Division	23,419	28	3,630	6	16,746	28	2	2,944	34
Grand Total	220,794	228	60,858	208	35,866	56,449	119	63,520	3,545

Ref. Report on the census of population, 1960, table 1, Jones, L.W. (1962).

Table 18

Density of rural population per District

	area sq. miles	total population	density per sq. mile
Lundu	679	13,408	19
Bau	330	23,119	73
Kuching	927	98,877	107
Lower Sadong	660	37,378	62
Upper Sadong	781	24,593	32
Simanggang Area	900	20,194	22
Lubok Antu Area	99	3,225	33

Fig. III. 1

Movements of the Bukar-Sadong Land Dayaks (Upper Sadong District)

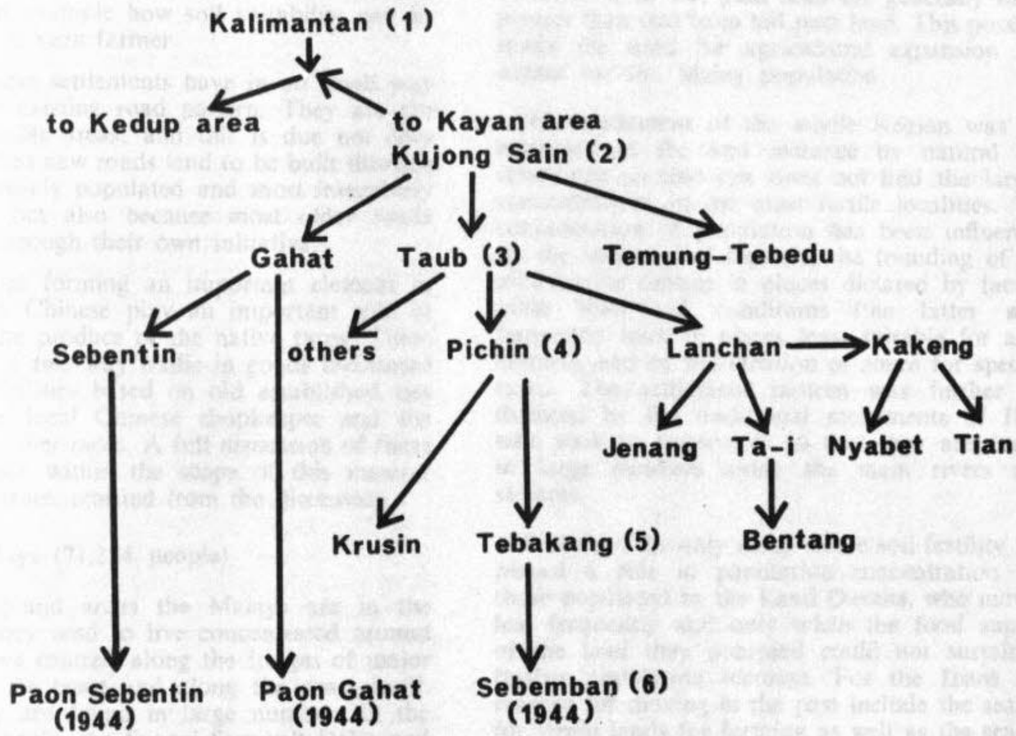
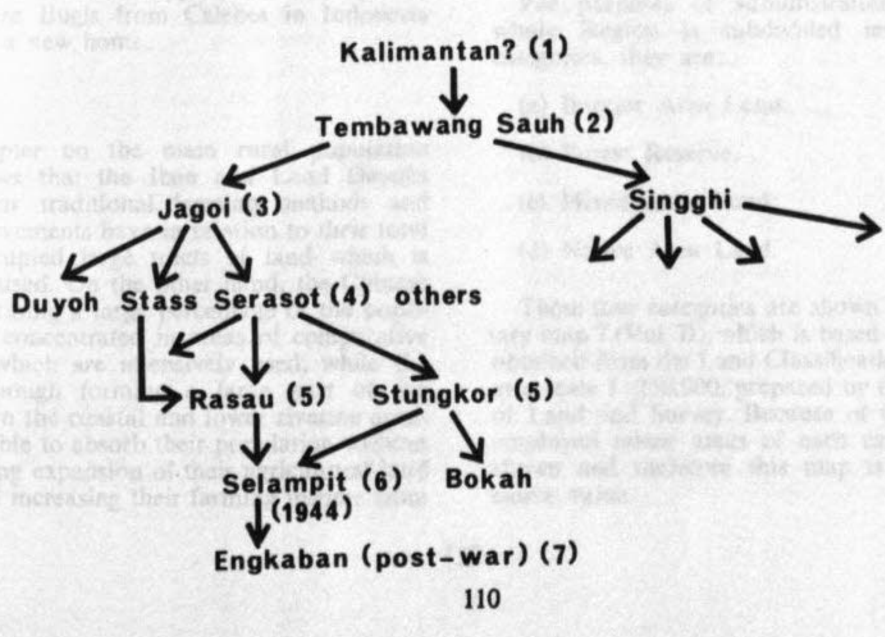


Fig. III. 2

Movements of the Sauh-Jagoi Land Dayaks (Bau-Lundu Districts)



be the only land available to them, by building large mounds using upland soils carried from a neighbouring hill. Although in modern times this may not be regarded as economical, it nevertheless serves as an example how soil suitability can be changed by a keen farmer.

The Chinese settlements have in no small way affected the existing road pattern. They are the most accessable areas; and this is due not only to the fact that new roads tend to be built through the most densely populated and most intensively used areas but also because most older roads were built through their own initiative.

Apart from forming an important element in farming, the Chinese play an important role in marketing the produce of the native races. There is generally a two way traffic in goods facilitated by credit facilities based on old established ties between the local Chinese shopkeeper and the villagers of other races. A full discussion of these aspects is not within the scope of this memoir and is, therefore, omitted from the discussion.

5. **The Malays** (71,254 people)

In the upland areas the Malays are in the minority. They tend to live concentrated around administrative centres, along the fringes of major rivers near the coast and along the coast itself. The Malays are found in large numbers in the Nonok Peninsula, the Sungei Sarawak Delta and all along the coast up to Tanjong Datu. Traditionally, they are coconut and wet rice planters, while at the coast these farming activities are augmented by fishing and the exploitation of nipah palm.

Although they have been living in these areas for centuries, quite a number, originating from the Sambas area in Kalimantan, settled in relatively recent times in the Sematan-Tanjong Datu area. The same happened to the east of Nonok where Bugis from Celebes in Indonesia have found a new home.

Conclusion:

This chapter on the main rural population groups shows that the Iban and Land Dayaks through their traditional farming methods and frequent movements have in relation to their total number occupied large tracts of land which is extensively used. On the other hand, the Chinese although forming a large percentage of the population have concentrated in areas of comparative small size which are intensively used, while the Malays although forming a large part of the population in the coastal and lower riverine areas have been able to absorb their population without accompanying expansion of their agricultural land by means of increasing their farming income from other sources, such as fishing, the exploitation of the nipah palm and by finding employment in the non-agricultural sections. No doubt, the yields obtained from wet padi land are generally much greater than that from hill padi land. This possibly made the need for agricultural expansion less urgent for the Malay population.

The settlement of the whole Region was not regulated in the first instance by natural soil conditions so that one does not find the largest concentrations in the most fertile localities. The concentration of population has been influenced by the locations of bazaars, the founding of administrative centres in places dictated by factors other than soil conditions (the latter were frequently built in places least suitable for agriculture), and by the creation of zones for specific races. The settlement pattern was further influenced by the traditional movements of Iban who took to waterways so that they are found in large numbers along the main rivers and streams.

Probably, the only areas where soil fertility has played a role in population concentration are those populated by the Land Dayaks, who moved less frequently and only when the food supply of the land they occupied could not sustain a further population increase. For the Ibans the reasons for moving in the past include the search for virgin lands for farming as well as the search for new hunting ground; this was related to the author by one old Iban in a settlement sited on Kerangas soil. These Ibans had originally settled there because the area around provided good hunting, while the agricultural suitability of the land did not seem to play a role at all.

6. **Legal Status of Land**

For purposes of administration of land the whole Region is subdivided into four main categories, they are:

(a) Interior Area Land;

(b) Forest Reserve;

(c) Mixed Zone Land;

(d) Native Area Land.

These four categories are shown on supplementary map 7 (Vol. II), which is based on information obtained from the Land Classification Map (1968), at a scale 1:250,000, prepared by the Department of Land and Survey. Because of the small scale employed minor areas of each category are not shown and therefore this map is only of indicative value.

The definitions of each land category are given in detail in the Land Code (The Laws of Sarawak, chapter 81, 1958) and are summarised as follows:

(a) Interior Area Land means land not falling within any of the other three categories and is therefore a residual category.

(b) Forest Reserves are forest areas which are together with all the produce thereof and things found therein, the property of the Government. (Laws of Sarawak, Chapter 126, 12.2, 1958).

(c) Mixed Zone Land means land in which natives and non-natives may acquire rights or privileges.

(b) Native Area Land means land in which normally only natives may acquire rights or privileges.

The interior Area Land in West Sarawak is by and large populated by Iban and Dayaks who practise shifting cultivation and they may therefore qualify, under the observation of certain rules, for native customary rights over the land. Some parts have been aliènated as Communal Forest Reserve or other Reserved Land, but the amount of primary forest left in these areas (except for the Fresh Water Peat Forests) is but small.

The Forest Reserves are partly made up of Protected Forest and National Parks, while the remainder has not received any permanent use. This type of land may in the future in part be allocated for agricultural use or for other purposes if the reasons are justifiable. The areas are not populated.

The Mixed Zone Land comprises for the majority alienated land because non-natives are allowed to procure rights only in these areas. Chinese, therefore, are found concentrated there. These areas are generally the most populated ones and the land is most intensively used.

Native Area Land is partly owned by natives, this type of land is partly well developed and intensively used. Where it is reserved for natives, the land may either still be forested or is under shifting cultivation.

The relationship between agricultural use and the legal status of land is therefore a strong one.

Generally speaking, the areas at present not used for some form of cultivation were from a topographical and soils point of view the most difficult ones to use for agriculture as practised in West Sarawak in the past. These areas were therefore left under primary forest. For this reason, Forest Reserves tend to be formed by mountainous or swampy terrain or by areas where the natives considered the soils to be too poor for hill padi cultivation. Parts of the Lundu District form an exception, since the natural spreading of population was more or less halted by administrative measures before more people had moved into these areas.

Part IV — SOILS

Chapter 9. CLASSIFICATION

1. General

The first attempt to bring some order to the various soil mapping units in use since 1960 was made in 1961/62 when a field classification was devised for correlating mapping units commonly found in the State. This field classification (Andriesse, 1962) did not aim at a grouping of soils on a taxonomic basis as it was felt then that insufficient knowledge was available for this purpose. The field classification was based mainly on topography and parent material which were considered the most important soil forming factors. Soil units found in defined topographic situations and on defined types of parent materials were assigned a code number rather than a name. This system was adopted to avoid frequent changes in definitions of a multitude of soil series which may otherwise have been created and which, if officially released, would be difficult to change at a later date. It was thought that with the pooling of sufficient information under these numbered soil units a taxonomic classification could then be made at a future date.

The field classification included an attempt to correlate soils found in Sarawak up to that date with established soil classification systems at the Great Group level. This with the intention to indicate the relationship existing in Sarawak between World Great Soil Groups and the soil forming factors topography and parent material. Shortly after, a provisional classification scheme was published by Dames (1962); this was based on field work by Dames prior to 1960. Table 19 (p.115) correlates units of the classification proposed by Dames with the provisional attempt by the author and soil groups currently in use. While Dames paid much attention to the drainage factor, the author tried to emphasize in his scheme the degree of podzolization and laterization, and for this reason, he recognised more groups in the upland soils than Dames. The fact that Dames was more concerned with lowland soils in his survey work may have partly influenced his tentative classification.

Both tentative classifications, however, recognise the value of a classification based on genetic criteria. This choice no doubt was obviated by the lack of sufficient laboratory and field data and the strong relation between soils and soil forming factors such as topography and parent material. This strong bias on genesis has played a role in the Sarawak soil classification attempts until the present date. Since 1962, several other soil groups were suggested in soil survey reports. The author (1964a and 1965b) introduced the REDDISH-BROWN LATERITIC SOILS and the PLANOSOLS, the former comprising soils formerly called RED LATOSOLS formed on basic igneous rocks and the latter comprising soils with Podzolic features and strong textural contrast. HALOMORPHIC SOILS were renamed as SALINE SOILS while BOG SOILS were subdivided into HALF BOG and BOG SOILS. The existence of MOUNTAIN PEAT SOILS was also recognised for the first time. (Andriesse, 1964a).

These later classification attempts deal only with soils found in parts of West Sarawak and involved also the separation of several series within the recognised groups and a provisional placing of series into families between the group and series level. It was, however, strongly felt by the majority of the Soil Survey Staff that a classification at the group and family level should firstly be put on a firm basis prior to the establishment of series. The author does not share this viewpoint, and is of the opinion that the soil series is the basic soil unit recognised in the field. This in accordance with the principles given in the U.S.D.A. Soil Survey Manual (1951, p.300), which states that differentiating criteria of the family must be drawn from characteristics accumulating between the Great Soil Group and Series level.

It is suggested that present classification problems in Sarawak are mainly the result of deviation from these principles. Soil groups and series should be mapped and defined prior to families. However, a subsequent attempt to classify Sarawak soils at the group and family level resulted in the first official Classification of Sarawak Soils issued in 1966 (Soil Survey Staff). The classification aims to group the soils of Sarawak on account of characteristics assumed to be of genetic importance. A strong relationship with previous attempts was maintained but the boundaries between the various groups and families were strictly defined in terms of diagnostic features mainly adopted from the American Classification System, 7th Approximation (U.S. D.A., 1960). It is, perhaps, unfortunate that some diagnostic features were defined in terms of the 7th Approximation while others adhered to older definitions, given in the U.S.D.A. Soil Survey Manual (1951).

This has resulted in a classification which claims to be of practical value in mapping but which does not allow for the occurrence of transitional forms between groups and families. Many diagnostic criteria chosen for a classifica-

Table 19

Correlation of Soil Groups in Soil Classification Systems Employed in Sarawak since 1960.

Dames (1962)	Andriesse (1962d)	Soil Survey Staff (1966)
Lithosols	Skeletal Soils	Skeletal Soils
Brown Latosols	Red Latosols (intergrade to Red-Yellow Podzolic)	Lateritic Soils (brown coloured)
	Red Latosol	Lateritic Soils (reddish-brown coloured)
Yellow Latosol	Red-Yellow Podzolic soils (only well-drained members)	Red-Yellow Podzolic soils (not differentiated)
Red-Yellow Podzolic Soils	Red-Yellow Podzolics soils (excluding imperfectly drained members)	Red-Yellow Podzolics soils (not differentiated)
	Red Podzolic soils	Red-Yellow Podzolic soils (members on acid igneous soils)
	Yellow Podzolic soils	Red-Yellow Podzolic soils (members with distinct albic A2)
Red-Yellow Podzolic Soils (concretionary)		Groundwater Laterites
Imperfectly drained Red-Yellow Podzolic Soils	Semi-Gley Soils	Red-Yellow Podzolic soils (not differentiated)
Grey-Hydromorphic Soils	Podzolic Soils	Grey-White Podzolic Soils
Humus Grey-Hydromorphic Soils	Hydromorphic Soils	Gley Soils (old alluvial members only)
Low Humic Gley	Groundwater Gley (only recent alluvial members)	Gley Soils (only recent alluvial members)
Humus Podzols	Humus Podzols	Podzols
Giant Humus Podzol	Regosol	'Podzols'
Bog Soils	Bog Soils	Peat Soils
Alluvial Soils	Halomorphic Soils Regosols	Saline-Gley Soils Recent Alluvial Soils

Table 20

SCHEMATIC LAY-OUT OF SARAWAK. SOIL CLASSIFICATION SCHEME (1966). (adjusted to West Sarawak conditions, 1970)

GROUP	DIFFERENTIATING DIAGNOSTIC FEATURES FOR FAMILIES: 1st LEVEL	2nd LEVEL	3rd LEVEL	4th LEVEL	FAMILIES	SERIES	
SKELETAL SOILS		R horizon within 10 inches			Meluan		
	Residual	C horizon within 10 inches	< 500 ppm phosporus in fine earth.		Kapit	Buri	immature - on acid igneous rocks
			> 500 ppm phosporus in fine earth		Sedong	Sedong	immature - on basic to intermediate igneous rocks
	Mixed	Well to imp. drained above IIC or IIR horizon			Binatong[3]		
		Poorly to very poorly drained above IIC or IIR horizon.			Kelupu[3]		
	Alluvial	Not further differentiated			Gaya (partly Regosols)	Lundu series (Kilong)	boulder fans - granitic/sandstone origin; deep old marine sands
BROWN FOREST SOILS		Not further differentiated		Heavy textured[1]	Kabuloh[3]		
				Light textured[1]	Kedadum[3]		
LATERITIC SOILS		Not further differentiated			Tarat	Bukit Batu; Tarat; Jebong; Antayan; Sejingkat	kaolinitic - crumbly; gibbsitic - crumbly; gibbsitic - blocky; blocky - yellow on ?; blocky - on silicified basic igneous rocks
RED-YELLOW PODZOLIC SOILS	Residual	Albic horizon present			Matang		
		No albic horizon present	More than 20% group III elements in A2 and B horizons.		Abok	Gading; Jagoi; Gumbang; Abok; Keladan; Bayur; Serin	strong coloured - on granites; light coloured - on granites; strong coloured - tonalites, hornfels; strong coloured - miscellaneous derivation; red - on tuffaceous material; on schist; on arkose
			Less than 20% group III elements in A2 and B horizons.	Light textured[1]	Nyalau		
				Medium textured[1]	Bekenu	Biawak	
				Heavy textured[1]	Merit	Bedup (Stoss); Semongok; Padawan; Stom; Rapak; Melugu; Begunan	well drained, with kaolinitic subsoils (Tria); well drained, on variegated shale (Cret); strongly mottled on variegated shale (Cret); pale coloured, on variegated shale (Cret); well drained, on mudstone; with thick concretionary layer; well drained, on hard shale; on red mudstone
	Alluvial	Recent deposits		Light textured	Semilajau[4]		in West Sarawak Kayan family
				Heavy textured	Malang[4]		in West Sarawak Seduau family
		Old deposits		Light textured	Sabangang[3]		
				Heavy textured	Lupar[3]		
GREY-WHITE PODZOLIC SOILS	Residual			Fine textured[1]	Kerait	Kerait; Rukam; Serayan	on carbonaceous shales; on chert and phyllites; on chert
				Coarser than fine textured[1]	Saratok	Lingga	on iron-poor granite
	Old alluvial			Fine textured	Lubai	Merang	bisequent
				Coarser than fine textured	Triboh		
PODZOLS and GROUNDWATER PODZOLS	Residual	With B_h	Strongly developed		Bako[3]		
			Weakly developed		Silantek	Butan	on tertiary sandstone
	Alluvial		Strongly developed		Miri		
			Weakly developed		Buso		
		With B_{ir}	Weakly developed		Jerijeh	Pueh; Stoh	continuous B_{ir}; incipient B_{ir}
GROUNDWATER LATERITES	Upland	Not further differentiated			Rapak[3]		probably non-existent in West Sarawak mapped respectively in Merit and Seduau families
	Lowland				Bentong[3]		
GLEY SOILS	Light textured		No peaty O horizon less than 10" thick		Tatau	Mundai	calcium rich, riverine
						Tatau	marine
						Plan	riverine, sedimentary rock derived
						Gong	old riverine
						Bokah	colluvial - bisequent
						Nyabu	basic ign. rock derived, riverine
			Peaty O horizon less than 10" thick		Matu[4]		in West Sarawak organic phase of Tatau family
	Heavy textured	Residual or old alluvial	No peaty O horizon less than 10" thick.		Semado	Semado; Embang	residual; old alluvial
			Peaty O horizon less than 10" thick		Gerawat[3]		
		Recent alluvial	No peaty O horizon less than 10" thick.		Bijat	Bijat; Samarahan; Daro[3]; Kakai; Paya Megok; Punda	large floodplains, mixed derivation; inland valleys; sedimentary rock derived; inland valleys; basic igneous rock derived; inland valleys; on limestone; inland valleys; with catclay
			Peaty O horizon less than 10" thick		Sebandi	Krian	with oolitic iron concretions
SALINE-GLEY SOILS	Mineral	Light textured	Weakly saline[1]	No peaty O horizon <10"	Not yet found		
				Peaty O horizon <10"	Nonak[3]		
			Strongly saline[1]	No peaty O horizon <10"	Belat[3]		
		Heavy textured	Weakly saline	No peaty O horizon <10"	Pendam	Pendam	in Nonok Peninsula
				Peaty O horizon <10"	Jol[4]		in West Sarawak organic phase of Tatau family
			Strongly saline	No peaty O horizon <10"	Rajang		
	Organic	Not further differentiated			Limbang[4]		in West Sarawak saline phase of Anderson
PEAT SOILS	Topogenic	O horizon 10 - 40" thick	Light textured mineral subsoil		Igan		
			Heavy textured mineral subsoil		Mukah		
		O horizon more than 40" thick			Anderson (includes Limbang in West Sarawak)		1. 40-80" deep. 2. 80-120" deep 3. >120" deep
	Climatogenic	O horizon 10 - 40" thick			Mulu[3]		
RECENT ALLUVIAL SOILS	Hues 7.5 YR or redder; values 5 or less.	Riverine	Light textured	no texture differentiation in West Sarawak	Ramun; Ramun (West Sarawak)	Ramun (light textured)	basic igneous rock derived
			Heavy textured		Terbat; Ramun (West Sarawak)	Terbat (heavy textured)	
						Entebar	mudstone derived
						Siar	granite derived
		Marine	Light textured		Sematan	Rambungan	not rubified, intergrade
						Sematan	leached, rubified
						Chupin	with petricalcic horizon
	Hues 10 YR or yellower; values 5 or less	Riverine	Light textured		Kayan	Kayan	sandstone derived
			Heavy textured		Seduau	Seduau	argillaceous rocks derived
						Sebat	micaceous, granite derived,
						Sekati	micaceous, granite derived intergrades to gley soil
						Paku	with oolitic iron concretions
						Malang	mixed origin, intergrade to gley soil
		Marine	Light textured		Kabong	Siru	with weatherable minerals
						Kabong[3]	without weatherable minerals

1) locally defined (Soil Survey staff, Sarawak, 1966)
2) defined according to U.S.D.A. system, 7th approximation (1960)
3) of none or very minor importance in West Sarawak
4) in West Sarawak mapped under other groups or families

tion at family level find a basis in the desirability that they must be mappable and therefore many classification units resemble mapping units. This has resulted in attaching undue importance to certain soil features, such as 'derivation' at too high a level of classification. The desire to be consistent throughout the scheme in the choice of diagnostic features regardless of the fact whether such a feature is of more importance in one group than in another has caused an imbalance between classification units and even in the creation of places for families which had not yet been found! Thus, the presence of an argillic horizon was used to differentiate PODZOLIC and LATERITIC SOILS. No doubt, the argillic horizon is an important diagnostic horizon used at the Order level in the 7th Approximation but to relegate it to the rank of a colour difference which is used to differentiate RED-YELLOW PODZOLIC SOILS from GREY-WHITE PODZOLIC SOILS is not justified. Similarly, the use of a 0 to 10 inches thick peat layer as a diagnostic criterion at the family level in lowland soils, is probably better considered as a phase difference at the series level since this thin organic matter layer will soon disappear upon cultivation and drainage.

Although the 1966 classification has many flaws, is nevertheless, fulfilled a purpose. Since 1965, all soils mapped according to this system have clearly defined characteristics which greatly facilitated soil correlation in Sarawak.

In the following section the Sarawak classification is discussed in detail, but only soils of importance for West Sarawak are mentioned. Some alterations have been made in this scheme for purposes of mapping West Sarawak soils. Notes to this effect and appropriate remarks on the reasons for these changes have been added. For ease of reference, the classification units together with the series recognised in West Sarawak are shown in a schematic form in Table 20 (p.116). For full descriptions of the families and/or series reference is made to Chapter 11.

Reviews and correlations with other important classification schemes on a World or Regional scale follow the discussion of the Sarawak classification.

2. The Sarawak Soil Classification (Soil Survey Staff, 1966)

This classification divides Sarawak soils into 11 groups comparable, as far as the categorical level is concerned, to the Great Soil Groups suggested by Baldwell, *et. al.* (1938) and Thorp and Smith (1949).

The groups are:

(a) SKELETAL SOILS
(b) BROWN FOREST SOILS
(c) LATERITIC SOILS
(d) RED-YELLOW PODZOLIC SOILS
(e) GREY-WHITE PODZOLIC SOILS
(f) PODZOLS and GROUNDWATER PODZOLS
(g) GROUNDWATER LATERITE SOILS
(h) GLEY SOILS
(i) SALINE-GLEY SOILS
(j) PEAT SOILS
(k) RECENT ALLUVIAL SOILS

(a) SKELETAL SOILS

These are soils with an incomplete solum and with no clearly expressed morphology and are defined as follows:

SKELETAL SOILS are mineral soils in which an R or C horizon is present within 10 inches of the base of an O horizon.

The definition is meant to correspond closely with the Lithosol group defined by Thorp and Smith (*op. cit*). In practise, the recognition of an R horizon does not present much difficulty but the recognition of the C horizon is a source of confusion. The C horizon in this definition refers to the old definition (U.S. Soil Survey Manual, 1951, p.180) and is meant to be the partially weathered parent rock. Colluvial rubble commonly occurring on steep slopes and extending to great depth is not a C horizon according to this definition but it is according to the new one given in the U.S.D.A. 7th Approximation (1960). In other classifications SKELETAL SOILS are commonly separated as LITHOSOLS based on the occurence of only an R horizon at shallow depth.

SKELETAL SOILS are subdivided into 6 families based on parent material, presence of an R or C horizon and drainage. These diagnostic features bear little relation to one another. While the type of parent material is considered to be of importance for the residual soils, drainage is taken as a differentiating feature in the soils of mixed origin, and alluvial soils are not subdivided at all. The **Meluan Family** with an R horizon at shallow depth is the only true LITHIC SOIL and may overly all types of parent materials, but, it is mainly found on Limestone and igneous rocks, and can also include bouldery and rocky land. The **Kapit** and **Sedong Families** are deeper than the **Meluan** having a C horizon found at shallow depth but extending to over 3 feet. Because they are agriculturally of importance a separation is made on account of origin. The **Kapit** is derived from acid igneous and sedimentary rocks and the **Sedong** from basic igneous rocks, total phosphorus is used as a diagnostic feature for derivation, as shown by experience.

Both families may comprise soils on colluvial rubble, weakly developed young soils or truncated mature soils. For this reason, they show great variations in chemical characteristics which would make further subdivision necessary. The range in chemical characteristics is particularly great in the **Sedong Family** where the soils include weakly developed young soils and eroded LATERITIC SOILS. It is suggested, therefore, that in future classification attempts a lithic contact at shallow depth can better be used for a subdivision under the relevant Soil Group. This would be more in agreement with principles adopted in the 7th Approximation since in reality these soils are shallow phases of different genetic soil groups.

In the **Sedong Family**, one series, the *Suka series*, has been separated; this is a weakly developed soil on fresh rock material. A similar soil type occurring in the **Kapit Family** and developed on granite has been mapped as *Buri series*.

The **Binatang** and **Kelupu Families** are of very minor importance and are normally mapped in association with other soil units. They occur in small valley bottoms, and may either overly hard rock or weathered soft rock. The soil material of these families is commonly colluvium mixed with alluvium. A separation based on drainage in the 1966 classification is not justified. More logical at this level would have been presence of an R or C horizon within 10 inches from the surface.

The **Gaya Family** is a heterogeneous family and includes soils which cannot be regarded as being truly SKELETAL but more REGOSOLIC in character. For this reason, in West Sarawak REGOSOLS have been mapped instead of SKELETAL SOILS in areas where **Gaya Family** soils comprise deep sand or gravel deposits without diagnostic horizons other than an A horizon.

One series provisionally placed within the **Gaya Family,** the *Kilong series,* is found in marine terrace deposits and is in fact a GIANT PODZOL in which the Bh is found below a depth of 4 feet. Another series, the *Lundu series,* mapped in mapping unit 23 (p.218), contains weakly developed soils on boulder beds. It is difficult to assign a family for this series because it is not clear whether the boulder beds mixed with clay and sand can be regarded as IIC horizon and the overlying soils are a different deposit, or whether the weakly developed soils are related to the underlying deposit. In the latter case, they should be regarded as shallow phases of other genetic groups instead of SKELETAL SOILS.

(b) BROWN FOREST SOILS

These are mineral soils in which:

(i) There is no C or R horizon within 10 inches of the base of an O horizon;

(ii) The C.E.C. of the lower B horizon exceeds 20 meq. %;

(iii) Chromas are 4 or more in the B horizon;

(iv) There is no gley horizon within 20 inches of the base of any O horizon;

(v) There is no argillic horizon.

These are considered to be young soils (INCEPTISOLS, 7th Approximation) without appreciable clay illuviation, with high cation exchange capacity and high base saturation. They have not been mapped in West Sarawak since they have formed mainly from calcareous rocks which are absent in the Region, with the exception of limestone too pure to give rise to soil development of any significance. However, the definition for BROWN FOREST SOILS is applicable to a variety of soils which have nothing in common with the intended groups of BROWN FOREST SOILS; some LATERITIC SOILS with a C.E.C. of more than 20 meq. would fall in this group. The definition should be more explicit in terms of presence of a well developed cambic horizon and base saturation percentage in order to characterise them adequately. Because of the very minor importance of this group in West Sarawak, the family classification is not discussed.

(c) LATERITIC SOILS

These are mineral soils of residual origin in which:

(i) There is no C or R horizon within 10 inches of the base of an O horizon;

(ii) The content of Group III elements as oxides is more than 25% in the A2 and B horizons;

(iii) Colours have chromas 4 or more in the A2 and B horizons;

(iv) There is no gley horizon within 20 inches of the base of an O horizon;

(v) There is no hardened plinthite.

The soils have strong affinities with the REDDISH-BROWN LATERITIC SOILS described by McCaleb (1959) but lack an illuvial clay horizon. Group III elements comprise mainly iron and aluminium oxides extracted by hot concentrated hydrochloric acid (see Analytical methods, Appendix, p.268) and the content of these oxides was inserted in the definition to emphasize their importance for the strong structural development and the basic igneous rock derivation. Subsequent studies have revealed that this limit of 25% cannot be maintained since there are soils rich in aluminium oxides which greatly influences the content of group III elements. The typical friable consistency and crumb structure of the LATERITIC SOILS is caused mainly by the iron oxides and therefore Group III content can better be replaced by content of iron oxides extracted by 6N. HCl which appears to be quite consistent for this group. Characteristics such as structure and colour vary considerably but none of these features have been found to be consistent with other features considered to be of greater importance and which may be used for a differentiation at family level. For this reason, only one family has been recognised, the **Tarat Family.** A number of series have been separated within this family namely: the *Tarat series*, representing the dominant soil type in the **Tarat Family.** It is characterised by a reddish brown to yellowish red colour, strong crumb structure and friable consistency. It is found on basic to intermediate igneous rocks. The *Bukit Batu series* is of similar nature as the *Tarat series* but has a different clay mineralogy (*Tarat*-kaolinitic, *Bukit-Batu*-gibbsitic). The *Jebong series* is strongly gibbsitic with blocky structure and yellow colour. The *Antayan series* is blocky and yellow but kaolinitic. All these series are found on basic to intermediate igneous rocks. The differences between the *Tarat, Bukit Batu and Antayan series*, although apparent in the field, cannot be easily explained by position, drainage or parent material. The soils are often found in complex. Degree of iron hydration plays a role but there are too many transitions in colour and structure between the *Tarat* and *Antayan series* to indicate a significant causal relationship between environment and soil characteristics. The *Sejingkat series* has a strong angular blocky structure also but varies in colour from red to yellow. This series is, however, mainly found on silicified volcanic rocks and is therefore mappable. Apart from its blocky structure there are also other chemical differences between this series and other soils in the family, such as content of Group III elements, which tends to be lower than normal for a **Tarat Family** soil, while also the total phosphorus content is lower.

The LATERITIC SOILS were thought to be all typical Oxisols (7th Approximation) having an oxic horizon. However, the blocky structure in the *Jebong, Antayan* and *Sejingkat series* is not normally found in Oxisols. There are also indications that the C.E.C. content of some *Antayan* soils is too high for an oxic horizon. Much more information on clay mineralogy will be needed to sort out these differences. For the present, it is reasonable to suggest that the great majority of LATERITIC SOILS are Oxisols.

(d) RED-YELLOW PODZOLIC SOILS

This group covers the largest upland area in the Region and also in Sarawak, and is therefore of great importance. The group has all the characteristics of RED-YELLOW PODZOLICS as defined by Thorp and Smith (1949). The intention of the local definition was to be more specific and exclusive and reads as follows:

RED-YELLOW PODZOLIC SOILS are mineral soils in which:

(i) An R or C horizon is not found within 10 inches of the base of an O horizon;

(ii) Chromas are 5 or more in the B horizon, hues are 2.5Y or redder in the B horizon, values are 5 or less in the B horizon;

(iii) There is no gley horizon within 20 inches of the base of an O horizon;

(iv) There is an A2 (possibly albic) horizon over an argillic horizon;

(v) If a Bir horizon is present there is no gley horizon within 48 inches of the base of an O horizon.

Because of the presence of an argillic horizon the definition excludes soils classified as LATERITIC SOILS. The original definition by Thorp and Smith does not mention the need for the presence of an illuvial clay horizon although the presence of more clay in the B is mentioned. For this reason, RED-YELLOW PODZOLICS in Sarawak are for the majority correctly classified in terms of the old definition. But quite a number may not be RED-YELLOW PODZOLIC SOILS in terms of the local definition. This sounds illogical but this is mainly caused by the fact that the local definition explicitly mentions the presence of an argillic B horizon. The insertion was based on speculation rather than on facts and a clay bulge in the B horizon is rarely encountered in these soils while micropedological investigations so far carried out indicate that insufficient amounts of orientated clay are present in the assumed argillic B horizons, to qualify as such. Moreover, a number of soils otherwise qualifying as RED-YELLOW PODZOLICS may have too high C.E.C. values and too high a weatherable clay content in the B horizon for an oxic horizon and they may have cambic horizons although probably only marginally so. For these reasons, the present definition is not tenable anymore and is in need for thorough revision.

What soils then have been classified as RED-YELLOW PODZOLICS? In practise, it means that upland soils with too low a content of Group III elements to qualify for LATERITIC SOILS and with colours too strong for GREY-WHITE PODZOLIC SOILS were regarded as RED-YELLOW PODZOLIC SOILS. (GLEY SOILS and PODZOLS being excluded because of other diagnostic features). Other environmental considerations such as parent material, texture and structure played a role as well but these characteristics are not considered to be diagnostic at the group level.

The parent materials are usually sandstones, shales and acid igneous rocks; structures are massive in the clay soils to crumb in the sandy soils; textures vary, depending on parent material but all soils generally show an increase in clay content with depth. LATERITIC SOILS show an opposite trend, clays overlying clay loams.

The separation of RED-YELLOW PODZOLIC SOILS from LATERITIC SOILS is a sensible one and of agricultural significance. Clay mineralogy is decidedly different as are texture and structure. However, more adequate means will have to be found to define these differences in diagnostic terms. The many transitions which occur between these groups should not be forgotten. A separation based on the presence or absence of an oxic, cambic or argillic horizon would probably solve the problem. This would need much more basic analytical information than is presently available.

The family classification is firstly based on origin of parent material, it being either residual or alluvial.

The residual families are separated on account of the presence or non-presence of an albic horizon. Those with an albic horizon are again split into families with more or less than 20% Group III elements as oxides. Only soils with less than 20% Group III are subdivided on account of texture.

The alluvial families are subdivided on account of age of the deposits, whereafter, they are separated on account of texture. It would appear that the criteria on which a differentiation at family level is based are not equally evaluated. The family with an albic horizon, **Matang Family,** was thought to be a sandy soil in all cases and therefore no further subdivision on account of texture was thought necessary. Some of the soils without an albic horizon had contents of group III elements transitional to LATERITIC SOILS and were therefore group in the **Abok Family** (more than 20% group III elements in the A3 and B) but also these were not further subdivided on account of texture. Finally, those residual soils without an albic horizon and with less than 20% group III elements are the only ones for which texture was used for a further differentiation. (**Nyalau, Bekenu** and **Merit Families**). The use of this great variety of diagnostic features for a separation of soils at the same categorical level has given rise to much classification difficulty. The **Matang** and **Abok Families** are comparable to subgroups (genetic features being used for a separation) and have a wide range of characteristics, while the **Nyalau, Bekenu** and **Merit Families** may together be regarded as one subgroup of the same categorical level as the **Matang** and **Abok Families** individually.

Mapping difficulties are also encountered for the alluvial families in this group. It seems illogical to assume the formation of RED-YELLOW PODZOLIC SOILS, such as the **Semilajau** and **Malang Families,** in recent deposits. RED-YELLOW PODZOLICS commonly form on old stable land surfaces and not in recent deposits. For this reason, **Semilajau** and **Malang Families** soils are not shown on the soil map for West Sarawak. The **Semilajau** is generally mapped as a drainage phase of the **Kayan Family** in the group of RECENT ALLUVIAL SOILS, because an argillic horizon in what should be **Semilajau** soils have never been observed by the author. For the same reason, **Malang Family** soils were not mapped in West Sarawak and soils comparable to this family mapped as such elsewhere, have been mapped in West Sarawak as imperfectly drained **Seduau Family** soils in the group of RECENT ALLUVIALS SOILS, the *Malang series* being the prototype.

The formation of RED-YELLOW PODZOLIC SOILS in old alluvials such as the **Sebangang** and **Lupar Families** is possible but if the alluvial nature of the soils cannot be assessed from soil characteristics found within 4 feet from the surface, it is suggested that this difference should not be used at such a high classification level.

In order to overcome mapping difficulties encountered with the RED-YELLOW PODZOLIC SOILS, many series were created in west Sarawak. It may appear that this provisional series classification may offer prospects for a redistribution of soils over new groups or subgroups. The series are based on:

(i) Genetic features such as clay mineral system;

(ii) Parent material;

(iii) Drainage features;

(iv) Presence of concretionary stonelines.

Some series represent soils transitional to other recognised soil groups. The **Matang Family** was not differentiated because this soil type rarely occurs and is normally mapped in complex with the **Nyalau Family.**

The **Abok Family** had to be separated into many series because of its subgroup nature and the consequently great variations in characteristics such as texture, structure and parent material. The *Gading* and *Jagoi series* occur on granites, the *Gading* having a strong brownish to red colour, the *Jagoi* being yellowish. Both series have a Group III content lower than 20% which is caused by the coarse texture (sandy loam to sandy clay loam). The influence of texture on Group III content was not recognised in the classification and for this reason the series officially does not belong to the **Abok Family** although according to all other characteristics it must have been the intention to include them.

The *Gumbang series* occurs on intermediate to acid, fine textured igneous rocks such as hornfels, dacite and diorite and is heavy textured; the colour ranges from olive yellow to brown yellow. This series is commonly very shallow. The *Abok series* is the prototype of the family as originally defined, and occurs mainly on microgranodiorite and related rock types. It has a reddish-yellow colour and commonly has a strong blocky structure. It is closely related to the *Gumbang series* which may be a less mature *Abok series*.

The *Keladan series* is of minor importance and is characterised by a typical mauve colour, its derivation is uncertain but the parent material is probably a metamorphosed sedimentary or volcanic rock type. The *Bayur series* is developed over schist, has a very friable consistency and resembles the *Tarat series* in the LATERITIC SOILS but for the texture which is coarser in the *Bayur series*.

The *Serin series* is developed over arkose and is difficult to separate within the **Merit Family** unless the C horizon is found within a profile depth of 4 feet. The colour has a wide range from red to yellow; the red phase is physically much similar to the *Tarat series* of the LATERITIC GROUP but for the chemical and mineralogical characteristics, the *Serin* being very poor in all nutrients. The yellow phase has characteristics similar to **Merit Family** soils.

The **Merit Family,** although texturally homogeneous, shows a wide range in drainage, colour and horizonation. The well drained soils overlying a strongly mottled C horizon with intensive iron accumulation as limonite sheets have provisionally been placed in the *Bedup series*. The intensively grey and red mottled soils have been placed in the *Semongok series* while soils with a pale yellow colours regarded as transitional to GREY-WHITE PODZOLIC SOILS are classified as *Padawan series*. Semongok and Padawan soils appear to be chemically and mineralogically closely related. The *Stom series* is found on mudstones of very low fertility and is further characterised by an intensively red/white mottled deep subsoil. The *Rapak series* which is officially classified in the group of GROUNDWATER LATERITES (p.122) has been placed under the **Merit Family** since the iron-rich material found in the profile and commonly overlying a C horizon appears to be of depositional origin. This was not yet known when the GROUNDWATER LATERITE GROUP was proposed. The *Begunan series* is strong brown to red coloured and derived from mudstones. Finally, the *Melugu series* is characterised by a content of group III elements higher than 20%, and on account of this it should have been placed in the **Abok Family.** It is however, derived from shale and other characteristics indicate it to be more like a **Merit Family** soil.

In the **Bekenu Family,** which has intermediate textures, only one series was separated, the *Biawak series*, occurring on greywacke sandstone. The soils have a typical greenish yellow colour.

The **Nyalau Family** is light textured and has not been differentiated into series because characteristics very little in West Sarawak.

(e) GREY-WHITE PODZOLIC SOILS

Much of the observations made on the RED-YELLOW PODZOLIC SOILS are also applicable to the GREY-WHITE PODZOLIC SOILS. At the time this group was established the intention was to create a place for intergrades between PODZOLIC SOILS and PODZOLS. Some of the GREY-WHITE PODZOLICS do show leaching of humus but there is insufficient accumulation to qualify for a Spodic horizon (Bh). Because of the very pale colouration, humus leaching is easily observed in these soils but the same process may operate in the RED-YELLOW PODZOLIC SOILS in which stronger colours may mark the process so that field identification is impossible. In any case, the analytical figures do not indicate that this process is of much importance in the GREY-WHITE PODZOLICS either. The presence of an albic horizon is difficult to prove because of the pale colour of the whole solum.

The official definition would differentiate this group from the RED-YELLOW PODZOLIC SOILS on account of colour only.

GREY-WHITE PODZOLIC SOILS are mineral soils in which:

(i) An R or C horizon is not within 10 inches of the base of an O horizon;

(ii) There is an argillic horizon;

(iii) There is no gley horizon within 20 inches of the base of an O horizon;

(iv) There is no spodic horizon;

(v) Chromas are 3 or less in the A2 horizon, 4 or less in the B horizon; hues are more yellow than 2.5Y in the A2 and B horizons; values are 6 or more in the A2 and B horizons.

Great care has been exercised to define the colour limits, but is a colour difference at this level of classification of such importance? The analytical data indicate that the GREY-WHITE PODZOLIC SOILS only differ from the RED-YELLOW PODZOLIC SOILS in iron content which causes the colour difference. Since the colour range in all PODZOLIC SOILS covers the whole spectrum from white to red the chosen limits between the GREY-WHITE and RED-

YELLOW PODZOLICS cannot be more than arbitrary ones if they are not accompanied by other characteristics. An argillic horizon has not been proven to exist in these soils, although a strong textural contrast may be found in some. Soils with strong textural contrast could probably better be accommodated in a group of PLANOSOLS as proposed by Andriesse (1965b), the remainder would probably best be placed together with other presently called RED-YELLOW PODZOLIC SOILS and then split on account of presence of an oxic, cambic or argillic horizon. The colour could be used to differentiate between soils at the family or series level.

The group is presently subdivided into 4 families based on origin of parent material and the texture of the B horizon. This subdivision could better have followed the same system as adopted for closely allied soils, the RED-YELLOW PODZOLICS, in which three texture ranges are employed while the GREY-WHITE PODZOLIC SOILS have only two.

The residual families are subdivided into fine textured soils, **Kerait Family** and coarser than fine textured soils, **Saratok Family.** The soils on old alluvium are subdivided into **Lubai Family** (fine textured), and **Triboh Family** (coarser than fine textured).

In the **Kerait Family** three series are recognised. The *Kerait series*, the prototype of the family, occurs on carbonaceous shales of commonly schistose nature. The *Rukam series* is found on probably phyllites and chert; this series has a typical bluish grey colour. The *Serayan series*, occurs on pinkish coloured chert. The latter two series are very oxic while the *Kerait series* may be weakly cambic. The *Lingga series*, provisionally placed in the **Saratok Family,** is an anomaly. It is derived from iron-poor microgranites and on account of most characteristics should be placed in the **Abok Family**. However, the colour is diagnostic for GREY-WHITE PODZOLIC SOILS. The *Merang series* in the **Lubai Family** is bisequent and shows a strong texural contrast between the A and B horizons.

(f) PODZOLS AND GROUNDWATER PODZOLS

This group is well classified in Sarawak; undoubtedly a result of the presence of well-developed diagnostic horizons which can be easily identified.

PODZOLS and GROUNDWATER PODZOLS are mineral soils in which:

(i) An R or C horizon is not within 10 inches of the base of an O horizon;

(ii) There is an albic horizon;

(iii) There is a spodic horizon;

(iv) Groundwater is periodically present in at least the A2 or B horizons.

The last qualification is only tenable if GROUNDWATER PODZOLS are involved, and there is no need for it in the definition. Probably also the second qualification, presence of an albic horizon, is not strictly necessary since the PODZOLS are already characterised by the presence of a spodic horizon.

The group is subdivided into families developed either on residual material or in alluvial material. The family classification is further based on the chemical nature of the spodic horizon, a Bh or Bir, and on the physical character of the spodic horizon, strongly or weakly developed. The chemical and physical nature of the spodic horizon is probably more signifiacnt than the derivation; the latter diagnostic feature could therefore better be given last place in future classification attempts.

Residual PODZOLS are: the **Silantek Family** with a weakly developed Bh horizon, and the **Bako Family** with a strongly developed Bh horizon. Alluvial PODZOLS are: the **Buso Family** with a weakly developed Bh horizon and the **Miri Family** with a strongly developed Bh horizon. Finally, the only PODZOL with a Bir, the **Jerijeh Family,** is also classified under the Alluvial PODZOLS.

The **Silantek Family** presently has only one series, the *Butan series.*

The **Jerijeh Family** is differentiated into two series. The *Pueh series* is characterised by a well developed Bh.ir horizon and a well developed thick albic horizon. When this horizon attains a thickness of more than 4 feet it is classified as a REGOSOL, *Kilong series* (see SKELETAL SOILS, p.117). The *Stoh series* has an incipient Bh.ir horizon.

(g) GROUNDWATER LATERITE SOILS

These are mineral soils in which:

(i) There is hardened plinthite but not within 10 inches of the base of an O horizon;

(ii) There is no albic horizon.

The definition is confusing in that it excludes soils with unhardened plinthite. The general remarks on this group (Soil Survey Staff, 1966, p.22) however, indicate that unhardened plinthite should be included.

The family classification considers two types of plinthite, that present in upland localities and assumedly fossil in nature, **Rapak Family;** and that found in lowland areas formed by the present groundwater table, **Bentang Family.**

Subsequent information collected on the **Rapak Family** has revealed that the plinthitic layers are in fact stratified, consisting of non-cemented iron concretions and containing laterized root channels, parts of broken up limonitic veins occuring in sedimentary rocks and iron-cemented shale pieces. This concretionary mass is found commonly overlying weathered rock and must have formed there as a result of soil drift from upper slope areas. It cannot be considered to be plinthite. For this reason, no **Rapak Family** was mapped in West Sarawak. Instead a *Rapak series* was established for soils in the **Merit Family** (see RED-YELLOW PODZOLIC SOILS, p.119) with a concretionary iron layer. The **Bentang Family,** thought to contain unhardened plinthite, appears to have a considerable amount of sesquioxides in the redox horizon but the material does not harden within a reasonable span of time (if it hardens at all) and therefore low level GROUNDWATER LATERITES classified as **Bentang Family** soils, were also not mapped. These soils are classified as imperfectly drained **Seduau Family** soils in the group of RECENT ALLUVIAL SOILS (p.125).

It appears, therefore, that both families comprising the GROUNDWATER LATERITE SOILS are not present in West Sarawak and it is quite probable that they are non-existent in the whole State. The only true fossil GROUNDWATER LATERITES found are those developed in LATERITIC SOILS (*Tarat series*). These occur at the 20 and 50 feet levels and the laterite (hardened plinthite) may presumably have formed through a groundwater table present at that level in the past. Some of these true laterite formations were also found at the 200 feet level in the *Gong series* (GLEY SOILS, p.123), and these are also considered to be of fossil origin. Such areas of fossil laterite are, however, of very minor extent and unmappable. They could best be classified as lateritic phases of the normal series in which they have formed.

(h) GLEY SOILS

GLEY SOILS are mineral soils in which:

(i) An R or C horizon is not within 10 inches of the base of an O horizon;

(ii) Any peaty O horizon is not more than 10 inches in thickness;

(iii) A gley horizon is present within 20 inches of the base of an O horizon;

(iv) Groundwater conductivity does not exceed 500 micromhos. per cm at 25°C at any time of the year;

(v) There is no spodic horizon;

(vi) There is no hardened plinthite.

The use of the term gley horizon is unfortunate and is undefined, but in practise, a layer in which the matrix colour indicates that reduction is more important than oxidation is taken to be a gley horizon. It more or less compares with the G horizon defined in the U.S.D.A. Soil Survey Manual (1959, p.180). It means that most poorly and very poorly drained mineral soils, with the exclusion of PODZOLS and soils with saline features are included in this group. It also means that the group comprises soils with a wide range of other characteristics such as, clay mineral systems, texture, structure, colour and derivation. For this reason, it would have been sensible to distinguish some subgroups between the group and family level to accommodate soils which have important genetic features in common such as, weak or strongly developed diagnostic horizons (presence or absence of redox, possible oxic or cambic horizons). Such features have been totally ignored, and the main diagnostic criteria on which the group is presently subdivided into families are the presence or non-presence of an O horizon and texture. While texture is an important characteristic for classification at family level, the existence of a thin O horizon would, in the view of the author, only indicate a drainage phase.

The family classification of 1966 was revised in 1967 (Scott, 1967, pp.12-13). In this revision, the parent material was partially maintained as a diagnostic feature for heavy-textured soils; for the light-textured soils this was dropped.

Light textured soils are now subdivided into two families. The **Tatau Family** without a peaty O horizon and the **Matu Family** with a peaty O horizon of 0-10 inches thick. The heavy-textured soils are subdivided into soils of residual or old alluvial derivation, and into soils of recent alluvial derivation. The first mentioned soils comprise two families, the **Semadoh Family,** without a peaty O horizon and formed in residual material as well as old alluvial material and the **Gerawat Family,** with a peaty O horizon of 0-10 inches thick, also formed in residual as well as old alluvial material.

Soils developed in recent alluvium are the **Bijat Family** without a peaty O horizon and the **Sebandi Family** with a peaty O horizon less than 10 inches thick.

The combination of residual and old alluvial soils in one unit is illogical but is useful for mapping purposes. It may, however, cause the combining of oxic soils (old alluvium derived) and cambic soils (residual) in one family. The presence of a thin peaty topsoil as a diagnostic criteria for a separation at family level is over-evaluated in relation to texture. For this reason, most of the families with a thin peaty top horizon have been ignored in West Sarawak, with the exception of the **Sebandi Family** which has been mapped only when it occurs extensively and in localities where

GLEY SOILS are really transitional to PEAT SOILS. In most other places they have been regarded as organic phases of other families in the GLEY SOILS with which they commonly occur in complex.

The families are differentiated into the following series:

Tatau Family into the *Tatau series* (on recent marine deposits), the *Plan series* (on recent riverine deposits), the *Gong series* (on old riverine deposits), the *Bokah series* (on colluvial material), the *Mundai series* (on old riverine deposits with calcium enrichment, and the *Nyabu series* (derived from basic igneous rocks). The latter two are not yet officially recognised.

The **Matu Family** is not mapped in West Sarawak and the series are not relevant.

The **Semadoh Family** is subdivided into the *Semadoh series* (on residual material), rarely mapped in West Sarawak, and the *Embang series* (on old alluvium). The **Gerawat Family** is in West Sarawak not represented.

Of the **Bijat Family**, the *Bijat series* (recent riverine) is extensive. The *Daro series* is of marine derivation, but since marine influence is very difficult to trace, these soils, if occurring, have been mapped as *Bijat series*.

Other not officially recognised series in West Sarawak mapped in the **Bijat Family** are the *Kakai series* which is derived from basic igneous rocks, the *Paya Megok series* overlying limestone and the *Punda series* with catclay features. In the **Sebandi Family** only one specific series was separated, the *Krian series* characterised by a high calcium content and containing oolitic iron concretions.

The present series classification is unsatisfactory and suffers from the choice of diagnostic criteria adopted at the family level and which had to be carried through in the series classification. This may substantiate the point made earlier (p.114) that the series should provide the diagnostic criteria for the creation of families, rather than that a family has to be split up into series.

(i) SALINE-GLEY SOILS

These are mineral soils in which:

(i) An R or C horizon is not within 10 inches of the base of an O horizon;

(ii) Groundwater conductivity exceeds 500 micromhos per cm at 25°C at some time of the year;

(iii) A gley horizon occurs within 20 inches of the base of an O horizon.

The SALINE-GLEY SOILS were separated from the GLEY SOILS on account of the presence of salt or brackish groundwater. The chosen limit of 500 micromhos per cm at 25°C, is an arbitrary one since crop growth is generally not severely restricted at even much higher levels. The U.S. Salinity Bureau (Andriesse and Sim, 1968) indicates that a limit of 500 micromhos. in a 1:5 soil/water extract may be more indicative for crop growth. The latter values are generally lower than those indicating the salinity of the groundwater.

Conductivity measurements are difficult to carry out in the field particularly if fresh or distilled water is unavailable, and without laboratory analyses it is impossible to draw a boundary between GLEY and SALINE-GLEY SOILS. Even with laboratory analyses a delineation is difficult since the salinity of the groundwater shows seasonal fluctuations. The soils are therefore generally classified by inference from other characteristics than given in the definition. Vegetation and locality are important consideraions.

It is suggested that in future classification attempts the 1:5 soil/water ratio be used and the limits brought in line with crop performance. The salinity of the soil would fluctuate less than that of the groundwater.

As in the case with the GLEY SOILS the family classification of the SALINE-GLEY SOIL has been revised in 1967 (Scott). Table 20 (p.116) shows that parent material, presence of a thin peaty O horizon, salinity and texture have been used as diagnostic criteria for a family separation. The parent material makes distinction between mineral soils and organic soils. This is inconsistent with the group definition stating that the soils are mineral. The organic soils in this group comprise mainly freshwater peat swamps which through coastal erosion have been influenced by saltwater. Such peats could be better classified under the group of PEAT SOILS and this has been done in the Detailed-Reconnaissance Soil Map for West Sarawak.

The limit between weakly saline and strongly saline families is 4,000 micromhos./cm at 25°C (groundwater), but in practise the vegetation is taken as a guide. In West Sarawak, however, the ripening factor has been taken as a means to distinguish between these two salinity classes. The strongly saline soils generally have an N factor greater than 0.5 while weakly saline soils have an N factor of just below 0.5. Although the exact N factor can only be calculated from laboratory data, it can be quite accurately assessed in the field from the degree of ripening.

Finally, the presence or non-presence of a peaty O horizon less than 10 inches thick has been ignored in West Sarawak. Where occurring, a phase difference has been commonly mapped.

A typical example of the underlying philosophy of the present Sarawak classification is shown by the layout of the family classification for the SALINE-GLEY SOILS in which a place is kept open for a family which has not yet been found nor the series it should accommodate but which according to the system should somewhere exist.

No series classification has been attempted for the majority of soils in this group. Only the **Pendam** series is separated within the **Pendam Family.** Because of the occurrence in this group of soils with potential catclay a separate series should be created for such soils, or perhaps, a thionic subgroup or family should be established.

(j) PEAT SOILS

These are soils in which:

(i) The O horizon consists of peat or muck (more than 35% of organic matter) and is more than 10 inches deep;

(ii) Groundwater conductivity does not exceed 500 micromhos. per cm at 25°C at any time of the year.

The latter qualification has been added to exclude the Saline PEAT SOILS referred to in the SALINE-GLEY SOILS (see (i), this section, p.124). It is, however, felt that the organic nature is more important than the salinity of the groundwater and that such soils should be included in the PEAT SOILS.

The family classification is straight forward and is based on origin of the peat, depth and the nature of the mineral subsoil. Mountain peats regarded as of climatogenic origin are classified as **Mulu Family,** while the basin peats are classified as topogenic soils in which three families are recognised: the **Anderson Family** which is deeper than 40 inches and the **Igan** and **Mukah Families** which are less than 40 inches deep, the former overlying a light textured mineral subsoil, while the latter overlies a heavy-textured mineral deposits.

No series have yet been recognised in West Sarawak. Some peats have a mineral topsoil, commonly clay. Such soils are classified as a phase of the normal occurring family when the mineral deposit is less than half the profile depth. They are classified as GLEY SOILS if the total thickness of mineral soil is greater than the total thickness of peat over a total deph of four feet. These characteristics may be used for a series differentiation either in the PEAT or GLEY SOILS.

It would, furthermore, be useful to recognise a unit of drained PEAT SOILS in which the topsoils have been considerably changed by oxidation, mineralization and stabilization.

(k) RECENT ALLUVIAL SOILS

These are mineral soils in which:

(i) An R horizon, or a C horizon, consisting of rock weathered *in situ*, is not within 10 inches of the base of an O horizon;

(ii) Where the profile consists of bands of coarse and fine earth there is no band of material with more than 80% coarse earth which is more than 20 inches thick and is within 10 inches of the base of an O horizon;

(iii) A gley horizon, if present, is not within 20 inches of the base of an O horizon;

(iv) Neither albic nor spodic nor argillic horizons are present.

Although it was the intention to combine in this group all soils with little profile development the definition does not exclude soils with well developed gley and redox features below a depth of 20 inches. Such soils cannot be officially classified as GLEY SOILS because the gley horizon is found too deep but they are nevertheless well developed soils, and are closely related to GLEY SOILS. The U.S.D.A. Soil Survey Manual (1951, p.180) states that one may appropriately speak of a 'GLEY SOIL' because the whole genesis of the profile is involved, but hardly of a gley horizon! The existence of a cambic horizon must be suspected in some. Some of these soils are transitional to SKELETAL SOILS if gravels occur in the subsoil. It would have been logical to use such transitional criteria for a subdivision into families. This has not been done and instead colour, origin of parent material either marine or riverine, and texture, was used for separating families in this group.

Strongly coloured soils are related to oxic features and colour in general is a valuable indication to other characteristics. The origin of the parent material is of little genetic importance, at least if such a broad grouping such as marine and riverine is used. If a group of REGOSOLS is created (see (a), this section, p.117) then all the families of marine origin would be classified as such and the RECENT ALLUVIAL SOILS would only comprise soils of riverine alluvium. It is further suggested that in the family classification the drainage factor is considered so that soils with decidedly gleyed features are not combined with well drained members in one family. Otherwise, separate drainage phases or series based on drainage will have to be created for all families.

In order to bring out important differences within the families, quite a number of series had to be established in West Sarawak. Firstly, the **Ramun** and **Terbat Families** were joined to form one family, the **Ramun Family** only. This family therefore comprises all soils, light and heavy textured having a strong brown to red colour. Two series, derived from basic to intermediate igneous rock, the *Terbat* and *Ramun series*, were established; the *Terbat series* being light textured. This means in practice, that texure used as a differeniating criterion at the family level in the official classification was in West Sarawak employed at the series level. This was necessary because of the very gradual texture change which can be observed in riverine floodplains and which made the distinction between the two original families very difficult. A third series in the **Ramun Family** is the heavy-textured *Entebar series*, of minor importance and derived from red mudstone found in specific localities. A fourth series is the light-textured *Siar series* derived from granites. The same principle as used for the creation of the new **Ramun Family** could have been applied to the **Seduau** and **Kayan Families** (the light coloured soils); namely, combining all light coloured soils into the **Kayan Family** and separate further into series on account of texture. This has not been done yet, because not much mapping difficulties were encountered, the light textured soils being not commonly found together with heavy-extured soils. This is related to the specific areal distribution of parent materials, the **Kayan Family** soils being mainly found in areas with sandstone, while the **Seduau Family** is commonly found in shale dominated areas.

It is, however, suggested that in future texture could best be used for a differentiation at the series level, so that the drainage factor could be employed at the family level.

The **Seduau Family** has been separated into several series, mainly on account of derivation and drainage. The *Seduau series* is the major series in the family and is derived from shales mainly. The *Sebat series* is derived from granites and is characterised by much micaceous material and good drainage. The *Sekati series* is very similar to the *Sebat* but is gleyed below a depth of two feet and has a well developed redox horizon. The *Paku series* is derived from shales and probably limestone but has oolitic iron concretions. The *Malang series* is derived from a mixture of basic igneous rocks and shales and has a brown colour with intense red mottling.

In the marine soils the **Sematan Family** is subdivided into the *Rambungan series*, which is transitional to the **Kabong Family;** and the *Sematan series*. The *Chupin series*, also in the **Sematan Family,** has a petricalcic horizon.

The **Kabong Family** is subdivided into the *Siru series* characterised by a high mica and shell content while the *Kabong series* is dominantly pure quartz sand. The series classification is incomplete and not always satisfactory. However, it is thought that the established series can be easily grouped under any new family classification which may be attempted in future.

3. Classification according to the U.S.D.A., Comprehensive System, 7th Approximation (1960 1967, 1969).

(a) **General**

This classification system attempts to classify soils on their morphological characteristics, which can either be seen and measured in the field or detected by laboratory methods. It aims to replace established world wide classifications which are strongly biased to genetics. In the latter, commonly soil forming processes are used as diagnostic characteristics rather than the soil profile morphology. Although the 7th Approximation claims to be a morphological system, the relative importance of diagnostic features in soil profiles is still evaluated on its genetic significance, because these features are manifestations of soil forming processes. This is particularly so in the grouping of soils at the highest levels, the Orders and Suborders. However, the system is a great improvement on the older one in which many genetic processes, used to classify soils, are based on assumptions and lack in precise definition of profile characteristics. The 7th Approximation is presently widely used outside tropical regions but is for tropical soils still undeveloped and incomplete.

Since 1966, attempts have been made to accommodate Sarawak soils in this system and since it is anticipated that it will play an important role in future classification work in Sarawak, it is of importance that the system is evaluated on its present state of development and usefulness for Sarawak conditions.

(b) **Diagnostic Features**

The system is heavily dependent on the presence or non-presence of diagnostic horizon in soils. For Sarawak the following subsurface horizons are relevant, the Spodic horizon, the Albic horizon, the Argillic horizon, the Cambic horizon and the Oxic horizon. The placing of Sarawak soils in the highest categorical level, namely that of the Orders is dependent on the existence of one or more of these horizons.

The recognition of the Spodic horizon, either in the field or by laboratory methods does not present much difficulty and for this reason soils with such horizons can be easily placed in the classification. The soils concerned are those now classified as PODZOLS which can all be classified in the Order of SPODOSOLS in the 7th Approximation.

The presence of an Albic horizon is difficult to prove in soils with a very low iron content such as the GREY-WHITE PODZOLIC SOILS. In somewhat stronger coloured soils such as the RED-YELLOW PODZOLICS it can be recognised and it present in some soils, while in the case of PODZOLS no difficulties arise because of the strong relationship and contrast between the Albic horizon and the underlying Spodic horizon

Table 21: Calculated Cation Exchange Capacities in meq. /% clay in some soils of West Sarawak.

Horizon	Tarat I	Tarat II	Gading	Gumbang	Stass	Padawan	Semongok	Semongok (shallow)	Stom	Bekenu	Nyalau	Kerait I	Kerait II	Bijat	Terbat
A2	16.91	-	51.36	27.73	45.68	48.87	32.19	32.78	29.29	48.95	20.52	51.31	10.93	52.27	65.04
B1	10.69	14.11	87.88	23.70	39.32	41.11	36.11	36.42	25.57	37.28	14.40	18.38	12.73	41.96	-
B2	11.90	16.55	100.56	19.44	71.19	37.27	-	39.70	27.68	32.89	13.15	16.55	17.66	55.07	-
B/C	11.21	16.88	-	-	38.69	52.85	43.51	50.30	30.51	31.67	14.51	24.25	-	47.16	72.12
C	-	16.88	-	-	-	56.60	44.20	-	-	32.56	-	25.63	13.82	-	89.08
clay minerals	kaolinite	kaolinite	kaolinite	vermiculite/ kaolinite	vermiculite/ kaolinite	kaolinite/ vermiculite	vermiculite/ kaolinite	vermiculite/ kaolinite	kaolinite/ vermiculite	kaolinite/ vermiculite	kaolinite	quartz/ kaol./verm.	quartz/ kaol./verm.	kaolinite/ vermiculite	kaolinite/ vermiculite
possible diagnostic horizon	oxic	oxic	cambic?	cambic?	cambic	cambic	cambic	cambic	cambic?	cambic	oxic	oxic	oxic	cambic	cambic

Table 22 - Tentative Correlation of Important West Sarawak Soils with the U.S.D.A. System (7th Approx. with amendments).

Order:	ENTISOLS	
Suborder:	Aquents	Most Gley and Saline-Gley Soils with textures heavier than loamy fine sand.
Great Group:	Hydraquents	Saline-Gley Soils, Rajang Fam. (only on account of N 0.5)
	Tropaquents	Most poorly drained Bijat Fam. soils without cambic horizon (insufficient weathering)
Subgroup:	Typic Tropaquents	Some soils in Bijat, Kakai, Paya Megok and Punda series (without cambic horizon), all Emban.
Suborder:	Fluvents	These are separated from the suborder Orthents because of stratification identified by an irregular content of organic matter Although stratification is present, org. matter is of little diagnostic value in West Sarawak because the values are always low. A general decrease in org. matter is normally found, thus most dry alluvials will be Orthents.
Suborder:	Orthents	Most dry Recent Alluvial Soils if textures are finer than loamy fine sand.
Great Group:	Troporthents	Seduau Fam. and most Kayan Fam. soils, most Ramun Fam. soils.
Subgroup:	Typic Troporthents	Seduau and Sebat series if no sand layer within 30" (otherwise andic). Paku series, Terbat series, Entebar series (may be vertic).
	Andic Troporthents	Most Kayan series, Siar series, some Sebat and some Seduau series. Ramun series (if gravel present within 30 inches).
Suborder:	Psamments	All Recent Alluvial Soils, Saline-Gley and Gley Soils with texture coarser than loamy fine sand. Some Skeletal Soils. (generally Regosols).
Great Group:	Quartzipsamments	Sematan Fam. and Kabong Fam., if less than 5% weatherable minerals. Gaya Fam., Tatau Fam. and Kilong series.
Subgroup:	Aquic quartzipsamments	Chupin series (with petrocalcic horizon), Tatau series, Pian series, Gong series, Mundai series, Nyabu series? (generally all Tatau Fam. soils), Nonok Fam. and Belat Fam.
	Oxic quartzipsamments	Sematan Fam. (Sematan and Rambungan series), Kabong Fam. (Kabong series). Kabong Fam. (Siru series) because of 5% weatherable minerals is difficult to place as quartzipsamment.
Order:	INCEPTISOLS	
Suborder:	Aquepts	
Great Group:	Tropaquepts	Some heavy textured Gley and Saline Gley Soils with cambic horizon. (duripans and fragipans being absent).
Subgroup:	Typic Tropaquepts	Probably most Pendam Fam. soils and some soils in Bijat, Kakai, Paya Megok and Punda series.
	Histic Tropaquepts	Probably some Sebandi Fam. soils and organic phases of Pendam Fam., Bijat, Kakai, Paya Megok and Punda series.
	Lithic Tropaquepts	Probably some Binatang and Kalupe Fam. soils.
Suborder:	Tropepts	
Great Group:	Dystropepts	Lateritic, Skeletal, Red-Yellow and Grey-White Podzolic and Recent Alluvial Soils with cambic horizon.
Subgroup:	Typic Dystropepts	Probably some Antayan and Sejinkat series soils, some well drained Merit Fam. soils (excluding Stom series), some Malang series. All with C.E.C. more than 24 meq./100 gr. clay.
	Aquic Dystropepts	Some Semongok and Padawan series. Some Kapit Fam. soils (depending on mottling).
	Oxic Dystropepts	Some Antayan and Sejinkat series, some well drained Merit soils (excluding Stom series). Some Semongok and Padawan series. Some Kerait Fam. soils, some Malang series. All with C.E.C. of 16-24 meq./100 gr. clay.
	Lithic Dystropepts	Some Sedong Fam. soils, some Meluso Fam. soils and some Kapit Fam. soils (these may be oxic/lithic, particularly the Buri series).
Soils such as Semongok and Padawan series may be both Aquic and Oxic and cannot be separated in the present system.		
Order:	OXISOLS	
Suborder:	Orthox	
Great Group:	Haplorthox	Most Lateritic Soils, and those Red-Yellow Podzolic and Grey-White Podzolic Soils with oxic horizons.
Subgroup:	Typic Haplorthox	Tarat series, Bukit Batu series, some well drained Merit Fam. soils.
	Aquic Haplorthox	Some moderately and imperfectly drained Merit, Bekar and Kerait Fam. soils. Lingga series and some Semongok series.
	Psammentic Haplorthox	Most Nyalau, Saratok and Triboh Fam. soils (textures coarser than s.cl.l.)
	Tropeptic Haplorthox	Some Antayan and Sejinkat series. Some well structured Merit (Stom series) and Bekenu Fam. soils. Jebong, Gumbang, Beguma and Abok series. Some Kerait Fam. soils.
Order:	SPODOSOLS	
Suborder:	Acquod	
Great Group:	Tropaquod	All Podzols with well developed cemented spodic horizon.
Subgroup:	Histic Tropaquod	Mirt Fam. soils and some Bako Fam. soils. Bako Fam. soils with hard parent material within 20 inches, Lithic Tropaquod (not in classification).
Suborder:	Humods	
Great Group:	Tropohumod	All Podzols with a non-cemented spodic horizon.
Subgroup:	Typic Tropohumod	Stiantek and Buso Fam. soils. (both are histic but there is no histic subgroup).
	Ferrudalfic Tropohumod	All Jerijeh Fam. soils.
Order:	HISTOSOLS	
Suborder:	Fibrists	
Great Group:	Tropofibrists	Great majority of Peat soils.
Subgroup:	Typic Tropofibrists	Undrained Anderson, without mineral layering below 24 inches.
	Fluventic Tropofibrists	Undrained Anderson Fam. with mineral layering below 24 inches.
	Terric Tropofibrists	Most undrained Mukah and Igan Fam. soils if deeper than 16 inches.
	Sapric Tropofibrists	Most drained Anderson Anderson Fam. soils.
	Sapric Terric Tropofibrists	Drained Mukah and Igan Fam. soils.
Suborder:	Folists	
Great Group:	Tropofibrists	
Subgroup:	Lithic Tropofibrists.	Some thick Mulu Fam. soils.

The recognition of an Argillic horizon is rather more difficult. In the 1966 Sarawak Classification it was assumed that an Argillic horizon commonly occurs in many Sarawak soils and for this reason a large proportion was classified and defined as RED-YELLOW PODZOLICS and GREY-WHITE PODZOLIC SOILS in which the existence of an Argillic horizon is one of the main diagnostic features. The presence of an Argillic horizon was assumed from granulometric analyses which indicated a sufficient clay increase in the profiles. Moreover, field observations indicated the presence of clayskins. Clayskins appeared to be more developed in light-textured soils than in heavy-textured ones.

In recent years doubt has risen whether the clay increase is in fact related to illuviated clay and whether the reported clayskins are really caused by illuviation. For this reason, it became necessary to obtain microscopic evidence on the orientation of clays in the so-called Argillic horizons. Results of micro-pedological examinations of some West Sarawak soils are presented in Chapter 15, section 2 (p.260). The studied profiles concern soils which, according to either field or laboratory investigations, contained well-developed clayskins or showed a considerable clay increase, qualifying for an Argillic horizon. Although much more micropedological work will be required, the present information indicates that the previous assumption may have been a wrong one, at least for West Sarawak soils. There are other reasons why the presence of an Argillic horizon in West Sarawak must be suspected. Argillic horizons commonly form on old stable land surfaces since they need a long period to develop and the climate under which they form is although humid, commonly characterised by a pronounced dry season. Both factors are not present in West Sarawak, the climate being humid throughout the year and most of the landscape is strongly dissected and constantly rejuvenating. Old terrace sites may be the only liable places where an Argillic horizon would have sufficient time to develop. As shown in Chapter 15, section 2 (p.260), the **Triboh Family,** developed on such terrace summits has insufficient orientated clay to qualify for an Argillic horizon.

The non-existence of an Argillic horizon would exclude the Order of Ultisols from West Sarawak soils.

The recognition of the Oxic horizon is similarly problematic. By definition, the Oxic horizon should not contain more than 1% weatherable minerals. The analyses on sand mineralogy indicate that West Sarawak soils rarely have this amount. Even in the RECENT ALLUVIAL SOILS weatherable minerals are rare. This is caused by the very low weatherable mineral content of most parent rock types and rapid chemical maturation of soils. Therefore, most upland soils would become oxic in a very early stage of development. However, it appears that in a number of soils and specifically those derived from shales, mixed layer and 2-1 lattice clays, amorphous alluminium and silica compounds qualifying as stabile allophane (Jackson, 1956), occur in appreciable amounts. These are per definition also weatherable, and because of this nature of the clay mineralogy the weatherable mineral content may be more than 1% in these soils. The presence of mixed layer clays in particular would influence the cation exchange capacity and the analyses show that such soils have a C.E.C. of more than 16 meq/100 grammes clay. Therefore, as shown in Table 21, (p.127) such soils, on account of C.E.C. and qualitative clay mineralogy, would not qualify for having an Oxic horizon, but rather for a Cambic horizon, although marginally so.

The absence of an Argillic or Oxic horizon and the presence of a Cambic horizon would place such soils in the Order of INCEPTISOLS. It will appear that a proportion of the soils now classified as RED-YELLOW and GREY-WHITE PODZOLIC SOILS will belong to the Order of OXISOLS, while the remainder will largely be INCEPTISOLS. A differentiation should be made on C.E.C. and clay mineralogy. The light-textured soils not qualifying as INCEPTISOLS would probably end up in the ENTISOLS because they are excluded from the OXISOLS on account of texture. The soils now classified as LATERITIC SOILS will largely belong to the OXISOLS since the C.E.C. is generally low while 2-1 lattice clays and allophane do not occur in sufficient quantity. It is, however, possible that some series may qualify for a Cambic horizon (see Table 21, p.127).

The absence of diagnostic subsurface horizons would place most of the RECENT ALLUVIAL SOILS and GLEY SOILS in the Order of ENTISOLS. RECENT ALLUVIAL SOILS and GLEY SOILS having an Oxic horizon and textures heavier than sandy clay loam would be classified as OXISOLS. RECENT ALLUVIAL SOILS and GLEY SOILS with light textures would be placed in the ENTISOLS even if they have an Oxic horizon. Some of the GLEY SOILS and RECENT ALLUVIAL SOILS if heavier than loamy fine sand may have a Cambic horizon, particularly the better drained ones showing signs of development and alteration of the original deposits (see Table 21, p.127). SALINE-GLEY SOILS if properly drained would probably qualify as INCEPTISOLS; without a Cambic horizon they would fall in the Order of ENTISOLS.

There is no difficulty to place the PEAT SOILS in the Order of Histosols.

Finally, most of the local SKETETAL SOILS must be divided over the various Orders as lithic subgroups.

In West Sarawak the following surface horizons can be recognised:

An *umbric epipedon* is usually present in LATERITIC, GREY-WHITE and RED-YELLOW PODZOLIC SOILS if occurring under primary forest. Generally an *ochric epipedon* is present under secondary growth or when a soil is degraded.

A *histic epipedon* is found in some GLEY SOILS and in most PODZOLS, excluding the **Jerijeh Family.** It may also occur under a thick coarse fern vegetation (*Resam*) on RED-YELLOW and GREY-WHITE PODZOLIC SOILS and on some PEAT SOILS if these are covered by a mineral top layer.

A *mollic epipedon* probably does not occur in West Sarawak but may occur elsewhere in soils well supplied with divalent cations.

A *petricalcic horizon* was found only in one coastal series (*Chupin series*), **Sematan Family**, RECENT ALLUVIAL SOIL.

Unhardened plinthite is notoriously absent in West Sarawak soils. Material, qualifying as *hardened plinthite* is found very localised in some LATERITIC SOILS and some GLEY SOILS and is of fossil origin. Soils previously classified as GROUNDWATER LATERITES do contain laminar iron accumulations of iron or soft concretions. Subsequent investigations have shown that the concretionary accumulations are largely depositional, being orientated, and they have not formed in the present profile. In any case, they are discontinuous and not cemented and could best be regarded as iron stonelines. Iron accumulations in the soft form do not appear to harden when exposed for more than two years and can therefore be classified as *unhardened plinthite*.

Finally, *fragipans* are not found in West Sarawak. Some form of a *duripan* may be present in the Albic horizon of PODZOLS but it loses its cementing character upon wetting and can therefore not qualify as a true *duripan*.

(c) **Discussion**

This summary of diagnostic criteria used for the classification of soils in the U.S. 7th Approximation shows that much information necessary to identify these criteria is still lacking for many soils in West Sarawak. Although detailed analyses for single profiles indicate that certain diagnostic horizons are present or not present, without more information, it is difficult to decide whether such features occur as a rule. Since the existence of an Oxic as well Cambic horizon is most important for a placing of many soils in either the OXISOLS or INCEPTISOLS, much more information on cation exchange capacity and clay mineralogy is necessary. In many soils the differences between these horizons are marginal and cannot be assessed from field observations only. Weatherable minerals in the sand fraction are in most cases very low and commonly less than 1%. The deciding factor is therefore often the clay mineralogy. The latter, if qualitatively analysed, must be supported by the C.E.C. to enable a more or less quantitative assessment. Quantitative clay mineralogical analyses are still irreliable, particularly if marginal values are concerned.

It will appear that the diagnostic horizons used for a classification at the Order level will cut across many diagnostic features used in the present local classification system. For this reason, there are no single classification units in the 7th Approximation equivalent to the Sarawak Soil Groups and most Sarawak Groups will have to be split up. The SKELETAL SOILS would need to be divided over Lithic Subgroups of mainly the ENTISOLS, INCEPTISOLS and OXISOLS. LATERITIC and PODZOLIC SOILS will be either INCEPTISOLS, ULTISOLS or OXISOLS. The GLEY and SALINE GLEY SOILS will have to be classified as aquatic Suborders of the ENTISOLS and INCEPTISOLS.

The greatest difficulties will, however, be encountered with the Sarawak families and series. These have been differentiated within the Sarawak Groups on account of defined characteristics which either appear to play no role whatsoever in the 7th Approximation or, in case the chosen features are identical to those used in the 7th Approximation, the local limits are not in agreement with those in the 7th Approximation. For instance a Cambic horizon may be present or not present in a *Semongok series*, an Oxic horizon may be present or not in an *Antayan series*. Base saturation which is used at the subgroup level in the Order of INCEPTISOLS is used in Sarawak at the series level. Therefore, if in the future a system is developed based on the criteria used in the 7th Approximation, all these criteria will need to be introduced at the lowest level of classification, the series, and the system would have to be built up from this level.

Table 22 (p.128) tries to indicate the present position of the Sarawak classification units if classified according to the 7th Approximation. It is only schematic in nature and incomplete, the aim being to indicate where correlation difficulties are most severe. It is realised that several families or series could be placed in various subgroups because they have often more than one diagnostic feature in combination, each of which being of importance at the same level of classification, e.g. oxic, psammentic and histic features may be found together in the same subgroup and it is difficult to decide which of the three is the most important one.

Table 23

Correlation of Southeast Asian Soil Groups and Soil Groups in the Sarawak Classification

ALLUVIAL SOILS	Recent Alluvial Soils (riverine only) Gley Soils (alluvial only) Saline-Gley Soils
REGOSOLS	No equivalent group. Within Skeletal Soils - some Gaya Family. Within Recent Alluvial Soils - Sematan and Kabong Families (on marine sands). Within Podzols - Kilong series ('Giant Podzol')
GRUMUSOL	No equivalent
ANDOSOL	No equivalent
(ACID) BROWN FOREST SOILS	Brown Forest Soils. Possibly some Lateritic Soils (some Sejingkat and Antayan series)
NON-CALCIC BROWN SOILS	No equivalent
LOW HUMIC GLEY SOILS and GREY HYDROMORPHIC SOILS	Probably no equivalent on account of textural B, otherwise very similar to Kerait Family in Grey-White Podzolic Soils and Semado Family in Gley Soils.
RED-YELLOW PODZOLIC SOILS	Probably no equivalent on account of textural B, otherwise very similar chemically to Red-Yellow Podzolics (no laterite however)
GREY-PODZOLIC SOILS	Probably no equivalent on account of textural B, otherwise very similar to Triboh and Saratok Families in Grey-White Podzolic Soils. (no laterite however).
DARK RED and REDDISH BROWN LATOSOLS	Most Lateritic Soils (Tarat and Bukit Batu series, Jebong series but for structure)
RED-YELLOW LATOSOLS	Very similar to Red-Yellow Podzolic Soils which are oxic.
ORGANIC SOILS	Peat Soils.

Table 24

Correlation of units for the World Soil Map and Sarawak Soil Classification units*

FLUVISOLS	Most Recent Alluvial Soils
Dystric Fluvisol	Kayan Fam., Kabong Fam. (Kabong series), Sematan Fam., some Seduau Fam. soils.
Eutric Fluvisols	Ramun Fam. (Terbat and Ramun series),Kabong Fam. (Siru series), Seduau Fam. (Malang and Bentang series).
Gleyic Fluvisols	Poorly drained Saline Gley and Gley Soils without potential catclay characteristics.
RHEGOSOLS	Part of Skeletal Soils (old alluvials).
Dystric Rhegosols	Some Gaya Fam. soils, Kilong series (Giant Humus Podzol).
ARENOSOL	Probably Siar series (Kayan Fam.), and Sematan series (Sematan Fam.) if Oxic B horizon can be proved.
GLEYSOLS	
Histic Gleysols	All very poorly drained Gley Soils and Saline Gley Soils without characteristics of potential catclay.
Thionic Gleysols	Some Saline Gley Soils (part of Rajang Fam. with potential catclay) and some Gley Soils, Pundu series (Bijat Fam.) with catclay.
PLANOSOLS	Possibly some Grey-White Podzolic Soils if abrupt textural contrast is not caused by bisequency of parent materials but due to illuviation.
CAMBISOLS	
Ochric Cambisol	Those Red-Yellow and Grey-White Podzolics, and Lateritic Soils with a Cambic B horizon.
PODZOLS	Podzols
Gleyic Podzols	Miri Fam., probably part of Bako Family.
Humo-Ferric Podzols	Jerijeh Family
Humic Podzol	Silantek and Buso Families, probably part of the Bako Family, if not lithic.
ACRISOLS	Probably only present if existence of Argilluvic B horizon in Red-Yellow and Grey-White Podzolics can be proved.
FERRALSOLS	Most Lateritic Soils and Red-Yellow Podzolic Soils if no Cambic B or Argilluvic B horizon present.
Helvic Ferralsols	Most Lateritic Soils and heavy textured Abok Fam. soils in the Red-Yellow Podzolic Soils.
Ochric Ferralsols	Most Red-Yellow Podzolic Soils without heavy textured Abok Fam. Soils. (Grey-White Podzolic Soils).
HISTOSOLS	
Dystric Histosols	All Peat Soils.
LITHOSOLS	Meluan Family
Eutric Lithosols	Meluan Family on basalts and limestone.
Dystric Lithosols	Remainder of Meluan Family.

* Note: Only lower classification units of importance are mentioned.

Certain features which hitherto received very little attention in Sarawak appear to play an important role in the 7th Approximation. This is particularly so in the Order of HISTOSOLS which is split into subgroups on account of the nature of the peat. For this reason, drained and undrained peats will have to be classified into different subgroups when the nature of the peat has changed upon drainage.

Since the system is not yet well developed for tropical soils it will be impossible to place a number of Sarawak soils in the present scheme. A full adoption of the system is still out of the question, however, as a start, criteria for a separation of soils within Sarawak could be brought in line with those used in the 7th Approximation. Although, as stated in the Classification of Sarawak Soils (Soil Survey Staff, 1966, p.2) 'the limits of many diagnostic horizons and other features used in defining the families have been chosen to agree with those of the American Classification', in reality this agreement appears to be a far cry from what it should be.

4. Correlation with the South-East Asian Soil Classification Scheme (Dudal and Moormann, 1964).

This Scheme attempts to classify the major soils of South-East Asia at the Great Group level. The nomenclature is derived either from the classification by Baldwin *et. al.* (1938) as amended by the United States Department of Agriculture (Thorp and Smith, 1949) or the names are commonly used by F.A.O. soil scientists.

Since the basis of this scheme is very similar to that of the Sarawak classification, although for the latter more precise definitions are given for the diagnostic features, it is useful to try correlate the Sarawak Soil Groups with this Scheme which has been given wide publication and has been used for the preparation of the World Soil Map for the region. It is now more or less outdated but still useful for correlation purposes. A tentative correlation is given in Table 23 (p.131).

The ALLUVIAL SOILS in this Scheme are in Sarawak separated on account of salinity and drainage into three soils groups, the GLEY SOILS, SALINE GLEY SOILS and RECENT ALLUVIAL SOILS.

The REGOSOLS have no equivalent as such in the Sarawak System but some soils can be correlated with them. These are the marine sands classified as RECENT ALLUVIAL SOILS, and some **Gaya Family** Soils, classified as **SKELETAL** SOILS, e.g. the *Kilong series* which is a Giant PODZOL with a Bh below a depth of 4 feet.

GRUMUSOLS and ANDOSOLS have no equivalent soils in Sarawak. This is caused by the perhumid climate in Sarawak.

(ACID) BROWN FOREST SOILS are only found in very minor localities which have not received much attention in this memoir because of their unsuitability for agriculture. In the Sarawak classification they are classified as BROWN FOREST SOILS and are for the majority derived from material enriched by calcium.

PODZOLS have as their equivalent in Sarawak the PODZOL GROUP.

The NON-CALCIC BROWN SOILS and the RED-BROWN EARTHS have no equivalents in Sarawak probably because of the perhumid climate.

LOW HUMIC GLEY SOILS and GREY HYDROMORPHIC SOILS may have as equivalents the **Kerait Family** in the GREY-WHITE PODZOLIC group and the **Semadoh Family** in the GLEY SOILS, but this is dependent on existence of a textural B horizon. If the textural B is taken as synonymous to an Argillic horizon than quite probably both groups have no equivalents in Sarawak. If the textural B horizon is defined as just an increase of clay in the subsoil, without a decrease in the C horizon then the **Kerait** and **Semadoh Families** could be placed in these groups.

Similarly, the RED-YELLOW PODZOLIC SOILS of the S.E. Asian Scheme may be equivalent to the RED-YELLOW PODZOLIC SOILS in Sarawak but for the textural B, which is absent in most Sarawak soils. Also laterite does not occur in Sarawak RED-YELLOW PODZOLIC SOILS. According to Dudal and Moormann (1964) most profiles have a C.E.C. of less than 25 meq/100 gms clay and the dominant mineral is of a kaolinitic type with little or no illite and montmorillonite. Quite probably some of these soils may have a Cambic horizon as is the case in Sarawak and they may be INCEPTISOLS provided an Argillic horizon is not present. It was probably not the intention to include soils of this Order in this group and it is assumed that they should all be ULTISOLS on account of the presence of an Argillic horizon. In that case most RED-YELLOW PODZOLIC SOILS in Sarawak would not be equivalent. The nearest equivalent of those RED-YELLOW PODZOLIC SOILS in Sarawak with a Cambic horizon would then be the (ACID)-BROWN FOREST SOILS which is an unlikely place for them, since the latter are decidedly much richer in weatherable minerals and have much higher cation exchange capacities. The Sarawak RED-YELLOW PODZOLICS must be regarded as transitional having chemical characteristics much the same as the Southeast Asian RED-YELLOW PODZOLICS but lacking the profile morphology. Quite probably the perhumid climate and poor parent materials may have induced very rapid chemical weathering without the commonly accompanying formation of diagnostic horizons indicating old age. Probably for the same reasons the Sarawak RED-YELLOW PODZOLICS have no laterite which is common in the South-East Asian ones, although topography may play a role as well.

The GREY PODZOLIC SOILS would have their equivalents in the **Saratok** and **Triboh Families** of the GREY-WHITE PODZOLIC SOILS but for the Argillic horizon which is probably not present in these Sarawak soils. Also laterite commonly occurring in the GREY PODZOLIC SOILS does not occur in the GREY-WHITE PODZOLIC SOILS in Sarawak, probably caused by the same reasons as indicated for the absence of laterite in the Sarawak RED-YELLOW PODZOLIC SOILS. The GREY-WHITE PODZOLIC SOILS in Sarawak are therefore difficult to place in this scheme, there being no nearer equivalent than the GREY-PODZOLIC SOILS.

The DARK RED and REDDISH BROWN LATOSOLS find their equivalents in most LATERITIC SOILS in Sarawak, particularly in the *Tarat* and *Bukit Batu series*. Other series in the LATERITIC SOILS do not have the friability and crumb structure characteristic for the REDDISH BROWN LATOSOLS but are difficult to place in any other group since they have no Argillic horizon. Some of the LATERITIC SOILS in Sarawak may even have a Cambic horizon, although marginally so.

The RED-YELLOW LATOSOLS are very similar to those RED-YELLOW PODZOLICS in Sarawak which are Oxic. They have identical chemical and morphological characteristics but for the structure which in Sarawak is commonly not much developed. The RED-YELLOW LATOSOLS are characterised by an open structure which is generally absent in the more blocky, massive Sarawak RED-YELLOW PODZOLICS. This is probably a variable characteristic in this group caused by differences in climate. The RED-YELLOW PODZOLIC SOILS with Cambic horizons cannot be placed in this group.

ORGANIC SOILS are equivalent to PEAT SOILS in Sarawak.

It appears that correlation difficulties are mainly centred around the presence or non-presence of a textural B horizon and the existence of soils in Sarawak which are chemically thoroughly weathered without having acquired the morphology indicating old age. This is probably caused by the constant rejuvenation through erosion combined with the intense chemical weathering into the C horizon. Transitional characteristics and marginal diagnostic horizons are therefore common in Sarawak. It would be difficult to accommodate such local combinations of characteristics in a scheme encompassing the whole of South-East Asia unless specific groups are being created for these transitional soils.

5. Correlation with the Mapping Units for the Soil Map of the World (Dudal, 1968)

'The soil units for the Soil Map of the World have been selected on the basis of present knowledge of genesis, characteristics and distribution of the major soils covering the earth's surface, their significance as resources for production and the feasibility of representing them on a small scale map. As a result, the proposed subdivisions may not strictly adhere to taxonomic rules and consequently may belong to different levels of generalisation'. (Dudal, 1968, p.1). The soil units however generally correspond to the Group level commonly used in other soil classification systems.

The nomenclature used and the diagnostic characteristics selected for differentiating between soils follow closely principles adopted for the 7th Approximation of the U.S.D.A. system. (U.S. Soil Survey Staff, 1960, 1966).

Among the diagnostic horizons are the Cambic B horizon, the Oxic B horizon, the Spodic B horizon and the Argilluvic B horizon. Although not identical to the Cambic, Oxic, Spodic and Argillic horizons of the 7th Approximation, they can practically be regarded as being synonymous. The limits chosen in the definitions of diagnostic horizons and other soil features are in instances different from those adopted for the 7th Approximation and in some cases resemble more closely those used in the Sarawak Classification. Moreover, the scheme or legend, recognises units such as REGOSOLS, LITHOSOLS and GLEYSOLS which are not separated as such in the 7th Approximation but which can be found in the Sarawak Classification. For these reasons, a correlation between Sarawak soils and the soil units of the World Soil Map does not present such great difficulties as is experienced in the same exercise with the 7th Approximation. It will be seen, however, that the presence and non-presence of an Argilluvic B, Oxic B, or Cambic B horizon, are also here sources of disagreement.

A schematic correlation is shown in Table 24 (p.132). The following discussion covers only units of the World Soil Map which are either present in West Sarawak or have closely similar soils in that Region.

FLUVISOLS are represented in the Sarawak scheme by all soils classified as RECENT ALLUVIAL SOILS. There will be no correlation difficulty at this level. The suborders **Dystric** and **Eutric Fluvials** are represented in Sarawak by families as shown in the correlation table. Since these two subgroups are differentiated on account of pH KC1 in the top 20 inches of soil (pH 4.2-Dystric, and pH 4.2-Eutric) there will be some difficulty to accommodate all soils of a family or even series on one or the other subgroups. pH KCl is normally not analysed in Sarawak, but is generally about one unit lower than pH H_2O. Also many RECENT ALLUVIAL SOILS may have a pH just around this limit and since pH is not taken as a diagnostic feature on its own, some series may contain soils of both subgroups.

The subgroup **Gleyic Fluvials** is represented by the most poorly drained GLEY and SALINE-GLEY SOILS which have no histic A horizon and which have no characteristics inducing the formation of catclay upon oxidation. For this reason, the *Punda series* in the GLEY SOILS and parts of the **Rajang Family** cannot be classified in this group. Potential catclay has not been used in Sarawak as a diagnostic characteristic for a separation of soils in the **Rajang Family** but this is strongly recommended for future classification work.

The REGOSOLS are represented by part of the SKELETAL SOILS, mainly those found on unconsolidated old alluvials. Only the subgroup **Dystric** is present, all alluvial deposits being very poor in bases and having a low pH. Difficulties arise when using pH H_2O as a diagnostic feature in these very sandy soils since they show generally too high values because of the low buffering capacity.

Probably the *Siar series* in the **Kayan Family** and the *Sematan series* of the **Sematan Family** (both RECENT ALLUVIAL SOILS) could be placed in the ARENOSOLS on account of the existence of an Oxic B. This needs further analytical confirmation, particularly on the content of free iron. These light textured deposits, however, cannot be regarded as Oxic in the sense of the 7th Approximation.

GLEYSOLS can be correlated with the very poorly drained SALINE-GLEY and GLEY SOILS and those SALINE-GLEY and GLEY SOILS having a pH KCl upon oxidation of less than 3.5 within 40 inches from the surface. The subgroup **Histic Gleysols** finds its equivalent in the **Sebandi Family** and other families in the SALINE-GLEY and GLEY SOILS with a histic A horizon. The soils with potential catclay characteristics are placed in the **Thionic Gleysols** subgroup (some **Rajang Family** soils with SALINE-GLEY SOILS and the *Punda series* in the GLEY SOILS).

PLANOSOLS are probably not present in West Sarawak since they must have an Argilluvic B horizon. Although a strong textural contrast is found in some GREY-WHITE and RED-YELLOW PODZOLIC SOILS this is thought to be mainly due to a bisequency in parent materials and not caused by clay illuviation.

The presence of CAMBISOLS is dependent on the existence of a Cambic B horizon. For this reason, some RED-YELLOW PODZOLIC SOILS, and GREY-WHITE PODZOLIC SOILS may have to be classified as **Ochric Cambisols.** Features marginally diagnostic for a Cambic B are also found in some LATERITIC SOILS. (*Antayan series*) Much more information is needed, however, before such soils can be firmly classified in this scheme.

The group of PODZOLS is well represented in Sarawak by the local PODZOLS. The subgroup **Gleyic Podzols** is formed by most soils in the **Miri Family**, the subgroup **Humo-Ferric Podzols** by the **Jerijeh Family** and the subgroup **Humic Podzol** by the **Silantek** and **Buso Families.** Probably the **Bako Family** belongs also to the latter group but may have to be placed either in a lithic subgroup or in the **Gleyic Podzols** if a Gleyic subsoil is present.

The ACRISOLS would be the logical place for those RED-YELLOW and GREY-WHITE PODZOLIC SOILS without a Cambic B horizon. However, most of these soils most probably do not have an Argilluvic B horizon either, on account of which they cannot be placed in the ACRISOLS. Dudal (1968, p.9) has recognised these transitional soils and proposed a Group of NITOSOLS for soils with an Oxic horizon having a stretched clay bulge not qualifying as an Argilluvic B. The adoption of such a group would probably solve the placing of many Sarawak RED-YELLOW PODZOLIC SOILS having Oxic and Acric features.

The group of FERRALSOLS is represented in Sarawak by most LATERITIC SOILS and RED-YELLOW PODZOLIC SOILS without a Cambic horizon, although the latter could probably be better placed in the proposed NITOSOLS. Most LATERITIC SOILS (*Tarat, Bukit Batu* and *Jebong series*) are placed in the subgroup Helvic Ferralsols because of their low SiO_2/Fe_2O_3 ratio (less than 13) while the clayey members of the **Abok Family** (*Gumbang, Abok* and *Keladan series*) are also provisionally classified as **Helvic Ferralsols.** The remainder of the RED-YELLOW GROUP not mapped in other groups although having often stronger colours than yellow to pale yellow must be placed in the subgroup **Ochric Ferralsols** because of the high SiO_2/Fe_2O_3 ratios (more than 13). The placing of many of the GREY-WHITE PODZOLIC SOILS is difficult because of their very pale colour but they could be accommodated in the Ochric subgroup if the colour range is extended to include paler coloured soils. Some may be placed in the **Humic Ferralsols** since particularly the sandy members (**Saratok** and **Triboh Families**) have a high organic matter content.

PEAT SOILS in Sarawak are all correlated with the HISTOSOLS, **Dystric Histosol** subgroup.

The LITHOSOLS correspond with the **Meluan Family** of the SKELETAL SOILS. This family if occurring on limestone and basalt would probably qualify as an **Eutric Lithosol,** the remainder being **Dystric Lithosols.**

The presented correlation is only schematic and covers only the majority of soils. It is realised e.g. that some Sarawak PEAT SOILS are not included in the HISTOSOLS because in Sarawak any soil with an organic surface horizon of more than 10 inches qualifies for a PEAT SOIL, while HISTOSOLS must have a thickness of 12 inches. The same difficulty presents itself with the LITHOSOLS, for which in the Sarawak SKELETAL SOILS, a distinction is made between a lithic or paralithic contact which may extent to a depth of more than 10 inches. For this reason, many SKELETAL SOILS in Sarawak are only lithic subgroups of soils other than LITHOSOLS.

Chapter 10. SOIL GENESIS

1. Evaluation of Soil Forming Factors

In this section the classical independent variables or soil forming factors that define the soil system and which are commonly conveniently regarded as the 'creators' of soil, are evaluated on their importance in soil formation under West Sarawak conditions. Jenny (1941, p.15) lists these independent variables as Climate, Organisms, Topography, Parent Material and Time. The influence of man is sometimes separately added but is in this list regarded as an organic factor. Factual detailed information on these subjects can be found in Chapters 2 to 5.

(a) Climate

The available data on the different aspects of the atmospheric climate have been discussed in Chapter 3 (p.23). From this it can be learned that the general characteristics of the climate in West Sarawak vary little from place to place, although minor variations of possible importance to crop growth occur. It has been shown that the climate in West Sarawak is characterised by generally constant humid conditions in which mean precipitation exceeds evaporation. The mean surplus precipitation over evaporation, however, varies over the Region and through the year. Thus, in Kuching this ranges from 26 inches in January to 1½ inches in June, while in Simanggang the maximum differences is 11 inches in January and 3 inches in July (Fig. II.6, p.42).

Allowing for direct evaporation of a considerable part of the precipitation through the vegetation cover and for the runoff, it can be assumed that for the greatest part of the year more water infiltrates in the soil than is evaporated from it. This is also borne out by field observations which indicate that under the natural forest vegetation soils are commonly moist throughout the year and never dry out to any marked extent. Leaching should therefore be a common characteristic in soil formation in West Sarawak. The magnitude of leaching, however, is strongly governed by soil characteristics such as texture, permeability and topography. The influence of leaching on soil formation therefore varies with such characteristics. Atmospheric temperatures vary little throughout the year and variations in soil temperatures are assumed to be even less. Table 4 (p.39) shows that the diurnal differences between high and low temperatures under a forest canopy are less than over grass, the absolute range being 70-90°F. This probably indicates that under the normal primary jungle cover soil temperatures would show an even smaller range.

Temperature data from high mountainous areas are not available but the difference in temperature cannot be very great since most of the Region lies below the 1,000 feet level. The atmospheric climate therefore induces over the whole Region a warm, humid environment in the naturally occurring soil and varies little throughout the year. The factor Climate can therefore be taken as being constant throughout the Region. The degree in which soil climate influences soil formation is very much dependent on the other invariables, Time, Topography, Parent Material, and Organisms which, with a constant atmospheric climate, will relatively play a more important role in soil formation.

(b) **Organisms**

The most important organisms 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, p.199) introduces therefore the biotic factor being the quality aspect of organisms as the true independent organic variable; while he regards the quantity aspect of organisms as a dependent factor. For our purpose, it is sufficient to say that vegetation, animals and man, being independent or not, are probably the most significant organisms playing a role in soil development in Sarawak. Micro-organisms in their quantity are related to other factors such as climate and fertility (parent material), and little is known about the quality so that this factor will have to be omitted in the discussion.

(i) **Vegetation**

The natural vegetation types in West Sarawak are very much a reflection of soil conditions and cannot be regarded as an independent factor. Their quality is largely fixed by the atmospheric climate which is homogeneous over the Region while the differentiation into vegetation types is caused mainly by the influence of Parent Material, Topography and Time.

It is often said that the role of vegetation in soil formation is an important one and no doubt, many soil types are characterised by a specific vegetation type. This, however, does not need to imply that the specific vegetation was responsible for the formation of that type of soil. This may be so in temperate regions where a specific vegetation, such as a coniferous one, is very much dependent on the atmospheric climate and if that specific vegetation induced by the climate influences soil formation through production of acid litter one can speak of a causal relationship between vegetation and soil weathering. However, in West Sarawak and for that matter in all tropical areas with a homogeneous atmospheric climate, the vegetation types are not influenced by the climate but by factors such as Topography, Parent Material, and Time.

Topography has a bearing on the physical environment and on the soil climate and plays a role in the formation of vegetation types such as Peat Swamp Forest and Mangrove and Nipah Forest. Kerangas Forest is influenced by topography and parent material, the latter being too poor to support any other type of natural vegetation. This brings the factor 'time' to the fore. The areas covered with Kerangas Forest probably have the oldest soils, not only in relative age but also in absolute age, the Kerangas Forest types can probably be considered as a type of climax vegetation on specific parent materials. It is of interest to note that forest found on bauxitic materials previously occurring at Munggu Belian and still present at Bukit Jebong, both localities near Sematan, is much alike Kerangas Forest usually found on poor quartzitic sands in which PODZOLS have formed. This may indicate that where soil formation on widely different parent materials reached a climax the differences between the vegetation types may be narrowed.

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 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 more light textured the soil (which means in West Sarawak 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 microbiological activity is extremely low. Probably both factors play a role. The litter is extremely poor in bases and phosphate, which is a reflection of the poor nutrient status of the soil and there are probably insufficient energy supplying nutrients in the litter to maintain a highly developed microfauna and flora. Mohr and van Baren (1953, p.278) indicate that bacterial activity is generally low at high acidities while fungal growth is little affected. The generally low pH of the soils in West Sarawak would indicate that the fungi population is expected to be high. However, fungi do not thrive well at tropical temperatures (1953, Mohr and van Baren) and it could be that a combination of factors such as low pH, low base status and high temperature inhibits the microbiological activity to such a level that litter can accumulate. The extreme case is found in the PODZOLS where acid humus layers more than one foot thick are common. Humus accumulation may also be enhanced by waterlogged conditions. It is of interest to note the strong resemblance between surface humus layers on PODZOLS and the organic deposits accumulating in basin swamps. Probably the cause for their formation is related in some way.

The litter accumulations produce highly acidic conditions in the soils and accelerate podzolization processes, so that the Kerangas vegetation can be regarded as a sort of catalyst in soil formation.

Mangrove and nipah vegetation appears to be connected with the occurrence of potential 'cat-clays'. Deltaic deposits commonly have a high percentage of organic matter derived from mangrove and nipah. When the soils are drained this buried vegetative material plays a role in the processes leading to the formation of catclays (see Chapter 13, section 2, p.228).

Finally, a quantitative aspect of the influence of vegetation on soil formation may be its sheer weight. Baillie (pers. comm., 1970) is of the opinion that if 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. Such land slips play an important role in the rejuvenation of soils.

(ii) **Animals**

Termite activity is low in Sarawak and although ants do occur in large populations they usually build their nests in rotten trees or surface horizons so that soil disturbance caused by ants must be rated as low. Burrowing animals may enhance erosion through intense channelling 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, initiate land slips. This process is particularly common in sandstone areas of steep topography.

The mudlobster (*Thallasima anomala*) throws up large mounds in deltaic areas; soils occupied by nipah vegetation are particularly affected. These mudlobsters play an important role in the formation of catclays (see Chapter 13, section 2, p.228).

(iii) **Man**

Finally, man has played only a relatively minor role in soil formation in West Sarawak. Shifting cultivation practises may have influenced soil fertility but has not greatly affected soil formation. In some areas erosion and resulting rejuvenation may be partly due to shifting cultivation but generally the effect has not been great. The effect of cutting down primary jungle over extensive areas may have increased flooding in middle and lower riverine floodplains. There is some evidence that mineral soils were deposited on peat in recent times (Andriesse, 1966a, 1968a) but this could also have been caused by a change in erosion base level. Artificial drainage has changed the environment of soils in some minor areas. The Nonok Peninsula is probably the largest area where human activity has greatly changed the soil environment. The change over from the **Rajang Family** into **Pendam Family** for example, is largely due to human interference which changed a reduced saline environment into a more oxidized and less saline one.

(c) **Topography**

According to Jenny (1941, p.89), topography plays an important role in runoff and erosion, but according to the author, these processes essentially promote soil removal and destruction and are therefore not truly soil forming factors. It can be argued that when there is soil removal there must be deposition somewhere else, and while removal may be a soil destructive force, deposition is very much a constructive one. In view of the author, therefore, erosion and related deposition are as much soil building as soil destructing processes and they cannot be excluded from the discussion.

The configuration of the landscape dictates whether erosion or deposition predominates. Steeply sloping areas will, under the prevailing climate, show erosion of some kind while low-lying, flat areas will receive material removed from adjacent higher-lying country. Erosion and deposition are both rejuvenating processes. In areas with strong relief, erosion continuously removes strongly weathered material from the surface and relatively less strongly weathered material will be exposed. Strongly sloping terrain therefore is generally occupied by immature soils. Gently sloping areas because of less soil removal will as a result show more maturation in the soil profiles. Flat areas will either show constant rejuvenation by fresh deposits if they are frequently flooded and soils will be immature or if no deposition takes place the maturation process is allowed to proceed uninterruptedly and the whole range from weakly developed to strongly developed soils may be present. Under such conditions, the degree of soil development is dependent on the factor 'time'.

An example of the combined effect of topography and time on soil formation can be found in terrace sites. Very old preserved terraces have strongly developed soils while sub-recent terraces show less strongly developed ones. The same is true for coastal deposits. Although such deposits occur in flat areas, the distance from the coast indicates the time which has elapsed since the soil material was deposited and soil formation was initiated.

Apart from the influencing erosion and deposition topography has an effect on the height of the watertable which has a strong impact on the mode of soil formation. Areas with a high watertable have soils strongly influenced by an aquatic environment while those with a low watertable have soils formed in a subaerial environment. The latter may show strong leaching with vertical and lateral removal of chemical compounds, the former may have some removal of chemical compounds mainly by lateral flow of groundwater, but accumulation is rather the rule.

Because of the relationships between topography, soil maturation and mode of soil formation topographic boundaries are often indicative of soil changes. Such changes are *a priori* of genetic significance and for this reason most boundaries of soil mapping units in West Sarawak have a strong genetic basis. For this reason, much attention was given in Chapter 4, section 3 (p.59) to a description of landscape units which are closely related to the soil mapping units. The strong emphasis given to the use of topographic units for embounding soil mapping unit is one of the reasons why soil classification in Sarawak is so much biased to inferred soil forming processes rather than profile morphology. The use of profile morphology in soil mapping does not exclude consideration of genetic processes, because profile morphology commonly is an expression of genetic processes, but the use of profile morphology alone creates great mapping difficulties in Sarawak. Because of the inaccessibility of the terrain in most areas the reliance on topography with its inferred genetic importance cannot be dispensed with in reconnaissance and semi-detailed mapping.

(d) **Parent material**

Rocks together with Climate and Time are probably the only true independent factors of soil formation. Particularly in West Sarawak topography is strongly influenced by rock type. This is caused by differential erosion on hard or soft consolidated rock types and bedding planes in sedimentary rocks. The reverse is true for the topography of the unconsolidated materials such as old and recent alluvials, since the latter were deposited in an existing landscape which has influenced their characteristics. Many examples can be given to indicate a relationship between rock type and topography. As descibed in Chapter 4, section 3 (p.59), the Bau physiographic unit is characterised by limestone, the Penrissen physiographic unit by horizontally bedded sandstone and the Pueh and Stapok physiographic units by igneous rocks. Relationships between parent materials and physiography are shown in full in Table 9 (p.55).

The influence of the parent rock on soil formation is most strongly felt in the uplands where it not only influences the physiography of the terrain, but also the nature of soils and in some cases that of the vegetation, e.g. Limestone vegetation. Under West Sarawak conditions, the parent rocks generally set a trend in soil formation. Poor quartzitic sandstones give rise to soils potentially prone to podzolization, basic igneous rocks carry the seed of laterization. Such soil-forming processes need certain chemical and physical conditions which are inherited from the parent rock.

Since the influence of Climate is uniformly felt over the Region it is mainly the nature of the material submitted to the climate elements, the parent materials of soils, which causes a differentiation in soil forming processes and resulting diversification of soil types. The intensity of this interaction between climate and parent material is dependent on Time and on Topography of which the latter, as indicated, is also strongly influenced by the parent material if that is formed by consolidated rocks.

Andriesse (1969c) has shown that with a prevailing humid tropical climate as found in West Sarawak, a close relationship exists between the chemical and physical properties of rock types and soils derived from them, thus, that with increasing acidity as measured by the total SiO_2 content of the rock type, the main soil forming process shifts from laterization to podzolization. The range is affected by the texture of the rock type in that, with a given acidity of rocks, podzolization is more marked in soils on coarse-textured rocks than in soils on fine-textured rocks. In the case of recent and subrecent alluvial deposits a stronger relationship is found between topography and soil. As stated before, this is caused by the fact that in floodplains parent materials are related to topography while in the uplands a reverse relationship is found. This has a practical implication in soil mapping. In floodplains the boundaries between the main soil types are regular and adhering to certain patterns related to deposition and topography. In hilly country where the underlying rock types dictate more or less the soil pattern, an irregular distribution of main soil types is found because the geology is irregular. No wonder that in West Sarawak parent material and topography are regarded as the most important soil-forming factors or, better, as the most indicative factors playing a role in the distribution of soils.

(e) **Time**

In studies dealing with soil formation, the factor Time must be separated into Time as an absolute measurement and Time as a relative measurement. The absolute time in soil formation indicates the time elapsed since soil forming processes started to operate. Time as a relative measurement indicates the progress in soil formation. Mature soils such as PODZOLS are in a very advanced stage of development but the period required to reach this stage may be relatively short. Weathering on basalts may be very slow and although in absolute time the soils on basalt may be older than the PODZOLS referred to above the soils may be much younger in terms of maturation.

For estimating the absolute age of a soil, reference must be made to the age of the landscape. In Chapter 4, section 2 (p.46) it is argued that the oldest peneplain level of 200 to 350 feet may be Mid-Pleistocene age. Because of continuous erosion and strong rejuvenation since that time, one has to conclude that most soils in this landscape are relatively young in age. This may be said of most areas with strong relief where erosion constantly rejuvenates the soils. An absolute age measure cannot be given for these soils but in relative terms they must be regarded as young, because they are quite immature. Preserved landscape features, such as dip slopes of cuestas where erosion is absent or of little importance, have old soils in terms of maturity (PODZOLS). They are probably also the oldest in term of absolute age. If they occur above a level of 350 feet they may be older than half a million years. Many apparent similar soils, however, are found in terraces of lower levels and of younger age. PODZOLS on the 90 to 120 foot terraces in the Kuching area may date back to the Mid to Late Pleistocene. PODZOLS in the 20 to 50 feet terraces may be as old as 25,000 years as indicated by C14 dating on fossil wood found in a Bh of a PODZOL near Silantek (see Chapter 4, section 2, p.48). Soils of the same nature are also found at a level below that of the 20 feet terraces and may even be younger. Investigations into the development of the PODZOL morphology in a sequence of coastal ridges found at Sematan (Sematan physiographic unit, p.59) have shown that a full PODZOL morphology is developed in less than 6,000 years. The **Jerijeh Family,** being the oldest ridge in this area, was probably formed at the beginning of the Holocene (Andriesse, 1970). Most alluvial deposits which are mapped as being Recent are by inference not older than 6,000 years at the most and many of them are much younger. The same applies to the PEAT SOILS. The lowest layers of PEAT started to accumulate about 6,000 years ago (see Chapter 4, section 2, p.46), but the surface horizons are much younger. Most GLEY SOILS and SALINE GLEY SOILS are also younger than 6,000 years old.

It can be said that the Region is generally characterised by a young landscape with comparatively immature soils, the PODZOLS forming an exception. The latter, together with the LATERITIC SOILS, are probably the oldest in terms of maturation but the LATERITIC SOILS are considered to be much younger in absolute age which may be comparable to that of the soils found in the strongly dissected shale and sandstone country, (Tebedu unit, p.67). Upland PODZOLS are probably the oldest soils in terms of absolute and relative age, those of the lowlands are old in relative age but some may be younger than 6,000 years, the great majority being older than that.

Although the soils generally give the impression of being of young age the chemical properties indicate that they are thoroughly weathered. This applies in particular to the upland soils. It should, however, be mentioned that although the soils may chemically be of relative old age, the horizonation does not necessarily indicate the same. This is probably the result of rejuvenation caused by erosion through which much material making up the soil mantle on slopes is reworked by sliding and slumping. The parent materials being mainly of secondary rock origin and inherently poor is also a contributory factor to the thoroughly weathered nature of the material. These rock types may have gone through several weathering stages before they were consolidated in their present form. By the same token, recent alluvium originating from poor parent material may be chemically less weathered than subrecent alluvium derived from much richer parent rock sources.

2. General Aspects of Soil Formation in West Sarawak

Studies in soil formation are made difficult in West Sarawak by a number of conditions probably not encountered in such measure in other tropical areas.

(a) Most parent materials of soils are of a sedimentary rock origin of which the lithology may be quite easily determined but the chemical composition is generally not or insufficiently known. Even when such information is available the true parent material of a specific soil is difficult to find if the soils occur in a strongly dissected landscape with steep slopes where much removal, resorting and redeposition of soil takes place. When sedimentary rocks show rapid successions of different rock types (argillaceous or arenaceous) with contrasting chemical composition it is difficult to assess how much each type of material has contributed to overlying soils, occurring on steep slopes. Therefore, on such soils, it is extremely difficult to study leaching processes since the starting point is generally not

Plate 11

The chemical B horizon developed in weathered Cretaceous mudstone at a depth of 10 to 20 feet, showing flaky limonitic concentrations in a macro honey-comb pattern. Exposure road cutting 4th. mile Bau - Lundu road.

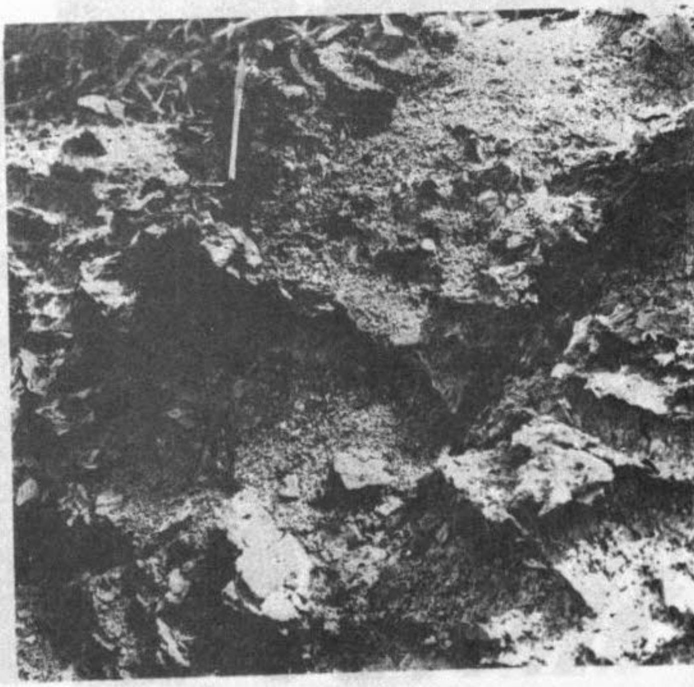


Plate 12

Close view of macro honey-comb pattern formed by flaky limonitic concentrations in partially weathered Cretaceous mudstone of plate 11.

Plate 13

Close succession of steeply folded Tertiary sandstone beds and mudstone. Terraces in the poorly consolidated mudstone are totally destroyed, those in sandstone are much better preserved after 6 years exposure to erosion. Roadcutting 9th. mile Bau – Lundu road.

Plate 14

Close view of contact zone between Tertiary sandstone and mudstone, showing differential erosion after 6 years of exposure. Limonitic iron sheets have developed at the contact zone and show flow structures.

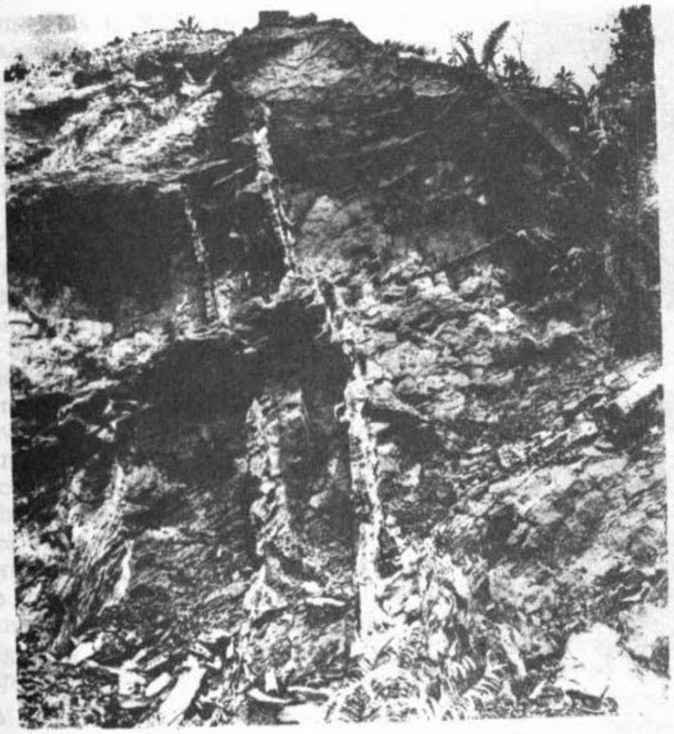


Plate 15

Hard sheets of limonite in cracks and joints of Triassic Shale found below the *Bedup series* (RED-YELLOW PODZOLIC SOIL) illustrating the deep penetration of the chemical B horizon into the weathering shale material.

Plate 16

Close view of hard limonite sheets as shown in Plate 15.
Note the discolouration of dark shale along joints also present in the *Kerait series* (Plate 18), and the flow-structure of the iron sheets where in contact with the shale.

Plate 17

Abrupt change over from black carbonaceous shale to the white illitic sub-horizon of a *Kerait series* (GREY-WHITE PODZOLIC SOIL).
Note the advancing dis-colouration along joints in the massive shale. 51th.mile Kuching - Simanggang road.

Plate 18

Close view of abrupt colour change in subsoil of *Kerait series* shown in plate 17.

known. This is much easier in soils on igneous rocks which are more uniform in composition, and although the parent material may not be exactly the same as the unweathered rock found in the profile, chemically it is very similar in composition. Further, a bisequency in parent material if this is formed by sedimentary rocks, may induce the formation of soil characteristics, otherwise not occurring, and commonly it is very difficult to distinguish between soil properties caused by an inherent bisequency or by true soil forming processes. Textural changes in the profile may be caused by illuviation of clay during soil formation or they may relate to a fossil sedimentation process preserved in the parent material. Likewise, leaching of iron oxides may have occurred during deposition of sediments prior to the consolidation of sedimentary rocks and may not be the result of present-day soil forming processes. Also certain clay minerals may have been inherited from the sedimentary rocks, others may have formed in the present soil. These problems are not encountered when studying soil genesis on igneous rocks which are uniform in chemical composition and consist of primary minerals only.

(b) Under a humid tropical climate, weathering is very intense. The rate of decomposition of the rock is governed by the influence of the climate and the hardness of the rock. Igneous rocks are usually harder than sedimentary rocks which in West Sarawak commonly consist of poorly consolidated soft shales, or poorly consolidated porous sandstones. The soils formed on igneous rocks are comparatively thin. This is partly caused by the hardness of the rock but mainly because of the steepness of the terrain which prevents the formation of deeply weathered soils commonly associated with stable landscapes.

The soils developed on sedimentary rocks are also thin in terms of distance from the surface to the C horizon, either formed by the partially weatherer rock in which the original structure or bedding is still noticeable, or formed by unrecognisable colluvial debris comprising rock fragments of various rock types and partially weathered rock material. The chemical processes usually extend far beyond this physical C horizon and the chemical B horizon may overlap the C horizon (Plates 11 and 12, p.141). This is particularly evident where the underlying sedimentary rocks contain porous sandstone beds through which percolating rainwater is able to move downwards. Removal of chemical compounds and subsequent accumulation of leached products takes place at great depth and if soil genetic studies have to be made on such soils, such chemical changes must also be taken into account. These changes may not take place over a horizontal front but they are frequently vertical or lateral because this depends on the movement of soil water along strongly dipping sandstone or shale beds. Limonite sheets are commonly formed along bedding planes of sedimentary rocks showing textural contrast (see Plate 14, p.142). The source of this iron must be sought in the originally overlying material which was probably leached in the very early stages of rock weathering. The pH of sedimentary rocks in West Sarawak is generally in the acid range and where sulphides occur it may reach a value of less than 3 if the sulphides are weathered and oxidized. The C horizon is therefore chemically already much impoverished before it attains the physical characteristics of a B horizon. These aspects can be readily studied in road cuttings showing deep soil sections.

When following mapping procedures as used in temperate regions where chemical weathering does not extent to great depth, the full soil profile including weathered rock can be studied within a depth of 4 feet from the soil surface. Soils are usually mapped on properties present within such depth, a practice also followed in Sarawak. Normal soil studies are therefore mainly concerned with the surface 4 or 5 feet but great difficulties are encountered to interpret the results of such studies in relation to soil forming processes. This is particularly so in soils derived from sedimentary rocks. In such soils, the chemical composition of a 4 feet deep profile may only be representative for the lower part of the A and the upper part of the chemical B horizons, while the complete chemical B may extend far beyond the horizon designated as the B/C or C. In soils derived from igneous rocks these difficulties are not present in such magnitude and the interpretation of the horizons is relatively easy.

In the discussion on the genesis of the most important soil groups in Sarawak one must therefore differentiate between the chemical and the physical profile. Only the physical profile, that which is commonly described and extending to a depth of 5 feet was subjected to chemical analyses, and these show in general not well expressed chemical features indicative of a certain type of soil weathering. For this, the deep chemical profile must be brought into the discussion.

3. Genesis of the Upland Soils*

(a) LATERITIC SOILS

LATERITIC SOILS develop over basic igneous to intermediate rock types. In this group, two main series were studied in detail, the *Tarat series* (p.164) and the *Bukit Batu series* (p.164). Although the solum is commonly quite shallow the soils are strongly leached and depleted of bases. The total analyses of these two soil series show great losses in total silica from the soil compared with the parent rocks on which they have formed.

***For descriptions and analyses of the mentioned series reference is made to the Appendix.**

The total silica contents in the gabbro-andesite range is 49.58 to 55.8% (Tables 12 and 13, p.85 and p.86). The total SiO_2 content of the *Bukit Batu series* is 9 to 13%, while that of the *Tarat series* is considerably higher, ranging from 30 to 47. In the *Tarat series* the total silica content shows an increase with depth which indicates increased weathering in the surface horizons.

Fig. IV.1 (p.147) shows that the SiO_2/R_2O_3 ratios of the colloidal fraction in the *Bukit Batu series* are all below 0.5 and there is very little change throughout the profile. The low SiO_2/R_2O_3 ratio together with the very low content of total silica indicates marked laterization and a mature stage in soil formation. This is confirmed by the clay mineralogy which indicates that well crystallized gibbsite is dominant throughout the profile. Small amounts of kaolinite and vermiculite are still present in the subsoil where weathered rock is found. A fairly high amount of X-ray amorphous material (Si and Al oxides) in the surface horizon may point to a breakdown of vermiculite or kaolinite by probably fulvic acids and may be partly a transitional form to gibbsite. The presence of these X-ray amorphous compounds are found in most Sarawak upland soils and is further discussed in section 1 of Chapter 15 (p.254). Fig. IV.2 (p.148) indicates that the *Bukit Batu series* shows a relative increase of both aluminium and iron oxides in the surface horizons, aluminium showing a stronger increase than iron.

The *Tarat series* is less mature and although strongly leached and almost depleted of weatherable minerals, the content of total silica is still high, particularly in the subsoil. The SiO_2/R_2O_3 ratios of the colloidal fraction (Fig. IV.1, p.147) show values of less than 1 in the surface horizon, approaching 1 or being slightly over 1 in the subsoil. The SiO_2/Al_2O_3 and SiO_2/Fe_2O_3 ratios (Fig. IV.2, p.148) of the *Tarat series*, indicate that as in the *Bukit Batu series*, the aluminium and iron oxides increase relative to SiO_2 in the surface horizons, with aluminium dominant over iron.

The clay mineralogy confirms that the *Tarat series* is less mature than the *Bukit Batu series*. Poorly crystallized kaolinite is dominant in the *Tarat series* the surface soil showing better crystallization of kaolinite than the subsoil. A fair amount of gibbsite is present throughout the profile. The content of vermiculite increases with depth and in the subsoil some interlayered illite-vermiculite-chlorite minerals may still be present. The *Bukit Batu series* contains dominantly gibbsite in the colloidal fraction throughout the profile.

The clay mineralogy of the *Tarat series* suggests that the primary minerals weather into illite-vermiculite, which in a more advanced weathering stage change over into kaolinite. The poor crystallization of the latter, particularly in the subsoil may indicate lack of stability in the mineral part of the soil. The kaolinite may finally be broken down into SiO_2 and Al_2O_3 and gibbsite is formed.

The difference between the *Bukit Batu* and *Tarat series* is mainly one of weathering stage, the *Bukit Batu* being in a more advanced gibbsitic stage than the *Tarat*. The nature of the parent material may have caused this difference since the soils are probably in absolute age comparable. The *Tarat series* (Profile 254) is derived from strongly altered intermediate igneous rocks showing incipient chloritization and serpentinization which may have influenced the formation of mixed layer and 2:1 lattice clays in the subsoil, and which is not found in Profile 75, *Bukit Batu series*, which is developed on unaltered basic igneous rocks. It is possible that, because of different environmental conditions and a difference in parent material, gibbsite may form directly from primary minerals in the *Bukit Batu series*, while in the *Tarat series* this is achieved through several stages.

Other minor series in the LATERITIC SOILS have not been studied in detail. From the blocky structure of the *Jebong*, *Antayan* and *Sejingkat series*, in contrast with the well developed granular structure of the *Tarat* and *Bukit Batu series* one may infer that the clay mineralogy may be different. The analytical data on Profile 11 (*Jebong series*) and Profile 92 (*Antayan series*) show that the soils are still quite siliceous, particularly the *Antayan* profile, and the clays may contain a higher content of 2:1 or mixed lattice-clays, indicative of a relatively less advanced stage in weathering than observed in the *Bukit Batu* and *Tarat series*.

The difference in clay mineralogy may also be caused by a difference in parent material. Particularly the parent material of the *Sejingkat series* consisting of a silicified volcanic rock type, must be considered to be more siliceous.

The intense weathering observed in the dominant series of the LATERITIC SOILS is no doubt caused by the very porous nature of the solum which enhances rapid leaching of bases and silica. Of particular interest is the generally rapid change over from unweathered rock to completely weathered soil. A complete transformation is achieved within a zone of less than one inch. The *Suka series* in the SKELETAL SOILS (p.162) which can be regarded as an immature *Tarat series* soil, illustrates the complete decomposition of weatherable primary minerals and the intense leaching taking place in the early stages of soil formation. Weathering does not penetrate to great depth into the rocks and the weathering zone is generally quite uniform in depth, and is disturbed only by erosion on steep slopes and colluviation at gentle foot slopes.

Fig. IV. I SiO_2/R_2O_3 ratio's of some selected West Sarawak soils.

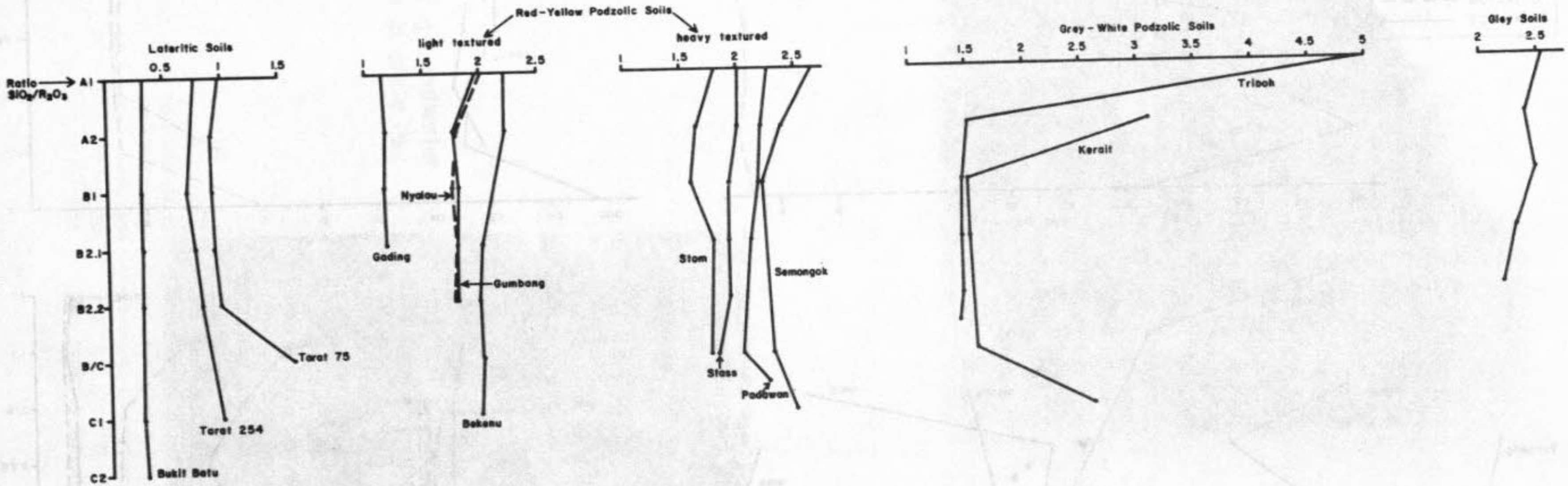
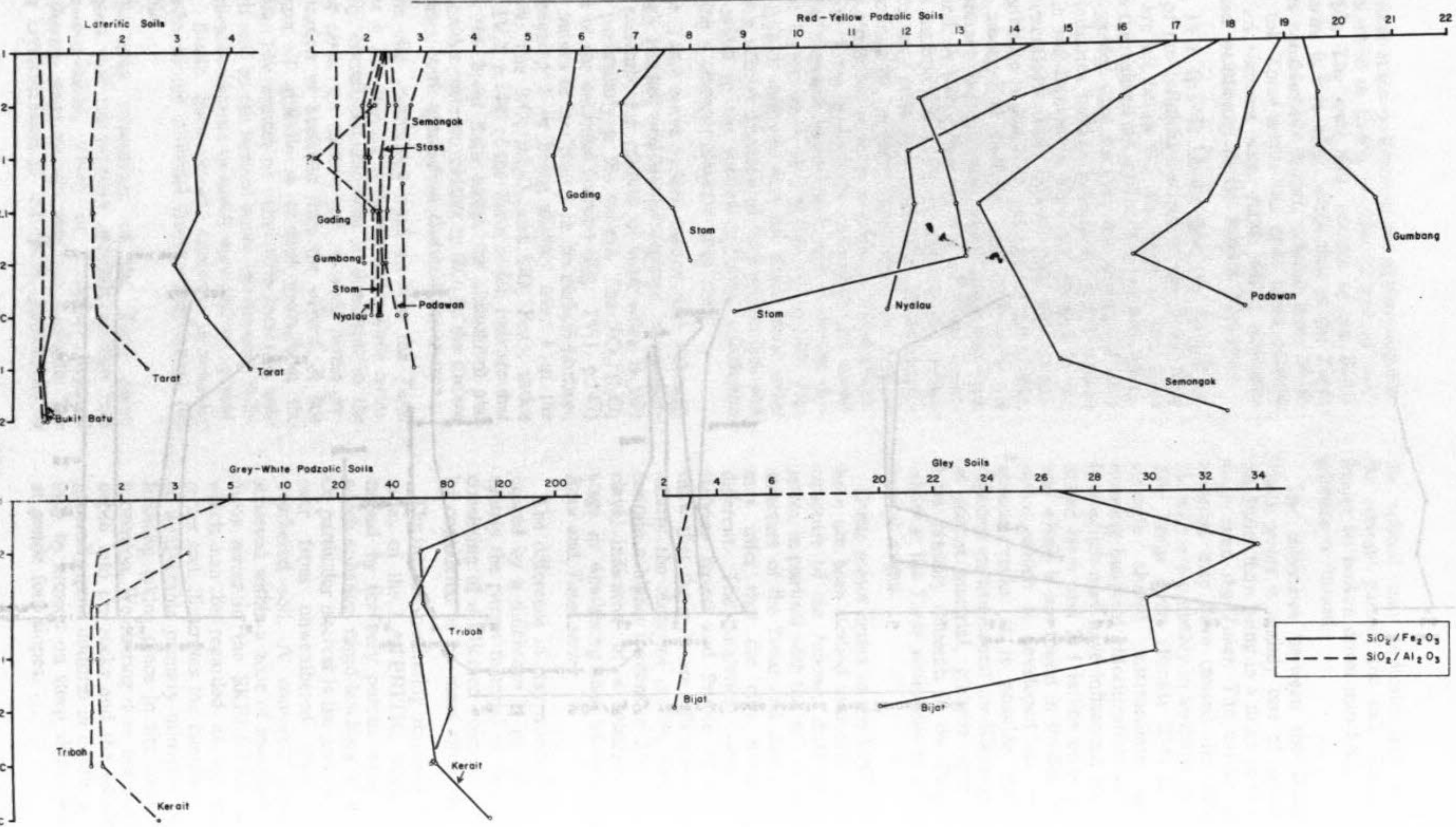


Fig. IV 2 SiO_2/Al_2O_3 and SiO_2/Fe_2O_3 ratio's in some selected West Sarawak soils.



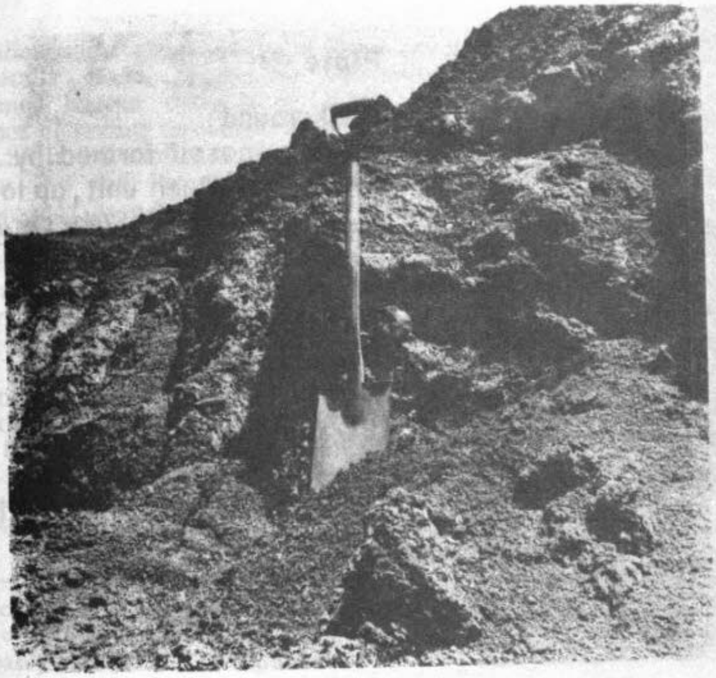
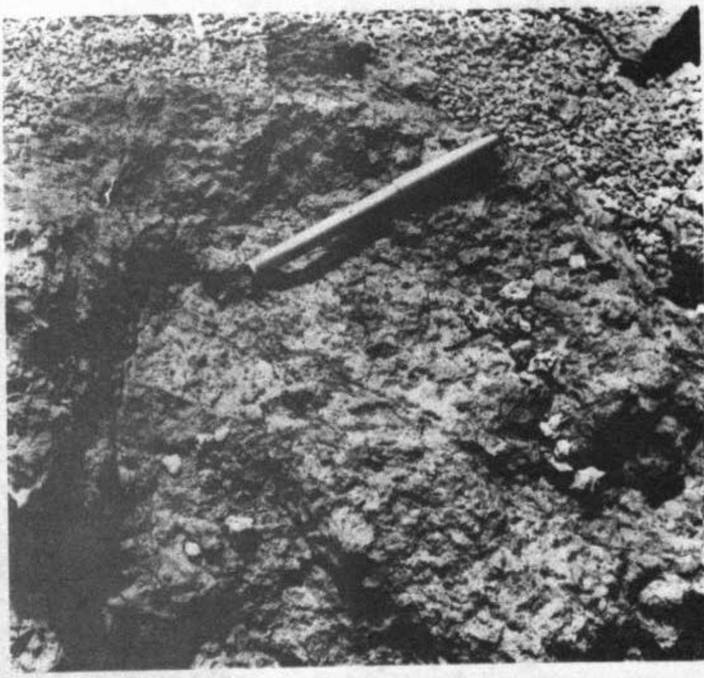


Plate 19

Fossil ground water laterite in a *Tarat series* (LATERITIC SOILS) developed ± 20 feet above base level. 60th. mile Kuching - Simanggang road.

Plate 20

Close view of groundwater laterite shown in plate 19.



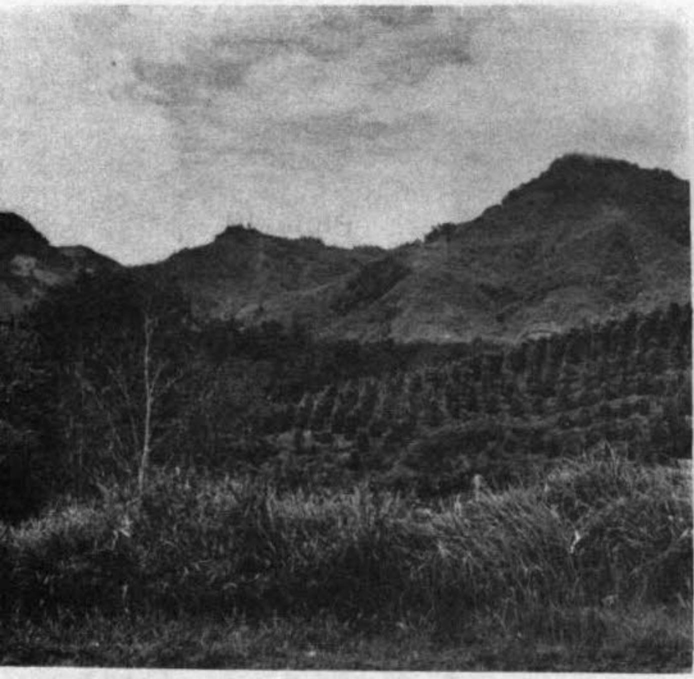


Plate 21

Background:
Igneous massif formed by andesites (Pueh unit, up to 2000 feet high). *Suka series* (SKELETAL SOILS) used for shifting cultivation.
Foreground:
Typical Quop B unit terrain (summit plain of 150 feet) with partial use for pepper. *Serin series* (RED - YELLOW PODZOLIC SOILS). 35 th. mile Kuching - Serian road.

Plate 22

Background:
Igneous massif (Pueh Unit) as Plate 21.
Foreground:
Interior valley used for wet padi cultivation.
Kakai series (GLEY SOILS). 16½ mile Kuching - Serian road.

Although the *Bukit Batu* and *Tarat series* are chemically much similar in composition to hardened laterite, there is an almost complete absence of laterite formation in the LATERITIC SOILS. It has been shown in several studies (Mohr and van Baren, 1953, p.379) that hard laterite may have SiO_2/R_2O_3 ratios of more than 2 and the amount of iron and aluminium oxides present is therefore, not the main cause for its formation. The above authors conclude from observations carried out by many research workers in tropical areas that the formation of hard laterite is more related to a fluctuating groundwater table than to climate. This conclusion is confirmed by field evidence in Sarawak. The LATERITIC SOILS occur on hilly, strongly dissected terrain in which the watertable is too low to influence soil formation. In the one locality where true laterite was found the soils occurred at a very low level near local floodplains (see Plates 19 and 20, p.149). As indicated in the section on the physiographic history of West Sarawak in Chapter 4 (p.46), the groundwater has probably subsided in a magnitude of 10 to 20 feet in geological recent times and the hard laterite found may be a relic of groundwater laterite formed during periods when the groundwater was higher. Because of the absence of stable land surfaces commonly typified by a rolling topography, no extensive laterite could develop and the high groundwater level is only locally effective at lower foot slopes.

(b) **RED-YELLOW PODZOLIC SOILS**

Because of the great variability of soils in this group, soil genesis is difficult to discuss at group level. Some soils in the group show lateritic features while others are podzolized. It is, therefore, necessary to split this group into two subgroups:

(i) All soils developed over igneous rocks;

(ii) All soils developed over sedimentary rocks.

Soils developed over igneous rocks do not show deep chemical and physical weathering, the chemical and physical C horizon being normally found within a depth of 4 feet. Chemical studies on such profiles are therefore relevant to the soil forming process extending from surface to the weathered rock.

Soils over sedimentary rocks show generally deep chemical weathering far beyond the 4 feet profile depth and although weathered sedimentary rock may be found within 4 feet from the surface, it may have been greatly impoverished or enriched by chemical compounds such as iron or aluminium and this C horizon must be regarded either as an eluviated or an illuviated horizon.

(i) The soils overlying igneous rocks are firstly discussed. Two profiles have been studied in detail, the *Gading series* overlying adamellite (p.165) and the *Gumbang series* overlying porphyritic tonalite (p.166). The *Gading* is light textured, while the *Gumbang* is slightly heavier textured. The SiO_2/R_2O_3 ratios of the colloidal fraction (Fig. IV.1, p.147) show a close relationship with the LATERITIC SOILS, being less than 2 in both series. The *Gading* shows a slight relative increase in sesquioxides in the upper horizons while in the *Gumbang* the sesquioxides content is rather uniform. The SiO_2/Al_2O_3 and SiO_2/Fe_2O_3 ratios of the profiles (Fig. IV.2, p.148) indicate a slight relative increase of iron in the subsoil of the *Gading* but the aluminium remains constant. The *Gumbang* shows a marked relative increase in iron in the upper horizons, while aluminium also remains fairly constant. One may conclude from this that the *Gumbang* shows incipient laterization while the *Gading* shows incipient podzolization. This is also borne out by the total SiO_2 content which shows a marked decrease in the *Gading* with depth while it remains fairly constant in the *Gumbang*.

The clay mineralogy shows that both soils contain dominantly well crystallized kaolinite throughout the profile, but in the *Gading series* some gibbsitic and X-ray amorphous aluminium and silica compounds are present in the topsoil while the *Gumbang* has a rather high amount of vermiculite. The *Gading series* is probably more mature than the *Gumbang*. Both profiles occur on strongly dissected terrain with steep slopes and the soils are not influenced by groundwater. The difference in maturation may be explained by the textural dissimilarity, the *Gading* being lighter in texture which enhances more pronounced leaching and rapid weathering.

(ii) Studied soils overlying sedimentary rocks comprise heavy textured ones represented by the *Stass series* (p.168), *Stom series* (p.170), *Semongok series* (p.169) and *Padawan series* (p.170) and light textured ones represented by the *Nyalau series* (p.172) and the **Bekenu Family** (p.171) respectively occuring on sandstone and on a mixture of sandstone and shale.

The *Stass* and *Stom series* have well drained features with little mottling and have a high porosity which enhances intense leaching, while the *Semongok* and *Padawan series* are imperfectly drained with massive structures and low porosity, indicating less rapid movement of soil water.

The *Stom series* occurs on a gently rolling landscape underlain by gently dipping mudstones, while the *Stass*, *Padawan* and *Semongok* occur on strongly folded carbonaceous shales, the *Stass* occurring on more massive hard shale, the *Semongok* and *Padawan* occurring on soft, finely laminated shales.

Except for the *Stom series* all soils show a deep chemical B horizon in which considerable accumulations of iron in the form of limonitic sheets have formed along major bedding planes joints and cracks in the physical C horizon (see Plates 11 to 16, p.141-143). Commonly, these series have also a thin layer of iron concretionary material overlying the physical C horizon. This material has accumulated in that position through a breakdown of the limonitic sheets when weathering and truncation bring them nearer the soil surface. The material of the broken up sheets is deflected downslope through slow mass removal along the slope and the iron rubble ends up as stonelines overlying the partially weathered sedimentary rock. This stoneline is an indication of the boundary between the stable part of the profile and the part constantly on the move.

For the formation of these limonitic sheets deep down into the sedimentary rocks the following explanation is offered. The areas most effected are those with elevations lower than 200 feet. Probably these areas had high groundwater tables up to that level in periods dating back to the Mid-Pleistocene. This groundwater was rich in iron compounds leached from overlying soil or sedimentary rock material. The particular shales involved are rich in carbon and pyritic materials, the latter being present between the laminae. Above the watertable, the pyrites are oxidized in a mixed subaerial/subaquatic environment, the high carbon content of the shale probably playing a role in the breakdown of the pyrites into sulphates and iron compounds. This process is very similar to that responsible for the formation of catclays in the present SALINE-GLEY SOILS (see Chapter 13, section 2, p.228).

With the very low pH caused by the highly sulphiric environment considerable amounts of iron were removed by the groundwater. After a gradual lowering of the groundwater table, these were subsequently lodged either in the more porous slightly coarser textured layers or in joints or cracks existing in underlying shale through which the groundwater could move. This process is still active up to the present day and the low pH in the subsoil of the *Semongok* profile (Profile 77) may illustrate this. The release of iron from pyrites is noticeable as thin films of yellow to brown iron oxides coating the shale laminae. Where there is no movement, the iron will eventually colour most of the soil yellow to brown, depending on the rate of dehydration. It can, therefore, be concluded that much of the material forming the present soil to a depth of 4 feet or to the iron stoneline, is derived from a partially iron impoverished parent material (eluviated C horizon).

The strongly dipping limonitic sheets may be compared with an illuvial podzol Bir horizon of which the iron is mainly in an inert state and does not play a further role in soil formation except as a contributing factor to the formation of iron stonelines. The eluviated parent material has become highly siliceous and aluminous which is adequately shown by the total analyses of the series involved.

Because of constant soil removal along the generally steep slopes of the dissected landscape associated with these soils one cannot expect to find soils with a marked horizonation indicating specific soil forming processes. Although the material may be old, the landscape is too unstable to bring about marked changes in the soil horizonation through prolonged leaching processes. This is well illustrated by the analyses.

The SiO_2/R_2O_3 ratios of the colloidal fraction (Fig. IV.1, p.147) indicate that there is incipient podzolization in the *Semongok* and *Padawan series*, there being a slight increase in sesquioxides relative to the silica content in the new chemical B horizon. This increase is, however, mainly caused by iron as shown in the SiO_2/Fe_2O_3 and SiO_2/Al_2O_3 ratios in Fig. IV.2 (p.148). The relative increase of iron in the A2 of the *Stass series* probably indicates that the A2 may in fact be an eroded B. The sudden increase of iron in the B/C horizon of this series may be caused by the iron released from pyrites in the weathered shale. The *Stom series* developed in a rolling landscape with less soil movement along slopes shows the same features but the iron content in the colloidal fraction is higher. This series has developed in terrestial mudstone in which pyritic material is not present and which shows no signs of iron leaching.

The clay mineralogy indicates that kaolinite is dominant in all series studied. Poorly crystallized kaolinite is present in the *Stom series* and in the *Padawan series;* the kaolinite is moderately crystallized in the *Stass series* and moderately well crystallized in the *Semongok series*. All soils have important admixtures of poorly crystallized vermiculite, most strongly so in the *Stass* and *Semongok series*, less in the *Padawan*, while the *Stom series* has vermiculite in the subsoil only. Particularly the *Semongok series* has a considerable amount of secondary quartz which increases with depth. Of considerable interest is the clay mineralogy of the unweathered and the partially weathered mudstone of the *Stom series*. They show respectively a dominance of poorly crystallized illite, and poorly crystallized kaolinite-illite interstratified with vermiculite, indicating a weathering sequence from the illite in the original rock into vermiculite and finally into kaolinite. This weathering sequence is found in all shale soils studied, the amount of kaolinite present indicating the maturation stage of the soil. The quartz, usually present in the colloidal fraction of these soils, may be excess quartz remaining after the breakdown of the mixed layer clays and the reconstitution of kaolinite or gibbsite. None of these soils have reached the gibbsite stage yet, although traces of this mineral are present. Gibbsitic materials occur, however, in most soils, but they lack strong crystallization.

The poorly crystallized state of the kaolinite and other clay minerals in general may indicate the lack of stability and the constant changes taking place in the colloidal fractions. Of significance in these profiles are also the X-ray amorphous aluminium and silica compounds present mainly in the surface horizons.

To summarize, the heavy textured series of the RED-YELLOW PODZOLIC SOILS developed over argillaceous rocks show incipient podzolization, in which mainly iron accumulates in the B position, the aluminium being more stable. This feature is most clearly present in soils mantling a comparatively stable landscape. All soils show intense leaching with low amounts of bases left. The clay minerals show the following weathering sequence: illite-vermiculite-kaolinite-gibbsite. The later stages are indicated by presence of excess quartz which is not leached as is the case in the LATERITIC SOILS. Most soils are in the intermediate weathering stage, showing a dominance of kaolinite-vermiculite minerals, except the *Stom series* which shows most advanced weathering with almost complete breakdown of vermiculite.

It is of agricultural importance to note that the least mature soils show the highest values for phosphate retention. This is probably caused by the high mobility of aluminium oxides which are present in gel form, and the presence of mixed and 2:1 lattice clays which are capable of fixing phosphate between the lattice sheets. In more advanced weathering stages, this phosphate is released through breakdown of the mixed layer clays, and if it is not taken up by plants, it may combine with iron into the occluded form, with the result that the phosphate may become permanently unavailable. The mobility and activity of the aluminium, indicating relative youthfulness, is also shown by the general high exchangeable aluminium which tends to increase with depth. This increase is probably caused by the fact that surface horizons are most weathered and the clays are better crystallized.

The light textured soils, the **Nyalau Family** (p.172) and *Bekenu series* (p.171) overlying sandstones or sandstones mixed with clays, show very similar characteristics as the soils developed over argillaceous rocks. The main difference between the light textured and heavy textured soils is that the iron does not tend to accumulate in an accumulation horizon in the new chemical B position. There is a relative increase of iron down the profile (see Fig. IV.1, p.147 and Fig. IV.2, p.148). For practical reasons, the **Bekenu** profile is not shown in Fig. IV.2 (p.148), the range in SiO_2/Fe_2O_3 ratios being too great, but the analyses of the colloidal fraction show this very regular increase adequately. Quite probably because of greater porosity, the iron leaches down to greater depth beyond the 4 feet limit.

Both series are in a more advanced weathering stage than the heavy textured series, vermiculite being hardly present. The clay mineralogy of the parent rock of the **Nyalau** however shows a dominance of illite. A fair amount of gibbsite has already formed but well crystallized kaolinite is still dominant in the soils. Residual quartz is present in both profiles. The more advanced weathering may be attributed to the well drained, porous nature of these soils. The greater percolation rate enhances rapid leaching of bases and iron and weathering proceeds faster than in the less well drained soils. The same difference was observed between the heavy textured and light textured soils developed over igneous rocks.

(c) GREY-WHITE PODZOLIC SOILS

GREY-WHITE PODZOLIC SOILS are divided into light and heavy textured ones. The landscape of these soils is varied. When occuring on sedimentary rocks it is commonly formed by strongly dissected hilly terrain, when formed on old alluvium the landscape is formed by flat to low undulating terraces. It can be expected that soils developing on the stable surface of a terrace would show signs of a more advanced maturation than those developing in a constantly rejuvenating hilly landscape with strong relief.

Two series in this group were studied. The *Kerait series* (p.174) is formed on carbonaceous shales of a schistose nature and has developed in a strongly dissected hilly landscape. It represents the clayey members in the group developed over argillaceous rocks. The second series is the *Triboh series* (p.176) developed over light textured terrace alluvium.

The *Kerait* and *Triboh series* are both highly siliceous as shown by the high total SiO_2 content throughout the profiles. The SiO_2/R_2O_3 ratios of the colloidal fraction in the A2 and B horizons (Fig. IV.1, p.147) show lower values than those found in the heavy textured RED-YELLOW PODZOLIC SOILS but are similar to values found in the light textured soils of this group. However, this is mainly caused by the highly aluminous nature of the soil. The A1 and A2 horizons are relatively strongly enriched by silica (the surface horizon in profile 425 is mainly an O horizon and should be ignored). This may be characteristic for the group since the same feature is present in both the heavy and light textured soils. There is strong relative enrichment of sesquioxides in the B horizon, indicating podzolization. Both aluminium and iron oxides are accumulating in the B as shown by the SiO_2/Fe_2O_3 ratios in Fig. IV.2 (p.148), and in this respect the GREY-WHITE PODZOLIC SOILS may differ from the RED-YELLOW PODZOLIC SOILS. However, more information will be required to confirm whether this is a consistent feature in all soils. If this is the case, then the GREY-WHITE PODZOLIC SOILS can be regarded as transitional between RED-YELLOW PODZOLIC SOILS and PODZOLS, iron and aluminium being more strongly leached from the surface horizons in the latter. The strong relative increase of quartz in the colloidal fraction of the A1 horizon in the GREY-WHITE PODZOLICS may indicate incipient breakdown of clay minerals and removal of the released aluminium oxides rather than recrystallization into gibbsite, a process operating in the LATERITIC SOILS.

The clay mineralogy of both the **Triboh** and particularly the *Kerait series* do show the presence of large amounts of quartz. In the *Kerait series* a moderately high amount of illite-vermiculite is still present throughout the profile and is probably caused by the comparatively high amount of muscovite in the schistose shales. The weathering sequence from bottom to top in the profile shows changes from muscovite to illite-vermiculite to kaolinite. The large amount of mica would upon weathering produce surplus SiO_2, ultimately accumulating in the surface horizon. This is very well illustrated by the clay mineral analyses. The *Triboh series* contains less quartz which is probably caused by the initial low amount of 2:1 lattice clays present.

The presence of traces of gibbsite in all soils indicates that not all aluminium oxides are leached out. This may be a process taking place during more advanced weathering.

The **Triboh** is in an advanced stage of weathering, while the *Kerait* is in an intermediate stage because the amount of illite present is still high. Both soils are, however, strongly leached and contain few weatherable primary minerals.

(d) PODZOLS

The genesis of these soils has been studied in detail by Andriesse (1969c).

Two podzol profiles were studied: the **Buso Family** (p.177) is formed on terrace alluvium in a stable landscape and the *Butan series* (p.176) is formed on Tertiary sandstone and is found on a long, gentle, stable dip slope.

Both soils are strongly developed and mature as expected from the landscape in which they form. No analyses were carried out on the colloidal fraction, because the amount of clay obtained from the samples was too small for complete chemical analyses. However, the total analysis on the fine earth fraction indicates the extreme siliceous nature of the soils, particularly in the A1 and A2 horizons.

The strong leaching of iron and aluminium from the surface horizons is also well shown by the total analyses. There appears to be little accumulation of either aluminium or iron in the Bir horizon of the **Buso Family** but an incipient Bir is present below the Bh in the *Butan* profile.

The clay mineralogy indicates extreme weathering. Quartz is dominant throughout the profile, but mostly so in the A horizon. Almost all 2:1 lattice clays have disappeared from the profile, with only small amounts present in the subsoil. There may have been an initial formation of kaolinite after weathering of the 2:1 lattice clays but the kaolinite also weathers rapidly in the surface horizons which show a decrease in kaolinite and an increase in quartz.

4. Genesis of Floodplain Soils

Floodplain soils comprise all recent alluvial deposits still actively accumulating. They may either be deposited in localities with hydromorphic conditions, such as low lying floodplains with a high watertable and true swamps with water at the surface, or they occur in localities with a low watertable throughout the year or during part of the year. The latter areas comprise river banks, levees and valleys in upper riverine basins.

All soils are regularly rejuvenated at the surface by frequent or infrequent flooding through which new deposits are added to the surface: In terms of age the soils must be regarded as very young. Soil formation takes place either subaerially or subaquatically. Subaerial weathering occurs in deposits with a low water table. Subaquatic weathering occurs in soils with a watertable permanently or for long periods present near or at the surface. Subaerial weathering is therefore confined mainly to the group of RECENT ALLUVIAL SOILS, while subaquatic weathering is dominant in the GLEY SOILS and SALINE-GLEY SOILS.

The study of soil genesis in Floodplain soils is hampered by the fact that each layer of deposit, however thin it may be, is chemically and texturally different in composition. Strong layering may be observed, particularly in soils occupying river banks and developed on levees. It is extremely difficult to distinguish between chemical and textural changes caused by deposition or by soil forming processes. For this reason, little attention has been given to the genesis of these soils and few profiles have been studied in detail. Therefore only some general comments can be made.

(a) RECENT ALLUVIAL SOILS

A leaching and weathering sequence is found in the marine sands building the Sematan physiographic unit (p.59). The sequence has been studied in detail by Andriesse (1970), and the following is extracted from this study. The sequence is made up of the following series: *Siru series—Rambungan series—Sematan series—Pueh series* and *Kilong series*. The *Siru series* is actively accumulating at the present beaches while the *Pueh* and *Kilong series* are formed in the oldest deposits furthest from the sea, the *Rambungan* and *Sematan* being of intermediate age.

The sequence indicates that a mature podzol (*Pueh series*) is formed from a recent deposit (*Siru series*) in less than 6,000 years. Fig. IV.3 and 4 (p.157) show that in this leaching sequence calcium and magnesium are rapidly leached out, followed by manganese as observed in the *Siru* and *Rambungan series*. The soils of intermediate age, *Sematan series*, show strong rubefaction of the solum caused by release of iron from weathering of iron-bearing minerals. In subsequent stages the iron is leached giving rise to the formation of an iron podzol as in the *Pueh series*. Since iron podzols are absent in the old terraces it must be assumed that the Bir in the iron podzols may eventually disintegrate and replaced by a Bh in the humus podzol stage. If this trend is not followed one has to assume that all humus podzols have developed on initially very iron poor parent materials, and this is doubtful.

This leaching sequence in almost pure marine sands may also help to illustrate the possible fate of the light textured riverine RECENT ALLUVIAL SOILS presently depositing. Light textured riverine RECENT ALLUVIAL SOILS are mainly classified as **Kayan Family** (p.190), dominantly derived from sandstone. Many of these soils were originally very low in bases and most of these bases have already been leached out. Incipient accumulations of manganese are commonly found in layers in the slightly heavier textured subsoil. Such manganese accumulations are more pronounced in the more clayey soils of the **Seduau Family** (see *Sebat series*, Appendix, p.327). The amount of manganese accumulating is related to the manganese present in the source material of the sediments and it can be expected that sediments from igneous rocks are generally richer in manganese than sediments from shales or sandstones. Most soils do not show strong rubefaction and have probably not gone beyond the early leaching stages, but this is difficult to indicate if the original chemical composition of the deposits is not known. Most soils are yellowish-brown to brownish-yellow. It is, however, suggested that in clayey materials the rubefaction process is not caused by a coating of mineral particles from which iron is released upon weathering but rather by accumulation of colloidal iron oxides. The soils are commonly moist and therefore show mainly yellow or brown colours related to hydrated forms of iron oxides. That leaching and accumulation of iron occurs in iron rich soils is illustrated by Profile 499, *Malang series* (Appendix, p.413), which shows a sharp relative increase in colloidal iron in the B horizon. This is a common feature in most heavy textured RECENT ALLUVIAL SOILS but is particularly noticeable in deposits rich in iron. The iron accumulates in a horizon commonly referred to as the redox horizon in which reducing and oxidizing conditions alternate throughout the year. In the *Malang series* this redox horizon may be over two feet thick. In soils with a high groundwater table the horizon is commonly only a few inches thick. The removal of iron in the early stages of soil formation may indicate that incipient podzolization may be present in most alluvial soils, particularly where they are light textured and leaching is more severe. This is probably caused by the low pH commonly found in these base-depleted soils. That removal of iron may take place even in soils derived from basic igneous rocks which have a comparatively high pH is shown by the SiO_2/Fe_2O_3 ratios of the *Ramun* and *Terbat series* (Profile 242 and 209, Appendix, p.319 and p.320). These soils show, however, strong stratification and the values may be partly influenced by differences in iron contents of the original deposits.

The clay mineralogy of the *Sebat*, *Ramun* and *Terbat series* show that weathering is more pronounced in the B horizon than in the A horizon, caused probably by rejuvenation at the surface. The subsoil of the *Sebat series* shows fairly well crystallized kaolinite and some gibbsite while vermiculite is only present in the topsoil. It is of interest to note that X-ray amorphous compounds of aluminium and silica also occur in the topsoils of alluvial soils. Since these soils show a weathering sequence which is the reverse of the upland soils, X-ray amorphous material would be expected to be present in the subsoil because in the upland soils they are found in the surface horizon. This is not so and this amorphous material appears to be exclusively present in topsoils suggesting a relation with organic matter.

The clay mineralogy of the *Terbat* and *Ramun series* shows a strong relationship with that found in related upland soils, such as the *Tarat series* and the clays may not have formed *in situ* but might be inherited from eroded *Tarat series* soils.

In conclusion, it can be assumed that the most quartzitic light textured recent deposits will show rapid podzolization after deposition, particularly where these are free from the influence of floods. The heavy textured deposits are less rapidly leached but nevertheless show signs of iron leaching indicating incipient podzolization in the early stages of soil formation. Since a true podzol is only formed after complete weathering of the clays in the surface horizons, podzolization in heavy textured soils takes place at a much slower pace than in the light textured soils. That complete podzolization may eventually occur in the clay soils may be inferred from the presence and association of **Triboh** and **Miri** soils on terraces even at the 20 feet level. It must be assumed that these alluvial Podzols showing strong textural contrast within the profile, may have been uniformly heavy textured soils in their juvenile state and that the sandy surface horizons were formed by complete breakdown of the clay minerals, followed by removal and either accumulation of aluminium oxides or new formation of clay minerals in the B horizon, as has been found to be the case in the formation of Podzols. It appears unlikely that all alluvial deposits were initially light textured. Heavy textured deposits are notably absent in the terraces and this can only be explained by suggesting that if left undisturbed the heavy textured RECENT ALLUVIAL SOILS eventually end up as Podzols with strong textural contrast.

(b) GLEY SOILS and SALINE-GLEY SOILS

These soils are influenced by subaquatic weathering. The high groundwater table causes a reduced environment as evidenced by the presence of a gley horizon which is either greenish grey or bluish grey, dependent on the colour of the reduced iron in these soils. In the SALINE-GLEY SOILS because of the high pH caused by brackish groundwater, chemical activity is low and soil formation is almost static. In the GLEY SOILS, acidic conditions may occur and lateral removal of bases and iron is possible. High mobility of iron in the GLEY SOILS is illustrated by the intense iron mottling and iron coatings of root channels present in a gley horizon periodically oxidized in the dry season when the level of the groundwater is lower. Iron coated root channels may penetrate deeply into the permanently reduced layer indicating that either air penetrates in these root channels for very short period or roots are able to oxidize the iron present in the ferrous forms. Where the deposits are iron rich, an intermittent groundwater table is indicated by a strongly developed redox horizon. Soils with acid surface horizons overlying subhorizons with a high pH caused by brackish groundwater show strong accumulation of iron oxides in the subsoil. This iron, leached from the surface horizons, precipitates occasionally in root channels which are concretised (see Plate 27, p.197).

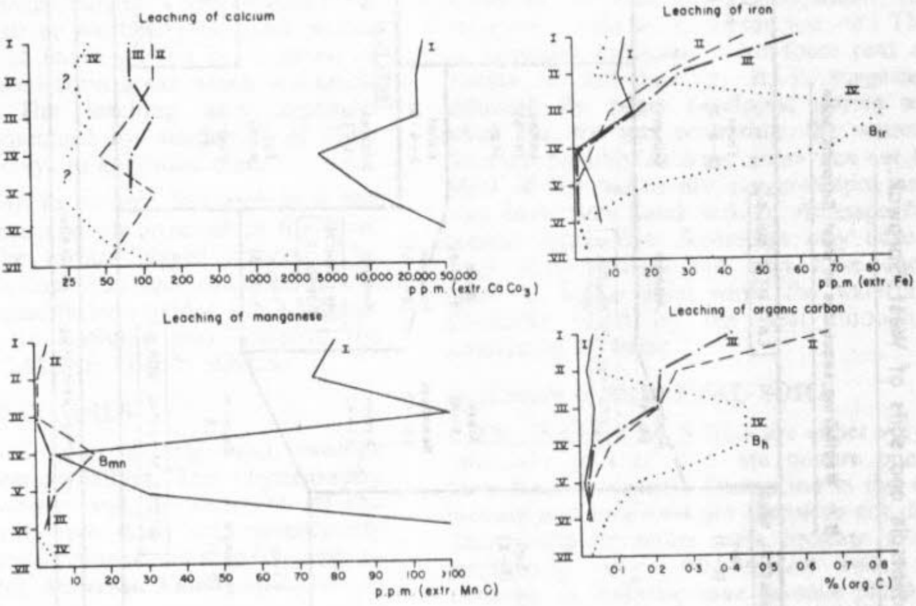
Leaching and accumulation of iron is illustrated by the SiO_2/Fe_2O_3 ratios of the one GLEY SOIL studied, the *Bijat series* (p.181). Fig. IV.2 (p.148) shows that colloidal iron is removed from the A/B horizons with possible accumulation in the Cg, the permanently gleyed horizon. The relative accumulation of iron in the A1 horizon may be caused by recent accretions from flooding.

The clay mineralogy of the *Bijat series* indicates that moderately crystallized kaolinite is dominant; subordinate are small amounts of vermiculite and some quartz and traces of gibbsite. This mineral assemblage would indicate that most of the clays are inherited from well weathered upland soils and the parent material of this RECENT ALLUVIAL SOIL must be considered to be moderately well weathered.

In contrast, the clay mineralogy of the SALINE-GLEY SOILS shows only weak weathering. In the two profiles analyses (Profiles 37 and 38, Appendix, p.397) the clays are dominantly poorly crystallized illite, possibly an illite-vermiculite integrate. Some kaolinite and gibbsitic material is present. This would indicate that the SALINE-GLEY SOILS are less weathered than the GLEY SOILS. Since the deposits in which SALINE-GLEY SOILS develop come from similar sources as the GLEY SOILS, it is more likely that recrystallization of kaolinite into illite caused under a marine environment rich in potassium and magnesium takes place.

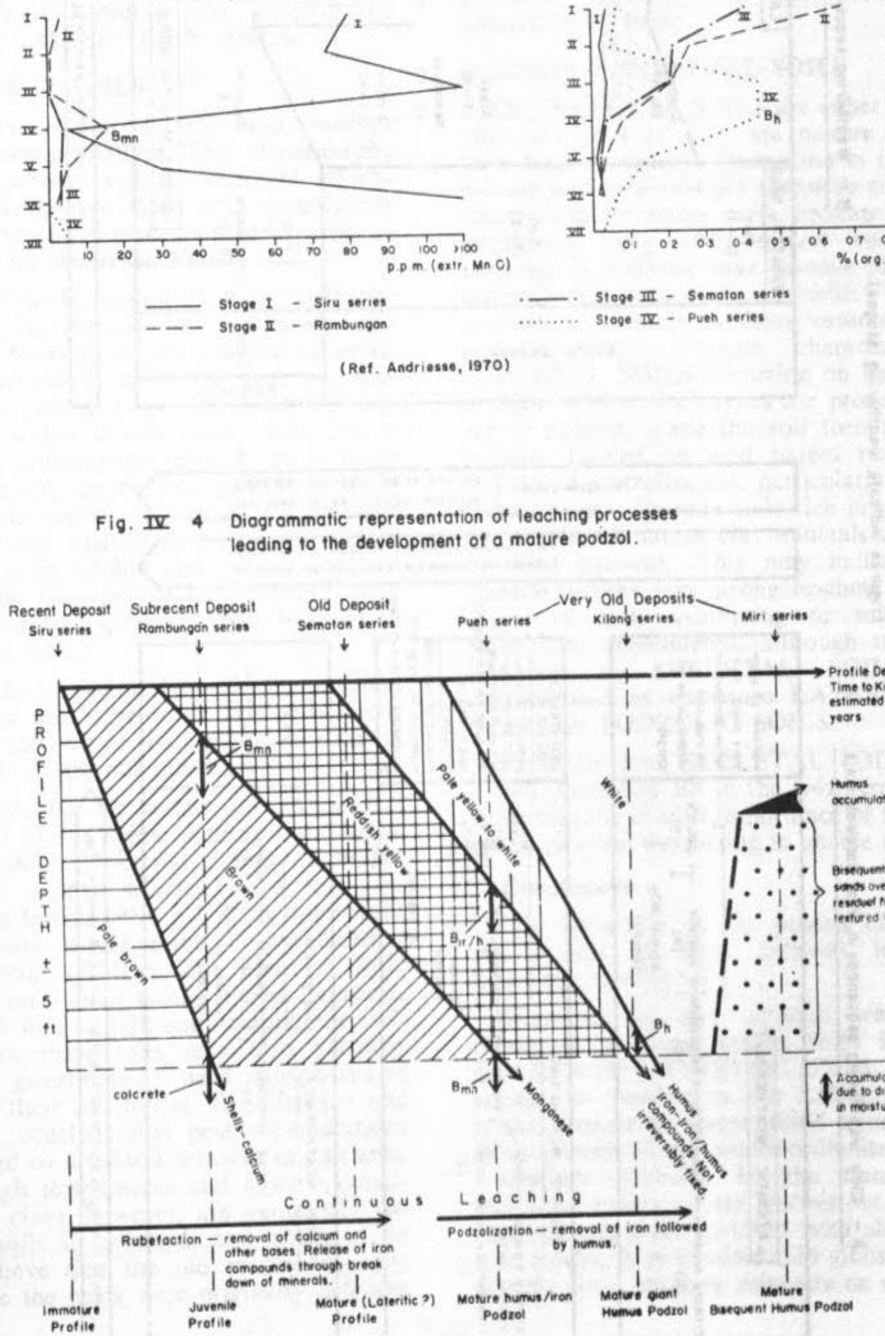
The specific deltaic and estuarine environment with its characteristic mangrove and nipah vegetation has caused the incorporation of much comminuted organic matter in the deposits. Some layering of coarser debris may also occur. During the sedimentation process and reducing conditions sulphur from the sea water is fixed, mainly in the form of sulphides and mixed with the deposits. These sulphur enriched materials play an important role in the formation of catclays which takes place when the watertable is lowered and subaerial weathering replaces a subaquatic one. This process is discussed in detail in Chapter 13, section 2 (p.228).

Fig. IV 3 Progressive stages in leaching of coastal sands.



(Ref. Andriesse, 1970)

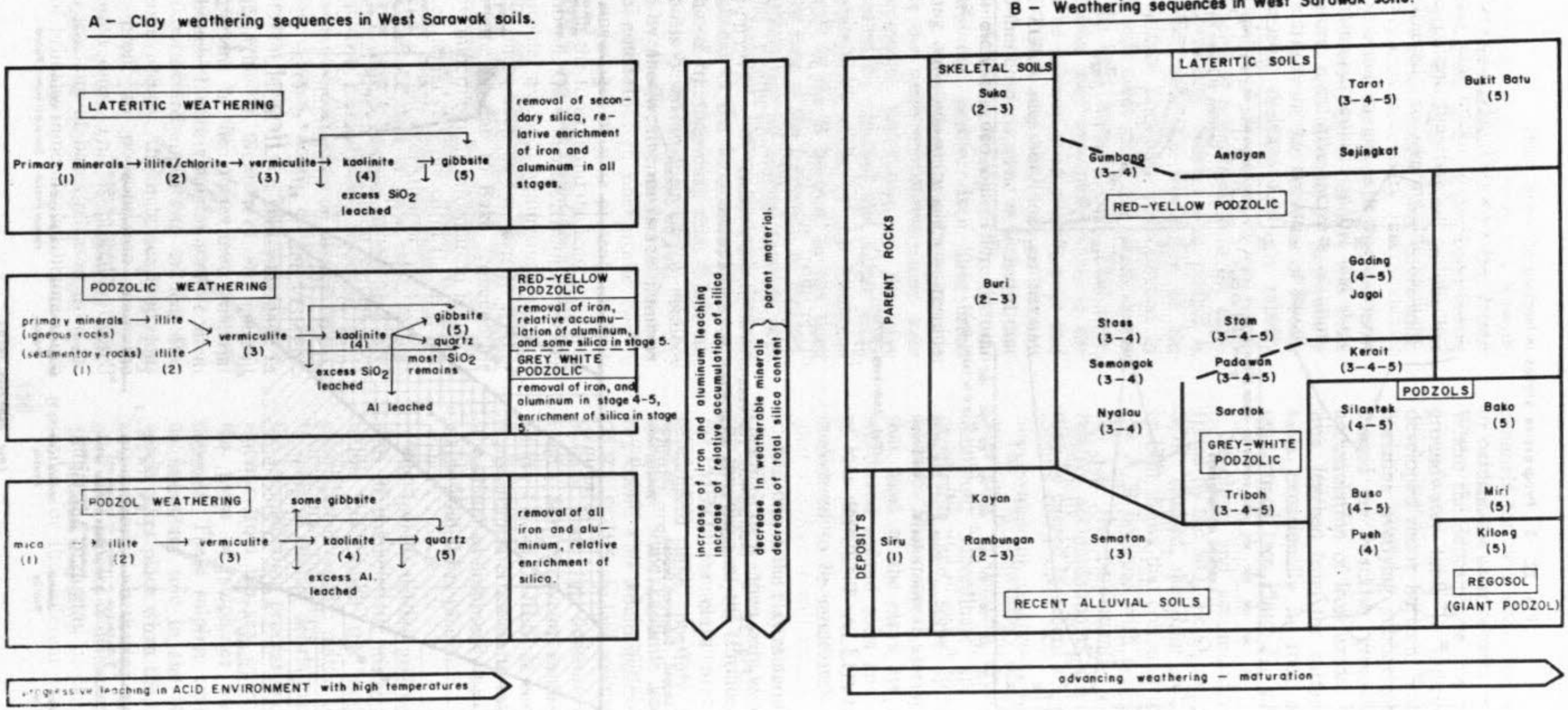
Fig. IV 4 Diagrammatic representation of leaching processes leading to the development of a mature podzol.



(Ref. Andriesse, 1970)

Fig. IV. 5 Diagrammatic presentation of weathering sequences in clay minerals and soils of West Sarawak.

(figures indicate weathering stages)



Artificial drainage changes a gleyed soil from a reduced state to an oxidized one. This would lead to leaching of bases, as can be observed in the analyses of soils from areas which are artificially drained. The leaching and improved drainage is accompanied by weathering of illitic and vermiculitic clays to kaolinitic ones.

Iron oxides tend to become less mobile in the oxidized B horizon and are arrested in the form of mottles in the former gleyed horizon. The former redox horizon is in fact extended downwards. This increase in iron oxides and a change over from illite to kaolinite may improve the structure of the SALINE GLEY SOILS.

5. **Genesis of PEAT SOILS**

PEAT SOILS develop in large basin swamps and in small interior valleys. The physiography of these peat swamps and the character of the peat deposits have been dealt with respectively in Chapter 4 under *Nonok unit* (p.63) and in Chapter 11, under **Anderson Family** (p.188).

The cause of the formation of thick accumulations of peat in tropical lowland areas and specifically in Sarawak is the subject of much speculation, particularly since the peat accumulated during a period when the coastline was retreating and which should have resulted in a lowering of the groundwater table. Mohr and van Baren (1953, p.269) suggest that possibly a toxin in the sediments prevent decomposition through sterilization of the microflora. Anderson (1962) infers that the high sulphur and sodium contents found in marine clays in places (catclays?) may be toxic to microbiological activities but not to the forest flora itself.

However, thick accumulations of peat-like organic material also develop as surface horizons of upland podzols where toxic elements such as sulphur or sodium are not present.

The accumulation of humus on PODZOLS may be caused by the acidic nature of the forest litter which inhibits bacterial activity although fungal growth is little effected by a low pH. (Mohr and van Baren, 1953, p.278). A dominance of fungal growth would result in humification rather than mineralization, but there is little evidence of humification either. Fungi, however, do not flourish well at high temperature; the lack of nutrients in these soils may also partially restrict fungal growth which need phosphorus in particular for their cell nuclei. By inference one may therefore conclude that peat accumulations may be induced by a subsoil deficient in nutrients, a low pH, high temperature and aquatic conditions. Marine clays, however, are commonly the most fertile soils in Sarawak and there is no reason to believe that the old marine deposits which underlie the peats were originally deficient in nutrient contents, although apparently the opposite view is held by Anderson (*op. cit.*) Therefore, an adequate explanation for these peat accumulations is still lacking. It is suggested that, although the peats developed during a period when the sea was retreating, the watertable in the then possibly swampy areas was not lowered. Most of the basins are saucer-shaped and there may have been total lack of drainage from the central areas. Peat formation may have started from these centres and may have encroached onto the higher land while the watertable was gradually lifted by the peat through strong absorption of water.

6. **Genesis of SKELETAL SOILS**

The SKELETAL SOILS are either very young, immature soils or they are mature ones which have been truncated. Truncation is the result of erosion and such soils are therefore not discussed. The young immature soils indicate a stage in weathering only. All upland soils, whether Lateritic or Podzolic have juvenile phases which, although not classified as either Lateritic or Podzolic soils, carry in them features which predestinate their ultimate characteristics. All SKELETAL SOILS occurring on basic to intermediate igneous rock types are prone to a laterization process, while the soil forming processes in soils formed on acid parent materials tend to lead to podzolization, particularly in the light textured ones. Juvenile soils rich in nutrients and high in double lattice clay minerals are very rare in West Sarawak. This may indicate that the climate induces very strong leaching in the early stages of rock weathering or soil formation. Most soils encountered, although taxonomically classified as SKELETAL SOILS can be characterised as immature LATERITIC, RED-YELLOW PODZOLIC SOILS.

There are even SKELETAL PODZOLS, with a well developed Bh in the weathered sandstone, indicating the overall importance of leaching with which physical weathering is unable to keep pace.

7. **Conclusions**

The discussion on the genesis of the various soil groups in West Sarawak leads to the following conclusions:

Sequences in clay mineral weathering are shown in a diagrammatic form in Fig. IV.5 (p.158). In the LATERITIC SOILS, clay minerals appear to weather in the following sequence: primary minerals-interstratified minerals such as chlorite–vermiculate–montmorillonite intergrades —kaolinite—gibbsite. In the transition stages excess secondary quartz leaches out, and the soil becomes relatively enriched with aluminium and iron oxides. It is possible that gibbsite may form directly from primary minerals or vermiculite.

In the RED-YELLOW PODZOLIC SOILS primary minerals and micas or illite, originally present in the parent material of sedimentary rocks is weathered to vermiculite-kaolinite-gibbsite. Probably most secondary quartz released during the transitional stages is leached out but some may remain, particularly in the last stage. There is, therefore, a relative increase of aluminium in the surface horizons while gradually quartz and also iron are leached out.

The GREY-WHITE PODZOLIC SOILS show weathering from mica or illite-vermiculite-kaolinite-quartz and gibbsite. In these soils iron is moved out together with much of the aluminium, probably the latter mainly in the later stages. Silica accumulates in the surface horizons where there is incipient breakdown of clay minerals in the last stage.

In the PODZOLS micas or illite weather into vermiculite-kaolinite-quartz. The iron and aluminium is completely leached out. There is total breakdown of the clay minerals in the surface horizons leaving only secondary silica as residual quartz.

The most important soil profiles studied have been placed in a diagram (Fig. IV.5B, p.158) which shows increasing leaching and progressive weathering along the horizontal axis from left to right. The vertical axis from top to bottom represents the weathering type: Lateritic to Podzolic to PODZOL.

The placing of the various series along the horizontal line is based on their clay mineralogy as indicated by the weathering stage numbers. It should be noted that in one profile two or more weathering stages may be present; the most advanced one in the topsoil and the least advanced one in the subsoil. Only in *Bukit Batu series* has the whole profile reached weathering stage 4. Other soil sequences such as the *Siru* to *Kilong* sequence, and the **Nyalau** to **Bako** sequence for which no clay mineralogical information is available have been tentatively placed in the diagram, based on general characteristics or position in natural sequences found in the field. The placing along the vertical line is based on evidence of the magnitude of leaching of silica, iron or combined iron and aluminium. For the RED-YELLOW PODZOLIC SOILS and GREY-WHITE PODZOLIC SOILS a split was made in sequences occurring in light textured material and those present in heavy textured material because although the original mineral content may be similar, texture appears to influence the leaching regime greatly, the light textured soils being more prone to podzolization than the heavier textured ones. This is probably caused by the rapid leaching of bases released from the weathering of primary minerals and before much secondary minerals have formed. The pH has thus been lowered significantly causing removal of iron and aluminium in an early stage of soil development. Typical examples to illustrate this textural control in the podzolization process are the *Gading*, *Jagoi* and *Nyalau*; their heavy counterparts being respectively the *Gumbang* and the *Stass*.

The diagram further indicates that the *Bukit Batu*, **Bako**, **Miri** and *Kilong* soils are in the final stage of weathering. However, no inference can be made of the ultimate stage from the present position of a particular series in the diagram. Thus whether a *Tarat* will change into a *Bukit Batu* or a **Nyalau** into **Bako** would depend on the environmental conditions. For instance, a **Nyalau** occurring on a stable land surface may eventually reach the **Bako** stage but where it occurs on a steep slope, rejuvenation will keep the **Nyalau** in its present weathering stage until the land is degraded to such an extent that there would be sufficient stability for the formation of a **Saratok** and finally a **Bako.**

The *Siru-Kilong* sequence is an ideal leaching sequence as occurring in the field.

It is possible that a *Semongok* may change into a *Kerait* if sufficient iron has been leached, and that the *Kerait* will change into a *Butan* if the conditions ensure continuous leaching and weathering. Only then would complete destruction of the clays in the surface horizons occur and a PODZOL may then form from a RED-YELLOW or GREY-WHITE PODZOLIC SOIL. Quite probably the constant changes in the landscape does not permit the factor Time to play its role in the full completion of these sequences.

Diagram IV.5B (p.158) shows the strong relationship existing between the vertical placement of the soils from laterization towards podzolization and the chemical composition of the parent materials. As indicated by the arrow, the amount of primary minerals decreases from top to bottom while the content of total silica increases. This relationship has been studied in detail by Andriesse (1969d) who suggests that with a uniform climate as occurring in West Sarawak, the nature of the parent material plays the dominant role whether soil formation would lead to podzolization or laterization. Apart from the chemical composition of the rock, the weathering type is also dependent on the physical nature of the rocks, in that coarse textured parent materials such as granites, although having as much SiO_2 as a fine grained rock type, will podzolize more readily. As already explained, this is caused by the porous nature of the lixivium which enhances rapid leaching and limits the formation of clay material. The actual cause for the different leaching regimes leading to either laterization or podzolization is difficult to indicate with the present available information. Andriesse (1969d) suggests that the nature of the organic matter may be involved, and believes that with a decrease of primary minerals in the rock types the produced litter will be increasingly less rich in bases. The base content of the litter may be responsible for the production of either humic or fulvic acids; the formation of the latter being enhanced by a low pH. It is a well-known fact that fulvic acids are rather more active than humic acids in the removal of aluminium and iron through the form of mineral-organic compounds as chelates. Apart from the initial difference caused by the contents of primary minerals in rocks, increasing maturation of the soil also impoverishes the litter of bases, and fulvic acids will become more dominant. Consequently, the rate of clay breakdown and leaching of aluminium will increase with maturation.

In this connection the presence of the X-ray amorphous materials present in the A1 and A2 horizons of most soils must be mentioned. The D.T.A. analyses indicate that these may be mainly discrete aluminium and silica compounds. The gradual disappearance of these X-ray amorphous materials with depth strongly indicates a relationship with humus and it is possible that they represent chelates related to the presence of fulvic acids in the soils. Detailed studies on humus forms in the various soil groups will, however, be required to investigate these aspects properly. An interesting feature observed in most upland soils, with the exception of the LATERITIC ones is the gradual increase of clay content with depth. This gradual increase culminates in the strong textural contrast in the PODZOLS suggesting that it is related to clay breakdown in the surface horizons rather than to illuviation of clay. The fulvic acids may be responsible for causing this breakdown and removal of aluminium. It is not certain whether there is any new formation of secondary minerals in the subsoil but this may be possible in certain conditions. The assumed observed argillic horizons in the field may thus be explained, not by illuviation but by a relative enrichment of sand and silt in the surface horizons through removal of the clay components.

Chapter 11. DESCRIPTION OF SOIL CLASSIFICATION UNITS

The description of the various soil classification units follows the outline given in Table 20 (p.116) but units of very minor importance have been omitted. Classification aspects are only mentioned in so far this is necessary for characterization purposes. All other relevant information on classification is given in Chapter 9 (p.114).

The units are described in general terms giving brief information on the range of characteristics and agricultural potential. Characteristics already described for groups or families and which are therefore also diagnostic for the series within groups and families are not repeated in the series descriptions. Instead, a specific profile description of the series is discussed on its physical and chemical aspects and the range of these characteristics present in the series is commented upon.

Quite a number of series are not shown on the Detailed-Reconnaissance Soil Maps (Vol. II), but they are of importance in some localities mapped at a semi-detailed level. Their localities are described and reference is made to the relevant soil survey reports which give more detailed information.

For some series no type profiles are given. Such series are very subordinate and detailed studies were not made.

Type profiles together with their analytical data are found in the Appendix. The profiles have been subdivided into two groups. Group A concerns profiles which because of their relative importance have been well studied and documented. Group B comprises profiles of series on which little analytical information is available or they are supplenmentary to well studied profiles of the same series in Group A.

Type profiles of families do not exist. If the family is not differentiated into series, a type profile of the dominant soil in the family is used instead.

1. SKELETAL SOILS

Occurrence: Mapping units 12 and 13, 22 and subunit 23b; and as parts of subunit b in mapping units 1, 2, 3, 4, 5, 8 and 9.

Families: **Meluan, Sedong** and **Kapit. Gaya Family** (in part mapped as REGOSOLS)

Series: *Suka* (in **Sedong Family**), *Buri* and *Kapit* (in **Kapit Family**). *Kilong series, Lundu series* **(Gaya Family)**.

(i) **General character**

SKELETAL SOILS are very shallow soils which commonly show weak or no horizonation with the exception of an A horizon. They are found over all types of consolidated parent rocks occurring in West Sarawak. Soils developed in unconsolidated sandy parent materials have been mapped as REGOSOLS, *Kilong series.* By definition these should, however, be classified as SKELETAL SOILS. With the exception of the REGOSOLS and the **Gaya Family,** SKELETAL SOILS are commonly found on steep to very steep slopes where erosion constantly rejuvenates the soil profiles. The soils are usually characterised by bouldery and rocky land; weathered rock is either found at the surface or at shallow depth (within 10 inches) but the hard rock may occur deeper, and in places beyond a depth of 11 feet. The soils in this group are either very young undeveloped soils or they are truncated mature soils. This causes a great variability in chemical characteristics.

(ii) **Families**

Meluan Family (mapping units 12 and 13)

This family occurs mainly on limestone and on acid igneous rocks, and is characterised by almost bare rock. The vegetation roots in cracks in which some soil and organic litter generally has accumulated. The soils have not been studied in detail as they are of no importance for agriculture.

Sedong Family (mapping unit 16)

The soils in this family have derived from basic to intermediate igneous rocks and may either be young, undeveloped soils or truncated soils belonging to the group of LATERITIC SOILS. In the latter case, they must be regarded as shallow phases of series in this group.

Suka series (Appendix, p.332 and p.335)

This series is characteristic for the young, immature soils. Profile 431 is representative for a common soil on steep slopes; Profile 84 rarely occurs and is found on very gently undulating terrain. The *Suka series* is dark brown to yellowish brown with a well developed angular blocky to crumb structure. Weathered rock is found within a depth of 10 inches. The surface may show many outcrops of rocks while large boulders are commonly found at shallow depth. This soil type has great significance for hill padi cultivation because the vegetation rapidly regenerates and the rotation cycle in shifting cultivation can be short without the soil losing much of its fertility. The analyses show that the soils are better supplied with calcium and magnesium than in other commonly occurring upland soils; in particular magnesium is high. This is probably caused by the high content of ferro-magnesium minerals. The total phosphate content is moderate to low while also the potassium content is low. Quite probably nitrogen and phosphate are the nutrients most deficient, most of the phosphate being in a non-available form. No detailed chemical analyses are available on this series, the soils being unsuitable for agriculture by common standards because of the steepness of the terrain. It is, however, thought that some form of cultivation should be allowed on this steep terrain. The soils are potentially capable to sustain a good growth of perennials, particularly fruit trees and with the establishment of a closed canopy with a tree vegetation, these, for Sarawak standards rich soils could be used with advantage, particularly if there is a shortage of good land elsewhere. However, the local farmer must be very selective in choosing a proper site, avoiding the most steep slopes and the most bouldery type of land (see Plate 21, p.150 and Plate 23, p.195).

Kapit Family (In mapping units 2, 3, 4, 5, 8 and 9 as subunits b)

This family comprises shallow immature soils developed on consolidated rock types other than basic to intermediate igneous rocks. Those formed on sedimentary rocks, such as shale and sandstone, are rare in the Region. Shallow soils developed on these types of parent material are generally sufficiently deep to qualify for shallow phases of mature soils. The main series in this family is the *Buri series.* It is found on a wide range of acid igneous rock types of variable physical and chemical composition. The series is related to the more mature soils developed on these rock types, commonly mapped as **Abok Family** soils in the Group of RED-YELLOW PODZOLICS (p.165). The soils therefore show a great variability in texture, structure and chemical composition but they have all in common the very shallow nature, weathered rock being present within a depth of 10 inches from the surface. In addition to the variability caused by the range in parent materials, the soils may be either very young and immature or they may be truncated mature soils. For these reasons, no type profile of the *Buri series* is given. Because of the shallow nature of the soils, the rocky surface, steepness of slope and the low chemical fertility which can be inferred from its derivation, the series has no agricultural potential and for this reason it has not been studied in detail.

Gaya Family

Soils in this family are all derived from unconsolidated materials. The family may contain some undeveloped soils which cannot be classified as SKELETAL SOILS. These comprise deep sand deposits of quartzitic nature such as the *Kilong series* which is better classified as a REGOSOL. This series is only found in the Sematan area, and is formed by a deep white quartz sand deposit in which a thin dark coloured A horizon may be present. A brown to black humus pan may be present at a depth below 4 feet. This pan may influence water movements in the profile and if found just below the 4 feet limit a perched groundwater table may be found within the profile depth. The *Kilong* series is extremely poor and the cultivation of crops is only possible if all nutrients are supplied by fertilizers. Because of its very low agricultural potential the series is not further discussed.

The **Gaya Family** comprises further very coarse bouldery to gravelly soils in which no soil development has taken place other than the formation of an organic rich surface horizon. Where the parent material is formed by large boulders the soils can be compared with true SKELETAL SOILS since the surface horizon may have partially formed through weathering of the boulder deposits. Such soils are mapped as the *Lundu series*. This series is formed by colluvial deposits on foot slopes and in colluvial fans. The material may be heterogeneous in texture, clays being mixed with boulders, and boulder beds may alternate with sandy layers. The topsoil is usually formed by sandy loam textures with boulders within 10 inches. The internal drainage is varied and depends on locality. The *Lundu series* may be split into a number of phases depending on source material, texture and drainage. It could also be elevated to the family level. No attempt has been made to differentiate between all the variables making up the series. Although the areas mapped as *Lundu series* are mainly formed by soils derived from sandstone or granite materials, it would be reasonable to suggest that they may also form in materials from other sources. The soils have not been studied in detail, their agricultural significance being very low. Except for the topography, which is gently undulating, other characteristics such as fertility can be compared with those of the *Buri series* (p.162). Those formed in colluvial material of sandstone are the poorest and least suitable for agriculture. It should be noted that certain parts of the areas mapped as *Lundu series* may contain deep coarse sand deposits of colluvial wash from granites. These may be better placed under the group of REGOSOLS (see also *Jagoi series*, RED-YELLOW PODZOLICS SOILS, p.166).

Finally, soils formed by quartz gravel deposits with or without interlayering of finer textured material and found mainly in the Batu Kitang—Batu Kawa area, are also mapped as **Gaya Family** soils. Gravels occur either at the surface or are found at shallow depth in which case they are overlain by a sandy surface soil. Such undeveloped soils, although provisionally classified as **Gaya Family** are not truly SKELETAL SOILS and have therefore been placed in the group of REGOSOLS.

2. LATERITIC SOILS

Occurrence: Mapping units 1 and 2.

Families: **Tarat**.

Series: *Tarat, Bukit Batu, Antayan, Jebong* and *Sejingkat* (all in **Tarat Family**).

(i) General character

LATERITIC SOILS are all derived from basic to intermediate igneous rocks and silicified basic volcanic rock types, commonly with a high content of ferro-magnesium minerals. Clay content is commonly high, more than 40% in the surface horizons and more than 30% in the subsoil horizons. The silt fraction is high for Sarawak soils and is more than 20% in all horizons. The clay content decreases with depth while that of the silt fraction increases at almost the same rate. This may indicate more advanced maturation in the surface horizon. Structure is well developed, it being either subangular blocky or crumbly. Weak clayskins are frequently present but are in most cases not related to clay illuviation. The content of weatherable minerals in the sand fraction is less than 1%. The content of iron and aluminium oxides is high and more than 25% of the fine earth fraction. The content of free iron is commonly over 15% in all horizons. The clay mineralogy is variable. The pH varies between 4.5 and 5.5. Exchange capacities are commonly low (lower than 15 meq.% of the fine earth fraction). All soils are poor in major nutrients, although total phosphate tends to be high for Sarawak standards. Drainage is excellent in all soils.

(ii) Families

There is only one family in this group, the **Tarat Family** which is differentiated into five series based on differences in structure, colour and clay mineralogy.

Tarat series (Appendix p.272 and 275)

This series is the most commonly occuring soil in the family. The colours in this series vary from strong brown to red; the structure is crumbly to very weak subangular blocky. The soils are very friable and porous. Distinct horizonation is absent. Shiny ped surfaces, when present, are probably caused by weak stress coatings. No illuvial clay has been detected in micro-pedological investigations. The soils are chemically characterised by a high total phosphate content. Phosphate is mainly present in the occluded form and bound with iron oxides which form more than 15% and usually over 20% of the fine earth fraction. All other major nutrients show low values. The C.E.C. may be over 10 meq. % fine earth in the surface horizons due to presence of organic matter but in the subsoils it is generally lower. Under primary forest topsoils are commonly well supplied with exchangeable nutrients but the soil is impoverished rapidly when cultivated. Phosphate fixation is moderate to high; this is mainly caused by the high iron oxide content. The clay mineralogy is characterised by mainly poorly crystallized kaolinite in all horizons. The surface horizons may have much X-ray amorphous material, while the subsoils may have some chlorite, illite and vermiculite. The latter minerals are probably related to interbedded shale commonly present in the Serian Volcanic Formation. A fair amount of gibbsitic material is also present.

The *Tarat series* has great agricultural potential, if only because of the excellent physical properties. The soils need to be well fertilized for sustained yields of crops, but otherwise there are no limitations for a very wide range of crops which can be grown. Phosphate fertilization may present difficulties because of the high phosphate fixation but in experimental work so far carried out the problems do not appear to be great.

Bukit Batu series (Appendix, p.276)

This series is only found in one single area in the Second Division. It differs from the *Tarat series* in its clay mineralogy. The *Bukit Batu series* has a highly crystallized clay mineral system; the content of gibbsite is high and kaolinite is subordinate. The reasons for this difference are difficult to indicate. Age may be a factor, the *Bukit Batu series* being older. Field observations, however, indicate that this may be a less mature, shallow soil. Parent material may be another factor. The *Tarat series* is found on highly altered andesitic materials while the *Bukit Batu* is formed over unaltered basalt.

Another characteristic of the *Bukit Batu series* is its high content of sesquioxides. This may be indicative to old age, but could also be caused by a difference in parent material. Apart from these chemical differences the *Bukit Batu* is comparable to the *Tarat series*. It is probably somewhate lower in major nutrient contents but since the *Tarat series* is already a poor soil chemically, small differences at this fertility level are not of great agricultural importance. Particularly pepper cultivation is flourishing on this series.

Antayan series (Appendix, p.339)

The *Antayan series* originally reported as occurring over porphyritic andesite (15th mile, Kuching-Serian Road) differs from the *Tarat series* in colour and structure, the *Antayan series* being pale brown to yellowish brown and its structure being strong blocky. Soils closely similar to the *Antayan series* are also found in complex with the *Tarat series*. These soils do not show a distinct blocky structure, but the colour is characteristic for an *Antayan series*. It is thought that in these soils the iron oxides occur in a more hydrated form than those found in the *Tarat series* thereby causing the yellowish colours. In that case such soils could best be regarded as a yellow phase of the *Tarat series*. The type locality of the *Antayan series* does not show much complexity with the *Tarat series* soils and probably the difference is here caused by parent material or age. The *Antayan series* is not richer than the *Tarat series:* a noteworthy difference is, however, the high exchangeable and extractable aluminium content and the high C.E.C. Although no clay mineral analyses are available, it is thought that the content of X-ray amorphous materials or double lattice clays may be higher in the *Antayan* than in the *Tarat*, causing the structural difference. This needs further confirmation. Agriculturally, the *Antayan series* is not much different from the *Tarat series*, although the drainage is better in the latter.

In comparison with the *Tarat series*, the areal extent of the *Antayan series* is but small. The series is mainly confined to areas around the 15th mile of the Kuching-Serian Road.

Jebong series (Appendix, p.340)

The *Jebong series* occurs only on gabbro building Bukit Jebong in the Lundu district. The series is characterised by a very compact clay, blocky structure and a strong brown over reddish yellow colour. The bulk density of this soil is higher than that of the *Antayan series* and much higher than that of the *Tarat series*. The soils tend to be shallow. They are very gibbsitic in character as shown by the analyses, but low in iron. Because of its minor occurrence the *Jebong* is of no agricultural significance. It is probably not found outside its type locality area.

Sejingkat series (Appendix, p.343)

The *Sejingkat series* is developed mainly over silicified, in origin basic, volcanic rocks found in the Sejingkat Formation. The series is confined to small isolated shills in the Sarawak River Delta and to some larger mountainous areas between the Sadong and Lupar estuaries. The chemical characteristics of the soils are very similar to the *Tarat series* while physically they are more like the *Antayan series*. Colours range from brown and yellowish brown to red; the structure is characteristically blocky. The difference in structure between the *Sejingkat* and the *Tarat series* cannot be explained without having the clay mineralogical analyses of the former. It may be caused by a higher content of X-ray amorphous materials. In that case the *Sejingkat* and *Antayan series* may probably be comparable. Only part of the series is suitable for agriculture. the steepness of the terrain and the general shallow character of the soils are the main limitations. Where slopes are reasonable the soils may be profitably used.

3. RED-YELLOW PODZOLIC SOILS

Occurrence: In mapping units 2, 3, 4, 6, 7 and 8 as subunit a; as parts of mapping unit 14a and b, and as areas indicated by the symbol T (**Sabangang** and **Lupar Families**).

Families: **Abok, Merit, Bekenu, Nyalau, Matang, Sabangang** and **Lupar.**

Series: *Gading, Jagoi, Gumbang, Abok, Keladan, Bayur* and *Serin*, all in the **Abok Family**. *Biawak* in **Bekenu Family**. *Bedup, Semongok, Padawan, Stom, Rapak, Melugu* and *Begunan* in **Merit Family**.

(i) General character

The group covers a very wide range of soils having in common chemical and mineralogical features indicative to strong weathering and mature age but they do not show the distinct horizonation characteristic for mature soils. Intergrades to REGOSOLS, LATERITIC SOILS, and GREY-WHITE PODZOLIC SOILS form part of this group.

Most soils, regardless the texture, show a gradual increase in clay content with depth. This increase continues into the C horizon and the lower boundary of a horizon with clay increase is generally absent unless bisequency is involved. Horizons with strong textural contrast may occur but this is generally caused by a bisequency in parent materials.

The structure may be crumbly to blocky depending on texture, probably clay mineralogy and free iron oxide content. The textures vary from sands to heavy clays. The clay mineralogy is varied, depending on the parent material, but commonly poorly crystallized kaolinite is dominant. When shales form the parent material illite and vermiculite are subordinately found only in subsoils, while in the surface horizons X-ray amorphous silica and aluminium compounds are present in variable amounts. The total sesquioxides content expressed as Group III elements is commonly less than 20% in the fine earth fraction, but in one family it is over 20%. The iron oxide content analysed as 6N.HCl extractable iron is less than 10%. The pH varies between 4.5 and 5.5. Cation exchange capacity of the fine earth varies from less than 10 to over 20 meq. %. Base saturation is commonly low, a large part of the exchange sites being occupied by aluminium.

Internal drainage varies from imperfectly drained to well drained. Depth is variable and shallow phases are as common as deep ones.

(ii) **Families**

Abok Family

This family is derived from acid igneous and metamorphic rock types, and comprises intergrades between the LATERITIC SOILS and RED-YELLOW PODZOLIC SOILS. The soils are separated from other soils in the RED-YELLOW PODZOLIC group by the provision that the A2 or B horizons must have more than 20% Group III elements in the fine earth fraction. In practice, this appears to be untenable since soils derived from shales may have more than this percentage while some soils on granites may have far less. In the latter case, this is caused by the light texture. Soils with more than 20% sesquioxides but derived from sedimentary rocks were placed in the **Merit Family**, the general characteristics being more similar to the **Merit Family** than to the **Abok Family**. The separation of the **Abok Family** soils from the LATERITIC SOILS is more problematic and has been done on other important characteristics such as textures, structure, sand and clay mineralogy. Because the **Abok Family** has a very wide range in characteristics, quite a number of series were mapped in this family.

Gading series (Appendix, p.279)

This series is developed over coarse textured granites and granodiorites. The texture ranges from sandy loam or sandy clay loam in the surface horizons to a gritty clay or coarse sandy clay in the subsoil. Colours range from dark brown in the surface horizon to red in the subsoil, but reddish yellow colours may occur throughout the profile if it is truncated. The soils are porous, have a weak crumb structure and are well drained. The depth varies, depending on slope. Commonly deeper soils are found at lower slopes whereas the steep upper and middle slope areas have shallow soils. The soils show strong weathering. The sand fraction contains few or none weatherable minerals, the clays are dominantly well crystallized kaolinite with important admixtures of gibbsite. The total sesquioxide content is low, particularly the iron oxide content, which is reflected in the low phosphate retention percentage.

The pH is around 5; the cation exchange capacity is surprisingly high for a soil with a low clay content showing a dominance of gibbsite and kaolinite. This needs further verification. The base saturation is very low and all major nutrients are in low supply. Particularly potassium in surprisingly low for a soil of which the parent material contains large amounts of potassium bearing biotite and felspars. This is probably caused by the low content of 2-1 lattice clays which are able to fix potassium in considerable amounts in other RED-YELLOW PODZOLIC SOILS containing such clays. The *Gading series* is physically a good soil but needs to be well fertilized for most crops. The shallow phases are probably potentially best for tree crops as the roots may be able to take up nutrients from the weathering rock. Phosphate fertilization is not expected to be troublesome, since the phosphate retention is low. However, most of the series occurs on steep land where surface erosion may be severe if these sandy soils are exposed. For this reason, only the moderately sloping land can be used for agriculture.

Jagoi series (Appendix, p.344)

The *Jagoi series* is derived from coarse grained granite and granodiorite but is paler coloured than the related *Gading series*. This may be caused either by a lower iron content of the parent material or by the locality. The latter observation needs some explanation. Although the *Jagoi series* appears to occur dominantly in the Second Division (Ulu Strap) where the granites are reported to be low in iron, they also occur in the Lundu District together with the *Gading series* on much the same parent material, biotite granite, which is richer in iron. In the latter area, the *Jagoi* tends to occur on pediments, probably built by colluvial material, while the *Gading series* occupies higher slope positions. In this area, therefore, the low iron contents may be caused by selective sedimentation. The colloidal iron may be washed out in suspension by the surface run-off water while the quartz sand and silt particles accumulate at the footslopes. The *Jagoi series* soils tend to be also coarser textured than those found on the hills in the Ulu Strap area and may contain granite boulders (Andriesse, 1969a). Some of these deep sand deposits may be classified as REGOSOLS. Profile 362 is from the Ulu Strap area and concerns a true residual profile. Except for the iron content, the *Jagoi series* is very similar to the *Gading series* which has been discussed in detail and to which the reader is referred to for other characteristics (p.165). The agricultural significance of the *Jagoi* is the same as for the *Gading series*, but since the *Jagoi* tends to occur on less steep terrain than the *Gading*, soils tend to be deeper and there is more prospect for tree cultivation. In some areas with gently sloping terrain oil palm may do well, but the soils need to be well fertilized and surface erosion must be prevented by the construction of terraces.

Gumbang series (Appendix, p.280)

The *Gumbang series* is derived from a variety of rocks but mainly from fine grained hornfels and quartz diorite (tonalite). It is often found on the slopes of monadnock type hills where shale has been metamorphosed by igneous intrusions which may outcrop at the summit. Many of these soils are therefore of mixed derivation and a true residual soil derived *in situ* is difficult to find. There is, however, very little variation between most of these soils unless the igneous outcrops are chemically and texturally decidely different from the metamorphosed rocks, and therefore they are combined into one series.

The soils are commonly of a brown to olive brown colour, the textures are heavy loams to clay; structure is generally weakly developed but tends to be blocky when dry. The soils are commonly shallow since they occur generally on steeply sloping terrain. Profile 76 is thought to be derived from tonalite porphyry and is a shallow profile occurring on a steep slope. The pH is normal for RED-YELLOW PODZOLIC SOILS. The cation exchange capacity is somewhat lower than normal but this may be caused by the high content of sand and the well crystallized kaolinite present in the clay fraction. The latter does also contain some vermiculite. The low phosphate retention is however indicative for a low content of 2-1 lattice clays and a highly crystallized mineral system. The soils are poorly supplied with all major nutrients; but exchangeable calcium is higher than normal for **Abok Family** soils.

The *Gumbang* soils are mainly suitable for perennial crops. The steep topography and bouldery nature of the land is not suited to the growing of annuals. Particularly fruit crops would do well. Fertilizing is advisable for sustained high yields. Pepper can be grown in selected places; the most steep terrain more than 35 degrees should be left under primary forest.

Abok series (Appendix, p.347)

The *Abok series* is not very common and is usually found only in relation to small acid igneous sills and dykes occurring in sedimentary rocks. It is derived mainly from microgranodiorite and associated rock types. The soils are closely similar to the *Gumbang series* and are often found in similar positions. The parent materials are, however, considered to be more acid than those of the *Gumbang series*. The structure is usually strong blocky; this is, however, dependent on the iron content and with a high content of free iron oxides the soils are quite crumbly. This structural difference may be used for a further differentiation into series but since structure is difficult to assess in the generally moist soils, parent material is used instead. In practice, the *Abok series* has been used as a 'dustbin' for all **Abok Family** soils which cannot be placed in other series so far distinguished and it is therefore quite heterogeneous as far as structure, and colour is concerned. The latter may range from red to yellow. The textures are commonly on the heavy side, but loams do occur. Probably the most significant difference between the *Abok* and the *Gumbang* series is the soil depth. The *Abok* being commonly deeper than four feet, while the *Gumbang* invariably has boulders or comparatively little weathered rock fragments at shallow depth and it may therefore be a less mature *Abok series* soil.

Profile 424 is found in the type locality near Abok village, Serian-Simanggang Road. This is a crumbly to subangular blocky heavy loam derived from microgranodiorite. The iron concretions found at depth and forming a stoneline indicate mass removal along the slope so that the profile cannot be regarded as truly residual. Characteristic is the high content of extractable aluminium, typical for a RED-YELLOW PODZOLIC SOIL. The clays are dominated by kaolinite. The cation exchange capacity is very low and approaching that of the LATERITIC SOILS. Also the base saturation is extremely low. This is, however, much dependent on the vegetation. Under primary forest, this is commonly higher, particularly in the surface horizon. The series is not of areal importance. However, the soils are locally of great value for pepper cultivation mainly because of the well drained character of the soils and possibly because they are less deficient in trace elements than the soils on sedimentary rock types, dominantly found in surrounding areas.

Keladan series (Appendix, p.348)

This series is also of little importance and is found in some very small localities in the lower Sadong District. A very small area is also found near the junction of the 19th mile Kuching-Serian Road with the Tijirak Road. It is characterised by a typical red almost mauve colour, strong angular blocky structure and purplish coloured weathered rock in the subsoil, thought to be a volcanic rock type (probably silicified) of tuffaceous nature. The soils are all heavy clays.

For **Abok Family** soils, they are quite rich in reserve potassium and magnesium. The contents are more common for soils derived from shales. Until the nature of the parent material can be ascertained the placing of this series in the **Abok Family** is tentative. The soils are of no agricultural importance for the Region but in the small areas where they occur they can be used with advantage for the growing of more demanding crops requiring small acreages only, e.g. pepper.

Bayur series (Appendix, p.351)

This series is developed over schist found only in the area between Serian and Balai Ringin. It it characterised by a typical brownish-yellow orange colour, a crumbly structure, high friability and a homogeneous profile showing little horizonation. In some localities, bauxitic nodules are found in the subsoil. Textures range from sandy loam to sandy clay loam. The series is very low in phosphate and calcium and is moderately supplied with magnesium and potassium. The soils are excellent for pepper cultivation because of their good physical status but need to be well fertilized. They are suitable for a wide range of other crops but the total area is but small. The topography is mainly formed by moderately dissected hilly terrain well suited to the cultivation of pepper and tree crops.

Serin series (Appendix, p.352)

This series covers a large area of mapping unit 4a. It is derived from arkose, in chemical composition closely resembling tonalite and for this reason the series has been placed in the **Abok Family**. The content of Group III oxides in the subsoil is higher than 20% but is largely caused by a high content of aluminium oxides. The *Serin series* is characterised by a high clay content throughout the profile, the clay showing a regular increase with depth. Textures are generally clay loam overlying clays. The colours vary from brownish-yellow to reddish-yellow. The yellow coloured soils are classified as the yellow phase, the red coloured soils as the red phase. The reason for this colour difference is not understand. It may be caused by local differences in iron content of the arkose, drainage conditions, or soil depth. The yellow coloured soils are strong blockly, compact and massif while the stronger coloured soils tend to be crumbly. The latter are also shallower and weathered rock is encountered within a depth of 11 feet. Drainage varies and imperfectly drained phases occur in complex with well drained ones; the latter are, however, dominant. The chemical characteristics indicate that the soils are well weathered. The pH is usually around 5 but a pH of 4.5 is not uncommon. The C.E.C. is very low for clay soils and is less than commonly found in RED-YELLOW PODZOLIC SOILS. The clay mineralogy is probably dominantly kaolinitic with some gibbsite. The phosphate retention in this series is high and since the iron oxide content is low it is assumed that the high P. retention is caused by aluminium compounds probably present as X-ray amorphous compounds. The base saturation is low, the main exchangeable cation being aluminium. Also total phosphate is very low. Reserve calcium, magnesium and potassium are all very low, particularly the latter. This may indicate that no 2:1 or mixed lattice clays are present. The chemical fertility of this series is extremely low but many crops thrive on this soil if adequately fertilized. The high phosphate retention may give problems with phosphate fertilization and responses may be low in the initial periods. The low iron content may, however, prevent the phosphate to be fixed in the occluded form so that eventually the phosphate may become available. The physical status of this soil is moderately good, the red phase being better than the yellow phase. The local population (mainly Chinese) has shown that on this series many crops can be grown with success. The main limitations being low fertility and steep slopes in places. Because of the compact nature of particularly the yellow phase, foot-rot may occur in pepper gardens if not properly drained.

Merit Family (mapping unit 6)

The **Merit Family** comprises RED-YELLOW PODZOLIC SOILS with less than 20% group III oxides in the fine earth fraction. They have **no** Albic (light coloured A2) horizon, a texture of clay loam or finer in the A2; and a clay, silty clay or sandy clay texture in the B horizon.

These textural limits have been put in the definition to ensure that the **Merit Family** would mainly comprise soils derived from argillaceous rocks (shales, phyllites and mudstones). The colour ranges from pale yellow to red but the **Merit Family** soils commonly are brownish yellow over reddish yellow. The soils may be mottled or unmottled, imperfectly, moderately or well-drained, shallow or deep and with or without iron concretion layers. Such a wide range of characteristics has made it necessary in West Sarawak to create a number of series which would delimit at least some important characteristics.

Bedup series (Appendix, p.355)

The *Bedup series* is found on Triassic shales and is characterised by deep yellowish brown soils in which reddish yellow and yellow mottles occur at depth. At a depth below 4 feet, this soil commonly overlies strongly weathered white kaolinitic clays with strong red mottling. Between this weathered shale and the yellowish brown coloured B horizon, a thin layer of iron concretions comprising concretised shale flakes and root channels may be present. This indicates mass removal along slopes so that the underlying shale cannot be regarded as being the true parent material although in most cases this is chemically and physically similar to the true parent rock present on upper slopes. The *Bedup series* is moderately to well drained. The structure is moderately well developed and tends to be blocky but in moist conditions the soils are massive and compact. The clay content shows a regular increase with depth. The pH show values between 4 and 5; C.E.C. is low for a **Merit Family** soil and is related to the highly kaolinitic character of the clay. The base saturation is extremely low but this is very much dependent on land use. Significant are the high contents of exchangeable and extractable aluminium indicating strong mobility of this element in the profile, particularly in the surface horizons.

The *Bedup series* is a common **Merit Family** soil occurring extensively in the Serian-Balai Ringin area. Whether the strong kaolinitic weathering of the C horizon at great depth is of any significance cannot be assessed. It appears to be occurring mainly in hills of low elevation. The shale is often highly carbonaceous and contains pyritic material. Thick limonitic veins have developed in cracks or along bedding planes (see Plates 15 and 16, p.143), and it is thought that groundwater previously present at a higher level than at present may have caused gleization in much of the shale with subsequent lodging of the iron in cracks through which groundwater could move and oxidation could take place. These limonitic veins appear to be the source of much iron concretionary material found as stonelines in the *Bedup series*. The series is suitable for most tree crops if adequately fertilized. The topography is a limitation in some localities.

Stass series (Appendix, p.283)

The *Stass series* is characterised by a brownish yellow surface horizon overlying a reddish-yellow or yellow coloured subsoil. The series is dominantly found on Cretaceous shales in interior areas above a level of 150 feet and is derived from non-carbonaceous, non-laminated, massive hard shales. Mottling, if present at all, is only found in the subsoil. The mottles are not more than different shades of the yellow or reddish matrix colours and are probably more related to presence of weathered shale pieces than to drainage conditions. These 'mottles' increase with depth in intensity and merge into a multicoloured (variegated) pale yellow, yellow to red coloured weathered shale horizon which is often impregnated by iron oxides along fracture and bedding planes. These iron accumulations are soft, however, and colloidal, and occur mainly in the silt and clay fraction. It is possible that these thin iron coatings are formed by illuviated iron oxides or they are iron oxides released upon weathering of pyrites present between the shale laminae.

Structure in these soils is well developed, but depends on the moisture condition. In moist condition, the soils tend to be massive and compact but, as observed in road cuttings, strong blocky structures develop when the soils dry out. Iron concretionary material may be found throughout the profile but commonly a thin layer overlies the weathered shale indicating soil drift and resorting along slopes.

A chemical difference between the *Bedup series* and the *Stass series* is the high C.E.C. in the latter. This is caused by a different clay mineralogy (a rather high amount of vermiculite in the latter) which is possibly caused by a difference in parent material or less advanced weathering in the *Stass series*. A high activity of aluminium is shown by the high exchangeable aluminium figures and the high phosphate retention percentage. The overall chemical fertility of the soil is, however, of the same low standard as the *Bedup series*. The *Stass series* appears to be relatively less iron rich than the *Bedup*. This is shown by the SiO_2/Fe_2O_3 ratios of the colloidal fractions. The aluminium content as indicated by the SiO_2/Al_2O_3 ratios is almost equal in both series.

The *Stass series* is suitable for agriculture, but needs to be adequately fertilized for most crops. The topography is not well suited for annual crops and therefore only perennials are recommended. Phosphate fertilization may be problematic because of the high phosphate retention capacity of the soils. Since the iron content is low most of the applied phosphate will not enter into the occluded form and may become available eventually.

Semongok series (Appendix, pp. 284, 287 and 356)

The *Semongok series* occurs mainly on Cretaceous shales and generally in a landscape below the 150 feet level. The parent material comprises thinly laminated carbonaceous shales in which pyritic material is commonly present between the laminae. In places the shale has mudstone characteristics and does not show lamination. Instead of breaking into small flakes, the material shows concoidal fracture planes. The shale is generally soft and easily broken up by hand. The series is found throughout the Semongok Agricultural Research Station, and for this reason, it has been studied in more detail than any other series in the **Merit Family**.

The series is characterised by brownish yellow to yellowish brown heavy loams to clays. The texture in the surface is usually a heavy loam and the clay content increases regularly with depth until the weathered shale is reached. The C horizon is commonly somewhat lighter textured. The soils are strongly mottled from the A horizon downwards to the weathered shale. The mottles are commonly reddish-yellow and grey coloured, the grey colours increasing in intensity with depth. The B/C is usually strongly variegated with red, yellow brown and grey colours. In the C horizon the red colours give way to brown and yellow colours while the grey mottles merge into the dark grey colour of the weathered shale.

The cause of these mottles is still subject to much speculation (see Chapter 10, p.136) but there is reason to believe that imperfectly drained conditions are not the main cause. Probably, the nature of the parent material plays a considerable role and the variegated colours of the C horizon persist in successive stages of soil formation.

The strongly mottled soils intergrade into light coloured soils in which less red colours are present (see *Padawan series*, p.170). The soils may be shallow or deep, but the general characteristics remain the same. A layer of laterized shale flakes, broken up limonitic vein material originally existing in the shale, and concretised root channels is commonly present in between the B and the C horizons. This indicates soil drift over the C horizon, and churning with subsequent lodging of coarse fragments in a horizon above the stable C. Most of this concretionary material must be related to a soil forming process foreign to the present soils. Some of it was probably formed in the parent rock before it was consolidated (root channels), some of it was formed after consolidation (limonitic sheets). It is of interest to note that this concretionary layer may be present, even in the soils of upper slope areas and in those found on hill summits. The series is chemically much similar to the *Stass series* found also over Cretaceous shales. The pH is around 5 in most soils. Highly acidic conditions are sometimes found in the C horizon where pyritic material has oxidized and sulphuric acid is formed (note pH in C horizon of Profile 77).

The C.E.C. values are high for RED-YELLOW PODZOLIC SOILS. This is caused by a rather high amount of mixed lattice clays (vermiculite) and X-ray amorphous aluminium compounds present in the clay fraction. The very high exchangeable aluminium and high phosphate retention figures point also to an influence of active aluminium compounds usually associated with an amorphous mineral system. Base saturation is low, but varies depending on the vegetation. The series is low in total phosphate, but has a high reserve in potassium and magnesium which must be attributed to the influence of 2:1 and mixed lattice clays which are able to fix these elements.

The soils are suitable for a wide variety of crops, but the drainage must be improved for sensitive crops such as pepper. Foot-rot may otherwise easily occur. The commonly very broken terrain is a limitation to the growing of annuals and therefore perennials are the obvious crops to grow on this type of soil. They need to be well fertilized and because of the high phosphate fixation initial responses to phosphate fertilizing may be poor. The low iron content may however, prevent strong fixation of applied phosphate in the occluded form.

Padawan series (Appendix, p.288 and p.359)

The *Padawan series* is an intergrade between the *Semongok series* and the *Kerait series* (GREY-WHITE PODZOLIC SOILS, p.173). In the range *Semongok-Padawan-Kerait* reddish matrix colours give way to yellow matrix colours while the grey colours of the mottles tend to increase in intensity and area reaching a maximum in the *Kerait series* in which the matrix colour is grey to white. In that state the soil is classified as a GREY-WHITE PODZOLIC.

The *Padawan series* has been delimited from other soils in the **Merit Family** to allow for this transition. The *Padawan* soils have all the characteristics of the *Semongok series* but for the matrix colours which are pale yellow or pale brown instead of brownish yellow and the mottles are commonly grey and brown. Red colours may only be present in the variegated B/C or C horizon. The analyses show a tendency for less iron to be present in the *Padawan* so that these colours are not related to different iron forms but rather to the iron poor nature of the parent material. The *Padawan series* is locally influenced by calcareous material. This is shown in the exchangeable calcium content in the lower subsoil of Profile 198. It is, however, not very significant in this profile.

The *Padawan series* can, as far as agricultural potential is concerned, be compared with the *Semongok series*. There is a strong relationship in chemical composition, clay mineralogy and cation exchange. Fertilizer recommendations for the *Semongok series* would most likely also be applicable to the *Padawan series*.

Stom series (Appendix, p.291)

The *Stom series* is of particular importance along the Bau-Lundu Road (Stinggang-Stungkor area) where it is derived from Tertiary mudstone (Andriesse, 1967). The soils occur in a low undulating landscape well suited to agriculture. They occur also in a similar landscape at the foot of the Klingkang Range between the 85th and 95th mile, Simanggang Road, also over mudstones (Andriesse, 1965b). The series is characterised by a loam topsoil which merges into a clay at depth. This medium textured topsoil is usually not present in other **Merit Family** soils. The soils are further characterised by a strong brownish yellow colour throughout the profile. Red coloured mottles occur in the subsoil and increase in intensity and area with depth giving way to an almost white-red coloured variegated horizon which in field descriptions is commonly referred to as 'corned beef'. This layer may overly at a depth of more than four feet purplish or greenish coloured mudstone. The depth at which the 'corned beef' horizon is found is used to differentiate the series into phases. In this 'corned beef' horizon many laterised root channels are present, but they do not form a layer and are not caused by soil drift. It can be observed in road cuttings that the concretised root channels extend into the underlying mudstone and these root channels may originate from vegetation growing during the depositional stage of the mudstone. Because of the very weak consolidated nature of the mudstone and the absence of folding the original root channels have remained largely undisturbed. The soils are well drained and have a well developed structure. In moist condition, they tend to be friable and crumbly, in dry condition the soils are blocky and hard.

The chemical analyses indicate that the soils are poorer in major nutrients than other series in the **Merit Family.** The C.E.C. is also low and much similar to that of LATERITIC SOILS. The clay mineralogy indicates that poorly crystallized kaolinite is the main clay mineral present, together with a fair amount of gibbsite and X-ray amorphous material. The low C.E.C. and low phosphate retention values may indicate that most of the aluminium oxides present is well crystallized. The soils are, as far as clay mineralogy is concerned, much similar to the *Tarat series* (p.164).

Of considerable interest is the change in clay mineralogy with depth. In the studied profile poorly crystallized illite and vermiculite present in the parent rock progressively weathers through vermiculite into kaolinite in the A and B horizons. This change is well illustrated by the change in SiO_2/R_2O_3 ratios of the colloidal fraction in the various horizons.

The *Stom series* is physically a good soil but chemically it is quite poor. With the generally favourable topography, agriculture on this soil would be quite profitable particularly if crops such as pepper and oil palm are cultivated. The soils would need adequate amounts of compound fertilizers for most crops.

Rapak series (Appendix, p.360)

This series may be found in complex with most other series of the **Merit Family** but occurs mainly in areas where the *Stom series* is dominant. It is characterised by a thick layer of iron concretionary material of more than 6 inches thick present within a depth of 4 feet in soils otherwise identical to other series in the **Merit Family.** The series occurs widespread in areas at the foot of the Klingkang Range between the 85th and 95th mile and is there related to the occurrence of mudstone. As described for the *Stom series* (p.170), Tertiary mudstones contain many old concretised root channels, more so than found in shales of Cretaceous and Triassic Age. Given the right conditions of these to accumulate as thick stonelines, the *Rapak series* is formed. Except for this stoneline, which shows a high content of iron oxides, the soils are chemically very similar to related series. Profile 118 is related to a well drained **Merit Family,** not belonging to the *Stom series* but drived from shales of probably Jurassic Age.

If occurring at shallow depth, the concretionary layer may hinder root development; otherwise the soils are of comparable value to the related series. The *Rapak series,* although of local significance, is for the Region of only minor importance.

Melugu series (Appendix, p.363)

The series occurs widespread in the Simanggang District and overlies shales of the Kantu Beds of lower Tertiary age. The series is separated from other series in the **Merit Family** on account of the high sesquioxide content which is sufficiently high to place the series in the **Abok Family.** For reasons stated in Chapter 9, p.113, the series is classified in the **Merit Family.** It has all the physical characteristics of the *Stass series* described for the Cretaceous shales (p.168). The soils are homogeneously yellowish brown to brownish yellow coloured, some faint red mottles may occur. Structure is well developed. The soil usually overlies hard comparatively little weathered shale. It lacks the thick soft weathered shale horizon which is commonly present in the *Semongok, Padawan* and *Bedup series.* The series has not been studied in detail but there are no indications to show that their value for agriculture is different from other well drained **Merit** soils. The Melugu Rubber Planting Scheme is for its largest area situated on this series and although the soils are commonly quite shallow they are able to support a good stand of rubber if sufficient fertilizers are applied. Pepper would do equally well, as would oil palm. For the latter crop, topography is a limitation over large areas of this series.

Begunan series (Appendix, p.364)

This series is of very localised extent and is formed on red mudstone outcropping mainly at the foot of the Klingkang Range in the Simanggang District. It is usually mapped in complex with other **Merit Family** soils occurring dominantly in the area (Andriesse, 1960a and 1965a). There may be a relationship between this series, the *Rapak series* and the *Stom series,* mapped also on mudstones. The *Stom series,* however, is characterised by a strongly mottled white and red deep subsoil and a strong brownish yellow matrix colour throughout the profile. The *Begunan* has a typical reddish-brown colour with only a few yellow mottles. Textures are heavy loams to clays; structure is commonly well developed and is strong blocky when dry but crumbly when moist. The soils are poor in nutrients. The pH is low; however, the very low values found in the analyses of the type profile need verification. The exchangeable sodium content is high for soils which are developed on what are probably terrestial deposits. The soils have not been studied in detail since they are only of very local importance. When fertilized, they appear to be able to support a wide range of crops, particularly pepper thrives well on them. This is mainly due to the favourable physical status of the soils.

Bekenu Family (Mapping unit 7)

This family does not cover extensive areas in West Sarawak, and commonly occurs localised in areas where the **Merit Family** is dominant, (indicated by the symbol B on the Detailed-Reconnaissance Soil Map). In the Upper Sadong District some single large areas are found. The family is derived from fine sandstone, sandy shales or from a mixture of sandstone and shale. The texture range of this family is well-defined. The B horizon has a silty clay loam, clay loam or finer texture but is not clay unless the A2 horizon is a sandy clay loam or lighter. An Albic horizon is not present. Excepting the texture, the **Bekenu Family** may have all the variable characteristics found also in the **Merit** soils. The total content of Group III oxides is not more than 20% in the B horizon. The colour may range from red to pale yellow, the soils may be imperfectly, moderately well drained, or well drained. The imperfectly drained phases, however, are not very common. This is probably caused by the lighter texture than that found in the **Merit Family.** Structures may be blocky or crumbly. It is, however, commonly indicated as massive since most soils are usually found in the moist state. Mottles may be absent or may occur abundantly. A layer of concretionary laterite may occur but is not as common as in the **Merit Family.** The topography is commonly moderately to strongly dissected hilly terrain in which slopes of 15-25 degrees are dominant.

The **Bekenu Family** may occur on mixed parent materials and when a succession of thin sandstone and shale beds is found in one profile, bisequent soils showing a strong textural contrast are found. Also, a C horizon present in the lower part of the profile may have no relation to the soils found above it. An example is shown in Profile 172 (p.295), which is a typical **Bekenu Family** soil occurring on Triassic sediments. Below the B horizon a quartz stoneline is present, the source of which could be traced to quartz veins existing in shale beds found at lower depth. The overlying material is derived from a mixture of sandstone and shale occurring on upper slope areas, the shale underneath bearing no relation to the A and B horizons. The clayskins detected in the profile are probably recently washed in silt and clay particles from surface horizons and probably do not indicate the presence of an argillic horizon. With the intense soil removal along the slope a real illuvial clay horizon could hardly develop. If any clay movement is present, it is mainly confined to cracks, which in normal conditions rarely develop (Profile 172 is from a road cutting). The only significant analytical clue to the bisequent nature of this profile is supplied by the mineralogical examination of the heavy sand fraction, which shows a significant change in the zircon/tournaline ratio in the IIC horizon.

The C.E.C. is low but too high for a crystalline kaolinitic system. The clay mineralogy confirms that although poorly crystallized kaolinite is dominant some X-ray amorphous aluminium and silica compounds are present. Phosphate retention is moderately high in the topsoil but low in the subsoil. The iron content appears to increase with depth, and the exchangeable aluminium decreases. This may indicate that phosphate retention is more related to active aluminium than to iron oxides, at least in these soils.

Base saturation is low and all major nutrients are in very low supply. The pH range is normal for a RED-YELLOW PODZOLIC SOIL. The **Bekenu** soils are good agricultural soils but they must be well fertilized for most crops. The choice of crops is limited by the topography which in most localities would be only suited to the growing of perennial crops.

Biawak series (Appendix, p.292)

The *Biawak series* is the only series separated within the **Bekenu Family.** It occurs on a specific type of parent material mainly found in the Biawak-Lundu area and comprises greywacke sandstone of the Serabang Formation. The soils are of a typical light olive brown colour. Apart from the colour the sand particles show up as crystal clear quartz which is typical for most **Bekenu** soils. The sand mineralogy is characterised by a 'flood' of andalusite indicating the metamorphic nature of the parent material. The clay mineralogy shows that the dominant clays are fairly well crystallized kaolinites with a fair amount of gibbsite. Although no analyses are available it can be expected that the C.E.C. of this series will be low. The contents of reserve nutrients show that the major elements are all in very low supply. The series may differ from other **Bekenu** soils in clay mineralogy and C.E.C., it having more oxic characteristics; agriculturally speaking, the soils do not differ much. The topography is in general less steep than that of other **Bekenu Family** soils, and for this reason, the *Biawak series* offers more prospects for agriculture. However, because of the poor chemical fertility, the soils must be well fertilized for most crops.

Nyalau Family (Mapping unit 8)

Nyalau Family soils are residual soils in the RED-YELLOW PODZOLIC GROUP having a content of Group III oxides less than 20% in the B horizon and having textures in the B horizon of sand, light loam, light silt, heavy sandy loam or sandy clay loam. An Albic horizon is not present. The **Nyalau** soils are derived from medium to coarse grained sandstones. The largest area in West Sarawak is developed over Tertiary sandstones which are highly quartzitic but containing a fair amount of orthoclase. For this reason, most of the **Nyalau** soils have a moderate clay content and textures of sandy loam to sandy clay loam are common, very sandy textures being rare.

The drainage in these soils varies, but the majority of soils are found on rather steep slopes and are well drained. Imperfectly drained phases are very rare and only occur where sandstone outcrops in gently undulating terrain. The latter is the case in the Rasau area in the Lundu District.

Concretionary layers, common in the **Merit** and less common in the **Bekenu Family,** are almost absent in the **Nyalau Family,** but where thin beds of shales are found in the sandstone they invariably give rise to the development of limonitic veins along the contact zone of shale and sandstone (see Plate 16, p.143) and this material if broken up may be found as stonelines in the **Nyalau** soils. Such occurrences are, however, of very localised extent. Structure is not well developed, but tends to be crumbly. Mottles are commonly absent but a weak brown or red mottling may be present. Grey mottles usually indicate partially weathered sandstone fragments. These are often surrounded by a brown coating of soft iron oxide.

Profile 24 (Appendix, p.296) is typical for a common **Nyalau** soil in the Region and is derived from Tertiary sandstone. It is chemically an extremely poor soil. The C.E.C. is very low and therefore the high base saturation values are meaningless. Phosphate is in extremely low supply. The clay mineralogy shows that fairly well crystallized kaolinite is dominant, with some gibbsite, vermiculite and a fair amount of quartz being present. The clay fraction of the unweathered sandstone consists of poorly crystallized illite which weathers successively through vermiculite into kaolinite. **Nyalau** soils are generally extremely poor soils but, because of the porosity and low bulk density, roots can develop freely and, if well supplied with nutrients, perennial crops such as rubber are doing very well. Fertilizing is not problematic as ready responses are obtained in this highly quartzitic soil. But for more demanding crops than rubber, fertilization may be uneconomic. Apart from the very low fertility, surface erosion is a severe limitation on steep slopes. The overall agricultural potential of the **Nyalau** soils is therefore low. They can only be used with success on gentle sloping terrain and then preferably only for rubber.

Matang Family

This family combines all residual RED-YELLOW PODZOLIC SOILS with a well developed A2 horizon showing a distinct eluviated character. The colour of the A2 is diagnostic and qualifies for an Albic horizon (7th Approximation, 1960). An Albic horizon is very rarely encountered in West Sarawak and if present it is very weakly expressed and always associated with a **Nyalau Family** soil. For this reason, the **Matang Family** has not been mapped as a separate unit and there is no need to discuss this family in detail. Where it occurs it has been mapped in complex with **Nyalau Family** soils and for agricultural purposes they can be regarded as being similar.

Profile 423 (Appendix, p.299) represents the type of **Matang Family** soil found in West Sarawak. It is hardly distinguishable from a **Nyalau** soil. Of interest in this profile is, however, the heavy sand mineralogy which indicates that the soil is particularly derived from probably a metamorphosed sandstone. The extreme poverty in major nutrients is well expressed in the base saturation and the values for exchangeable calcium, magnesium, potassium and sodium.

Sabangang Family (Symbol T)

This family is very similar to the **Nyalau Family.** It differs mainly in the deep subsoil where gravel layers occur indicating the alluvial origin. The family is of very minor importance in West Sarawak and has been commonly mapped as a **Nyalau Family** soil if the diagnostic gravel layer occurs below a depth of 4 feet. For an assessment of its agricultural potential read under **Nyalau Family** in this section (p.172).

Lupar Family (Symbol T)

This family is very similar to the **Merit** and **Bekenu Families.** It differs mainly in the deep subsoil in which a gravelly layer indicates its alluvial origin (see Plate 29, p.198). The family is of minor importance in West Sarawak and has commonly been mapped either as **Merit** or **Bekenu Family,** depending on the texture. For an assessment of its agricultural potential read under **Merit** or **Bekenu Family** in this section (p.168 and p.171).

4. GREY-WHITE PODZOLIC SOILS

Occurrence: As mapping units 5, 11 and 21, part of mapping unit 14.

Families: **Kerait, Saratok, Lubai and Triboh.**

Series: *Kerait, Rukam* and *Serayan,* all in **Kerait Family**; *Lingga* in **Saratok Family**; *Merang* in **Lubai Family**.

(i) General character

The GREY-WHITE PODZOLIC SOILS are per definition very similar to the RED-YELLOW PODZOLIC SOILS, the main difference being the iron content which is very low in the former and which causes the very pale colours by which this group is characterised. 6H.HCL extractable iron oxide is commonly less than 1% and the total iron oxide content is not much more. The low iron content is related to the chemical composition of the parent materials. These are formed by acid igneous rocks, sandstones, shales and old alluvials, having all in common a very low iron content. The sandy soils are highly quartzitic while the more clayey ones are characterised by a high aluminium content. The topography is varied, ranging from mountainous to low undulating hilly terrain. Textures range from heavy clays to almost pure sands. By definition the soils should have an Argillic horizon. Although subsoils tend to be more clayey than the surface horizons there is generally a gradual increase in clay content with depth and illuviation of clay is probably not significant. If a strong textural contrast is met the soils are commonly bisequent caused by stratification in the parent material. A textural contrast, however, may also be the result of destruction of clay in surface horizons. Drainage phases are difficult to recognise because of the near absence of iron so that reduction and oxidation processes are not very well expressed by colouration. Weak pale yellow mottles may, however, be present in clayey subsoils, particularly when the soils are bisequent in nature. Structures vary from coarse blocky in the clay soils to crumbly in the more sandy ones. All GREY-WHITE PODZOLIC SOILS are of low chemical fertility equal to that of most of the RED-YELLOW PODZOLIC SOILS. The clayey soils are agriculturally better than the sandy members. The group is differentiated into families on account of derivation, residual or alluvial, and on the texture of the B horizon.

(ii) **Families**

Kerait Family (Mapping unit 11)

The **Kerait Family** is dominantly derived from carbonaceous shales. Other rock types comprise chert and phyllites. In some localities the soils are bisequent and probably old alluvium overlies residual material. All **Kerait** soils are characterised by textures of clay, silty clay and sandy clay in the B horizons. Several series have been differentiated in this family.

Kerait series (Appendix, pp.300,303)

This is the dominant series in the **Kerait Family** and is found over Triassic carbonaceous shales of commonly a schistose nature. The schistosity is revealed by the large amount of muscovite found in these shales. The shales commonly contain small pyrites which upon weathering and oxidation give rise to very acid conditions in the C horizon (see pH, Profile 425). The pH causes intense chemical weathering through which probably most of the muscovite present in the parent rock is weathered into illite, and subsequently into kaolinite. It may also be one of the reasons why these soils are so poor in iron since the iron may have leached out in the very early stages of soil development. The textures in the surface horizon are generally loamy, those of the subsoils are clays or silty clays. The C.E.C. of the soils is low and base saturation is very low, the exchange sites being mainly occupied by aluminium. Although chemically thoroughly weathered the profiles do not show much horizonation. In field observations the presence of clayskins is frequently mentioned but these may be mainly stress coatings, or formed by material leached down from the surface horizon through cracks. Their real nature needs further study but it is suggested that illuviation of clay does not occur in sufficient quantity to form an illuvial clay horizon. Structure is commonly well developed, particularly in dry soils. The structure is then coarse blocky and large cracks may form confirming the presence of 2:1 lattice clays. In moist condition the structure is massive and the soils are very compact. As far as agricultural potential is concerned, the *Kerait series* can be compared with the *Padawan series* described under the RED-YELLOW PODZOLIC SOILS (p.170). Many crops can be grown but they need to be well fertilized. The compact nature of the soil may hinder root development. However, it has been shown that pepper can be grown with success on this soil type. This may be largely due to the fact that in pepper cultivation use is made of mounds of loose soil so that the pepper does not root in the compact subsoil, most roots being confined to the mounds.

Rukam series (Appendix, p. 367)

The *Rukam series* is formed from phyllites and/or chert. Some minor areas occur in the Lundu District and the series is characterised by a typical bluish-grey colour, inherited from the parent material. The topsoils are rather silty but the subsoils are formed by a compact clay. Some olive brown mottling may be present. The analyses show extreme low values for iron and for all major nutrients; reserve magnesium and potassium values are usually much higher in soils derived from argillaceous rocks. This extremely poor soil does not offer much prospect for agriculture. Nevertheless, rubber is planted on these soils with moderate success. Given sufficient fertilizers the soils are capable of supporting some crops but it is unlikely that farming on this soil type is very economic.

Serayan series (Appendix, p. 368)

As in the case with the *Rukam series*, the *Serayan* is also exclusively found in the Lundu District where it occupies some small areas formed by chert mainly. The soils have a typical pink colour inherited from the chert and they are further characterised by small puppet-like concretions occurring at depth, which are probably formed by silica.

The *Serayan series* has not been studied in detail, it being of very minor importance.

Saratok Family (mapping unit 9)

This family is formed over sandstones or colluvial material derived from it. The textures in the B horizon range from sand to silty clay loam but in West Sarawak they mainly comprise sandy loam and sandy clay loam. The **Saratok Family** generally occurs in association with the **Nyalau Family** and is thought to have der ved from much the same parent material. However, the **Saratok** soils tend to occur on less steep terrain than the **Nyalau** soils and the pale colours may have developed through leaching of iron which is intense in these porous materials, particularly on gently sloping terrain. The difference may also be caused by a lower iron content of the parent material. Because of the influence of slope on leaching, the **Saratok** may occupy an inter--mediate position in a leaching sequence formed by RED-YELLOW PODZOLIC SOILS **(Nyalau Family)**—GREY-WHITE PODZOLIC SOILS **(Saratok Family)**—PODZOLS **(Silantek Family)**. It is very difficult to locate a typical **Saratok Family** soil which is not marginally a **Nyalau** soil or a PODZOL **(Silantek Family)** and for this reason no profile is shown to represent the family. For agricultural purposes the **Saratok Family** must be regarded as being intermediate between the **Nyalau Family** (p.172) and the **Silantek Family** described under the PODZOL group (p.176).

Lingga series (Appendix, p.371)

The *Lingga series* is an anomalous series in the **Saratok Family** which on account of its colour range had to be classified as a GREY-WHITE PODZOLIC SOIL but which on account of derivation (granite) is better placed in the **Abok Family** (RED-YELLOW PODZOLIC SOILS). The GROUP III content is extremely low. This is caused by the very low iron content of the parent rock which is formed by microgranite The series is only found in one locality near Lingga (mapping unit 5) and commonly mantles steep mountainous terrain. Deeper soils are commonly found on colluvial foot slopes. The soils are characterised by very pale brown to very pale yellow colours. Textures are very silty and range from silty loam in the surface to silty clay in the subsoil. Structure tends to be blocky, but is commonly weakly developed because of the general moist condition of the soils. The subsoils are mottled grey and yellow, particularly at lower slopes where drainage is imperfect. Boulders of weathered microgranite occur commonly at shallow depth if the terrain is steep The soils are chemically very poor. 6N.HCL extractable iron oxide content is less than 1%. The high reserve potassium may indicate that some 2:1 lattice clays may be present. The heavy sand fraction is characterised by a high content of monazite. The soils can be used for agriculture if adequately fertilized but would be mainly suitable for tree crops. Citrus may do well. Because of the highly siliceous nature of the soil, good responses can be expected from the application of compound fertilizers.

Lubai Family (part of Mapping unit 14b)

This family is found on old alluvial deposits and has textures of clay, silty clay or sandy clay in the B horizon. Most of these soils are found in an area east of the Kuching-Serian Road stretch between the 10th and 20th milestones. The soils are found in an undulating weakly dissected hilly landscape (Quop A unit, p.64) and many of them are bisequent in nature. Either the surface horizons are formed by wash from neighbouring hills or a strong textural contrast in the profiles is caused by stratification in the old alluvial deposits.

Typical bisequent profiles are classified as the *Merang series*.

Merang series (Appendix, p.372)

In this series clays are overlain by a loamy sand deposit. The bisequency is also indicated by the contrast in values for reserve potassium and magnesium between top and subsoil. High values for these elements may indicate a possible marine derivation of the soil but could also be caused by parent materials formed by phyllites. In the latter case, the series should be placed in the **Kerait Family** if the residual part of the profile is thicker than alluvial cover. This may serve of an example that the factor 'origin of parent material' is difficult to use at a high level of classification particularly if this cannot be assessed with accuracy. The *Merang series* is an extremely infertile soil. The physical properties are unfavourably influenced by the strong textural contrast which may cause wet conditions in horizons above the impervious clayey subsoils. Imperfect drainage conditions are therefore more the rule than the exception. If located at a favourable site, e.g. near the main road, vegetable gardening may be profitable on this soil, otherwise the soils are considered to be too poor to make farming a profitable enterprise.

Triboh Family (Mapping unit 21 and parts of mapping unit 14)

The **Triboh Family** comprises GREY-WHITE PODZOLIC SOILS of old alluvial origin in which the texture of the B horizon is a silty clay loam or lighter. As is the case with the heavy textured **Lubai Family** soils, a strong textural contrast may also be present in **Triboh Family** soils. This is commonly caused by stratification of parent materials but may partly be due to clay illuviation or clay breakdown in the surface horizons. One profile studied did not appear to have appreciable amounts of illuviated clays; at least it had insufficient amounts to qualify for an Argillic horizon (see Chapter 15 (p.260). A typical example of the **Triboh Family** is Profile 79 (Appendix, p.304). The C.E.C. is extremely low. All major nutrients are in very low supply. The clay mineralogy shows a dominance of well crystallized kaolinite, while a fair amount of quartz and some gibbsite is also present in all horizons. In the A1 and A2 horizons some X-ray amorphous material is present. The mineralogy of the heavy sand fraction indicates that the deep B horizon is probably foreign to the material forming the A horizon. The opaque/non-opaque ratios are decidedly different. The **Triboh Family** comprises very poor soils, chemically as well as physically and farming is only recommended if the soils are located near large markets so that vegetable growing or citrus cultivation may be economical. The soils are suitable for rubber cultivation but only if heavily fertilized.

5. PODZOLS AND GROUNDWATER PODZOLS

Occurrence: In mapping units 10, 20 and 26. Subordinate in mapping units 9, 14 and 21.

Families: **Silantek, Bako, Buso, Miri** and **Jerijeh.**

Series: *Butan* in **Silantek Family**, *Pueh* and *Stoh* in **Jerijeh Family**.

(i) General character

PODZOLS developed on very porous, quartzitic sandstones occupy long gently sloping dip slopes of cuesta's; when formed in old to subrecent sand deposits they are found on terraces. All PODZOLS are characterised by very light textured surface horizons. In soils developed on parent materials which contain some clay, or minerals which weather into clays, the clay content may increase with depth. B horizons commonly show a textural contrast with the A horizon. This may be caused by a bisequency in parent material or by clay breakdown in surface horizons. The clay fraction is commonly dominated by quartz and kaolinite.

The A horizon normally has a single grain structure, the B horizon is generally structureless and massive unless it is formed by sand. In the latter case, also the B horizon has a single grain structure.

The soils have a well developed, leached A2 horizon overlying either a weakly developed, uncemented or strongly developed, cemented humus enriched B horizon. In some soils the humus B may overly a thin iron B. In some localities, particularly on terraces, more than one humus B horizon may be present (see Plate 25, p.196).

All soils are extremely poor in all major nutrients and it is inferred from the very quartzitic nature of the parent materials that they are also deficient in most trace elements.

(ii) Families

Silantek Family (Mapping unit 10)

This family has formed on sandstone and conglomerates and is characterised by a weakly developed humus B horizon.

Butan series (Appendix, p.307)

The *Butan series* is the dominant occurring soil in the **Silantek Family.** It is found on Tertiary sandstones and conglomerates. The topography is characterised by long gently undulating dip slopes of cuesta's. The slope gradient varies but is commonly less than 10 degrees. The natural vegetation is a poor Kerangas Forest. A well-developed organic surface horizon is usually present and may be several inches thick. The humus is formed by raw litter resembling peat. The A horizon has a sand texture and overlies a clayey B horizon. The A2 is well developed and has a pinkish white colour, stained with humus. Bh is weakly developed but continuous, not or weakly cemented and well augerable. The lower boundary of the humus B may be very irregular and tongues of humus may extend to a considerable depth into the B2 horizon. The latter is generally of a very pale yellow to white colour stained with humus and mottled brown or yellow.

Although the Bh shows an increase in total iron content, this is insufficient to qualify for a Bir. The bisequent nature of the profile shown in the Appendix is illustrated by the significant change in opaque/non-opaque ratios of the heavy sand fraction below the B1/2 horizon. The clay increase in the deep horizons is mainly caused by a lithological discontinuity in the underlying roccks. The clay mineralogy shows a dominance of quartz with some 2:1 lattice clays present in the subsoil.

A watertable is not found within the profile depth, although a perched one may be present in the wet season, particularly when shale beds underly sandstone.

This series is chemically extremely poor. The C.E.C. is very low and is dominated by exchangeable aluminium.

If heavily fertilized, the series can support some crops such as pineapple and citrus but most areas are too remote to be presently of any economic significance. The soils are able to support some coniferous tree species and may be useful for silviculture. An initial fertilizer dressing for adequate development of the root system is probably required for the growing of commercial tree species. Little information on this is presently available.

Bako Family (Mapping unit 10b)

The **Bako Family** is very similar to the **Silantek Family** (p.176) but has a strongly cemented humus accumulation horizon in the B position. The family is found on identical material giving rise to the formation of the **Silantek Family.** The **Bako,** however, is found on less sloping terrain and this may have caused the development of a cemented Bh since leaching on this more or less flat terrain is more severe and soil development may have advanced more rapidly. A perched watertable formed on the cemented Bh is present at shallow depth. Very shallow **Bako Family** soils are found in the Bako Peninsula. They have there developed on more or less flat hill summits and hard sandstone is present at shallow depth rendering the soils to be SKELETAL in nature. The **Bako Family** is not as common as the **Silantek** and because of their extremely low agricultural potential the soils have not been studied in great detail. They usually occur in complex with the **Silantek Family** and have generally been included in mapping unit 10.

Buso Family (Mapping unit 20)

The **Buso Family** is developed in coarse textured, quartzitic terrace materials. The topography is flat to gently undulating. The family is characterised by a weakly developed non-cemented humus accumulation horizon in the B position and is therefore comparable to the **Silantek Family** (p.176) except for the parent material. A typical soil in this family is Prof. 422 (Appendix, p.308). This soil is characterised by bisequent parent materials, as is shown by the abrupt textural change at a depth of 80 inches. The clay fraction is dominated by quartz. The structure in the surface horizon is weak crumbly to single grain, but is quite massive in the B horizon. The A2 may be compact and impenetrable by auger, but this pseudo-cementation disappears upon wetting. The Bh can be easily penetrated by auger, but this is more difficult in dry conditions. A watertable is commonly not present within profile depth but imperfectly drained conditions are commonly found in the lower subsoil.

The soils are chemically extremely poor. The C.E.C. is very low and much dependent on the organic matter content. The exchange complex is dominated by aluminium.

The **Buso Family** is of little agricultural significance. Although crops such as pineapple, citrus and vegetables can be grown with success, they need to be heavily fertilized and only if sited near large markets this type of farming may be economical. Because of its quartzitic nature the soils will readily respond to fertilizers but because of their low exchange capacity, nutrients will be rapidly leached. For this reason, a mixed farming system in which the animal factor is introduced may be well suited to this soil type. The manure will considerably raise the cation exchange capacity so that leaching of nutrients thereafter applied in the form of compound fertilizers will be partially prevented.

Miri Family (Mapping unit 20)

This family commonly occurs on terraces in complex with the **Buso Family.** The soils are derived from quartzitic, coarse textured old alluvium.

The family differs from the **Buso Family** in that it has a strongly cemented humus B horizon (Bh).

Profile 5 (Appendix, p.375) is a typical example of a **Miri Family** soil. A bisequency in the underlying horizons is also here indicated by a strong textural contrast. The bisequency is confirmed by the heavy mineral suite of the sand fraction which in the lower horizons is characterised by a flood of sillimanite, while this mineral is absent in the surface horizons.

The strong textural contrast may have played a role in the formation of a well developed Bh horizon at the contact of the two layers with contrasting textures.

The **Miri** soils are extremely poor, the chemical characteristics being very similar to those of the **Buso Family** (p.177). The physical condition of the **Miri** is, however, inferior because of the Bh which causes the formation of a perched watertable in the surface horizons; poorly to very poorly drained conditions therefore prevail for most of the year. This is probably the reason why a thick peat-like litter layer develops on the surface.

The **Miri Family** is of extremely low agricultural value. Apart from lacking in most major nutrients and trace elements, the poor internal drainage would unfavourably effect the few crops which might possibly be grown on these poor soils. The **Miri Family** is therefore not recommended for agriculture.

Jerijeh Family (Mapping unit 26)

This family is found on subrecent, coarse textured, marine deposits found in coastal ridges between Tanjong Datu and the Santubong Peninsula. Although the total acreage of the family is small, it is of some local importance between Sematan and Kuala Pueh. The family is characterised by a well developed white A2 horizon overlying a well developed to incipient Bh.ir horizon. It is the only family in the PODZOL group in which a B.ir is found. The soils are almost devoid of clay, the parent materials being mainly quartz sand. Because of the high porosity of the deposits leaching is severe. A watertable may be present in the lower subsoil.

Within this family, two series are separated.

Pueh series (Appendix, p.311)

The *Pueh series* is characterised by a strong white A2 horizon, a continuous Bh.ir horizon, and a strong brown to reddish coloured B2 horizon. The A2 may be thin or thick. If the thickness of this horizon exceeds the normal profile depth of 4 feet the soil is classified as *Kilong series* in the group of REGOSOLS (see SKELETAL SOILS, **Gaya Family**, p.163).

The very sandy *Pueh series* is extremely poor in all major nutrients and no form of agriculture is possible unless the soils are heavily fertilized. The soils have very low exchange capacities and the incorporation of organic manure may enlarge this in the topsoils so that much leaching of artificial fertilizers could be prevented. In case these soils must be used at all, cattle grazing in combination with the growing of coconut may be the best form of agriculture. However, the economics of such an enterprise should be thoroughly studied before any firm recommendation can be made.

Stoh series (Appendix, p.376)

The *Stoh series* occupies small ridges along the coast between Kuala Lundu and the Santubong Peninsula. It differs from the *Pueh series* by a less developed incipient Bh.ir horizon which presence is indicated only by small, soft iron/humus concretions found in the B position. The light coloured A2 is well developed. The strong coloured B2 horizon present in the *Pueh series* is of a more yellowish colour in the *Stoh series*.

The series is of very insignificant extent, its agricultural usefulness being comparable to that of the *Pueh series* in the same family.

6. GLEY SOILS

Occurrence: Mapping units 16, 17 and 18. Subordinate in units 14 and 19.

Families: **Tatau, Matu, Semadoh, Gerawat, Bijat, Sebandi.**

Series: *Mundai, Tatau, Plan, Gong, Bokah, Nyabu,* all in **Tatau Family**; *Semadoh, Embang* in **Semadoh Family**; *Bijat, Samarahan, Kakai, Paya Megok, Punda,* all in **Bijat Family; *Krian*** in **Sebandi Family.**

(i) **General character**

GLEY SOILS are by definition non-saline mineral soils in which a gley horizon is found within 20 inches from the surface and which have no Spodic horizon. As explained in Chapter 9 (p.123), the characteristics of the gley horizon are not adequately defined, but in practice a horizon in which greenish-grey, grey or bluish matrix colours denote that reduction is dominant over oxidation is taken to be a gley horizon.

Because of the 20 inch limit for the depth of the gley horizon, many soils, although strongly gleyed below this depth, cannot be classified as GLEY SOILS. In areas mapped at a semi-detailed level prior to 1966, such soils were however classified as GLEY SOILS. The areas involved are the Bukit Punda area, the Serian Development Area and the Nonok Peninsula. (Andriesse, 1962b, 1964a and 1964b). In these areas any soil with a completely reduced horizon within a depth of 4 feet from the surface was classified as a GLEY SOIL. In the present official classification some of these soils would need to be classified as RECENT ALLUVIAL SOILS.

The result is that quite a number of series defined in mentioned reports cover now two soil groups and for bringing the series classification into line with present criteria adopted for a separation at the group and family level, these series would have to be split up. It is felt that the difference between such GLEY SOILS and RECENT ALLUVIAL SOILS is only one of drainage and therefore in this memoir names for these series have been retained but in order to avoid any misunderstanding the limits of them have been redefined so that they are in agreement with the official classification. Therefore, in the mentioned areas, these series cover a wider range of drainage phases than the official classification recognises.

GLEY SOILS are characterised by poorly to very poorly drained conditions. The watertable is permanently or temporary at the surface, or is found below a depth of 4 feet, the height of the watertable within the profile depth being of no diagnostic importance. The topography is flat to gently undulating. Textures range from very light to very fine. A thin, less than 10 inches thick organic surface horizon may be present but soils with a well drained surface horizon are also included, as long as a gley horizon occurs within 20 inches from the surface. The chemical characteristics vary much and depend on texture, drainage and chemical composition of the parent material.

(ii) Families

The group is differentiated into families based on differences in texture, parent material and the presence or non-presence of a thin organic surface horizon.

The GLEY SOILS have been comparatively little studied; particularly detailed chemical analyses are scarse.

Tatau Family (Mapping units 16b and 18b, subordinately in mapping units 14b and 19b).

This family is of minor areal importance in the Region. The soils are characterised by sandy, light loamy and light silty textures (less than 15% clay) and have no peaty O horizon. The following series are recognised in this family.

Mundai series (Appendix, p.379)

This series is of very localised extent and is mainly found in common border areas of the Kuching Rural and Upper Sadong Districts. It occurs in limestone flats usually surrounding limestone hills. The parent material is very quartzitic and the deposits are dominantly derived from sandstones found interbedded with the limestone. The series is often bisequent in nature and subsoils may be formed by clayey materials. Significant is the high pH throughout the profile and the dominance of calcium in the exchange complex. The high calcium content is most likely caused by the presence of limestone particles in the sediments or is due to outcrops of limestone in close proximity through which the groundwater may be locally enriched with calcium.

The series may be suitable for vegetable growing if adequate amounts of fertilizers, particularly nitrogen and phosphate, are applied. If irrigation water is available, wet padi can also be grown but only with sufficient fertilization good yields can be expected.

Tatau series (No profile in Appendix)

The *Tatau series* is developed in marine sands occupying swales or found on very low incipient coastal ridges. The series is of very minor occurrence but some areas are found in the Nonok Peninsula (Andriesse, 1964b), and in the coastal areas between Kuala Samunsam and Sematan.

The series is commonly characterised by a fine sand to sandy loam deposit commonly overlying clays at a depth of over 5 feet. The surface horizon is usually dark brown to greyish brown and overlies a gleyed bluish grey coloured subsoil. A mottled redox horizon is only present in higher parts where the watertable is lower. The drainage is generally poor to very poor. No analyses are available for the series. Common crops grown are coconut and vegetable (melons). If drained, and adequately fertilized, good yields can be obtained. Rough grazing may be an alternative use.

Plan series (No profile in Appendix)

This series has developed in light textured riverine deposits found in small interior valleys. In places they may overly heavy textured materials. The watertable is usually high and the soils are very poorly drained. The origin of the deposits depends on the locality but is commonly granite or sandstone. The series is dominantly found in small floodplains occurring near the granitic massifs in the Lundu District and in the Strap area (Lingga Subdistrict). The series has not been studied in detail, partly because of their insignificant areal extent, partly because of their low agricultural value. Locally, they may be of importance for wet rice cultivation, particularly if they have a thin cover of muck. Although such soils would officially belong to the **Matu Family**, soils within the *Plan series* having a thin muck cover have generally been mapped as an organic phase.

Gong series (Mapping unit 18b)

The *Gong series* is found in two distinctly different localities.

(a) Present valley bottoms, in which case the parent material is formed by recent deposits derived either from sandstone or from neighbouring terraces occupied by old alluvium. The latter is most commonly present in the Lundu area where terrace alluvium occurs widespread and the series has formed in small valleys developed after dissection of the terraces.

(b) Old floodplains which have not been rejuvenated by dissection and in which the parent materials may be of the same age as that of the terrace alluvium mentioned under (a). In the latter localities, the soils are commonly found in association with the *Embang series* (p.181) which is very similar to the *Gong* but has a clay texture. Old floodplain remnants with *Gong series* soils occur along the Kuching-Serian Road (11th-13th mile) and in the Mongkos area (Upper Sadong District). Because of the very low iron content, gleying is difficult to observe in the *Gong series*. A layer of oolitic iron concretions (iron-shot) is sometimes present in localities where the materials could have derived from soils influenced by limestone (see *Paku series*, p.192). In the *Gong series* it is essentially a depositional feature and could be mapped as a phase difference.

The series is agriculturally of very little importance. The combination of poor, leached out quartzitic sandy material and hydromorphic conditions is not favourable for farming. Vegetables may be grown if heavily fertilized, and where markets are nearby.

Bokah series

The *Bokah series* has been mapped only along the Bau-Lundu Road (Andriesse, 1967) where it is commonly found at the foot of long dip slopes which merge into flat valley bottoms occupied by the *Gong series* (p.179). The *Bokah series* may be bisequent because of a strong textural contrast in the subsoil. The surface horizons may be formed by wash from the upper slope areas while the subsoils may be residual. In this area, mudstone and sandstone beds occur in sequence on one slope and the origin of the materials building the series is therefore mixed. The soils have a pale colour throughout the profile. Strong gley features occur within 20 inches from the surface. These are followed by a grey gleyed horizon. It is possible that the poorly drained conditions are caused by the strong textural contrast, the underlying material being formed by quite impervious compact heavy clays. The *Bokah series* is probably the sandy equivalent of the *Semadoh series* (see p.181) which occurs in much similar positions. No analyses are available on the *Bokah series* but it can be inferred from the strong siliceous nature of the parent materials and the poor chemical nature of related upland soils that the soils are chemically poor. The soils are difficult to use for wet padi since, because of the local topography, irrigation is difficult to provide. Perennial cropping offers some prospect but the physical properties of the soil prevent the cultivation of crops with sensitive root systems. Moreover, heavy fertilization will be necessary. The topography is reasonably good for the growing of annual crops but the heavy fertilizer applications needed may probably make the growing of annuals uneconomic. Rought grazing may be a possibility.

Nyabu series (Appendix, p.380)

The *Nyabu series* is only of importance in the Upper Sadong and Kuching Rural Districts. Because of the small areal extent of the series it has been commonly mapped in association with the more extensively occurring clayey GLEY SOILS (mapping unit 16). The series is found in small inland valleys near the debouching point of streams originating in basic to intermediate igneous massifs. The parent material is formed by recent alluvium deposits originating from andesites and allied rock types. The soils are stratified, sandy layers alternating with clay ones. In the *Nyabu series* sand dominates over clay. The level of the permanent watertable is commonly quite deep, but during the wet season groundwater rises up to the surface. This fluctuating watertable gives rise to a strongly developed redox horizon which is amplified by the high content of iron oxides present in the deposits. *Nyabu* soils are comparatively well supplied with nutrients, particularly since fresh deposits accumulate at the surface through yearly occurring floods. This effect is well illustrated in the analyses of the type profile. The soils are well suitable for the cultivation of wet padi and with improved drainage, for off-season crops. For sustained high yields fertilizers must be added; phosphate fixation may possibly occur in some degree, particularly with improved drainage.

Matu Family

The **Matu Family** is similar to soils found in the **Tatau Family** but it has a surface layer of muck or peat not thicker than 10 inches. This thin organic layer denotes very poorly drained conditions and the watertable is at the surface or close to it throughout the year. **Matu** soils are commonly mapped together with related **Tatau Family** soils (p.179) having no muck or peat surface horizon, the difference being regarded as a drainage phase.

Semadoh Family (Mapping unit 18, and subordinately in unit 14)

Semadoh Family *soils have a gley horizon found* within a depth of 20 inches from the surface. They have textures finer than heavy sandy loam (more than 15% clay), and have no organic surface horizon. The **Semadoh** soils may be either formed in old alluvial deposits or in residual material. The soils developed in residual material are separated as *Semadoh series*, while those found in old alluvium are classified as *Embang series*.

Semadoh series (Appendix, p.384)

This series is not very common in West Sarawak. However, closely related soils occur in some areas, notably along the Serian-Simanggang Road, 90th-100th mile (Andriesse, 1965a), and in small localities in the Lundu District (Andriesse, 1969a), but in these soils the gley horizon is found below a depth of 20 inches; and they must therefore be classified as imperfectly drained RED-YELLOW PODZOLIC SOILS. It is, however, suggested that such soils should be included in the GLEY SOILS because their gleyed nature is overruling all other diagnostic features. For sake of completeness these soils are mentioned here.

A typical example of such a soil is Profile 351. These soils are found on very low hills and have been mapped as possible intergrade between RED-YELLOW PODZOLIC SOILS (*Stom series*, p.170) and GLEY SOILS. Although having a gley horizon in the subsoil, the watertable is generally found well below a depth of 4 feet. The gley horizon may be a fossil one and the soils may be so impervious that oxidation takes place very slowly.

Known localities show a stunted growth of secondary vegetation. The cause is not known but this may be due to overfarming. These soils are chemically quite similar to related upland RED-YELLOW PODZOLIC or GREY-WHITE PODZOLIC SOILS. With improved drainage and adequate fertilization the soils would probably be able to support oil palm, the topography in particular is well suited to this crop.

Embang series (Apendix, p.383)

The *Embang series* is derived from old, heavy textured alluvium and is closely similar to the *Merang series* classified as GREY-WHITE PODZOLIC SOILS (p.175). The difference is mainly caused by drainage, the gley horizon in the latter occurring at greater depth. The series occupies probable relics of an old coastal plain at the 50 feet level (Kuching Rural District) or is found in old interior floodplains situated at the 200 feet level. (Upper Sadong District) where they occur associated with *Gong series* (p.179). The soils are very pale coloured and the iron content is very low.

It is possible that the type profile in the Appendix is bisequent due to stratification in the parent material and the A horizon may have formed in material different from that found in the B horizon. It is, therefore, extremely difficult to study genetic processes operating in such materials.

The *Embang series* is physically a poor soil. Although most major nutrients are in low supply, in comparison with other Sarawak soils the values are not unduly low. Particularly reserve calcium is higher than normally encountered in GLEY SOILS. Since this profile is from a locality where limestone of the Terbat Formation is found at close proximity, it is possible that limestone outcrops have influenced the chemical characteristics of this profile.

The *Embang* soils are of little agricultural importance. They usually occur in remote areas where farming on inferior soils is not recommended. If occurring near large markets, vegetable growing may be profitable, but the soils are physically of inferior quality. Near Kuching such soils are used for the making of fish ponds.

Gerawat Family

This family is the equivalent of the **Semadoh Family** (p.180), but for its peaty surface horizon. Such soils are of very minor areal significance in West Sarawak and they are usually mapped as **Semadoh Family** soils, in which they form a drained phase.

Bijat Family (Mapping unit 16a, 17 and parts of 14, 19 and 32)

The **Bijat Family** comprises the most important soils in the group of GLEY SOILS. It covers extensive areas and occurs in large and small floodplains throughout the Region.

All soils in this family have formed in recent riverine alluvium and have by definition no organic surface horizon. In practice, however, very thin mucky top soils are included as organic phases of **Bijat Family** soils. The **Bijat Family** includes soils with poorly and very poorly drained conditions; they may be rich in major nutrients or poor; they may have a high or low iron content and some of them have catclay properties.

To indicate such agriculturally important differences, the family has been differentiated into several series.

Bijat series (Appendix, p.312)

The majority of soils in the **Bijat Family** belong to this series which is typically found in the larger floodplains of major river courses.

Profile 271 has a high silt and clay content throughout the profile. The C.E.C. is moderately high which is probably caused by the high organic matter content since the clays contain mainly moderately crystallized kaolinite with small amounts of vermiculite. The base saturation is ow. The content of calcium and magnesium in the exchange complex is moderately high throughout the profile, but the main exchangeable cation is aluminium. Calcium and magnesium may be much lower in soils occupying other floodplains in which the alluvial deposits mainly originate from sedimentary rocks. No phosphate determinations were carried out on this profile, but the total phosphate shows in general high yields, a considerable proportion of it being in the organic form. There are no weatherable minerals in the sand fraction. For Sarawak standards, the *Bijat series* is of high fertility and with proper drainage it can support a wide range of crops. Wet padi, if properly irrigated, gives high yields. For sustained high yields, however, adequate fertilizers must be applied, particularly when also off-season crops are grown. The likelihood that wet padi is able to obtain some nutrients from the irrigation water cannot be ruled out.

The *Bijat series* soils have great agricultural potential and particularly with the scarcity of good soils in the Region, every effort should be made to bring these soils under permanent cultivation and to tap their potential. Limitations in the *Bijat series* are poor drainage and flooding.

Samarahan series (Appendix, p.387)

The *Samarahan series* is found in small interior valleys surrounded by hills formed by sedimentary rocks and comprises soils which have formed in sediments derived from argillaceous rocks which have not been enriched by magnesium, calcium or potassium from tidal water. Therefore, recent alluvial deposits in these interior valleys are generally less fertile than those deposited along major rivers.

The relatively high total magnesium and potassium values are related to the sources of the alluvial deposits, this being mainly argillaceous rocks. However, it is of interest to note that the values decrease with depth while those in upland soils increase. This is probably caused by rejuvenation at the surface through the addition of fresh deposits, while in upland soils the most fresh material is found in the subsoil where weathering rock is found.

The moderately high values for total phosphate are caused by the high contents of organic phosphate commonly found in these very poorly drained soils. It is to be expected that upon drainage the phosphate will combine either with iron or aluminium and therefore may become less available.

The *Samarahan* soils are particularly suited to the growing of wet padi but the drainage needs improvement. Back flooding may occur in some localities. When properly drained, off-season crops following wet padi can be grown. For sustained high yields fertilizers will be needed for both wet rice and off-season crops.

Kakai series (Appendix, p.388)

This series is formed in recent alluvium originating from basic to intermediate igneous rocks and the soils are therefore better supplied with major nutrients than the related *Samarahan series* (p.182). The series is found in small inland valleys surrounded by hills formed by basic to intermediate rocks and is the heavy textured counterpart of the *Nyabu series* (p.180). Apart from being more fertile than the *Samarahan series* it also has a higher content of iron and manganese oxides which tend to concentrate as soft concretions in the redox horizon situated above the gley horizon.

The soils are comparatively well supplied with total calcium, magnesium and potassium but the contents decrease with depth. The soils in this series are of excellent quality for wet rice cultivation and off-season cropping. Drainage, however, needs to be improved. It is to be expected that the phosphate will become less available after drainage since most of the organic phosphate may revert to aluminium and iron phosphates if the soils become well-aerated.

Paya Megok series (Appendix, p.391)

This series is found in inland valleys and is formed by recent deposits derived from mixed sources, comprising basic igneous rocks, limestone, and shales. The soils are very similar to the *Kakai series* (p.182), but the influence of limestone is well illustrated by the high exchangeable calcium values. The *Paya Megok series* has a well developed redox horizon caused by a fluctuating watertable, good aeration and a high iron content. The vegetative material found in the subsoil of Profile 136 is probably of nipah origin and this may indicate a probable former marine influence in this locality. The occurrence of vegetative material is, however, not typical for the series and is commonly absent. The *Paya Megok series* is usually found in valleys floored by limestone which may influence the pH of the groundwater. For this reason, the pH in the *Paya Megok* soils is commonly higher than those found in other **Bijat Family** soils.

This series is an excellent soil for wet padi and off-season crops, particularly if the drainage is improved. Flooding may be severe in some places and may prevent the growing of wet padi. In such localities, off-season cropping with cattle grazing is recommended. The largest part of the former wet rice experimental station 'Paya Megok' is occupied by this series, and the results of experimental work with wet rice and off-season crops which has been carried out there are applicable to this series.

Punda series (Appendix, p.392)

This series is found in interior valleys and has formed in recent deposits originating from mixed sources but mainly from shale and basic to intermediate igneous rocks. It is morphologically and chemically very similar to the *Paya Megok series* (p.182) but all *Punda* soils are characterised by a high organic matter content, particularly in the subsoil, in which vegetative debris is usually present in considerable amounts.

The soils occur widespread in the upper stream areas of the Simunjan Kanan river and are subjected to high flooding during the wet season. During this period these areas resemble lakes which revert to dry grassland in the dry season. The vegetative material incorporated in these soils is thought to be of nipah origin. The subsoils are rich in pyritic material which causes a low pH upon oxidation. The grey clay found in the subsoil tends to turn pitch black if exposed. This is indicative for the presence of so-called potential catclay (Andriesse, 1962b).

The *Punda series* is of considerable academic interest. Its presence indicates a probable marine or deltaic environment far into the interior in comparatively recent times. The high exchangeable calcium and magnesium contents, together with the presence of potential catclay in the subsoil show a strong relationship with **Pendam Family** soils (p.185) found in present day deltaic areas.

The soils can only be used during the dry season. Off-season cropping may offer good prospects. The soils could also be well used for cattle grazing. The drainage is very poor and with the high floods which annually occur, it is probably not worth improving the drainage beyond the digging of shallow drains necesary for the growing of off-season crops. Deep drainage is in any case not recommended because of the danger of catclay formation in the subsoil (see Chapter 13, section 2, p.228).

Sebandi Family

Sebandi Family soils are similar to **Bijat Family** soils but have a thin muck or peaty surface horizon not thicker than 10 inches. **Sebandi** soils are not shown separately on the Detailed Reconnaissance Soil Map because they are usually included in **Bijat Family** soils. Only in Semi-Detailed and Detailed mapping of major flood plains this difference has been delineated. In small interior valleys, where **Sebandi** soils occur in a complex pattern, they are usually regarded as organic phases of related series in the **Bijat Family.** The agricultural potential of the **Sebandi Family** soils is at par with that of related series in the **Bijat Family.**

Krian series (Appendix, p.395)

One atypical series in the **Sebandi Family** is the *Krian series* mapped in unit 19, where it occurs in complex with many other floodplain soils. This series is characterised by a high calcium content and by presence in the subsoil of oolitic iron concretions. Such concretions are also found in some localities of *Gong series* soils (p.179) and their existence appears to be related to a close proximity of limestone and/or high calcium content in the soil (see also under *Paku series*, p.192). The areal extent of the *Krian series* is too small to be of any agricultural significance.

7. SALINE-GLEY SOILS

Occurrence: In mapping units 27 and 28.

Families: **Rejang, Pendam, Belat and Nonok.**

Series: *Pendam* in **Pendam Family.**

(i) General character

The SALINE-GLEY SOILS are agriculturally of great importance. They cover extensive areas and are relatively undeveloped but potentially rich soils. With the shortage of suitable land in West Sarawak agricultural expansion on the SALINE-GLEY SOILS will reduce much of the pressure for land in the Region. There are, however, considerable problems in ameliorating SALINE-GLEY SOILS and these have been discussed in detail in Chapter 13 (p.228). The present discussion deals only with their physical and chemical properties.

SALINE-GLEY SOILS have formed in recent marine deposits which have accumulated in coastal flats, in riverine delta's and in fringe areas of estuaries. The marine influence is indicated by the salinity of the groundwater which exceeds 500 micromhos per cm at 25°C. Parts of the soils are frequently flooded by brackish water while other parts may show only an influence of brackish groundwater in the subsoil. The salinity of flood and groundwater fluctuates throughout the year, it being most saline in the driest period.

Intergrades to GLEY SOILS in which the salinity of the groundwater may be around 500 micromhos are difficult to recognise in the field, since this low salinity level does neither affect cultivated crops nor the natural vegetation and this limit in salinity level is therefore a difficult one to use, unless many samples are analysed in different periods of the year.

For this reason, other means will have to be found to separate the SALINE-GLEYS from the GLEY SOILS. Possibilities are: the degree of ripening, or chemical values for calcium, magnesium and potassium which may indicate a marine influence. Both factors are, however, not related to salinity. Probably the best way to classify these soils is to separate firstly soils with distinct saline features from those with distinct freshwater features. The transitional soils should be differentiated as phases. Weakly saline features in the subsoil, which are agriculturally of no importance, can be regarded as phase differences of GLEY SOILS.

Although the formal classification defines salinity limits for families, little use has been made of such limits in mapping. Instead vegetation and degree of ripening have been used. Thus: The **Rajang Family** comprises all soils in which the A2 and underlying horizons have textures of clay loam or heavier, and which are found under a mangrove or nipah than well mixed nipah/mangrove vegetation. The N factor is generally more than 0.5 (unripe to semi-ripe) in all horizons.

The **Pendam Family** comprises soils of the same texture range as given for the **Rajang Family** but the primary vegetation is either nibong (*Oncosperma filamentosa*) or the land is cultivated, while the N factor in the A horizon is less than 0.5.

Soils with an N factor of less than 0.5 throughout the profile are rare, even in GLEY SOILS and this factor can therefore not be used to distinguish the **Pendam Family** from real freshwater GLEY SOILS, and is therefore useless to indicate transitional forms. In practice, this has lead to mapping difficulties only in estuarine fringe areas where SALINE-GLEY and GLEY SOILS may overlap. In other areas, **Rajang** and **Pendam** soils occur exclusively in the Santubong physiographic unit (see p.60) which is easily recognised.

SALINE-GLEY SOILS with textures lighter than clay loam in the A2 horizon and above it have been mapped as **Belat Family** when they have strongly saline conditions. Weakly saline soils with textures lighter than clay loams in the A2 horizon and above it belong to the **Nonok Family**, which is the sandy equivalent of the **Pendam Family.** Its weakly saline nature is very difficult to assess and these soil shave been mapped only if occurring in an area of **Pendam Family** soils. Both **Belat** and **Nonok Family** soils are of very minor extent and are not further considered in this discussion.

(ii) **Families**

Rajang Family (Mapping unit 27a, subordinate in mapping unit 28a)

The digging of pits is extremely difficult in these soils and detailed profile descriptions are rare. Most information, therefore, is obtained from auger descriptions. A typical profile is,

0- 8 inches	Greyish brown to dark greyish brown (2.5YR 4.5/2) and dark grey (5Y 4/1) clay; common, medium, distinct, diffuse, dark yellowish brown (10YR 4/4) and reddish brown (5Y 4/4) mottles; weak, angular blocky structure; common very fine to fine pores; gradual, smooth boundary to
8-24 inches	Dark grey (5Y 4/1) clay, many, coarse, prominent, sharp, reddish brown (5YR 4/5) mottles as 1 to 2 mm thick coatings inside large (diameter 2-10 mm) root channels; very weak blocky structure, many, very fine biopores.
24-48 inches	Grey to dark (5Y 4.5/1) clay, locally, few small pockets of greenish grey (5GY 4/1) clay; locally, common, dark grey (5Y 3/1) clay associated with undecomposed organic material, unmottled. Groundwater with distinct smell of H_2S.

The watertable of **Rajang Family** soils fluctuates with the tide, depending on proximity to large channels. The soils are extremely poorly drained and water movement within the soil is very slow. The soil may contain pockets or layers of rotten vegetative debris from nipah leaves or stumps. The salinity of the groundwater normally exceeds 4,000 micromhos per cm at 25°C.

The surface of areas formed by **Rajang** soils is commonly hummocky because of the presence of large mounds, built by mudlobsters (*Thallisima Anomala*). These may be 3 feet high and 4 feet wide, but commonly 2 feet high and 3 feet wide. In some areas as much as 70% of the area may be affected, in other areas they are absent. There are indications that these mud lobsters avoid the most saline areas while weakly saline areas where the **Rajang** merges into a **Pendam** appear to be most severely affected.

Large areas of **Rajang** soils may have potential catclay in the subsoil. This is recognised in the field by the smell of H_2S when augering, by the presence of bright yellow coatings on dried out soil, mantling the mud lobster mounds, and by the presence of black groundwater which turns colourless upon exposure to air.

The yellow colours are indicative to jarosite while the black colour of the water is caused by mono-ferrosulphide which oxidises on exposure. Where mud lobster mounds are common much of this potential catclay material has been brought to the surface, but it occurs normally at a depth well below 2 feet. For analytical information, the reader is referred to Profiles 37 and 38 (p.396) in the Appendix. These analyses are typical for the range of chemical properties usually found in the **Rajang Family**.

The chemical analyses show moderate to high amounts of exchangeable cations. The values for reserve nutrients do not show much greater values than those normally found in upland soils (RED-YELLOW PODZOLICS). The C.E.C. is high for Sarawak soils which is probably due to the generally high organic matter content throughout the soils. The clay mineralogy shows that the dominant clay mineral is poorly crystallized illite intergrading into vermiculite. Some kaolinite and gibbsite is present. The amount of kaolinite varies from place to place probably due to a difference in intensity of clay weathering. The total sulphate content varies but is generally highest in the subsoil with values of as much as 2%.

From the available analytical information, it can be expected that the soils when properly reclaimed will revert to good agricultural land. Improvement would involve drainage improvement, flood control and salinity control. However, the presence of potential catclay may induce toxic conditions to plant growth upon drainage and this problem will have to be studied and remedied before recommendations on expensive reclamation schemes can be made (see Chapter 13, section 2, p.228).

No series have been separated in the **Rajang Family** but it is suggested that those soils with decidedly potential catclay features, probably best defined by the total sulphur content, be known as the *Santubong series*, since they seem to occur dominantly in the area. **Rajang** soils affected by mudlobster mounds may be indicated as a phase. The combination of a *Santubong series* with mudlobster mounds is then indicative to the most severe potential catclay conditions.

Pendam Family (Mapping unit 28a, subordinate in mapping unit 27a)

The **Pendam Family** is formed by intergrades covering soils ranging from saline **Rajang Family** soils (p.184) to freshwater GLEY SOILS, **Bijat Family** (p.181). As explained in p.184 the limits of the family are difficult to recognise in the field. Some of these soils were formerly **Rajang** soils in which the salinity level has been reducced through bunding and artificial drainage. This reclamation process takes place within a reasonably short span of time. Many soils in the Nonok Peninsula which have been in use for 25 years or so, do not show any signs of salinity, that is, not in the samples taken during surveying. In that area such soils were mapped as the *Pendam series* in which a number of phases were recognised to indicate where weakly saline features are still present in the subsoil and where a thin organic surface layer is present. Both features are only of temporary nature, since upon drainage improvement and bunding the salinity will disappear altogether while the organic surface horizon will oxidise upon drainage. The use of a phase difference to indicate such characteristics is therefore well justified (Andriesse, 1964b).

The only series, therefore, separated in the **Pendam Family** is the *Pendam series*, occurring in the Nonok Peninsula. Many other undifferentiated soils in this family will appear to be identical to the *Pendam series*. Other soils are mainly those **Pendam** soils which are recently reclaimed **Rajang** soils which original condition is well known. For the Nonok Peninsula this is still an open question, and part of the non-saline phase of the *Pendam series* may never have been **Rajang Family** soils.

A typical profile of the **Pendam Family** soil formerly under nipah and nibong vegetation but reclaimed about 10 years ago, is:

0- 2 inches	Rootmat.
1- 8 inches	Dark brown, (10YR 3/3), clay, unmottled; friable and slightly plastic, slightly sticky; fine and medium subangular blocky and medium to coarse crumb structure; many fine roots, common fine and medium biopores, many worms; gradual wavy boundary to

8-13 inches	**Dark grey to dark greyish brown (10YR 4/1.5) clay; common, fine to medium, distinct, clear, brown to dark brown (7.5YR 4/4) and yellowish brown (10YR 5/8) mottles along root channels and biopores; weak, medium, subangular blocky structure, slightly plastic, slightly sticky; many fine, medium and coarse biopores, many decaying root remnants.**
14-18 inches	Dark grey (5Y 4/1) clay, few, medium, distinct, clear, strong brown (7.5YR 5/6) mottles, structureless, massive; slightly plastic, sticky.
14-48 inches	Olive grey (5Y 5/2) and very dark grey (5Y 3/1) clay, unmottled; many, partly decomposed plant remains; locally very mucky at about 20 inches from the surface.

Detailed investigations of the **Pendam** and **Rajang** soils in the Santubong area (Andriesse and Sim, 1968) indicate that the main difference between the **Pendam** and **Rajang Families** in this area is mainly the low salinity of the former and the lack of oxidation in the latter. The **Pendam** may have a better developed redox horizon. The C.E.C. in both soils do not differ much and there is no indication of great difference in exchangeable bases either. Whether leaching of bases takes place upon reclamation is difficult to investigate since the range in both the **Rajang** and the **Pendam** soils is great so that comparisons can hardly be made unless changes are studied in one profile during a full reclamation period. Catclay features are commonly not detectable in the field because there are no mudlobster mounds left. These have either been removed manually or have eroded. It is also possible that they never existed. The analyses of the soils, however, indicate that the high sulphur content and the low pH of subsoils upon drying, associated with potential catclay, are as much present in the **Pendam** as in the **Rajang** soil. Whether these soils were initially selected by the local population because of the absence of mudlobster mounds is uncertain. The original vegetation may indicate that the soils were originally weakly saline, since nibong is naturally found in areas with weakly saline conditions. It is therefore dangerous to draw conclusions from the apparent agriculturally well suitable **Pendam** soils with respect to the behaviour of **Rajang** soils upon reclamation. There is not sufficient evidence to support the assumption that **Pendam** soils were all **Rajang** soils prior to reclamation. The only means open to study these changes is by experimenting with an area which initial status is known.

Pendam series (Appendix, p.397)

This series occupies the largest area of the Nonok Peninsula and is there of great economic importance. Detailed studies on these soils were carried out in 1964 (Andriesse, 1964b). The overall morphological characteristics of the series are much the same as the profile described for the **Pendam Family** in the Santubong area (p.185). Most of the series is artificially drained by varying degree. This has resulted in the formation of better oxidized surface horizons and more intense mottling to greater depth than normally encountered in **Pendam Family** soils in their natural state. Because of the variable drainage conditions the changes in these soils have not been uniform in all localities and various drainage phases therefore occur in complex. The *Pendam series* is differentiated into a leached phase, a saline phase, an organic phase and a peat and muck layered phase. In the 'leached phase' the surface horizons are completely depleted of soluble salts. The subsoils may still be affected by salty groundwater. The 'saline phase' is weakly saline in the surface horizons (1000-4000 micromhos/cm). The saline phase is often indicated by the presence of mudlobster mounds and is transitional between a **Rajang Family** soil and a **Pendam Family** soil.

Although the organic matter content is usually high throughout the soil (a particular characteristic of all **Rajang** and **Pendam** soils) some *Pendam series* soils mapped as the 'organic phase' have a thin organic surface horizon (0-6 inches). The organic surface horizon was much thicker in the past but has partly oxidised upon continued drainage and this phase may therefore eventually change into a normal *Pendam series* (leached phase). Some *Pendam series* soils are 'muck or peat layered'. These soils behave differently upon drainage and show subsidence if deep drainage is provided.

The *Pendam series* appears to be chemically different from the **Pendam Family** soils occurring in the Santubong area. Some analyses are shown in the Appendix (pp.397 and 398). They have higher contents of exchangeable calcium and magnesium, some of them are even higher than those reported for **Rajang Family** soils in the Santubong area. Subsoils are particularly rich in exchangeable calcium. Although in some areas the *Pendam series* may have potential catclay in the subsoil, the total sulphur contents are much lower than those **Pendam Family** soils found in the Santubong area, and the danger of catclay formation is not very great.

The *Pendam series* is an extremely good soil for agriculture and is one of the best occurring in the Region. It can be used for a great variety of crops, annuals and perennials, particularly when the drainage is improved. Fertilizers will have to be applied to sustain high yields of cultivated crops.

8. PEAT SOILS

Occurrence: Mapping units 29, 30, 31 and part of 32.

Families: **Igan, Mukah, Anderson, Limbang.**

Series: No series separation. Depth phases 1, 2 and 3 in **Anderson Family.**

(i) General character

Topogenic PEAT SOILS are of great areal importance in the Region. Climatogenic ones are not shown on the Detailed-Reconnaissance Soil Map. Although the latter occur on limestones in very localised small areas, they are not of agricultural importance and have been omited from the discussion.

Topogenic peats have developed in large interfluvial basins and in small interior valleys and are subdivided into families on account of depth of the peat and the nature of the underlying mineral material. PEAT SOILS, less than 40 inches deep and underlain by light textured material, **Igan Family,** are very rare in the Region. For this reason, not much attention is given to this family.

The remaining two families are the **Mukah Family** and **Anderson Family** which together cover over one third of the whole surface area of the Region.

All topogenic PEAT SOILS are formed by accumulations of dark brown to reddish brown, quite raw, woody, to coarse fragmented vegetative material, derived from a tree vegetation. The materials are acid and low in all major nutrients. The bulk density is extremely low, and less than 0.1 in most soils.

Surface peat horizons may be fine textured and partly decomposed. If drained, the decomposition and breakdown of fibres is rapid and the organic materials show a granular structure. The watertable is generally high and is commonly present at a few inches below the surface but in some localities, particularly at the summits of dome-shaped peat areas, the watertable may be found at a depth of more than a foot. Large holes filled with water are commonly present within the peats. Some peats may show interlayering of mineral deposits and if of considerable thickness these should be classified as specific series. No attempt has been made to define them and areas with such peats have commonly been indicated as a phase difference. Thin mineral layers may be present at the surface of peats. This is quite common near meander bends where basin peat is bordering river beds. Such occurrences are of agricultural significance and are usually indicated on Semi-Detailed Maps as phases of the related family.

(ii) Families

Igan Family (mapping unit 29b)

This family is characterised by peat, 10-40 inches in thickness, and is underlain by light textured mineral deposits (less than 15% clay). This family has only been mapped in one area in the Lundu District and is of very minor importance.

For agricultural potential, see under **Mukah Family**.

Mukah Family (mapping unit 29a)

This family comprises peats 10 to 40 inches in thickness and is underlain by heavy textured mineral deposits (more than 15% clay). This family occurs widespread but is usually confined to margins of peat swamps where GLEY SOILS merge via organic phases into PEAT SOILS. The general characteristics of the peat are those given for the group. Chemical analyses are given in the Appendix (pp.399-401). The analyses are from **Mukah Family** in the Nonok Peninsula where soils tend to be more fertile than elsewhere. This is particularly noticeable in the underlying mineral deposits which influence the chemical composition of the peat. High values for exchangeable cations on PEAT SOILS, however, cannot be compared with those of mineral soils. Because of the very low bulk density, values for C.E.C. must be reduced by a large factor to make justifiable comparisons on fertility levels with soils having a much higher bulk density. The high acidity of the peat is well illustrated by the low pH.

The **Mukah** soils need drainage before they can be used for agriculture. If shallow, they can be used for tree crops such as coconut and oil palm. Shrub crops such as coffee are also doing well on these soils as do most annuals. Heavy fertilization is however essential. Subsidence will occur upon drainage. The problems related to the reclamation of Peats have been dealt with in detail in Chapter 13, section 2 (p.231). The **Igan Family** has less agricultural potential than the **Mukah Family** since the light textured mineral subsoil is very infertile and once the peat has subsided or has disappeared altogether through oxidation, crops will root in highly quartzitic, chemically poor material, which without heavy fertilizer applications will not support any crops.

Anderson Family (mapping units 30 and 31)

The general characteristics of the family are the same as described for the group. The limits for the family denote only a depth phase and the family comprises all peats over 40 inches in depth. The character of the underlying mineral deposits is not considered to be of importance. The family is split into three phases. Anderson 1, 40-80 inches deep, Anderson 2, 80-120 inches, and Anderson 3, over 120 inches deep. The Anderson 1 phase is of some agricultural significance and has therefore been mapped separately as unit 30; for reasons explained in detail in Chapter 13, section 2 (p.231) all other deeper peats are for the present regarded as unsuitable for agriculture.

The extremely low chemical composition of the peats is shown in the analyses of profiles 81 and 225 (Appendix, p.315 and p. 316). Profile 81 is from the Stapok Peat Research Station at the Batu Kawa Road, while Profile 225 is from a peat swamp in the Sadong River basin. The peat of the Stapok station appears to be somewhat richer in nutrients than the Sadong peat, but with such low values, the difference may be of little agricultural significance. The surface peats show a somewhat higher bulk density than the layers found at lower depth. This indicates some decomposition of the peat in the surface horizon which may be classified as Fibric/Hemic while the lower horizons are Fibric in character (Boelter, 1969).

The change over from a coarse, raw fibric peat to a friable more granular hemic peat when drained, is very characteristic and is of agricultural significance since the physical nature of the peat is greatly improved by this. Such differences, however, have hitherto not been used for classification purposes but deserve attention in future work.

Limbang Family

The **Limbang Family** comprises peats, either **Mukah** or **Anderson** types which are influenced by saline water. This may occur in coastal areas where peat swamps are exposed to ingress of sea or tidal water due to erosion of the belt of mineral soils which formerly separated the peat deposits from the sea. The family is only mapped in the Lundu District where the vegetation is different from a normal peat swamp forest and therefore boundaries of the family could be accurately delineated from air photographs. Other areas of this family undoubtedly exist along the coast between the estuaries of the Sadong and Batang Lupar rivers, where much peat is exposed to the sea. Because of lack of detailed analytical information for this area, the existence of this family there can only be assumed by inference from its position. The agricultural value of these peats is the same as for the related fresh water families. They may have been enriched by calcium, magnesium and phosphate.

9. RECENT ALLUVIAL SOILS

Occurrence: Mapping Units 15, 23, 24 and 25, and parts of units 19 and 23b.

Families: **Ramun, Sematan, Kayan, Seduau, Kabong.**

Series: *Ramun, Terbat Entebar* and *Siar* in **Ramun Family;** *Rambungan, Sematan, Chupin* in **Sematan Family;** *Kayan* in **Kayan Family;** *Seduau, Sebat, Sekati, Paku* and *Malang* in **Seduau Family;** *Siru* in **Kabong Family.**

(i) General character

RECENT ALLUVIAL SOILS are characterised by deep generally homogeneous profiles without much horizon differentiation except for a well developed A1 horizon. Alluvial soils with a gley horizon below a depth of 20 inches are included in the RECENT ALLUVIAL SOILS, and for this reason well drained, moderately well drained and imperfectly drained phases occur in the group for most soils. Well drained phases are characterised by weak mottling in the subsoil; in the moderately well drained phases mottles are strongly developed in the subsoil; the imperfectly drained phases are characterised by well-developed redox horizons with strong mottling and by the presence of a gley horizon in the deeper subsoil. The colours of the soils range from almost white to strong brown and red. This depends on the origin of the alluvial deposits. Textures cover the full range from sands to clays. Structures may be absent or are single grain to strong blocky. Most soils are liable to infrequent flooding during the wet season but floods are commonly of short duration. The soils show much chemical variation; this is dependent on texture and origin of the deposits. Some soils show stratification and are strongly bisequent others have a very uniform solum.

The agricultural suitability is much dependent on the texture and the chemical fertility. The topography is flat to gently undulating and well suited to intensive cultivation of a wide range of crops comprising both annuals and perennials.

(ii) Families

Ramun Family (mapping unit 23a)

The **Ramun Family** soils are characterised by strong colours, commonly strong brown, brown and reddish yellow to red, and are all of riverine origin. The origin of the deposits comprises basic to intermediate igneous rocks (*Ramun* and *Terbat series*), hybridised biotite granite or adamellite (*Siar series*), and red mudstones (*Entebar series*).

Most **Ramun** soils are confined to levees and small interior valleys of upper reaches of minor streams, reason why they have characteristics strongly associated with certain types of parent materials. Lower down stream the alluvial sediments are generally of a more mixed origin.

Ramun series (Appendix, p.319)

The *Ramun series* is found near the debouching points of streams originating in massifs built by basic to intermediate igneous rocks. They are all very gravelly since the most coarse material commonly accumulates near debouching points of streams. Nearest the mountains, gravels may be present at the surface but with increasing distance from their sources gravelly material occurs at increasing depth in the profile and gravels are gradually replaced by more clayey material. Profile 242 is a typical example of the series and shows the characteristic increase of coarse textured material with depth. The heavy sand mineral fraction shows that some weatherable minerals, particularly hornblende, may be present in the subsoil (no analyses submitted). An exact percentage cannot be given because of the insufficient sand material available but the low amount of heavy minerals present may indicate that it is insignificant. The C.E.C. is considerably high for a soil with such a low clay content and is caused by the high vermiculite content. The base saturation is higher than normal in Sarawak soils and the exchange complex is well supplied with calcium and magnesium. The pH is also high for Sarawak soils.

The *Ramun series* is chemically the most fertile one in the group of RECENT ALLUVIAL SOILS and is excellently suitable for many crops. Because of the high content of coarse rock fragments, the soils are well drained, probably somewhat excessively, and they may be prone to drought conditions during long spells of dry weather. Annual crops may suffer from this. The soils would be excellently suitable for cocoa, coffee, oil palm and many other fruit crops. Part of the Tarat Agricultural Station is formed by this series and experimental work on this soil type has confirmed its great agricultural potential. Unfortunately, the total acreage in the Region is small but where existing, every effort should be made to intensify agriculture on this soil type. A large area is found in the Terbat-Muiat-Bunan triangle (Upper Sadong District) which for this reason has a great potential for development (Andriesse, 1962c).

Terbat series (Appendix, p.320)

The *Terbat series* is closely associated with the *Ramun series* and is formed by loam and clay deposits which accumulate at greater distance from the debouching point of streams originating in basic to intermediate igneous massifs. The *Terbat series* overlaps the *Ramun* formed by the coarse textured material deposited nearer the debouching points of streams, and a boundary between the two series is difficult to draw. Profile 209 is a typical example of the series. Gravel layers may be found at depth but are commonly absent. The heavy mineral sand fraction indicates that an admixture from shale derived material may be present in the subsoil. No weatherable minerals were found but the amount of non-opaque minerals was too small to investigate this properly.

The clay mineralogical analyses show that poorly crystallized kaolinite is dominant with some vermiculite occurring subordinately. This indicates that most of the clays in this profile are probably derived from eroded *Tarat series* soils (p.164). The soils are usually well drained and the watertable is normally found well below a depth of 4 feet. The C.E.C. is moderately high and and is well in agreement with the clay mineralogy. The exchangeable calcium and magnesium are moderate for Sarawak conditions. The high phosphate retention is related to the high content of iron oxides. Although chemically not as fertile as the *Ramun*, the *Terbat* is an excellent soil on which a wide range of crops can be grown. It is less prone to drought than the *Ramun series* and is suitable for all perennials and annuals which are not sensitive to floods of short duration. The flood risk is the only limitation to agriculture in this series. Every effort should be made to make full use of the great agricultural potential of these soils.

Entebar series (Appendix, p.403)

This series has formed in alluvium from red mudstones occurring in the Kantu Beds outcropping in some localities at the foot of the Klingkang Range, notably in headwaters of Sungei Entebar (Undup basin) and Sungei Dor (Klauh basin). For this reason, the series is only found as small ribbons along Sungei Entebar and Sungei Dor in the Simanggang District. The series has not been studied in detail and is only of very local significance. The analyses indicate that the soils are as poor as the related upland soils, the *Begunan series*, classified as RED-YELLOW PODZOLIC SOILS (p.171). Its high agricultural value is due to the high clay content, and the excellent physical properties. Although suitable for a wide range of crops the soils need to be well fertilized. Flooding is a yearly occurring risk and crops sensitive to floods of short duration should not be grown.

Siar series (Appendix, p.404)

This series is of very localised extent in the Lundu District and occurs north of Bukit Gading. It is formed in deposits derived from hybridized adamellite and probably gabbro. The soils are sandy throughout and are strongly coloured. Imperfectly drained conditions occur near the coast where the series may overly marine deposits. Because of its very minor agricultural importance the soils have not been studied in detail. The soils are chemically poor. Although strongly coloured, the iron content is low, most of it being present as a thin iron oxide coating of quartz grains.

Sematan Family (mapping unit 25)

This family is characterised by strong brown to reddish colours, and deep homogeneously textured medium to fine sandy soils. They have formed in subrecent marine deposits building a coastal ridge landscape in the Lundu and Kuching Rural Districts. The soils are all excessively drained and prone to drought conditions, particularly in the Sematan area where long spells of dry weather occur regularly. The watertable is generally low but may be formed within a depth of 4 feet in some localities. Incipient iron leaching may take place and accumulations of iron oxides in the form of soft concretions are commonly present in the B horizon. The total amount is, however, insignificant.

Sematan series (Appendix, p.323)

This series is dominant in the family. The type profile shows weak gleying in the subsoil. The presence of mica is a common feature and indicates that a large part of the deposits originates from the adamellite in the Lundu District, the only rock types in the whole Region having appreciable amounts of mica. The analyses illustrate the highly quartzitic nature of the series. The amount of weatherable minerals is small but hornblende may form an appreciable part of it in some localities. Although the soils are strongly coloured, the amount of iron oxides present is low. The high pH is caused by the lack of buffer in the very sandy deposits and is not indicative to a high base content. The soils are very poor and deficient in all major nutrients and need to be heavily fertilized if used for agriculture. Coconut is probably the only crop which can successfully be established on this soil but only if adequate amounts of fertilizers are applied. The use of this series for rough grazing should be investigated. The addition of organic manure would greatly improve on the low base exchange complex of the surface soil and would make the application of artificial fertilizers more economical.

Rambungan series (Appendix, p.324)

The *Rambungan series* is of very minor extent and is formed by soils which are transitional from the most recent beach deposits not affected by leaching or weathering, the *Siru series* (p.193), and the strongly leached and more mature *Sematan series*. The colour is less strongly developed than in the *Sematan series* and little iron has been liberated from iron bearing minerals. Leaching is however pronounced. The type profile shows that the soils contain more bivalent cations than are present in the *Sematan series* but the amounts are less than those found in the *Siru series*. Manganese in particular is present in comparatively large amounts as is shown by the MnO contents. In the Sematan area, manganese may accumulate in the B horizon. The total calcium content of the deep subsoil may be high in some localities. This depends very much on the occurrence of shell layers which tend to form in storm beaches in the Sematan-Lundu area.

The *Rambungan* is a good soil for coconut, but would need adequate amounts of fertilizer for obtaining good yields. Melons are also planted with success (see Plate 34, p.200).

Chupin series (Appendix, p.407)

This series is of very localised extent and occurs within areas of the *Sematan series* where shell layers in the subsoil have been cemented into hard pans. The cementing agent is probably silica. These petricalcic pans or horizons develop at the lower slopes of ridges where the ground watertable is high and where silica leached from surface horizons is lodged in the shell layer. The series occurs commonly in the Kuala Lundu area where the existence of these cemented shell layers can frequently be seen in water wells dug in a *Sematan series* soil. It is quite possible that during the wet season a perched freshwater table is maintained above such shell banks.

The *Chupin series* is not of great agricultural significance. The cemented layer may cause poorly drained conditions during the wet season and coconuts commonly planted on this soil type will suffer from these temporary aquatic conditions.

Kayan Family (mapping unit 15a)

This family is characterised by light textures (less than 15% clay), sandy loams and sands being dominant. The colours are commonly brownish yellow to yellow but strong brown colours may locally occur. Although in the local classification the colour range has been strictly defined the motivation was to express origin of the deposits, the **Kayan** being developed in deposits originating from sedimentary and acid igneous rocks mainly. For localities where this derivation could be proven the colour of the soil has been ignored.

The **Kayan Family** is found widespread throughout the Region but is mainly confined to river banks and levees occurring in the middle parts of riverine basins in which sandstone forms the dominant rocktype. **Kayan Family** soils are generally well to excessively drained, but imperfectly drained to poorly drained phases may occur in low lying localities. In such drainage phases mottling and gleying is present within a depth of 4 feet. In some surveys, **Kayan** soils have been partially mapped as **Semilajau Family** soils, erroneously classified as RED-YELLOW PODZOLIC SOILS. They are in fact imperfectly drained phase of **Kayan** soils, and are not very common in the Region. The dominant soils are characterised by homogeneously coloured deep profiles in which stratification is a common feature.

Kayan series (Appendix, p.408)

The *Kayan series* is the dominant soil in the **Kayan Family.** It is characterised by strong stratification, excessive drainage, the homogeneous colour, except for some weak mottling in layers of a less pervious nature, and it is formed in material derived from sandstone and/or acid igneous rocks. The analyses show that the C.E.C. is surprisingly high for such sandy soils. This may be caused by the presence of 2:1 lattice clays which may not yet have weathered to kaolinite in such recent deposits. Clay mineralogical analyses are not available to substantiate this. The aluminium content is very high and dominates the exchange complex. Major nutrients are in low supply and the series must be regarded as chemically very poor. However, the annual addition of fresh deposits at the surface may maintain the fertility of the surface horizon which appears to be well supplied with nutrients.

This soil type can be profitably used for the cultivation of fruit trees. Many longhouses and villages built alongside river courses are situated on this series and the soils could therefore be profitably used for the growing of vegetables and fruits for domestic use. The areas are generally of too small extent to be of use for commercial exploitation.

Seduau Family (mapping unit 15a)

This family is the equivalent of the **Kayan Family** (p.190) but for the texture, all **Seduau** soils having textures with more than 15% clay. The family is usually found in small floodplains, on levees and on river banks in the upper and middle parts of drainage basins and is formed in deposits derived from mixed sources but mainly from shales. The family is characterised by generally deep, homogeneously yellowish brown to yellow coloured sandy clay loam to heavy clay soils in which mottling and gleization may occur in the lower subsoil. Small mottles caused by manganese are usually present in the heavy textured soils or in layers showing a textural increase in relation to overlying material. Stratification is common but because of the smaller texture range than found in the **Kayan Family** it is less distinct. The soils are generally well to moderately well drained.

Seduau series (Appendix, p.411)

The *Seduau series* comprises the dominant soils in the family and occurs widespread in small flood plains of areas where shales and fine sandstones are dominant. The series is rather poor in major nutrients although it is of higher fertility than related upland soils derived from the same parent materials. However, little detailed information is available on this series, the areas being comparatively small and the range in fertility being probably quite large depending on age of the deposits and the frequency of flooding. Its value lies in the excellent topography and the generally well drained nature. The soils are very suitable for vegetable growing and for fruit trees such as citrus, rambutan, durian and others. Coffee is doing equally well but there is little prospect for much commercial production because the series occurs only as small acreages in any one locality.

Sebat series (Appendix, p.327)

The *Sebat series* is very similar to the *Seduau series* but the parent material is mainly derived from biotite granite (adamellite). It is therefore mainly found in the Lundu District where the series occupies a considerable area and comprises the best soils found in the District (Andriesse, 1969a). The series is characterised by pronounced accumulations of manganese in the form of mottles, distinct stratification and by presence of large amounts of micas. The series is more fertile than the *Seduau series,* probably because it still has a large content of weatherable minerals in the sand fraction, particularly hornblende, which are able to supply magnesium and other cations upon weathering. The *Sebat series* is a well drained soil and excellently suitable for the growing of annual crops and perennials. Because of the comparatively small area available and the necessity to make intensive use of this series, crops such as rubber should preferably not be grown. At present, a large part of the series is occupied by Engkabang plantations. The prospects of the cultivation of Engkabang which may give a crop only once in the 5 year are not known, but it may well be that one bumper crop would give a better net return per acre than the total obtained from annual crops for a period of 5 years. It is worth to investigate this aspect of land use, particularly since Engkabang does not require much maintenance and is only labour consuming during harvesting time (taking place only once in the 5 or 7 years). Flooding may be a severe risk in some localities.

Sekati series (Appendix, p.412)

The *Sekati series* is, as the *Sebat series* (p.191), derived from biotite granite (adamellite) and is therefore mainly found in the Lundu District. It is similar to the *Sebat series* but is characterised by the strongly mottled redox horizon overlying a gley horizon. It could be regarded as a drainage phase of the *Sebat series* intergrading to GLEY SOILS, (*Kakai series*, p.182). A strong accumulation of iron oxides in the redox horizon is well illustrated by the values for extractable iron shown in the Appendix and it is, therefore, suggested that the *Sekati* with its strong horizonation cannot be well classified as just a drainage phase of the *Sebat series*.

The soils are chemically fertile, particularly in the surface horizon and the series is suitable for a wide range of crops excepting those with a root system sensitive to wet conditions for short periods. Flooding is also an annual risk.

Paku series

The *Paku series* occurs in mapping unit 17 and is much similar to the *Malang series* soils but for the presence of scattered rather soft and easily broken oolitic iron concretions. The scattered nature of these concretions and their non-hardened character may indicate that they are formed *in situ*. Similar, but hard concretions were found as layers in old alluvial materials (*Gong series*, p.179; *Krian series*, p.183). The occurrence of these iron forms in the later series are of sedimentary origin but those in the *Paku series* may presently form in the profile around small particles of limestone present in the soil. The iron oxides tend to accumulate around the particles because of very localised pH differences in the solum (Andriesse, 1966b). There is a definite relationship between the occurrence of such concretions and the presence of limestone but for establishing the exact causality further investigations are needed.

The *Paku series* occurs as a very minor soil in the Bau, Kuching Rural and Upper Sadong Districts, and its agricultural potential is similar to that of the *Malang series* with which it occurs in association.

Malang series (Appendix, p.415)

The *Malang series* is derived from a mixture of basic igneous to intermediate igneous rocks, argillaceous rocks and limestone and occurs typically in the Bau, Upper Sadong and Kuching Rural Districts where such rock types commonly occur together in one drainage basin. The soils are usually homogeneously textured, showing little stratification. Also the matrix colour throughout the profile is homogeneously yellowish brown. Characteristic for the series are the profuse reddish-yellow to red coloured mottles giving way to more yellow colours at depth. A gley horizon is sometimes present within the profile depth but this is uncommon.

The series is transitional to the *Kakai series* in the group of GLEY SOILS (p.182) and may be compared with the *Sekati series* also in the **Seduau Family** but the latter is developed over material derived from granitic material. The *Malang series* may have been mapped as **Malang Family** and classified as RED-YELLOW PODZOLIC SOILS elsewhere in the State. It is suggested that the typical mottling indicates an extended redox horizon and is not related to podzolization, so that its proper place in the classification system be the RECENT ALLUVIAL SOILS.

The surface horizons of *Malang* soils are well supplied with major nutrients. This may be the result of regular rejuvenation through deposition of fresh material during floods. The soils are suitable for a wide range of crops, except for those with root systems sensitive to wet conditions which prevail during parts of the year. The soils are liable to flooding of short duration.

Kabong Family (mapping unit 24)

The **Kabong Family** soils are found on recent marine sand deposits forming present beaches. They are very undeveloped soils and as illustrated on Plate 34 (p.200) they carry a pioneer vegetation only where they merge into subrecent deposits formed by the *Rambungan series* (p.190) The family is differentiated into two series of which the *Kabong series*, occurring dominantly in the State, is almost absent in West Sarawak. This series is formed by highly quarzitic sands without weatherable minerals. The second series, the *Siru series* is formed by deposits having an appreciable amount of weatherable minerals and mica's.

Siru series (Appendix, p.328)

This series commonly occurs on present beaches between Tanjong Datu and the Santubong Peninsula. It is characterised by a pale brown colour which may be caused by finely divided manganese oxide commonly present in recent coastal deposits in this locality. In places shell fragments and shell layers may occur in the deposits.

Extractable calcium and magnesium contents are very high for Sarawak soils and illustrate the recent marine character of these deposits. Analyses of the heavy mineral sand fraction indicate that weatherable minerals, dominantly hornblende, occur in some magnitude. This varies with locality and although the content of weatherable minerals is very low in Profile 1, near Santubong as much as 40% of the heavy minerals in the sand is made up of hornblende (Andriesse, 1969c). A significant characteristic of the *Siru series* is further the high content of micas which is related to the source of the deposits namely the adamellite forming Bukits Pueh and Gading.

Only that part of the *Siru series* not influenced by sea water during king tides can be used for agriculture. Coconut is the only crop well adapted to the specific coastal environment of the *Siru series* and thrives well.

Chapter 12. THE DETAILED RECONNAISSANCE SOIL MAP

1. Compilation of the Map

The Detailed-Reconnaissance Soil Map was compiled following principles discussed under Chapter 2, section 6 (p.17) and is issued in four sheets; three sheets show the soil pattern of the Region, while the fourth, containing the key to the mapping units, supplies information on the soil types depicted together with relevant information on parent material and landforms.

In order to facilitate the use of these maps at district level, care has been taken that the map sheets as far as possible cover one or more districts. Sheet one covers the Lundu and Bau Districts, sheet two covers the Kuching Rural District, the Lower Sadong District and the Upper Sadong District, while sheet three covers the remaining part of the Region taken up by the western parts of the Simanggang and Lubok Antu Districts.

In order to avoid obscuring soil information by too much detailed topographic information and ensuing indicative lettering, the topographic data has been kept as simple as possible. Since the topo-base was constructed by a simple photographic reduction process from the 1:50,000 scale topographic maps, detailed topographic information can be readily obtained from these and if necessary inserted, or a reduced version on film can be used as a transparent overlay.

2. Explanation of the Key to the Map

The Key sheet shows the colour scheme and symbols used for indicating mapped soil types and combination of soil types.

In the Key, the soil mapping units have been combined to form five main groups. These groups are related to topographic position and comprise:

(a) **Mountain and Hill Soils,** which are soils occurring on high land, not affected by flooding and without a high water table. The soils are generally developed on parent rock *in situ*. The group contains a unit of soils developed on mixed materials in which residual soils and alluvial soils occur in complex.

(b) **Floodplain Soils** occur on flat land, generally liable to flooding of varying magnitude. The water table is commonly high. The soils are derived mainly from transported materials. As is the case with group (a), a compound mapping unit comprising soils of mixed origin is used for areas where for cartographic reasons a separation of upland and lowland soils was impossible.

(c) **Terrace and Fan Soils** occupy terrace sites and foothills. Although derived from transported materials, they are not found in floodplains. They generally have a low watertable.

(d) **Coastal Soils.** As the name implies, these soils are found along the coast, where they have derived from dominantly marine deposits. Most of the soil types in this group occupy flat areas and are liable to flooding; the water table is generally high.

(e) **Basin Swamp Soils** are mainly formed by organic deposits which have accumulated in interfluvial basins swamps. A subgroup of mixed origin, comprising soils of mineral and organic derivation is found in areas where these soils occur in complex. All soils are liable to flooding and the watertable is high.

These five main groups of mapping units have each been divided into subgroups. Type of parent material appears to be the most logical choice for forming a basis for further subdivision because derivation plays next to topography an important role in soil formation.

The Mountain and Hill Soils therefore are divided under the subheads: 'formed on igneous rocks', 'on sedimentary rocks' and 'on miscellaneous rock types'. The subgroup formed 'on mixed materials' comprises soils from both residual and alluvial derivation.

The Floodplain Soils are divided into: 'on Recent Riverine Alluvium', 'on Old Alluvium' and again under a subgroup 'on mixed materials', in which soils of alluvial and residual origin occur in complex.

The Terrace and Fan Soils have two subgroups namely those formed 'on Old Alluvium' and 'on Fan deposits'.

The Coastal Soils are divided into subgroups formed by soils 'on Recent Marine Alluvium' and those formed 'on Subrecent Marine Alluvium'. In this group the age of the parent material is indicative to maturation of the soil profile. A third subgroup is formed by soils developed 'on Recent Deltaic and Estuarine deposits'.

The principle of using type of parent material as a basis for subgrouping could not be followed for the **Basin Swamp Soils.** For these, depth has been used as a criterion since in some way this property appears to be related to maturation.

The choice of colours is generally based on these groups and subgroups. There are some exceptions, namely for certain alluvial soils colours are indicative to either derivation or soil forming process operating in these soils. Therefore, a close colour match may either indicate kinship in derivation or kinship in soil forming process; this would depend on which of the two is most strongly expressed in the morphology of the soil. In any case both factors are strongly related to each other.

It should be emphasized that great colour differences denote main soil differences, commonly of the magnitude used for a separation of soils at the Soil Group level. Undeveloped soils are uncoloured. The use of symbols in combination with colours made it possible to indicate specific characteristics of soils which may not be present in the whole mapping units. Letter symbols indicate specific families or series.

Small dots always indicate sandy soils and since both, light and heavy textured soils occur in most alluvial mapping units, this symbol is dominantly used in these mapping units. Likewise, steep land associated with shallow soils in most Mountain and Hill Soils is indicated by crosses.

It was, with a few exceptions, impossible to show on the map simple mapping units comprising one soil type only. Therefore, most mapping units are compound units comprising closely allied soil types for which the predominance of some soils over others is indicated by the columns 'predominant' and 'subordinate'. Indications are further given on the specific type of parent material on which the mapping unit has formed and the specific landform in which it is found.

Names of soil classification units within the mapping units are indicated by capital letters for the Soil Groups; names of soil families are indicated by small lettering and specific soil series by italics. Commonly only soil families have been mapped, but areas in which specific soil series of a family could be emboundered are indicated by a two-letter symbol. Therefore, areas of the same colour but without a two-letter symbol belong to the soil family as indicated and may be formed by soils of various series within the family.

Also, if in a certain mapping unit a soil family dominantly occurs in some minor areas which cannot be indicated on the map, this soil family is indicated by a one-letter symbol referring to the family involved. Occurrences of soil classification units indicated in the Key under the column 'subordinate' are not further indicated on the map.

3. Descriptions of the Soil Mapping Units

Most mapping units are associations of soil families. In some families specific series were mapped. Since the boundaries of the mapping units are mainly based on physiographic boundaries and/or boundaries between geological formations, the soils within one mapping unit are closely associated as far as topography and derivation is concerned. Because topography and parent materials strongly influence soil formation in the Region, other soil characteristics within the mapping unit are commonly also closely related.

The soil mapping units are of great practical importance since land use or potential land use, is by and large the same for each individual mapping unit. In development planning of a scale related to the reconnaissance nature of the soil map, the soil mapping units can therefore be used for an assessment of the agricultural potential for a given area.

To this end, the main characteristics of the mapping units are described in general terms. The descriptions comprise notes on the occurrence, topography, landscape elements, parent materials, erosion and flooding risk, overall fertility aspects and agricultural potential. Reference is made to

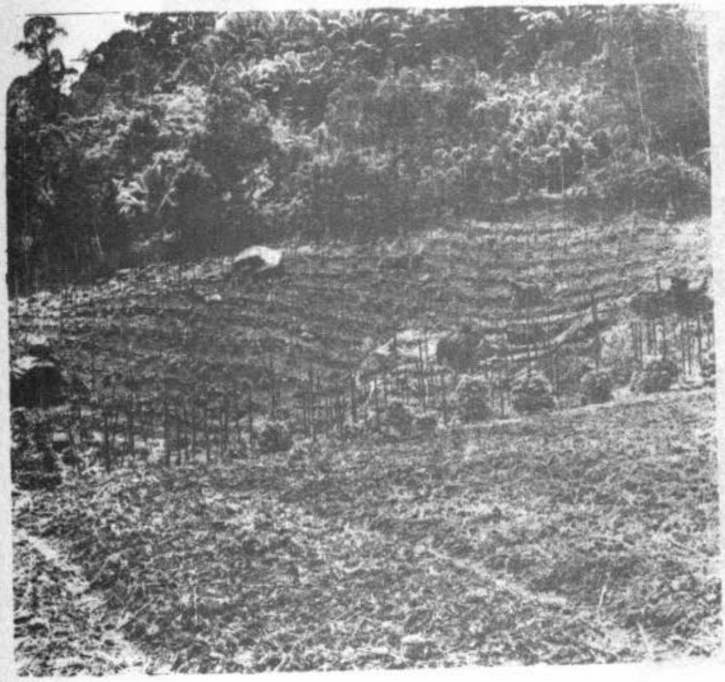
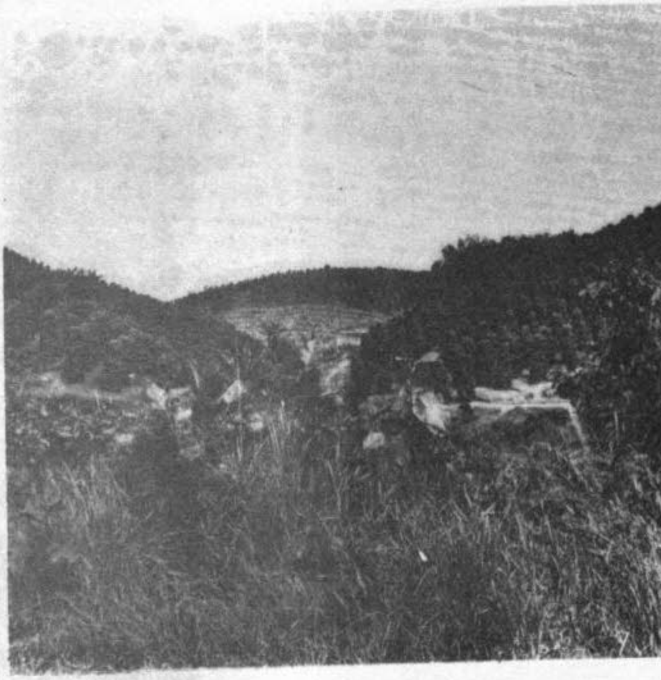


Plate 23

Pepper cultivation on footslopes of a basic igneous rock massif. *Suka series* (SKELETAL SOILS). Note the large colluvial boulders and the stony nature of these soils. 36 th. mile Kuching - Simanggang road.

Plate 24

Pepper cultivation on rounded hills of the Quop B unit (150 feet high summit plain). *Bayur series* (RED-YELLOW PODZOLIC SOILS). 53 rd. mile Kuching - Simanggang road.



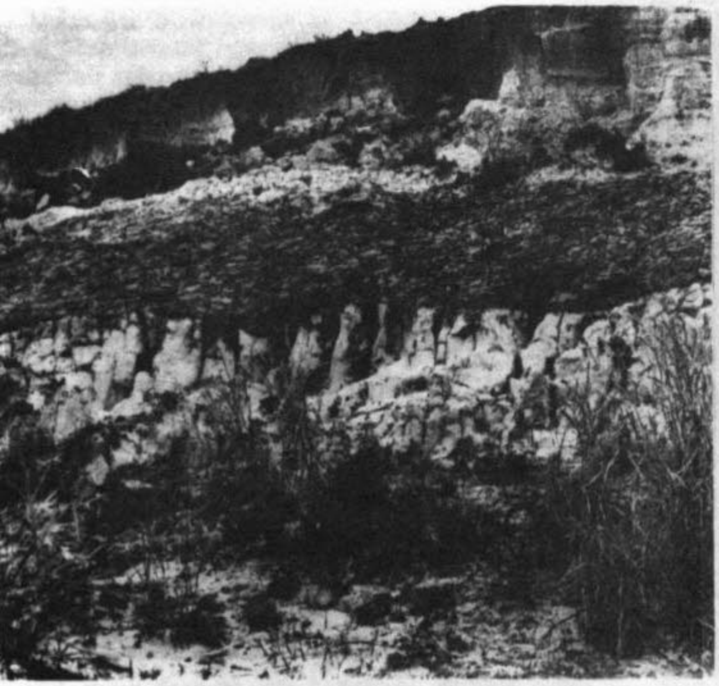


Plate 25

Truncated Humus Podzols (Miri Family) with several B_h horizons, underlain by dark coloured fossil catclays. 90 – 120 feet high terraces at Kuching Airport.

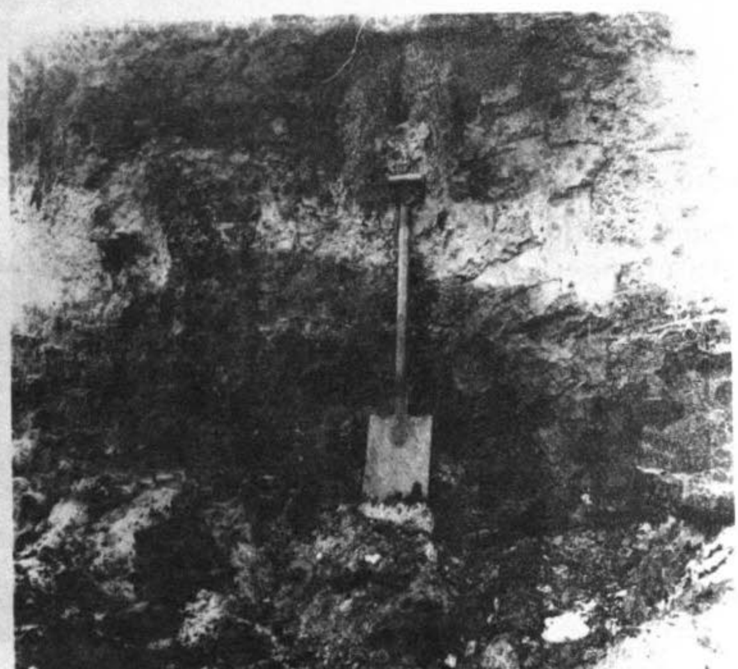


Plate 26

Close view of truncated Miri Family soil of Plate 25 with more than one B_h horizons.

Plate 27.
Concretised rootchannels presently developing in the *Sematan series* (RECENT ALLUVIAL SOILS) where subsoil is in contact with saline water. Sibu Laut coastal area.

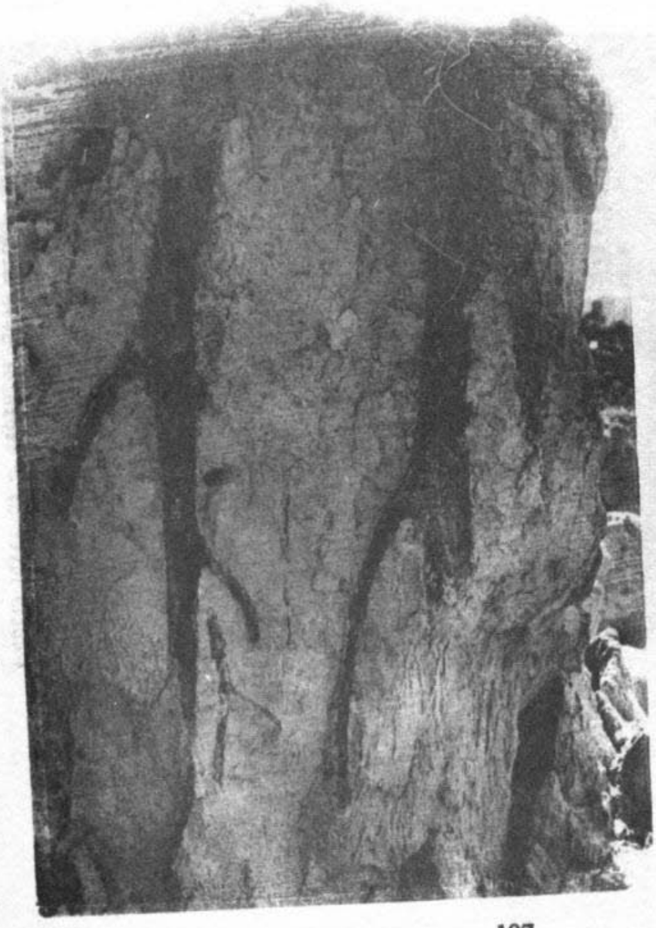


Plate 28.
Infiltration of surface soil and humus accumulation in old rootchannels. Saratok Family (GREY-WHITE PODZOLIC SOILS). 19th mile Bau-Lundu road.

Plate 29.
Pebble layer at a depth of over 4 feet denoting alluvial derivation of overlying soil which is otherwise identical to a residual one. Lupar Family mapped as Merit Family. Tebakang-Mongkos road.

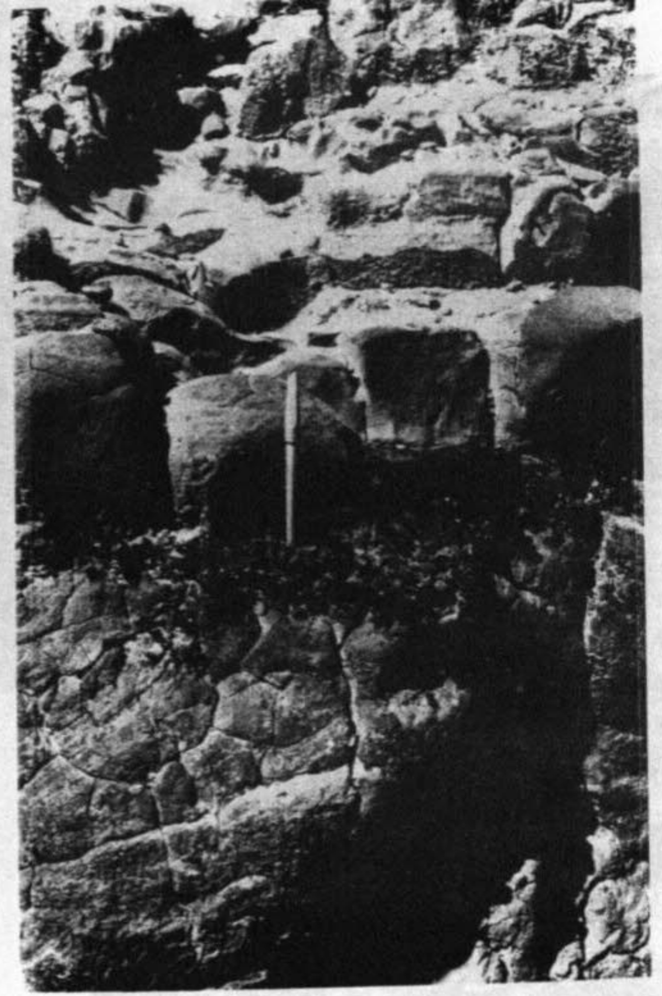


Plate 30.
Close view of fossil catclay underlying a Saratok Family soil, in Tertiary mudstone with interlayering of lignite. Note the strong columnar structure developing on drying. 19th mile Bau-Lundu road.

Plate 31.
Subsidence of peat due to drainage in old rubber garden at Matang road.

Plate 32.
2 years old reclaimed peat planted up with oilpalm. Initial subsidence of two feet indicated by old tree stumps. Stapok Peat Research Station.

Plate 33

Uprooted coconut due to poor anchorage of roots in the soft peat .

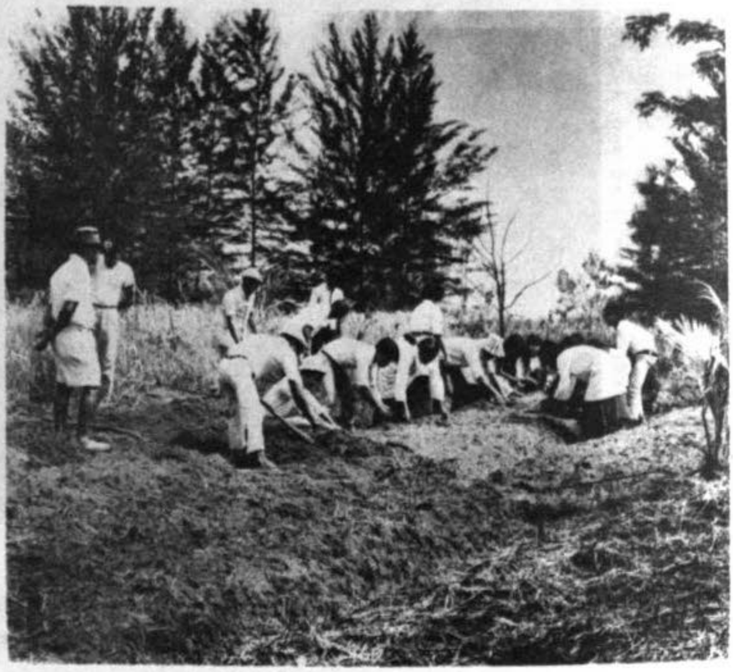


Plate 34

Vegetable growing on the *Rambungan series*. Note the pioneer vegetation *(Casuarina Sumatrana)* on the present beach formed by *Siru series* the specific soil classification units found within the mapping unit but apart from some general notes on the characteristics of these soils detailed descriptions have been omitted.

Instead constant reference is made to Chapter 11 (p.161) in which the soil classification units are described in detail under the respective soil groups and readers requiring this detailed information are advised to consult these sections.

(a) **Mountain and Hill Soils**

Mapping unit 1

(i) *Occurrence.* As large areas forming steep mountainous terrain in the Upper Sadong District and as smaller areas forming steep mountainous terrain in the Kuching Rural and Lower Sadong Districts. Small areas of single hills occur throughout the Region but their total areal extent is of minor importance although locally their occurrence is of agricultural significance.

(ii) *Topography.* Most of the unit builds moderately steep to steep mountainous terrain, generally with slopes in the 15-30 degrees range. Footslopes are commonly the most gentle ones in this range, while upper slope areas may be steeper. Deeply incised gullies and valleys occur where large mountain complexes are involved. Minor areas are formed by single monadnock type hills with steep slopes. Erosion is evidenced as mass-movements of soil and rock debris along slopes; landslides commonly occur and colluvial debris accumulates at the footslopes and is gradually removed by streams.

(iii) *Parent Materials.* The unit is found exclusively on igneous rocks of basic to intermediate composition. The range is from gabbro to andesite, the latter being the most common.

(iv) *Soils.* Soils, comprising SKELETAL SOILS of the **Sedong Family** (p.162) are usually associated with steep land. Shallow soils occur in complex with bouldery and rocky land, the latter being dominant where recent landslides have removed much of the original soil mantle. This steep land is indicated as mapping unit 1b. On more gentle sloping land the soils are deeper and belong to the LATERITIC SOILS in which the *Tarat series* is dominant (p.164). Small areas belong to the *Antayan series* (p.164) which is separated from the *Tarat series* on account of a more blocky structure and more yellowish colouration. The areas are indicated on the map by the symbol At. Although the **Tarat Family** soils are generally well developed, shallow and deep phases occur in complex in most areas. This is caused by mass-movements of soils along slopes through which in some places the normal soil has been truncated, while in others it may be found buried. The latter phase is commonly found at lower slopes where much colluvial material accumulates. The soils, although prone to erosion through mass-movements are genera.ly stable to surface-wash. Even at exposed sites surface wash is not much in evidence although some gullying is taking place. Flooding does not occur in the soils of the mapping unit.

(v) *Fertility Aspects.* By Sarawak standards, the soils are among the best upland soils to be found in Sarawak. This is not so much caused by the nutrient content which is generally low, but by the favourable physical conditions. If sufficient nutrients are added, roots develop freely in these soils and are not hampered by excessive water or impenetrable horizons. When exposed, the horizon surface may dry out during long spells of dry weather and sensitive crops may suffer from drought. The more shallow, immature soils in this unit, the *Suka series,* are the most fertile ones in the range, because they are relatively young. However, because they occur on the most difficult terrain, the steep slopes, they are present mainly used for shifting cultivation. Tree crops are difficult to establish because of the shallowness of the soil. The soils generally respond to fertilizers although the phosphate retention is moderately high.

(vi) *Agricultural Potential.* The areas are not suitable for large scale development based on intensive land-use. Parts of the unit, particularly those formed by footslopes can be used for crops with a high income per surface area. Pepper is particularly suited to such land use and since also the soil types are eminently suitable for pepper cultivation this crop is the best choice for this type of land. The shallow soils on steep slopes which should be kept under permanent cover could be used for fruit trees if planted in holes. Although in this mapping unit the topography forms the greatest limitation to agriculture every endeavour should be made to find means of using this land, because of all the upland soils they comprise the most fertile soils. The most appropriate system to make use of this land would be to have small farm units on selected sites with crops giving a high income per surface area planted. Although the steepness of the slope may normally carry a high risk of erosion, the author is of the opinion that with proper mangement involving permanent coverage of the soil, the slope factor is off-set by the relative high agricultural potential and the low erodability of these soils. The necessity to make use of this land is further emphasized by the low potential of other available upland soils in the areas surrounding this mapping unit and the large population concentrations usually found in close proximity.

Mapping unit 2

(i) *Occurrence*. As many small areas forming monadnock type hills in the Bau District, some larger areas of mountainous terrain in the Upper Sadong District and to a minor extent in the Kuching Rural District. Some single small areas in the Simanggang District.

(ii) *Topography*. The mapping unit is characterised by single hills and mountains rising steeply from surrounding plains and low hilly country. An exception is the large area found in the Upper Sadong District where in the Sungei Roban drainage basin, the mapping unit builds strongly disected hilly terrain merging into mountainous terrain. Large streams are generally absent, the areas being drained by small gullies fed by springs which are often tapped by the local population for domestic use. The slopes are commonly in the 20-35 degrees range or over. Erosion occurs as mass-movement through landslides. At the foot of steep hills, a pediment of boulders overlying a buried soil is commonly found.

(iii) *Parent Materials*. The unit is found on acid igneous, intrusive and extrusive rock types of fine texture. The range of rock types is large and includes dacite, rhyolite, microgranodiorite and associated porphyritic rocks and tuffs.

(iv) *Soils*. The soils comprise SKELETAL SOILS found on steep slopes where the soil mantle has been removed by erosion. The soils are therefore commonly associated with rocky and bouldery land. Although this is indicated by mapping unit 2b, it does not mean that the remaining portion of the unit, formed by subunit 2a does not contain skeletal and shallow soils. Subunit 2a comprises mainly RED-YELLOW PODZOLIC SOILS of the **Abok Family**, the *Gumbang series* being dominant (p.166). This series is characterised by shallow, undeveloped soils and therefore most of the mapping unit can be regarded as having generally shallow soils, in which boulders and rock outcrops occur in abundance. It should be mentioned that the extent of the mapping unit has probably been exaggerated. This is caused by the fact that the acid intrusions are commonly only outcropping near the summit of the hills. Although bouldery material may have spread over the slopes, it frequently overlies soils which belong to neighbouring mapping units. The exact boundary is very difficult to indicate and the topography has generally served as an indication. Typical examples of the *Gumbang series* are therefore difficult to find.

(v) *Fertility Aspects*. The soils are commonly of moderate fertility and can as far as the nutrient status is concerned, be compared with the RED-YELLOW PODZOLIC SOILS derived from shales. Structurally, they are often better than the shale derived soils and the internal drainage is superior. Since very little permanent agriculture is practised on these soils, it is difficult to give indications on their crop performance. The local inhabitants, however, regard them as better padi soils than the ones derived from sedimentary rocks, occupying much of the surrounding areas. Probably the vegetation is able to regenerate faster because of the nutrients obtained from weathering rock found at shallow depth.

(vi) *Agricultural Potential*. Because of shallowness of soil, the occurrence of bouldery and rocky land, combined with the general steep terrain, the agricultural potential of this mapping unit is low. The areas are small and locally they can be used for the cultivation of fruit trees and some pepper. Old native fruit plantations indicating old settlements are often found on these soils. (Bukit Gumbang is a good example). This usage could be encouraged. Only in the larger areas in the Upper Sadong District permanent cultivation would be possible on moderately steep land. Pepper and fruit crops are the most obvious crops. Areas still under primary forest should be kept as Communal Reserves, as this use is probably of more economic value for the local inhabitants than agricultural exploitation.

Mapping unit 3

(i) *Occurrence*. This unit is found in four major areas. The first two are found in the Lundu District where they comprise the Pueh and Gading massifs. The third one is found in the Bau District comprising the Jagoi-Kisam massif and the fourth is found in the Simanggang District where it forms the Tabong-Telaga mountains in the Ulu Strap area. The mapping unit is further forming minor, single hills mainly in the Lower Sadong and Simanggang Districts.

(ii) *Topography*. The mapping unit is commonly found on moderately to steep mountainous terrain with deeply incised valleys and gullies. Those areas forming the Pueh and Gading massifs are the most steep one, and reach heights of 5,000 feet in places. Erosion under natural cover is generally by mass-movement along slopes. Particularly the Jagoi-Kisam area is prone to many landslides leaving steep rocky cliffs at the mountain sides. Without a natural soil cover, sheet erosion occurs.

(iii) *Parent Materials*. These comprise coarse grained acid igneous rock types, mainly coarse grained granites and granodiorites of varying chemical composition. Those in the Lundu District contain large amounts of biotite and the rocks are commonly referred to as adamellite. In the Bau District, granodiorite of very acid nature is found while areas in the Simanggang District are mainly built by very acid granites with few ferro-magnesium minerals.

FIG. IV 6

SCHEMATIC RELATIONSHIP BETWEEN UPLAND SOIL MAPPING UNITS, TERRAIN AND PARENT MATERIAL

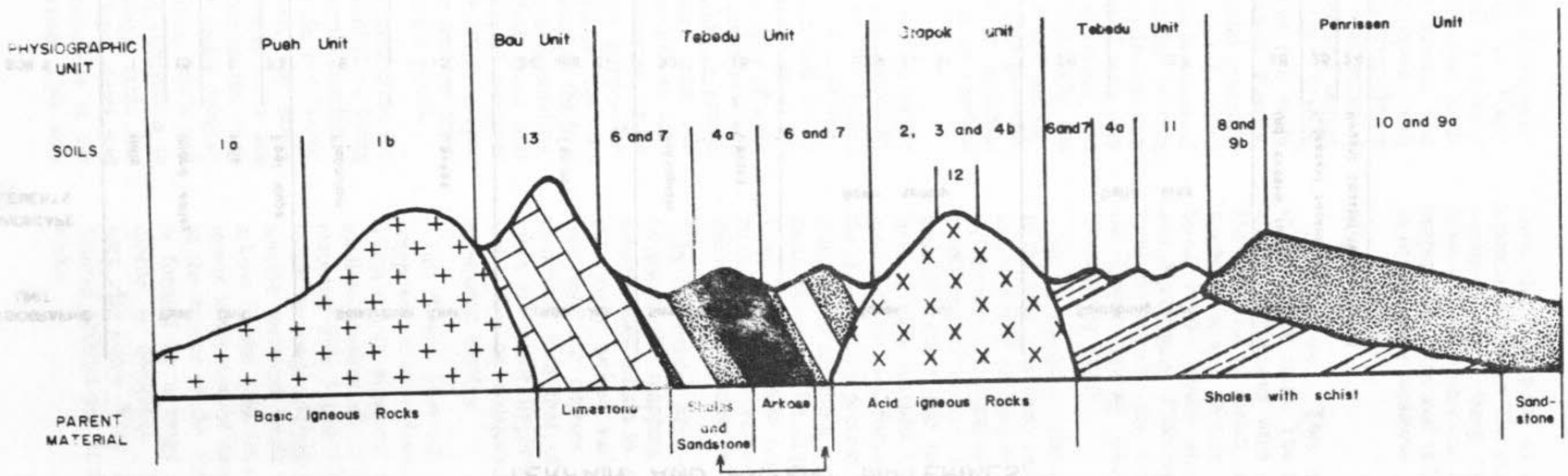
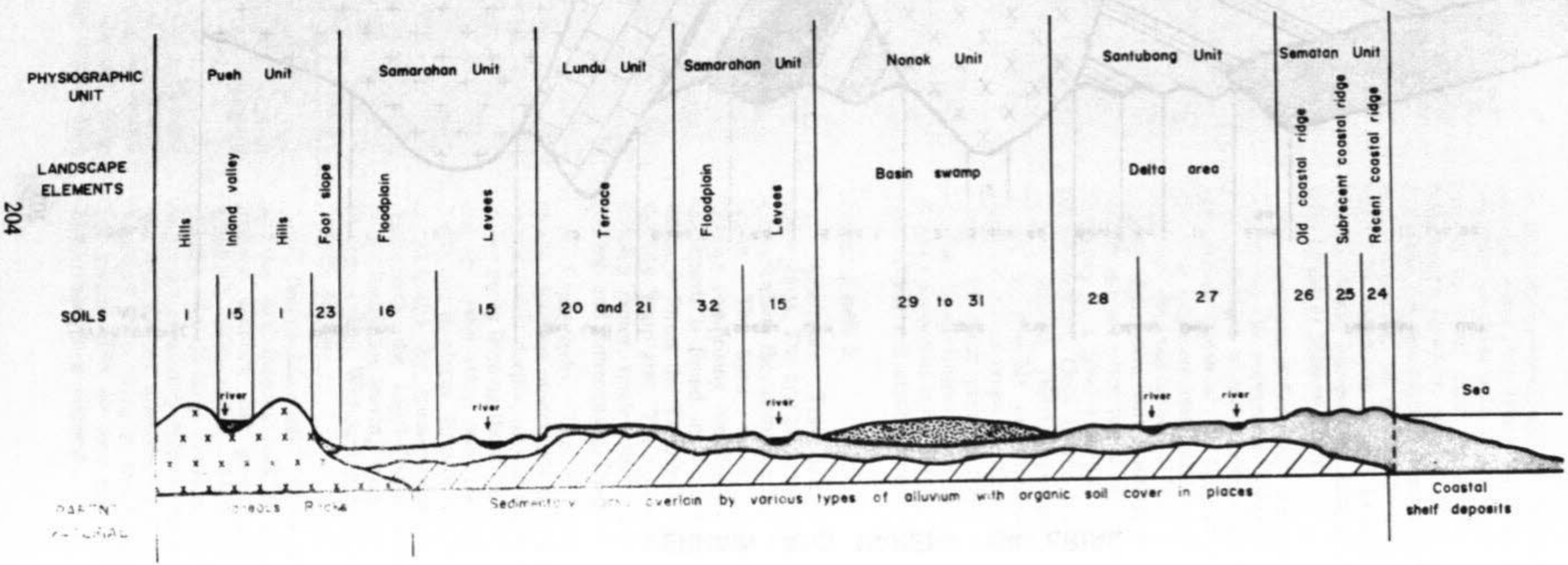


Fig. IV 7

SCHEMATIC RELATIONSHIP BETWEEN LOWLAND SOIL MAPPING UNITS, TERRAIN AND PARENT MATERIALS.



(iv) *Soils.* The mapping unit is dominantly formed by SKELETAL SOILS of the **Kapit Family**, *Buri series*, (p.162) indicated by subunit 3b. This series occurs on steep land where landslides constantly rejuvenate the soil mantle. The series is commonly found in complex with bouldery and rocky land. On the less steep slopes and on the footslopes where colluvial material may accumulate, the soils are deeper and belong to the RED-YELLOW PODZOLIC SOILS, **Abok Family.** In this mapping unit two main series are separated within the **Abok Family,** namely the *Gading series* (p.165) found generally on granodiorite and the *Jagoi series* (p.166) found generally on granites. The *Jagoi series* is indicated as such on the map (Jg), the remainder belongs to the *Gading series*. Both series have in common a granitic texture in which coarse sand with clay dominates over silt. They differ in colour, the *Gading* being stronger coloured. Generally the *Jagoi* is deeper and found at lower slopes and one cannot escape from the impression that probably the *Jagoi series* is more related to colluvial material wh le the *Gading series* is its residual counterpart on the steeper slopes.

(v) *Fertility Aspects.* The soils are physically of favourable condition but they are chemically very poor. The latter is caused by the highly acidic nature of the parent materials. The primary forest shows generally a good stand but this is probably more related to the surface area of the root system than to inherent high fertility of soils. The favourable physical conditions result in a well developed root system which is able to extract the necessary nutrients over a large area. The soils are generally not used for permanent agriculture but where this has been attempted, as for instance in the Simanggang District, pepper has been a failure while also rubber did not do very well. Although this must be attributed to the low amounts of fertilizers used by the local population, it confirms the conclusion reached from soil analyses that the soils are deficient in all nutrients and need to be heavily fertilized. With proper fertilization, most crops should do well on these soils since the physical conditions are goods.

(vi) *Agricultural Potential.* For most areas the agricultural potential must be regarded as being very low. The steepness of the terrain combined with the low fertility of the soils do not favour agricultural exploitation. Moreover, the sandy soils when not kept under permanent cover are prone to sheet erosion, and therefore on the steep slopes the soils could best be left under primary forest. In the Pueh and Gading areas, this is still the case but the result of shifting cultivation in the Jagoi-Kisam and Tabong-Telaga areas has been devastating. Sheet erosion, land slides and lallang infestation (the latter particularly in the Tabong area) are much in evidence. This may prove the desirability to keep these areas under a permanent cover. The generally more undulating terrain in the Tabong region may be used for crops such as rubber and oil palm if the soils are properly fertilized and sufficient attention is given to conservation measures. (Andriesse, 1968a).

Mapping unit 4

(i) *Occurrence.* This mapping unit is found in two major areas. The first one is found as an almost continuous area in the Upper Sadong District, west of Serian and transgresses into the Kuching Rural District. The second area is found in the border area of the lower Sadong and Simanggang Districts. Small areas of only local importance are further found mainly in the Upper Sadong District along the Serian-Simanggang Road.

(ii) *Topography.* The topography is very varied. In the first mentioned locality where the mapping unit is found on arkose, the landscape is formed by moderately dissected hilly terrain, showing deeply incised valleys. The amplitude in relief is generally about 100 feet and where the small streams have reached local base level small inland valleys have formed. In the interior where the downcutting process still proceeds, the landscape is cut up into a multitude of hills by many small streams. The slopes are commonly in the 15-25 degrees range. Locally this may be less or more. Erosion is caused mainly by slipping or sliding. Sheet erosion is not much in evidence.

In the border area of the First and Second Divisions the mapping unit forms steep, high, mountainous terrain in which small streams have cut deeply incised valleys. Slopes are generally well over 20 degrees. This landscape can be compared with that of mapping unit 3. Other areas of minor importance have a topography which can be compared with that of the first mentioned locality.

(iii) *Parent Materials.* This mapping unit is composed of soils developed on parent materials which can be regarded as being chemically intermediate between the basic igneous rocks forming mapping unit 1 and those of the acid igneous rocks forming mapping unit 3. In some areas specific materials could be differentiated such as arkose in the area west of Serian and schist in minor areas east of Serian, while the large area at the border of the First and Second Divisions is formed by a range of rock types in which diorite is dominant. Granite and granodiorite may also occur. Very small areas in the Lower Sadong District are formed by silicified volcanic rocks.

(iv) *Soils.* On account of terrain, a main subdivision is made between SKELETAL SOILS and RED-YELLOW PODZOLIC SOILS. The steeply sloping mountainous terrain in the border area of First and Second Divisions is dominantly covered by SKELETAL SOILS of the **Kapit Family** (p.162). Well-developed soils are rare and usually occur only at some moderately sloping land or on colluvial footslopes. These developed soils belong to the **Abok Family** (p.165) and since the complex geology makes it impossible to establish with some certainty the parent material no differentiation into series has been made. In other areas, this has been possible and most soils are mapped there as RED-YELLOW PODZOLIC SOILS, also belonging to the **Abok Family** but comprising specific series related to the kind of parent material on which they have formed. So is the *Serin series* (p.167) related to arkose, the *Bayur series* (p.167) to schist and the *Keladan series* (p.167) to silicified volcanic rocks. These series have been indicated as such on the map respectively Sn, By and Kl. Where this has not been done, the soils belong to the undifferentiated **Abok Family.**

(v) *Fertility Aspects.* The SKELETAL SOILS and the undifferentiated **Abok Family** soils occurring in subunit 4b are the best supplied with nutrients. This statement is made by inference from the parent materials because very little analytical information is available. The soils have received very little attention because the terrain is not suited to agriculture and most areas are still under primary forest and uninhabited. Where used in fringe areas, pepper cultivation is carried out with success. This is probably more related to the good physical properties of the soils than to nutrient status.

The *Serin series* is intensively used for pepper, rubber and various other crops, as is the *Bayur series* and both give excellent results if intensive farming methods are used and sufficient fertilizers are supplied. The soil analyses reveal a deficiency in all major nutrients, potassium being least deficient. The structure of the *Serin series* is inferior to that of the *Bayur* and root development in the latter is commonly better. For this reason, the latter soils are much favoured for pepper cultivation along the Serian-Balai Ringin Road. The soils appear to respond favourably to fertilization although phosphate is liable to be highly fixed in the *Serin series.*

(vi) *Agricultural Potential.* The areas at the border of the First and Second Divisions have a low agricultural potential because of bad topography. Fringe areas may be used by the local inhabitants if slopes are not too steep. But this is only of local significance. The *Serin series* can be used for intensive agriculture although soil conservation measures and fertilization need constant attention. The steepest areas (mainly those along the Padawan Road) are topographically the least suitable. Rubber is an excellent crop for this type, particularly since it provides an excellent permanent soil cover. Pepper can be grown with proper fertilization but erosion should be controlled by terracing. The latter, although preventing sheet erosion may not be able to control mass-movement such as slips and landslides which are natural phenomena in this area. They may be particularly dangerous if houses are built on unstable sites.

The *Bayur series* is an excellent soil for pepper. The areas, being small in extent, are admirably suited to intensify farming in an area in which soils suitable for intensive agriculture are rare.

The *Keladan series,* although suitable for intensive farming is too small in areal extent to be of any agricultural significance beyond the local level.

Mapping unit 5

(i) *Occurrence.* This mapping unit occurs exclusively in the Lingga Subdistrict in the east of the Region. Its largest extent is found on Bukit Lingga or Bukit Lesong (as it is called by the local population). The unit is further found in two isolated areas in the immediate surroundings of the first mentioned location (Bukit Apeng and Bukit Krepok).

(ii) *Topography.* The unit builds generally mountainous terrain; a minor area north of Bukit Lingga is formed by low hilly terrain. The mountainous areas comprise two single mountains, namely Bukit Lingga and to the west Bukit Apeng. They rise steeply up from the surrounding plains and hilly terrain of low elevation. The footslopes are moderately steep to gently sloping. Upper slope areas are very steep, usually more than 30 degrees. The mountains are drained on all sides by small deeply incised streams forming a radial pattern. The hilly terrain in the small area north of Bukit Lingga, however, comprises moderately sloping land but footslopes are steep. On the mountains where the surface is exposed, erosion is severe. Footslope areas are covered with large boulders and other colluvial material of smaller size. Landslides are common but because of the absence of youthful streams at the foot of the mountains the scree material formed at the footslopes is not very rapidly removed and long concave slopes are therefore most common.

(iii) *Parent Materials.* This consists of microgranite with exceptional small amounts of ferromagnesium minerals. Accessory minerals are dominated by monazite.

(iv) *Soils.* The *Lingga series* (p.175) is commonly found on moderately steep to gently sloping terrain, thus the footslopes. This series is classified as a GREY-WHITE PODZOLIC SOILS because of its very pale colouration which is related to the low iron content of the parent rock. On account of derivation, it should have been placed in the **Abok Family,** RED-YELLOW PODZOLIC SOIL GROUP. The *Lingga series* is, therefore, anomalous and is difficult to place in the present classification system.

The soils are characterised by a silty texture. This, and its pale colour makes it easy to distinguish them from other soils, particularly as they occur in such a localised area. The heavy mineral monazite dominantly occurring in the heavy mineral fraction is another diagnostic characteristic.

On the steep slopes, the *Lingga series* occurs in complex with SKELETAL SOILS and bouldery and rocky land.

(v) *Fertility Aspects.* The soils are chemically very poor. When occurring in footslope areas, the soils are also generally imperfectly drained. Much surface run-off water tends to collect there and infiltrates into the porous soils. The local people have indicated that on the steep slopes good hill padi yields can be obtained, particularly on Bukit Apeng. This must be attributed to the shallow nature of the soil and constant rejuvenation so that the forest is able to regenerate rapidly. This is not the case at the more gentle footslopes, where older soil material tends to accumulate.

(vi) *Agricultural Potential.* Because of the small total area involved, the unit is of very minor importance for the Region. Locally, the soils can be used for rubber and fruit crops. Citrus appears to do well on the lower footslopes if adequate attention is given to drainage. The steep slopes with more fertile soils are not suited to agriculture and are better left under primary forest and if they must be used, fruit crops should be planted in selected places with easier or more manageable slopes.

Mapping units 6 and 7

These two units are best described together because they have many characteristics in common.

(i) *Occurrence.* The units occur throughout the Region and comprise the dominant upland soils in the Bau, Kuching Rural, Upper Sadong and Simanggang Districts. Unit 6 is most common, while unit 7 is of local importance only in some areas of the Upper Sadong District.

(ii) *Topography.* The units generally built moderately dissected to strongly dissected terrain of which the height varies between 50 and 350 feet. The terrain is described in detail under Chapter 4 (p.64). The hill summits in this landscape indicate the existence of former floodplains and their height increases gradually from about 50 feet near the coast or present floodplain level to about 350 feet in the interior. The slopes are of surprisingly equal magnitude throughout the Region, regardless the amplitude of relief. There is, however, a tendency to more rounded hills towards the present floodplains, which may in some localities possibly be caused by the presence of less hard parent materials in which present floodplains have formed, the rivers seeking their way to the sea through the most easily erodable materials. Slopes are complex and generally within a range of 15 to 25 degrees, they rarely exceed it. Upper slopes and footslopes may be steeper than the mid-slope areas, but the reverse also happens. No general rules can be given. Land slips and slides are very common, because the underlying rock formations are formed by generally folded stratified materials. Slips and slides create an undulating slope surface.

Sheet erosion is not much in evidence in this landscape, particularly if the soil is under permanent vegetative cover.

Subunits 6b and 7b occur on higher land than subunits 6a and 7a and because the amplitude of relief is greater mass removal of soil-rock debris is of a greater magnitude than that occurring on short slopes. Examples of the landscape of subunit 6b are found in the Undup area in the extreme east of the Region.

Although sheet-wash is commonly not of significance, in unit 7 one generally finds a thin veneer of sand on native paths if these are located along slopes. Since the topsoils in unit 7 are more sandy than in unit 6 this may indicate that some sheet-wash is taking place in the more sandy soils. These native paths induce gullying as run-off water tends to concentrate in the small indents the paths make on the surface. The coarse particles settle on these paths while the clay particles are carried away along the slope in suspension. Soil observations along such paths may over-emphasize the sandy texture of these soils.

(iii) *Parent Materials.* Unit 6 comprises soils on argillaceous rocks while those in unit 7 are derived from arenaceous rock types or a mixture of argillaceous and arenaceous types. Commonly thin or thick sandstone beds occur within sedimentary rocks composed mainly of shales; the reverse also happens. It is therefore possible that on one slope, soils of unit 6 and 7 occur in succession although as a rule the materials derived from beds of different texture is completely mixed through mass-movement along the slope. It is also possible that soils develop through various beds of sedimentary rocks, giving rise to the occurrence of bisequent soil.

(iv) *Soils.* The soils in both mapping units belong all to the RED-YELLOW PODZOLIC GROUP. While in unit 6 the **Merit Family** (p.168) is dominant and the **Bekenu Family** (p.171) occurs subordinate, the reverse is the case in unit 7. This is caused by the complex manner in which arenaceous and argillaceous rocks usually occur. Where argillaceous rocks are dominant the **Merit Family** is the common soil type, locally the **Bekenu Family** may be present if beds of sandstone influence the shale. Where fine sandstone is dominant, the **Bekenu Family** is the normal occurring soil type, while the **Merit Family** may be of local importance where shale outcrops. Again, both families occur as deep and shallow phases, depending on the steepness of the terrain. The dominance of shallow phases is indicated by subunits b mapped on steep land.

The **Merit** and **Bekenu Families** cover a wide range of soils with great variations in characteristics such as drainage, permeability, porosity and content of iron concretions. The main distinction between the families is based on texture, the **Merit** being more clayey. Other characteristics have not yet been used officially for a further differentiation of the families into series. Chemical characteristics often relate to type of parent material and this was used as a criteria for the separation of some series (see Chapter 11, p.168) but on the map only two are indicated, namely the *Padawan series* (Pw) which has a lighter colour than is usually the case for the **Merit Family** and which is transitional to the GREY-WHITE PODZOLIC SOILS, and the *Begunan series* (Bg) which has strong red colours and is related to the occurrence of red mudstone. General indications relevant to all soils involved in these mapping units cannot be given, and the reader is referred to Chapter 11 for detailed information.

(v) *Fertility Aspects.* The soils in both mapping units are of moderate fertility. The overall fertility rating may be influenced by physical characteristics such as drainage. The better drained members of the unit give a better crop growth than the imperfectly drained ones. Particularly pepper is very sensitive to this soil property. Rubber, also tends to do better on the better drained soils. Most soils respond well to fertilizers although phosphate fixation is a problem in some series. This factor is discussed in detail in Chapter 14 (p.248). Trace element deficiencies pose other problems, particularly in the cultivation of pepper. Generally, with adequate fertilizers and in places with control of drainage (depending on the crop), the soils can support many crops but because of the difficult terrain perennial crops are best suited to them.

(vi) *Agricultural Potential.* Because of the dominance of mapping units 6 and 7 in the uplands the use of this land is of great economic importance. The main limitation is topography, which apart from the danger of erosion makes farming difficult and expensive. It would be impossible to condemn agriculture in this large area for reasons of topography only because a very large portion of the rural population is already making use of this land and depends on it. Therefore, ways and means have to be found to make optimum use of this land.

Firstly, it is important that the generally moderately steep land should be used for perennial crops mainly. Some more gently sloping land, such as occurring along the Bau-Lundu Road (Andriesse, 1967) and along the Serian-Simanggang Road (Andriesse, 1965a) may probably be used for some annuals. Present choices are rubber and oil palm of which the latter is also restricted by slope limits and transportation difficulties. Pepper could be grown in selected areas, but does not bring a solution for the use of the largest part of the area. Suggestions have been made to introduce the *taunya* system from Burma into these areas (Dutch University Team, 1970). This system is based on shifting cultivation in which use is made of commercial trees during the forest regeneration period.

The Semongok Agricultural Research Station has been located on land of mapping unit 6 to carry out research with crops and management practices on this type of topography. Crops being tested also include coffee and tea and any firm recommendation, with the exception of rubber and pepper, must await results of these investigations.

Mapping unit 8

(i) *Occurrence.* The largest expanse of this unit is found in the Lundu District where it is almost exclusively confined to the Sampadi and Pueh Forest Reserves.

Another large area is formed by the Matang-Bukit Raya Range along the Bau-Lundu District border and within the Kuching Rural District.

A large area of this unit is also found in the Penrissen-Bungoh mountain complex at the border with Indonesia and comprises the upper catchment areas of the Sarawak and Sadong rivers.

The unit is found widespread in the Upper Sadong and Lower Sadong Districts towards the border with Indonesia as is the case in the Simanggang District. Smaller isolated areas of this unit are found throughout the Region.

(ii) *Topography*. The unit is usually found in terrain displaying cuesta features. Because of uplift and easily erodable parent materials, very deeply incised rivers have cut up the landscape into very steep high ranges. This is enhanced by strong folding. A typical example is the Penrissen-Bungoh complex. Where the sandstone is more or less horizontally bedded the landscape is much more subdued. Sequences of scarp and dip slopes are common, as are mesas, hogbacks and other mountain types. The mapping unit is mainly confined to the scarp slopes. Where the unit is formed by low undulating hilly terrain, small differences between these two slope types do not give rise to the formation of different soil types. The unit builds also conspicuous mountain ranges such as the Matang, Bungoh-Penrissen, Klingkang and Marup Ranges.

Steep scarp slopes are indicated on the map by subunit 8b while the more moderately sloping terrain is indicated by subunit 8a. Erosion in the form of landslides is very much in evidence on scarp slopes where well developed pediments are commonly found at the foot. In more undulating terrain mass-movements of soils are less common but gully and sheet erosion are more in evidence, particularly when the soils are exposed.

(iii) *Parent Materials*. These are invariably poorly consolidated coarse-grained sandstones. The sandstones are generally highly quartzitic and poor in weatherable minerals.

(iv) *Soils*. On steeply sloping land such as scarp slopes, the **Kapit Family** (p.162) is very common. This family belongs to the group of SKELETAL SOILS. On moderately steep terrain and gently sloping land **Nyalau Family** soils (p.172) are found. This family belongs to the RED-YELLOW PODZOLIC SOILS. The latter family is characterised by light textures related to the coarseness of the parent materials. Deep and shallow phases both occur, but the latter are more common on steep terrain where they occur in association with SKELETAL SOILS. Although some soils in the **Nyalau Family** are imperfectly drained, the well drained phase is usually dominant. Because of their light texture and porosity they are easily eroded, particularly where within the sandstone thin beds of shale occur which provide a slipping surface. During periods of intensive rainfall the soils become saturated and if the slopes are disturbed by cutting or even the fall of a single tree large landslides may occur. Crests of mountain spurs may have a very thin soil cover or are formed by almost bare rock. Where beds of fine textured sandstone or argillaceous rocks occur mixed with coarse sandstone the **Bekenu Family** is dominant, indicated by the symbol B. Likewise the **Nyalau Family** occurs as small areas within mapping units 6 and 7. This is indicated on the map by the symbol N.

(v) *Fertility Aspects*. The soils are very poor in nutrients. This is to be expected from the siliceous nature of the parent material. The **Nyalau** soils, however, have moderately good physical properties. Given sufficient fertilizers most crop will grow on the **Nyalau Family** soils. Rapid leaching may necessitate the giving of split fertilizer applications. Rubber is an excellent crop for this soil type. This is probably mainly caused by the favourable physical conditions which promotes free development of the rooting system. Indications in Land Development Schemes are that with the same fertilizer applications rubber grows better on the **Nyalau** soils than on the more clayey soils in units 6 and 7. Whether this holds for oil palm can only be assessed by experimentation. For more nutrient demanding crops than rubber, the soils are probably too deficient in nutrients to make fertilization economical. This is much dependent on the economic value of the crop and the locality. It would not be advisable to use these soils for pepper cultivation, unless the market price justifies the expenses.

(vi) *Agricultural Potential*. The overall agricultural potential is low. Large areas are too steep for cultivation and should be left under primary forest. In areas with slopes of less than 15 degrees, the land could be used profitable for tree crops if market prices are high. Terracing is not recommended, even on steep slopes, since this would probably aggravate the erosion problem. Trees should be planted in holes.

Mapping units 9 and 10

These two units are described together because of their close relationship in landscape and in parent materials.

(i) *Occurrence*. The largest single area of these combined units is found in the Sampadi Forest Reserve in the Lundu District. Another area is found in the Bungoh-Penrissen mountain complex. Unit 9 occurs singly in a large area in the Lower Sadong District near the Indonesian border, while unit 10 is found widespread throughout the Region where flat mountain tops are formed by horizontally bedded sandstone.

(ii) *Topography*. The units are found generally on dip slopes of cuestas and on the summits of mesas. With the same type of parent material there is a strong relationship between the degree of slope and the mapping unit present. With slopes of less than 5 degrees, mapping unit 10 is dominant while on land with slopes of more than 5 degrees mapping unit 9 commonly occurs. Mapping unit 10 may however occur on slopes of more than 5 degrees if the parent material is coarse enough to allow sufficient rapid percolation of rainwater. There is generally very little slump along these slopes, but sheet erosion may occur if the soil is bared of vegetation. Gullying occurs at the edges of dip slopes and may extend into these, forming deeply incised valleys. Undulations in the commonly long dip slopes are caused by outcropping sandstone beds which may form small scarps. Unit 9 is also found on colluvial footslopes of mountains built by unit 8 but the areas are too small to show in detail on the map.

(iii) *Parent Materials.* Parent materials are formed by poorly consolidated, coarse grained quartzitic sandstones. In some localities unit 9 is derived from colluvial wash from mountains built also by coarse sandstones.

(iv) *Soils.* Soils in unit 9 belong to the **Saratok Family** (p.175). GREY-WHITE PODZOLIC SOIL GROUP. This family is characterised by a light texture and very pale colours. Soils in unit 10 belong to the**Silantek Family** (p.176) in the group of PODZOLS. This family is also light textured and pale coloured but an illuviated humus accumulation layer is present in the B horizon. Both soils of unit 9 and unit 10 are strongly related and the difference is probably caused by more intense leaching in the PODZOLS than in the GREY-WHITE PODZOLIC SOILS. Both soils are derived from the same parent material but the difference in slope is probably sufficient to bring about this change. The PODZOLS are considered to be the most mature soils found in the Region. They occur on very stable slopes where little rejuvenation and truncation take place. The leaching process enhanced by the porosity of the soils has, therefore, reached a climax in which all bases have been washed out and only humus is transported downwards. On steeper land SKELETAL SOILS are found. These belong to the **Kapit Family** (p. 162). The total area of this steep land is small. In the Bako Peninsula very shallow soils of unit 10 are found. Probably most of this land was stripped of its soil cover since the Mid-Pleistocene. Wave-cut platforms are to be found at several levels. For this reason, soils occur identical to those generally found on steep slopes.

(v) *Fertility Aspects.* The soils in both units are poor in nutrients, those in unit 10 being the poorest. Due to prolonged leaching most of the nutrients originally present have been removed and what has remained is stored in the vegetation and the humus. The latter is also of very poor composition. The fertility of the soils in unit 9 is almost similar to that of the **Nyalau** soils of unit 8, the difference being mainly in iron content. The soils of units 9 and 10 lack structure and when exposed become quickly degraded.

(vi) *Agricultural Potential.* Both units offer very little prospect for agriculture. Where they occur near large markets, small areas may be made use of for the cultivation of vegetables. This would entail the application of most nutrients needed and since the soils are almost pure sand, the cultivation would be a form of hydroponics. In such localities, the planting of fruit trees in combination with the rearing of pigs may also be an economic proposition. Generally, the land occurs in remote areas and although the topography may be suitable for farming the soils are too poor to grow crops economically. The better soils of the **Saratok Family** (unit 9) can be used for rubber where no other land is available. Most of the land is at present still under primary forest, an indication that it did not offer much prospect for the shifting cultivator either. They could best be left under this type of land use, or if possible be used for tree plantations with commercial species.

Mapping unit 11

(i) *Occurrence.* The mapping units occur as two major areas, one in the Lundu District and the other in the Upper Sadong District, and as small scattered areas in these two Districts.

(ii) *Topography.* The unit generally builds dissected hilly terrain of low elevation, mainly below the 250 feet level. In the Lundu area the topography is subdued and only moderately dissected with large tracts of smooth relief. The unit commonly forms edges of terraces where overlying old alluvium was removed by erosion. In the Upper Sadong District, north and south of the Serian-Balai Ringin Road, the topography shows strong relief in the south but becomes gently undulating towards the north.

The steepest parts have slopes within the 20-25 degrees range but slopes of 10-15 degrees are more common, particularly in the areas with more smooth topography. Generally, the unit has more rounded hills than found in units 6 and 7 with which it is closely associated. It is not clear whether this is caused by softer parent materials or is due to the occurrence of the mapping units in locations with another morphological history (below the 150 feet). Slipping and sliding of soil-rock material along slopes is not very serious.

(iii) *Parent Materials.* In the Lundu area they are formed by phyllites and cherts, while in the Upper Sadong District they comprise carbonaceous shales locally of schistose nature. They all have in common a very low iron content. The presence of many small pyrites, particularly in the carbonaceous shales, may indicate that the material was originally deposited in deltaic conditions, to which also the high carbon content must be attributed.

The cherts in the Lundu area are of a pinkish and bluish colouration which persists in the soils making identification easy. Greywacke sandstone occurring mixed with cherts and phyllites in the Lundu area gives rise to soils with an olive green colour.

(iv) *Soils.* The soils belong to the GREY-WHITE PODZOLIC SOILS which is separated from the RED-YELLOW PODZOLIC SOILS on account of the pale colours. In the mapping unit they belong to one family, the **Kerait Family** (p.174) which is separated into two series, the *Rukam series* (Rk) found in the Lundu area and the *Kerait series* (Kt) occurring in the Upper Sadong District. A series of minor importance, the *Serayan series*, on pink chert, is also found in the Lundu area but is not indicated on the map. The soils have in common medium textured topsoils overlying massive, blocky clay subsoils. In the series on chert, silica nodules may be present in the subsoils. The soils are all pale coloured, the *Rukam series* having a faint bluish hue, while the *Serayan series* is slightly pinkish. The *Kerait series* is grey-white to white. In the Lundu area beds of greywacke sandstone give rise to a subordinate occurrence of more sandy soils of the **Bekenu Family** (p.171), which on account of a typical olive-green colour are mapped as *Biawak series*. They are, however, not shown on the map as such.

(v) *Fertility Aspects.* The very pale colouration gives the impression that the soils are inferior to the more strongly coloured ones classified as RED-YELLOW PODZOLIC SOILS. There is, however, no analytical evidence to support this. Analyses show differences only in the iron content. Chemically, therefore, the soils can be compared with the **Merit** and **Bekenu Families** which are regarded as chemically of moderate low fertility, meaning that fertilizers are needed for most crops.

The soils are physically somewhat inferior to the RED-YELLOW PODZOLIC SOILS and are commonly imperfectly drained. This may be due to the gentle topography. Because of the lack of iron, gley features are only weakly expressed. In the Serian area the *Kerait series* is used for pepper with moderately good success, but heavy fertilization is needed. The *Rukam* and *Serayan* series are probably inferior to the *Kerait series* but have not been sufficiently studied to substantiate this. All soils can be used for rubber cultivation.

(vi) *Agricultural Potential.* This must be rated as moderate to low. The topography is generally suitable for agriculture but the chemical fertility and structure of soils are limitations, particularly where demanding crops are concerned. In the Lundu area, where good soils are rare, use can be made of the unit for rubber cultivation. Nothing is known of the behaviour of oil palm on these soils but it is thought that the dense massive subsoil is not a very good rooting medium. Although oil palm has a great adapting capacity, the soils are not the most obvious ones to select if better soils are available, but it is probably right to say that particularly in the Lundu area where there is need for agricultural expansion on this type of soil, experimental work with some crops may be justified.

Mapping units 12 and 13

(i) *Occurrence.* The units are found on steep mountain ranges throughout the Region. Mapping unit 13 which is the largest in area of the two units occurs exclusively in the middle part of the Region, namely the Bau District and in border areas of the Kuching Rural and Upper Sadong Districts.

(ii) *Topography.* Unit 12 is found on very steep mountain tops or crests where erosion has laid bare the underlying rock formations. Unit 13 forms very steep haystack shaped hills and mountains in which karst features commonly occur.

Erosion is here caused by solution of limestone along cracks through which large boulders are separated from the rock mass causing colluviation with accumulation of angular limestone blocks at the footslopes.

Streams are usually absent in both units; in unit 13 subterranean streams have formed an intricate pattern of caves with outlets at various levels which may indicate former erosion base levels.

(iii) *Parent Materials.* Unit 12 is formed mainly by igneous rocks, particularly granite. Sandstones form the parent material in some localities such as the Penrissen-Bungoh Range and the Klingkang Range. The parent material of unit 13 is exclusively formed by limestone in which locally intrusive veins of acid to intermediate igneous rocks are found.

(iv) *Soils.* Unit 12 comprises weakly developed SKELETAL SOILS. They belong to the **Meluan Family** (p.162). This family is associated with bouldery and rocky land. The unit is dominated by bare rock with a very thin veneer of soil and rock rubble. Unit 13 commonly has no soil cover; in places some soil material has collected in hollows and cracks. This material is mainly derived from igneous intrusions or from alien rocks and old alluvium which still overlies the limestone.

The latter soils are classified as BROWN-FOREST SOILS, **Kabuloh Family.** The soils are of no importance for agriculture in this Region and further details are therefore omitted.

(v) *Agricultural Potential*. Both mapping units has no agricultural potential. The terrain is too steep and the soil cover if present too thin to be of any agricultural significance. Both units should be left under primary forest.

Mapping unit 14

(i) *Occurrence*. This mapping unit is of a very heterogeneous nature and occurs in three localities. The first locality is found west and south of Kuching Town between the deltaic deposits and peat swamps in the east and the uplands in the west. The second locality is found in the eastern part of the Upper Sadong District where it trangresses into the Lower Sadong District. These two areas comprise mainly subunit b. A third area is found in the Simanggang District along and north of the Serian-Simanggang Road from approximately 85th mile to 105th mile. The latter area is formed by subunit a. Areas of minor importance, mainly belonging to subunit b. occur throughout the Region and are confined to areas where uplands merge into peat swamps.

(ii) *Topography*. The landscape is characterised by very low rounded hills which merge into interspersed valleys. The amplitude of relief is very small and commonly not over 20 feet. A distinction between valleys and hill land is very difficult to make on air photographs if high vegetation is present. Incision has come to a halt in these areas and sediments are actively accumulating. The valleys are frequently flooding during times of high rainfall. The slopes of the hilly terrain are gentle and for the majority less than 10 degrees. Little erosion is taking place. Most of the uplands in this unit is degraded by overfarming in the past. Probably the excellent topography made the land very suitable to hill padi farming but too intensive use has destroyed much of its original value.

(iii) *Parent Materials*. These are varied. In subunit a. the hilly land is commonly underlain by argillaceous rock types, mainly mudstones and shales. The hills in subunit b. are formed by more arenaceous rocks such as feldspathic grit, cherts and sandstones with thin beds of phyllites. The valleys are filled by organic deposits of variable depths or by mineral deposits, the latter of varying composition. In subunit a. they are generally more clayey than in subunit b. The organic deposits vary in depth. Old alluvial deposits may be found overlying low hills or may occur at lower footslopes where hilly land merges into recent valleys.

(iv) *Soils*. In subunit a. the upland soils belong to the GREY-WHITE PODZOLIC and RED-YELLOW PODZOLIC SOILS in which respectively the **Kerait Family** (p.174) and the **Merit Family** (p.168) are represented. Some **Bekenu Family** (p.171) soils may occur in places. The classification of soils in these areas causes some difficulty because the pale colouration of soils may be relic gley features caused by high groundwater tables in the past. Therefore, GREY-WHITE PODZOLIC SOILS are found in some localities, notably in the Simanggang District and the subsoils may be fossil gleyed horizons.

To clarify this, further studies are needed. In subunit b. soils of the same groups are found but since the textures are generally lighter they belong respectively to the **Saratok Family** (p.175) and **Nyalau Family** (p.172). For the **Saratok** soils, the gley horizons may be fossil features. In the terrace deposits commonly the **Triboh Family** (p.175) has formed. This family belongs to the group of GREY-WHITE PODZOLIC SOILS, but PODZOLS of the lowland type also occur. In the valleys strongly gleyed sediments are found. They belong to the group of GLEY SOILS in which the **Bijat Family** (p.181) is represented in subunit a. while soils of lighter texture, the **Tatau Family** (p.179) is commonly found in subunit b. Small areas of dry RECENT ALLUVIAL SOILS may occupy levee positions along small streams. Drowned valleys are commonly occupied by PEAT SOILS of varying depth.

This mapping unit requires semi-detailed surveying at a large scale for a proper delineation of soil types. Because of the heterogenity of the soils, the fertility aspects cannot be discussed. Indications can be obtained from the descriptions of the soil classification units in Chapter 11.

(v) *Agricultural Potential*. The topography of this mapping unit offers prospects for permanent agricultural use. The slopes are gentle and the erosion hazard is not great. Many of the small valleys offer opportunities for the cultivation of wet padi, but the flooding hazard is a limitation. Because of the heterogenity of soil the areas should be studied in detail to delineate the more suitable ones. A disadvantage is that large tracts of uplands have suffered from overfarming in the past and the soils are degraded. The area in the Simanggang District probably has the greatest potential for intensive farming but a solution to the problem of reusing degraded soils should first be found. Experimentation with crops and fertilizers should assess the economic prospects of the various soil types. The flooding in the valleys should be controlled for the cultivation of wet padi. The latter is however of not great significance as only minor areas will appear to be suitable for that crop. Oil palm, particularly in the Simanggang area, could offer some prospects (Andriesse, 1965a).

(b) Floodplain Soils

Mapping unit 15

(i) *Occurrence*. This unit occurs as long stretched areas in the narrow upper and middle reaches of riverine valleys. Although most of this mapping unit occurs in the Lundu-Bau and Kuching Rural Districts, it should be noted that the mapping unit forms also part of mapping unit 19. The latter is a heterogeneous unit in which unit 15 could not be shown separately because of lack of detailed information or cartographic limitations. For this reason, the description of mapping unit 15 includes also part of unit 19 (p.216).

(ii) *Topography*. The unit forms generally flat terrain, commonly above normal flood level of the river. Microrelief may be hummocky, particularly where it borders the river course. Small river banks may be present. The rivers usually have steep embankments and meander in their own deposits. Flooding is in most localities an annual occurrence, but it is usually of short duration, 2 to 3 days. However, several floods may occur in one wet season, but flooding may be totally absent for a number of years.

Erosion is confined to the river banks where flush floods may cause lateral erosion of river banks through slumping.

(iii) *Parent Materials*. The parent materials comprise recent riverine deposits of varying texture and origin. Generally, the alluvium from basic igneous to intermediate igneous rocks, shales and mudstones, is heavy textured while that from acid igneous rocks and sandstones is light textured. The heavy textured alluvials are in the clay loam or clay range, those of light texture are commonly sandy loams to sandy clay loams. Sands occur only in some localities where the source rock is composed of coarse textured sandstone or granite. Although the parent materials are of recent origin they may contain large amounts of material derived from strongly weathered and eroded soils in the uplands.

(iv) *Soils*. Characteristics of the soils vary in texture, drainage and parent material. They are all grouped as RECENT ALLUVIAL SOILS of which the heavy textured members—subunit a. are mapped as **Seduau Family** (p.191) while the light textured members—subunit b. are mapped as the **Kayan Family** (p.190). Both families can be subdivided into series on account of colour, drainage, and source material but on the map only one series is shown separately, namely the *Sebat series* (St), which occurs extensively in the Lundu District and is derived from adamellite. All series are described in Chapter 11, section 9 (p.188). The symbol Mx has been used to indicate those areas where heavy and light textured soils occur together and where a separation into subunits a. and b. was impossible because of cartographic limitations.

(v) *Fertility Aspects*. Because of the heterogenity of the soil parent materials and texture, the fertility of the soils varies widely. Those whose parent materials include limestone and basic igneous rocks are among the most fertile soils in the Region. Those derived solely from quartzitic sandstones are among the poorest. This difference is brought out by the series to which the particular soil belongs.

Generally, the **Seduau Family** soils are of higher fertility than the **Kayan Family** soils. The former are capable of supporting a wide variety of crops, annuals as well as perennials. Fertilization for sustained high yields is necessary for both types of crops.

(vi) *Agricultural Potential*. The unit is of great potential value, particularly subunit 15a. Although the total area is not great, the local importance is emphasized by the fact that over large tracts of land it contains the only soils which can support intensive agriculture. Existing permanent agriculture is usually found concentrated in this unit. Unfortunately, much of the unit is occupied by old rubber gardens which at present is not the most economic way to make use of these valuable soils. Fruit trees, coffee, high yielding rubber and annuals would probably give a better income per surface unit, and land use for these crops should be encouraged. The only limitation in subunit 15a. is posed by the flooding risk, which may be severe in some localities. The main limitation for subunit 15b. is the sandy nature of the soils. Imperfectly drainage conditions may be present throughout the unit, but this is not difficult to remedy. The areas are generally too small to be of value for development schemes and the like. Development of this unit should be realised through intensive extension work.

Mapping unit 16

(i) *Occurrence*. The unit occurs concentrated in the lower floodplains of main river basins as a continuous belt on either side of a river stretching from the middle reaches to the coast. Of minor importance are floodplains of small rivers which could not be separately shown on the map and which form part of mapping unit 32 (p.224).

(ii) *Topography.* The unit is characterised by flat terrain, commonly waterlogged or with a high watertable. The land usually slopes away from the river where an incipient levee is commonly present, and merges into basin peat swamps. River embankments are usually concave. Tidal influence, particularly during the wet season when flooding may occur, causes lateral erosion of levees. Prolonged wet conditions may occur but high floods are rare.

(iii) *Parent Materials.* Parent materials of the unit are formed by clay to silty clay deposits from heterogeneous sources but mainly from shale. Deposits along the Samarahan and Sadong rivers are partly derived from basic to intermediate igneous rocks. In other river basins this is of minor importance and only of local significance.

Light textured parent materials are rare and are commonly found only in close proximity of sandstones and granites. Near the coast marine sand deposits form some incipient ridges which have high watertables.

(iv) *Soils.* The dominant soil types in this unit belong to the GLEY SOILS which are characterised by reduced conditions below a depth of 20 inches. The heavy textured soils, mapped as subunit 16a, belong to the **Bijat Family** (p.181). The light textured soils of subunit 16b. belong to the **Tatau Family** (p.179). Series within these families and occurring in the unit are not shown on the map. This appeared to be impossible because of the generally small areal extent of these series. For details at the series level, reference is made to Chapter 11, section 6 (p.178). One series is shown separately as unit 17. RECENT ALLUVIAL SOILS described under mapping 15 are subordinate in unit 16. Commonly, the **Seduau Family** (p.191) occurs in association with the **Bijat Family** (p.181) while the **Kayan Family** is found together with the **Tatau Family.**

(v) *Fertility Aspects.* The **Bijat Family** is one of the most fertile soils found in the Region and is suitable for wet padi cultivation. If drained, it could be used for a variety of other crops such as coconut, coffee, cocoa and oil palm. Those soils along the Samarahan river and the Sadong river are probably of the best quality. This is related to the nature of the parent material. However, for sustained high yields, fertilization is necessary. The greatest limitation for agriculculture is the poor drainage. The light textured soils in this unit, the **Tatau Family,** are not well supplied with nutrients and must be rated as poor soils. If they are overlain by a thin layer of muck, wet rice can be grown, but heavy fertilization is necessary. Drainage would increase the crop range but the **Tatau Family** soils would be more expensive to use than the **Bijat Family** soils.

(vi) *Agricultural Potential.* Only the heavy textured soils, the **Bijat Family**, are of interest for agricultural development. They are potentially suitable for intensive cultivation but efforts are required to improve the drainage and to reduce the flood hazard. Large areas are still used in rotation for wet rice cultivation without fertilizers. Intensification is recommened. This family, although of considerable total extent, is difficult to develop since the soils commonly occur as narrow belts along rivers where measures to control flooding and drainage are expensive and difficult. However, as an alternative, much could be done by a proper location of crops e.g. coconut on the higher ground near the river, while wet rice could be planted on the lower ground which is not so well drained. Schemes should preferably encompass a whole floodplain or an important part of it, because any measure aimed to limit the flooding risk will affect the drainage either in upstream areas or downstream. Straightening of river courses by indiscriminate cutting of meanders can adversely affect the drainage conditions downstream. Small inland valleys should if possible be treated as one drainage parcel; piecemeal development would make it difficult to improve the conditions in the whole valley at a later stage.

Mapping unit 17

(i) *Occurrence.* The unit occurs in association with mapping unit 13 (p.211) and is only found in valleys surrounding limestone outcrops. For this reason, it is only found in the Bau, Kuching Rural and Upper Sadong Districts.

(ii) *Topography.* The unit occupies valley bottoms underlain by limestone. Small limestone outcrops commonly occur. Low lying places are commonly waterlogged or have a high watertable. On somewhat higher ground a low watertable is found and terrace remnants may occur intermixed with Recent Alluvials. On air photographs the unit looks flat but in reality it is microhummocky.

(iii) *Parent Materials.* This is mainly recent alluvium derived from shales but it may contain small pieces of limestone. Terrace remnants are formed by old light textured alluvium commonly derived from sandstone. Old alluvium may occur at levels where commonly recent deposits are found. This is caused by a gradual lowering of the land surface by solution of the underlying limestone and results in preservation of old alluvium at local base level or even below that. In the latter case, recent alluvium overlies the old alluvium. Where possible such areas have been mapped separately as unit 18 (p.215).

(iv) *Soils*. These are very varied but the majority of the soils belong to the GLEY SOILS, **Bijat Family**, *Paya Megok series* (p.182). RECENT ALLUVIAL SOILS in the unit mainly belong to the *Paku series* (p.192). *Paya Megok series* is separated from other series in the **Bijat Family** on account of its occurrence on limestone; it is usually better supplied with calcium than other soils in the **Bijat Family,** but otherwise the characteristics are much the same as those of the other soils in the family. *Paku series* is characterised by a high content of rounded oolitic iron concretions, and as the formation of these concretions is not yet well understood (they may form *in situ* or are derived from other sources), no attempt has been made to place the series into a family. Such oolitic iron concretions are also found in some localities in the *Paya Megok series*, notably in the Bau area but no separate series has been created for such occurrences. Soil developed on old alluvium of low lying sites with a high calcium content indicating influence from limestone outcropping nearby are classified as the *Mundai series* in the **Tatau Family** (p.179). Also here oolitic iron concretions are found in places and because the concretions generally occur concentrated in layers, an alluvial origin is suggested in these soils.

(v) *Fertility Aspects*. The *Paya Megok series* is generally well supplied with nutrients, that is, for Sarawak standards. Calcium in particular is high. Apart from the drainage, which is poor, the soils are well suitable for agriculture. With drainage improvement they could support a wide range of crops. Experiments with this series in the former Paya Megok Padi Station have shown that a variety of off-season crops can be grown with success, particularly if rotated. The *Paku series* is also capable to support many crops of which pepper may be mentioned as the most important one. Drainage may be too imperfect for this crop in places, but this can be remedied. Citrus is another crop doing well on these soils. The *Mundai series* is poor in nutrients, except for calcium. However, the sandy texture and the proximity to markets make soils of the *Mundai series* particularly favourable for vegetable growing provided the soils are well fertilized.

(vi) *Agricultural Potential*. This unit comprises some of the most valuable land in the Region and every effort should be made to make optimum use of it. The unit as a whole is suitable for intensive farming. In the Bau area, a large part is still reserved for mining, leaving little land available for farming. This situation needs to be reviewed, when the need for land becomes pressing. Because of their location and the favourable topography, the areas are particularly suited for cattle farming in rotation with vegetables, food crops and cattle fodder. Some areas, particularly Paya Megok, have a high flooding hazard and this should be taken into account in planning the use of these soils. To obtain maximum use of these areas annual crops are recommended during the dry seasons. Some areas may be used for wet padi under a small irrigation scheme but sources of water may be difficult to find.

Mapping unit 18

(i) *Occurrence*. The total area of this unit is small and of very little importance for the Region. It is found in the Lundu District as some valley bottoms and in the Kuching Rural District as small areas near the coast where it generally backs recent deltaic deposits, or it occupies limestone flats. In the Upper Sadong District, it covers an old floodplain near Muara Mongkos.

(ii) *Topography*. This is varied, and is formed by flat valley bottoms often including footslopes of surrounding hills. Near the coast the areas resemble slightly raised terraces. The relief is generally very subdued, being gently undulating to flat.

(iii) *Parent Materials*. These are mainly old alluvial deposits of heavy texture for subunit a. and of light texture for subunit b. They are highly quartzitic. Near the coast they are very silty while in the interior sandy materials prevail. The deposits in the area near Muara Mongkos in the Upper Sadong District are probably the oldest in age, their level being more or less at 200 feet. Although being old alluvial deposits, they generally do not occupy terrace positions but are still found at local base level, probably because dissection has not yet reached these comparatively remote areas.

(iv) *Soils*. Most soils belong to the group of GLEY SOILS which is characterised by a high watertable. The heavy texured soils belong to the **Semadoh Family,** *Embang series* (p.181), while the light textured ones belong to the **Tatau Family**, *Gong series*. Both *Embang* and *Gong series* are separated within their respective families because of their old alluvial nature. They have very pale colours which is probably due to the age of the soils and may be caused by strong leaching if not gleying. The absence of iron makes it difficult to decide which of the two factors has caused the light colour. Iron pans do, however, occur in *Gong series* soils at Muara Mongkos so that in that locality leaching cannot be ruled out. The old alluvial derivation is again difficult to prove if the soils occur at local base level which is the case in areas where they rest on subsiding limestone or where they occur in old not yet dissected floodplains.

Some of the soils, notably in the Lundu District, have derived from old terrace alluvium which accumulated in valley bottoms through colluviation.

(v) *Fertility Aspects.* The soils are all highly leached and are of a quartzitic nature. The chemical fertility therefore is extremely low. Physically they are also of poor quality. The heavy textured soils are massive and poorly drained, the light textured ones are poorly drained also. They do not offer much prospect for agriculture unless occurring near large markets. In that case, they can be used for market gardening and pig rearing. If drained, the light textured soils can be used for citrus if heavily fertilized.

(vi) *Agricultural Potential.* This is very low. Agricultural development should not be considered unless the locality justifies the expenses required for improvement.

Mapping unit 19

This mapping unit occurs widespread in the middle and upper riverine valleys of most Districts. It is a very heterogeneous unit comprising RECENT ALLUVIAL SOILS found in units 15 and 16 (p.213) and residual soils found in mapping units 6 and 7 (p.207) mainly. This interior valley association is complex in topography and consequently in soils. The landscape is formed by generally small levees, with local floodplains or valley bottoms also of small extent, together with low gently undulating hills mantled by residual soils. The scale of mapping did not allow a separation of all the soil classification units found in this mapping unit. Semi-detailed or detailed surveys are needed to adequately delineate the great variety of soils which occurs. For this reason, no adequate description can be given for the mapping unit as a whole and reference must be made to the descriptions of the mapping units making up this association.

The mapping unit is agriculturally of great importance. Much of the existing permanent agriculture in the interior areas is found concentrated in this unit. Probably its locality along rivers has influenced this land use, but the fertility of the soils, particularly the recent alluvial ones, and the gentle topography must have played a role as well.

Subunit b. is least fertile since the soils are of a light textured character and terrace alluvium forms part of the subunit. Subunit a. which is characterised by generally heavy textured soils has the greatest agricultural potential, not only because this unit is topographically suitable for intensive farming but also because it contains the relatively most fertile soils.

(c) **Terrace and Fan Soils**

Mapping unit 20

(i) *Occurrence.* This unit occurs throughout the area but the largest acreage is found in the Lundu District followed by the Kuching Rural District. In these Districts the unit is commonly found near the coast. Minor areas occur in other Districts but more in the interior. The mapping unit is similar to the Lundu physiographic unit described in Chapter 4, section 3(f) (p.64). The unit also occurs as small areas within other mapping units which are indicated by the letter symbol P.

(ii) *Topography.* The unit is found on flat very gently sloping preserved terrace summits or on terrace remnants. The external drainage is poor and is partly caused by the micro-hummocky surface of the terraces which induces ponding in shallow depressions. The internal drainage is also very poor because of the presence of hard pans which induces the formation of a perched watertable during periods of high rainfall. The areas are not liable to flooding but waterlogging as a result of poor internal drainage commonly occurs.

(iii) *Parent Materials.* The parent materials are formed by light textured old alluvium. This alluvium is stratified and the various layers may be formed by deposits with strong textural contrast. Gravel and clay may alternate with sandy loam and sandy deposits, the latter two being dominant. The deposits are all highly quartzitic and have derived mainly from Tertiary sandstones and conglomerates. In the Lundu District, the deposits originate largely from the adamellite of Bukits Pueh and Gading.

(iv) *Soils.* The soils belong dominantly to the PODZOL group of which two families, the **Miri Family** and the **Buso Family** (p.177) commonly occur in complex. Both families are characterised by a humus accumulation horizon in the subsoil but in the **Miri Family** this forms a hardpan while in the **Buso Family** the horizon is soft and penetrable by auger. All soils are highly permeable to water but the hardpan of the **Miri Family** does not allow penetrations to greater depth and gives rise to the formation of a perched watertable. The surface textures in both soils are very sandy, but commonly at the depth of the humus accumulation horizon or just below it a distinct textural change occurs, and sandy clay loam to heavy clay may form the subsoil. A pebble or bouldery layer in which the humus accumulation horizon has formed is commonly found at the footslopes of the Matang mountain massif in the Kuching Rural District.

The **Triboh Family** (p.176) in the GREY-WHITE PODZOLIC SOILS is subordinate in the unit. It is strongly related to the **Buso Family** but has no humus accumulation horizon in the subsoil. This difference may be caused either by age or by topography, the **Triboh Family** being younger in development and occurring on more steeply sloping terrain so that lateral drainage and leaching dominates over vertical drainage and leaching.

(v) *Fertility Aspects.* All soils in this unit are characterised by light surface textures in which sand to sandy loam dominates. The sands are highly quartzitic. A low base exchange capacity coupled with a very low nutrient content makes these soils extremely poor chemically. The physical properties of the **Miri Family** are very poor, because of the hardpan; those of the **Buso Family** are somewhat better since the internal drainage is not hampered by the existence of a hardpan. Of all the soils in unit 20, the **Triboh Family** soils are rated as physically the best. The **Miri Family** must be rated as having a very low suitability for agriculture, the **Buso Family** is somewhat better but must still be rated as a poor soil while the **Triboh Family** although again of better quality than the **Buso Family** must still be regarded as of low quality even for Sarawak conditions.

The fertility level of the **Buso** and **Triboh Families** can be raised by heavy fertilizer applications. Since their physical properties are somewhat better than those of the **Miri Family** they can be used for some form of agriculture. The latter soils are of very little use since even with fertilizer applications the unfavourable physical conditions will make farming a very poor proposition.

(iv) *Agricultural Potential.* The **Miri Family** soils have a very low development potential and can best be left untouched, particularly if they occur in remote areas. The same can be said of the **Buso Family** soils, although the latter offer some prospects if sufficient fertilizers are applied. Where they occur near markets, the **Buso** soils can be used for citrus and vegetable gardening in combination with pig or cattle rearing. With sufficient fertilizers, the **Buso Family** and **Triboh Family** soils can also be used for rough grazing. This potential is, however, only present if the location justifies the high expenses for amelioration. This may be the case near Kuching Town where some of these soils are presently used for such agricultural enterprises.

Mapping unit 21

(i) *Occurrence.* This unit, although present in all districts, is only of importance in the Kuching Rural and Upper Sadong Districts. In the latter, they occupy some large continuous areas while in the other districts occurrences are scattered and of small areal extent. A considerable area in the Upper Sadong District occurs in complex with peat soils.

(ii) *Topography.* The unit occurs on summits and slopes of old terraces and on gently sloping colluvial foot hills or pediments of mountain massifs built mainly by sandstones or granite. Some very small colluvial footslopes may occur in minor valleys where the country-rock is dominantly sandstone. The unit is characterised by slopes generally less than 10 degrees. Dissection has not progressed very much yet and is mainly confined to the edges of terraces. Flooding does not occur, the exception being areas occuring in the Upper Sadong District where they are low lying and form a complex with peat soils.

(iii) *Parent Materials.* The parent materials mainly comprise old, light textured terrace deposits and light textured colluvium on colluvial footslopes. The materials are highly quartzitic and have mainly derived from quartzitic sandstones of Tertiary age or from granite. If occuring on terraces the material may be stratified with interlayering of coarse and heavy textured deposits. The former are, however, dominant.

(iv) *Soils.* These belong mainly to the GREY-WHITE PODZOLIC SOILS which are represented in this unit by the **Triboh Family** (p.176). The **Miri** and **Buso Families** (p.177), dominantly occurring in mapping unit 20, are found in this unit as subordinate members. The **Triboh Family** soils have light textured topsoils and medium to heavy textured subsoils. This distinct textural contrast may either be a result of soil forming processes or be caused by the bisequent nature of the old alluvial deposits.

(v) *Fertility Aspects.* The **Triboh Family** soils are chemically poor to very poor. The nutrient content is very low. Because of the sandy nature of these soils fertilizer responses are good since interactions between nutrients and soils will not occur. Particularly phosphate fixation is low for Sarawak standards.

(vi) *Agricultural Potential.* The development potential is not very great but depending on location the unit offers prospects for citrus cultivation, pineapple, market-gardening and cattle rearing with rought grazing. The fertilizer requirements are high and for this reason the introduction of cattle for incorporating much needed organic manures into the soils would be advisable. Since the areas of this unit are generally small and other soil types usually occur mixed with this unit, it will be difficult to develop these areas with the use of organised farming methods. Where better soils are available the unit will be the last one to select for agriculture. However, with strict adherence to the advice given above. the unit may have some potential where sited close to population centres, but the economics of any farming enterprise on this unit should be subjected to thorough studies before it is recommended for development.

Mapping unit 22

(i) *Occurrence.* This unit is of very small extent and occurs almost exclusively around Kuching Town. A small area is found near Sematan in the Lundu District. Other minor occurrences are of no significance for the Region.

(ii) *Topography.* In the Kuching Rural District the unit occupies mainly terrace summits and terrace escarpments. The summits have a smooth topography but are micro-hummocky with incipient dissection. The terrace escarpments are dissected and gullies are common on steep slopes. In some places, notably in the Semobah area the unit is formed probably by old river beds. The terrace topography is absent and the unit is found in valley locations. In the Sematan area, the unit forms old beach ridges which slope gently towards the coast. The watertable in all areas is low. Flooding is not known to occur although in the Kuching Rural District where parts of the unit occupy old valley positions a flooding risk may exist.

(iii) *Parent Materials.* They consist of old terrace and coarse riverine deposits. Pebbles and coarse sand dominate. These materials are mainly composed of quartz and are probably related to conglomerates in the Tertiary deposits found in the interior in the Bungo-Penrissen mountain complex. The old marine ridges are composed of quartz sand derived mainly from the adamellite of Bukits Pueh and Gading.

(iv) *Soils.* The soils on the river terraces and those found in the old river beds are classified as REGOSOLS and belong to the **Gaya Family** (p.163). This family is characterised by an impenetrable layer of boulders or gravels at a depth of less than 10 inches. The depth of this very coarse textured material varies and in some localities the depth is more than 10 inches. In such localities, the soils are classed in the **Triboh Family** (p.176) discussed under mapping unit 21 (p.217). In the Lundu District, the soils formed on the old marine ridges also belong to the REGOSOLS but are classified there as the *Kilong series* (p.163) and are indicated on the map by the symbol Kg. This series is characterised by coarse to medium-grained sand deposits which may have a humus accumulation horizon at a depth greater than 4 feet. These soils belong to the so-called Giant PODZOLS. Since diagnostic horizons occurring below a depth of 4 feet are not considered in the Sarawak Classification the soils cannot be classified as PODZOLS, although genetically they belong to this group. No separate family has yet been defined for these soils. All soils in this unit are highly quartzitic, light textured, and have a high water infiltration rate.

(v) *Fertility Aspects.* The soils are chemically poor. They have little or no base exchange capacity and the nutrient content is extremely low. Moreover, the high infiltration rate and excessive internal drainage make these soils prone to drought conditions in the short dry periods which are particularly common in the Sematan area.

Any form of agriculture would amount to a hydroponic culture which is extremely costly.

(vi) *Agricultural Potential.* The development potential for agriculture is extremely low. This unit can best be used for residential or industrial sites.

Mapping unit 23

(i) *Occurrence.* This unit occurs widespread throughout the Region but is mainly confined to the Lundu, Bau, Kuching Rural and Upper Sadong Districts. Subunit a. is found in the upper valleys of minor rivers draining igneous massifs while subunit b. is generally located at the foot of such massifs or in alluvial fans.

(ii) *Topography.* The topography is varied. Subunit a. is generally found in valley bottoms with a flat to gently undulating topography. A typical example of subunit a. is to be found in the Tarat Agricultural Station. Flooding may locally occur but is generally of short duration. Subunit b. is formed by typical cone-shaped alluvial fan deposits with a more undulating topography merging onto hilly terrain. The slopes are gentle and rarely exceed 10 degrees. Gullying is, however, much in evidence. Flooding does not occur in subunit b. This subunit is further characterised by the existence of many small streams with boulder beds. These rivers frequently change their courses when their outlets are blocked by coarse debris, and the terrain is therefore marked by many fossil stream beds which may in a later stage in development of the alluvial cones again be reused by the same river originally responsible for its formation.

(iii) *Parent Materials.* The parent materials consist of coarse to heavy textured alluvial and colluvial material. The heavy textured materials are mainly derived from basic to intermediate igneous rocks. In subunit a. much of the material comprises eroded soil from areas forming mapping unit 1 (p.201). Subunit b. is formed mainly by light and coarse-textured material derived from granite and associated rock types and sandstone. Much of it is colluvial wash related to areas forming unit 3 (p.202).

(iv) *Soils.* The soils are very varied in texture, colour and chemical composition. Those in subunit a. all belong to the group of RECENT ALLUVIAL SOILS represented by the **Ramun Family** (p.188). This family is mainly derived from basic to intermediate igneous rocks. A further subdivision into series is based on texture. The gravelly clays or clays at shallow depth underlain by gravel are classified as the *Ramun series* (p.189), while the clays, or loams with or without gravel at a depth below 2 feet are classified as *Terbat series* (p.189). The *Ramun series* is commonly found near the debouching point of streams where the sudden change in stream velocity causes the coarse material to be deposited. Further downstream the clayey *Terbat series* is dominant; this soil is strongly related to the **Tarat Family** described under mapping unit 1 (p.201).

The **Ramun Family** soils are weakly developed. It should, however, be noted that a large part of the alluvial deposits comprises eroded material from well developed upland soils. This has greatly affected the chemical composition of the colluvial and alluvial deposits and although being classified as RECENT ALLUVIAL SOILS, the material is generally well weathered, the *Terbat series* more so than the *Ramun series.* Subunit b. comprises light textured soils in which sandy loam mixed with boulders or with boulders at depth is dominant. These soils have been classified as the *Lundu series* (p.163). The series is not yet well defined since it comprises material of varying sources, granite and sandstone, while the amount and depth of bouldery material may vary considerably.

In the *Lundu series,* an incipient A2 horizon may sometimes be found in places, indicating that leaching is present. Detailed mapping would be necessary to delineate the variations within this series.

(v) *Fertility Aspects.* The *Ramun series* soils are chemically fertile by Sarawak standards. Because of the large amounts of relatively unweathered or weakly weathered basic to intermediate igneous rock fragments, they are relatively well supplied with nutrients and they have a high nutrient reserve. The *Terbat series* although of good quality, is less well supplied with nutrients and also the nutrient reserve is much lower because its material is derived from eroded weathered upland soils. The *Ramun* and *Terbat series* have well-developed structures. The main limitation in the *Ramun series* is the gravelly layer which in some places may be impenetrable for roots, while also because of the high infiltration rate drought conditions may occur in dry periods.

The **Ramun Family** is highly suitable for tree crops such as rambutan. bananas, citrus and coffee. The *Terbat series* in this family can also be used for a wide variety of annual crops. They need fertilizers in some degree depending on the crops grown. Phosphate fixation is moderately high but the overall fertility of these soils must be rated as one of the best for Sarawak standards.

Because the *Lundu series* is derived from acid igneous rocks and quartzitic sandstone, it is less fertile than the *Ramun* or *Terbat series.* The *Lundu series* is well drained as the **Ramun Family** but this depends much on locality. In places, the coarse fraction of the soil may attain the nature of boulder beds and this would hinder root development. Also the bouldery subsoils would make the growing of annual crops very difficult since ploughing will be impossible.

(vi) *Agricultural Potential.* The development potential for the **Ramun Family** soils is high. One limitation is the small size of areas but every effort should be made to intensify and diversify agriculture on these soils, particularly in interior areas where the population is presently depending much on shifting cultivation. A large range of crops can be grown on these soils, although those sensitive to flooding or wet conditions for short periods should be omitted. The *Lundu series* has only a very moderate agricultural potential. Only perennial crops can be grown. Coconut has been attempted in the area along the Serikin River but does not prove to be a success. Coffee can be grown if the soils are well fertilized. Rubber is probably the only crop which can be recommended without reservation. The development of this series will depend very much on the local population and the situation at each locality since the soil conditions vary from place to place and the owner needs to be critical in the selection of crops for each particular area.

(d) Coastal Soils

Mapping units 24, 25 and 26

These units are intimately related and occur in sequence. For this reason, they are described together.

(i) *Occurrence.* The units are confined only to the Kuching Rural and Lundu Districts and are exclusively found in the coastal area between the Santubong Peninsula and Tanjong Datu.

(ii) *Topography.* The units build a coastal ridge landscape in which unit 24 forms the most recent beach. It rises to only a few feet above normal high tide level and is commonly separated from unit 25 by a slightly higher, small storm beach where a very low incipient dune has formed. Unit 25 is backing the present beach and consists of a series of low lying ridges separated by swales. The watertable in the latter may be high in the wet period. Small tidal creeks usually originate in these swales. Commonly the ridge furthest away from the coast is the most extensive one and slopes gently away from the coast to a creek commonly forming its boundary with unit 26. The latter unit rises quite steeply from this creek towards the landside to a height of approximately 14 feet above sea level whereafter the surface is more gently sloping. Unit 26 is characterised by a series of small ridges at the extreme landward side probably representing incipient dunes. The watertable in unit 26 is moderately high and can usually be found within a depth of 6 feet.

(iii) *Parent Materials.* The units are respectively built by recent to subrecent, medium- to fine-textured marine sands. Most of the material originates from the adamellite building the Gading and Pueh massifs but between Lundu and the Santubong Peninsula material from Tertiary sandstones and metamorphosed sedimentary rocks of Early Cretaceous age form important admixtures. The amount of weatherable minerals in the deposits is low but in some localities, notably near Santubong. the content of hornblende is moderately high. This may indicate an influence from intermediate igneous rocks at Pulau Salak.

(iv) *Soils.* The soils form a weathering sequence in which the most recent undeveloped deposits on the present beach form unit 24, weakly developed soils on the ridges of intermediate age form unit 25, while well developed iron/humus podzols on the oldest deposits form unit 26. The soils in units 24 and 25 are classified as RECENT ALLUVIAL SOILS but are probably better placed in the group of REGOSOLS, particularly unit 24. This unit is formed by the *Siru series* (p.193) of the **Kabong Family.** The *Siru series* is separated from other series in the **Kabong Family** because of its high content of mica and manganese, which bears relation to specific source materials of the deposits. Shells commonly occur in this series but they tend to concentrate in layers.

Unit 25 is formed by two series both belonging to the **Sematan Family.** The latter is characterised by a distinct reddish-yellow to yellowish-red colouration. The *Sematan series* (p.190) is dominant in this family and has incipient soft iron concretions in the lower horizons. These may be absent in some localities. They are probably caused by an intermittent ground watertable and for this reason, the iron accumulations are more common near swales than on the crest of ridges. The *Rambungan series* (p.190) in the **Sematan Family** is of very small extent and is transitional between the **Kabong Family** and the **Sematan Family;** it is always found between the *Siru series* and the *Sematan series*. Progressive leaching has, however, removed most of the calcium, while iron is liberated from weatherable minerals and coats the quartz grains brown. Manganese may accumulate in the B horizon, but the development of a Bmn depends on the original manganese content of the deposits and is not always present.

Unit 26 is formed by PODZOLS, represented by the **Jerijeh Family** (p.178). This family is characterised by a well developed white A2 horizon overlying a well developed humus-iron accumulation horizon formed on the unaltered reddish coloured material found in the **Sematan Family.** It thus represents a further stage in the leaching and podzolization sequence. Several series make up this family but none have been mapped separately. They are differentiated on account of the depth of the A2 which in this soil type reflects the rate of podzolization. The ultimate stage is reached in the *Kilong series* (p.163), mapped as a REGOSOL and which is described under mapping unit 22 (p.218). In this soil type, which occurs subordinately in mapping unit 26, the A2 reaches to below a depth of 4 feet.

(v) *Fertility Aspects.* The chemical fertility of the soils declines from unit 24 to unit 26. Thus, the *Siru series* is potentially the most fertile one, followed by the *Rambungan series, Sematan series* and *Pueh series*. The latter is extremely poor. The *Sematan* is poor while the *Rambungan* is probably the best agricultural soil in this range since most nutrients are here liberated and in solution. In the *Siru series* a high salinity level prevents the growing of crops. By world standards, however, all soils are quite poor, the only element in sufficient supply is calcium, and this is present only in the *Siru series*. Crops, particularly coconut and water melons do well on the *Rambungan series*. Coconut is also planted on the *Sematan series* but without fertilizers the palm do not grow well. The *Pueh series* only supports a low shrub or lallang vegetation once the original forest cover has been removed.

(vi) *Agricultural Potential.* The area is small but is of local importance since most of the local population on this land depends on agriculture to supplement their income from fishing. The *Rambungan series* can best be planted up with coconut and annual crops such as water-melons. Additional fertilization would improve yields. The *Sematan series* can be used for coconut if properly fertilized. The use of this land for rough grazing under coconut should be investigated. Most of this soil is at present only sparcely used. The use of the *Pueh series* forms a difficult problem. Probably the application of fertilizers will be uneconomic on this soil but little information on this is available. The series is, however, of small extent and only of importance near Kpg. Siru and Kpg. Pueh. Rough grazing and coconut would be the only possibilities since the soils need an initial organic topsoil to prevent loss by leaching of fertilizers applied later on. If the topsoils can be improved probably other crops can be grown as well.

Mapping units 27 and 28

(i) *Occurrence.* These units occur in deltaic and estuarine areas and are found most widespread in the Kuching Rural and Lower Sadong Districts where they occupy the Sarawak River Delta and the Nonok Peninsula.

Smaller areas are formed by the Sematan and Lundu river deltas, and are found at the margins of the Sadong, Lupar estuaries.

(ii) *Topography.* The units are characterised by a flat, low-lying landscape situated a few feet above normal high tide level. Unit 27 is generally somewhat lower than unit 28 (see Santubong unit, Chapter 4, section 3b; p.60). A great many tidal creeks intersect this low lying land, particularly in the delta's. In the estuaries where the units are found as small ribbons on incipient levees along the river channel, tidal creeks drain basin swamps backing the levees. The ground watertable is high and commonly occurs within one foot from the surface; in unit 28 the watertable is somewhat lower depending on artificial drainage. During peak high tides, unit 27 is frequently flooded by brackish water and affects the groundwater to varying degree. The groundwater in unit 28 may be brackish during the less wet season but may be fresh during the wet season. Flooding in unit 28 is less frequent than in unit 27. This depends, however, on locality, thus in the Nonok Peninsula freshwater flooding may occur during the wet season. Most of this water originates from the large basin swamps found to the south of this area. Areas of unit 28, flanking river channels may be flooded with fresh water during the wet season when the rivers are at peak level. Unit 27 has in some localities a micro-hummocky surface, caused by the presence of mud lobster mounds. This is notably so in the Sarawak River Delta. Unit 28 is affected as well but only to a minor extent.

(iii) *Parent Materials.* The parent materials are formed by recent, heavy textured deltaic and estuarine deposits; but in a few minor localities, the deposits are light textured. The heavy textured materials are silty clays which were deposited in a saline to brackish water environment. The deposited materials originate from the interior areas of West Sarawak and were carried down to the sea mainly by the Lundu, Sarawak, Sadong and Lupar rivers. The deposits were enriched by the sea with magnesium and potassium, but calcium is, however, extremely low. Some layers of shell debris may be found within the deposits but these are rare.

(iv) *Soils.* All soils have been grouped under the SALINE-GLEY SOILS. These are characterised by strong gleying caused by a high watertable and saline or brackish conditions in part of the profile during parts of the year.

In the formal Sarawak Classification units 27 and 28 are separated on account of degree of salinity. The soils in unit 27 are moderately to strongly saline throughout the year while the soils in unit 27 may have only brackish conditions during part of the year. Soils of unit 27 dominantly belong to the **Rajang Family** (p.184), while soils of unit 28 for the majority belong to the **Pendam Family** (p.185). The salinity factor is difficult to use in the field as a diagnostic feature, particularly where changes occur throughout the year. For this reason, natural vegetation is normally used to differentiate between the **Rajang** and **Pendam Families.** The **Rajang** soils support a mangrove/nipah vegetation and all areas with this type of vegetation have been mapped as such. Where the natural vegetation has been removed, areas were mapped as **Pendam Family** soils, since the salinity decreases with cultivation and drainage improvement. Nevertheless, it is safe to infer that areas mapped as **Pendam Family** contain soils belonging to the **Rajang Family,** particularly in areas where no artificial drainage was provided. For this reason, the **Rajang Family** is mapped as a subordinate member in unit 28. The light textured and strongly saline members of the SALINE-GLEY SOILS are mapped as subunit 27b. of **Belat Family** (p.184), while the light textured but weakly saline soils are mapped as subunit 28b. of the **Nonok Family** (p.184). Both subunits are of very minor importance.

Since the separation of the **Pendam** and **Rajang Families,** based on degree of salinity, appears to be unsatisfactory, and the **Rajang Family** may change to a **Pendam Family** soil when environmental conditions are modified by man, other criteria are needed to identify the families. For this reason, degree of ripening has replaced the salinity status in the Key. The ripening class indicates the degree of structural development and consistency changes in these soils which accompany the process of desalinization. The ripening class can be assessed in the field. Although a ripe soil may still have saline properties in the subsoil, its ripeness indicates that the soil can be used for agriculture. However, detailed studies are needed to find adequate diagnostic means for a more precise differentiation of the various soils in the SALINE-GLEY GROUP.

(v) *Fertility Aspects.* Both units are for Sarawak standards, well supplied with nutrients; magnesium and potassium are particularly high. However, the low calcium status may cause a nutrient imbalance. The **Pendam Family** may be lower in nutrients than the **Rajang,** but not necessarily so. This is dependent on locality. The phosphate status in both families is generally good and is little affected by leaching. The presence of organic matter in the topsoil improves its fertility. Limitations for agriculture in units 27 and 28 are salinity and poor drainage.

Certain parts of the **Rajang Family** may contain high amounts of pyrites which pose a potential danger to the formation of 'catclay' after the draining is improved and the soils are oxidized. This problem should not be under-rated, particularly when large sums of money are invested in amelioration schemes and should be thoroughly investigated. The problems related to the formation of 'catclays' in the **Rajang Family** soils are discussed in detail in Chapter 13, section 2 (p.228).

(vi) *Agricultural Potential.* Units 27 and 28 have a great development potential for agriculture if the problems related to salinity, drainage, flooding and the formation of catclay can be overcome. The soils in these units are potentially rich but the cost of amelioration is high and may be prohibitive. Particularly the problem of the formation of catclay in the **Rajang Family,** which may cause crop-failures upon drainage in some areas, will need intensive investigations (see Chapter 13, section 2, p.228). Any recommendation for the use of **Rajang Family** soils must therefore await results of experimental work presently conducted in Sarawak. The **Pendam Family** soils, as mapped, generally do not present these difficulties and with improved drainage could be raised to a high level of productivity. As with all drainage improvement work piece-meal development of large areas may result in a chaotic drainage system, such as presently found in the Nonok Peninsula. Therefore, a suitable drainage improvement scheme should be designed for as large an area as possible before controlled settlement is allowed to take place. Uncontrolled settlement and fragmented drainage improvement will in the long run probably result in an uneffective drainage system.

(e) Basin Swamp Soils

Mapping units 29, 30 and 31

(i) *Occurrence.* These three mapping units comprise the largest combined area in the Region. A large proportion of the Lower Sadong and Simanggang Districts is formed by these units. A considerable area is also found in the Kuching Rural District and small areas occur in the Lundu District, but the units are almost absent in the Bau and Engkilili Districts. Soils within these units have also been mapped in unit 32 (p.224) where they occur in complex with other soils.

The units commonly form large basin swamps situated between the lower reaches of major river courses. However, small areas are found in some interior valleys.

(ii) *Topography.* The large basin swamps are dome-shaped. The surface level rises gently from the river towards the centre of the basin. In some localities, there is an initial steep rise, after which the surface slopes up almost imperceptibly but very gradually to the highest point of the dome. This is not always the centre of the basin swamp, in fact some summits are found at very close proximity to a major river course. This may indicate a possible change in the river course after the basin peat was formed but this can also have been caused by other factors. The surface of the peat is undulating with small mounds and local hollows. Within these hollows, water tends to accumulate and such areas are commonly flooded. Local mounds and summits of peat domes are commonly free of surface water although a watertable is present at shallow depth. Inland valleys lack the dome-shaped topography and are generally more waterlogged. External drainage is radial in large peat swamps but is almost absent in the interior valleys (for more details the reader is referred to Chapter 4, section 3d, Nonok unit, p.63).

(iii) *Parent Materials.* The parent material of organic deposits is difficult to define. The organic deposits can be regarded as being parent materials themselves on which soils form after adequate drainage is provided, and the organic deposits are exposed to the influence of the atmospheric climate. Thick organic deposits commonly consist of coarse woody debris, mixed with comminuted plant remains, while shallow peat deposits are usually finer in texture. The content of water in a bulk sample is very high. The organic deposits may either overly light textured or heavy textured mineral deposits. The depth of the organic deposits varies from 10 inches to over 10 feet. Shallow peat deposits up to 40 inches in depth are probably still strongly related to the mineral deposits found underneath and the mineral deposits should be regarded as part of the parent materials. The distinction between a thick O horizon formed on a gleyed soil and that of a true deep peat deposit is difficult to draw.

Most deep peat deposits are chemically poor. Generally the thicker the accumulation, the poorer the chemical composition of the surface peat. This may be related to a decreasing influence of the underlying mineral deposits on the peat, as the mineral deposits are too deep to be reached by the feeding roots of the vegetation.

(iv) *Soils*. All soils in these units are classified as PEAT SOILS. In their natural state they are all non-developed soils. When drained and brought into cultivation the surface horizon changes its characteristics and a crumbly friable organic horizon may form a coarse woody peat. Probably the shallow PEAT SOILS mapped as unit 29 and characterised by peat of 10 to 40 inches thick, can be regarded as weakly developed soils since the peat still bears some relation to the underlying mineral deposits and may be regarded as an O horizon of a mineral soil. For this reason, shallow peat has been differentiated into subnit 29a, **Mukah Family** (p.187), which overlies heavy textured mineral deposits and subunit 29b, **Igan Family** (p.187), which overlies light textured mineral deposits. Unit 29 is commonly found nearest to the river where mineral levee soils gradually merge into peat soils. Peats with a depth of 40 to 80 inches are mapped as **Anderson 1 Family** (p.188), those with a depth of 80 to 120 inches as **Anderson 2 Family** (p188), while peats with a depth of more than 120 inches belong to the **Anderson 3 Family** (p.188). **Anderson 1** is individually mapped as unit 30 because it still has some agricultural value. **Anderson 2 and 3 Families** are mapped in combination to form unit 31 because peats exceeding a depth of 80 inches are usually not recommended for agriculture. A small area in the Lundu District is mapped as the **Limbang Family** (p.188), indicated by the letter symbol L. In this area, saltwater has infiltrated a peat swamp causing a change in the environmental conditions from a freshwater peat swamp to a saltwater peat swamp.

(v) *Fertility Aspects*. The peats are inherently very poor in plant nutrients. The shallow peats in unit 29a. are probably the most fertile of all the peat soils in these units. Commonly there is a flush of liberated nitrogen during the first two years of cultivation, particularly if the surface peat has been burned and drained. After that, the initial fertility declines rapidly and many deficiencies occur. Trace elements, particularly iron and copper, are usually deficient. After drainage, a favourable granular structure may develop in the surface horizon, but if allowed to dry out, the surface becomes very compact due to irreversible drying. Exchangeable nutrients calculated on a oven dry basis usually give high values. Since the bulk density of the peats is very low, these values when extrapolated to the field condition should be reduced by as much as 90%. The fertility of peats, particularly that of the shallow phases, varies greatly with locality. Peats in the Sadong River basin are generally more fertile than elsewhere. This may be caused by the influence of the underlying mineral deposits, since the mineral deposits in that area are also richer in plant nutrients than riverine deposits elsewhere.

The drainage problem is probably the most difficult one to solve. For this reason, deep peat soils are commonly not recommended for agricultural use.

(vi) *Agricultural Potential*. The shallow peat soils of unit 29 can be used for agriculture if properly drained. An allowance of up to 2 feet for shrinkage and subsidence following the first few years of reclamation should be made. After the first few years, the subsidence rate decreases to less than an inch or so per year. To keep pace with the subsidence, drainage channels will have to be deepened periodically. It is estimated that if the drainage is sufficiently maintained, 40 inches of peat may take roughly 30 years to disappear altogether. If drainage is not maintained then the areas would probably become waterlogged again and the subsidence will be halted. Drainage should therefore be carefully controlled and initial deep drainage is not recommended. If properly drained, most suitable crops are probably pineapple, coffee and oil palm. Coconut may be grown in shallow peats if they can root in the mineral subsoil because the peat itself does not provide sufficient anchorage for top heavy tree crops. No doubt many crops, annuals and bush-type perennials can be grown, as shown in the Peat Research Station at Batu Kawa Road, near Kuching. The economics of the use of peat for agriculture should be thoroughly studied before appropriate recommendations can be given. Subunit 29b. is not very suitable for agriculture because of the very poor mineral soils found below the peat. If the peat upon drainage has subsided or disappeared altogether, the sandy subsoil would not form a good medium for plant growth. Wet padi can be grown if the water can be properly controlled but yields are not very good unless fertilizers are applied. Fertilizing peat soils, however, is still in the experimental stages. Unit 30 can also be used for agriculture, but the drainage and ensuing subsidence present even greater problems in this unit than in unit 29. If the peat is allowed to subside too much, than the level may become lower than the major drainage channel, the river, and flooding will occur unless water is removed by pumping. For this reason, deep peat soils, mapped as unit 31, are not recommended for agriculture.

The development of peat soils is a risky venture, and the long term influence of continued drainage is not yet known. A special section on this subject deals with his problem and the reader is referred to this section for further details (Chapter 13, section 2, p.231).

Mapping unit 32

This is a compound unit and comprises soils commonly found in units 16, 29, 30 and 31. The soils within these units range from GLEY SOILS to PEAT SOILS. The composing soil units can not be separated, either, because of the complexity of the soils and the impossibility to show all boundaries on the employed scale or, because insufficient field information is available on the areas to differentiate between the various component units. Most of the areas would need semi-detailed surveying techniques on at least a scale of 1:25,000 to show all soil types present. Part of this unit is made up of GLEY SOILS mainly belonging to the **Bijat Family** (p.181). These are excellent soils for wet padi and when drained a variety of other crops can also be grown (see under mapping unit 16, p.213). The remainder of the unit is mainly peat of varying depth (see under mapping units 29 to 31, p.222).

The agricultural potential of the areas justifies further investigations at a semi-detailed level if such information is not yet avalable. Many small wet padi improvement schemes could be accommodated in this unit.

(f) Disturbed Soils

Mapping unit 33

This unit comprises disturbed soils and includes areas occupied by mining or town land. It has no agricultural significance and is therefore not further discussed.

Letter Symbol T

Finally, the symbol T, inserted in some mapping units in the soil maps indicates the existence of terrace deposits belonging to the **Sabangang** and **Lupar Families** (p.173). These families have not yet been described since they have not been mapped separately and do not form a common part of other mapping units.

These terrace deposits are mainly found in the Sarawak Kiri, Sarawak Kanan and Batang Lupar drainage basins. The **Sabangang Family** is characterised by yellow to reddish-yellow colours, and the texture range is the same as that of the **Nyalau Family** (mapping unit 8, p.208), commonly sandy loam over sandy clay loam. The soils are, however, differentiated from **Nyalau** soils by a distinct layer of rounded gravels occurring at depth which indicates its alluvial nature. The **Sabangang** soils may have partly derived from colluvial material of neighbouring hills. The **Lupar Family** is heavy textured and the soils are compared to **Merit Family** soils (mapping unit 6, p.207), but also contains a layer of rounded gravels at depth which indicates its alluvial origin and for this reason, it is separated from the **Merit Family.**

Agriculturally, the **Sabangang** and **Lupar Families** can be compared with the **Nyalau Family** and the **Merit Family** respectively but they differ in topography. Since the gravel deposits commonly occur at great depth many other localities with **Sabangang** and **Lupar** soils may have been overlooked. Diagnostic features occurring at such depth are in any case not of agricultural significance and can therefore be ignored.

(g) Summary

Table 25 (p.225) summarizes in an easily available form the most important features of all soil mapping units described in this chapter.

This Table shows the total area in square miles of each mapping unit by District (column A). Since the areal extent of a mapping unit does not give any indication to its agricultural potential each mapping unit has been assigned a certain use percentage. This figure represents the maximum percentage of arable land within the unit if properly used, and is based on the survey experience of the author. Column B therefore indicates, although subjectively so, the amount of land actually suitable for agriculture at maximum use level for each mapping unit.

The limitations for agriculture for each unit are furthermore listed in accordance with their degree of severity. The coding used to indicate the severity of the limitations is explained at the bottom of Table 25. Finally, the agricultural development potential of each unit is given in the last column, together with the most important limitations to agriculture.

From Table 25, it is possible to calculate for each district the total amount of land available for agriculture. In Table 26 (p.226), an attempt has been made to use these calculated figures to indicate in what district land is most scarse in relation to the present population. Quite probably in Table 26 the number of farming families for each district is exaggerated because they are calculated over the whole rural population. In fact, a certain percentage of this population is not engaged in agriculture at all. Therefore, the arrived at figures shown in the last column of this Table and indicating the land available for each family at present is on the pessimistic side. However, Table 26 illustrates adequately that it would not take long to reach total saturation of agriculturally engaged population in for instance the Kuching Rural District where the total amount of available suitable land is approaching the 10 acres per family which is considered necessary for an adequate living standard.

TABLE 25 AVAILABILITY OF ARABLE LAND IN SQUARE MILES BY DISTRICT, AND ITS AGRICULTURAL SUITABILITY

A – total areal extent
B – calculated maximum area suitable to agriculture if improved

Soil group	Parent material	Mapping unit	Estimated percentage suitable	Lundu A	Lundu B	Bau A	Bau B	Kuching Rural A	Kuching Rural B	Upper Sadong A	Upper Sadong B	Lower Sadong A	Lower Sadong B	Simanggang A	Simanggang B	Lubok Antu A	Lubok Antu B	Limitations to Agriculture: Topography	Drainage	Surface erosion risk	Flooding risk	Chemical fertility status	Physical status	Agricultural suitability
MOUNTAIN AND HILL SOILS	ON IGNEOUS ROCKS	1a	75%	3.39	2.54	0.57	0.43	15.60	11.70	16.86	12.65	2.30	1.73	3.37	2.53	-	0	3/4	1	2	1	2	1	Very suitable to suitable, depending on slope.
		1b	30%	5.00	1.50	0.17	0.05	33.20	9.96	96.15	28.85	12.04	3.61	1.15	0.35	-	0	5/4	1	3	1	1	1	Marginally to moderately suitable depending on slope. Tree crops recommended
		2a	20%	2.04	0.41	11.70	2.34	-	0	20.00	4.00	-	0	-	0	-	0	3	1	2	1	2	2	Marginally to moderately suitable depending on slope. Tree crops recommended.
		2b	10%	-	0	-	0	6.65	0.67	3.67	0.37	0.42	0.04	3.46	0.35	0.94	0.09	5/4	1	3	1	2	2	Marginally suitable to unsuitable.
		3a	50%	12.15	6.08	2.05	1.03	-	0	-	0	-	0	3.15	1.58	-	0	4/3	1	3	1	3	1	Suitable to moderately suitable depending on slope. Terraces needed for crops with open canopy.
		3b	5%	53.38	2.67	18.40	0.92	-	0	-	0	1.57	0.79	42.52	2.13	3.04	0.15	5/4	1	4	1	2	1	Marginally suitable to unsuitable.
		4a	60%	3.13	1.88	0.39	0.23	23.87	14.32	32.04	19.22	1.36	0.82	0.84	0.54	-	0	3/4	1/2	2	1	3	2	Suitable to moderately suitable depending on slope. Terraces needed for crops with open canopy.
		4b	60%	-	0	-	0	0.52	0.31	-	0	19.90	11.94	16.96	10.18	-	0	5/4	1/2	3	1	3	2	Marginally suitable to unsuitable
		5a	60%	-	0	-	0	-	0	-	0	-	0	5.03	3.02	-	0	3	2/3	3	1	3	3	Moderately suitable, expensive to fertilize. Terraces needed for crops with open canopy.
		5b	0%	-	0	-	0	-	-	-	-	-	-	6.49	0	-	0	5/4	2	4	1	3	2	Unsuitable
	ON SEDIMENTARY ROCKS	6a	60%	26.81	16.09	161.00	96.60	126.09	75.65	141.81	85.09	17.28	10.37	70.77	42.46	14.14	8.48	4/3/2	1/2/3	2	1	2	1/2/3	Suitable to moderately suitable, depending on slope. Terraces needed for crops with open canopy.
		6b	20%	22.3	0.45	-	0	-	0	-	0	-	0	85.57	17.11	15.19	3.04	4	1/2/3	3	1	2	1/2/3	Marginally suitable to unsuitable
		7a	60%	15.45	9.27	7.83	4.70	10.15	6.09	28.28	16.97	-	0	3.36	2.02	-	0	4/3/2	1/2/3	2	1	2/3	1/2	Suitable to moderately suitable, depending on slope. Terraces needed for crops with open canopy.
		7b	20%	-	0	-	0	-	0	8.90	1.78	-	0	-	0	-	0	4	1/2/3	3	1	2/3	1/2	Marginally suitable to unsuitable
		8a	60%	59.08	35.45	8.78	5.27	15.71	9.43	57.60	34.56	14.04	8.42	10.47	6.28	0.73	0.44	4/3	1/2	3	1	3/4	2	Moderately to marginally suitable, depending on slope. Tree crops recommended only.
		8b	0%	24.14	-	20.11	-	55.92	-	11.00	-	3.15	-	27.02	0	15.82	0	5/4	1/2	4	1	3/4	2	Unsuitable
		9a	30%	89.87	26.96	7.61	2.28	29.11	8.73	34.98	10.49	46.50	13.95	54.67	16.40	5.23	1.57	4/3/2	1/2/3	3	1	3/4	2/3	Moderately to marginally suitable depending on slope. Tree crops recommended only.
		9b	0%	1.51	-	2.07	-	8.68	-	3.35	-	-	-	7.12	0	-	0	4/5	1/2	4	1	3/4	2/3	Unsuitable
		10a	10%	67.40	6.74	15.38	1.54	7.64	0.76	0.53	0.05	14.04	1.40	17.18	1.72	-	0	2/3	3/4	2	-	4	3/4	Marginally suitable to unsuitable. Very expensive to fertilize
		10b	0%	-	0	-	-	12.99	-	-		-	-	-	0	-	0	4/3/2	2/3	3	1	4	3/4	Unsuitable
		11	60%	49.81	29.88	-	0	0.85	0.51	18.01	10.81	0.84	0.50	20.53	12.32	-	0	3/4	2/3	3	-	2/3	2/3	Moderately suitable. Terraces needed for crops with open canopy
	ON VARIOUS ROCKS	12	0%	4.02	-	3.47	-	0.85	-	8.27	-	8.69	-	3.98	0	0.52	0	5	1	4	1	-	-	Unsuitable for agriculture.
		13	0%	-	0	9.27	-	21.88	-	0.41	-	2.83	-	-	0	-	0	5	1	4	1	-	-	Unsuitable for agriculture.
MIXED UNIT		14a	70%	-	0	-	0	12.04	8.43	45.24	31.67	-	0	-	0	-	0	3/2/1	1-5	2	3	2/3	2/3/4	Moderately suitable. Needs drainage in places, expensive to fertilize, floodrisk in places
		14b	70%	-	0	-	0	27.75	19.43	3.77	2.64	10.89	7.62	16.97	11.88	-	0	3/2/1	1-5	2	3	3	2/3/4	Marginally suitable. Needs drainage, expensive to fertilize, floodrisk in places
FLOODPLAIN SOILS	RECENT RIVERINE ALLUVIUM	15a	75%	38.64	28.98	7.14	5.34	8.27	6.20	-	0	1.15	0.86	4.92	3.69	-	0	1	1/2/3	1	2	1/2	1/2	Very suitable. Floodrisk in places
		15b	50%	-	0	-	0	2.30	1.15	40.95	20.48	0.42	0.21	0.21	0.11	-	0	1	1/2/3	1	2	3	2/3	Moderately suitable. Expensive to fertilize, floodrisk in places.
		16a	75%	15.93	11.95	3.12	2.34	37.28	27.96	0.21	0.16	23.25	17.44	25.34	19.01	4.40	3.30	1	2-5	1	4	1/2	3	Suitable. Needs drainage, floodrisk
		16b	60%	3.54	2.12	-	0	0.83	0.50	6.29	3.77	0.52	0.31	-	0	-	0	1	2-5	1	4	3/4	3	Moderately suitable. Needs drainage, expensive to fertilize floodrisk
		17	75%	-	0	7.11	5.33	10.05	7.54	-	0	-	0	-	0	-	0	1	4/5	1	3	1/2	3	Very suitable to suitable. Needs drainage in places, floodrisk in places
	OLD ALLUVIUM	18a	50%	0.72	0.36	-	0	5.66	2.83	-	0	-	0	-	0	-	0	1/2	4/5	1	3	3/4	3/4	Marginally to moderately suitable. Needs drainage, expensive to fertilize, floodrisk in places
		18b	50%	1.09	0.55	-	0	-	0	25.04	12.52	-	0	-	0	-	0	1/2	4/5	1	3	3/4	3/4	Marginally suitable. Needs drainage, expensive to fertilize, floodrisk in places
MIXED UNIT		19a	75%	11.13	8.35	26.07	19.55	23.97	17.98	20.43	15.32	0.73	0.55	17.18	12.89	10.89	8.17	1/2/3	1/2/3	2	2	1/2/3	1/2/3	Very suitable to suitable. Floodrisk in places.
		19b	75%	3.78	2.84	8.41	6.31	1.25	0.93	5.97	4.48	4.93	3.70	7.33	5.50	0.52	0.39	1/2/3	1/2/3	2	2	2/3/4	1/2/3	Moderately suitable. Floodrisk in places.
TERRACE AND FAN SOILS	TERRACES	20	10%	67.17	6.72	-	0	21.05	2.11	16.86	1.69	5.66	0.57	8.90	0.89	2.51	0.25	1/2	4/5	1	1	4	4	Marginally suitable to unsuitable, depending on locality. Very expensive to ferlize
		21	50%	3.17	1.59	3.89	1.95	20.42	10.21	-	0	17.39	8.70	7.54	3.77	3.14	1.57	2/1	2/3	1	1	3/4	4	Marginally to moderately suitable depending on locality. Expensive to fertilize.
		22	0%	0.75	-	-	-	4.82	-	13.62	-	0.10	-	-	0	-	0	1/2/3	1	1	2/1	4	3	Unsuitable.
	FANS	23a	80%	-	0	5.48	4.38	7.75	6.20	3.77	3.02	0.21	0.17	-	0	-	0	1/2/3	1	1	2/1	1/2	3	Very suitable
		23b	25%	1.60	0.40	-	0	2.93	0.73	-	0	1.05	0.26	-	0	-	0	1/2	1/2/3	1	1/2	3/4	4	Marginally to moderately suitable depending on locality.
COASTAL SOILS	BEACH DEPOSITS	24	50%	3.39	1.70	-	0	2.51	1.25	-	0	-	0	-	0	-	0	1	1	1	1/2	2	1/2	Suitable. Fertilizer required, drought problem
		25	80%	6.92	5.54	-	0	4.08	3.26	-	0	-	0	-	0	-	0	1	1/2	1	1	3	2/3	Moderately suitable. Expensive to fertilize, drought problem
		26	0%	1.30	-	-	-	-	0	-	0	-	0	-	0	-	0	1	1	1	1	4	4	Marginally suitable. Very expensive to fertilize, drought problem
	DELTAIC DEPOSITS	27a	?	50.77	?	-	0	148.30	?	-	0	4.82	?	1.99	?	-	0	1	2/5	1	4	1	4/3	Under investigation needs drainage. Catclay and salinity problems. Floodrisk
		27b	20%	-	0	-	0	0.21	0.04	-	0	-	0	-	0	-	0	1	4/5	1	4	3	4	Marginally suitable. Needs drainage, expensive to fertilize.
		28a	75%	2.04	1.53	-	0	73.41	55.06	-	0	34.04	25.53	-	0	-	0	1	4/5	1	4	1	4/2	Suitable. Needs drainage, salinity and flood control.
		28b	20%	-	0	-	0	1.47	0.29	-	0	-	0	0.21	0.04	-	0	1	4/5	1	4	3	3/2	Marginally suitable. Needs drainage, expensive to fertilize.
BASIN SWAMP SOILS	PEATS	29a	75%	1.20	0.90	0.13	0.09	14.14	10.61	13.82	0	22.30	16.73	-	0	-	0	1	5	1	4	3	4	Moderately suitable. Needs drainage, subsidence problem.
		29b	75%	1.25	0.94	-	0	-	0	-	0	-	0	3.98	2.99	-	0	1	5	1	4	4	4	Marginally suitable. Needs drainage, subsidence problem, expensive to fertilize.
		30	75%	1.04	0.78	-	0	13.09	9.81	12.33	9.24	32.26	24.18	27.76	20.82	-	0	1	5	1	4	4	4	Moderately suitable. Needs drainage, subsidence problem
		31	?	34.20	?	-	0	104.94	?	64.10	?	340.90	?	343.21	?	14.66	?	1	5	1	4	4	4	Probably suitable. At present not recommended because of severe subsidence problems
MISCELLANEOUS UNITS		32	50%	9.10	4.55	-	0	0.32	0.16	27.13	13.57	14.14	7.07	51.11	25.56	6.91	3.46	1	4/5	1	4	1-4	3/4	Suitable in part. Needs drainage
		33	0%	0.64	0	-	0	7.96	0	-	0	-	0	-	0	-	0	-	-	-	-	-	-	Not to be used for agriculture.
	Total			678.78	219.72	330.15	160.68	926.51	330.81	781.39	343.40	659.72	167.47	900.29	226.14	98.64	30.91							

EXPLANATION

TOPOGRAPHY
1 – Flat (< 2°)
2 – Gently sloping (2°–10°)
3 – Moderate steep (10°–20°)
4 – Steep (20°–35°)
5 – Very steep (> 35°)

DRAINAGE
1. – Well drained
2. Moderately well drained
3. Imperfectly drained.
4. Poorly drained.
5. Very poorly drained

FLOODING RISK
1. – None
2. – Low (infrequent, short duration)
3. – Moderate (infrequent)
4. – High (every year)

SURFACE EROSION RISK
1. – None
2. – Slight
3. – Moderate
4. – High

CHEMICAL FERTILITY STATUS
1 – High
2 – Moderate
3 – Low
4. – Very low

PHYSICAL STATUS
1 – Very good
2 – Good
3 – Poor
(1–3: depending on results of experimentation)
4 Very poor. At present difficult to assess.

Table 26

Estimated availability of arable land per family by District (First Division) (1970 population).

District	estimated rural population 1970 1)	average size household 1960 2)	estimated farming families 1970	estimated total arable land needed if fully developed	% of total land area	estimated total available arable land if fully developed 3)	land available at present per family
Lundu	18,087	5.4	3,294	32,940 ac.	32.9	140,800 ac.	± 43 ac.
Bau	31,187	5.7	5,471	54,710 ac.	48.7	102,835 ac.	± 19 ac.
Kuching (Rural)	133,384	5.9	22,607	220,070 ac.	35.6	211,718 ac.	± 9 ac.
Upper Sadong	50,422	6	8,403	84,030 ac.	44.0	220,896 ac.	± 26 ac.
Lower Sadong	33,176	5.5	6,032	60,320 ac.	25.4	107,190 ac.	± 17 ac.

1) Ref. Development Plan, Dutch University Team, 1970.

2) Ref. Sarawak Population Census, 1960, Jones, L. W., 1962.

3) Calculations based on detailed-reconnaissance soil map, West Sarawak (table 25), this memoir.

Table 27

Influence of air-drying on topsoils and subsoils of Saline-Gley Soils showing features of potential catclay.

Condition	Wet				Air-dried			
Acidity	high	medium	low	very low	high	medium	low	very low
pH	3.5	3.6-4.5	4.6-5.9	6.0	3.5	3.6-4.5	4.6-5.9	6.0
Depth (ins.)								
0 - 6	18.0	26.1	19.2	36.7	39.6	22.8	13.6	24.0
12 - 18	10.9	25.2	22.3	41.6	38.0	28.0	14.0	20.0
24 - 30	6.7	11.7	29.4	52.2	43.4	29.2	15.1	12.3

It should be mentioned that in these calculations SALINE-GLEY SOILS (**Rajang Family**) and PEAT SOILS (**Anderson 2 and 3**) are not included. Since such soils are particularly widespread in the Kuching Rural District, Table 26 emphasizes the need for extension of agriculture on such soils and the urgency for research into the use of this type of land is apparent.

It should further be mentioned that at present a large part of the land is used for shifting cultivation. regardless the fact whether it is suitable or unsuitable for permanent use. For this reason, the relatively low availability of land in the Bau and Upper Sadong Districts may not be apparent in the field but nevertheless there will be a shortage in the not too distant future if all suitable land is to be reverted into proper permanent use. A doubling of the present population would probably saturate the suitable arable land.

This would emphasize the need for studies into alternative uses of non arable land presently used for shifting cultivation of which silviculture on a rotation basis may be one of the possibilities.

Chapter 13. PROBLEM SOILS

1. General

In the context of this chapter problem soils are defined as soils having considerable potential for agriculture but in which the limitations to agriculture are very difficult to overcome due to the specific nature of the soils. Soils which are regarded as problem soils are the SALINE-GLEY SOILS mapped as units 27 and 28 and the deep PEAT SOILS mapped as unit 31.

The problems connected with the reclamation of such soils are presently being studied but the final outcome of such studies will take a considerable time and firm recommendations to the use of these soils cannot be given until the reclamation problems are sorted out and proper amelioration measures have been thoroughly tested.

The problems connected with the reclamation of SALINE-GLEY SOILS are related to the finding of remedies to prevent the formation of catclays in soils in which the presence of potential catclay forming materials is indicated by certain chemical characteristics.

The problems connected with the reclamation of deep PEAT SOILS are related to drainage and subsequent oxidation, shrinkage and subsidence of the peat which would ultimately lead to such a lowering of the land surface that drainage by gravity will become impossible.

2. Potential Catclay Soils

To familiarize the reader with the terminology used in this section some descriptive terms are firstly defined:

Potential catclays

These are soils in which the chemical characteristics indicate that upon drainage and subsequent oxidation highly acidic conditions will be created which will be detrimental to crop growth.

Catclays

These are soils characterised by a grey to black colour with whitish-yellow and lemon-yellow streaks or blotches indicating the presence of basic aluminium sulphate and ferri-sulphate (Beers, 1962, p.21). The name is derived from Dutch soils which colour and consistency can be associated with cat's excrements. These features are indicative of very acid conditions.

Acid-Sulphate Soils

A more technical term denoting the same as 'catclays' but emphasizing its chemical character.

Wall (1960a) was the first to report on very acid conditions found in some GLEY SOILS in small interior valleys in the Samarahan Estate and suggested that they were related to the presence of catclays. Frequent crop failures of wet padi in that area experienced in the years 1940-1960 may possibly have been caused by the occurrence of such soils in that area.

After 1960 such acid conditions were reported from several other areas in the State, among which is the Bukit Punda area (Andriesse, 1962b). In the latter area very dark coloured **Bijat Family** soils were encountered in which a former marine influence in the subsoil was indicated by the presence of organic materials from possibly a nipah vegetation (see *Punda series,* p.183).

These isolated occurrences of only local significance did not indicate that the presence of such soils may be more widespread. Semi-detailed investigations in the Nonok Peninsula (Andriesse, 1964b) also indicated that the more recent coastal clay deposits mapped as *Pendam series* (p.186) did not contain appreciable amounts of what could be called potential catclay. It was not until the Government directed the attention to the possible reclamation of large deltaic mudflats in the

Sarawak River Delta that the problems connected with the occurrence of potential catclay were given serious thoughts. It was known from other areas in the world, such as Sierra Leone and Thailand, that potential catclays are frequently found in brackish water deposits which are poor in calcium and which have a relative high organic matter content. Such conditions were all met in the Sarawak River Delta.

It was subsequently discovered that in this delta potential catclays occur over quite large areas but mainly in the subsoils. The occurrence of potential catclay at the surface was found to be closely connected with the presence of mounds built by mudlobsters (*Thallasima anomala*). Detailed investigations (Andriesse and Sim, 1968) also indicated that the subsoils of the **Rajang Family** (p.184) are as much affected as those in the **Pendam Family** (p.185) but the surface horizons of the latter family showed little signs of the presence of catclays because of the non-presence of the mudlobster mounds.

Before touching on the specific problems involved in finding preventive measures for the development of catclays, the nature of the deposits involved is firstly discussed.

For the formation of potential catclays four conditions must be met:

(i) A supply of sulphur;

(ii) A highly reducing environment;

(iii) Presence of readily oxidizable organic matter;

(iv) The presence of mobile iron compounds.

The sulphur content in most riverine water is quite low and large amounts of sulphur will therefore normally not accumulate in riverine deposits. Sea water is rich in sulphur, mainly $CaSO_4$, and therefore large amounts of sulphur in the soil usually indicate a marine influence. The change of accumulation of sulphur compounds is much greater in localities where marine sediments slowly accumulate than in places where deposition takes place at a rapid pace. For this reason, high sulphur contents are usually found in deltaic areas where the accumulation of deposits in a brackish water environment is slow. The accumulation of sulphur compounds from sea water is realised through reduction processes which take place in an aquatic environment. Micro-organisms play an important role in these reduction processes but they need energy which they are able to obtain only through the oxidation of organic matter. When there is no organic matter, the activity of the micro-organism will be low and sulphur compounds will not accumulate in large amounts. Again, the tropical deltaic areas with their lush vegetation (mangrove and nipah) readily supply the organic matter in the form of litter which is accumulating together and thoroughly mixed with the mineral deposits. Upon the reduction of sulphur compounds from seawater hydrogen sulphide is formed which reacts with iron, if present, and the sulphur enters into a sulphide form as either hydrotroilite ($FeS.nH_2O$) or melnikovit ($FeS_2.nH_2O$). Both these sulphides are black and they give the soil a black colour. The formation of H_2S is very noticeable when the soils are disturbed and the gas is allowed to escape. The formation of monosulphides is readily seen in the water of small pools which is frequently pitch black in affected areas, or this water may be seeping out through cracks and root channels in banks of creeks or drains. Most monosulphides will eventually revert to polysulphides such as pyrites (cubical FeS_2) or marcasite (rhombic FeS_2) but this process takes a long time. However, if the sulphides have entered into the polysulphide form they appear difficult to oxidize (van Beers, 1962, p.19).

It should be clear from this that, when there is no mobile iron present in the soils, the sulphur compounds would not accumulate as sulphide and they would be largely leached out.

As mentioned, field investigations in the Sarawak River Delta (Andriesse and Sim, 1968) have shown that potential catclays are present in that area. This is also confirmed by chemical analyses. The total sulphur contents in topsoils (0-6″) is on average 0·56% and this increases to an average content of 1·67% in the subsoil (24-30 inches).

The reason why the sulphur content is higher in the subsoil than in the topsoil may be due to the permanently reduced conditions of the former and the stronger influence of sea water in the groundwater while the topsoils do only get flooded during peak tides. During the relatively more subaerial conditions in between the floods the sulphur accumulated in the topsoils may oxidize and leach out before they have entered into the more stable polysulphide form.

The sulphides themselves are not very harmful to plants although toxicity symptoms may occur. The danger starts when these potential catclays are drained and the watertable is lowered through which the reduced environment is transformed into an oxidized one. The iron sulphides will oxidize into basic ferric-sulphate while during this oxidation process sulphuric acid is released which results in a steep drop of pH and very acid conditions are then created. With the presence of much calcium in the soil the sulphuric acid will be neutralized and $CaSO_4$ (gypsum) will form.

The reactions are much more complicated than given here and the whole chain of reactions taking place is not yet well understood but in the context of this section it is not necessary to go into further detail.

The problem can now be stated as follows: Once the presence of potential catclays is established, by laboratory analyses it is possible to predict to what magnitude catclays will form once an oxidized environment is created through the provision of drainage

The oxidation of sulphides can be reproduced in the laboratory. This has been done with a considerable number of samples from the Sarawak River Delta of which the majority showed neutral or weakly acid reactions. After air drying and rewetting a large number of samples, particularly subsoil samples, turned strongly acid.

This is illustrated by Table 27 (p.227) which gives the frequency distribution of different pH groups before and after drying for samples of 600 profiles collected at random in the Sarawak River Delta (after Andriesse and Sim, 1968).

The Table indicates that with rigorous oxidation achieved under laboratory conditions about 40% of the samples would probably revert to catclays.

Having established this fact it will be necessary to find out in what magnitude such catcay formation will take place under actual field conditions. Although drainage is provided it does not necessarily mean that the soils will be thoroughly drained, aerated and oxidized in a reasonably short time, such as is done by air drying a soil in the laboratory. In nature this will be a very slow process, particularly in the heavy clays of the **Rajang Family** in which water moves very slowly. It has been observed in areas opposite Pending point which have been drained for longer than three years that the watertable was not deeper than 12 inches from the surface at places only 10 feet away from a main drain. The water level in the drain was at 3 feet. This may indicate that in these soils aeration and oxidation in the inter-ditch areas will not necessarily follow the establishment of a drainage network. It was also noticed that the yellow colour indicative of the presence of jarosite (basic ferri-sulphate) only developed along drains and in spoil from subsoil. Further away from the drains very little development of jarosite was observed. It is therefore extremely difficult to make prognoses on the possible formation of real catclays upon the drainage of potential catclays. This will depend on the rate and effectiveness of the artificial drainage works, the rate of oxidation, the amount of calcium present in the soil and the leaching rate of sulphuric acid once it has formed.

It appears that in the Sarawak River Delta the formation of catclays in the top 6 inches would not be very serious since the total amount of sulphur is generally not very great and if the watertable could be kept high, not much oxidation of sulphides would take place. This would favour the cultivation of rice for which deep drainage is not required.

However, as stated, a large proportion of the **Rajang Family** soils is affected by mudlobsters which have brought a considerable amount of potential catclay material to the surface by using this soil as building material of their mounds which protrude from the surface to a height varying between 1 to 3 feet. Because of subaerial weathering these lobster mounds show in 75 out of a 100 cases (Andriesse and Sim, *op. cit.*) strong formation of catclay, which can be observed in the field by the strong yellow colouration (jarosite) and in the laboratory by the very low pH values of soils in field conditions.

For wet padi cultivation these lobster mounds would have to be destroyed and the material scattered over the surface. The result will be a strong contamination of the topsoil with catclay which will quite probably have an adverse effect on crop growth.*

There would be several ways to partially ameliorate the conditions created by the formation of catclays or to partially prevent the formation itself. The most commonly used measures are:

(i) Liming; the addition of calcium will neutralize the sulphuric acid in the form of gypsum.

(ii) Controlled drainage; keeping the watertable high.

(iii) Frequent flooding to leach out the acid forming compounds. This may also be done by brackish water which, as has been shown in Sierra Leone, may be beneficial or by having available a well controlled fresh water supply.

Long term studies in the field and laboratory will be needed for selecting the most economic and most effective means to prevent the occurrence of strongly acid conditions in these soils. Particularly where large investments are concerned the knowledge that potential catclay is present in soils should be a warning that a cautious approach to development is required.

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* **Subsequent to this writing, it is reported from experimental plots with rice in the Sarawak River Delta that the formation of jarosite on the surface is severe in areas where mudlobster mounds have been levelled and the surface soil is allowed to dry out.**

Although the SALINE-GLEY SOILS are in general chemically among the most fertile ones in the State, because of the danger of catclay development, the problems involved in their reclamation should not be underestimated. For this reason, in Table 25 (p.225), no special use percentage for agricultural development purposes is allocated to these soil types.

It should be mentioned that not all **Rajang Family** or **Pendam Family** soils contain potential catclay. The Nonok Peninsula e.g. does not seem to be much affected. The reasons are difficult to indicate. It may be that the conditions were not right for an accumulation of much sulphides in the soil. Near Lundu, the position may also be different. Coastal soils in that area are generally calcium rich and this may be beneficial because the calcium will partially neutralize acid if formed. It is also possible that sulphides never accumulated in these soils to a great extent. Very little information is, however, available on this area.

It is perhaps of interest to note that although quite a considerable acreage of **Rajang** and **Pendam** soils have been reclaimed in the past, no detrimental effects in the growth of crops was reported. Most of these reclaimed soils were planted up with coconut and frequently signs of yellowing of leaves was noted. In some areas, the coconut died following severe symptoms of yellowing of leaves. Salinity and lack of drainage where almost invariably blamed for these symptoms, since commonly little artificial drainage was provided in this form of uncontrolled reclamation. The usual recommendation therefore has been to provide proper drainage or to curb to ingress of salt water. With the present knowledge that potential catclay may be present in these soils, one wonders whether the yellowing of leaves could in cases not be attributed to the formation of catclay. If this is the case, deep drainage would have an unfavourable effect and would magnify the condition rather than cure it.

It is, therefore, important to be always aware of the fact that catclay may be involved in physiological disorders in crops when grown on these soils. It may be that in the past, because no proper drainage was provided, the cultivation of coconuts on these soils has been successful, although in the economic sense probably only marginally so. The introduction of drainage schemes on these soils with the intention to grow better coconut could have the opposite effect since the more effective the drainage, the more catclay may form. The only possible way to acquire this sort of information is by long term experimentation to which there is no short-cut.

3. Deep Peat Soils

Deep peat soils are those classified as **Anderson Family,** depth phases 2 and 3. The general characteristics of these soils are described in Chapter 11, p.188. Fig. IV.8 (p.233) indicates in a schematic form the common situation in which these soils are found, while Fig. IV.9 (p.233) gives a cross section of a large basin peat swamp. It should be noted that the peat accumulations are dome-shaped and that the surface of the peat rises gently from the river levee to the centre of the peat.

The underlying basin clay shows a reverse trend and dips down from the levees, the lowest point of its surface commonly coinciding with the highest point of the dome.

All peats suffer from a high ground watertable which is commonly at the surface or slightly below it. If peats are to be used for agriculture, drainage must be provided so that the watertable is lowered. Artificial drainage of basin peats is initially easily accomplished. Commonly, there is sufficient gravity for the water to flow off to a river acting as the main drainage channel. However, owing to its organic nature the peat will decompose and oxidise when brought in contact with the air, the rate of decomposition and oxidation being dependent on the effectiveness of the drainage, the temperature and the biological activity in the soils. The oxidation rate will be acccelerated if deep drainage is provided while the addition if fertilizers and the subaerial environment subsequently created upon drainage, will bring about a rapid increase in the microbiological activity. Although in Sarawak, no proper studies have been carried out on the rate of peat shrinkage due to oxidation and loss of water through deep drainage, observations in the field indicate that the initial subsidence may be as great as two feet in the initial years of reclamation. Thereafter, the surface peat attains a very granular structure through decomposition and mineralization of the peat and the rate of subsidence may then be slowed down to an annual 2 to 2½ inches. This is also the experience of pineapple growers in the State of Johore where large peat areas of similar nature as existing in Sarawak and used for pineapple growing have been subjected to artificial drainage for quite some time.

Experience in the Nonok Peninsula shows much similar trends (Andriesse, 1964b). There, deep peat has been subjected to drainage for at least 15 years. In 1964, areas, originally having a peat cover of about 3 feet did not show more than a mucky top layer of 6 inches after a 10 years drainage period.

Large areas which previously did not suffer flooding are now annually subjected to floods because of the following reasons:

(a) The drained peat areas have subsided and gravity drainage to the main channel, the river, has become less effective because of the decreasing difference in height.

(b) From the neighbouring undrained peat areas which have not subsided or very little, water is discharged into the drained and subsided area much more rapidly than before because the height difference has been increased.

This is particularly noticeable in times of heavy rain when much surplus rainwater from undrained peat areas is rapidly discharged into the drained parcels in which the drainage system is unable to cope with such large amounts of water within a reasonable short period.

The fate of a peat swamp when drained is shown schematically in Fig. IV.10 (p.234). Stage I indicates the original situation before drainage. Stage II indicates the situation where the peat has subsided to such an extent that the surface is almost at the same level as that of the mean water level in the main discharge channel, the river. At this stage drainage through gravity will natural conditions and the water balance is maintained net returns from forest with strict adherence to sound silvi-cultural practices may well prove to be higher in the long run than those obtained from agricultural produce.

Experiences in other countries, notably in Holland where large basin peats have been drained since a 1000 years A.C., have been, that once the shrinkage process has started it is necessary to maintain effective drainage by regularly deepening the drainage channels until a stage is reached in which no water will move because of lack in gravity. This may take 50 years or more than 100 years, the time being dependent on the original difference in height between the peat surface, the mean water level in the river and the rate of decomposition of the peat.

The regular adjustments of the drainage system to the subsidence of the land will affect the economic feasibility of any agricultural enterprise envisaged for deep peat areas. The problems of drainage, and risk of flooding will slowly increase until they are unsurmountable unless use is made of the ultimate remedy which has been adopted in Holland, namely pumping. When stage II has been reached, the only way to drain off surplus water is to empolder the basin swamp by the construction of dykes and to make its drainage independent from gravity by pumping the water out.

When this is accomplished the peat will continue to subside until in the final stage (Stage III) very little peat remains and the surface of the basin swamp has reached a level far below that of the mean water level in the river.

It is therefore technically possible to permanently drain peats, but the costs become exorbitantly high once the empoldering stage is reached and this can only be economically justified if the return from agricultural produce is of significant magnitude to cover the costs involved.

With the present economic conditions this is very doubtful and for this reason, the agricultural use of deep basin peats is presently not recommended, not because the peats would not support crops. If properly fertilized a wide range of crops could be grown but only if the peats are adequately drained. As explained, once drained, there are no means to prevent the peats from subsiding and it will be extremely difficult to stop agricultural development once it has been initiated. The problems which will most probably arise in future are therefore better prevented by a policy of non-interference with the intricate drainage of peat swamps. When kept under natural conditions and the water balance is maintained net returns from forest with strict adherence to sound silvi-cultural practices may well prove to be higher in the long run than those obtained from agricultural produce.

Only those peats, overlying clays at a level higher than the mean water level in the main potential drainage channel, can be permanently drained without too high costs and agriculture should be allowed in such areas. Any other deep peat area is best left in its natural state until such times when it would be economically justified to initiate reclaiming, thereby keeping in mind the problems which will be created and which will have to be overcome by possibly future generations.

Fig. IV. 8 Location of peat

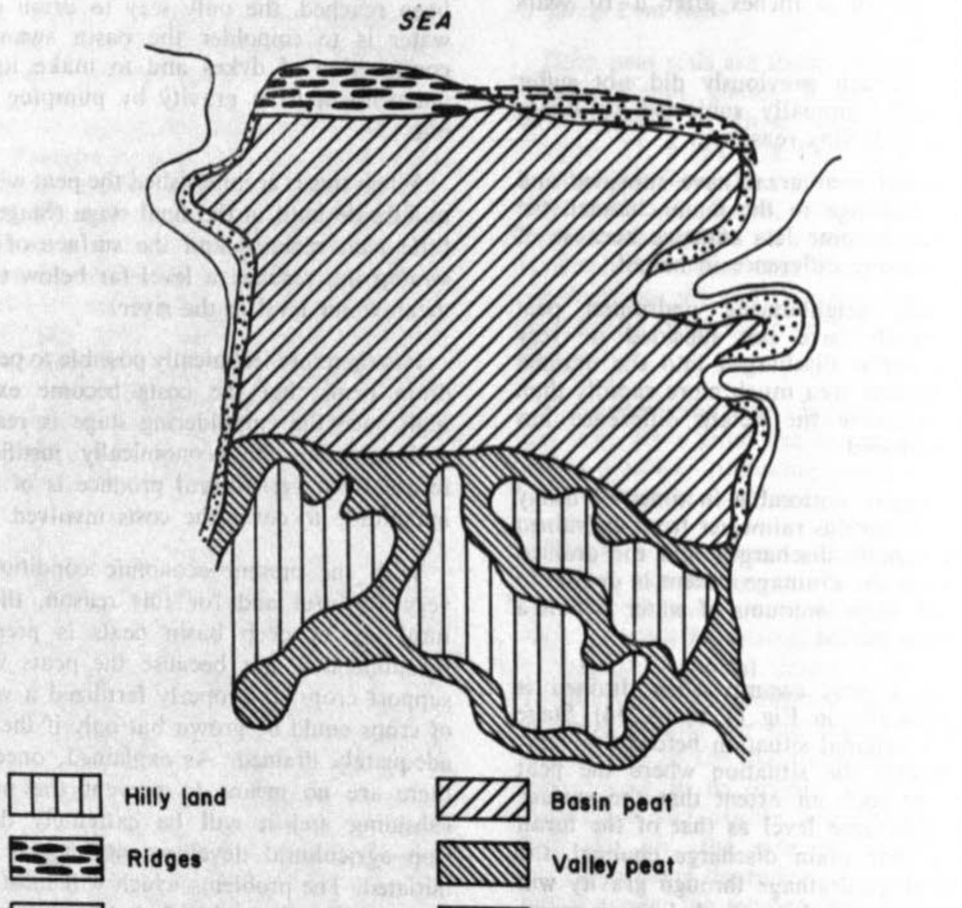


Fig. IV. 9 Cross-section of basin

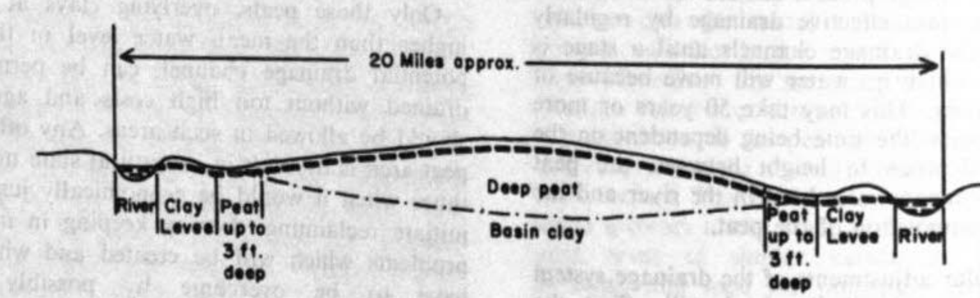
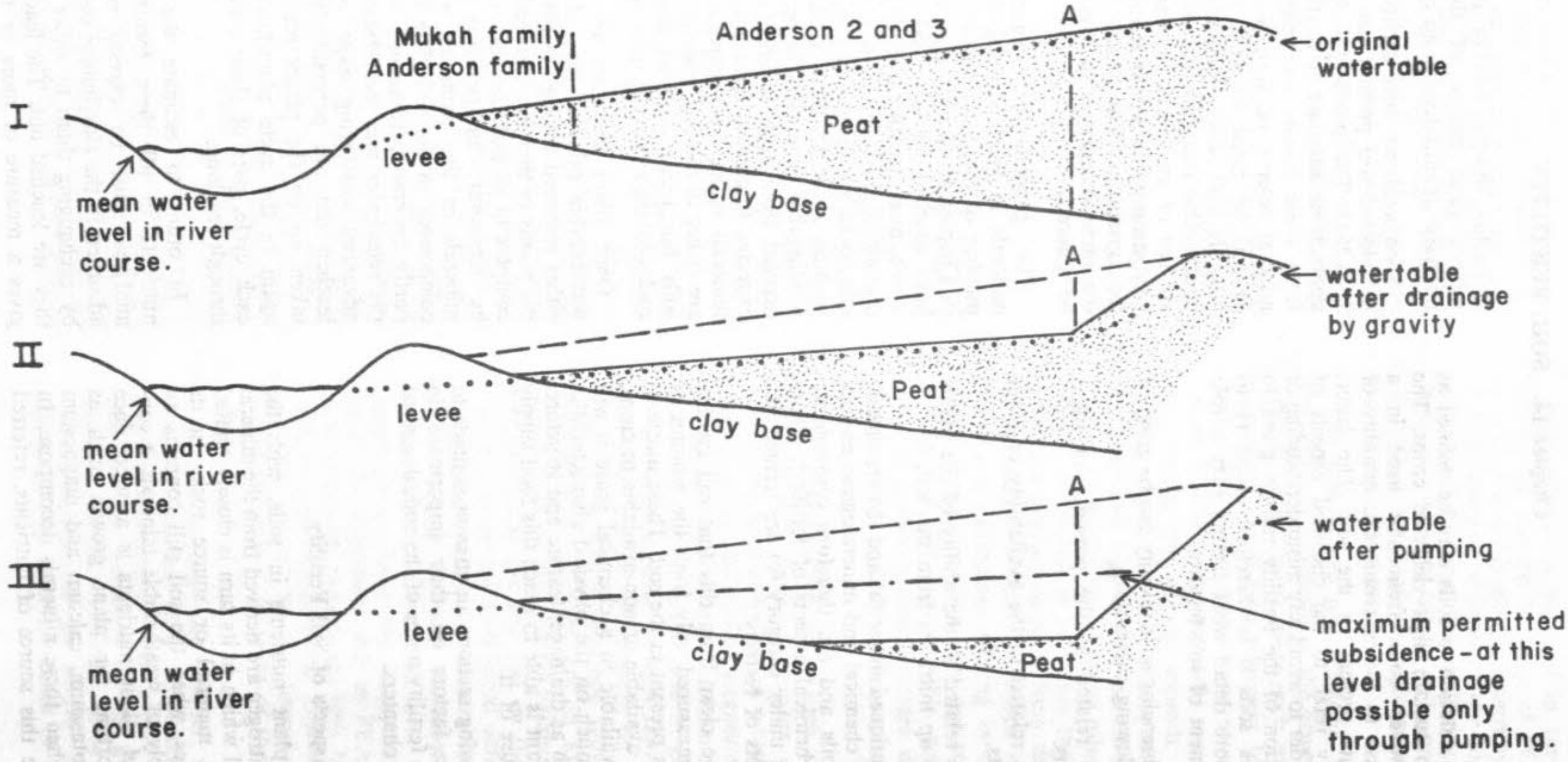


Fig. IV. 10 Stages in subsidence of peat following drainage.



(vertical scale exaggerated)

Chapter 14. SOIL FERTILITY

1. General

Fertility in relation to soils may be defined as the ability to sustain high yields of crops. The term is however quite frequently used in a restricted sense to indicate only the quantity of plant nutrients present in the soil. The latter, however, only refer to the chemical aspects of fertility. In order to avoid any misunderstanding or misinterpretation of the fertility ratings given to West Sarawak soils it is therefore necessary to explain in more detail what factors play a role in the assessment of soil fertility.

Factors influencing soils fertility can be grouped under the following categories:

(a) Factors related to the presence of plant nutrients.

(b) Factors related to the availability of plant nutrients.

(c) Factors related to the ability of the plants to take up nutrients from the soil.

Factors mentioned under (a) and (b) are closely related to the chemical and mineralogical characteristics of soils and are therefore conveniently termed 'the chemical aspects of fertility'. Those factors falling under category (c) are termed 'the physical aspects of fertility'.

It should be clear from this that soil fertility is not to be measured only from the amount of plant nutrients present in the soil. These nutrients may either be available or non-available to crops. Even when available in a chemical sense it will depend very much on the physical characteristics of the soil such as drainage, texture and structure, whether the plant is able to reach this food supply and to make use of it.

In the following sections an attempt is made to evaluate these factors on their importance in controlling the fertility status of the soils described in preceeding chapters.

2. Chemical Aspects of Soil Fertility

All major plant nutrients in soils, with the exception of nitrogen are derived from the mineral part of the soil which in its turn is closely related to the parent material or source rock. In its immature stages, when the soil still contains an abundant supply of weatherable minerals a constant supply of plant nutrients is assured since elements important for plant growth such as phosphorus, potassium, calcium and magnesium are released when these minerals decompose. In order to gauge this source of nutrients, referred to as the 'mineral reserve' present in a soil, the mineralogical nature of the sand fraction is analysed quantitatively and qualitatively.

Such analyses were carried out for a number of selected soil profiles (see Chapter 15, section 1, p.254). The profiles studied did not contain appreciable amounts of weatherable minerals and from these results one may conclude that the mineral reserve in West Sarawak soils must in general be rated as very low. Although it is possible that some immature soils may contain weatherable minerals in some quantity such soils are not of any areal importance or they mantle very steep mountainous terrain largely unsuitable for agriculture. For practical purposes therefore the mineral reserves in West Sarawak soils can be ignored.

The general low content of weatherable minerals in West Sarawak soils is caused by a number of factors. From the observations made in Chapter 10 (p.136), it is clear that most soils have reached an advanced maturation stage in which most weatherable minerals have already decomposed. Moreover, soils formed on sedimentary rocks are inherently poor in mineral reserves because most of these rock types contain few weatherable minerals. The recent alluvial deposits derived from such sedimentary rocks cannot be expected to contain large amounts of weatherable minerals either but comparatively speaking they are richer in mineral reserves than related upland soils but recent alluvial deposits from igneous rock contain relatively most weatherable minerals.

Once plant nutrients are released from the weatherable mineral part of the soil, they are either removed through leaching, are taken up by the plants or they are adsorbed by the clay-humus complex in an exchangeable form. Also, they may be temporary or permanently fixed by clay minerals or they combine with other chemical compounds in the soil. The latter nutrients may partly become permanently non-available, while the remainder may be released again in a more advanced weathering stage. Nutrients which are leached out are permanently lost, while those taken up by the plants may become available again in the cycle plant-litter-soil-plant, but in each cycle, part of these nutrients are lost also through leaching.

In order to estimate the content of plant nutrients in all these forms several types of analyses must be carried out. The nutrients adsorbed in the clay/humus complex are analysed by exchanging them by other cations whereafter they are leached out. The leachate thus collected gives a measure of more or less available plant food. The amounts of these exchangeable nutrients are indicated in the analytical data found in the Appendix as milligram equivalent percentages of dry soil (meq. %). The nutrients in a fixed or less available form can be extracted by a more rigorous method, the soil being treated with hot concentrated hydrochloric acid and the nutrients thus dissolved give a measure of the 'reserve' amounts present in the soil. Part of it may become available in time, the remainder being permanently unavailable.

Such analyses are indicated in the analytical data shown in the Appendix, as 'reserve nutrients' and they are expressed as parts per million (p.p.m.) of dry soil.

Before discussing the results of these analyses, it is necessary to comment briefly on the acidity of West Sarawak soils since this greatly influences leaching and availability of plant nutrients.

(a) **Acidity**

Most soils in West Sarawak are very acid, the pH measured in water suspension being commonly between 4 and 5.5. Since in this pH range hydrolyses of aluminium compounds takes place (Coleman and Thomas, 1967), the likelihood that most soils are dominated by aluminium clays is great. This is largely confirmed by measurements of the exchange acidity, pH in KC1, which is largely controlled by monomeric aluminium ions (Coleman and Thomas, *op. cit.*) and which in Sarawak soils appears to be in general approximately one unit lower than the pH in water. The dominance of aluminium in the exchange complex, as revealed by the analyses, also indicates a high mobility of aluminium. It is possible that in top soils the pH is more hydrogen dependent as suggested by Yuan (1963) and the acidity may be related to presence of carbonic acid rather than to presence of hydrolized aluminium compounds. The very low pH generally found in PEAT SOILS (Prof. 81, p.315) cannot be attributed to hydrolysed aluminium compounds nor to the presence of carbonic acids and the low pH in soils must be attributed mainly to the presence of organic acids (humic or fulvic). These may also play a role in topsoils of podzolic soils in which the amount of carbonic acids is probably insignificant. Very low pH values (less than 4) were obtained in potential catclay soils and in the weathered parent material of some podzolic soils (Prof. 425, p.300, 226, p.303, and 77, p.284). Such a low acidity is most probably caused by the presence of sulphuric acid formed upon oxidation of sulphides present in these soils and parent materials. Highest pH values (more than 7) were encountered in the SALINE-GLEY SOILS and are caused by high amounts of bases present due to salt water flooding.

High pH values obtained in very sandy soils such as the surface horizons of PODZOLS and some marine sands are not caused by the presence of large amounts of bases. These high pH values are caused by the low buffering capacity of these soils, the pH of the soil approaching that of distilled water or the basic solution used for the pH determinations.

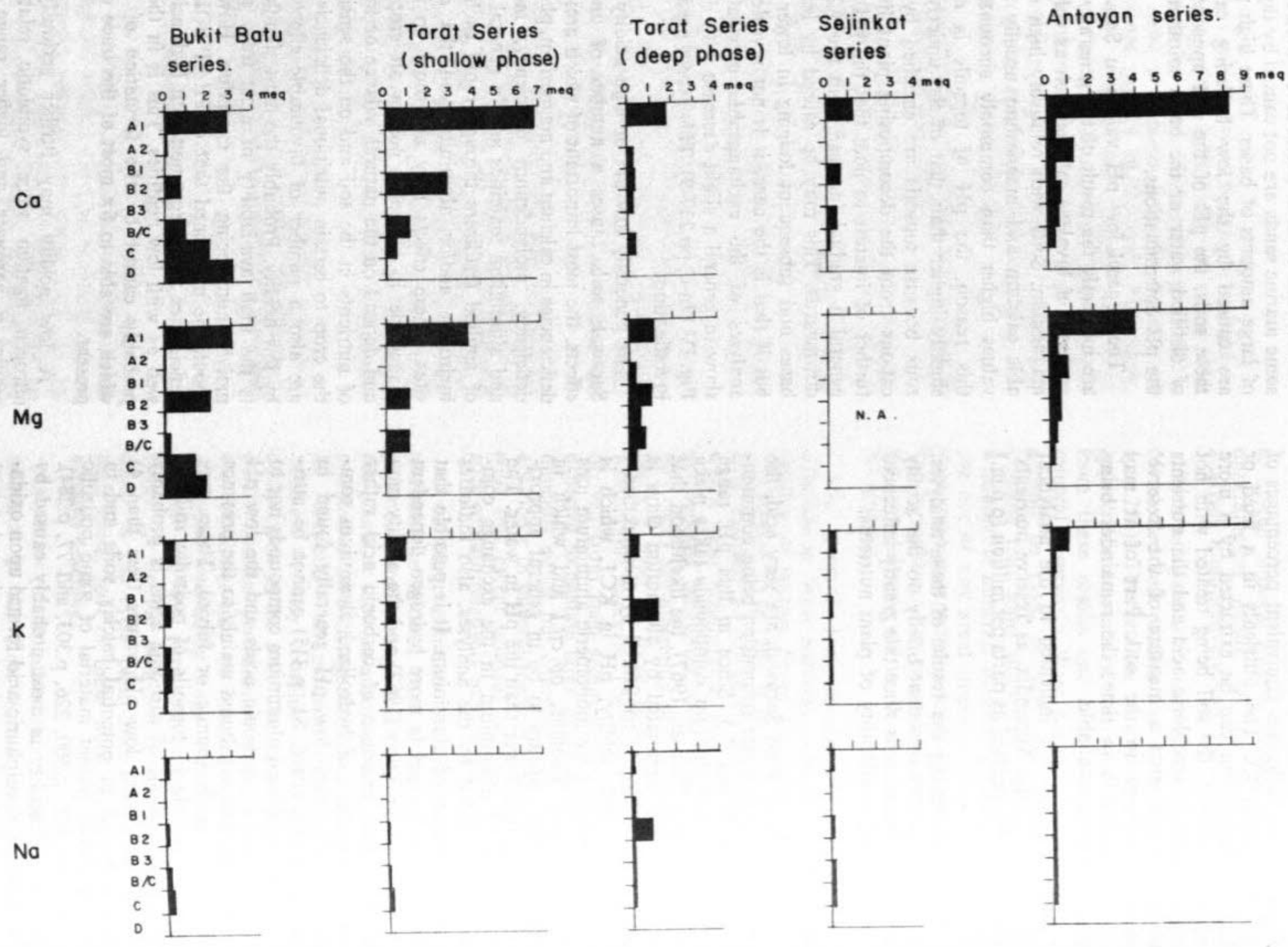
The general low pH values in Sarawak soils are indirectly the result of the generally very low contents of bivalent cations such as calcium and magnesium. Soils with relatively high exchangeable calcium and magnesium usually show pH values higher than commonly encountered. For this reason, the pH of topsoils is commonly slightly higher than that of the underlying horizons because topsoils are enriched by bivalent cations from the decomposing plant litter. It is further of interest to note that the pH shows in general a gradual increase from the A2 horizon downwards. This may be caused by leaching of bases and subsequent lodging in lower horizons but if that is the case, it is not revealed by the analyses of the exchangeable nutrients, which show in general a slight decrease with depth (see Fig. IV.11a-c, pp.237-9). This aspect needs further investigation.

The generally low pH or high acidity in West Sarawak soils causes a number of undesirable effects, the most important of which are: nutrient deficiencies in calcium and magnesium, phosphorus deficiency, molybdenum deficiency, manganese and aluminium toxicities and in general leaching of applied fertilizers through rapid exchange by hydrogen and/or aluminium on the exchange sites. These effects may not show up in equal magnitude in all soils, nor in all crops grown and depend on the natural balance or imbalance of nutrients in the soil and on the sensitivity of the crop to certain nutritional deficiencies. There are also a number of favourable effects caused by low acidity. Probably the most significant one is the high availability of most trace elements, molybdenum being the exception. However, it should be mentioned that in PEAT SOILS such deficiencies are as common with high acidities as well as with low acidities. This is in these soils probably caused by the formation of chelates which are able to fix most of the trace elements present.

A low acidity may further seriously affect nitrogen fixation since symbiotic relationships require a narrower and higher range of soil reaction than necessary for the growth of plants (Jackson, 1967). Although these ill-effects may not be obvious in the natural unfertilized soil, the more the natural balance of nutrients in the

Fig. IV. IIa

Mean values of exchangeable nutrients in soil series of the Lateritic Soil Group on basic to intermediate igneous rock type.



N. A. — NOT ANALYSED.

Fig. IV. IIb

Mean values of exchangeable nutrients in soil series of the Red-Yellow Podzolic Soil Group on igneous and metamorphosed rock types.

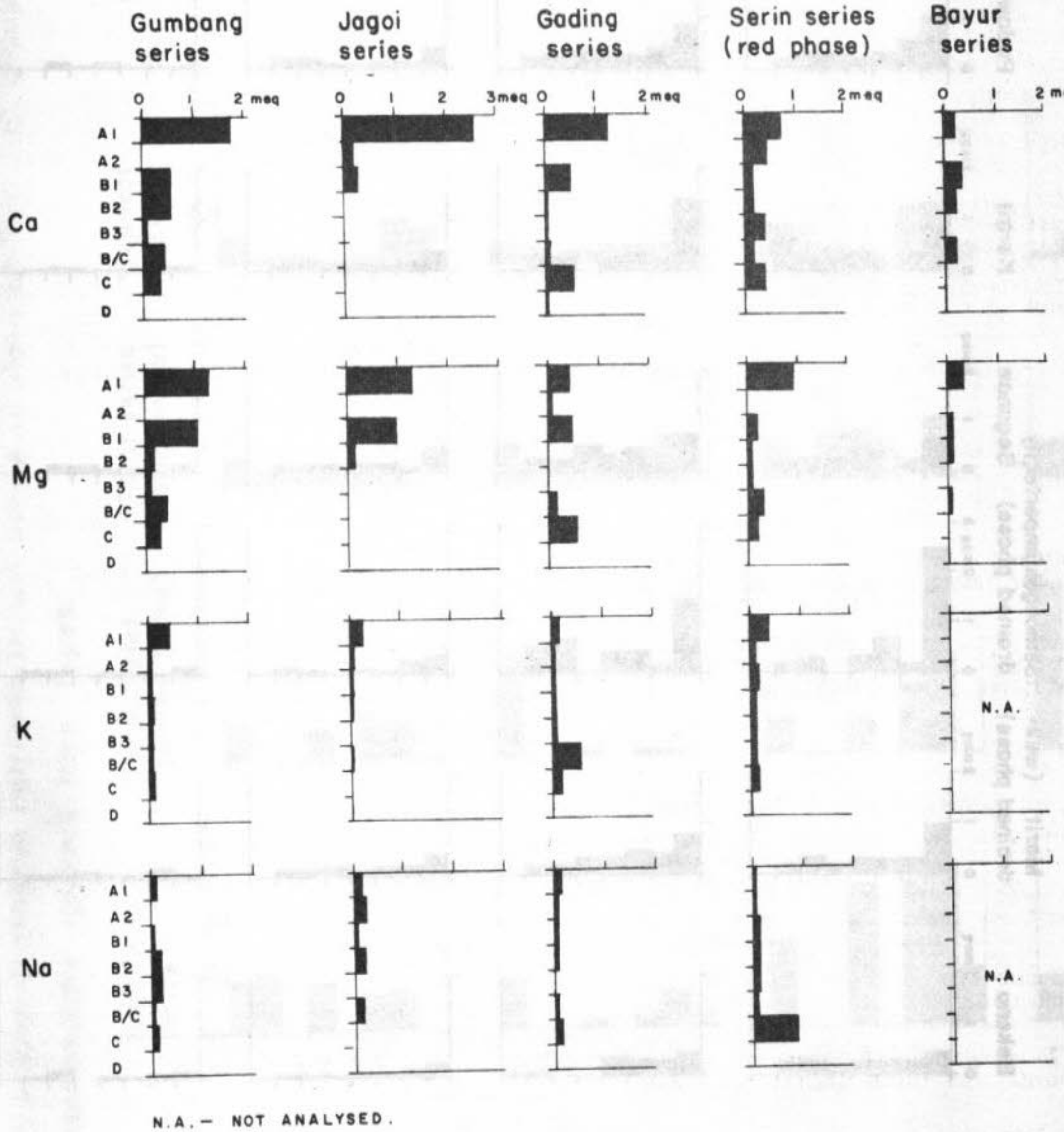


Fig. IV. IIc

Mean values of exchangeable nutrients in soil families of the Red-Yellow and Grey-White Podzolic Soil Group on sedimentary rock type.

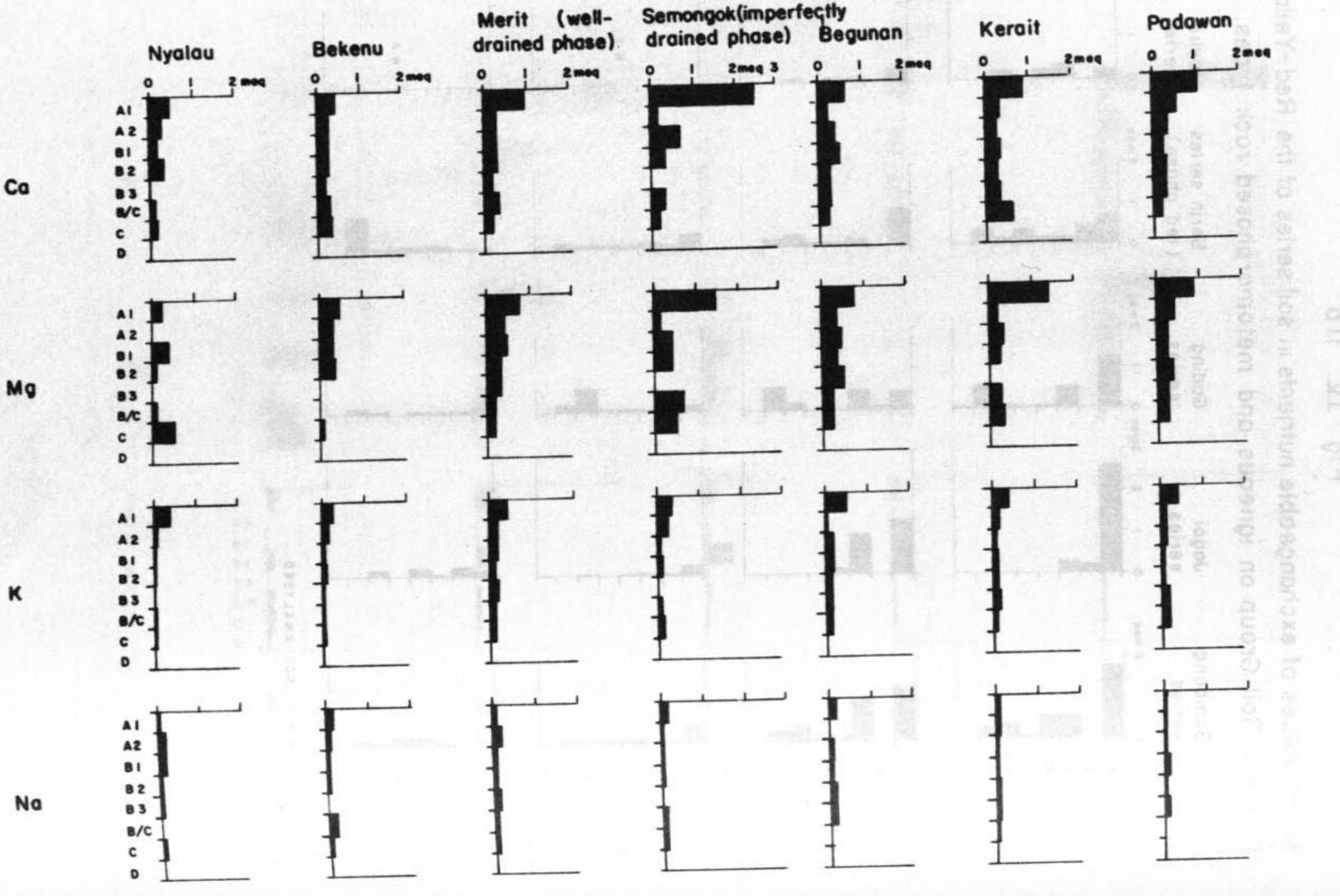


Fig. IV. 12 a

Mean values of reserve nutrients in soil series of the Lateritic Soil Group on basic to intermediate igneous rock types.

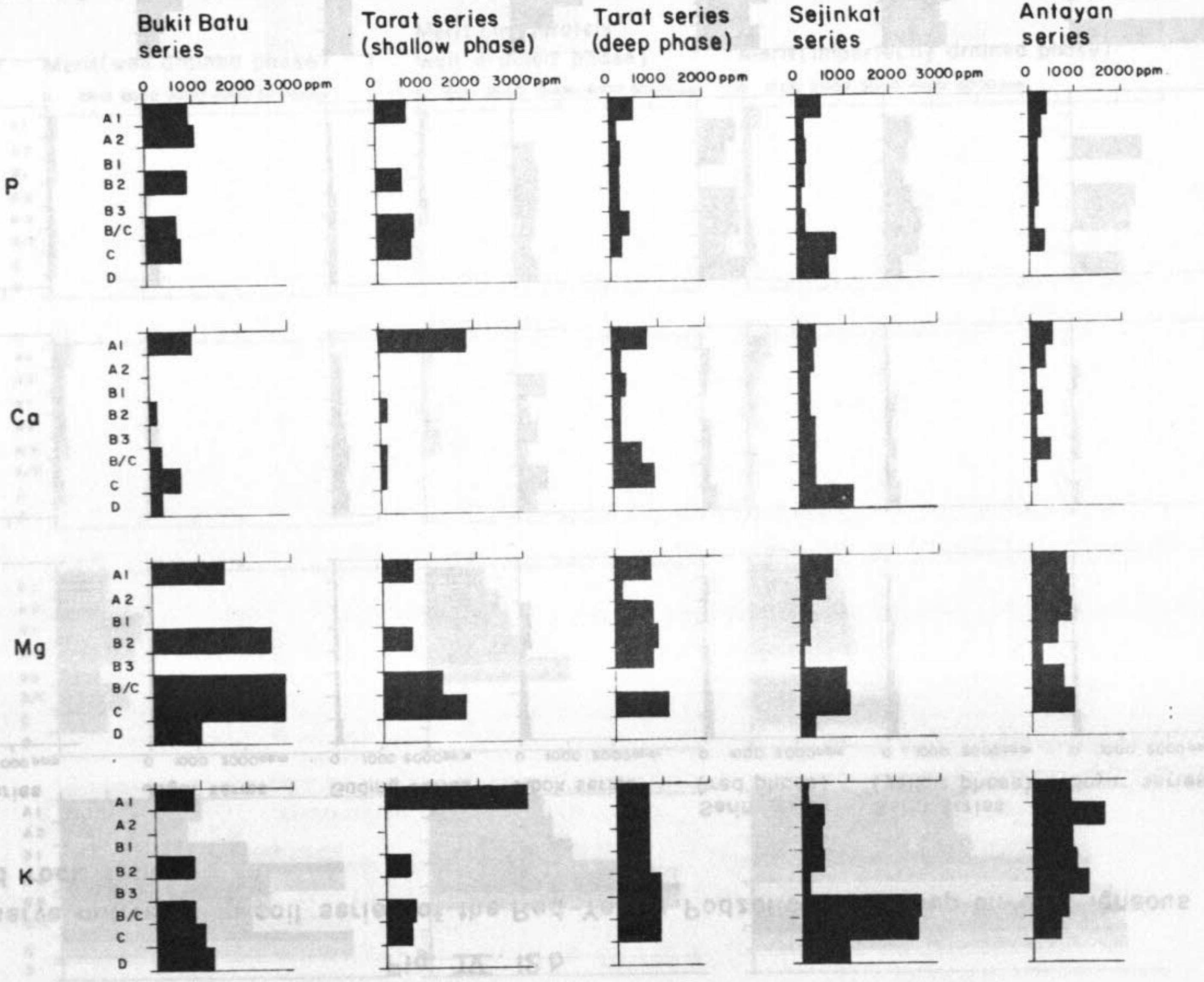


Fig. IV. 12 b

Mean values of reserve nutrients in soil series of the Red-Yellow Podzolic Soil Group on acid igneous and metamorphosed rock types.

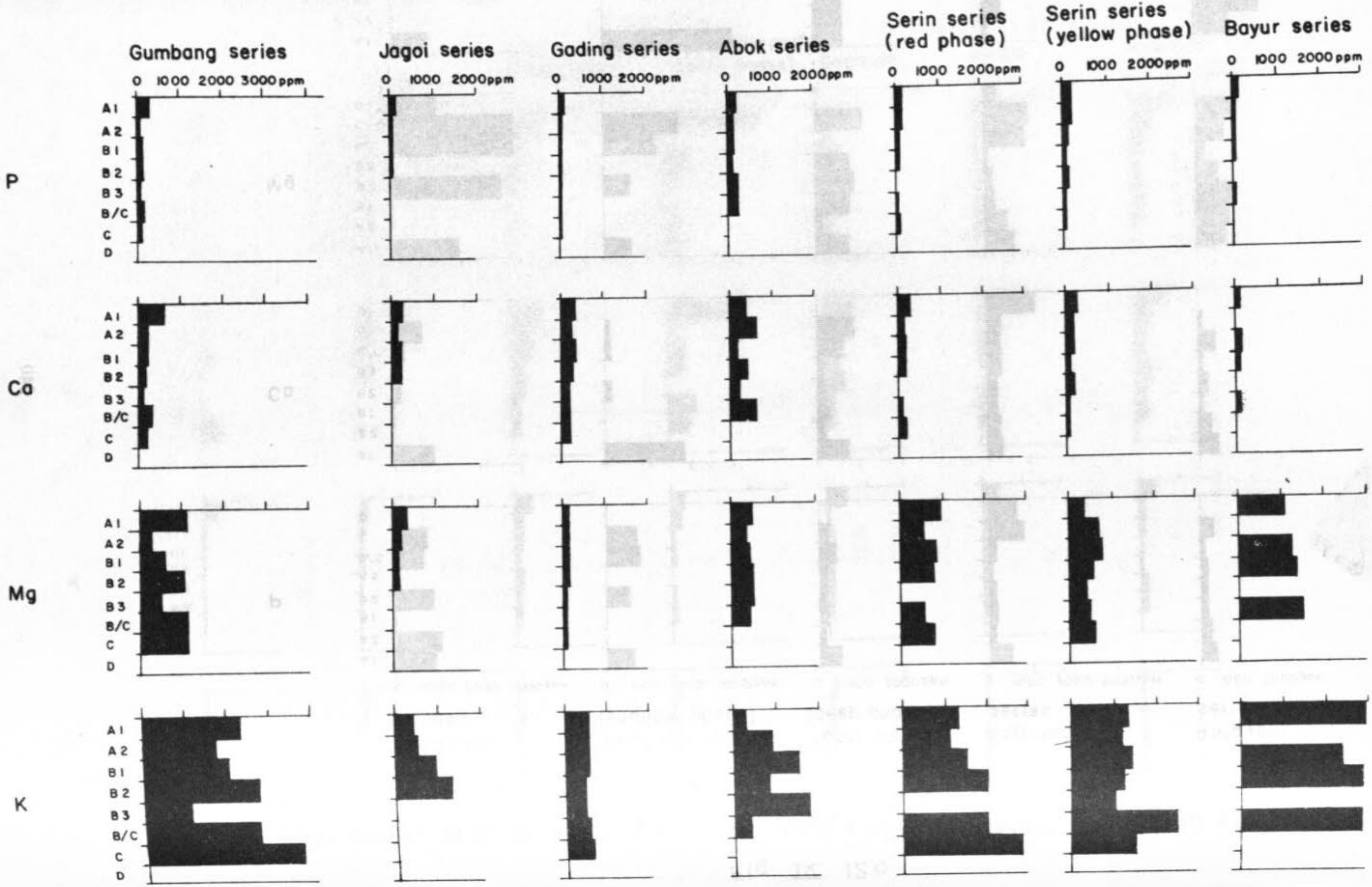


Fig. IV. 12c

Mean values of reserve nutrients in soil families of the Red-Yellow Podzolic Soil Group on sedimentary rock types.

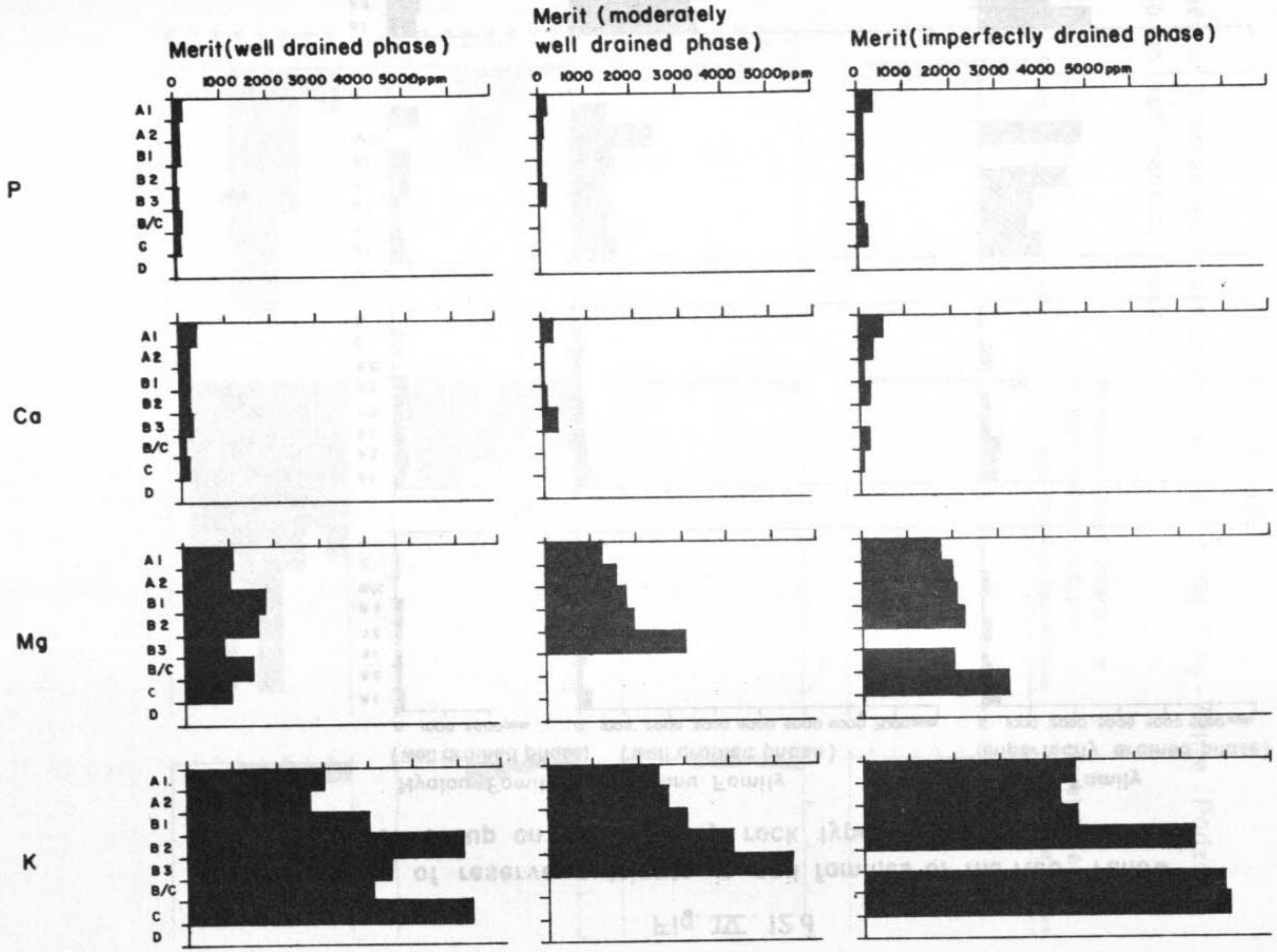


Fig. IV. 12d

Mean values of reserve nutrients in soil families of the Red-Yellow Podzolic Soil Group on sedimentary rock types.

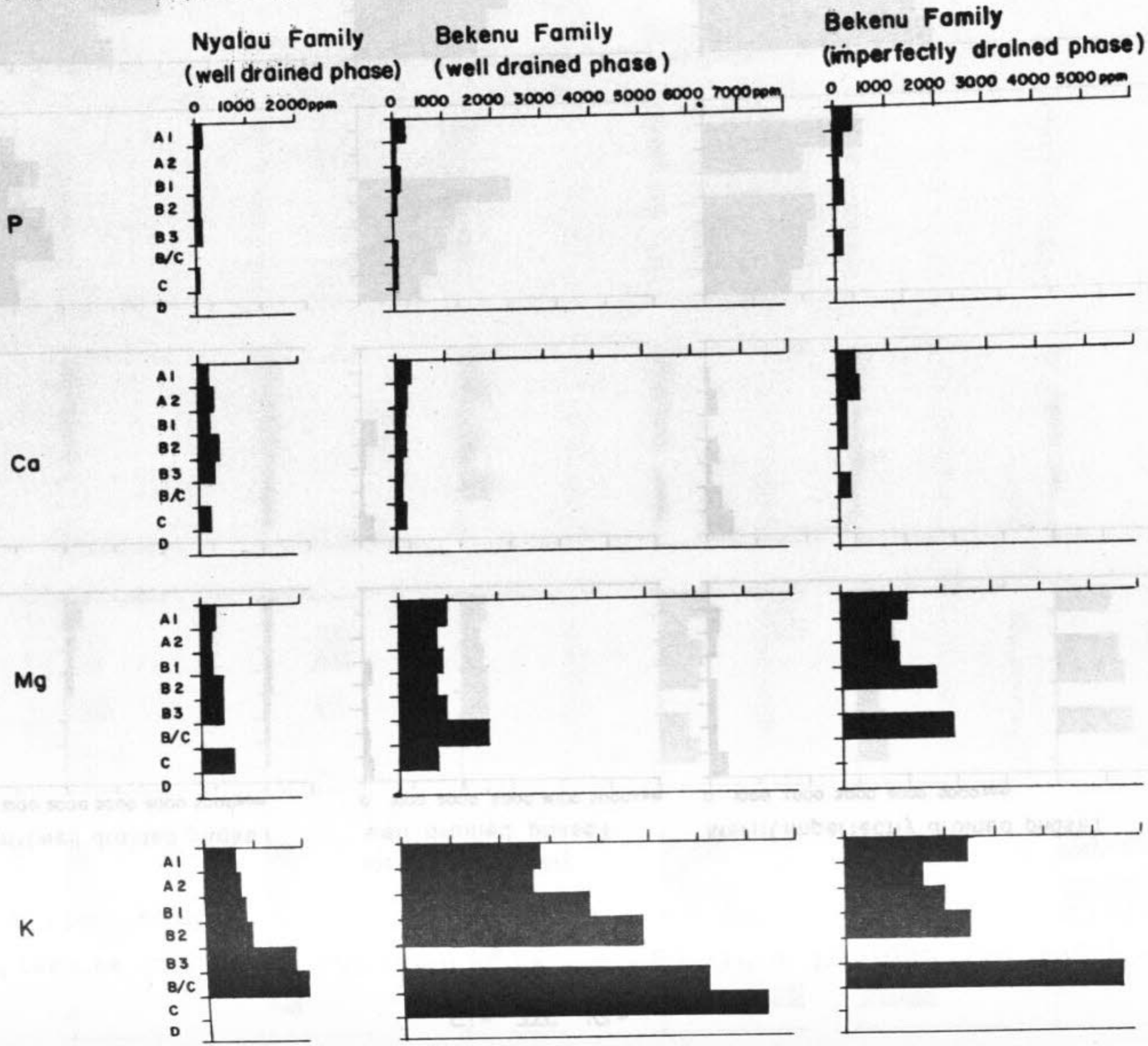
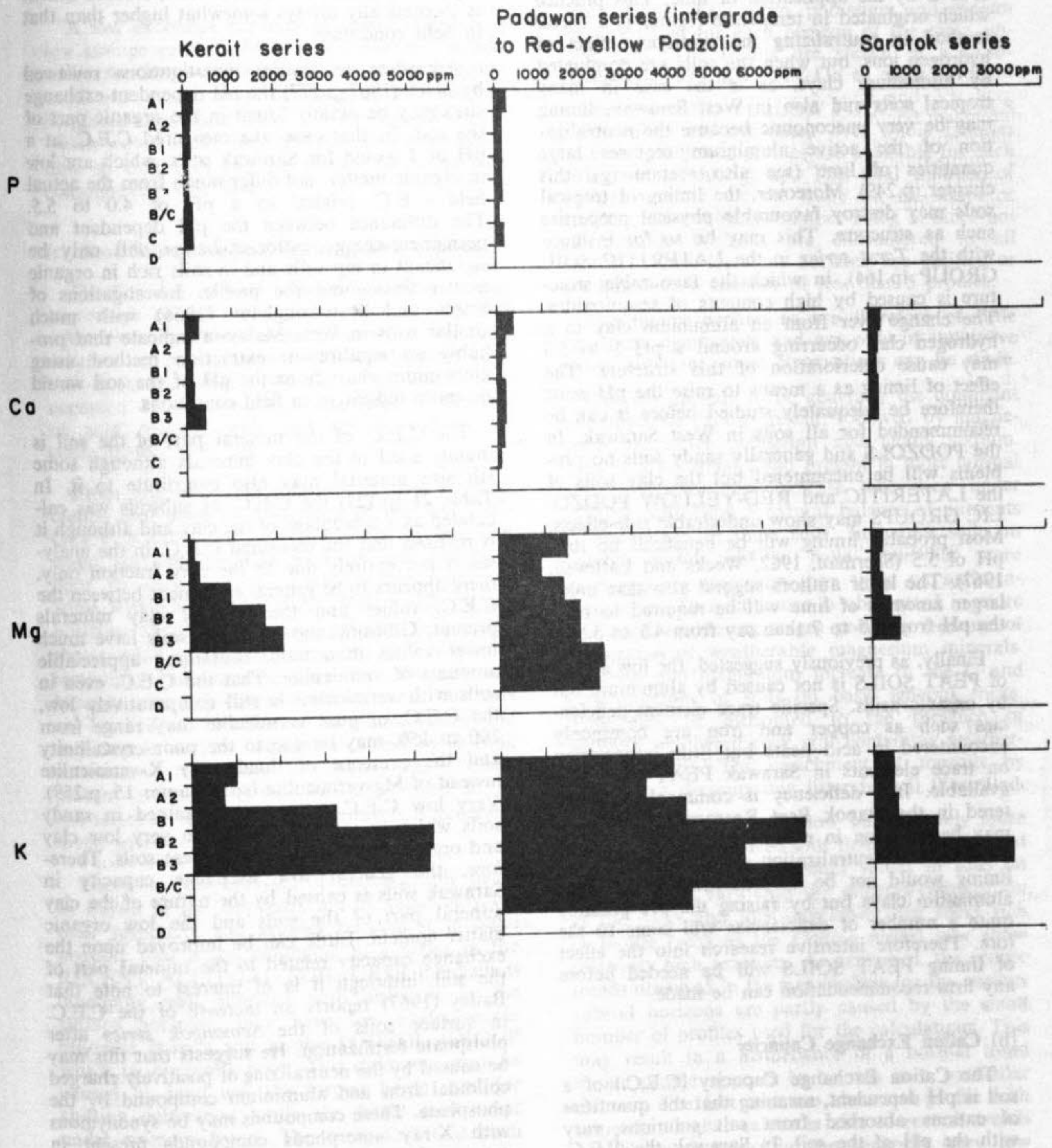


Fig. IV. 12e

Mean values of reserve nutrients in soil series of the Grey-White Podzolic Soil Group on sedimentary rocks.



soil is disturbed by addition of fertilizers, the more deficiency symptoms will appear. An example in question is the so-called 'acid soil disease' in pepper, originally reported as aluminium toxicity (de Waard and Sutton, 1960).

A conventional means to cure low acidities in soils is by the application of lime. This practice which originated in temperate regions is a useful method in neutralizing the acidifying effect of hydrogen ions, but when the soils are dominated by aluminium clays, as is the case in many tropical soils and also in West Sarawak, liming may be very uneconomic because the neutralization of the active aluminium requires large quantities of lime (see also section (g), this chapter, p.249). Moreover, the liming of tropical soils may destroy favourable physical properties such as structure. This may be so for instance with the *Tarat series* in the LATERITIC SOIL GROUP (p.164), in which the favourable structure is caused by high contents of sesquioxides. The change over from an aluminium clay to a hydrogen clay occurring around a pH 5 to 5.5 may cause deterioration of this structure. The effect of liming as a means to raise the pH must therefore be adequately studied before it can be recommended for all soils in West Sarawak. In the PODZOLS and generally sandy soils no problems will be encountered but the clay soils of the LATERITIC and RED-YELLOW PODZOLIC GROUPS may show undesirable side-effects. Most probably liming will be beneficial up to a pH of 5.5 (Sherman, 1962, Weeks and Lathwell, 1967). The latter authors suggest also that much larger amounts of lime will be required to raise the pH from 5.5 to 7 than say from 4.5 to 5.5.

Finally, as previously suggested, the low acidity of PEAT SOILS is not caused by aluminium but by organic acids. Specific trace element deficiencies such as copper and iron are commonly encountered in acid peats but little information on trace elements in Sarawak PEAT SOILS is available. Iron deficiency is commonly encountered in the Stapok Peat Research Station and may be common in most West Sarawak PEAT SOILS. The neutralization of organic acids by liming would not be as problematic as that of aluminium clays but by raising the pH possibly quite a number of deficiencies will come to the fore. Therefore intensive research into the effect of liming PEAT SOILS will be needed before any firm recommendation can be made.

(b) Cation Exchange Capacity

The Cation Exchange Capacity (C.E.C.) of a soil is pH dependent, meaning that the quantities of cations absorbed from salt solutions vary with the pH of the soil. In Sarawak the C.E.C. is measured at a pH of 7. **The disadvantage of** using neutral ammonium acetate in the measurement of C.E.C. is, that it does not truly reflect the C.E.C. in the field conditions. A positive point is however that it indicates what C.E.C. will be reached if the pH is raised by liming. For most soils this would probably never be higher than 5.5 and therefore the measured C.E.C. is theoretically always somewhat higher than that in field conditions.

According to several investigations reviewed by Black (1967, p.277) the pH dependent exchange sites may be mainly found in the organic part of the soil. In that case, the measured C.E.C. at a pH of 7 would for Sarawak soils, which are low in organic matter, not differ much from the actual field C.E.C. related to a pH of 4.0 to 5.5. The difference between the pH dependent and permanent-charge cation-exchange will only be significant in top soils and in soils rich in organic matter throughout the profile. Investigations of Singh and Ratnasingham (1966) with much similar soils in West Malaysia indicate that probably an equilibrium extraction method using ammonium chloride at the pH of the soil would be more indicative to field conditions.

The C.E.C. of the mineral part of the soil is mainly sited in the clay minerals although some silt size material may also contribute to it. In Table 21 (p.127) the C.E.C. of subsoils was calculated as a percentage of the clay and although it is realized that the measured C.E.C. in the analyses is not entirely due to the clay fraction only, there appears to be general agreement between the C.E.C. values and the type of clay minerals present. Gibbsitic and kaolinitic soils have much lower values than those containing appreciable amounts of vermiculite. That the C.E.C. even in soils with vermiculite is still comparatively low, the C.E.C. of pure vermiculite may range from 100 to 150, may be due to the poor crystallinity and the presence of dominantly K-vermiculite instead of Mg-vermiculite (see Chapter 15, p.259). Very low C.E.C. values are obtained in sandy soils which is entirely due to the very low clay and organic matter contents in these soils. Therefore, the general low exchange capacity in Sarawak soils is caused by the nature of the clay mineral part of the soils and the low organic matter content. Little can be improved upon the exchange capacity related to the mineral part of the soil, although it is of interest to note that Bailey (1967) reports an increase of the C.E.C. in surface soils of the *Semongok series* after phosphate fertilization. He suggests that this may be caused by the neutralizing of positively charged colloidal iron and aluminium compound by the phosphate. These compounds may be synonymous with X-ray amorphous compounds present in most surface horizons and detected by D.T.A. methods (see Chapter 15, p.256). The exchange capacity related to the organic part in the soil could be built up by the incorporating of organic manure in the topsoils. This will be particularly beneficial in sandy soils which are very low in exchange capacity due to the very low clay content.

A low exchange capacity of a soil indicates a low storage capacity for added fertilizers, so that either fertilizers have to be applied in frequent small amounts to avoid leaching, or they need to be placed near plant roots in a concentrated form which would make the fertilizers gradually available so that they can be readily taken up and consequently very low.

(c) **Base Saturation and Exchangeable Cations**

The S. value or base saturation indicates what percentage of the exchange complex is saturated with exchangeable bases, commonly calcium, magnesium, potassium and sodium. In most soils the exchange sites appear to be dominantly occupied by aluminium, a characteristic feature of acid tropical soils and the S. values are consequently very low.

From the available analyses it can be concluded that with the exception of the SALINE-GLEY SOILS which are influenced by brackish water, all soils in West Sarawak are inherently poor to very poor in exchangeable nutrients. Some RECENT ALLUVIAL SOILS and surface horizons of soils still under primary forest may shows relative high amounts, but this is a very temporary characteristic since once the soils are brought into cultivation much of these nutrients are leached out or taken up by plants. Due to the variation in natural vegetation caused by shifting cultivation, the range of exchangeable bases present in topsoils is therefore wide, even at the soil series level, while that of subsoils is generally much narrower.

Therefore, the analyses of exchangeable bases as shown in the Appendix are of value only for their respective soil profiles because it is quite possible that a soil belonging to a series in the RECENT ALLUVIAL SOIL GROUP which is inherently well supplied with nutrients in the surface horizons, may have less exchangeable nutrients than a soil in the PODZOL GROUP which is inherently poor. This difference may be caused by land use, the former being used for shifting cultivation while the latter may occur under primary forest. The mere fact that such variations are possible stresses the fact that the differences in exchangeable nutrients between the soils groups are generally not very great otherwise shifting cultivation would not be able to wipe these out so rapidly.

However, in order to investigate whether the content of exchangeable bases is related to soil group or family, the mean values for exchangeable calcium, magnesium, potassium and sodium are calculated for each horizon of the main upland soils. The results are shown in a histogrammatic form in Fig. IV.11a to c (pp.237-9).

For some RED-YELLOW PODZOLIC SOILS mean values are calculated over whole families because insufficient profiles are available for each series within this group. The total number of profiles used is not the same for all series or families, the minimum number being 5. Since not all possible horizons are encountered in all profiles, values for some horizons are omitted or are based on a number of less than 5 profiles.

The figures arrived at are therefore of little statistical significance and are only of indicative value. However, some observations can be made.

Calcium appears to be generally the dominant exchangeable cation present, followed by magnesium, thereafter potassium and finally sodium. This is a universal trend present in most normal soils and this may indicate that even under shifting cultivation a natural balance of nutrients is maintained in these soils. Immature soils on igneous rocks tend to have somewhat more exchangeable magesium than those on sedimentary rocks. This difference is obliterated in more advanced weathering stages probably because of exhaustion of weatherable magnesium minerals. Calcium and magnesium increase in the C and C/R horizons of soils on basic igneous rocks. This may be attributed to the presence of partially weathered rock still containing weatherable minerals. The enrichment of topsoils by bases from decomposing litter is well illustrated.

Potassium is generally low but relatively more present in shale derived soils than in those formed on sandstone. The potassium values in soils on igneous rocks vary with the mineral composition of the rocks and soils developed over rocks rich in biotite (such as the *Gading series*) may show relatively high amounts. As explained, the erratic trends observed in the mean values for the various subsoil horizons are partly caused by the small number of profiles used for the calculations. This may result in a disturbance of a normal trend if one profile appears to be rich in a particular element. The fact that one abnormal profile with somewhat higher values is able to reverse trends emphasizes once again the generally very low base status of most soils.

Natural fertility is maintained by a primary forest cover through the production and decomposition of litter. Released bases will enrich the topsoils and complete leaching is prevented through rapid take-up by existing vegetation. Without a natural vegetation the base reserve present in the soils is rapidly lost, a fact which plays a considerable role in the degradation of soils when overfarmed by wrong shifting cultivation practices (see Chapter 6, section 3, p.97).

The exchangeable nutrients in floodplain soils are usually higher than in upland soils. This is caused by the generally less strongly leached, more immature nature of recent alluvial deposits comprising the bulk of floodplain soils, and the incorporation of organic matter which preserves nutrients which would otherwise have been partially leached. The richest soils in this category are those influenced by brackish water or which have been influenced by seawater in the recent past. Examples of these are the *Pendam series* soils (Profs. 40, p.399; and 43, p.398.

From this discussion, it can be concluded that generally speaking most soils of West Sarawak and particularly those in the uplands, are low in exchangeable plant nutrients. The contents in lowland soils vary and although relatively higher than in upland soils they must be considered to be too low for an adequate performance of most crops. Those soils presently or in the recent past influenced by seawater form the exception.

(d) **Reserve Nutrients**

The content of the easily soluble and less mobile nutrients in the soils are determined by extracting with hot concentrated hydrochloric acid whereafter each element in the extract is quantitatively measured. Values for phosphorus, calcium, magnesium and potassium thus obtained are extracted as 'reserve' in the analyses sheets (Appendix). The extracted iron and aluminium oxides are also commonly analysed and the values are included as 'Group III oxides'. Mean values of reserve nutrients were calculated for each horizon of a number of upland soils in much the same way as has been done for the exchangeable nutrients.

The results are shown in Figs. IV.12a to e (p.240 to p.244) from which the following information can be extracted.

The values for reserve nutrients give a better indication to soil type than the values for exchangeable nutrients and they are therefore useful for classification purposes. Whether the values are also of agricultural significance is difficult to assess with the present information available. Particularly, values for 'reserve' potassium appear to be of some relevance for agriculture.

It is immediately obvious from these histograms that the values for reserve potassium are higher than for other major nutrient in all soils examined. This is very strongly so in soils derived from argillaceous rocks, less strongly so in those derived from sandstone and coarse grained acid igneous rocks and least in the soils derived from basic igneous rocks. The relatively large amount of reserve potassium appears to be strongly related to the clay mineralogy of the soils. Soils with a high illite and vermiculite content give high reserve potassium values while soils with kaolinitic or gibbsitic clay systems show much lower values. From this, it can be inferred that most of the potassium is fixed in between the lattice sheets of illite and vermiculite clays, through which the potassium is prevented from leaching. There is a general increase in reserve potasium from topsoil to subsoil which is most probably caused by the increasing vermiculite/illite content with depth. The breakdown of illite/vermiculite minerals taking place in the more weathered surface horizon causes release of potassium from the mixed lattice or 2:1 lattice clays whereafter it is either leached out or taken up by the plants (see Chapter 10, section 7; p.159).

It can, therefore, be expected that potassium fixed in the mixed lattice and 2:1 lattice clays may eventually become available to plants when weathering progresses. In this connection, it is of interest to note that potassium is commonly least deficient in West Sarawak soils, potassium demanding crops excepting, and this must be attributed to a regular supply of potassium from the clay minerals released upon weathering.

This breakdown of vermiculite is quite easily accomplished in an acid environment by replacement of the potassium ion by hydrogen. In this connection, it may be of interest to note that liming (immobilization of hydrogen) commonly decreases the availability of potassium through increased potassium fixation. This may be largely dependent on the presence of non-exchangeable interlayer aluminium which may gradually disappear upon liming (Black, 1967, p.705).

Next to potassium, the most dominant reserve nutrient present is magnesium. This is probably also related to the presence of vermiculite and 2:1 lattice clays, although quite probably potassium has replaced much of the magnesium in the vermiculite otherwise the soils should have more pronounced swelling properties (see Chapter 15, p.254). Magnesium increases strongly with depth which may indicate that also in the surface horizon magnesium is released from the interlayer exchange sites through breakdown of clay minerals and lost through leaching. Both potassium and magnesium values correlate strongly with parent material and in shale derived soils their contents are often 5 times of those found in igneous rock derived soils. The analyses are therefore very indicative of the origin of a soil.

Magnesium deficiency is commonly encountered in the cultivation of pepper. This may be largely due to the large amounts of potassium which are commonly applied for a highly demanding crop like pepper and may be caused by a nutrient imbalance. The addition of dolomite (magnesium limestone) is generally beneficial if applied together with a complete compound fertilizer (A.R.R.B. 1969, 91-113). Probably both, calcium and magnesium play a role in the response obtained by the addition of dolomite.

Calcium is usually lowest in the reserve nutrients. This is to be expected since calcium is not fixed by clay minerals and easily leached out. The LATERITIC SOILS, derived from basic igneous rocks, appear to have highest values for reserve calcium. This is probably related to the initial high content of Ca-bearing plagioclase in these rocks while sedimentary rocks commonly have a very low content.

The phosphate status in these soils is discussed in more detail in section (f) but it is worth mentioning here that whereas high potassium and magnesium values commonly indicate an argillaceous rock derivation, high reserve phosphate figures denote a basic igneous rock derivation. This is well illustrated by Fig. IV.12a. This is caused by the high content of occluded phosphates in the soils on basic igneous rocks. These phosphate compounds are inert and the phosphate thus fixed is prevented from leaching.

(e) **Nitrogen**

Nitrogen is not inherited from the parent material but adsorbed from the atmosphere through the vegetation and the activity of micro-organisms. Little investigations have been carried out on the form of nitrogen present in Sarawak soils. This is regrettable since in all soils nitrogen is probably after phosphorus most deficient. The low total nitrogen values generally found in Sarawak soils is caused by the generally low organic matter content. Most nitrogen formed is probably rapidly oxidized because of prevailing high temperatures. This process may be accelerated by the low pH (Black, 1967; p.466). It can, however, be remarked that the C/N ratio's of most soils appear to be reasonably low (less than 15). This would be favourable for nitrogen mineralization but the amount of organic matter present is very small. In PODZOLS and strongly podzolized soils the C/N ratio's are high while also the organic matter content is high. This may indicate that mineralization of humus and oxidation of nitrogen is quite rapid in the non-podzolized soils while these processes are much retarded in the PODZOLS because of the high lignin content of the humus.

The slow rate of humus mineralization caused by a high lignin content is probably also responsible for the accumulation of lowland peats.

Because of the little information available on these aspects it is not possible to discuss this in further detail.

(f) **Phosphate Status**

Experimental work carried out with a wide range of crops (A.R.R.B. 1963-69) has indicated that phosphorus is a limiting factor for many crops in Sarawak, but particularly in rice. Phosphate and nitrogen deficiencies appear to go hand in hand and with the application of phosphorus fertilizers nitrogen deficiency is the first to appear.

(i) **Phosphorus Forms**

Phosphorus fractionation studies (A.R.R.B. 1964) show that the main forms of phosphorus in most residual soils are in decreasing order: occluded P-organic P-iron P. For most alluvial soils this is in decreasing order: organic P-occluded P-iron P. The observation is made that the alluvial soils used in these studies were of a hydromorphic nature. One soil in the alluvial group being much similar to the upland soils was a dry RECENT ALLUVIAL SOILS (*Malang series*, p.192). The position of aluminium P is not mentioned in this range, but from the tabular matter present it is inferred that aluminium P occurred almost in the same order as calcium P and was generally very low in most soils. Topsoils, however, appeared to show the highest values.

In order to assess the relevance of these findings for West Sarawak soils, it should be mentioned that the upland soils used in these studies comprised a LATERITIC SOILS (*Tarat series*, p.336) and coarse to medium textured RED-YELLOW PODZOLIC SOILS, not derived from shales. These results therefore are not relevant to the great majority of upland soils, namely those derived from shales. This may also be the cause of the low aluminium phosphate figures reported, since the soils on argillaceous rocks generally show the highest values for active aluminium compounds and these were not studied. The high aluminium phosphate reported for the topsoils may be related to the presence of X-ray amorphous compounds, thought to be mainly aluminium oxides. The occurrence of these compounds is discussed in detailed in Chapter 15, section 1, p.254).

(ii) **Easily Soluble Phosphate**

The easily-soluble phosphate in Sarawak soils is extremely low. It is probably highest in the GLEY SOILS where most of the phosphorus occurs in the organic and therefore available form. It is possible that some of the easily-soluble phosphorus may be bound to aluminium.

According to Bailey (1967, p.47) the 'available phosphate' in topsoils of the *Semongok series* shows a linear correlation with aluminium bound phosphate and this form of phosphate may give a useful prediction to crop response. Phosphorus in the aluminium form may therefore become available in time. Its availability is probably linked to weathering processes in soils but it may also enter into the occluded form in which it is permanently unavailable.

(iii) **Unavailable Phosphate**

Although the 'reserve phosphate' in some Sarawak soils may be relatively high such as in the LATERITIC SOILS (Fig. IV. 12a.), the fact that most of it is found in the occluded form indicates that these high values are agriculturally meaningless since this phosphorus will be unavailable. The high amounts of occluded phosphorus found in the upland soils indicate strong chemical weathering. This is largely confirmed by other chemical characteristics (Chapter 10, p.136). The observation that less occluded phosphorus occurs in the GLEY SOILS also corroborates earlier statements that the alluvial soils are less weathered than the upland soils.

Because of the unfavourable phosphate status of most West Sarawak soils, the application of phosphate fertilizers is one of the first measures to be taken to raise crop yields and in this connection the phosphate retention or fixation rate of a soil becomes an important characteristic. This factor is therefore discussed in some detail in the following paragraphs.

(g) **Phosphorus Retention** (fixation)

Phosphorus retention studies carried out by the Chemistry Division of the Department of Agriculture (A.R.R.B., 1962/63, p.52-58; and A.R.R.B., 1964, p.59-70) have shown that fixation of phosphate is highly significant in Sarawak soils. The phosphate retention (hereafter referred to as P. retention) figures shown in the analytical data on West Sarawak soils confirm this. The magnitude of the P. retention however is highly dependent on the chemical composition of the soil type.

As a result of the studies carried out in 1962/63, the Chemistry Division indicates that for soils having an average cation exchange capacity of 6.6 meq. 100 gm fine earth, an excellent relationship was found between the amount of phosphorus absorbed and the amount of hot concentrated hydrochloric acid extractable group III oxides (mainly iron and aluminium oxides). No such relationship was found in soils having an average cation exchange capacity of about 12.6 meq. 100 gm fine earth, but for the latter soils, particularly those derived from shales, there is a relationship between exchangeable aluminium and phosphorus retention (A.R.R.B. 1962/63).

Studies carried out in 1964 indicated that the correlation between HC1 extractable Group III elements as oxides and phosphorus retention is generally good and highly significant (*op. cit.*, 1964). The results of these two studies seem to contradict each other in some way but this is probably caused by the fact that in the early study a wide range of soils was involved and correlations were based on the mean values obtained from the various horizons of each profile, while in the latter study only topsoils of a much smaller range of soils were used. Therefore, the studies conducted in 1962/63 have more relevance to genetic soil types than those of 1964.

If the relationship between HC1 extractable Group III elements as oxides and phosphorus retention is a simple one than this would also be present in all horizons of each individual profile.

Fig. IV.13 (p.251) shows that this is not the case. In fact, in the RED-YELLOW PODZOLIC SOILS, there is an inverse relationship between Group III and phosphorus retention throughout the profile. Phosphorus retention decreases in the lower horizons while HC1 extractable Group III elements increase. The *Tarat* profile (LATERITIC SOIL) is the only soil in which the correlation is more or less positive and this profile belongs to the group of soils which according to the Chemistry Division's findings in 1962/63 have an average C.E.C. of less than 6.6 meq. 100/gm fine earth.

The discrepancies are probably caused by the fact that the relationship between HC1-extractable Group III elements as oxides and phosphorus retention is highly influenced by the extraction method used for the sesquioxides. It is calculated from the total chemical composition by sodium carbonate fusion that HC1-extractable Group III elements as oxides represent 50%, to in cases more than 90% of the total Fe_2O_3 and Al_2O_3 present in the soil. The percentage appears to be related to soil type. HC1-extractable Group III elements as oxides are further highly related to clay content in that a high clay content correlates with a high HC1-extractable Group III content and although soils may have a relatively high content of iron oxides as e.g. the *Gading series*, the HC1-extractable Group III content is low if the clay content is low. It is, therefore, concluded that most of the Al_2O_3 extracted in the HCl-extractable Group III analysis is related to clay breakdown, caused by the concentrated hydrochloric acid, and to aluminium oxides present in the clay fraction.

This may also explain the difference in relationship between phosphorus retention and HCl-extractable Group III elements as oxides for the different genetic soil groups because the clay mineralogy in the latter varies. In some soils the aluminium in the clay fraction is highly active while in others it is not. This difference is also present between horizons of each single profile since surface horizons appear to have more chemically active aluminium compounds than subsoils. (High X-ray amorphous compounds, and high contents of aluminium P).

Sherman (1962, p.31) divides the clay mineral systems of soils into four groups;

(i) *Ionic system*

This system is of no relevance to West Sarawak soils.

(ii) *Amorphous system*

A highly hydrated colloidal system ranging from a gel to a relatively stable hydrous colloidal oxide, but lacking in atomic order so that it cannot give thermal characteristics of a mineral or X-ray diffraction patterns.

(iii) *Cryptocrystalline system*

A system of hydrous oxides of a high degree of purity, possessing sufficient lattice arrangement to give thermal characteristics of a mineral, but lacking in lattice orientation to provide identification by X-ray techniques.

(iv) *Crystalline system*

A system of relatively pure compounds having well developed atomic structures with lattice orientation which will identify it as a mineral by both thermal characteristics and X-ray diffraction patterns.

Transitions between the systems occur, since they are never pure. The clay mineralogical investigations of West Sarawak soils (Chapter 15, section 1, p.256) indicate that the heavy textured members of the GREY-WHITE PODZOLIC SOILS and the RED-YELLOW PODZOLIC SOILS generally have a Crytocrystalline system transitional to an Amorphous one. Lower horizons attain more the characteristics of a Cryptocrystalline system.

The LATERITIC SOILS and light-textured members of the RED-YELLOW PODZOLIC and GREY-WHITE PODZOLIC SOILS have a Crystalline system although a transition to a more Cryptocrystalline system is noticeable in the surface horizons.

According to Sherman (*op. cit.*) the composition and activity of the amorphous system are reflected in the physical and chemical properties since the chemical activity decreases from the ionic system to the crystalline system.

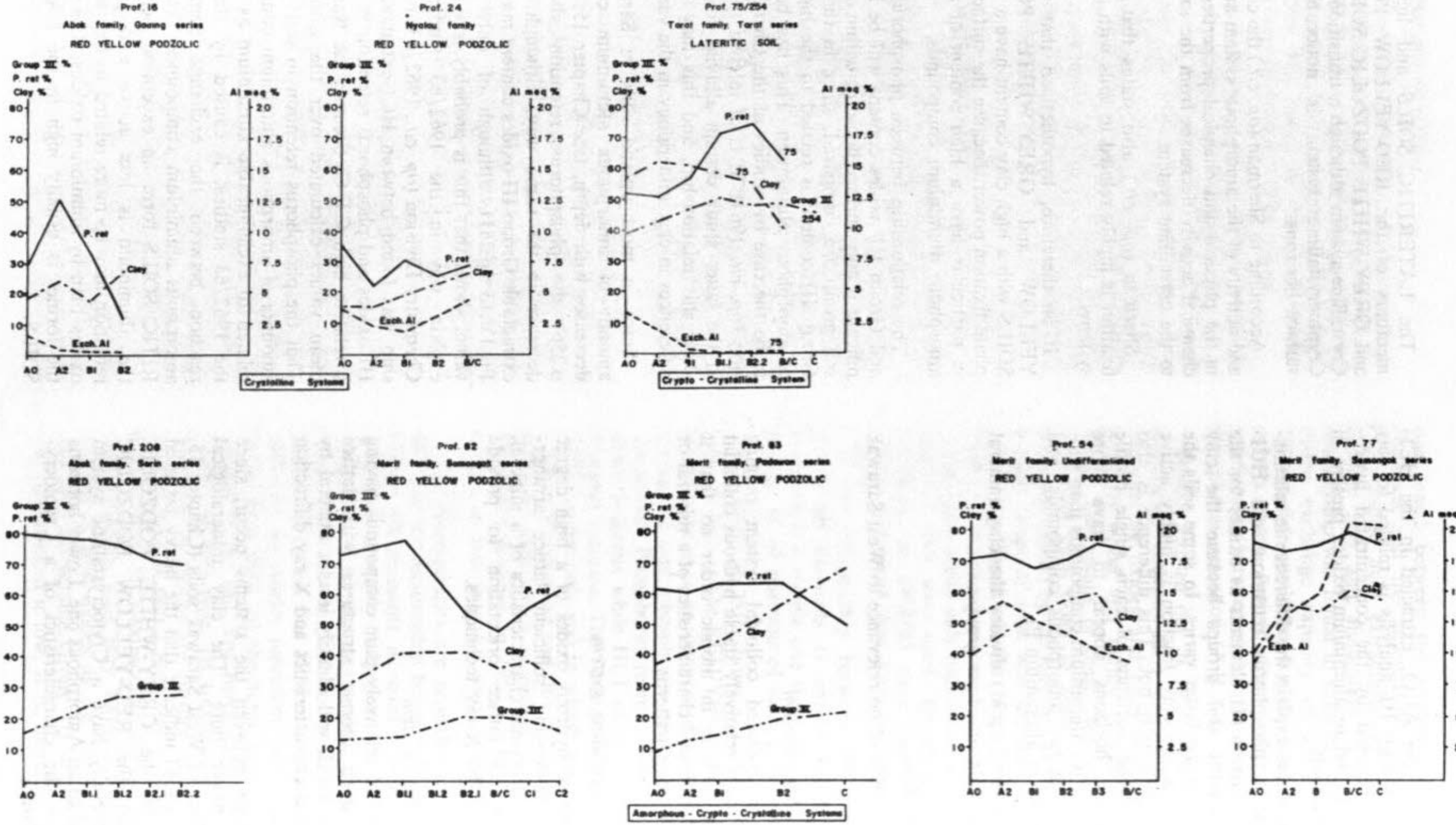
Sherman (*op. cit.*) also states that phosphate fixation is highly related to soils with amorphous systems.

It is, therefore, hypothesized that the RED-YELLOW and GREY-WHITE PODZOLIC SOILS with a high clay content have a high phosphate fixation power, because the surface horizons in particular have a high content of active and amorphous aluminium compounds.

The relationship between phosphorus retention and Group III oxides content will be highly significant if only surface horizons within one genetic soil group are compared, since in this case the Group III content is related to the high amount of amorphous aluminium. This has been shown to be the case by studies of the Chemistry Division (*op. cit.* 1964). It is of interest to note that in the latter study certain alluvial soils did not show this relationship, and this may be due to differences in clay mineralogy in the various soils.

Since in most upland soils of Sarawak, the amount of amorphous aluminium compounds decreases with depth, (see Chapter 15, section 1, p.256) the phosphorus retention should also decrease in the same way, although the HCl-extractable Group III oxides content may increase. Fig.IV.13 (p.251), although of only indicative value, shows that this is probably true. This may explain why in the 1962/63 studies of the Chemistry Division (*op. cit.*, 1962/63) no relationship was found between HCl-extractable Group III oxides and phosphorus retention in soils with a relative high C.E.C. because use was made of mean values calculated over the whole profile. That the phosphorus retention in soils with high amounts of amorphous aluminium compounds is related to exchangeable aluminium as shown by the 1962/63 studies, is caused by the intimate reaction between the exchange complex and amorphous aluminium compounds. The LATERITIC SOILS form an exception here because the aluminium is less active and phosphorus retention may be more related to fixation by iron oxides than by aluminium oxides. The content of the former is usually high in the LATERITIC SOILS.

Fig. IV. 13 Relationships between Phosphate retention and mineral systems in Lateritic and Podzolic soils



For this reason, in the LATERITIC SOILS the HCl-extractable Group III oxides are probably more related to iron than to aluminium and a correlation between HCl-extractable Group III and phosphorus retention may be significant. The *Tarat* profile in Fig.IV.13 shows this trend.

For a complete understanding of phosphate fixation the available information is yet insufficient. Much more data on the nature and characteristics of the active mineral part of the soil is needed, particularly quantitative clay mineralogical analyses.

The conclusion drawn by the Chemistry Division (A.R.R.B., 1964; p.62) that strong red and yellow colours in upland soils commonly imply high fixing power of phosphate cannot be corroborated by the author. Characteristics such as clay mineralogy and texture are probably of more importance.

With the available information one could place the main genetic soil groups into four categories showing decreasing phosphorus fixation.

Category I	—high P. fixation	—Heavy textured families of the RED-YELLOW and GREY-WHITE PODZOLIC SOILS.
Category II	—moderate P. fixation	—LATERITIC SOILS.
Category III	—moderate to low P. fixation	—Light textured families of the RED-YELLOW and GREY-WHITE PODZOLIC SOILS.
Category IV	—low P. fixation	—REGOSOLS and PODZOLS.

Very little information is available on the GLEY and SALINE-GLEY SOILS and they have, therefore, been omitted.

It should be realised that the foregoing discussion is based on laboratory investigations in which maximum phosphate fixation is achieved by a thorough mixing of the soil with a phosphate compound. In reality, such a thorough contact of soils and fertilizers never occurs and therefore the measured P. retention of a soil is only a relative indication of its ability to fix phosphate.

In experimental work with crops frequently no responses to phosphate fertilizers are reported.

The following relevant information was extracted from the Annual Report of the Research Branch for 1969.

'Pepper shows a significant response to phosphate on the *Semongok series,* but on the *Serin series* no response is obtained but there are indications that yields increase slightly with increasing amounts of phosphate'. On the other hand, coffee and lemon grass give no response to P and K' P. retention alone therefore is never a good indicator to probable fixation of applied phosphorus under field conditions.

The reactions and interactions are more complex than under controlled laboratory conditions. Moreover, the phosphate demand of the crop is an important factor. Therefore, all what can be stated for the present is, that the response to phosphorus fertilizer under field conditions will probably increase in the Categories I to IV. This will also depend on the placement, the amount and the nature of the applied fertilizer, the crop type, and whether other nutrients are applied simultaneously. In the latter case, interactions do start to play a role as well.

To restrict a possible fixation of phosphate, the Chemistry Division (*op. cit.,* 1964) recommends to place phosphate fertilizer rather than to broadcast it. This practice would be particularly valuable for soils in Categories I and II.

Liming, which is generally advocated in temperate regions to curb phosphate fixation may be economically less useful in the tropics. Sherman (1962, and Monteith and Sherman, 1962) state that applications can be high on soils with amorphous systems because the effect of liming on the chemical activity of a gel containing Al, Fe, Si, and Ti, will be very small. However, they recommend liming on soils with a crystalline system such as the LATERITIC SOILS but applications should be done such that a pH of 5.5 is not exceeded.

(h) **Conclusions**

One may conclude from the foregoing discussions covering the chemical aspects of soil fertility, that the chemical fertility of West Sarawak soils must in general be rated as low to very low. Although soil types may show differences in chemical fertility the range is very small indeed and probably not of distinct agricultural significance. This would mean that all soils require adequate amounts of applied fertilizers for sustained high yields. With the necessity to grade up the chemical fertility of most soils, other characteristics than those related to chemical fertility become important. These concern the nature of the clay mineral part of the soil, the drainage status, texture, structure and porosity which together form what has been termed the 'physical aspects of soil fertility.'

3. **Physical Aspects of Soil Fertility**

(a) **Structure**

It is surprising to note the great qualitative and quantitative variations existing in natural forest stands on virgin soils showing no significant differences in chemical fertility. It should, however, be realised that the growth rate of plants is not only dependent on the availability of plant nutrients but also on the compactness of the soil r the bulk density. Trouse and Baver (1962, p.258-63), showed that in LATOSOLS root longation was considerably retarded with a bulk ensity of more than 1.12 g/cc, although this igure may not be the same in all soils. The general massive structure, characteristically found n shale derived soils (*Semongok series, Padawan series* and *Kerait series*) may result in retardation of root development, particularly in subsoils. In this connection, it is of interest to note that Watson (A.R.R.B., 1967, p.98) reports that the growth rate of rubber on light textured, porous **Nyalau Family** soils is better than on the generally chemically more fertile but heavy textured and massive structured **Merit Family** soils. He mentions also that drainage appears to play an important factor in the rate of growth, thus that the well drained **Merit** soils perform better than the imperfectly drained ones. Whether the same will be true with latex yields can only be ascertained by experimental means. However, these observations stress the point that well-aerated soils with probably few available nutrients per volume unit of soil can show a better crop performance than massive structured soils with a much better amount of available nutrients per volume unit of soil. The general good stand of primary jungle on well-aerated soils such as the **Nyalau Family** may well be due to the well developed root systems of the vegetation through which the plants are able to obtain nutrients in sufficient quantities from a large volume of soil. However, because of the open structure of such soils leaching will be more severe and these soils will loose their natural fertility rapidly after the primary forest has been removed. Leaching will be less rapid in the more massive structured soils, partly because the water penetration rate is slower, partly because the clay content enables the soil to retain more bases. Possibly for this reason, clay soils are generally preferred for shifting cultivation as the regeneration of forest will be relatively more rapid than that on sandy soils. Other factors such as weed infestation are of course playing a role as well but are not considered here.

The same effects will be noted if artificial fertilizers are applied. Namely, the sandy soils will perform well if adequately fertilized, but the leaching rate will be much higher. A good structure and adequate clay content are therefore favourable soil properties. Such characteristics must probably be rated higher in West Sarawak soils than content of available nutrients, which is low in any case, since these physical properties are important in assessing the economics of applying fertilizers. In any soil suitability classification therefore due attention must be paid to such factors which are permanently influencing the economics of farming.

(b) **Drainage**

A badly aerated soil impairs root development. Plants are therefore limited in their ability to take up plant food from horizons which are poorly drained (wet rice probably being the only exception). Although the chemical fertility may be high, without essential good growing conditions crops will perform badly. Improvement of drainage is therefore necessary if the natural fertility of a soil is to be fully exploited.

Since the most fertile soils in Sarawak are for the majority GLEY SOILS characterised by poor drainage conditions, the provision of good drainage is an essential prerequisite for a full exploitation of the natural fertility of these soils. The expenses for drainage requirements will considerably influence the economic feasibility of farming on such soils.

(c) **Colloidal Fraction**

The nature of the colloidal or clay fraction greatly influences the soil structure and the soil permeability. If the clay fraction is dominated by well crystallized iron and aluminium oxides, such as in the LATERITIC SOILS, a good open structure normally develops. These soils generally have crumb structures and are very friable. If 2:1 lattice or mixed layer clays are dominant, massive structures commonly form when the soil is moist, while the structure is strong coarse blocky to prismatic when dry. Drainage is normally retarded in such soils. Because of the swelling properties of the latter clays the soils show signs of stress when moist. In Sarawak, 2:1 lattice and mixed layer clays are generally only present in moderate to small amounts and mainly in soils derived from shales. It is possible that the drainage phases encountered in these soils may be related to the nature of the colloidal fraction.

It has also been observed that clay soils with a low iron content generally have massive structures (e.g. *Kerait series, Padawan series*) and the total iron content of the clay fraction may therefore be important for the development of a favourable structure. The clay mineralogy, apart from influencing the physical characteristics of soils, will also have a bearing on the fixation and adsorption, than well leaching of applied nutrients.

The physical characteristics of Sarawak soils have been little studied but it should be clear from this brief discussion that detailed investigations are well worth considering. Although the physical properties of soils are studied in the field by visual observations, the qualitative and quantitative aspects of structure, bulk density, porosity and moisture retention etc. should in future receive more attention, because they appear to be as important for soil fertility as the chemical properties, particularly when the fertility status is low.

Chapter 15. SPECIAL INVESTIGATION

1. Mineralogical Analyses

The study of the soil mineralogy covers two aspects, the mineralogy of the coarse particles-sand mineralogy, and that of the fine particles-clay mineralogy. To study the sand mineralogy the sand fractions were separated from the soil, treated with hydrochloric acid and hydrogen peroxide to remove carbonates, iron and humus coatings so that the minerals can be examined under a polarizing microscope. For studying the clay mineralogy the fraction smaller than 2 micron were separated and treated with hydrogen peroxide and hydrochloric acid to remove interfering humus and iron. The clay was studied by using X-ray Diffraction (photography) and Differential Thermal Analysis (D.T.A.).

(a) Sand Mineralogy

(i) General

An investigation of the sand mineralogy serves several purposes. Firstly, by examining the mineral assemblage it is possible to detect in a soil profile whether all horizons are autochthonous or whether foreign material has been incorporated in the soil to a certain depth. This helps interpretation of the chemical analyses and their pedogenetic significance can be more accurately assessed.

Secondly, the mineral assemblage may reveal from what type of parent material the soil has derived and this information may be useful for soil mapping and classification.

Thirdly, the sand mineralogy gives an indication of the potential fertility of the soil, since it shows whether there are still weatherable minerals in the soil which release nutrients to the plant upon weathering.

(ii) Methods

For the sand mineralogical examination the methods advocated by Mohr and v. Baren (1954, p.219-22) were employed with the following modification. Instead of studying all the separate sand fractions, only the fraction 500 to 250 micron and in some cases the fraction 500 to 100 micron were studied. Most sand in West Sarawak soils falls into these fractions.

Previous investigations on heavy sand fractions carried out in 1962 by the Royal Tropical Institute in Amsterdam indicated that the main soil types of Sarawak did not contain any weatherable minerals or at least they were so scarce that the effect on soil fertility must be considered to be negligible or non-existent. The light minerals with specific gravity of less than 2.9 comprise mainly quartz and muscovite, the latter mineral occurring only in a few soils. For this reason, in subsequent work carried out by the author only the heavy mineral fractions were selected for investigation. The heavy minerals were mounted in Canada balsam for petrological examination.

For the analyses, the line-count method was used. According to Mohr and van Baren (*op. cit.*) a count of one 100 non-opaque minerals gives an accuracy within 5%.

It appeared that samples of some soils, notably the clay soils, did not yield sufficient heavy minerals for a 100 count and for these samples a qualitative assessment of the mineral association was made.

(iii) Results

The complete mineralogical analyses for the main soil types are given in the Appendix together with other analytical information.

(iv) Discussion

The investigations indicate that the heavy mineral associations of West Sarawak soils are poor in species. In all not more than 25 mineral species occur and only 5 of them regularly. Further, the amount of heavy minerals in most soils is very low and in most cases a considerable quantity of sand was needed to separate an adequate amount for analysis.

Opaque minerals

The opaque/non-opaque ratio is generally greater than unity. Of the opaque minerals, ilmenite is dominant. The habit of ilmenite varies but is commonly euhedral. Fresh minerals of this species can be observed near the source of its derivation either in autochtonous soils on igneous rocks or in recent alluvials derived from them. The coastal soils between Pueh and Santubong in particular contain large amounts of fresh euhedral ilmenite derived from the adamellite of Bukit Gading and Bukit Pueh. Soils over sedimentary rocks and alluvials derived from them generally have a large percentage of rounded ilmenite but euhedral forms may still be found. Of specific interest are the many transitional forms of ilmenite to the titaniferous minerals such as anatase, rutile and brookite. In most samples these transitions have been labelled leucoxene but for some profiles they have been named alterites. The latter name was used by the Royal Tropical Institute for these transitions found in soil samples which date from 1962. Samples of that date have been given laboratory numbers without a letter code. The author has tried to differentiate between alterites which are titaniferous transitions from ilmenite and those which are skeletal forms of other minerals. The latter no longer show characteristics of the original mineral because of intense weathering. The former have been labelled leucoxene but probably some of these may be either brookites or anatase or transitions to them. A separation of these from leucoxene has not been attempted because of inadequate equipment and lack of time.

Andriesse (1970, pp.271-73) reports on the apparently rapid change from ilmenite to leucoxene in the coastal sands at Sematan. This transition which occurs mainly through release of iron from the ilmenite crystal structure is considered to be the cause of the red colouration of the sands because other iron bearing minerals are absent. Subsequent investigations have revealed that the *Lingga series* (Prof. 332, p.371) developed over iron poor microgranite contained no appreciable amounts of ilmenite. Similarly, the *Kerait series* (Prof. 425, p.300) is also almost devoid of ilmenite. Both soils belong to the GREY-WHITE PODZOLIC SOIL GROUP which are considered to be identical to the RED-YELLOW PODZOLIC SOIL GROUP except for the very pale to white colours in the former. The heavy sand fraction of the LATERITIC SOILS, **Tarat Family** consists mainly of ilmenite and other iron oxides, only traces of non-opaque minerals. The strong red colouration of these soils may be partially caused by the iron derived from the ilmenite. These observations therefore substantiate the conclusion reached by Andriesse in 1970 (*op. cit.*) that the ilmenite of the parent material may be mainly responsible for the rubefaction process in at least some upland soils of West Sarawak.

Non-opaque minerals

Of the non-opaque minerals zircon and tourmaline appear to occur most abundantly. Depending on the parent rock either zircon or tourmaline may be dominant. Frequently tourmaline is dominant in the larger grain sizes while zircon tends to concentrate in the smaller fractions. This is particularly evident in coastal deposits and is probably caused by selective sorting during sedimentation due to a difference in specific gravity, the zircon being heavier. The zircon minerals are often specific in habit, for example, in the recent shore deposits at Lundu-Sematan, zircon appears as small perfect euhedral minerals. They are probably derived from clusters of similar zircon which occur as inclusions in the large biotite accumulations in the adamellite of Bukits Pueh and Gading (Wolfenden, 1963, p.82). This zircon is released upon weathering of the biotite. Rounded zircons are common in soils formed on sedimentary rocks but they may occur together with fragmented euhedral ones. The occurrence of rounded zircon in RECENT ALLUVIAL SOILS generally indicates a relationship with sedimentary rock sources, for example, the *Terbat series* (Prof. 209, p.320) which was thought to be of basaltic origin appears to be underlain by material partly derived from sedimentary rocks as revealed by the rounded zircons.

The colour of the zircon is also significant. Pink, rounded zircons of apparent old age occur dominantly in some Triassic sediments (see Prof. 172, p.295). The Tertiary rocks also contain some of these pink rounded zircon but there they are not dominant. There is therefore, a possibility that the Triassic sediments may have contributed to the Tertiary sediments. In the Cretaceous sediments they are almost absent. They, however, occur again in some quantity in the older alluvial soils which are mainly derived from Tertiary sediments.

Tourmaline occurs as one of the dominant minerals in the heavy sand fraction in most of the examined profiles, but in some soils abundant tourmaline may occur as in the *Gading series* occurring near pegmatitic veins, in which tourmaline may be the only mineral present. Such a high content of one species normally indicates proximity to its source. Tourmaline occurs both as euhedral, fragmented and rounded crystals, the former being dominant. Brown and green varieties normally occur, but blue tourmaline occurs conspicuously in some localities, particularly in the Lundu area where it is mainly derived from metamorphosed sedimentary rock types.

Andalusite and sillimanite appear to be excellent index minerals to show a certain derivation. In the metamorphosed rock types in the Lundu area where they are most common, sillimanite is conspicuous near the contact zones with the adamellite, proving that the sedimentary rocks are older than the adamellite. The very localised occurrence of the source rock of sillimanite makes it a specific mineral to indicate derivation. Andalusite occurs more widespread but is normally present in all soils derived from the metamorphosed sedimentary rocks in the Lundu area.

The occurrence of excellent species of andalusite (chiastolite) showing red pleochroism in the shore deposits between Pueh and Santubong indicates that the metamorphosed sedimentary rocks in the Lundu area have contributed to these shore deposits. Through coastal drift they have moved from west to east, the andalusite in these deposits becomes gradually of less significance east of Lundu.

Epidote occurs in small amounts and often in combination with andalusite. In the *Padawan series* (Prof. 198, p.288) developed over Cretaceous shales large epidotes are dominant. This may indicate either local metamorphism in the sedimentary rocks or the sediments were enriched from an igneous source nearby during the Cretaceous. These perfect euhedral epidotes are little affected by transport and since it occurs in association with perfect large brookite minerals probably derived from igneous rocks, the epidote is also thought to be anthochtonous.

Green hornblende mainly occurs in recent sediments. It is the most weatherable of the heavy minerals found in West Sarawak soils and it is not found in the older deposits and the strongly weathered upland soils. Most of the hornblende present in soils is of acid or basic igneous rock derivation. Hornblende occurs abundantly in coastal sands near Sibu Laut, and it is probably related to the occurrence of basic igneous rocks at Pulau Salak which may have contributed to the coastal sands nearby. Green hornblende is also prolific in the *Ramun series* (prof. 242, p.319) derived from basic to intermediate igneous rocks.

As indicated before, titaniferous minerals such as anatase, rutile and brookite occur in relatively large amounts in most West Sarawak soils, although there is a tendency that in soils of the older sedimentary rocks they are more dominant. This may indicate that the transition of ilmenite to titaniferous minerals occurred *in situ* and was stretched out over long geological periods. Quite probably the older sediments have contributed little to the material of younger sedimentary rocks. Otherwise, the most recent sedimentary rocks should contain more titaniferous minerals than the older ones.

Garnet is a conspicuous mineral in coastal soils of the Lundu-Sematan area where it is derived from the adamellite of the Pueh and Gading massifs which is the only rock type in the area containing appreciable amounts of this mineral.

Monazite is a specific mineral occurring only in the *Lingga series* (Prof. 332, p.371). Its occurrence was also reported by Haile (1954, p.36) and it is derived from the microgranite building the Lingga mountain. Muscovite belongs to the group of light minerals on account of its specific gravity but was frequently detected in the heavy mineral separates It occurs in some soils, notably in those derived from schistose Triassic shales and sandstones and in mudstone of Tertiary Age. It also occurs in abundance in sands in the Sematan-Lundu area but there it is derived from the adamellite of the Gading and Pueh massifs.

(v) *Conclusion*

The sand mineralogical investigations have revealed that the soils in West Sarawak are extremely poor in weatherable primary minerals and hence in nutrient reserves. Most materials from which the soils have derived are of considerable age and have been thoroughly weathered. Heavy mineral associations in soils are poor in species and therefore, apart from some specific minerals like monazite, sillimanite and andalusite, are generally not indicative of derivation. This is particularly so where sedimentary rocks are concerned. A more detailed study of the habit and colour of some minerals such as zircon may be more helpful. Therefore further work should be concentrated on detailed characteristics of some minerals, such as colour, form and size.

Except for establishing proof that some soils are bisequent, the use of the heavy sand mineralogy for detailed classification purposes shows little prospect. The only significant fact which the analyses have revealed is that most soils examined have less than 1% weatherable minerals in the sand fraction and must therefore be classified as oxic in terms of the 7th Approximation (U.S.D.A 1967, p.63).

Even the RECENT ALLUVIAL SOILS examined do not contain appreciable amounts of weatherable minerals, with the exception of hornblende in some coastal soils, *Sematan* and *Siru series* and in the *Ramun series* derived from intermediate igneous rocks The sand mineralogy therefore, does generally show insufficient diagnostic characteristics to justify its application to soil classification at a level lower than the Orders. Most soil groups have more or less the same association of minerals which are strongly resistant to weathering and if there are differences then these are related to type of parent material rather than to pedogenetic processes or age. Probably the only soil group which shows a specific mineral suite is the group of LATERITIC SOILS which contains almost exclusively opaque minerals. This is to be expected since the group is found exclusively on basic to intermediate igneous and related rock types, in which very few or no detrital minerals are normally found.

(b) Clay Mineralogy

(i) General

Clay mineralogical studies were initiated in 1961 on a number of selected profiles of Sarawak soils comprising LATERITIC, RED-YELLOW PODZOLIC, GREY-WHITE PODZOLIC, GLEY and RESENT ALLUVIAL SOILS. Some of these profiles are shown in the Appendix under reference nos. 216 (*Tarat series,* p.336), 92 (*Antayan series,* p.339, 424, (*Abok series,* p.347), 418 (*Bedup series,* p.355), 423 (*Matang series,* p.299), 499 (*Malang series* p.413) and 157 (*Kayan series,* p.406). These studies involved Differential Thermal Analyses only

The results indicated that the clay fraction of all these soils is dominated by a type of fire clays, while limonite occurred in a fair amount in most samples It was reported that the clays contained considerable amounts of organic materials responsible for exothermic reactions in the 200-500°C range. Results obtained by other independent research workers (Wood and Beckett, 1961; Clare *et al.*, 1965) did, however, indicate that quite a number of Sarawak soils contained considerable amounts of 2:1 lattice and mixed lattice clays and further studies into the clay mineralogy were therefore resumed in 1968 and continue until the present day.

Since it was suspected that the results obtained in the 1961 studies suffered from the omission of X-ray Diffraction analyses such analyses were combined with the D.T.A. analyses in studies carried out since 1968. The latter largely confirmed the earlier formed impression that the D.T.A. curves in the 1961 studies were partially probably erroneously interpreted. This probably as a result of organic matter, particularly in the 100-500°C tract which probably masked the endothermic reactions indicative of the presence of X-ray amorphous materials, illite, vermiculite and gibbsitic materials. The latter clay minerals appear to be present in fair amounts in quite a number of samples, as shown by the 1968-70 studies. It would therefore be best to ignore the results obtained in the 1961 investigations.

(ii) **Methods**

Most clay mineral analyses were carried out by the Royal Tropical Institute in Amsterdam.

For the D.T.A. determinations in the 1968 to 1970 period, a home built oven with Pt/Pt-10% Rhodium thermocouples connected to Philips amplifiers and recorders was used. Use was made of a nitrogen controlled atmosphere to suppress the exothermic reactions due to organic matter still present after treatment with H_2O_2. The heating rate was 10°C per minute.

A Philip's camera using a CuKα radiation was employed for the X-ray diffraction analyses. The general crystallization of particularly the 2:1 lattice and mixed layer clays made it necessary to repeat X-ray analyses with various pre-treatments (heating, glycol, K and Mg saturation) in order to determine swelling properties.

(iii) **Results**

The results of the investigations are shown in a coded form in the analytical data sheets of the profiles studied (Appendix) but a more detailed account of the clay mineralogy is given here:

LATERITIC SOILS

Bukit Batu series (Prof. 361, p.276)

Gibbsite occurs dominantly in the whole profile. Small amounts of kaolinite are present in the whole profile. Small amounts of vermiculite are present but mainly in the subsoil. The content of X-ray amorphous materials, probably aluminium oxides mainly, is fairly high in surface horizons.

Tarat series (Prof. 254, p.275)

Poorly crystallized kaolinite is dominant in the whole profile, but it is best crystallized in surface horizons.

Small amounts of vermiculite are present in the topsoil. Subsoils contain larger amounts and may contain montmorillonite. Another possibility is the presence of a mixture of chlorite-illite-vermiculite. The latter is more likely since the parent rock, being a serpentinised andesite, is rich in chloritic material. A fair amount of gibbsitic material and other aluminium and iron oxides is present. X-ray amorphous material, mainly aluminium oxides, is present in the surface horizons mainly.

Tarat series (Prof. 75, p.272)

Poorly crystallized kaolinite is dominant in the whole profile; especially in the subsoil. Very small amounts of vermiculite are present, as are a fair amount of gibbsite and X-ray amorphous materials.

RED-YELLOW PODZOLIC SOILS

Gading series (Prof. 16, p.279)

Well crystallized kaolinite is dominant in the whole profile. Important admixtures of aluminium oxides are present, best crystallized as gibbsite in the surface horizons. In the subsoil possibly also other aluminium oxides (nordstrandite?) are involved. A fair amount of goethite and boehmite is present and the contents increase with depth.

Gumbang series (Prof. 76, p.280)

Kaolinite and vermiculite are dominant in the whole profile. The degree of crystallization decreases with depth. Some gibbsite is present. .

Stass series (Prof. 54, p.283)

Moderately crystallized kaolinite is dominant. A rather high amount of vermiculite is present in the whole profile as are traces of gibbsite, the latter mostly in the C horizon.

Stom series (Prof. 25, p.291)

Poorly crystallized kaolinite is dominant. Some vermiculite occurs in the subsoil. A fair amount of gibbsitic material is present and also some boehmite, probably mixed with goethite. X-ray amorphous material is present in all samples, but particularly in the B horizon. Some quartz is present but only in the topsoil.

Semongok series (Prof. 77, p.284)

Rather well crystallized kaolinite is dominant. A rather high amount of vermiculite is present, as are important admixtures of quartz, the content decreasing with depth. Traces of gibbsite are present.

Padawan series (Prof. 198, p.288)

Rather poorly crystallized kaolinite is dominant. Some vermiculite and quartz is present but mainly in the topsoil.

Bekenu Family (Prof. 172, p.295)

Poorly crystallized kaolinite and vermiculite are dominant. Crystallization is better in the A and upper B horizons than in the lower subsoil.

Biawak series (Prof. 9, p.292)

Well crystallized kaolinite is dominant in all samples. A fairly high amount of gibbsitic material is present, probably best crystallized as gibbsite in the subsoil; so are small admixtures of boehmite and goethite.

Nyalau Family (Prof. 24, p.296)

Fairly well crystallized kaolinite is dominant in all samples. Some vermiculite is present, particularly in the B horizon. A fair amount of quartz is present in the surface horizon. Some gibbsite occurs in the surface horizons. Kaolinite in the subsoil may be of a more ball-clay or fire-clay type than that in the surface horizons.

GREY-WHITE PODZOLIC SOILS

Kerait series (Prof. 425, p.300)

Fairly well crystallized vermiculite/illite is dominant. Fair amounts of kaolinite occur particularly in the A and upper B horizons. Some gibbsite is present only in the surface horizons (A and upper B).

Triboh Family (Prof. 79, p.304)

Well crystallized kaolinite is dominant in all samples. A fair amount of quartz and some gibbsite is present in the surface horizons. Some boehmite is found in the surface horizons. Possibly X-ray amorphous materials are present in the surface horizons.

GLEY SOILS

Bijat series (Prof. 271, p.312)

Moderately crystallized kaolinite is dominantly present in all horizons together with a rather small amount of vermiculite. Some quartz is present but mostly so in the upper B horizon. Traces of gibbsite are present.

SALINE-GLEY SOILS

Rajang Family (Prof. 37/38, p.397)

Both profiles contain dominantly poorly crystallized illite intergrading to vermiculite. Some kaolinite and gibbsitic material is present.

RECENT ALLUVIAL SOILS

Rumun series (Prof. 242, p.319)

Poorly crystallized kaolinite is dominant. Some vermiculite, gibbsite and X-ray amorphous materials are present.

Terbat series (Prof. 209, p.320)

Poorly crystalized kaolinite is dominant. Some vermiculite and gibbsite are present. Possibly some X-ray amorphous materials occur.

Sebat series (Prof. 10, p.327)

Fairly well crystallized kaolinite is dominant. Small admixtures of gibbsite and probably boehmite are present in the B horizon. Only small amounts of vermiculite are found in the B1 horizon.

Clay mineralogical investigations on PODZOLS and on GREY-WHITE PODZOLIC SOILS (*Kerait series*) were included in a separate study by the author on the genesis of these soils (Andriesse, 1969c).

In this study, the clay mineralogy of these soils was analysed by a Philip 2KW X-ray diffratometer with CoKα radiation.

The results of these investigations are as follows

PODZOLS

Bucan series (Prof. 50, p.307)

Quartz occurs dominantly in the A1 and A2 horizons with subordinate anatase and kaolinite.

Kaolinite occurs dominantly in the B horizon with considerable amounts of quartz and montmorillonite-vermiculite; small amounts of anatase are present. The C horizon, probably bisequent, contains mainly quartz and kaolinite with some montmorillonite.

Buso Family (Prof. 422, p.308)

Quartz is dominantly present in the A1 and A2 horizons together with small amounts of kaolinite and anatase. Quartz is dominant in the B horizons with large amounts of anatase and kaolinite being present. The lower B horizon has traces of montmorillonite-vermiculite.

In the GREY-WHITE PODZOLIC SOIL, *Kerait series* (Prof. 226, p.303) in which quartz and kaolinite appear to be dominant in the A1 and A2 horizons, the quartz content increases with depth together with the illite content, while the kaolinite stays fairly constant. The clay fraction of the parent material is dominated by quartz with subordinate illite and kaolinite, both being of equal importance.

The results of the clay mineralogcal analyses on this profile indicate that the clay mineralogy is different from that of the *Kerait series* (Prof. 425, p.300) analysed by D.T.A. and photographic X-ray diffraction. Either Prof. 226 is in a more advanced weathering stage or the content of quartz in Prof. 425 is not adequately measured by the X-ray diffraction photographic method.

Finally, the clay mineralogy of Tertiary sandstone and mudstone, respectively the parent material of the **Nyalau Family** soil (Prof. 24) and the *Stom series* (Prof. 25) was determined by D.T.A. and X-ray diffraction. Both the mudstone and sandstone have a clay fraction dominated by poorly crystallized illite while the partially weathered mudstone contains mainly an illite-kaolinite mixture, probably interstratified with vermiculite.

(iv) **Discussion**

Crystallinity

Some difficulties are experienced with the interpretation of the X-ray diffraction photographs. This is mainly caused by the general disordered nature of most clay minerals present. On account of the mode of crystallization of the dominantly occurring clay minerals, the soil series examined can be placed in three groups.

These are:

A. well crystallized—
Bukit Batu, Gading, Gumbang, Biawak, **Triboh.**

B. moderately crystallized—
Nyalau, *Stass, Semongok, Kerait, Bijat, Sebat.*

C. poorly crystallized—
Tarat, Stom, Padawan, **Bekenu,** *Terbat, Ramun.*

There are no obvious relationships between the series in these groups. Group A generally is characterised by well drained soils, but there are also well drained soils in group B e.g. **Nyalau** and in group C, which contains dominantly well drained soils. The weathering stage appears to be also of no significance, since soils showing advanced weathering occur in all three groups. It is possible that the mode of crystallization only signifies the degree of stability in the present weathering stage. Surface horizons show in general better crystallized clay minerals than subsoils. This may indicate that soil formation has reached a more advanced and probably more stable stage in surface horizons than in subsoil horizons.

Clay weathering

It can further be observed that soils derived from sedimentary rocks have inherited a considerable amount of illite from the parent material. The presence of sericite in the sand fraction of the *Stom series* and **Nyalau** soils (see p.291 and p.296) may indicate that the illite found in the parent rocks of these soils (mudstone and sandstone) may be associated with micas. The mica and illite appears to weather into kaolinite either directly or through a vermiculite stage. The formation of gibbsite and gibbsitic materials is noticeable in many soils showing advanced weathering. These aluminium oxides may either form directly through breakdown of illite and vermiculite or they may form in a more advanced weathering stage through breakdown of kaolinite. The presence of these materials in the subsoil may either indicate their direct formation through a breakdown of illite in that horizon or they may be leached excess aluminium oxides from the surface horizons after breakdown of kaolinite. The latter would be characteristic for strong weathering under acid conditions (Fieldes and Swindale, 1954; p.954).

The presence of subordinate vermiculite in most soils derived from sedimentary rocks is of interest. Vermiculite commonly has a high cation exchange capacity (100 to 150 meq.%, Bear, 1964; p.146) but most of the soils in which vermiculite occurs appears to have low exchange capacities (see Table 21, p.127). It is therefore suggested that much of the vermiculite is present as collapsed potassium vermiculite which resembles illite in many respects (Fieldes and Swindale, *op. cit.*). Without having access to the X-ray diffraction photographs it is not possible to check on this but the frequent mentioning in the reports of the Royal Tropical Institute of the presence of mixed illite-vermiculite may infer that it was difficult to distinguish between the two. This is possible since the basal spacing of 10Å for the illite lies closely to that of collapsed vermiculite (10.1Å, Marshall, 1964; p.120).

Even with glycol and Mg saturation which normally would bring out the difference between swelling and non-swelling clays, it was difficult to separate the two and this may indicate that most of the vermiculite may be of the non to weakly swelling type normally associated with K-vermiculite.

Differential Thermal Analysis

The D.T.A. interpretations were very much hampered by the presence of much organic material which even with pretreatment and the use of a nitrogen controlled atmosphere gave rise to exothermic reactions in the 200-600°C range. Some clays, notably those of the *Kerait series* (Prof. 226, p.303) still showed exothermic reactions up to 700°C.

These organic materials are mostly present in soils derived from sedimentary rocks which are generally highly carbonaceous if formed by shales. The nature of the carbonaceous matter is difficult to determine. Even with highly oxidizing reagents they fail to oxidise. Andriesse (1969d) suggests that the black colour of carbonaceous shale forming the parent material of Prof. 226 is caused by carbon present in the crystal structure of clay minerals which can only oxidize if the clay structure is destroyed. His original contention that the carbonaceous material may be enclosed in quartz present in the colloidal fraction may be wrong and the carbon could also be present in the double lattice clays minerals (Marshall, 1964, p.207). The disappearance of the black colour in the 700-750°C tract as reported by Andriesse (1969) may indicate that possibly montmorillonite may be involved which gives an endothermic peak near this range, the exact temperate being related to crystallinity (Fieldes, 1956, p.551).

D.T.A. curves of some selected soils are shown in Fig. IV.14a-h (pp.261-2).

Of particular interest are the 200-220°C endothermic reactions in Fig. IV.14 a, c, f and g. They are mainly present in the surface horizons, their intensity decreasing with depth and they are most likely caused by X-ray amorphous aluminium and silica compounds which presence is probably related to breakdown of vermiculite and kaolinite in the surface horizons. Such a breakdown might be caused by fulvic acids, a potent factor in podzolization (Marshall, 1964). These X-ray amorphouse aluminium compounds represent probably an initial stage in the formation of gibbisitic material which presence is indicated by endothermic reactions in the 280-350° range (see Fig. IV.14b and d) culminating in the full crystallization of gibbsite at 350°C and boehmite in the 420-450°C range (well illustrated in Fig. IV.14a and c). Fig. IV.14a also shows a strong endothermic reaction at 125°C and a weak one at 580°C which may be indicative of meta—halloysite (Fieldes, 1956, p.542).

It is possible that in strongly podzolised soils, aluminium may move downwards in the form of X-ray amorphous organo-mineral compounds which in the B horizon progressively crystallize into gibbsite or boehmite. The presence of these X-ray amorphous compounds mainly in the surface horizons strongly suggests the influence of organic matter. They are even present in the most laterized soil as in the ***Bukit Batu series***, Fig. IV.14a, suggesting that in the final stage of laterization aluminium may be leached through a chelating mechanism.

Much more investigations will be required to indicate the true nature of these compounds. They may be related to allophanic materials which Jackson (1956, p.527-8) describes as stabile allophane which is released from weathering of kaolinite in an advanced lateritic weathering stage and which has a very low exchange capacity. This description would fit in well with the nature and mode of occurrence of the material described as X-ray amorphous aluminium oxides.

Conclusion

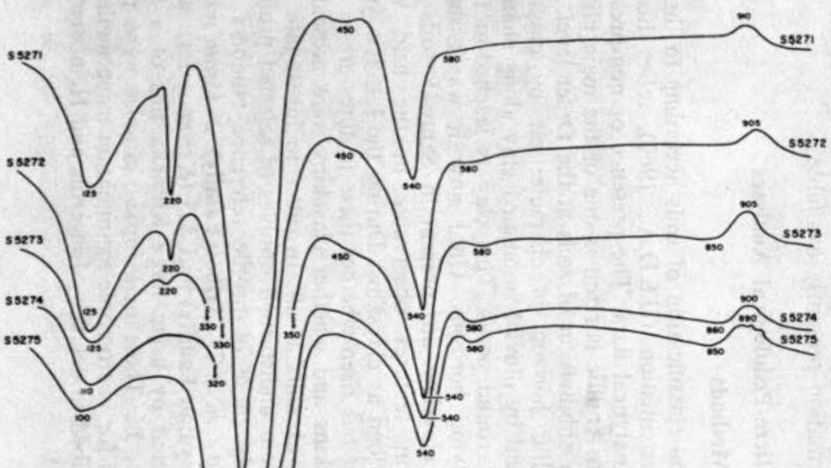
The study of clay minerals in Sarawak soils is only in its infancy but the investigations so far carried out do throw an interesting light on the use of clay mineral analyses in the understanding of soil forming processes operating in Sarawak soils. The X-ray diffraction analyses for which a recorder was employed allow an insight in the relative amount of each type of clay minerals present in the various horizons. This information is indispensable for soil genetic studies and analyses of this nature would enable a much more precise evaluation of the weathering processes involved than is possible with the information presently available.

2. **Micro-Pedological Analyses**

(a) **Methods**

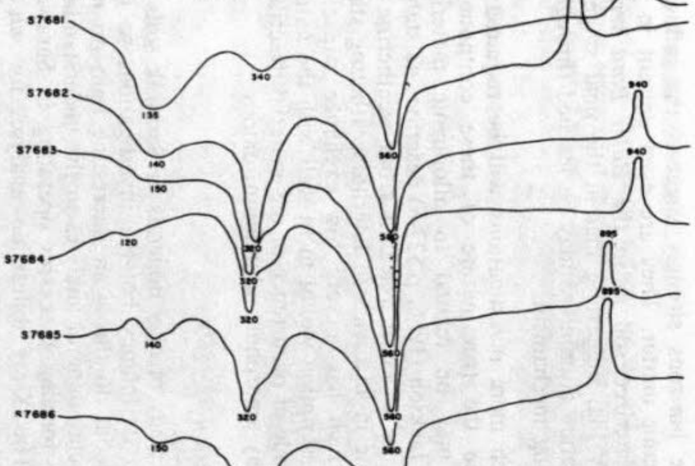
The classification of soils according to the 7th Approximation (U.S.D.A., 1960), relies heavily on analytical data. The presence or non-presence of an Argillic horizon is one of the main criteria for a subdivision of soils at the Order level. The Argillic horizon is characterised by clayskins formed by illuvial orientated clay along channels and around pores. This clay is leached-in from overlying horizons. Until now it was assumed that clayskins are present in Sarawak soils and certain features observable in the field were described as clayskins. During the last few years doubt has risen whether these features are in fact clayskins and whether clayskins were present in Sarawak soils at all. In order to investigate this problem undisturbed samples of selected profiles, namely those of profile reference numbers 254 (*Tarat series*), 79 (**Triboh Family**), 25 (*Stom series*) 24 (**Nyalau Family**) and 425 (*Kerait series*), were collected by using large Kubiena tins of a size 5″ × 3″. These undisturbed samples were prepared for microscopic examination using methods described in detail by Jongerius and Heintzberger (1969).

Fig. IV. 14a
D.T.A. curves (lower and higher temperature ranges)
Lateritic Soil - Tarat Family, Bukit Batu Series, Prof. No. 361



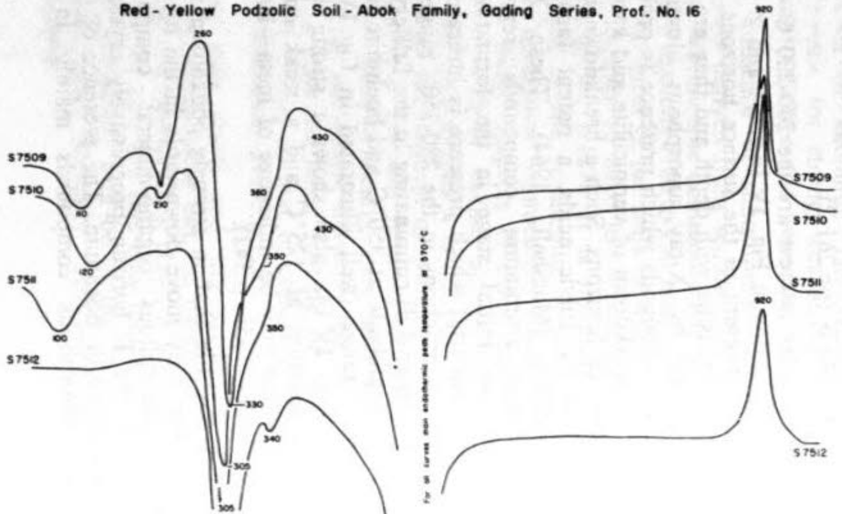
Typical gibbsite profile
X-ray amorphous compounds in surface horizons.

Fig. IV. 14b
D.T.A. curves (lower and higher temperature ranges)
Lateritic Soils - Tarat Family, Tarat Series, Prof. No. 75



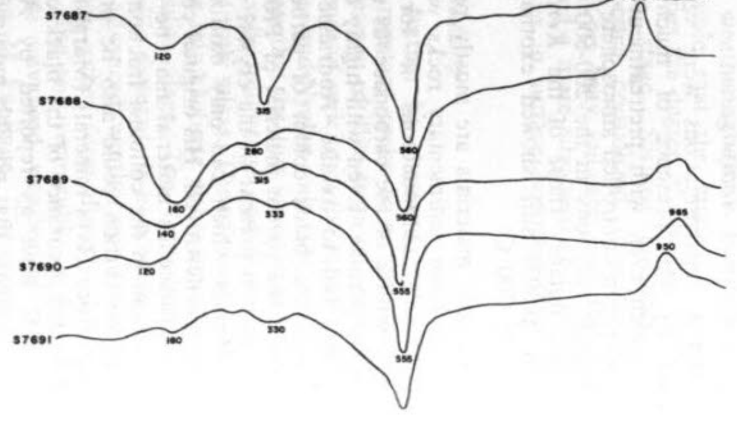
kaolinite - mixed layer - gibbsite profile.

Fig. IV. 14c
D.T.A. curves (lower and higher temperature ranges)
Red - Yellow Podzolic Soil - Abok Family, Gading Series, Prof. No. 16



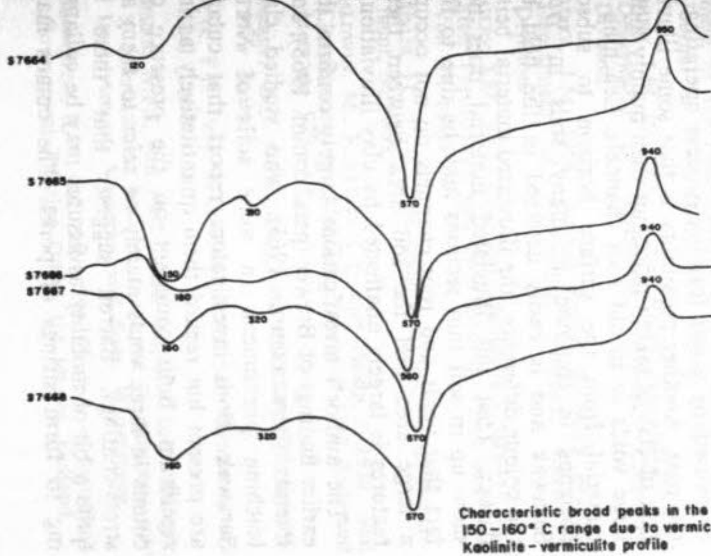
kaolinite - gibbsite profile

Fig. IV. 14d
D.T.A. curves (lower and higher temperature ranges)
Red-Yellow Podzolic Soil - Merit Family, Semongok Series, Prof. No. 77



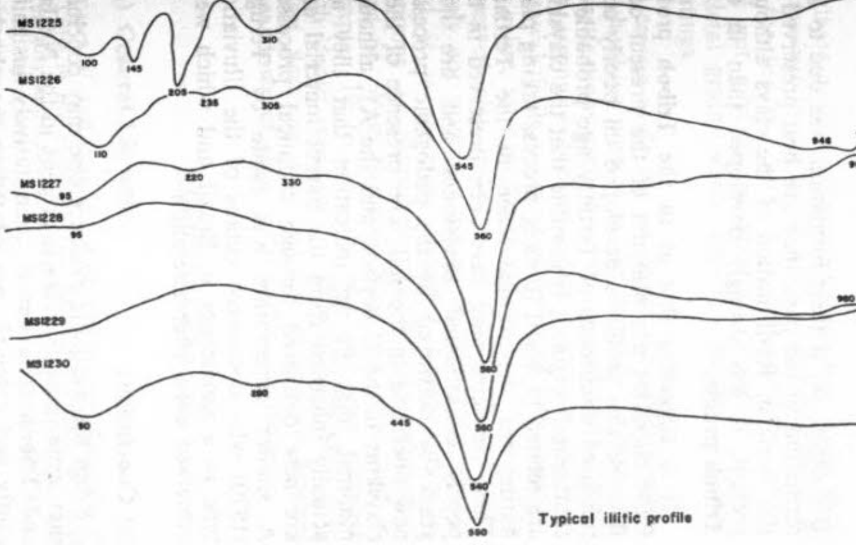
Typical kaolinite - vermiculite profile

Fig. IV. 14e D.T.A. curves (lower and higher temperature ranges)
Red-Yellow Podzolic Soil-Merit Family,
Padawan Series, Prof. No. 198



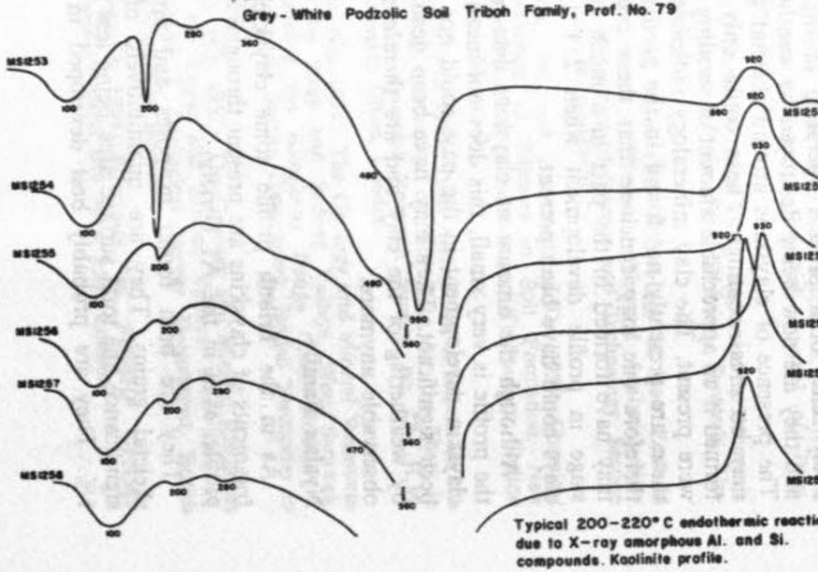
Characteristic broad peaks in the 150-160° C range due to vermiculite.
Kaolinite-vermiculite profile

Fig. IV. 14f D.T.A. (lower and higher temperature ranges)
Grey-White Podzolic Soil-Kerait Family,
Kerait Series, Prof. No. 425



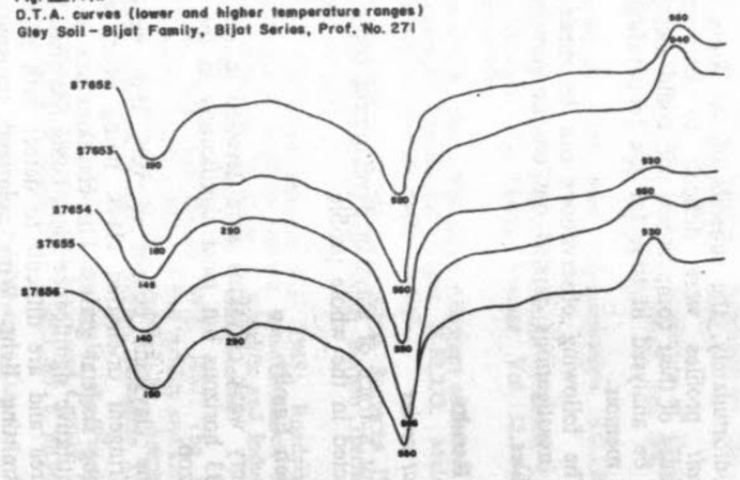
Typical illitic profile

Fig. IV. 14g
D.T.A. curves (lower and higher temperature ranges)
Grey-White Podzolic Soil Triboh Family, Prof. No. 79



Typical 200-220° C endothermic reactions due to X-ray amorphous Al. and Si. compounds. Kaolinite profile.

Fig. IV. 14h
D.T.A. curves (lower and higher temperature ranges)
Gley Soil-Bijat Family, Bijat Series, Prof. No. 271



Typical kaolinite-vermiculite profile

Unfortunately, the subsoils of the *Stom* and *Kerait* profiles were difficult to impregnate because of their compactness and could therefore not be analysed in time for the preparation of this memoir.

The following observations can be made on the investigations carried out on the remaining profiles.

(b) **Results**

Tarat series

Not a trace of clayskin development could be detected in the whole profile.

Triboh Family

Very weak clayskins were detected in the B1 to B3 horizons but most significantly in the B1 horizon.

The clayskins consist of very thin weakly birefringent orientated clays, lining pores and coating skeletal grains. The clayskins are of no quantitative significance them being less than 1% in area and are difficult to detect with normal transmitting light. With polarized transmitting light they show up as grey masses which attain a bluish colour under mercury light. They appear like weathered clays showing strong resilification. There is no indication that clayskins form during the present day and the ones present are probably relics of a process operating in the past and they are now being destroyed by weathering. The presence of clayskins around skeletal grains may be stress coatings. These could only have formed if an appreciable amount of swelling clays were present. The clay mineralogy indicates that these are presently not found in the profile and therefore one may conclude that these coatings may have formed in the past in a much earlier stage in profile development when 2:1 lattice clays could have been present.

Although the amount of clayskins detected in the profile is very small, this does not mean that clayskin development in the past could not have been significant. They may have been destroyed by weathering of the clay and are therefore not observable anymore.

Nyalau Family

As in the **Triboh** profile some clayskins or fragments of clayskins are present throughout the profile, even in the A1 horizon.

They are both found in pores and around skeletal grains. They are quantitatively of no significance, the total surface area being less than 1%. They are probably best developed in the B horizon, or, if their formation was due to soil formation in the past, they are best preserved in this horizon. Resilification of the clays although present, is less strongly developed than in the **Triboh** profile.

It is suggested that as in the **Triboh** profile these clayskins are also not of the present day. Because this profile is developed on poorly consolidated sandstones of Tertiary age probable of continental origin, it is possible that the clayskins are related to a soil forming process taking place during the depositional stage in the Tertiary. These clayskins may have been preserved in the poorly consolidated sandstones and are now gradually destroyed by the pedogenic processes now operating in the soil. The presence of these clayskins in the C horizon and the A1, although minimal, may be an indication that they are actually inherited from the parent material and are now destroyed through chemical processes. A similar observation was made by Teruggi (1970) who discovered cutans of the illuviation type in a sandstones in Brazil and which were preserved even after alteration.

(c) **Conclusions**

From the available evidence one may conclude that some illuviated clay is present in the **Nyalau** and **Triboh** soils but is quantitatively insignificantly and definitely not related to the observed presence of strong clayskin development in the field.

One possibility is that the cutans are relic features either inherited from the parent material or caused by a soil forming process operating in the past. Another possibility is that some illuviation of clay is taking place but then mainly along large voids or in old root channels. Leaching of material from the surface horizon to subsoil horizons is common in many soils in West Sarawak and is easily detected in the field by the colour difference, the illuviated material being darker. That this illuviated material does not show up in soil thin sections may be due to the fact that voids and root channels do not occupy a large area and the soil area between these features is largely unaffected by clay illuviation.

The author's investigations largely confirm the earlier findings of Brewer (pers. comm. 1965), and Barratt (pers. comm. 1965), who studied clay leaching phenomena in some soils of North Sarawak. Both investigators report that cutans are present but regard them quantitatively as insignificant. Both comment on the presence of cutans in large voids mainly or refer to them as stress-coatings. Barrett suggests that 'there is quite a bit of mobility as fissures may be collapsing to form strings of pores. The cutans may originate as illuvial fissure linings but would find themselves in the round mass after breakdown of of the fissues'. Such a process however would still not explain the presence of cutans around skeletal grains which Brewer classifies as stress-coatings.

Leaving aside the origin of the small amount of clayskins present in the investigated soils, the investigations carried out so far suggest that there are strong indications that clayskins in West Sarawak Soils are most probably of little diagnostic value, at least for classification purposes. The observed clay increases in these soils are most likely not primarily caused by illuviation of clay and it is therefore doubtful whether Argillic horizons as defined in the 7th Approximation exist in West Sarawak Soils. As explained in Chapter 10 (p.136), the observed clay increase with depth common for PODZOLIC SOILS in West Sarawak may be due largely to gradual breakdown of clay in the surface horizons.

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APPENDIX

1. ANALYTICAL METHODS

pH

Measured by a glass electrode using a PYE pH meter.

Electric Conductivity

Measured by a Mullard conductivity bridge with dipping electrodes, using a soil: water ratio of 1 to 5.

Total Nitrogen

Determined by the Kjeldahl method using a semi-micro distillation apparatus developed by Parnas and Wagner, (B.S. 1428, Part B. I, 1953).

Organic Carbon

Determined by Walkley-Black's wet digestion method, (Jackson, 1958).

Total Phosphorus

Determined by Fogg and Wilkinson's (1958) ascorbic acid method after digestion with perchloric acid.

Available Phosphorus

Extraction by Bray and Kurtz no. 2 extractant and measured colorimetrically using ammonium molybdate-stannous chloride blue colour method, (Jackson, 1958).

Organic Phosphorus

Determined by ignition method. Obtained by taking the difference in inorganic P, determined before and after ignition at 240°C by the ascorbic method, (Figg and Wilkinson, 1958).

Phosphorus Retention

The amount of phosphorus retained in soils is measured as the difference between the amount of phosphorus standard added to the soil and the phosphorus present in the filtrate obtained after shaking the soil with phosphorus standard solution and filtration.

Cation exchange capacity and exchangeable cations

Determined by neutral normal ammonium acetate as described by Metson (1956). Exchangeable Potassium and Sodium are determined flamephotometrically using an EEL Flame Photometer. Exchangeable calcium and magnesium are determined by EDTA titration using ammonium purpurate indicator for calcium and solochrome black and potassium chloride indicator for calcium plus magnesium, magnesium being obtained by difference.

Extractable Mn, Fe, Al, Mg and Ca

Determined after extraction with Morgan's extractant (10% sodium acetate and 3% acetic acid adjusted to pH 4.8). Calcium and magnesium are determined by EDTA titrations, iron colorimetrically by 2-2′ dipyridyl, aluminium by stabilised eriochrome cyanine (Jones and Thurman, 1957) and manganese colorimetrically by using potassium periodate.

Total Silicate analysis

Sodium carbonate fusion followed by separation of the silica by using gelatine. Determination of iron and aluminium by a back titration method using EDTA and zinc chloride. Manganese, titanium, calcium and magnesium are determined by colorimetic measurements and EDTA titrations. Sodium and potassium by a flame photometer and phosphorus by using perchloric acid, (Dobritskaya, 1962).

Exchangeable Aluminium and Hydrogen

Displaced by 1N. KC1 and determined by titration with and without the addition of sodium fluoride for hydrogen and aluminium respectively (Yuan, 1959).

Reserve Potassium, Magnesium, Calcium, Phosphorus and Group III elements (mainly Iron and Aluminium oxides)

According to a method described by Bailey, (1967).

Total sulphate

According to the method of Butters and Chenery, (1959).

Total iron (6N. HC1 extractable)

Determined colorimetrically in the 6N. HC1 digested extract after ignition (450°C), using hydroquinone orthophenanthroline and sodium citrate.

Mechanical analysis

According to the pipette method, (Piper, 1950).

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3. METHODS FOR FIELD DESCRIPTION

(a) Soil profiles are described according to the methods laid down in Handbook no. 18. U.S. Department of Agriculture, Soil Survey Manual. (1951).

(b) Colours are described according to the Munsell Color charts. If not stated otherwise soil colours are described in field condition.

(c) For horizon designations use is made of symbols defined in Soil Classification, A comprehensive System, 7th Approximation (U.S. Soil Survey Staff, 1960).

NOTE: Profile reference numbers refer to those depicted on supplementary Map 2. (Vol. II, Maps).

GROUP A—PROFILES

GROUP A — PROFILES

4. PROFILE DESCRIPTIONS AND ANALYSES OF SOILS STUDIED IN DETAIL,

PROFILE REF. NO. 75

Soil Group: LATERITIC.

Family: **Tarat.**

Series: *Tarat*.

Phase: Deep.

Location: Mls. 11, Kuching-Bau Road (Kuching Rural District).

Ltitude: 1° 27′ 30″ N.

Longitude: 110° 17′ E.

Topography: Strongly dissected hilly terrain.

Site: On moderately high hill with 16 degree slope.

Parent material: Basalt.

External drainage: Good.

Vegeation/Land Use: Old rubber garden (Thick undergrowth).

Altitude: ± 150 feet.

Rainfall: 159.10″ M.A.R. (Kuching Airport).

Lab. Nos: S 7681/86.

Date sampled: 17.1.70.

NOTE: On surface 1½ inches—mainly leave litter and decomposed roots.

A1	0–3″	Dark brown (7.5YR 4/4) loam. Many coarse to medium roots. Contains much organic matter. Many earth worms. Moist; crumbly. Porous. Clear wavy change to
A2	3–9½″	Red (5YR 5/8) clay loam with many fine to medium roots. No mottles. Moist crumbly. Diffuse wavy change to
B1	9½–17″	Red (2.5YR 5/8) clay. No mottles. Moist; crumbly structure. Gradual wavy change to
B2.1	17–32″	Red (2.5YR 4/8) clay. No mottles. Moist; crumbly structure; very friable when broken up. Few pieces of easily broken quartz. Diffuse wavy change to
B.2.2	32–44″	Red (2.5YR 4/8) clay. Few quartz grains. Weak 'clayskins' developed along cracks. Moist; very crumbly and friable. Diffuse wavy change to
B/C	44–60″ +	Red (2.5YR 4/8) clay, with increasingly more easily broken 'quartz'? and weathered rock fragments. Moist; very friable and crumbly structure.

Profile ref. No.: 75 Soil Group: LATERITIC SOIL Soil Family: TARAT Soil Series: TARAT

Phase: DEEP

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	Group III Oxides	% P Ret.
S 7681	A1	0-3	4.7		0.495	6.09	12.30			1.28	0.61	0.49	0.12	3.32	0.22	23.64	10.58					52.05
S 7682	A2	3-9½	4.1		0.170	2.26	13.29			1.04	0.21	0.08	0.09	1.89	0.11	10.50	13.52					51.21
S 7683	B1	9½-17	4.3		0.119	1.27	10.67			1.19	0.17	0.08	0.10	0.44	0.07	6.51	23.66					56.90
S 7684	B2.1	17-32	4.5		0.082	0.64	7.80			0.71	0.18	0.05	0.08	<0.16	0.02	8.49	12.01					17.29
S 7685	B2.2	32-44	4.6		0.051	0.04	0.78			0.74	0.18	<0.01	0.08	<0.16	0.02	6.64	15.06					74.17
S 7686	B/C	44-60+	4.8		0.016	0.02	1.25			0.53	0.17	<0.01	0.07	<0.16	0.02	7.76	9.92					61.79

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D. SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	Colloidal Fraction Total SiO_2	Fe_2O_3	Al_2O_3	Derived mol. ratio's SiO_2/R_2O_3	SiO_2/Fe_2O_3	SiO_2/Al_2O_3	Fe_2O_3/Al_2O_3	Extractable Morgan Al	Mn	Fe	6N HCL Fe
S 7681	A1	0-3	34.39	16.92	21.17	1.48	0.18	0.34		0.07	0.0248	0.0778	24.11	24.46	26.29	0.98	2.64	1.56	0.59				16.38
S 7682	A2	3-9½	34.67	20.16	24.60	2.85	0.11	0.28		0.04	0.0226	0.0401	23.75	25.06	28.41	0.90	2.53	1.40	0.55				19.52
S 7683	B1	9½-17	34.12	20.48	26.31	3.07	0.21	0.28		0.04	0.0227	0.0678	24.18	26.75	28.54	0.90	2.41	1.44	0.60				19.66
S 7684	B2.1	17-32	32.55	21.45	27.76	3.22	0.24	0.29		0.05	0.0287	0.0601	24.72	26.90	29.79	0.92	2.45	1.46	0.60				21.08
S 7685	B2.2	32-44	45.79	23.81	27.96	3.48	0.14	0.30		0.01	0.0321	0.0740	26.15	25.75	28.54	0.95	2.72	1.56	0.57				22.34
S 7686	B/C	44-60+	47.03	18.41	21.21	2.43	0.17	0.35		<0.01	0.0253	0.0241	36.30	20.81	25.42	1.60	4.65	2.47	0.52				17.15

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	Fine earth < 2 mm composition V.C.S. 2000µ-1000µ	C.S. 1000µ-500µ	M.S. 500µ-250µ	F.S. 250µ-100µ	V.F.S. 100µ-50µ	Sand Total 2000-50µ	Silt 50-2µ	Clay < 2µ	Total fine earth	Texture according to U.S. Survey Manual
S 7681	A1	0-3	2.79	3.96	3.91	4.13	2.36	17.95	21.79	57.43	97.17	clay
S 7682	A2	3-9½	1.68	1.39	1.67	3.45	5.34	13.53	24.23	62.11	99.87	"
S 7683	B1	9½-17	3.29	1.79	1.25	2.63	4.27	13.23	23.54	60.92	97.69	"
S 7684	B2.1	17-32	3.28	2.67	1.34	2.25	3.24	12.78	28.61	58.17	99.56	"
S 7685	B2.2	32-44	4.20	2.70	1.41	2.15	5.43	15.89	27.77	55.81	99.47	"
S 7686	B/C	44-60+	4.75	4.56	2.74	3.74	11.53	27.32	30.47	40.39	98.18	"

(d) Mineralogy.

Sample No.	Horizon	Depth in inch	Medium or fine sand fraction % — Heavy minerals: Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoizite	Clino-Zoizite	Hornblende	Corundum	Crystoballite	Alterite	Light minerals: Quartz	Felspars	Mica's	* Clay fraction: Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
S 7681	A1	0-3																					d			t	p				
S 7682	A2	3-9-																					d			t	p				
S 7683	B1	9--17																					d			t	p				
S 7684	B2.1	17-32																					d			t	p				
S 7685	B2.2	32-44																					d			t	p				
S 7686	B/C	44-60+																					d			t	p				

* d-dominant, p-present, t-trace.

Profile ref. No.: 254 Soil Group: LATERITIC Soil Family: TARAT Soil Series: TARAT

Phase: DEEP

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	Group III Oxides	% P Ret.
MS1213	A1	0-4	4.5	3.8	0.57	8.31	14.7	4	559	0.57	155	0.42	0.31			14.76	19.3	221	979	386	39.45	
MS1214	B1	4-14	4.9	4.0	0.21	4.50	21.8	1	430	0.28	0.49	0.08	0.08			9.12	10.2	111	759	167	46.99	
MS1215	B2	14-21	5.1	4.2	0.15	3.86	26.4	1	391	0.07	0.70	0.07	0.09			10.54	8.8	109	913	163	50.29	
MS1216	B3	21-52	5.5	4.5	0.07	2.96	45.6	1	400	0.35	0.62	0.05	0.10			5.66	19.8	194	791	216	47.79	
MS1217	B3/C	52-64	5.4	4.5	0.02	2.63	109.6	1	414	0.14	0.69	0.04	0.17			6.36	16.4	65	1646	594	48.48	
MS1218	C	64-80	5.3	4.3	0.02	2.37	112.9	1	411	0.14	0.55	0.03	0.09			5.98	13.5	289	1271	268	45.64	

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D. SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	Colloidal Fraction Total SiO_2	Fe_2O_3	Al_2O_3	Derived mol. ratio's $\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	Extractable Morgan Al	Mn	Fe	6N HCL Fe
MS1213	A1	0-4	30.63	17.04	38.55	0.14	0.04	0.19	0.87	0.39	0.05	0.14	25.50	17.17	45.17	0.77	3.97	0.96	0.38				15.57
MS1214	B1	4-14	32.85	20.70	42.92	0.15	0.06	0.20	0.43	0.26	0.04	0.08	24.53	19.71	47.35	0.69	3.32	0.88	0.42				17.82
MS1215	B2	14-21	33.68	19.32	51.30	0.18	!	0.21	0.86	0.26	0.08	0.08	25.71	20.15	48.44	0.76	3.39	0.80	0.41				17.15
MS1216	B3	21-52	32.36	22.20	44.21	0.23	0.04	0.32	0.42	0.13	0.14	0.08	26.13	23.63	46.62	0.71	2.93	0.95	0.51				14.63
MS1217	B3/C	52-64	34.24	19.72	53.40	0.18	0.08	0.37	0.84	0.50	0.15	0.04	28.64	22.35	45.30	0.82	3.53	1.07	0.49				19.21
MS1218	C	64-80	36.12	22.31	41.61	0.18	!	0.19	0.57	0.25	0.07	0.03	33.03	20.15	44.50	0.98	4.36	1.26	0.45				21.09

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	V.C.S. 2000µ-1000µ	C.S. 1000µ-500µ	M.S. 500µ-250µ	F.S. 250µ-100µ	V.F.S. 100µ-50µ	Sand Total 2000-50µ	Silt 50-2µ	Clay <2µ	Total fine earth	Texture according to U.S. Survey Manual
MS1213	A1	0-4	0.54	1.34	2.14	2.14	4.87	11.02	24.50	64.52	100.04	Clay
MS1214	B1	4-14	0.77	1.12	1.38	3.01	6.99	13.26	21.62	64.65	99.53	Clay
MS1215	B2	14-21	0.79	1.19	2.03	4.95	7.23	16.19	19.63	63.69	99.51	Clay
MS1216	B3	21-52	0.57	1.55	2.68	3.61	6.63	14.42	31.09	54.74	100.25	Clay
MS1217	B3/C	52-64	2.03	6.44	7.97	6.39	11.09	33.91	28.61	37.67	100.19	Stony clay loam
MS1218	C	64-80	0.59	2.45	6.52	6.57	15.04	31.16	33.69	35.43	100.28	Stony clay loam

(d) Mineralogy.

Medium or fine sand fraction %

Sample No.	Horizon	Depth in inch	Heavy minerals: Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoizite	Clino-Zoizite	Hornblende	Corundum	Crystobalite	Alterite	Light minerals: Quartz	Felspars	Mica's
1			Insufficient heavy minerals for statistical analysis.																					
MS1213	A1	0-4	Dominantly rounded and subrounded Zircon. Few Tourmaline and Rutile. Mainly Opaque - Ilmenite.																					
MS1214	B1	4-14	Mainly Opaque - Ilmenite. Some rounded Zircons.																					
MS1215	B2	4-21																						
MS1216	B3	21-52																						
MS1217	B3/C	52-64																						
MS1218	C	64-80	Mainly rounded large and small Zircons, some Tourmaline. Few Rutile and Leucoxene. Crystobalite ? present. Opaque - Ilmenite and Goethite.																					

Sample No.	* Clay fraction: Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
MS1213		d		p	p	p	
MS1214		d		p	p	p	
MS1215		d		t	p	p	
MS1216		d		t	p	p	
MS1217		d	t	t	p	p	
MS1218		d	t	t	p	p	

* d-dominant, p-present, t-trace.

PROFILE REF. NO. 254

Soil Group: LATERITIC SOILS.

Family: Tarat.

Series: *Tarat*.

Phase: Deep.

Location: 3rd mile Serian-Tebakang Road (Upper Sadong District).

Latitude: 1° 9′ 45″ N.

Longitude: 110° 31′ E.

Topography: Moderately steep terrain with slopes of 25 degrees and over. Strongly dissected.

Site: Midslope.

Slope: 10 degrees.

Parent material: Altered Basalt and Andesite (Triassic).

External Drainage: Good.

Vegetation/Land Use: Young rubber with dense mixed undergrowth in which ferns are dominant.

Altitude: Approximately 150 feet.

Rainfall: 139.13″ (8 years' mean) Tarat Station.

Rainfall Class (Mohr): I.

Lab. Nos: MS 1213/18.

Date sampled: 18.8.67.

		Very thin layer of leave litter (1/10 of an inch).
A1	0–4″	Reddish brown (5YR 4/4) clay, fine subangular blocky to fine angular blocky structure (nutty). Dry; friable. Abundant rootlets. Porous. Distinct boundary to
B1	4–14″	Red (2.5YR 5/6) clay. Moist, friable. Crumbly structure. Macro structure-coarse prismatic. Many roots. Shiny natural ped surfaces. Indistinct boundary to
B2	14–21″ 35–52	Red (2.5YR 5/6) clay. As above horizon but the soil is firm and does not break into crumbs on pressure. Slightly moist (possibly influence of difference in moisture content). Indistinct boundary to
B3	21–52″	Red (2.5YR 5/6) clay loam which breaks into small crumbs and fine angular blocky peds if slight pressure is applied. Dry; soft. Porous. Slight development of shiny ped surfaces. Many roots. Scattered small weathered rock pieces (possibly colluvial). Distinct wavy boundary to
C	52–80″	Mixed red (2.5YR 5/6) clay loam, very friable to powdery, and brittle, thoroughly weathered parent material in 50%-50% proportion. Slightly moist. Few rootlets. Porous.

NOTE: This horizon continues to a depth of approximately 8 feet where solid rock is met.

PROFILE REF. NO. 361

Soil Group: LATERITIC SOILS.

Family: **Tarat.**

Series: *Bukit Batu.*

Phase: Shallow.

Location: At Bukit Batu, Ulu S. Sawah, Second Division (Sebuyau Subdistrict).

Latitude: 1° 12′ 30″ N.

Longitude: 111° 1′ 50″ E.

Topography: Strongly sloping high monadnock type hill.

Parent material: Basalt.

External drainage: Good.

Vegetation/Land Use: Secondary growth approximately 4 to 5 years.

Altitude: ± 300 feet.

Rainfall: 140″ M.A.R. (estimated).

Rainfall Class (Mohr): I.

Lab. Nos: S 5271/75.

Date samples: March, 1968.

Site: On hill slope, approximately 15 degrees.

A1	0–5″	Strong brown (7.5YR 5/8) clay loam. Strong medium subangular blocky. Moist. Well rooted. Gradual change to
B	5–12″	Strong brown (7.5YR 5/6) clay. Crumbly. Friable. Few medium size roots, some reddish coloured weathered rock pieces; indistinct change to
B/C	12–60″	Homogeneous strong brown (7.5YR 5/6) clay. Moist; friable. Crumbly. Increasing amount of weathered rock at depth; very few roots; weathered rock pieces are coloured red. Some large boulder-size fresh rock, very dark grey in colour. At 26 inches more weathered rock than soil.

Profile ref. No.: 361 Soil Group: LATERITIC Soil Family: TARAT Soil Series: BUKIT BATU

Phase: SHALLOW

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH		% O. D.		C/N Value	ppm. O.D.		m.e.q. % (O.D.)								Reserves p.p.m O. D			%	%
			1:2.5 H_2O	1:5 KCL	Total N	Total C		Av. P	'Total' P $HClO_4$	Ca	Mg	K	Na	Al	H	C.E.C.	S Value	Ca	Mg	K	Group III Oxides	P Ret.
S5271	A1	0-5	5.7			4.63			844									1132	360	318	43.22	
S5272	B	5-12	5.3			1.64			709									231	388	260	51.16	
S5273	B/C	12-21	5.5			0.96			6 88									229	248	258	50.08	
S5274	C1	21-39	5.8			0.30			789									108	246	405	47.82	
S5275	C2	39-59	5.8			0.25			820									112	444	1374	50.53	

(b) Chemical composition.

Sample No	Horizon	Depth in inch	Total analyses of fine earth % O.D.										Colloidal Fraction							Extractable			
													Total			Derived mol. ratio's				Morgan			6N HCL
			SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	SiO_2	Fe_2O_3	Al_2O_3	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	Al	Mn	Fe	Fe
S5271	A1	0-5	13.21	23.62	30.80	0.60	0.06	0.21	<0.03	0.09	0.05	1.00	8.81	31.39	30.29	0.33	0.67	0.44	1.04				25.35
S5272	B	5-12	12.98	30.43	35.15	0.67	0.06	1.19	<0.03	0.10	<0.01	0.72	9.25	34.54	29.48	0.31	0.71	0.53	1.17				23.96
S5273	B/C	12-21	12.16	31.06	32.11	0.81	0.16	0.19	<0.03	0.12	<0.01	0.84	9.41	35.79	30.73	0.30	0.70	0.52	1.16				30.67
S5274	C1	21-39	17.36	32.70	30.22	0.96	0.06	0.28	<0.03	0.12	<0.01	0.96	8.23	42.03	27.67	0.25	0.51	0.51	1.52				24.25
S5275	C2	39-59	9.46	34.85	35.04	1.00	0.07	0.28	<0.03	0.15	<0.01	0.98	9.09	38.23	26.54	0.30	0.63	0.58	1.44				30.00

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	Fine earth < 2 mm composition								Total fine earth	Texture according to U.S. Survey Manual
			V.C.S. 2000µ-1000µ	C.S. 1000µ-500µ	M.S. 500µ-250µ	F.S. 250µ-100µ	V.F.S. 100µ-50µ	Sand Total 2000-50µ	Silt 50-2µ	Clay < 2µ		
S5271	A1	0-5	4.04	4.88	3.48	3.79	2.87	19.06	28.27	49.72	97.05	Clay
S5272	B	5-12	2.28	4.00	3.16	3.16	2.71	15.31	30.78	55.95	102.04	Clay
S5273	B/C	12-21	2.82	4.88	3.10	3.17	5.55	19.52	31.31	51.21	102.04	Clay
S5274	C1	21-39	7.40	12.05	4.88	4.88	6.67	35.88	29.35	34.65	99.88	Clay loam
S5275	C2	39-59	5.70	11.69	5.14	5.54	10.63	38.70	33.44	31.00	103.14	Clay loam.

(d) Mineralogy.

Sample No.	Horizon	Depth in inch	Medium or fine sand fraction % — Heavy minerals: Ratio Opaque/Non-opaque, Zircon, Tourmaline, Andalusite, Sillimanite, Epidote, Rutile, Anatase, Brookite, Leucoxene, Sphene, Garnet, Spinel, Zoizite, Clino-Zoizite, Hornblende, Corundum, Crystobalite, Alterite; Light minerals: Quartz, Felspars, Mica's	* Clay fraction: Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
			Insufficient heavy minerals for statistical analysis.							
					t		t	d	t	
S5271	A1	0-5	Subrounded and Euhedral Zircons. Epidote, rounded Tourmaline, Ilmenite.		t		t	d	t	
S5272	B	5-12	Mostly clusterminerals (Crystobalite ?). Some subrounded Zircon.							
			Ilmenite, Leucoxene and Rutile.		t		t	d	p	
S5273	B/C				t		t	d	p	
S5274	C1				t		t	d	p	
S5275	C2	48-59	Mostly Crystobalite ? Few Tourmaline and Anatose.	Fairly high content of X-ray						
			Opague minerals – Ilmenite and Goethite.	Amorphous material in all samples.						

* d-dominant, p-present, t-trace.

Profile ref. No.: 16 Soil Group: RED - YELLOW PODZOLIC Soil Family: ABOK Soil Series: GADING

Phase:

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P $HClO_4$	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	Group III Oxides	% P Ret.
S 7509	A1	0-5	5.2	4.5	0.156				392	0.26	0.60	0.11	0.11	1.56	0.14	5.47	19.7					29.83
S 7510	A2	7-16	5.5	4.4	0.057				127	0.13	0.06	0.03	0.09	0.54	0.03	12.63	2.5					50.89
S 7511	B1	18-37	5.5	4.4	0.026				163	0.13	0.26	0.02	0.05	0.51	0.06	15.50	3.0					33.34
S 7512	B2	37-53	5.5	4.4	0.020				154	0.65	1.04	0.02	0.08	0.45	0.06	26.96	6.6					12.58

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D. SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	Colloidal Fraction Total SiO_2	Fe_2O_3	Al_2O_3	Derived mol. ratio's $\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	Extractable Morgan Al	Mn	Fe	6N HCL Fe
S 7509	A1	0-5	72.33	3.02	10.85	0.52	0.04	0.12	0.05	0.06	0.01	1.17	26.91	12.18	31.91	1.15	5.89	1.43	0.38				
S 7510	A2	7-16	75.16	3.86	12.53	0.47	0.04	0.17	0.03	0.05	0.01	0.74	27.79	13.08	32.10	1.17	5.77	1.47	0.41				
S 7511	B1	18-37	71.87	4.74	15.21	0.52	<0.02	0.22	0.03	0.06	0.03	1.02	27.64	13.43	32.16	1.16	5.49	1.46	0.42				
S 7512	B2	37-53	62.98	5.65	18.45	0.53	0.06	0.15	0.05	0.08	0.05	0.51	27.96	13.18	31.72	1.18	5.68	1.49	0.42				

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	Fine earth < 2 mm composition V.C.S. 2000µ-1000µ	C.S. 1000µ-500µ	M.S. 500µ-250µ	F.S. 250µ-100µ	V.F.S. 100µ-50µ	Sand Total 2000-50µ	Silt 50-2µ	Clay < 2µ	Total fine earth	Texture according to U.S. Survey Manual
S 7509	A1	0-5	5.65	25.81	23.71	16.52	5.68	77.37	4.75	18.41	100.53	sandy loam
S 7510	A2	7-16	17.58	25.19	14.85	10.09	4.25	71.96	3.74	24.59	100.29	sandy clay loam
S 7511	B1	18-37	12.00	34.34	19.09	9.45	3.74	78.62	4.17	17.80	100.59	sandy loam
S 7512	B2	37-53	19.41	20.06	13.60	9.63	4.16	66.86	7.43	26.80	101.12	sandy clay loam

(d) Mineralogy.

Sample No.	Horizon	Depth in inch	Medium or fine sand fraction % — Heavy minerals: Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoisite	Clino-Zoisite	Hornblende	Corundum	Crystobalite	Alterite			Light minerals: Quartz	Felspars	Mica's		* Clay fraction: Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
S 7509	A1	0-5	65/35	3	81		13						1	1		1													d			p	t	p
S 7510	A2	7-16																											d			p	t	p
S 7511	B1	18-37																											d			p	p	p
S 7512	B2	37-53	44/65		87		12							1															d			p	p	p

* d-dominant, p-present, t-trace.

PROFILE REF. NO. 16

Soil Group: RED-YELLOW PODZOLIC.

Family: Abok.

Series: *Gading*.

Phase:

Location: Upstream Sungei Setumban (Lundu District).

Latitude: 1° 41′ 35″ N.

Longitude: 109° 35′ E.

Topography: Dissected hilly terrain, foothills.

Site: ± 30 feet from cliff, 15 degrees slope.

Parent material: Adamellite.

External drainage: Good.

Vegetation/Land Use: Old rubber garden with weed undergrowth.

Altitude: ± 50 feet.

Rainfall: 131.64″ M.A.R. (Lundu).

Rainfall Class (Mohr): I.

Lab. Nos: S 7509/12.

Date sampled: September, 1969.

A1	**0–5″**	Dark brown (10YR 4/3) weak subangular blocky sandy clay loam. Moist; friable. Organic matter present; well rooted; gradual but distinct change into
A2	**5–16″**	Yellowish brown (10YR 5/8) sandy clay loam, smeary, but containing individual coarse sand grains (gritty), possibly sandy clay. Most, friable. No apparent structure, very few roots. Very gradual change into
B1	**16–44″**	Reddish yellow (7.5YR 6/6) sandy clay loam. Moist; slightly firm. Slightly plastic, structureless to weak crumbly. No roots. Reddish colour increases with depth. Indistinct boundary to
B2	**44–56″**	Yellowish red (5YR 5/8) sandy clay loam, in places gritty. Moist; slightly firm. Weak crumbly structure. No roots. Gradual change into
B/C	**50–60″+**	Red (2.5YR 5/6) gritty sandy clay, smeary. Many micas in rock debris. Material in this horizon can be separarted into partly disintegrated weathered rock and red clay material. No roots. Moist. Structureless.

PROFILE REF. NO. 76

Soil Group: RED-YELLOW PODZOLIC.

Family: **Abok.**

Series: *Gumbang.*

Phase: Shallow.

Location: On upper slope of Gunong Serambu—Siniawan area (Bau District).

Latitude: 1° 25′ N.

Longitude: 110° 13′ E.

Topography: On top of high ridge (monadnock).

Site: On very steep slope, 40-45 degrees.

Parent material: Tonalite porphyry.

External drainage: Good.

Vegetation/Land Use: Primary forest.

Altitude: ± 1,200 feet.

Rainfall: 129.56″ M.A.R. (Bau).

Rainfall Class (Mohr): I.

Lab. Nos: S 7692/96.

Date sampled: 20.1.70.

NOTE: **On surface 2 inches of leave litter and decayed branches.**

A1	0–3″	Dark brown (10YR 4/3) loam with many coarse to medium roots. Many earthworms. Moist; very friable. Crumbly. Clear smooth change to
B1	3–11″	Yellowish brown (10YR 5/4) clay loam with many coarse to medium roots which mainly penetrate along cracks. No mottles. Few rock fragments. Moist. Slightly friable. Weak subangular blocky structure. Diffuse wavy change to
B2	11–17½″	Light yellowish brown (10YR 6/4) clay loam. Many fine to medium roots. Very weak 'clayskins' developed along cracks. Common coarse rock fragments. Moist; very friable. Crumbly. Diffuse wavy change to
B/C1	17½–26″	Light yellowish brown (10YR 6/4) clay. Accumulation of very hard large boulders. Weak clayskins developed along cracks. No mottles. Moist; slightly firm. Massive in profile. Weak subangular blocky structures. Diffuse wavy change to
B/C2	26–40″	Light yellowish brown (10YR 6/4) clay. Increasingly more large boulders in profile. Moist, slightly firm. Weak subangular blocky structure.
R	40″ +	Hard rocks (mainly large boulders).

Profile ref. No.: 76 **Soil Group:** RED-YELLOW PODZOLIC **Soil Family:** ABOK **Soil Series:** GUMBANG

Phase:

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	ppm. O.D. Av. P	ppm. O.D. 'Total' P	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	Group III Oxides	% P Ret.
87692	A1	0 - 3	5.2		0.378	4.08	10.79			7.97	2.07	0.40	0.17	0.16	0.08	16.22	65.41					28.01
93	B1	3 - 11	4.8		0.121	1.05	8.68			0.66	0.60	0.06	0.07	2.55	0.07	6.77	20.53					37.97
94	B2	11 - 17½	4.7		0.075	0.66	8.80			0.38	0.38	0.06	0.07	3.08	0.02	7.09	12.55					34.54
95	B/C1	17½-26	4.6		0.053	0.49	9.25			0.49	0.23	0.04	0.07	3.72	0.03	6.69	12.41					48.61
96	B/C2	26-40	4.7		0.031	0.29	9.35			0.33	0.12	0.02	0.07	4.18	0.02	6.60	8.18					50.55

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D. SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	Colloidal Fraction Total SiO_2	Fe_2O_3	Al_2O_3	Derived mol. ratio's $\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	Extractable Morgan Al	Mn	Fe	6N HCL Fe
87692	A1	0 - 3	76.49	2.27	8.46	0.71	0.40	0.53		0.07	0.0301	0.0325	39.49	5.49	31.04	1.95	19.35	2.16	0.11				1.73
93	B1	3 - 11	78.15	2.49	11.12	0.74	0.16	0.35		0.05	0.0264	0.0134	40.04	5.49	35.22	1.76	19.62	1.93	0.10				2.05
94	B2	11 - 17½	74.18	2.92	13.37	0.70	0.16	0.33		0.01	0.0266	0.0075	40.07	5.49	34.47	1.80	19.62	1.98	0.10				2.48
95	B/C1	17½-26	76.35	3.14	14.61	0.66	0.16	0.32		0.04	0.259	0.0045	39.75	5.24	34.53	1.79	20.69	1.96	0.09				2.82
96	B/C2	26-40	72.70	3.33	15.64	0.64	0.18	0.34		0.01	0.256	0.013	40.18	5.19	34.85	1.79	20.91	1.96	0.09				2.80

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	Fine earth < 2 mm composition V.C.S. 2000μ-1000μ	C.S. 1000μ-500μ	M.S. 500μ-250μ	F.S. 250μ-100μ	V.F.S. 100μ-50μ	Sand Total 2000-50μ	Silt 50-2μ	Clay < 2μ	Total fine earth	Texture according to U.S. Survey Manual
87692	A1	0 - 3	1.29	1.86	5.12	15.81	28.65	52.73	25.92	24.69	103.34	Sandy clay loam
93	B1	3 - 11	0.32	0.57	0.57	5.01	40.36	46.83	23.42	24.41	94.66	Loam
94	B2	11-17½	0.22	0.49	0.37	1.20	40.86	43.14	20.41	29.91	93.48	Clay loam
95	B/C1	17½-26	0.83	0.70	0.41	0.64	40.21	42.79	18.31	34.41	95.51	Clay loam
96	B/C2	26-40	0.30	0.31	0.32	0.53	39.25	40.71	17.76	38.24	96.71	Clay loam

(d) Mineralogy.

Sample No.	Horizon	Depth in inch	Medium or fine sand fraction %. Heavy minerals: Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoisite	Clino-Zoisite	Hornblende	Corundum	Crystobalite	Alterite	Light minerals: Quartz	Felspars	Mica's	* Clay fraction: Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
87692	A1	0 - 3																								d		p	t		
93	B1	3 - 11																								d		p	t		
94	B2	11 - 17½																								d		p	t		
95	B/C1	17½-26																								d		p	t		
96	B/C2	26-40																								d		p	t		

* d-dominant, p-present, t-trace

Profile ref. No.: 54 Soil Group: RED-YELLOW PODZOLIC Soil Family: MERIT Soil Series: STASS

Phase: WELL DRAINED DEEP

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH		% O.D.			p.p.m. O.D.		m.e.q. % (O.D.)								'Reserves' p.p.m. O.D.				%
			1:2.5 H_2O	1:5 KCL	Total N	Total C	C/N Value	Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value	Ca	Mg	K	Group III Oxides	P Ret.
S 7670	A1	0-2	4.6		0.314	3.93	12.52			1.50	1.76	0.36	0.08	12.58	0.23	27.27	13.57					71.41
S 7671	A2	2-12	4.7		0.107	1.07	10.00			<0.01	0.44	0.11	0.05	13.52	0.08	21.60	2.78					73.04
S 7672	B1	12-22	5.0		0.064	0.47	7.34			0.01	0.24	0.09	0.07	12.67	0.05	20.86	1.92					68.95
S 7673	B2	22-35	4.9		0.057	0.30	5.26			<0.01	0.20	0.09	0.08	12.06	0.02	41.34	0.90					71.06
S 7674	B3	35-54	5.0		0.042	0.34	8.10			0.15	0.22	0.10	0.08	10.36	0.02	22.29	2.47					75.91
S 7675	B/C	54-63+	5.0		0.055	0.29	5.27			1.15	0.16	0.09	0.05	9.42	0.03	18.33	7.91					74.47

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D.										Colloidal Fraction							Extractable			
													Total			Derived mol. ratio's				Morgan			6N HCL
			SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	SiO_2	Fe_2O_3	Al_2O_3	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	Al	Mn	Fe	Fe
S7670	A1	0-2	66.35	4.01	14.06	0.91	0.17	0.59		0.63	0.0053	0.0367	41.61	7.79	29.79	2.048	14.44	2.37	0.16				3.13
S 7671	A2	2-12	67.84	4.58	16.85	0.99	0.24	0.60		0.62	0.0037	0.0244	42.00	9.23	29.79	2.005	12.28	2.40	0.20				4.51
S7672	B1	12-22	68.82	5.36	17.92	0.96	0.17	0.58		0.62	0.0041	0.00313	41.74	8.93	31.16	1.930	12.64	2.28	0.18				4.23
S7673	B2	22-35	63.05	5.50	20.73	1.07	0.17	0.67		0.82	0.0041	0.0240	41.89	8.78	31.66	1.917	12.93	2.25	0.17				5.10
S 7674	B3	35-54	61.72	6.75	22.40	1.13	0.14	0.71		0.99	0.0044	0.0235	40.97	8.39	31.16	1.910	13.12	2.30	0.17				5.28
S 7675	B/C	54-63+	47.56	19.96	20.52	0.90	0.19	0.68		0.99	0.0049	0.0155	39.72	12.18	29.66	1.613	8.83	2.28	0.26				5.72

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	Fine earth < 2 mm composition								Total fine earth	Texture according to U.S. Survey Manual
			V.C.S.	C.S.	M.S.	F.S.	V.F.S.	Sand	Silt	Clay		
			2000µ-1000µ	1000µ-500µ	500µ-250µ	250µ-100µ	100µ-50µ	Total 2000-50µ	50-2µ	< 2µ		
S 7670	A1	0-2	0.32	0.88	0.94	11.54	13.05	26.73	24.91	40.49	92.13	clay/clay loam
S 7671	A2	2-12	0.27	0.32	0.71	12.06	15.90	29.26	23.13	47.29	99.68	clay
S 7672	B1	12-22	0.12	0.26	0.48	10.40	16.04	27.30	19.49	53.05	99.84	"
S 7673	B2	22-35	0.19	0.28	0.38	7.93	14.32	23.10	18.02	58.07	99.19	"
S 7674	B3	35-54	0.31	0.19	0.29	6.33	11.18	18.30	18.62	60.68	97.60	"
S 7675	B/C	54-63+	10.62	6.82	2.91	6.30	9.28	35.93	16.38	47.38	99.69	"

(d) Mineralogy.

Sample No.	Horizon	Depth in inch	Medium or fine sand fraction %																								* Clay fraction						
			Heavy minerals																				Light minerals										
			Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoizite	Clino-Zoizite	Hornblende	Corundum	Crystobalite	Alterite	Stone fragments		Quartz	Felspars	Mica's		Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
S 7670	A1	0-2	70/30	21	26			1	15	15	2	4	3			2						6							d		p	t		
S 7671	A2	2-12																											d		p	t		
S 7672	B1	12-22																											d		p	t		
S 7673	B2	22-35	54/46	21	14			1	14	12	7	31																	d		p	t		
S 7674	B3	35-54																											d		p	t		
S 7675	B/C	54-63+	55/45	35	21				5	17	4	18																	d		p	t		

Many transitional stages ilmenite to titaniferous minerals

Zircon are small and generally euhedral.

* d-dominant, p-present, t-trace.

PROFILE REF. NO. 54

Soil Group: RED-YELLOW PODZOLIC.

Family: **Merit.**

Series: *Stass.*

Phase: Well drained.

Location: End of Pejiru Road, near Kpg. Stass (Bau District).

Latitude: 1° 23′ 30″ N.

Longitude: 109° 59′ 10″ E.

Topography: Strongly dissected hilly terrain.

Site: On moderately high hill, slope 12 degrees.

Parent material: Shale (Cretaceous).

External drainage: Good.

Vegetation/Land Use: Secondary forest. Mostly cyperacea, lallang and soft wood trees.

Altitude: ± 200 feet.

Rainfall: 129.56″ M.A.R. (Bau).

Rainfall Class (Mohr): I.

Lab. Nos: S 7670/75.

Date sampled 16.1.70.

NOTE: On surface ½ inch—mainly leave litter and decayed branches.

A1	0–2″	Brown (10YR 5/3) loam. Many medium to fine slightly decomposed roots. Many worm-holes. Moist; friable. Clear smooth change to
A2	2–12″	Brownish yellow (10YR 6/6) clay loam with few coarse to fine roots. Infiltration of organic matter from above. No mottles. Moist; slightly friable. Weak angular blocky structure. Gradual wavy change to
B1	12–22″	Reddish yellow (7.5YR 7/8) clay with few roots. Very weak 'clayskins' developed along cracks. Massive in profile. Moist; slightly firm. Angular block structure. Diffuse wavy change to
B2	22–35″	Yellow (10YR 7/8) clay with common distinct reddish-yellow (5YR 7/8) mottles. Few fine dead roots. Massive in profile. Moist. Slightly firm. Strong angular blocky structure. Weak 'clayskins' along cracks. Diffuse wavy change to
B3	35–54″	Yellow (10YR 7/8), 50% and reddish yellow (7.5YR 7/8), 50%, clay. Common pale yellow (2.5Y 8/4) and yellowish red (5YR 5/6 mottles. Moist; firm. Strong blocky structure. Less 'clayskins' development than B2. Clear wavy change to
B/C	54–63″ +	Yellow (10YR 7/8) gritty clay with accumulation of red (2.5YR 4/6) weathered shale. Few white quartz pebbles. Prominent strong brown (7.5YR 5/8) iron—coated shale. Moist; firm.

PROFILE REF. NO. 77

Soil Group: RED-YELLOW PODZOLIC.

Family: **Merit.**

Series: *Semongok.*

Phase: Imperfectly drained.

Location: Milestone 13½, Penrissen Road (Kuching District).

Latitude: 1° 23′ 30″ N.

Longitude: 110° 19′ E.

Topography: Moderately dissected hilly terrain.

Site: On low hill with slope 8-10 degrees.

Parent material: Carbonaceous shale (Cretaceous).

External drainage: Good.

Vegetation/Land Use: Secondary forest, mainly cyperacea and thick ferns.

Altitude: ± 150 feet.

Rainfall: 164.03″ M.A.R. (Semongok).

Rainfall Class (Mohr): I.

Lab. Nos: S 7687/91.

Date sampled: 19.1.70.

NOTE: On surface very thin layer of partly decomposed leaves and branches.

A1	0–5″	Yellowish brown (10YR 5/4) loam with faint, few dark brown (7.5 YR 4/4) mottles along root channnels. Many fine to medium roots. Charcoal bits. Moist; friable. Clear smooth change to
A2	5–17½″	Brownish yellow (10YR 7/8) clay loam with prominent light grey (2.5Y 7/2) and few strong brown (7.5 YR 5/6) mottles. Common fine roots. Moist; slightly firm. Massive in profile. Strong angular blocky when broken up. Gradual wavy boundary merging into
B	17½–28″	50% yellow (10YR 7/6) and 50% reddish yellow (5YR 6/8) clay, with common, distinct light grey (2.5Y 7/2) mottles. Few soft and crushable iron concretions. Few dead roots. Moist; compact and firm. Strong angular blocky structure. Clear wavy change to
B/C	28–40″	Reddish yellow (7.5YR 7/6) clay with weathered grey (10YR 6/1) shale. Moist; firm. Very friable when broken up. Few dead roots. Diffuse wavy change to
C	40–51″ +	Grey (10YR 6/1) weathered shale with prominent reddish brown (2.5YR 4/4), common reddish brown (2.5YR 5/4), brownish yellow (10YR 6/6), and many red (2.5YR 4/6) mottles. Moist; very firm. Platy structure.

Profile ref. No.. 77 | Soil Group: RED-YELLOW PODZOLIC | Soil Family: MERIT | Soil Series: SEMONGOK

Phase: IMPERFECTLY DRAINED

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	Group III Oxides	% P Ret.
S 7687	A1	0-5	4.2		0.299	3.58	11.97			1.88	0.22	0.19	0.18	9.08	0.12	22.78	10.84					76.23
S 7688	A2	5-17½	4.4		0.101	0.48	4.75			1.04	0.49	0.13	0.06	13.18	0.11	18.08	9.51					73.65
S 7689	B	17½-28	4.5		0.087	0.47	5.40			0.48	0.15	0.15	0.10	14.97	0.02	19.74	4.46					75.09
S 7690	B/C	28-40	4.5		0.118	0.43	3.64			0.34	0.12	0.20	0.04	20.90	0.05	26.20	2.67					79.39
S 7691	C	40-51+	3.9		0.078	0.02	0.26			0.37	0.12	0.15	0.22	20.58	0.02	26.01	3.31					75.44

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D. SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	Colloidal Fraction Total SiO_2	Total Fe_2O_3	Total Al_2O_3	Derived mol. ratio's $\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	Extractable Morgan Al	Mn	Fe	6N HCL Fe
S 7687	A1	0-5	65.81	4.95	13.57	1.03	0.21	0.70		0.61	0.0067	0.0406	47.24	7.19	25.79	2.66	17.89	3.12	0.17				4.26
S 7688	A2	5-17½	68.62	5.58	16.05	1.08	0.17	0.69		0.80	0.0026	0.0231	45.17	7.74	27.42	2.39	16.00	2.81	0.18				4.61
S 7689	B	17½-28	61.87	9.03	18.82	1.10	0.13	0.81		0.99	0.0032	0.0204	44.20	8.88	28.29	2.22	13.38	2.66	0.20				7.27
S 7690	B/C	28-40	55.79	7.25	22.14	1.04	0.17	0.94		1.81	0.0026	0.0310	45.49	8.25	28.66	2.29	14.86	2.71	0.18				6.51
S 7691	C	40-51+	56.26	7.45	24.96	0.95	0.17	0.90		2.27	0.0032	0.0390	47.48	7.19	28.04	2.49	17.98	2.89	0.16				6.23

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	Fine earth < 2 mm composition V.C.S. 2000µ-1000µ	C.S. 1000µ-500µ	M.S. 500µ-250µ	F.S. 250µ-100µ	V.F.S. 100µ-50µ	Sand Total 2000-50µ	Silt 50-2µ	Clay < 2µ	Total fine earth	Texture according to U.S. Survey Manual
S 7687	A1	0-5	1.30	1.67	2.32	5.80	10.33	21.42	32.42	40.69	94.53	clay
S 7688	A2	5-17½	3.60	1.99	0.82	1.82	8.98	17.21	23.25	56.17	96.63	"
S 7689	B	17½-28	0.60	0.47	0.70	2.99	15.55	20.31	27.89	54.67	102.87	"
S 7690	B/C	28-40	1.47	1.51	0.92	1.03	3.82	8.75	30.06	60.22	99.03	"
S 7691	C	40-51+	2.98	2.56	1.01	0.87	2.03	9.45	29.62	58.84	97.91	"

(d) Mineralogy.

Sample No.	Horizon	Depth in inch	Medium or fine sand fraction % — Heavy minerals: Ratio Opaque/Non-opaque, Zircon, Tourmaline, Andalusite, Sillimanite, Epidote, Rutile, Anatase, Brookite, Leucoxene, Sphene, Garnet, Spinel, Zoizite, Clino-Zoizite, Hornblende, Corundum, Crystobalite, Alterite; Light minerals: Quartz, Felspars, Mica's	* Clay fraction Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
				p	d		d	t		
			insufficient minerals - association of	t	d		d	t		
			mainly large ilmenite without titaniferous	t	d		d	t		
			transitions. Some Tourmaline	t	d		d	t		
			insubsoil shale fragments with opaques.	t	d		d	t		

* d-dominant, p-present, t-trace.

Profile ref. No.: 74 | Soil Group: RED–YELLOW PODZOLIC | Soil Family: MERIT | Soil Series: SEMONGOK

Phase: IMPERFECTLY DRAINED SHALLOW

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	Group III Oxides	% P Ret.
57676	A1	0 – 2½	5.1		0.304	3.03	9.97			1.26	1.11	0.36	0.08	3.31	0.21	17.59	15.97					37.64
77	B	2½–12	4.9		0.091	0.77	8.46			0.66	0.56	0.10	0.04	6.64	0.07	15.22	8.94					49.02
78	B/C1	12 – 21	4.9		0.061	0.40	6.67			0.03	1.65	0.12	0.08	10.29	0.02	19.14	9.82					57.50
79	B/C2	21 – 36	5.0		0.054	0.23	4.26			0.86	0.28	0.12	0.06	10.27	0.02	18.01	7.33					57.50
80	C	36–51	5.1		0.030	0.09	3.00			1.27	0.25	0.11	0.06	9.19	0.02	15.81	10.69					36.42

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D. SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	Colloidal Fraction Total SiO_2	Fe_2O_3	Al_2O_3	Derived mol. ratio's $\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	Extractable Morgan Al	Mn	Fe	6N HCL Fe
57676	A1	0–2½	70.70	5.21	10.89	0.83	0.30	0.50		1.06	0.0246	0.0621	40.63	9.08	28.60	2.014	12.09	2.42	0.20				4.45
77	B	2½–12	68.50	6.42	15.73	0.83	0.14	0.54		1.83	0.0123	0.0344	41.71	10.38	28.54	2.026	10.86	2.49	0.23				5.53
78	B/C1	12–21	58.69	8.03	21.08	0.79	0.14	0.63		2.78	0.0087	0.0242	41.47	9.38	29.85	1.974	11.91	2.37	0.20				11.05
79	B/C2	21–36	56.83	8.55	22.79	0.84	0.29	0.61		3.54	0.0075	0.0288	42.90	9.08	30.60	2.008	12.77	2.38	0.19				6.88
80	C	36–51	56.00	9.43	22.17	0.87	0.22	0.65		3.72	0.0099	0.0238	45.13	6.39	30.16	2.251	19.28	2.55	0.13				8.50

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	Fine earth < 2 mm composition V.C.S. 2000µ–1000µ	C.S. 1000µ–500µ	M.S. 500µ–250µ	F.S. 250µ–100µ	V.F.S. 100µ–50µ	Sand Total 2000-50µ	Silt 50–2µ	Clay < 2µ	Total fine earth	Texture according to U.S. Survey Manual
57676	A1	0 – 2½	1.18	1.41	2.52	8.63	16.15	29.69	29.92	31.66	91.47	Clay loam
77	B	2½ –12	0.63	0.82	1.20	4.18	17.64	24.47	25.50	46.43	96.40	Clay
78	B/C1	12 – 21	0.69	2.01	1.58	2.38	8.22	14.88	29.84	52.56	97.28	Clay
79	B/C2	21–36	0.96	2.56	1.58	2.32	7.01	14.43	39.23	45.37	99.03	Clay/silty clay
80	C	36–51	4.84	5.88	2.67	1.89	4.40	19.68	45.10	31.43	96.21	Clay loam.

(d) Mineralogy.

Sample No.	Horizon	Depth in inch	Medium or fine sand fraction % Heavy minerals: Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoizite	Clino-Zoizite	Hornblende	Corundum	Crystobalite	Alterite	Light minerals: Quartz	Felspars	Mica's	* Clay fraction: Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite

* d-dominant, p-present, t-trace.

PROFILE REF. NO. 74

Soil Group: RED-YELLOW PODZOLIC.

Family: Merit.

Series: *Semongok*.

Phase: Imperfectly drained, shallow.

Location: Foot of Bukit Serambu—opposite Siniawan bazaar (Bau District).

Latitude: 1° 26′ 10″ N.

Longitude: 110° 13′ E.

Tepography: Strongly dissected hilly terrain.

Site: On steep slope, 30-50 degrees.

Parent material: Carbonaceous shale (Cretaceous).

External drainage: Good.

Vegetation/Land Use: Scattered young rubber trees and few fruit trees.

Altitude: ± 200 feet.

Rainfall: 129.56″ M.A.R. (Bau).

Rainfall Class (Mohr): I.

Lab. Nos: S 7676/80.

Date sampled: 16.1.70.

A1	0–2½″	Yellowish brown (10YR 6/4) loam with abundant medium to fine roots. Slightly porous. Moist; friable. Crumbly. Clear smooth change to
B	2½–12″	Brownish yellow (10YR 6/8) clay loam with few distinct, light red (2.5YR 6/8), mottles. Few dead roots. Moist; slightly firm. Massive in profile. Strong subangular blocky structure. Gradual wavy change to
B/C1	12–21″	Reddish yellow (7.5YR 6/8) clay. Accumulation of red (2.5YR 4/6) coloured weathered shale. 'Clayskins' present. Moist; slightly firm. Weak subangular blocky structure. Clear gradual change to
B/C2	21–36″	Reddish yellow (7.5YR 7/8) clay with increasing weathered, variegated-red, pinkish red, grey and white shale. Clear wavy change to
C	36–51″+	Weathered variegated shale. Moist; firm.

PROFILE REF. NO. 198

Soil Group: RED-YELLOW PODZOLIC.

Family: Merit.

Series: *Padawan.*

Phase: Imperfectly drained.

Location: Kampong Pisang, Padawan Road (Kuching Rural District).

Latitude: 1° 11′ 35″ N.

Longitude: 110° 20′ 50″ E.

Topography: Moderately dissected hilly terrain.

Site: On gentle hill, slope 8-10 degrees.

Parent material: Carbonaceous shale (Cretaceous).

External drainage: Good.

Vegetation/Land Use: Secondary forest, mainly thick rasam, bamboo and thick ferns undergrowth.

Altitude: 200 feet.

Rainfall: estimated 150″ M.A.R.

Rainfall Class (Mohr): I.

Lab. Nos: S 7664/69.

Date sampled: 15.1.70.

NOTE: On surface 2 inches—mainly fern roots and leave litter.

A1	0–4″	Dark greyish brown (10YR 4/2) loam with many fine to medium roots. Many worm-holes. Moist. Crumbly structure. Clear smooth change to
A2	4–10″	Yellow (2.5Y 7/6) clay loam. Few fine roots. No mottles. Moist; slightly firm. Weak subangular blocky structure. Diffuse wavy change to
B1	10–15″	Yellow (2.5YR 7/6) clay, with common light grey (10YR 7/2) and common brownish yellow (10YR 6/8) mottles. 'Clayskins' present along cracks. Moist; firm. Angular blocky when broken up. Gradual change to
B2	15–23″	Pale yellow (2.5Y 7/4) clay with accumulation of weathered grey shale pieces. Distinct, common brownish yellow (10YR 6/8) and light grey (10YR 7/2) mottles. Moist; very firm. Strong blocky structure. Diffuse wavy change to
B/C	23–28″	Transitional horizon; mixture of pale yellow (2.5Y 7/4) and red (2.5YR 4/8) clay. Strong blocky structure. Clear broken change to
C	28–49″+	Weathered grey (10YR 5/1) shale bed with prominent red (2.5YR 4/8), pale yellow (2.5Y 7/4), and brownish yellow (10YR 6/8) mottles. Moist; very firm.

Profile ref. No. 198 | Soil Group: RED - YELLOW PODZOLIC | Soil Family: MERIT | Soil Series: PADAWAN

Phase:

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	Group III Oxides	% P Ret.
S 7664	A1	0-4	4.2		0.440	5.84	13.27			0.52	0.32	0.24	0.12	14.18	0.34	35.06	3.43					77.17
S 7665	A2	4-10	4.4		0.138	1.21	8.77			<0.01	0.19	0.08	0.07	13.41	0.08	23.88	1.42					72.68
S 7666	B1	10-15	4.6		0.083	0.66	7.95			<0.01	0.16	0.07	0.06	11.87	0.02	20.95	1.38					70.03
S 7667	B2	15-23	4.9		0.077	0.45	5.84			<0.01	0.15	0.06	0.05	11.33	0.08	19.67	1.32					69.05
S 7668	B/C	23-28	5.1		0.064	0.43	6.72			1.98	0.16	0.07	0.06	14.03	<0.02	23.48	9.67					80.90
S 7669	C	28-49+	5.1		0.054	0.32	5.93			0.88	0.15	0.07	0.06	13.13	<0.02	21.43	5.41					89.11

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D. SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	Colloidal Fraction Total SiO_2	Fe_2O_3	Al_2O_3	Derived mol. ratio's SiO_2/R_2O_3	SiO_2/Fe_2O_3	SiO_2/Al_2O_3	Fe_2O_3/Al_2O_3	Extractable Morgan Al	Mn	Fe	6N HCL Fe
S 7664	A1	0-4	63.02	3.07	15.06	0.94	0.25	0.40		0.34	0.0050	0.0508	42.13	6.04	29.22	2.28	18.97	2.45	0.13				1.96
S 7665	A2	4-10	68.77	4.14	17.24	0.61	0.35	0.44		0.40	0.0047	0.0434	46.35	6.74	31.35	2.21	18.38	2.51	0.14				2.53
S 7666	B1	10-15	64.38	3.74	18.30	1.06	0.18	0.48		0.45	0.0048	0.0317	44.64	6.69	30.85	2.17	18.15	2.46	0.14				3.56
S 7667	B2	15-23	59.79	5.56	22.16	1.12	0.17	0.51		0.72	0.0066	0.0292	44.30	6.84	31.72	2.10	17.57	2.38	0.14				4.49
S 7668	B/C	23-28	55.41	6.65	26.00	1.06	0.39	0.53		0.80	0.0032	0.0541	43.80	6.89	32.22	2.03	16.22	2.32	0.14				5.87
S 7669	C	28-49+	61.94	7.15	20.32	0.88	0.16	0.48		0.80	0.0034	0.0694	46.11	6.84	30.54	2.25	18.29	2.57	0.14				6.32

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	Fine earth < 2 mm composition V.C.S. 2000µ-1000µ	C.S. 1000µ-500µ	M.S. 500µ-250µ	F.S. 250µ-100µ	V.F.S. 100µ-50µ	Sand Total 2000-50µ	Silt 50-2µ	Clay < 2µ	Total fine earth	Texture according to U.S. Survey Manual
S 7664	A1	0-4	1.02	2.65	3.80	5.86	5.32	18.65	29.79	49.35	89.79	clay
S 7665	A2	4-10	1.17	1.77	2.17	4.25	7.96	17.32	29.90	48.86	96.08	"
S 7666	B1	10-15	1.50	1.53	1.78	3.71	8.78	17.30	22.40	50.96	90.66	"
S 7667	B2	15-23	4.57	3.22	2.44	2.80	4.56	17.59	23.72	52.77	94.08	"
S 7668	B/C	23-28	3.30	5.64	3.45	3.17	5.30	20.86	31.56	44.43	96.85	"
S 7669	C	28-49+	3.07	4.96	3.14	4.11	7.33	22.61	39.07	37.86	99.54	clay loam

(d) Mineralogy.

Sample No.	Horizon	Depth in inch	Medium or fine sand fraction % — Heavy minerals: Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoizite	Clino-Zoizite	Hornblende	Corundum	Crystobalite	Alterite	Light minerals: Quartz	Felspars	Mica's	* Clay fraction: Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
S 7664	A1	0-4	64/36	3	8	1		8	2	2	1	14				2									p	d		p			
S 7665	A2	4-10																							t	d		t			
S 7666	B1	10-15	70/30	1	14			6		2	2	11		1		3									t	d		t			
S 7667	B2	15-23	Epidote - Tourmaline - Brookite dominant. Insufficient minerals.																						t	d		t			
S 7668	B/C	23-28																							t	d		t			
S 7669	C	28-49+																							t	d		t			
			Very good specimens of Brookite and large Epidote.																												

* d-dominant, p-present, t-trace.

Profile ref. No.: 25 **Soil Group:** RED-YELLOW PODZOLIC. **Soil Family:** MERIT **Soil Series:** Stom.

Phase:

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P $HClO_4$	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	Group III Oxides	% P Ret.
S7513	A1	0-4	5.1	4.3	0.14				137	0.40	0.06	0.21	0.12	4.27	0.20	8.01	7.2					52.54
S7514	A2	4-12	5.1	3.9	0.04				53	0.14	0.54	0.06	0.08	7.51	0.06	7.91	10.4					53.14
S7515	B1	12-30	5.2	3.9	0.04				63	0.72	0.66	0.04	0.05	9.18	0.14	9.11	16.1					57.48
S7516	B2	30-47	5.4	3.9	0.04				81	0.55	0.34	0.06	0.05	12.50	0.06	12.60	7.9					58.86
S7517	B/C	47-50	5.1	3.9	0.06				108	2.33	0.55	0.09	0.05	15.79	0.21	15.69	19.2					73.46

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D. SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	Colloidal Fraction Total SiO_2	Fe_2O_3	Al_2O_3	Derived mol. ratio's $\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	Extractable Morgan Al	Mn	Fe	6N HCL Fe
S7513	A1	0-4	84.88	2.31	2.85	0.48	0.14	0.41	0.03	0.09	<0.01	0.60	37.00	13.03	26.67	1.80	7.52	2.37	0.49				
S7514	A2	4-12	84.06	3.55	8.65	0.56	0.16	0.39	0.03	0.15	<0.01	0.36	36.79	14.62	28.91	1.64	6.73	2.16	0.51				
S7515	B1	12-30	78.65	5.24	11.38	0.60	0.10	0.49	0.05	0.24	<0.01	0.43	34.39	13.68	27.48	1.58	6.74	1.06	0.50				
S7516	B2	30-47	72.56	6.65	15.51	0.61	0.12	0.63	0.09	1.22	<0.01	0.49	37.84	13.08	28.04	1.77	7.69	2.19	0.47				
S7517	B/C	47-50	64.49	8.11	17.72	0.55	0.06	0.79	0.05	1.27	<0.01	0.62	38.07	12.63	27.48	1.74	8.00	2.24	0.46				
S7560	C												50.10	7.68	6.99	7.32	18.00	12.00	0.7				
S7599	R												50.02	4.99	5.37	10.-	27.00	16.00	0.6				

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	V.C.S. 2000µ-1000µ	C.S. 1000µ-500µ	M.S. 500µ-250µ	F.S. 250µ-100µ	V.F.S. 100µ-50µ	Sand Total 2000-50µ	Silt 50-2µ	Clay <2µ	Total fine earth	Texture according to U.S. Survey Manual
S7513	A1	0-4	0.63	0.56	18.64	13.55	19.28	52.66	25.20	19.04	96.90	Loam
S7514	A2	4.12	–	0.21	1.17	11.49	35.96	48.83	25.79	27.01	101.62	Sandy clay loam
S7515	B1	12.30	–	0.11	0.99	11.74	28.66	41.50	21.25	35.63	98.38	Clay loam
S7516	B2	30-47	–	0.22	0.80	5.32	27.57	33.91	21.70	45.52	101.13	Clay
S7517	B/C	47-50	0.18	0.22	0.53	3.75	20.68	25.36	19.60	51.42	96.38	Clay

(d) Mineralogy.

Medium or fine sand fraction % — Heavy minerals

Sample No.	Horizon	Depth in inch	Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoizite	Clino-Zoizite	Hornblende	Corundum	Crystobalite	Alterite
S7513	A1	0-4	52/48	55	4			1	5	23	3	6			2						
S7514	A2	4-12	63/37	50	7			2	10	11	1	14									
S7515	B1	12-30	65/35	41	16	2		1	11	13		12	1						1		
S7516	B2	30-47	52/48	48	13			3	2	18	1	12									
S7517	B/C	47-50	63/37	44	14	2			11	10	1	14	2								
S7560	C																				
S7599	R		63/37	20	37				7	8	2	26									

Many minute muscovite flakes present. Sericite.

Light minerals and * Clay fraction

Sample No.	Horizon	Light minerals: Quartz	Felspars	Mica's	Clay: Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
S7513	A1				p	d			p		t
S7514	A2					d			p		t
S7515	B1					d		t	p		t
S7516	B2					d		t	p		t
S7517	B/C					d	p	t	p		t
S7560	C					p	d	p			
S7599	R										

Much X-ray Amorphous material in all samples, particularly S7515

* d-dominant, p-present, t-trace

PROFILE REF. NO. 25

Soil Group: RED-YELLOW PODZOLIC.

Family: **Merit.**

Series: *Stom.*

Phase:

Location: 19th mile, Bau-Lundu Road (Lundu District).

Latitude: 1° 30′ N.

Longitude: 109° 55′ 30″ E.

Topography: Low, gently undulating terrain, slightly dissected.

Site: On top of low rounded hill. Slope ± 5 degrees.

Parent material: Soft purplish coloured mudstone (Tertiary).

External drainage: Good.

Vegetation/Land Use: Secondary growth. Much fern undergrowth.

Altitude: ± 30 feet.

Rainfall: ± 130″ M.A.R. (estimated).

Rainfall Class (Mohr): I.

Lab. Nos: S 7513/17.

Date sampled: July, 1969.

A1	**0–2″(4)**	Dark yellowish brown (10YR 4/4) clay. Friable; moist. Fine, moderately developed angular blocky to crumb structure. Many small roots. Distinct, irregular wavy boundary to
A2	**2(4)–12″**	Brownish yellow (10YR 6/8) clay. Moist; friable, compact in profile. Fine, moderately developed angular blocky to crumb structure. Moderately well rooted, (fine roots mainly). Porous. Diffuse boundary to
B1	**12–30″**	Brownish yellow to yellowish brown (10YR 6/8-5/8) clay with faint reddish yellow and yellow fine common mottles. Shiny ped surfaces weakly developed along large structural units. Porous. Moist; firm. Moderately developed medium angular blocky structure. Few small roots. Indistinct boundary to
B2	**30–47″**	Brownish yellow (10YR 6/6) clay with common, distinct, fine reddish yellow to yellow and few grey mottles. Moist; firm. Plastic; slightly sticky. Few small roots. Clayskins as in B1 horizon. Red colouration increases with depth reaching a maximum in B/C horizon. Gradual change to
B/C	**47–50″ +**	Red (2.5YR 4/8) compact clay with grey and yellow mottles. Moist; plastic, non-sticky. Few, rounded quartz pieces.

NOTE: Deeper down, the B/C horizon contains many laterised iron pipes (fossil root channels, infilled with iron oxides). This layer overlies purple coloured mudstone, which on weathering shows white, grey and red variegated colours.

PROFILE REF. NO. 9

Soil Group: RED-YELLOW PODZOLIC.

Family: Bekenu.

Series: *Biawak.*

Phase:

Location: Near Rh. Bakar (Pasir Tengah) along path to Pasir Ulu (Lundu District).

Latitude: 1° 37′ N.

Longitude: 109° 43′ 10″ E.

Topography: Low undulating terrain, on ridge between two streams.

Site: Almost on top of a ridge. Slope approximately 3 degrees.

Parent material: Serabang Formation. Possible greywacke sandstone.

External drainage: Moderately good.

Vegetation/Land Use: Rubber gardens.

Altitude: ± 150 feet.

Rainfall: ± 130″ M.A.R. (estimated).

Rainfall Class (Mohr): I.

Lab. Nos: S 5262/66.

Date sampled: October, 1967.

A1	0–6″	Very dark greyish brown (10YR 3/2) sandy clay loam. Dry; loose. Weak fine angular blocky. Well rooted. Distinct regular boundary to
A2	6–14″	Light olive brown (2.5Y 5/4) sandy clay loam. Dry; friable. Compact in profile. Weak blocky structure. Moderately well rooted. Much illuviation from 0-6″ through worm activity. Gradual change to
B1	14–24″	Light olive brown (2.5Y 5/4) clay loam with clear sand grains. Slightly moist; crumbly and friable upon pressure, few roots. Clayskins present. Porous; compact in profile. Gradual change to
B2	24–43″	Light yellowish brown (2.5Y 6/4) sandy clay, with large clear quartz grains mixed with clay. Slightly moist; very compact in profile but friable when broken up. Fine angular blocky. Few roots. Gradual change to
B/C	43–60″	Yellowish brown (10YR 5/6) sandy clay. Slightly moist; very firm. Weak blocky structure. Faint reddish yellow mottles, possibly from weathered rock, increasing with depth. Coarse, clear sand grains. Few roots.

REMARK: At 70 inches depth, greenish coloured weathered rock is present.

Profile ref. No.: 9 **Soil Group:** RED-YELLOW PODZOLIC **Soil Family:** BEKENU **Soil Series:** BIAWAK

Phase:

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P RESERVE	m.e.q.% (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	Group III Oxides	% P Ret.
S 5262	A1	0-6							103									217	390	697	7.92	
S 5263	A2	6-14							42									106	381	811	10.43	
S 5264	B1	14-24							38									1	507	1045	12.43	
S 5265	B2	24-43							35									1	385	1693	19.44	
S 5266	B/C	43-60							48									1	259	1769	17.45	

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D. SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	Colloidal Fraction Total SiO_2	Fe_2O_3	Al_2O_3	Derived mol. ratio's $\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	Extractable Morgan Al	Mn	Fe	6N HCL Fe
S 5262	A1	0-6																					1.67
S 5263	A2	6-14																					1.82
S 5264	B1	14-24																					2.58
S 5265	B2	24-43																					2.65
S 5266	B/C	43-60																					2.56

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	Fine earth < 2 mm composition V.C.S. 2000µ-1000µ	C.S. 1000µ-500µ	M.S. 500µ-250µ	F.S. 250µ-100µ	V.F.S. 100µ-50µ	Sand Total 2000-50µ	Silt 50-2µ	Clay < 2µ	Total fine earth	Texture according to U.S. Survey Manual

(d) Mineralogy.

Medium or fine sand fraction % — Heavy minerals

Sample No.	Horizon	Depth in inch	Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoizite	Clino-Zoizite	Hornblende	Corundum	Crystobalite	Alterite
S 5262	A1	0-6	65/35		60	39															1
S 5263	A2	6-14	69/31		57	39			1				1			2					
S 5264	B1	14-24	65/35	3	53	44															
S 5265	B2	24-43	61/39		57	40	1									1					1
S 5266	B/C	43-60	61/39		59	40							1								

Light minerals and * Clay fraction

Sample No.	Light minerals Quartz	Felspars	Mica's	* Clay fraction Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
S 5262					d			p	t	t
S 5263					d			p	t	t
S 5264					d			p	t	t
S 5265					d			p	t	t
S 5266										

* d-dominant, p-present, t-trace

Profile ref. No.: 172 Soil Group: RED-YELLOW PODZOLIC Soil Family: BEKENU Soil Series:

Phase:

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	Group III Oxides	% P Ret.
S 7645	A1	0-2½	4.2		0.327	5.53	16.91			0.87	0.15	0.41	0.12	15.32	0.18	27.06	5.73					70.29
7646	A2	2½-10	4.4		0.105	0.99	9.43			0.62	<0.01	0.15	0.09	11.84	0.02	17.04	5.05					58.37
7647	A3	10-19½	4.7		0.069	0.56	8.11			1.56	<0.01	0.07	0.07	9.06	0.02	13.66	12.45					58.69
7648	B1	19½-31	4.7		0.048	0.77	16.04			0.46	<0.01	0.08	0.08	8.72	0.07	14.80	4.19					50.87
7649	B2	31-51	4.8		0.028	0.15	5.36			0.43	<0.01	0.06	0.09	8.32	0.02	13.24	4.38					50.48
7650	Bat	51-56	4.9		0.034	0.17	5.00			0.29	<0.01	0.05	0.09	6.60	<0.02	10.78	3.99					47.94
7651	II C	56-62	5.0		0.042	0.15	3.57			0.36	<0.01	0.05	0.10	6.83	<0.02	11.52	4.43					50.48

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D. SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	Colloidal Fraction Total SiO_2	Fe_2O_3	Al_2O_3	Derived mol. ratio's SiO_2/R_2O_3	SiO_2/Fe_2O_3	SiO_2/Al_2O_3	Fe_2O_3/Al_2O_3	Extractable Morgan Al	Mn	Fe	6N HCL Fe
S 7645	A1	0-2	72.67	2.09	12.17	0.63	0.14	0.53		1.38	0.0017	0.0429	44.68	3.99	30.79	2.21	29.7	2.47	0.07				1.26
7646	A2	2½-10	73.64	2.31	15.51	0.66	0.16	0.62		2.06	0.0012	0.0286	44.17	4.64	30.60	2.23	25.5	2.12	0.09				0.96
7647	A3	10-19½	69.55	2.76	17.20	0.87	0.24	0.62		2.20	0.0017	0.0224	45.04	5.39	32.85	2.11	22.1	2.33	0.11				1.49
7648	B1	19½-31	68.94	2.82	18.40	0.74	0.12	0.62		2.46	0.0012	0.0239	41.22	5.14	31.41	2.02	21.4	2.22	0.11				1.89
7649	B2	31-51	64.49	3.16	19.82	0.69	0.16	0.69		2.44	0.0017	0.0193	42.43	6.29	32.22	1.97	18.0	2.22	0.12				2.22
7650	Bat	51-56	66.41	3.06	19.48	0.56	0.10	0.68		2.26	0.0017	0.0149	42.78	5.79	32.72	2.00	19.7	2.23	0.11				1.83
7651	II C	56-62	62.30	4.64	20.77	0.57	0.14	0.76		2.51	0.0022	0.0151	42.39	6.29	32.22	1.97	17.9	2.21	0.12				3.29

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	Fine earth < 2 mm composition: V.C.S. 2000µ-1000µ	C.S. 1000µ-500µ	M.S. 500µ-250µ	F.S. 250µ-100µ	V.F.S. 100µ-50µ	Sand Total 2000-50µ	Silt 50-2µ	Clay < 2µ	Total fine earth	Texture according to U.S. Survey Manual
S 7645	A1	0-2½	0.20	3.11	8.25	14.28	12.90	38.74	30-93	25.44	95.11	clay loam / loam
7646	A2	2½-10	0.44	2.56	6.77	12.88	24.44	47.08	24.83	34.81	106.72	sa-clay loam/clay loam
7647	A3	10-19½	0.50	2.38	6.76	12.34	15.29	37.27	22.79	36.64	96.70	clay loam
7648	B1	19½-31	0.58	1.93	4.92	10.89	15.48	33.80	23.25	40.06	97.11	clay
7649	B2	31-51	0.65	1.99	4.86	10.19	14.35	32.04	22.50	40.26	94.83	"
7650	Bat	51-56	5.62	7.30	7.45	10.67	13.09	44.13	21.25	34.04	99.42	clay loam
7651	IIC	56-62	3.35	3.76	6.11	13.85	22.34	39.41	23.81	35.38	98.60	"

(d) Mineralogy.

Medium or fine sand fraction % — Heavy minerals / Light minerals; * Clay fraction

Sample No.	Horizon	Depth in inch	Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoisite	Clino-Zoisite	Hornblende	Corundum	Crystobalite	Alterite	Muscovite		Light: Quartz	Felspars	Mica's		Clay: Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
S 7645	A1	0-2½	65/35	27	49				4	17	1	1									1								d		p			
7646	A2	2½-10	50/50	29	43			3	2	8	1	4	1									9							d		p			
7647	A3	10-19½	not analysed																										d		p			
7648	B1	19½-31	71/29	34	31			3	9	10	1	4									3	5							d		p			
7649	B2	31-51	almost 100% Opaque - traces Anatase																										d		p			
7650	Bat	51-56	78/22	36	30				4	6			2								4	18							d		p			
7651	II C	56-62	56/44	21	13	1			9	13	1										10	32							d		p			

mainly purple Zircon particularly in 7651

alterites are probably shale fragments

* d - dominant, p - present, t - trace

PROFILE REF. NO. 172

Soil Group: RED-YELLOW PODZOLIC.

Family: Bekenu.

Series: Not differentiated.

Phase: Moderately well drained.

Location: 11½ milstone, Mongkos Road, approx. 1 mile from Kpg. Krusen.

Latitude: 1° 2′ 40″ N.

Longitude: 110° 29′ 30″ E.

Topography: Strongly dissected hilly terrain.

Site: On moderately high hill, slope 12 degrees.

Parent material: Sandstone/shale (Triassic).

External drainage: Good.

Vegetation/Land Use: Secondary forest, mainly rasam, cyperacea, and soft-wood trees.

Altitude: ± 250 feet.

Rainfall: 132.60″ M.A.R. (Tebakang).

Rainfall Class (Mohr): I.

Lab. Nos: S 7645/51.

Date sampled: 12.1.70.

NOTE: 2 inches layer of undecomposed leaves and roots.

A1	0–2½″	Dark grey (10YR 4/1) loam. Abundant medium to coarse roots. Few charcoal bits. Moist. Friable. Weak crumbly structure. Clear smooth change to
A2	2½–10″	Yellow (10YR 7/6) fine sandy clay loam. Many slightly decomposed fine to medium roots. Illuviation from surface soil. No mottles. Massive in profile. Weak angular blocky structure when broken up. Moist and firm. Distinct boundary to
A3	10–19½″	Yellow (10YR 7/6) fine sandy clay loam to clay. No mottles. Few fine dead roots. Very weak 'clayskins' along cracks. Massive in profile. Subangular to angular blocky structure. Moist. Slightly firm. Gradual wavy boundary to
B1	19½–31″	Yellow (10YR 7/6) clay with distinct common pale yellow (2.5Y 8/4), and reddish yellow (7.5YR 6/6) mottles. Very few dead roots. Clear 'clayskins' in cracks. Strong angular blocky structure. Diffuse broken boundary to.
B2	31–51″	Reddish yellow (5YR 6/8) clay with prominent pale yellow (2.5Y 8/4) mottles. Many small pieces of quartz. Moist. Firm. Strong angular blocky structure. Diffuse broken boundary to
Bst	51–56″	Quartz stoneline. Gritty.
IIC	56–62″+	Reddish yellow (5YR 6/8) clay. Prominent pale yellow (2.5Y 8/4) mottles. Soft weathered shale pieces. Few quartz grit. Strong angular blocky structure. Moist. Very firm.

PROFILE REF. NO. 24

Soil Group: RED-YELLOW PODZOLIC.

Family: Nyalau.

Series: Not differentiated.

Phase:

Location: 23rd mile, Bau-Lundu Road (Lundu District).

Latitude: 1° 33′ N.

Longitude: 109° 54′ 30″ E.

Topography: Macro-strongly dissected hilly terrain, micro-dipslope.

Site: Nearly on top of a hill. Slope ± 15 degrees.

Parent material: Sandstone (Tertiary).

External drainage: Good.

Vegetation/Land Use: Poor Dipterocarp forest merging into 'Kerangas'.

Altitude: ± 350 feet.

Rainfall: 131.64″ M.A.R. (Lundu).

Rainfall Class (Mohr): I.

Lab. Nos: S 7518/22.

Date sampled: July, 1969.

A1	0–3″	Dark greyish brown (10YR 4/2) sandy loam. Moist; friable, crumbly. Porous. Many small and some large roots. Diffuse wavy boundary to
A2	3–12″	Yellow (10YR 7/6) sandy loam. Moist; friable. Weak crumb structure. Moderate small and medium roots. Porous. Pockets of humus-rich material from decayed roots. Indistinct boundary indicated by irregular dark brown pockets of mottles and very small soft iron concretions to
B1	12–30″	Brownish yellow (10YR 6/6) sandy clay loam. Moist; slightly firm. Weak crumbly structure. Porous. Weak 'clayskin' development-shiny and slightly darker coloured material mostly found in channels and small cavities. Moderate medium size roots. Indistinct change to
B2	30–40″	Brownish yellow (10YR 6/6) sandy clay loam. Gradual increase in clay with depth. Moist; firm. Slightly plastic. Macro-structure blocky. Faint light grey and pinkish coloured small mottles. Few medium roots. Slightly porous. Clayskins as in B1. Distinct regular boundary to
B/C	40–54″	Brownish yellow (10YR 5/6) sandy clay loam to clay loam, with common, medium reddish yellow (7.5YR 6/6) and light grey (7.5YR N7) mottling, increasing in intensity with depth. Moist; firm. Weak angular blocky. Very few roots. Weak 'clayskin' development a· in B1 and B2.

NOTE: At ± 7 feet conglomeratic sandstone, strongly mottled and overlying mudstone.

Profile ref. No.: 24 | Soil Group: RED-YELLOW PODZOLIC | Soil Family: NYALAU | Soil Series: | Phase:

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P $HClO_4$	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	Group III Oxides	% P Ret.
S 7518	A1	0-3	4.5	3.8	0.17				156	0.13	0.79	0.13	0.08	3.69	0.46	10.60	10.7					35.36
S 7519	A2	3-12	5.1	4.1	0.05				!	0.70	0.58	0.04	0.09	2.48	0.06	3.63	4.2					23.30
S 7520	B1	12-30	5.6	4.1	0.03				!	0.13	0.38	0.06	0.05	1.97	<0.03	2.80	22.1					31.10
S 7521	B2	30-40	5.5	4.0	0.02				!	0.13	0.39	0.06	0.05	2.98	<0.03	3.08	20.5					25.81
S 7522	B/C	40-54	5.4	3.9	0.02				!	0.26	0.13	0.03	0.04	4.28	0.06	3.94	11.7					29.17

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D. SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	Colloidal Fraction Total SiO_2	Fe_2O_3	Al_2O_3	Derived mol. ratio's SiO_2/R_2O_3	SiO_2/Fe_2O_3	SiO_2/Al_2O_3	Fe_2O_3/Al_2O_3	Extractable Morgan Al	Mn	Fe	6N HCL Fe
S 7518	A1	0-3	88.54	0.93	4.06	0.31	0.12	0.17	<0.03	0.05	0.03	<0.36	37.18	5.02	28.10	2.01	16.96	2.28	0.18				
S 7519	A2	3-12	88.87	1.32	6.86	0.29	0.06	0.29	<0.03	0.06	0.01	<0.36	38.84	7.44	31.34	1.78	14.06	2.06	0.29				
S 7520	B1	12-30	88.07	1.52	6.65	0.31	0.08	0.31	<0.03	0.08	0.02	<0.36	38.40	8.39	31.97	1.75	12.05	2.04	0.26				
S 7521	B2	30-40	85.20	1.97	8.38	0.34	0.31	0.29	0.03	0.08	<0.01	<0.26	39.47	8.28	31.97	1.79	12.17	2.10	0.27				
S 7522	B/C	40-54	82.07	2.50	10.41	0.33	0.06	0.72	0.03	0.13	0.02	1.02	39.42	8.98	31.97	1.77	11.16	2.10	0.28				
S 7561	R												47.90	2.54	1.62	25.70	53.00	49.00	0.90				

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	Fine earth < 2 mm composition V.C.S. 2000µ-1000µ	C.S. 1000µ-500µ	M.S. 500µ-250µ	F.S. 250µ-100µ	V.F.S. 100µ-50µ	Sand Total 2000-50µ	Silt 50-2µ	Clay < 2µ	Total fine earth	Texture according to U.S. Survey Manual
S 7518	A1	0-3	0.25	2.41	13.10	31.22	16.40	63.38	12.98	16.02	92.38	sandy loam
S 7519	A2	3-12	0.10	2.50	18.12	36.26	13.14	70.12	12.98	16.39	99.49	"
S 7520	B1	12-30	-	2.37	16.19	34.13	16.42	69.11	11.00	19.45	99.56	"
S 7521	B2	30-40	0.14	2.28	14.63	32.78	17.98	67.81	9.04	23.43	100.28	sandy clay loam
S 7522	B/C	40-54	0.10	1.66	12.41	29.03	18.41	61.61	12.18	27.16	100.95	"

(d) Mineralogy.

Sample No.	Horizon	Depth in inch	Medium or fine sand fraction % — Heavy minerals: Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoizite	Clino-Zoizite	Hornblende	Corundum	Crystobalite	Alterite			Light minerals: Quartz	Felspars	Mica's		* Clay fraction: Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
S 7518	A1	0-3	51/49	41	49				1	4	-	5			1						3							p	d		t	p		
S 7519	A2	3-12	52/48	38	31				2	11	3	11									1								d		t	p		
S 7520	B1	12-30	53/47	44	14				4	15	1	20	1								2								d		t			
S 7521	B2	30-40	35/65	45	16				6	11	2	15	2		1														d		t			
S 7522	B/C	40-54	44/56	40	27				5	8	1	18	1								3								d		t			
S 7561	R		51/49	46	22				4	3	2	20																		d				

* d-dominant, p-present, t-trace.

Profile ref. No.: 423 Soil Group: RED-YELLOW PODZOLIC Soil Family: MATANG Soil Series:

Phase:

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	Group III Oxides	% P Ret.
5775	O	0-2	3.8	3.5	0.21			0.7	125	0	0	0.14	0			14.8	1					
5776	A1	2-6½	4.8	3.9	0.14			7	64	0	0	0.09	0			10.8	1					
5777	A2	6½-22	4.8	4.1	0.02			2	94	0.10	0	0.02	0			4.7	3					
5778	B	22-45	4.7	3.9	0.02			1	161	0.10	0	0.02	0			4.3	3					
5779	B/C	45-54	5.2	3.9	0.16			1	44	0	0.10	0.02	0			4.1	3					

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D. SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	Colloidal Fraction Total SiO_2	Fe_2O_3	Al_2O_3	Derived mol. ratio's $\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	Extractable Morgan Al	Mn	Fe	6N HCL Fe
5775	O	0-2																		282	0	37	
5776	A1	2-6½														2.08	18.75	2.34	0.13	283	0	33	
5777	A2	6½-22														1.66	11.33	1.94	0.17	254	0	16	
5778	B	22-45														1.60	11.17	1.86	0.17	213	0	4	
5779	B/C	45-54														2.14	26.33	2.32	0.09	228	0	4	

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	Fine earth < 2 mm composition V.C.S. 2000µ-1000µ	C.S. 1000µ-500µ	M.S. 500µ-250µ	F.S. 250µ-100µ	V.F.S. 100µ-50µ	Sand Total 2000-50µ	Silt 50-2µ	Clay < 2µ	Total fine earth	Texture according to U.S. Survey Manual

(d) Mineralogy.

Sample No.	Horizon	Depth in inch	Medium or fine sand fraction % Heavy minerals: Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoizite	Clino-Zoizite	Hornblende	Corundum	Crystobalite	Alterite			Light minerals: Quartz	Felspars	Mica's	Rock Fragment	* Clay fraction: Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
5775	O	0-2	84/16	20	26	50			4	3											19			93			5		d				p	
5776	A1	2-6½	83/87	15	1	52		1	2	4											28			97			2		d				p	
5777	A2	6½-22	95/5	3	3	91			1	4											6			97		1	2		d				p	
5778	B	22-45	94/6	5	5	85			3	4											11			95			3		d				p	p
5779	B/C	45-54	88/12	5	6	84			4	2											8			91		1	5		d				p	p

* d-dominant, p-present, t-trace.

PROFILE REF. NO. 423

Soil Group: RED-YELLOW PODZOLIC.

Family: Matang.

Series: Not differentiated.

Phase:

Location: Matang. Path to summit approx. 500 feet above South China Sea (Kuching District).

Latitude: 1° 35′ 12″ N.

Longitude: 110° 12′ 25″ E.

Topography: Nearly on summit of a hill. Broken hilly terrain.

Site: Slope 15 degrees.

Parent material: Thick bedded sandstone. (Tertiary).

External drainage: Good.

Vegetation/Land Use: Dipterocarp forest.

Altitude: 350 feet.

Rainfall: 190″ M.A.R.

Rainfall Glass (Mohr): I.

Lab. Nos: S 5775/79.

Date sampled: July, 1961.

O	0–2″	Humus containing abundant fine to medium roots, leaves in varying stages of decomposition.
A1	2–6½″	Pale brown (10YR 6/3) sandy loam. Distinct common strong brown mottles. Moist; friable. Subangular blocky to crumbly structure. Common coarse to fine roots. Clear undulating change to
A2	6½–22″	Pale yellow (2.5Y 7/4) sandy loam. Common diffuse greyish brown (10YR 6/3) mottles. Pale brown coloured material from A1 leached through root channels and cracks. Subangular blocky. Moist; friable. Few coarse and medium roots. Diffuse change to
B	22–45″	Yellow (2.5Y 7/6) sandy clay loam with few distinct white and abundant distinct light grey and brownish yellow mottles. Moist to very moist; firm. Subangular blocky. Diffuse change to
B/C	45–54″	As B horizon but with also common white and strong brown mottles.

REMARK: Distinct O and A2 horizons.

PROFILE REF. NO. 425

Soil Group: GREY-WHITE PODZOLIC.

Family: Kerait.

Series: *Kerait*.

Phase:

Location: Tebakang Road, approx. 1½ mile (Upper Sadong District).

Latitude: 1° 9′ 50″ N.

Longitude: 110° 33′ E.

Topography: Moderately dissected hilly terrain.

Site: On low gently sloping hill. At site cut by road. Former slope estimated to be approx. 10 degrees.

Parent material: Carbonaceous shale. (Triassic).

External drainage: Moderate.

Vegetation/Land Use: Young rubber with dense undergrowth of mainly ferns.

Altitude: ± 50 feet.

Rainfall: 139.13″ (8 years' mean).

Rainfall Class (Mohr): I.

Lab. Nos: MS 1225/30.

Date sampled: 18.8.67.

O/A1	0–1″	Dark brown rootmat with partly decomposed litter of ferns. Mixed with some mineral soil, sandy clay loam.
A2	1–6″	Grey (10YR 6/1) fine sandy clay loam. Dry; friable. Fine angular blocky to crumbly. Well rooted (mainly small rootlets). Much charcoal present. Porous. Distinct wavy boundary to
B1	6–29″	Pale yellow (2.5Y 8/4) clay. Moist, slightly plastic, non-sticky, soapy feeling. Very firm and compact. Weak friable on pressure. Large blocky structural units break into small subangular blocky peds. Many small roots. Clayskins (colour 10YR 7/2, light grey) present on faces of larger structural units. Many cracks filled in by illuviated clay of light grey colour. Few, small yellowish brown (10YR 5/6) mottles. Gradual wavy boundary to
B2	29–52″	Very pale brown (10YR 7/3) clay with common coarse light grey (2.5Y 7/6) and common fine brownish yellow (10YR 6/8) mottles. Moist; slightly plastic, non-sticky. Soapy feeling. Very compact and firm in place. 'Clayskins' along large cracks (root follow these cracks). Grey mottles gradually increase in size and intensity with depth. Gradual change to
B2/C	52–65″	Light grey (2.5Y 7/N) clay loam with common fine brownish yellow (10YR 6/8) and common, coarse, pale yellow mottles. Moist: very compact. Slightly plastic: non-sticky. No roots.

NOTE: At approximately 20 feet depth this material changes into weathered, soft black shale.

Profile ref. No.. 425 Soil Group: GREY-WHITE PODZOLIC Soil Family: KERAIT Soil Series: KERAIT

Phase:

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	Group III Oxides	% P Ret.
MS1225	A1	0 – 1	4. 1	3.1	0.577	14. 30	24.8	13	218	2.03	3.41	1. 17	0.23			39.85	17. 2					
1226	A2	1 – 6	4. 1	3. 4	0.188	1 .50	8. 0	4	113	0.26	0.06	0.16	0.07			14.10	3. 8					
1227	B1	6 – 29	4. 9	3. 3	0.075	0. 21	2. 8	<1	80	0.19	0.45	0.07	0.10			7. 51	10. 7					
1228	B2	29 – 52	4. 9	3. 8	0.078	0.13	1. 7	<1	87	0.06	0.45	0.08	0.06			7. 80	8. 3					
1229	B/C	52 – 65	5. 1	3. 9	0.075	0. 41	5. 5	<1	111	0.13	0.26	0.08	0.13			9.49	6. 3					
1230	C	at 20'	2. 7	2. 6	0.009	0. 42	50.0	4	136	0.20	0.58	0.02	0.07			4.63	18.7					

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D. SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	Colloidal Fraction Total SiO_2	Fe_2O_3	Al_2O_3	Derived mol. ratio's SiO_2/R_2O_3	SiO_2/Fe_2O_3	SiO_2/Al_2O_3	Fe_2O_3/Al_2O_3	Extractable Morgan Al	Mn	Fe	6N HCL Fe
MS1225	A1	0 – 1	62. 97	0. 62	9. 96	0.05	0.04	0. 29	0.28	0.89	0.014	0.02	20. 30	0.64	19. 01	1.07	85	1. 83	0.03				0. 56
1226	A2	1 – 6	83. 37	0. 70	14. 64	0.06	0.04	0. 35	<0.13	1.10	0.006	<0.01	51. 66	1. 52	37. 62	3.10	74	3.21	0.04				0. 41
1227	B1	6 – 29	73.85	2. 50	28. 63	0.05	0.04	0. 54	0.28	2.48	0.018	<0.01	47. 34	2.40	50. 79	1. 52	56	1.56	0.05				0.76
1228	B2	29 – 52	67. 07	1. 15	32. 93	0.06	0.04	0.67	0.54	3.03	0.003	0.01	47. 12	2.05	30.79	1. 52	60	1. 56	0.07				0.66
1229	B2/C	52 – 65	71. 10	1. 10	31. 63	0.06	0.02	0.55	0.41	3.70	0.006	0.01	47. 76	1.79	49. 47	1. 59	72	1. 63	0.04				0.50
1230	C	at 20'	66. 10	1. 55	31. 89	0.04	0.02	0.61	0.56	3. 75	0.005	0.02	29.00	0.68	17. 28	2. 61	112	2 67	0.04				0. 44

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	Fine earth < 2 mm composition V.C.S. 2000µ–1000µ	C.S. 1000µ–500µ	M.S. 500µ–250µ	F.S. 250µ–100µ	V.F.S. 100µ–50µ	Sand Total 2000–50µ	Silt 50–2µ	Clay < 2µ	Total fine earth	Texture according to U.S. Survey Manual
MS1225	O/A1	0 – 1	0.05	0. 05	0. 53	1. 58	19 .79	22 .00	19 .58	26 .96	68. 54	Sandy clay loam
1226	A2	1 – 6	0.05	0. 05	2 . 06	5.72	34. 81	43. 16	29 . 25	27. 48	99. 89	" " "
1227	B1	6 – 29	0.05	0. 50	0. 40	2. 13	20. 84	27. 77	31. 14	40. 87	99. 78	Clay
1228	B2	29 – 52	0.05	0. 27	0. 27	1. 13	27. 22	18. 31	34. 45	47. 14	99. 89	Clay
1229	B2/C	52 – 65	0.25	0. 76	1. 01	1. 77	11. 62	24. 34	36. 11	39. 14	99. 59	Clay loam
1230	C	at 20'	0.05	0. 05	1. 23	1.39	8. 76	39. 11	42. 80	18. 14	100. 35	Loam

(d) Mineralogy.

Sample No.	Horizon	Depth in inch	Medium or fine sand fraction % — Heavy minerals (Ratio Opaque/Non-opaque, Zircon, Tourmaline, Andalusite, Sillimanite, Epidote, Rutile, Anatase, Brookite, Leucoxene, Sphene, Garnet, Spinel, Zoizite, Clino-Zoizite, Hornblende, Corundum, Crystobalite, Alterite)	Light minerals Quartz	Felspars	Mica's	* Clay fraction Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
MS1225	O/A1	0 – 1	One Opaque (rounded)					p	d-d		p		
1226	A2	1 – 6	Mainly Opaque (rounded,) few Tourmaline, some Leucoxene					p	d-d		t		
1227	B1	6 – 29	Few large Opaque, some Muscovite					p	d-d		t		
1228	B2	29 – 52	Small rounded Zircon dominant, some Rutile, some Muscovite, small opaques					p	d-d		t		
1229	B2/C	52 – 65	Mainly rounded small Zircon, some large purple, some Muscovite.					p	d-d		t		
1230	C	at 20'	No Opaque, dominant Muscovite and shale fragments					p	d-d		t		

* d-dominant, p-present, t-trace

Profile ref. No.: 226 | Soil Group: GREY-WHITE PODZOLIC | Soil Family: KERAIT | Soil Series: KERAIT

Phase:

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	Group III Oxides	% P Ret.
S 4298	A1	0-3	5.0		0.09	0.89	9.9			0.34	tr	0.11	0.02	4.0		4.41						
S 4299	A2	3-15	4.6		0.04	0.11	2.8			tr	0.24	0.19	0.10	4.4		2.94						
S 4300	B1.1	15-30	4.7		0.07	0.05	0.7			0.18	0.18	0.11	0.01	6.0		5.99						
S 4301	B1.2	30-60	4.5		0.09	0.03	0.3			0.06	0.24	0.14	0.01	7.15		7.77						
S 4302	B2.1	62-69	4.6		0.11	0.05	0.5			0.06	0.06	0.16	0.01	8.85		7.67						
S 4303	B2.2	90-98	4.7		0.10	0.05	5.0			0.12	tr	0.16	0.01	6.85		6.62						
S 4304	B3	124-136	4.6		0.07	0.03	0.4			0.12	0.06	0.16	0.02	4.65		4.41						
S 4305	C	160-172	4.5		0.08	0.05	0.6			0.06	0.12	0.18	0.07	4.40		4.41						
S 4306	C/R	at 180	4.3		0.12	0.08	0.7			tr	0.30	0.19	0.02	5.50		5.57						
S 4307	R	at 180	3.3		0.13	0.63	4.8			0.30	0.18	0.20	0.04	4.31		4.20						

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D. SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	SO_4	Colloidal Fraction Total SiO_2	Fe_2O_3	Al_2O_3	Derived mol. ratio's SiO_2/R_2O_3	SiO_2/Fe_2O_3	SiO_2/Al_2O_3	Fe_2O_3/Al_2O_3	Extractable Morgan Al	Mn	Fe	6N HCL Fe
S 4298	A1	0-3	83.72	0.99	9.67	0.96	0.07	0.22			0	0									0	73	
S 4299	A2	3-15	83.37	1.03	10.99	1.13	0.06	0.25			0	0									0	49	
S 4300	B1.1	15-30	69.15	1.60	20.07	0.92	0.02	0.59			0	0									0	5	
S 4301	B1.2	30-60	67.25	1.45	21.92	0.81	0.06	0.62			0	0									0	1	
S 4302	B2.1	62-69	63.46	1.40	23.84	0.81	0.04	0.74			0	0									0	3	
S 4303	B2.2	90-98	65.78	1.50	22.38	0.75	0.06	0.71			0	0									0	1	
S 4304	B3	124-136	68.91	1.00	20.13	0.42	0.02	0.52			0	0									0	1	
S 4305	C	160-172	69.64	0.84	20.33	0.65	0.04	0.51			0	0									0	3	
S 4306	C/R	at 180	66.14	1.50	21.85	0.69	0.09	0.75			0	0									0	7	
S 4307	R	at 180	66.66	1.60	18.54	0.75	0.09	0.64			0	0.08									0	76	

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	Fine earth < 2 mm composition V.C.S. 2000µ-1000µ	C.S. 1000µ-500µ	M.S. 500µ-250µ	F.S. 250µ-100µ	V.F.S. 100µ-50µ	Sand Total 2000-50µ	Silt 50-2µ	Clay < 2µ	Total fine earth	Texture according to U.S. Survey Manual
S 4298	A1	0-3	1.47	24.05		21.97		47.49	24.15	27.60	102.67	sandy clay loam
S 4299	A2	3-15	1.73	21.32		21.59		44.64	28.45	26.90	101.41	loam
S 4300	B1.1	15-30	3.02	14.46		12.65		30.14	25.17	47.07	102.85	clay
S 4301	B1.2	30-60	1.21	11.47		9.74		22.42	31.75	46.80	101.82	"
S 4302	B2.1	62-69	0.14	4.66		8.88		13.68	44.33	42.13	101.12	silty clay
S 4303	B2.2	90-98	0.69	7.27		8.45		16.51	46.86	37.51	101.69	silty clay loam
S 4304	B3	124-136	0.17	6.31		31.49		37.97	35.11	27.12	100.86	clay loam
S 4305	C	160-172	0.15	23.32		12.50		35.97	32.45	31.90	101.38	"
S 4306	C/R	at 180	0.17	27.49		4.37		32.03	39.20	29.68	101.76	"
S 4307	R	at 180	0.19	11.28		19.47		30.94	43.96	25.96	101.59	loam

(d) Mineralogy.

Sample No.	Horizon	Depth in inch	Medium or fine sand fraction % — Heavy minerals: Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoizite	Clino-Zoizite	Hornblende	Corundum	Crystobalite	Alterite			Light minerals: Quartz	Felspars	Mica's		* Clay fraction: Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
S 4298	A1	0-3																										p	p	t	p	t		
S 4299	A2	3-15																										d	p	p	p	t		
S 4300	B1.1	15-30	Insufficient minerals for analysis.																									d	p	p		t		
S 4301	B1.2	30-60																										d	p	p				
S 4302	B2.1	62-69																										d	p	p				
S 4303	B2.2	90-98																										d	p	p				
S 4304	B3	124-136																										d	p	p				
S 4305	C	160-172																										d	p	p				
S 4306	C/R	at 180																										d	p	p				
S 4307	R	at 180																										d	p	p				

* d-dominant, p-present, t-trace.

PROFILE REF. NO. 226

Soil Group: GREY-WHITE PODZOLIC.

Family: **Kerait.**

Series: *Kerait.*

Phase:

Location: 10th mile, Serian-Simanggang Road (Upper Sadong District).

Latitude: 1° 2′ N.

Longitude: 110° 40′ E.

Topography: Broken hilly terrain.

Site: Near top of a hill, slope approx. 10 degrees.

Parent material: Carbonaceous shale (schistose) —Triassic.

External drainage: Good.

Vegetation/Land Use: Secondary growth.

Altitude: ± 150 feet.

Rainfall: 131.56″ M.A.R.

Rainfall Class (Mohr): I.

Lab. Nos: S 4298/307.

Date sampled: July, 1965.

A1	0–3″	Light grey (2.5Y 7/2) sandy clay loam. Moist; friable. Weak platy structure. Weak humus staining from 2-3 inches, surface gleying also present. Densely rooted. Clear regular boundary to
A2	3–15″	Light grey (2.5Y 7/2) sandy clay with faint, few light grey (10YR 7/1) and yellow (10YR 7/8) mottles. Moist; massive. Large cracks give rise to formation of large prisms when soil dries out. Dense root system in cracks; remainder of soil sparsely rooted. 'Clayskins' along cracks. Gradual increase of small yellow mottles. Gradual change to
B1.1	15–30″	White (2.5Y 8/0) clay with maximum concentration of yellow (10YR 7/8) mottles, particularly where quartz grit is present. Moist; massive. Strongly developed 'clay-skins'. Quartz grit occurs in pockets and as disturbed thin stonelines (possibly from quartz strings in parent material). Roots only present in cracks extending from surface horizon. Gradual change to
B1.2	30–60″	White (2.5Y 8/0) clay with pockets of quartz-grit, weakly mottled yellow. Light grey colour of A horizon persists along cracks (possibly clay illuviation). Moist; massive. Roots mainly confined to cracks. Gradual change to
B2	60–100″	Light grey (10YR 7/1) clay with common, fine, strong brown (7.5YR 5/8) mottles. Moist; massive. Illuvial clay noticeable in large cracks. No roots. Pockets of quartz-grit. Abrupt but irregular boundary to
B/C	100–172″	Light grey (10YR 7/1) silty clay. Slightly moist; massive and very compact. No roots. Abrupt irregular boundary to
R	172–?	Soft, easily cut black shale with quartz-strings. Inclusions of fossil roots and olive yellow coloured weathered pyritic material, particularly along fracture planes.

REMARK: Subsampled 62– 69″ as B2.1
90– 98″ as B2.2
124–136″ as B3
160–172″ as C

PROFILE REF. NO 79

Soil Group: GREY-WHITE PODZOLIC.

Family: **Triboh.**

Series: Not differentiated.

Phase:

Location: Bau Road, 7½ mile, opposite Green Spot Factory (Kuching Rural District).

Latitude: 1° 28′ N.

Longitude: 110° 19′ E.

Topography: Remnant of Pleistocene terrace, strongly dissected.

Site: On top of terrace, slope approximately 10 degrees.

Parent material: Pleistocene terrace deposits.

External drainage: Moderately good.

Vegetation/Land Use: Secondary jungle, undergrowth mainly ferns.

Altitude: Approx. 90 feet above sea level.

Rainfall: Kuching Airport 159.11′ (71 years' mean).

Rainfall Class (Mohr): I.

Lab. Nos: MS 1253/58.

Date sampled: 24.8.67.

		Thin litter layer at surface, partly decomposed leaves and twigs.
A1	0–3″	Grey (10YR 6/1) fine loamy sand. Dry; weak friable to loose. Weak crumbly structure. Well rooted. Indistinct boundary to
A2	3–7″	Greyish brown (10YR 5/2) loamy fine sand. Moist; friable. Compact in profile. Weak crumbly. Few roots. Few small light grey mottles. Many charcoal pieces. Distinct wavy boundary to
B1	7–23″	White (10YR 8/2), sandy loam with common, small brownish yellow mottles (mainly around root channels). Structureless to weak crumbly. Firm and compact. Few large roots, many fine dead roots. Moist. Distinct wavy boundary to
B2	23–38″	Light grey (10YR 7/2) sandy loam. Firm and compact. Crumbly. Yellowish brown coating along large roots. Illuvial clay distinctly present in cavities. Porous. Gradual change to
B3	38–50″	As above horizon, but clay content increases with depth. Moist. Gradual change to
IIC	50–55″	Light grey (10YR 7/2) sandy clay loam with few dark brown mottles, common white mottles. No roots. Small grit present. Moist; plastic, non-sticky.

REMARK: This profile may be bisequent (due to layering in parent material).

Profile ref. No.: 79 **Soil Group:** GREY-WHITE PODZOLIC **Soil Family:** TRIBOH **Soil Series:**

Phase:

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q.% (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	Group III Oxides	% P Ret.
MS 1253	A1	0-3	4.4	3.6	0.126	1.53	12.1	5	103	0.06	0.39	0.07	0.09			4.37						
MS 1254	A2	3-7	4.8	3.9	0.005	0.54	9.8	2	34	t	0.13	0.03	0.07			2.42						
MS 1255	B1	7-23	4.9	4.2	0.022	0.16	7.3	2	203	t	0.25	0.02	0.08			1.90						
MS 1256	B2	23-38	4.8	4.2	0.022	0.21	9.5	1	36	t	0.06	0.02	0.08			3.05						
MS 1257	B3	38-50	4.9	4.2	0.019	0.18	9.5	2	47	t	t	0.03	0.08			4.05						
MS 1258	IIC ?	50-55	4.8	4.1	0.023	0.16	7.0	1	33	t	t	0.03	0.07			4.38						

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D. SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	Colloidal Fraction Total SiO_2	Fe_2O_3	Al_2O_3	Derived mol. ratio's $\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	Extractable Morgan Al	Mn	Fe	6N HCL Fe
MS 1253	A1	0-3	93.03	0.40	3.89	0.02	0.02	0.10	<0.03	0.12	0.07	0.04	67.88	1.08	22.85	4.93	188	5.06	0.05				0.11
MS 1254	A2	3-7	93.38	1.43	4.26	0.02	0.12	0.09	<0.03	<0.12	0.02	0.03	47.19	2.10	50.13	1.53	60	1.57	0.04				0.07
MS 1255	B1	7-23	92.68	0.29	5.66	0.05	0.04	0.18	<0.03	0.12	0.01	0.02	44.88	1.91	51.13	1.46	62	1.49	0.04				0.08
MS 1256	B2	23-38	88.17	1.28	9.56	0.02	t	0.17	<0.03	0.24	0.01	0.02	44.52	1.52	51.13	1.45	82	1.47	0.03				0.15
MS 1257	B3	38-50	85.31	1.10	12.83	0.03	0.14	0.37	<0.03	0.26	0.01	0.02	45.21	1.48	51.13	1.47	83	1.49	0.03				0.17
MS 1258	IIC ?	50-55	84.04	1.10	14.92	0.03	0.04	0.28	<0.03	0.48	0.01	0.03	44.23	1.76	51.26	1.44	67	1.47	0.03				0.20

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	Fine earth < 2 mm composition V.C.S. 2000µ-1000µ	C.S. 1000µ-500µ	M.S. 500µ-250µ	F.S. 250µ-100µ	V.F.S. 100µ-50µ	Sand Total 2000-50µ	Silt 50-2µ	Clay < 2µ	Total fine earth	Texture according to U.S. Survey Manual
MS 1253	A1	0-3	0	1.82	24.44	26.10	23.30	76.66	13.78	10.14	99.58	loamy sand
MS 1254	A2	3-7	1.31	13.08	34.90	10.74	12.27	80.30	9.83	9.49	99.62	"
MS 1255	B1	7-23	0.70	8.03	28.84	22.12	17.62	77.32	12.22	10.58	100.12	sandy loam
MS 1256	B2	23-38	1.72	7.84	25.48	18.67	15.68	69.38	14.58	15.61	99.57	"
MS 1257	B3	38-50	1.55	7.05	22.60	17.50	16.95	65.65	21.80	15.93	99.58	"
MS 1258	IIC ?	50-55	1.50	5.35	19.00	16.40	16.55	58.80	17.10	31.75	107.65	sandy clay loam

(d) Mineralogy.

Sample No.	Horizon	Depth in inch	Medium or fine sand fraction % — Heavy minerals: Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoisite	Clino-Zoizite	Hornblende	Corundum	Crystobalite	Alterite	Sericite	Rock Fragments	Light minerals: Quartz	Felspars	Mica's		* Clay fraction: Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
* MS 1253	A1	0-3	59/41	35	32				5	2		19											7					p	d			p		p
MS 1254	A2	3-7	51/49	50	23				4	1	1	17	1										3					p	d			p		p
MS 1255	B1	7-23	25/75	50	15			2	8	7		9	5		1					1	2							t	d			t		
MS 1256	B2	23-38	34/66	48	20			1	3		1	12	13								1	2						t	d			t		
MS 1257	B3	38-50	37/63	50	16			1	3	1		8	13			2					3	2						t	d			t		

* d-dominant, p-present, t-trace.

Profile ref. No.: 50 **Soil Group:** PODZOLS **Soil Family:** SILANTEK **Soil Series:** BUTAN

Phase:

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P $HClO_4$	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	Group III Oxides	% P Ret.
S 4369	O	0-2	3.0		1.62	25.82	24.4	0	106	0.54	0.02	0.25	0.40	0.62		14.50	8.3					
S 4370	AI	2-5	3.3		0.16	4.78	27.4	0	1	0.42	0.02	0.17	0.39	0.61		6.4	15.6					
S 4371	AI/2	5-9	4.2		0.02	0.46	23.0	5	32	0.30	0.01	0.06	0.33	0.15		3.0	23.0					
S 4372	A2	9-13	4.7		0.004	0.14	35.0	20	19	0.42	0.02	0.05	0.33	0.10		0.5	164.0					
S 4373	BI.h	13-18	3.6		0.05	4.52	90.4	0	49	0.19	0.02	0.06	0.36	3.82		4.7	13.4					
S 4374	BI.2	18-22	3.9		0.006	2.64	4400	0	49	0.12	0.02	0.06	0.37	4.53		7.5	7.6					
S 4375	B2	22-33	4.3		0.01	0.57	57.0	0	42	0.19	0.02	0.06	0.33	2.41		1.0	60.0					
S 4376	IIC	33-44	4.3		0.003	0.18	60.0	0	36	0.19	0.01	0.06	0.33	2.55		0.5	118.0					
S 4377	IIR	44-68	4.1		0.003	0.05	16.7	0	54	0.42	0.01	0.07	0.33	1.70		0.5	166.0					
S 4378	IIIR	68-76	4.2		0.01	0.10	10.0	0	84	0.19	0.01	0.24	0.41	2.84		4.3	19.8					

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D. SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	Colloidal Fraction Total SiO_2	Fe_2O_3	Al_2O_3	Derived mol. ratio's $\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	Extractable Morgan Al	Mn	Fe	6N HCL Fe
S 4369	O	0-2	60.77	0.20	0	0.08	0.11	0.06			<0.005										<10	tr	
S 4370	AI	2-5	92.77	0.20	0.26	0.21	0.17	0.02			"										0	0	
S 4371	AI/2	5-9	97.25	0.10	0	0.27	0.15	0.06			"										0	0	
S 4372	A2	9-13	92.73	0.60	0	0.16	0.09	0.06			"										0	0	
S 4373	BI.h	13-18	94.42	0.60	2.65	0.42	0.13	0.11			"										0	0	
S 4374	BI.2	18-22	83.83	0.80	5.56	0.31	0.09	0.11			"										0	0	
S 4375	B2	22-33	88.15	1.20	7.15	0.27	0.11	0.11			"										0	0	
S 4376	IIC	33-44	85.57	2.10	7.95	0.42	0.24	0.06			"										0	0	
S 4377	IIR	44-68	92.47	0.80	5.56	0.21	0.11	0.08			"										0	tr	
S 4378	IIIR	68-76	77.91	1.10	16.49	0.42	0.13	0.06			"										0	2	

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	V.C.S. 2000µ-1000µ	C.S. 1000µ-500µ	M.S. 500µ-250µ	F.S. 250µ-100µ	V.F.S. 100µ-50µ	Sand Total 2000-50µ	Silt 50-2µ	Clay < 2µ	Total fine earth	Texture according to U.S. Survey Manual
S 4369	O	0-2	2.70	37.08		2.40		42.18	9.50	6.10	99.96	
S 4370	AI	2-5	5.33	76.58		4.49		86.40	9.53	4.73	100.63	loamy sand
S 4371	AI/2	5-9	6.69	76.89		8.06		91.44	4.66	4.80	101.73	sand
S 4372	A2	9-13	6.43	74.19		10.07		90.69	8.63	3.01	102.58	sand
S 4373	BI.h	13-18	5.06	65.73		7.95		78.74	11.55	8.31	101.95	loamy sand
S 4374	BI.2	18-22	5.43	59.21		6.85		71.49	9.65	15.70	102.39	sandy loam
S 4375	B2	22-33	4.43	59.70		8.28		72.81	10.48	17.20	102.39	sandy loam
S 4376	IIC	33-44	3.25	60.35		7.36		70.96	12.06	18.76	102.76	sandy loam
S 4377	IIR	44-68	12.72	58.99		6.51		78.22	14.35	9.56	102.41	sandy loam
S 4378	IIIR	68-76	9.02	32.07		5.82		46.91	19.46	35.10	102.52	sandy loam

(d) Mineralogy.

Sample No.	Horizon	Depth in inch	Medium or fine sand fraction % — Heavy minerals: Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoisite	Clino-Zoisite	Hornblende	Corundum	Crystobalite	Alterite			Light minerals: Quartz	Felspars	Mica's		* Clay fraction: Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
S 4369	O	0-2																																
S 4370	AI	2-5	48/52	34	58		1		2	2	2	7																						
S 4371	AI/2	5-9	51/49	30	48		1		1	3	3	14																d	t					
S 4372	A2	9-13	45/55	39	47				1	2	1	10																d	p					
S 4373	BI.h	13-18	57/43	43	34				1	5	2	15																d	d					
S 4374	BI.2	18-22	58/42	11	44		2	4		1	6	15										17						p	d		p			
S 4375	B2	22-33	35/65	11	30		3	1	1	1	13	21										43												
S 4376	IIC	33-44	36-64	3	30			1		3	13	13										37						p	d		p			
S 4377	IIR	44-68	11/89		6			1		1	1											50												
S 4378	IIIR	68-76	60/40	13	8				1	3	2	3										8						p	p	t	t			

* d-dominant, p-present, t-trace

PROFILE REF. NO. 50

Soil Group: PODZOL.

Family: Silantek.

Series: *Butan.*

Phase:

Location: Path Stunggang to S. Punguh (Lundu District).

Latitude: 1° 34′ 32″ N.

Longitude: 110° 1′ 5″ E.

Topography: Moderately dissected hilly terrain.

Site: On dipslope, approx. 10 degrees.

Parent material: Sandstone (Tertiary).

External drainage: Good.

Vegetation/Land Use: Primary forest, 'Kerangas'.

Altitude: ± 350 feet.

Rainfall: ± 130″ M.A.R. (estimated).

Rainfall Class (Mohr): I.

Lab. Nos: S 4360/78.

Date sampled: April, 1965.

O	**0–2″**	Dark reddish brown (5YR 2/2) partly decomposed organic matter with few sand grains, mixed with dense rootmat of fine roots mainly, some large roots. Slightly moist. Abrupt change to
A1	**2–5″**	Dark reddish brown (5YR 3/2) sand with much organic matter. Moist; friable. Crumbly. Transparent sand grains. Abrupt wavy boundary to
A1.2	**5–9″**	Reddish grey (5YR 5/2) medium sand, single grained, stained by humus. Moist; firm. Few roots. Clear wavy change to
A2	**9–13″**	Light grey (10YR 7/1) medium sand with reddish grey (75% light grey—25% reddish grey) staining in places. Single grained. Firm. Some veins of humic material run through this horizon in no apparent direction. No roots. Abrupt over
B1.h	**13–18″**	Dark reddish brown (5YR 2/2 and 3/2) loamy medium sand, weakly cemented. Some fine roots at boundary with horizon above. Irregular clear change to
B1.2	**18–22″**	Light yellowish brown (10YR 6/4) fine sandy loam. Slightly wet. Platy structure with humus accumulation between structure elements. Many old decomposed roots. Small pockets of dark reddish brown coloured cemented material. Distinct change to
B2	**22–33″**	Very pale brown (10YR 7/3) loamy sand to sandy loam. Slightly wet. Compact. Structureless. Many old root channels with organic material which also accumulates along fracture planes. Clear change to
IIC	**33–44″**	Pale yellow (2.5YR 8/4) sandy clay with brownish yellow (10YR 6/6) mottling, in some places as lateral bands, otherwise mainly along old root channels. Wet; sticky and plastic. Some rounded quartz pebbles at 44 inches, becoming more sandy and resembling sandstone.
IIR	**44–68″**	White medium grained sandstone. Perched watertable at 48 inches.

Note: Deep augering confirms occurrence of white clay bed at 68-76 inches.

PROFILE REF. NO. 422

Soil Group:. PODZOL.

Family: Buso.

Series: Not differentiated.

Phase:

Location: Batu Kawa Road, near Stapok quarry (Kuching Rural District).

Latitude: 1° 30′ 30″ N.

Longitude: 110° 17′ 28″ E.

Topography: On gently undulating terrace.

Site: Almost flat, on top of terrace.

Parent material: Pleistocene deposits.

External drainage: Ponded.

Vegetation/Land Use: Secondary growth, fern, soma (*Ploiarium alterniolium*).

Altitude: ± 50 feet.

Rainfall: 159.11″ M.A.R. (Kuching Airport).

Rainfall Class (Mohr): I.

Lab. Nos: S 4288/97.

Date sampled: June, 1965.

A1	**0–7″**	**Very dark grey (5YR 3/1) loamy medium to fine sand (finer fraction is mainly organic). Moist; friable to smeary. Crumbly. Porous. Many roots—approximately 50% of bulk material; clear regular boundary to**
A1.2	**7–9″**	**Dark grey (5YR 4/1) loamy medium sand with pinkish grey mottling. Wet. Structureless. Few small roots. Clear regular boundary to**
A2	**9–12″**	**Pinkish grey (10YR 7/2) loamy medium to fine sand with dark grey medium sand in old root channels washed in from above. Very moist. Structureless. Porous. Very few living roots. Faint pale brownish grey (10YR 6/2) staining. Clear regular boundary to**
A3	12–15″	Dark brown (7.5YR 5/2) and light brownish grey (10YR 6/2)—50%/50%, loamy fine to medium sand. Dark colour is confined to filled-in old root channels. Structureless. Porous. Moist; soft. Some large cracks show a film of humic material of smeary consistency. Clear regular boundary to
B1.1	**15–18″**	**Dark brown (7.5YR 3/2) and pinkish white (7.5YR 8/2)—50%/50%, loamy fine sand, dark material confined to filled-in old root channels. Slightly moist. Structureless. Few living roots. Clear, wavy boundary to**
B1.2	**18–24″**	**Dark reddish brown (5YR 3/3 and 3/2) silty to fine sandy loam. Darker coloured material in old root channels. Slightly moist. Structureless, weakly cemented. Clear wavy boundary to**
B2	**24–28″**	**Very pale brown (10YR 7/3) medium to fine sandy loam with few faint yellow (10YR 7/8) mottles. Compact. Structureless. Dark humic material has leached down through old large root channels, this material is wet and smeary. Few living roots. Gradual boundary to**
B3	28–60″	**White (10YR 8/2) medium to fine sandy loam. Moist. Structureless. In dried out** (at exposed places) this horizon displays strong columnar structure. Many vertical **old root channels filled in with humic material of dark brown colour. Many small rootlets. Gradual change to**
C	60–80″	**White (10YR 8/1) sandy clay loam. Moist; plastic, compact. Gradual change to**
IIC	**80–108″**	**White (10YR 8/1) sandy clay with few distinct yellow (10YR 7/8) mottles. Moist. Very compact, plastic, non-sticky.**

REMARK: Watertable at location was met at 13 feet depth. Below 50 inches material is probably bisequent.

Profile ref. No.: 422 Soil Group: PODZOLS Soil Family: BUSO Soil Series:

Phase:

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCl	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	Group III Oxides	% P Ret.
S4288	A1	0-7	4.2		0.03	2.50	83			0.63	1.55	0.10	0.06	1.31		6.51	35.9					
S4289	A1/2	7-9	4.2		0.04	0.47	12			0.40	0.97	0.05	0.02	0.22		1.47	90.2					
S4290	A2	9-12	5.0		0.01	0.16	16			0.38	0.79	0.04	0.04	0.11		0.63						
S4291	A3	12-15	4.7		0.03	0.65	22			0.34	0.73	0.04	0.27	1.30		1.89	73.0					
S4292	B1.1	15-18	4.5		0.06	1.38	23			0.38	0.77	0.04	0.27	2.10		4.52	32.3					
S4293	B1.2	18-24	4.8		0.07	3.36	48			0.68	0.73	0.04	0.38	5.80		18.58	9.8					
S4294	B2	24-28	5.1		0.06	1.61	27			0.18	1.03	0.04	0.38	4.92		11.24	14.5					
S4295	B3	28-60	5.1		0.03	0.44	15			0.37	0.78	0.04	0.27	1.51		3.78	38.6					
S4296	C	60-67	5.4		0.02	0.08	4			0.67	1.14	0.08	0.64	6.90		7.25	26.6					

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D. SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	Colloidal Fraction Total SiO_2	Fe_2O_3	Al_2O_3	Derived mol. ratio's $\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	Extractable Morgan Al	Mn	Fe	6N HCL Fe
S4288	A1	0-7	98.2	0.3	1.06	0.38	0.06	0.04			0										0	12	
S4289	A1/2	7-9	92.9	0.2	0.40	0.27	0	0.01			0										0	8	
S4290	A2	9-12	98.2	0.2	0.66	0.54	0	0.01			0										0	10	
S4291	A3	12-15	96.7	0.2	1.32	0.69	0.18	0.07			0										0	16	
S4292	B1.1	15-18	93.3	0.25	2.12	0.83	0.13	0.14			0										tr	21	
S4293	B1.2	18-24	93.2	0.30	3.58	0.60	0.01	0.04			0										0	54	
S4294	B2	24-28	86.5	0.55	5.70	0.65	0.05	0.07			0										0	99	
S4295	B3	28-60	86.5	0.65	7.68	0.69	0.05	0.12			0										0	53	
S4296	C	60-67	81.6	1.20	13.51	0.60	0.01	0.63			0										0	27	

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	Fine earth < 2 mm composition V.C.S. 2000µ-1000µ	C.S. 1000µ-500µ	M.S. 500µ-250µ	F.S. 250µ-100µ	V.F.S. 100µ-50µ	Sand Total 2000-50µ	Silt 50-2µ	Clay < 2µ	Total fine earth	Texture according to U.S. Survey Manual
S4288	A1	0-7	0.40	55.48		16.49		72.27	17.56	5.78	100.78	Sandy loam
S4289	A1/2	7-9	4.12	67.00		7.00		78.12	13.35	5.62	99.18	Loamy sand
S4290	A2	9-12	2.44	61.49		11.41		75.34	19.63	3.72	99.39	Loamy sand
S4291	A3	12-15	2.66	60.77		13.61		77.04	18.72	6.10	101.96	Loamy sand
S4292	B1.1	15-18	3.04	61.29		9.36		72.79	16.83	7.63	100.55	Sandy loam
S4293	B1.2	18-24	1.99	53.04		11.89		66.92	16.24	10.00	102.77	Sandy loam
S4294	B2	24-28	1.89	49.96		11.44		63.39	16.78	12.48	100.59	Sandy loam
S4295	B3	28-60	3.05	50.76		7.88		61.69	17.06	18.68	101.02	Sandy loam
S4296	C	60-67	0.87	46.48		6.94		54.29	15.38	31.23	101.66	Sandy clay loam

(d) Mineralogy.

Sample No.	Horizon	Depth in inch	Medium or fine sand fraction % — Heavy minerals: Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoizite	Clino-Zoizite	Hornblende	Corundum	Crystobalite	Alterite			Light minerals: Quartz	Felspars	Mica's		* Clay fraction: Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
S4288	A1	0-7	74/26	20	55	3		2	5	4	6	6																d	p					
S4289	A1/2	7-9	65/35	12	27			2	4	4		23	5						1									d						
S4290	A2	9-12	71/29	37	28	1		5	5	3	1	17	2															d	p					
S4291	A3	12-15	64/36	53	27		1	2	5	4	2	14	1															d	I					
S4292	B1.1	15-18	61/39	54	18			1	6	1	3	14	2															d	p					
S4293	B1.2	18-24	48/52	53	16			2		3	1	25																d	p					
S4294	B2	24-28	43/57	35	19				1	5	5	35																p	p					
S4295	B3	28-60	46/54	38	20				1	10	7	24																p	p		t			
S4296	C	60-67	66/34	20	27				4	1	1	44																t	p		t			
S4297	IIC	> 10ft.	76/24	12	11					1	3	23																						

* d-dominant, p-present, t-trace.

Profile ref. No.: 4 **Soil Group:** PODZOLS **Soil Family:** JERIJEH **Soil Series:** PUEH

Phase:

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	Group III Oxides	% P Ret.
S 7393	A1	1/2-7	7.2			0.06																
S 7394	A2	7-15	6.9			0.05																
S 7395	B_{hir}	15-19	6.4			0.44																
S 7396	B_{ir}	19-24	6.3			0.43																
S 7397	B2.1	24-44	6.4			0.15																
S 7398	B2.2	44-54	6.9			0.07																
S 7399	$B3_{mn}$	54-60	6.4			0.02																

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D. SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	Colloidal Fraction Total SiO_2	Fe_2O_3	Al_2O_3	Derived mol. ratio's $\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	Extractable Morgan Ca	Mn	Fe	Mg
S 7393	A1	1/2-7	99.50	1.06	0.07						0.015									<40	<1	9	48
S 7394	A2	7-15	98.99	0.55	0.40						0.014									40	<1	6	72
S 7395	B_{hir}	15-19	93.76	4.24	1.62						0.023									<40	<1	84	98
S 7396	B_{ir}	19-24	91.45	4.18	1.21						0.027									<40	<1	69	74
S 7397	B2.1	24-44	92.45	4.18	1.87						0.033									40	<1	19	48
S 7398	B2.2	44-54	84.11	10.17	3.56						0.132									141	<1	<2	97
S 7399	$B3_{mn}$	54-60	83.59	9.91	4.96						0.418									162	5	3	73

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	Fine earth < 2 mm composition V.C.S. 2000µ-1000µ	C.S. 1000µ-500µ	M.S. 500µ-250µ	F.S. 250µ-100µ	V.F.S. 100µ-50µ	Sand Total 2000-50µ	Silt 50-2µ	Clay < 2µ	Total fine earth	Texture according to U.S. Survey Manual
S 7393	A1	1/2-7		1.51	49.29	46.78	1.01	98.59	0.40	2.72	101.71	sand
S 7394	A2	7-15		1.00	45.14	50.10	2.11	98.35	1.17	2.22	101.74	"
S 7395	B_{hir}	15-19		0.61	47.42	44.67	1.54	94.24	2.27	5.13	101.64	"
S 7396	B_{ir}	19-24		0.51	81.22	40.49	0.72	94.66	2.04	4.64	101.34	"
S 7397	B2.1	24-44		0.05	15.18	52.94	1.27	97.72	0.35	3.81	101.88	"
S 7398	B2.2	44-54		0.05	9.12	58.50	2.02	97.80	0.61	3.90	102.31	"
S 7399	$B3_{mn}$	54-60		0.91	86.61	40.57	0.41	100.39	0.53	2.68	103.60	"

(d) Mineralogy.

Medium or fine sand fraction % — Heavy minerals

Sample No.	Horizon	Depth in inch	Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoizite	Clino-Zoizite	Hornblende	Corundum	Crystobalite	Alterite		
S 7393	A1	1/2-7	41/59	45	22	1						25		3									
S 7394	A2	7-15	46/54	28	38	2		2				24											
S 7395	A3	15-19	27/73	6	38	5		1				29		4							4		
S 7396	B_{hir}	19-24	44/56	8	41	5		4				35		3					1		2		
S 7397	B_{ir}	24-44	29/71	13	31	3						38		1		1		1			3		
S 7398	B2.1	44-54	74/26	23	38	3						30		4									
S 7399	$B3_{mn}$	54-60	24/76	53	8	3		2				28		2							1		

Medium or fine sand fraction % — Light minerals; * Clay fraction

Sample No.	Light minerals: Quartz	Felspars	Mica's		* Clay fraction: Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
S 7393											
S 7394											
S 7395											
S 7396											
S 7397											
S 7398											
S 7399											

* d-dominant, p-present, t-trace.

PROFILE REF. NO. 4

Soil Group: PODZOL.

Family: Jerijeh.

Series: *Pueh.*

Phase:

Location: Near Kpg. Pueh, 700 m from coast (Lundu District).

Latitude: 1° 49′ 20″ N.

Longitude: 109° 43′ E.

Topography: Undulating old raised beach. Very gently sloping land—inward.

Site: On slope of old storm beach.

Parent material: Subrecent beach sand.

External drainage: Good.

Vegetation/Land Use: Scattered *Diptranopteris curranii spp.*

Altitude: 14 feet.

Rainfall: ± 125″ M.A.R. (estimated).

Rainfall Class (Mohr): I.

Lab. Nos: S 7392/99.

Date sampled: October, 1968.

	0–1½″	Light grey (10YR 7/1) medium sand. Very dry; loose. No organic matter. Abruptly overlying
A1	½–7″	Light brownish grey (10YR 6/2) single grain medium sand. Slightly moist; loose. Structureless. Many roots; many dark grey worm channels. Gradual change to
A2	7–14″	White (10YR 8/2) medium sand. Slightly moist; loose. Structureless. Very small roots to 12 inches depth.
A3	14–15″	White sand, mottled brown.
Bh(ir)	15–19″	Dark brown (7.5YR 4/4) medium to fine sand with common, dark red (2.5YR 3/6) hard and soft concretions. Slightly moist. Structureless; in places this horizon is brittle and weakly cemented. Clear regular change to
Bir	19–24″	Reddish brown (5YR 4/4) medium sand. Slightly moist; firm. Structureless. Common dark red concretions and mottles (as 15-19″) but colour less brown. Clear, very wavy change to
B2.1	24–44″	Strong brown (7.5YR 5/8) fine sand. Slightly moist; firm. Structureless. No roots. Gradual wavy change to
B2.2	44–54″	Strong brown (7.5YR 5/6) fine sand with abundant brown to dark brown (7.5YR 4/4) and some red mottles. Structureless. Irregular wavy change to
B2(mn)	54–60″	Light olive brown (2.5YR 5/6) medium sand. Wet. In places strongly stained black to strong brown. Watertable at 60 inches.

PROFILE REF. NO. 271

Soil Group: GLEY SOIL.

Family: **Bijat.**

Series: *Bijat.*

Phase: Very poorly drained.

Location: Back of Kpg. Serian Illir (Upper Sadong District).

Latitude: 1° 9′ 20″N.

Longitude: 110° 33′ 50″ E.

Topography: Floodplain.

Site: On incipient levee.

Parent material: Recent alluvium.

External drainage: Fair.

Vegetation/Land Use: Secondary growth approx. 2 years old (mainly thick ferns, lallang, 'Banta' grass).

Altitude: ± 20 feet.

Rainfall: 139.13″ M.A.R. (Tarat).

Rainfall Class (Mohr): I.

Lab. Nos: S 7652/56.

Date sampled: 13.1.70.

A1	0–2″	Greyish brown (10YR 5/2) loam with many medium fine roots. Slightly wet; Non-sticky and non-plastic. Earthworms.
AB	2–9½″	Light grey (2.5Y 7/2) clay with prominent brownish yellow (10YR 6/8) mottles. Wet; slightly sticky, slightly plastic. Massive in profile.
Cgl	9½–21″	Grey (5Y 5/1) clay, with few distinct brownish yellow (10YR 5/8) mottles. Wet; sticky and slightly plastic. Massive in profile.
Cg2	21–48″	Grey (5Y 5/1) clay with organic matter. Wet; very sticky and plastic. Compact.
Cg3	48–54″+	Grey (5Y 5/1) clay. No mottles. No organic matter. Wet; very sticky and very plastic. Compact.

Profile ref. No.: 271 Soil Group: GLEY SOILS Soil Family: BIJAT Soil Series: BIJAT

Phase:

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	Group III Oxides	% P Ret.
S 76.52	A1	0-2	4.7		0.591	5.25	8.88			4.34	0.94	0.23	0.21	5.56	0.14	26.83	21.39					78.38
53	AB	2-9½	4.7		0.255	2.34	9.18			2.77	0.72	0.15	0.17			22.44	16.98					68.28
54	Cg.1	9½-21	4.7		0.138	1.10	7.97			2.80	1.05	0.14	0.12	8.00	0.13	22.63	18.16					69.94
55	Cg.2	21.48	4.3		0.247	3.54	14.33			2.82	1.15	0.14	0.16	7.81	0.24	25.26	16.90					75.00
56	Cg.3	48.54	4.3		0.151	1.50	9.93			2.00	0.71	0.13	0.09	8.77	0.36	21.98	13.33					80.56

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D. SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	Colloidal Fraction Total SiO_2	Fe_2O_3	Al_2O_3	Derived mol. ratio's SiO_2/R_2O_3	SiO_2/Fe_2O_3	SiO_2/Al_2O_3	Fe_2O_3/Al_2O_3	Extractable Morgan Al	Mn	Fe	6N HCL Fe
S76 52	A1	0-2	58.57	3.06	18.70	0.87	0.16	0.99		2.00	0.0138	0.1325	44.90	4.79	28.60	2	26.6	2.85	0.11				
53	AB	2-9½	60.04	2.67	19.88	0.94	0.19	0.93		2.29	0.0105	0.1116	45.35	3.44	29.91	2.39	34.2	2.57	0.07				
54	Cg1	9½-21	61.76	3.17	21.45	0.96	0.15	1.06		2.64	0.0108	0.0345	45.95	4.24	29.41	2.49	29.9	2.66	0.09				
55	Cg2	21-48	59.53	3.09	19.92	0.99	0.20	1.03		2.49	0.0126	0.0564	43.50	3.79	29.29	2.33	30.2	2.77	0.08				
56	Cg3	48-54	61.99	3.74	20.30	1.04	0.15	1.03		2.20	0.0156	0.0545	46.29	5.94	31.54	2.23	20.8	2.49	0.12				

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	Fine earth < 2 mm composition V.C.S. 2000µ-1000µ	C.S. 1000µ-500µ	M.S. 500µ-250µ	F.S. 250µ-100µ	V.F.S. 100µ-50µ	Sand Total 2000-50µ	Silt 50-2µ	Clay < 2µ	Total fine earth	Texture according to U.S. Survey Manual
S7652	A1	0-2				0.96	6.18	7.14	41.48	46.56	95.18	Silty clay
53	AB	2-9½	0.08	0.83	0.60	1.03	4.25	6.79	44.73	42.93	94.45	" "
54	Cg1	9½-21	0.08	0.03	0.12	0.15	2.98	3.36	40.95	53.93	98.24	" "
55	Cg2	21-48				0.70	4.70	5.40	42.24	45.87	93.51	" "
56	Cg3	48-54		0.11	0.16	0.127	3.92	4.47	43.95	46.61	95.02	" "

(d) Mineralogy.

Sample No.	Horizon	Depth in inch	Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoisite	Clino-Zoisite	Hornblende	Corundum	Crystobalite	Alterite	Light minerals: Quartz	Felspars	Mica's	* Clay fraction: Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
S7652	A1	0-2				No analyses — insufficient minerals																			t	d		p	t		
53	AB	2-9½				No analyses.																			p	d		p	t		
54	Cg1	9½-21				Opaque dominant (fresh Ilmenite). No Leucoxene transitions. Zircon, some Epidote and Sericite.																			t	d		p	t		
55	Cg2	21-48				As S7654 but hardly any Opaque.																			t	d		p	t		
56	Cg3	48-54				Very few Opaque, Zircon, Epidote, Tourmaline, Muscovite and shale fragments.																			t	d		p	t		

* d-dominant, p-present, t-trace.

Profile ref. No.: 81 Soil Group: PEAT SOILS Soil Family: ANDERSON Soil Series:

Phase: 3

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. P Org.	p.p.m. O.D. 'Total' P	Total ash %	Total p.p.m O.D. CaO	MgO	K_2O	P_2O_5	C.E.C.	S Value	'Reserves' p.p.m. Ca	Mg	K	% Group III Oxides	% P Ret.
S 7699	0.1	0-9	3.1		1.959	41.36	21.2	9		10.20	1496	2887	374	357						0.41	
S 7700	0.2 *	36-48	3.2		1.107	41.38	37.3	16		8.83	663	366	298	77						0.21	

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D. SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	Colloidal Fraction Total SiO_2	Fe_2O_3	Al_2O_3	Derived mol. ratio's SiO_2/R_2O_3	SiO_2/Fe_2O_3	SiO_2/Al_2O_3	Fe_2O_3/Al_2O_3	Extractable Morgan Al	Mn	Fe	6N HCL Fe

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	Composition of peat: V.C. fibres >2000μ	C. fibres 2000-1000μ	m.f. fibres 1000-500μ	fine fibres 500-250μ	v.f. fibres 250-100μ	Sand	Silt 50-2μ	Clay < 2μ	Bulk density gm/cc (O.D)	Texture according to 7th Approx.
S 7699	0.1	0-9	5.950	6.622	15.915	11.420	13.544				0.1419	Fibric/Hemic
S 7700	0.2	36-48	2.533	29.264	1.822	2.072	4.872				0.0882	Fibric

(d) Mineralogy.

Sample No.	Horizon	Depth in inch	Medium or fine sand fraction % — Heavy minerals: Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoizite	Clino-Zoizite	Hornblende	Corundum	Crystobalite	Alterite			Light minerals: Quartz	Felspars	Mica's		* Clay fraction: Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite

* d-dominant, p-present, t-trace.

PROFILE REF. NO. 81

Soil Group: DEEP PEAT.

Family: **Anderson.**

Series: Not differentiated.

Phase: Deep III.

Location: Behind Stapok Peat Experimental Station, Batu Kawa Road (Kuching Rural District.

Latitude: 1° 31′ N.

Longitude: 110° 18′ 5″ E.

Topography: Basin peat.

Site: Level.

Parent material: Organic deposits.

External drainage: Ponded.

Vegetation/Land Use: Secondary growth (2 years old), mainly soft trees and thick fern undergrowth.

Altitude: ± 20 feet.

Rainfall: 159.11″ M.A.R. (Kuching Airport).

Rainfall Class (Mohr): I.

Lab. Nos: S 7699/7700.

Date sampled: 14.1.70.

01	**0–9″**	**Very dark brown (10YR 2/2) peat consisting of abundant, slightly humified, coarse to medium roots. Moist; granular to crumbly structure.**
02	**9–48″**	Very dark brown (10YR 2/2) peat formed by decayed roots and wood. Wet.

PROFILE REF. NO. 225

Soil Group: DEEP PEAT.

Family: **Anderson.**

Series: Not differentiated.

Phase: Deep. III.

Location: End of Gedong Road (Upper Sadong District).

Latitude: 1° 11′ N.

Longitude: 110° 38′E.

Topography: Basin swamp.

Site: Level.

Parent material: Organic deposits.

External drainage: Ponded.

Vegetation/Land Use: Primary forest (Mixed Swamp forest).

Altitude: ± 40 feet.

Rainfall: 139.13″ M.A.R. (Tarat).

Rainfall Class (Mohr): I.

Lab. Nos: S 7697/98.

Date sampled: 14.1.70.

01	0–12″	Dark reddish brown (5YR 2/2) peat consisting of abundant, slightly humified roots, leaves and wood. Slightly wet. Structureless.
02	12–48″ +	Dark brown (7.5YR 3/2) peat consisting of decayed roots and wood. Wet. Structureless.

Profile ref. No.: 225 Soil Group: PEAT SOILS Soil Family: ANDERSON Soil Series:

Phase: 3

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	Total ash %	Total p.p.m O.D. CaO	Total p.p.m O.D. MgO	Total p.p.m O.D. K_2O	Total p.p.m O.D. P_2O_5	C.E.C.	S Value	'Reserve' p.p.m. O.D. Ca	'Reserve' p.p.m. O.D. Mg	'Reserve' p.p.m. O.D. K	% Group III Oxides	% P. Ret.
S 7697	O.1	0-12	3.4		1.9	39.5	21			2·91	860	810	952	614						0.34	
S 7698	O.2	24-48	3.3		1.7.	38.3	225			4·99	652	333	392	266						0.46	

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D. SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	Colloidal Fraction Total SiO_2	Fe_2O_3	Al_2O_3	Derived mol. ratio's $\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	Extractable Morgan Al	Mn	Fe	6N HCL Fe

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	Composition of peat V.C. fibres >2000 u	C. fibres 2000-1000u	m.f. fibres 1000-500 u	fine fibres 500-250 u	v.f. fibres 250-100 u	Sand Total 2000-50u	Silt 50-2u	Clay <2u	Bulk density gm/cc (O.D)	Texture according to 7th Approx.
S 7697	O.1	0-12									0.1056	Fibric / Hemic
S 7698	O.2	24-48	4.762	3.553	4.131	5.171	6.097				0.0844	Fibric

(d) Mineralogy.

Sample No.	Horizon	Depth in inch	Medium or fine sand fraction % Heavy minerals Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoisite	Clino-Zoisite	Hornblende	Corundum	Crystobalite	Alterite			Light minerals Quartz	Felspars	Mica's		Clay fraction* Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite

* d-dominant, p-present, t-trace.

Profile ref. No.: 242 Soil Group: RECENT ALLUVIAL SOIL Soil Family: RAMUN Soil Series: RAMUN

Phase:

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH		% O.D.			ppm. O.D.		m.e.q. % (O.D.)								'Reserves' p.p.m. O.D.				%
			1:2.5 H_2O	1:5 KCL	Total N	Total C	C/N Value	Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value	Ca	Mg	K	Group III Oxides	P Ret.
S7657	A1	0-3½	5.9		0.806	7.43	9.22			17.22	3.00	0.96	0.12	0.33	0.02	37.37	57.00					81.39
58	B	3½-13	6.3		0.118	0.98	8.31			11.89	1.43	0.61	0.09	0.20	<0.20	20.07	69.86					75.89
59	B/C	13-26	6.2		0.049	0.23	4.69			14.36	3.53	0.50	0.12	0.12	0.02	21.56	85.89					75.75

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D.										Colloidal Fraction							Extractable			
													Total			Derived mol. ratio's				Morgan			6N HCL
			SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	SiO_2	Fe_2O_3	Al_2O_3	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	Al	Mn	Fe	Fe
S7657	A1	0-3½	43.56	10.04	14.39	1.55	0.87	1.84		1.12	0.2830	0.1368	28.50	18.17	20.48	1.51	4.16	2.37	0.57				
58	B	3½-13	46.63	14.59	15.97	1.66	0.99	2.64		1.81	0.2723	0.1411	29.96	24.96	21.67	1.34	3.12	2.35	0.75				
59	B/C	13-26	45.49	16.02	17.06	1.77	1.00	2.37		1.76	0.3042	0.1123	32.00	22.01	24.04	1.49	4.26	2.26	0.53				

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	Fine earth < 2 mm composition								Total fine earth	Texture according to U.S. Survey Manual
			V.C.S.	C.S.	M.S.	F.S.	V.F.S.	Sand	Silt	Clay		
			2000µ-1000µ	1000µ-500µ	500µ-250µ	250µ-100µ	100µ-50µ	Total 2000-50µ	50-2µ	< 2µ		
S7657	A1	0-3½	33.47	15.19	4.95	2.50	0.94	57.02	20.01	17.42	94.45	Sandy clay loam/ Sandy loam.
58	B	3½-13	50.07	25.45	8.40	3.46	0.65	88.03	5.43	5.06	98.52	Loamy sand/sand
59	B/C	13-26	56.71	17.38	5.42	3.82	3.02	86.35	5.96	6.44	98.75	Sand/loamy sand

(d) Mineralogy.

Sample No.	Horizon	Depth in inch	Medium or fine sand fraction %																									* Clay fraction						
			Heavy minerals																					Light minerals										
			Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoizite	Clino-Zoizite	Hornblende	Corundum	Crystobalite	Alterite			Quartz	Felspars	Mica's		Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
S 7657	A1	0-3½																											d		p	p		
58	B	3½-13																											d		p	p		
59	B/C	13-16																											d		p	p		

* d-dominant, p-present, t-trace

PROFILE REF. NO. 242

Soil Group: RECENT ALLUVIAL SOIL.

Family: Ramun.

Series: *Ramun.*

Phase:

Location: Foot of Gunong Sedong—Tarat Agricultural Station (Upper Sadong District).

Latitude: 1° 12′ 20″ N.

Longitude: 110° 30′ 25″ E.

Topography: Alluvial fan.

Site: At footslope of a high hill.

Parent material: Recent alluvium and colluvium derived from basic to intermediate igneous rocks.

External drainage: Good.

Vegetation/Land Use: Secondary forest, few scattered fruit trees.

Altitude: ± 100 feet.

Rainfall: 139.13″ M.A.R. (Tarat).

Rainfall Class (Mohr): I.

Lab. Nos: S 7657/59.

Date sampled: 15.1.70.

NOTE: Surface soil covered with large to medium size boulders (colluvial influence).

O	1″–0	Thin layer of undecomposed roots and leaves.
A1	0–3½″	Very dark greyish brown (10YR 3/2) loam with common coarse to medium size rock pieces. Many fine and medium roots. Moist. Strong crumb structure. Porous. Clear smooth change to
B	3½–13″	Dark brown (7.5YR 4/4) gritty clay with common, medium and fine rock fragments. Moist. Friable. Few dead roots. Diffuse change to
B/C	13–26″+	Dark brown (7.5YR 4/4) gritty clay with increasing amount of coarse, medium rock fragments. Moist. Compact in profile. Strong crumb structure if broken up.

PROFILE REF. NO. 209

Soil Group: RECENT ALLUVIAL SOIL.

Family: **Ramun.**

Series: *Terbat.*

Phase: Bisequent.

Location: Sungai Baeh—Tarat Agricultral Station (Upper Sadong District).

Latitude: 1° 12′ N.

Longitude: 110° 31′ E.

Topography: Incipient levee.

Site: Level.

Parent material: Recent alluvium derived from basic to intermediate igneous rocks.

External drainage: Moderately good.

Vegetation/Land Use: Secondary forest (mainly).

Altitude: ± 50 feet.

Rainfall: 139.13″ M.A.R. (Tarat).

Rainfall Class (Mohr): I.

Lab. Nos: S 7660/63.

Date sampled: 15.1.70.

NOTE: On surface ½ inch of fresh leaves and decayed branches.

A1	**0–7″**	Brown (7.5YR 5/4) loam with abundant, fine to medium roots. Many earthworms. Few pieces of weathered rock. Moist. Strong crumb structure. Clear wavy boundary to
B	**7–22″**	Dark brown (7.5YR 4/4) loam. No mottles. Moist. Crumbly. Few fine to medium roots. Diffuse change to
B/C	**22–31″**	Dark brown (7.5YR 4/4) loam with few pieces of weathered rock. No mottles. Massive in profile. Crumbly when broken up. Few to medium roots.
IIC	**31–42″**	Light yellowish brown (10YR 6/4) loam containing distinct reddish brown (5YR 5/4) weathered rock pieces. Accumulation of hard gravels in profile. Moist. Crumbly.

Profile ref. No.: 209 Soil Group: RECENT ALLUVIAL SOIL Soil Family: RAMUN Soil Series: TERBAT

Phase:

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	Group III Oxides	% P Ret.
S7660	A I	0 – 7	5.6		0.232	2.10	9.05			4.46	1.75	0.20	0.10	2.03	0.13	21.58	30.17					73.70
61	B	7 – 22	5.6		0.093	0.66	7.10			2.31	1.31	0.09	0.11	4.13	0.08	17.75	21.32					86.80
62	B/C	22–31	5.6		0.065	0.51	7.85			1.64	2.33	0.10	0.14	4.35	0.05	18.88	22.30					86.56
63	IIC	31–42	5.7		0.049	0.43	8.78			2.07	2.81	0.17	0.25	4.49	0.05	20.43	25.94					79.56

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D. SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	Colloidal Fraction Total SiO_2	Fe_2O_3	Al_2O_3	Derived mol ratio's SiO_2/R_2O_3	SiO_2/Fe_2O_3	SiO_2/Al_2O_3	Fe_2O_3/Al_2O_3	Extractable Morgan Al	Mn	Fe	6N HCL Fe
S7660	AI	0 – 7	56.00	11.43	17.39	1.73	0.39	1.12		0.93	0.2012	0.1318	33.13	20.51	25.17	1.51	4.42	2.28	0.52				
61	B	7 – 22	54.78	13.34	17.55	1.81	0.21	1.19		0.95	0.2066	0.0948	32.81	21.56	26.04	1.31	3.32	2.14	0.62				
62	B/C	22–31	54.50	14.54	17.39	1.79	0.25	1.26		1.01	0.1891	0.1247	32.39	21.36	26.60	1.26	3.25	2.07	0.60				
63	IIC	31–42	56.52	12.04	17.99	1.78	0.23	1.38		1.09	0.1016	0.0917	34.71	18.77	27.29	1.50	4.94	2.15	0.42				

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	Fine earth < 2 mm composition: V.C.S. 2000µ–1000µ	C.S. 1000µ–500µ	M.S. 500µ–250µ	F.S. 250µ–100µ	V.F.S. 100µ–50µ	Sand Total 2000–50µ	Silt 50–2µ	Clay < 2µ	Total fine earth	Texture according to U.S. Survey Manual
S7660	AI	0 – 7	1.85	0.98	3.17	13.63	14.14	33.77	31.59	28.50	93.86	Clay loam
61	B	7 – 22	0.37	1.19	7.62	16.13	15.96	41.27	29.67	27.29	98.23	" "
62	B/C	22–31	0.97	7.97	14.92	14.92	13.27	52.05	19.33	26.18	97.56	Sandy clay loam
63	IIC	31–42	4.59	1400	14.46	13.91	10.46	57.42	17.80	22.78	98.00	" " "

(d) Mineralogy.

Sample No.	Horizon	Depth in inch	Medium or fine sand fraction % — Heavy minerals: Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoizite	Clino-Zoizite	Hornblende	Corundum	Crystobalite	Alterites	Muscovite	Light minerals: Quartz	Felspars	Mica's	* Clay fraction: Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
S7660	A I	0 – 7	100/0	t																							d		p	p		
61	B	7 – 22	100/0																								d		p	p		
62	B/C	22–31	100/0		t																5	14					d		p	p		
63	IIC	31–42	67/33	47	15				9	9	1																					

Mainly purple coloured rounded Zircon and undulose Muscovite in 7663.

* d-dominant, p-present, t-trace

Profile ref. No.: 3 Soil Group: RECENT ALLUVIAL SOILS Soil Family: SEMATAN Soil Series: SEMATAN

Phase:

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	ppm O.D. Av. P	ppm O.D. 'Total' P	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' ppm O.D. Ca	Mg	K	Group III Oxides	% P Ret.
S7387	A1	0-6	5.4			0.41																
S7388	A/B	6-12	5.5			0.22																
S7389	B1	12-22	6.2			0.21																
S7390	B2	22-38	6.7			0.04																
S7391	C(g)	38-68	6.4			0.04																

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D. SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	Colloidal Fraction Total SiO_2	Fe_2O_3	Al_2O_3	Derived mol. ratio's SiO_2/R_2O_3	SiO_2/Fe_2O_3	SiO_2/Al_2O_3	Fe_2O_3/Al_2O_3	Extractable Morgan Ca	Mn	Fe	Mg
S7387	A1	0-6	96.60	2.27	0.61						0.02									81	<1	60	97
S7388	A/B	6-12	96.05	2.79	1.54						0.01									81	<1	28	24
S7389	B1	12-22	99.36	2.88	1.33						0.02									121	<1	15	73
S7390	B2	22-38	97.02	2.67	1.53						0.01									81	4	<2	24
S7391	C(g)	38-68	96.29	1.86	1.60						0.02									80	3	<2	72

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	Fine earth < 2 mm composition: V.C.S. 2000μ-1000μ	C.S. 1000μ-500μ	M.S. 500μ-250μ	F.S. 250μ-100μ	V.F.S. 100μ-50μ	Sand Total 2000-50μ	Silt 50-2μ	Clay < 2μ	Total fine earth	Texture according to U.S. Survey Manual
S7387	A1	0-6		0.05	8.87	80.24	2.83	94.99	1.62	4.44	101.05	fine sand
S7388	A/B	6-12		0.05	10.06	83.28	1.95	95.34	1.70	5.28	102.32	fine sand
S7389	B1	12-22		0.05	7.88	87.47	1.96	97.36		4.70	102.06	fine sand
S7390	B2	22-38		–	2.32	94.71	1.40	98.43	0.53	2.82	101.78	fine sand
S7391	C(g)	38-68		0.25	33.63	64.00	0.81	98.69	0.58	2.66	101.85	fine sand

(d) Mineralogy.

Medium or fine sand fraction % — Heavy minerals

Sample No.	Horizon	Depth in inch	Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoisite	Clino-Zoisite	Hornblende	Corundum	Crystobalite	Alterite		
S7387	A1	0-6	42/58	41	10	3		4	2	2	1	31		3				1			1		
S7388	A/B	6/12	42/58	20	16	5		5	2	5	1	35		2	3			1			5		
S7389	B1	12-22	57/43	67	7				4	3		18									1		
S7390	B2	22-38	40/60	9	21	3		6	3		1	50		1				3			3		
S7391	C(g)	38-68	41/59	5	34			6		6	2	34		1				1			5		

Medium or fine sand fraction % — Light minerals; * Clay fraction

Sample No.	Horizon	Depth in inch	Quartz	Felspars	Mica's		* Clay fraction: Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
S7387	A1	0-6											
S7388	A/B	6/12											
S7389	B1	12-22											
S7390	B2	22-38											
S7391	C(g)	38-68											

* d - dominant, p - present, t - trace

PROFILE REF. NO. 3

Soil Group: RECENT ALLUVIAL SOIL.

Family: Sematan.

Series: *Sematan.*

Phase:

Location: 800 feet from coastline near Kpg. Pueh (Lundu District).

Latitude: 1° 49′ 40″ N.

Longitude: 109° 43′ E.

Topography: Almost flat, old raised beach.

Site: Slightly sloping (not more than 2 degrees) land-inward almost on top of fourth beach ridge from the sea.

Parent material: Subrecent beach sand probably dominantly derived from Pueh adamellite and Serabang Formation rocks.

External drainage: Good

Vegetation/Land Use: Much *Ditranopteris curranii spp.*, undergrowth: ***Ternstroemia spp.***

Altitude: ± 6 feet.

Rainfall: ± 125″ M.A.R. (estimated).

Lab. Nos: S 7387/91.

Date sampled: October, 1968.

		A veneer of white coloured sand (organic matter oxidized due to exposure) on surface.
A1	0–6″	Dark yellowish brown (10YR 4/4) fine sand. Slightly moist. Crumbly. Well rooted; many wormcasts. Gradual, regular change to
A/B	6–12″	Strong brown to reddish brown (7.5YR 5/8) fine sand. Slightly moist. Crumbly, with many wormcasts. Well rooted. Distinct regular boundary to
B1	12–22″	Strong brown (7.5YR 5/8) fine sand. Slightly moist. Very weak crumbly, very few roots. Gradual wavy boundary to
B2	22–38″	Yellowish brown (10YR 5/8) fine sand with common coarse brown and some coarse, light yellow coloured mottles. Slightly moist. Weak crumbly structure. One rounded green coloured rock fragment with dark brown coating. Many micas. Very gradual indistinct change to
C(g)	38–68″	Multicoloured-brown, yellow and yellowish brown medium sand, colour becomes inrecasingly lighter with depth. Slightly moist; loose; slightly wet at 68 inches.

PROFILE REF. NO. 2

Soil Group: RECENT ALLUVIAL SOIL.

Family: **Sematan.**

Series: *Rambungan.*

Phase:

Location: 80 feet from coastline near Kpg. Pueh (Lundu District).

Latitude: 1° 50′ N.

Longitude: 109° 43′ E.

Topography: Subrecent raised beach.

Site: On gentle slope land-inward; near swale separating two ridges.

Parent material: Subrecent beach sand.

External drainage: Fair.

Vegetation/Land Use: Mixed secondary jungle, some coconut (good growth).

Altitude: ± 4 feet.

Rainfall: ± 125″ M.A.R. (estimated).

Rainfall Class (Mohr): I.

Lab. Nos: S 7381/86.

Date sampled: October, 1968.

		Very thin litter layer on surface.
A1	0–6″	Yellowish brown (10YR 4/4) medium sand. Weak crumbly structure. Well rooted. Many wormcasts. Gradual regular change to
A1.2	6–12″	Yellowish brown (10YR 5/8) medium sand with faint pale brown mottles. Structureless. Well rooted. Distinct regular boundary to
A/B	12–18″	Strong brown (7.5YR 5/8) medium sand with strong brown (7.5YR 6/8) mottles. Structureless to weak crumbly. Well rooted. Distinct sloping boundary following surface slope but steeper inclination to
Bmn	18–30″	Dark reddish brown (5YR 3/4) medium sand with common reddish yellow (7.5YR 6/8) mottles; in places soft, dark reddish brown concretions often with a layer of more reddish material (iron oxide?) surrounding it; this material is most concentrated at 18-24 inches; from 24-30 inches it is less dark and more like mottles. Most roots stop at 18 inches. Gradual indistinct change to
B/C	30–48″	Dark brown (7.5YR 4/4) medium sand with light coloured mottles. Moist. Very weak crumbly. Few roots. Indistinct regular change to
C	48–60″	Light yellowish brown (10YR 6/4) medium sand. Slightly moist. Very weak crumbly structure.
IIC	at 60″	Coarser sand, distinctly micaceous.

Profile ref. No.: 2 | Soil Group: RECENT ALLUVIAL SOILS | Soil Family: SEMATAN | Soil Series: RAMBUNGAN

Phase:

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH 1:25 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	Group III Oxides	% P Ret.
S 7381	A1	0-6	5.8			0.67																
S 7382	A1.2	6-12	5.6			0.27																
S 7383	A/B	12-18	5.9			0.21																
S 7384	Bmn	18-30	6.4			0.08																
S 7385	B/C	30-48	7.0			0.03																
S 7386	C	48-60	7.0			0.02																

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D. SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	Colloidal Fraction Total SiO_2	Fe_2O_3	Al_2O_3	Derived mol. ratio's $\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	Extractable Morgan Ca	Mn	Fe	Mg
S 7381	A1	0-6	93.78	2.05	1.52						0.02									120	3	51	144
S 7382	A1.2	6-12	97.90	2.07	1.33						0.02									121	<1	25	48
S 7383	A/B	12-18	91.92	2.52	1.47						0.02									81	1	10	48
S 7384	Bmn	18-30	90.85	2.56	1.33						0.15									40	16	<2	120
S 7385	B/C	30-48	95.27	3.83	0.94						0.06									121	5	<2	48
S 7386	C	48-60	95.54	4.03	0.80						0.04									81	2	<2	73

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	V.C.S. 2000μ-1000μ	C.S. 1000μ-500μ	M.S. 500μ-250μ	F.S. 250μ-100μ	V.F.S. 100μ-50μ	Sand Total 2000-50μ	Silt 50-2μ	Clay <2μ	Total fine earth	Texture according to U.S. Survey Manual
S7381	A1	0-6		0.50	25.02	67.07	1.80	94.39	0.75	5.30	110.44	fine sand
S7382	A1.2	6-12		0.81	30.77	62.36	1.81	95.75	4.14	2.07	101.96	fine sand
S7383	A/B	12-18		2.01	35.50	57.40	0.75	95.66	3.52	2.19	101.37	fine sand
S7384	Bmn	18-30		1.00	35.24	58.18	1.41	95.83	0.58	3.81	100.02	medium sand
S7385	B/C	30/48		0.05	59.10	35.24	1.87	96.26	0.48	2.19	98.93	medium sand
S7386	C	48/60		0.05	4.08	93.15	1.41	98.69	0.48	1.91	101.08	fine sand

(d) Mineralogy.

Medium or fine sand fraction %

Sample No.	Horizon	Depth in inch	Heavy minerals: Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoizite	Clino-Zoizite	Hornblende	Corundum	Crystobalite	Alterite			Light minerals: Quartz	Felspars	Mica's	
S7381	A1	0-6	38/62	19	22	3		3	3	7		40		2							1						
S7382	A1.2	6-12	55/45	34	16	3		2	3	4		35		1				1			1						
S7383	A/B	12/18	35/65	13	21	8		4	2	10		39		1							2						
S7384	Bmn	18-30	41/59	24	28	3		1	2	3		36		2				1									
S7385	B/C	30/48	47/53	52	13	1		4	3			22						3			2						
S7386	C	48/60	49/51	47	10	2		3	4	2	1	29			1			1									

Sample No.	* Clay fraction: Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
S7381							
S7382							
S7383							
S7384							
S7385							
S7386							

* d-dominant, p-present, t-trace.

Profile ref. No.: 10 **Soil Group:** RECENT ALLUVIAL SOILS **Soil Family:** SEDUAU **Soil Series:** SEBAT

Phase:

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P Reserve	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D Ca	Mg	K	% Group III Oxides	% P Ret.
S5253	AI	0-7							332									455	2403	3156	18.38	
S5254	BI	7-26							126									436	686	3692	21.01	
S5255	B2	26-37							118									454	2725	3316	19.56	
S5256	IIC	37-48							103									217	2079	3270	19.47	
S5257	IIIC	48-60							151									225	2713	3571	28.18	

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D. SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	Colloidal Fraction Total SiO_2	Fe_2O_3	Al_2O_3	Derived mol. ratio's $\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	Extractable Morgan Al	Mn	Fe	6N HCL Fe %
S5253	AI	0-7																					4.74
S5254	BI	7-26																					5.68
S5255	B2	26-37																					5.54
S5256	IIC	37-48																					4.16
S5257	IIIC	48-60																					7.60

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	Fine earth < 2 mm composition V.C.S. 2000μ-1000μ	C.S. 1000μ-500μ	M.S. 500μ-250μ	F.S. 250μ-100μ	V.F.S. 100μ-50μ	Sand Total 2000-50μ	Silt 50-2μ	Clay < 2μ	Total fine earth	Texture according to U.S. Survey Manual

(d) Mineralogy.

Sample No.	Horizon	Depth in inch	Heavy minerals: Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoisite	Clino-Zoisite	Hornblende	Corundum	Crystobalite	Alterite	Tremolite/Actinolite ?		Light minerals: Quartz	Felspars	Mica's		* Clay fraction: Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
S5253	AI	0-7	39/61	37	15	4				1			1			3		37											d			t		
S5254	BI	7-26	34/66	19	20	4										6		43				8							d		t	t		
S5255	B2	26-37	28/72	10	22							1	1			8		57			1								d			t		t
S5256	IIC	37-48	34/66	14	41	4							1			4		36											d			t	t	t
S5257	IIIC	48-60	45/55	29	27	6						1	3			8		21				5							d			t	t	

* d-dominant, p-present, t-trace.

PROFILE REF. NO. 10

Soil Group: RECENT ALLUVIAL SOIL.

Family: **Seduau.**

Series: *Sebat.*

Phase:

Location: 1500 feet from Rh. Bakar, S. Pasir Tengah along path to Pasir Ilir (Lundu District).

Latitude: 1° 36′ 30″ N.

Longitude: 109° 43′ 40″ E.

Topography: Flat floodplain of Sungei Pasir.

Site: Incipient levee, level.

Parent material: Recent alluvium derived from adamellite and metamorphosed rocks in the Serabang Formation (greywacke, phyllite).

External drainage: Fair.

Vegetation/Land Use: Rubber garden, also many Engkabang.

Altitude: ± 50 feet.

Rainfall: ± 130″ M.A.R. (estimated).

Rainfall Class (Mohr): I.

Lab. Nos: S 5253/57.

Date sampled: October, 1967.

A1	0–7″	Dark greyish brown (10YR 4/2) sandy clay loam. Moist; weak friable. Strong angular blocky. Well rooted. Few micas. Porous. Distinct wavy boundary to
B1	7–26″	Yellowish brown (10YR 5/6) silty to fine sandy clay loam. Moist; friable. Fine angular blocky. Moderately well rooted. Porous. Few micas; very small specks of dark brown material (Mn?). Very gradual change to
B2	26–37″	Yellowish brown (10YR 5/6) fine sandy clay loam. Slightly moist; compact, friable whea broken up. Weak blocky structure. Few roots. Brown specks apparent (Mn?). Abrupt change to
IIC	37–48″	Light yellowish brown (2.5Y 6/4) sandy loam. With few brown mottles. Almost dry; very compact. Structureless. Many micas. Very wavy clear boundary to
IIIC	48–60″	Light yellowish brown (2.5YR 6/4) clay loam with common, brown (10YR 5/8) mottles. Moist; very friable; compact in profile. Weak crumbly structure. Many large, dark brown smeary specks (soft Mn concretions?), increasing in intensity with depth; micas present. No roots.

REMARK: Stratified alluvium. Possibly rich in Mn in sublayers.

PROFILE REF. NO. 1

Soil Group: RECENT ALLUVIAL SOIL.

Family: **Kabong.**

Series: *Siru.*

Phase:

Location: 30 feet from normal high-tide line, near Kpg. Pueh (Lundu District).

Latitude: 1° 50′ 20″ N.

Longitude: 109° 43′ E.

Topography: Present storm beach.

Site: Almost flat, long gentle slope towards sea.

Parent material: Recent marine deposits.

External drainage: Good.

Vegetation/Land Use: Pioneer beach association, creepers. *Casuarina sumatrana.*

Altitude: ± 2 feet.

Rainfall: ± 125″ M.A.R. (estimated).

Rainfall Class (Mohr): I.

Lab. Nos: S 7375/80.

Date sampled: October, 1968.

A/C	0–9″	Pale brown (10YR 6/3) medium sand with fine shell fragments. Slightly moist; loose. Structureless. Bits of organic matter (depositional); fine roots. Clear abrupt change to
C1	9–15″	Pale brown (10YR 6/3) slightly coarser sand than 0-9″. Dry. No roots; shell fragments and bits of organic matter (depositional). Clear change to
C2	15–28″	Yellowish brown (10YR 5/4) medium sand. Moist. Structureless. Micaceous; some large roots. Gradual change to
C3	28–43″	Yellowish brown (10YR 5/4) medium sand with common coarse strong brown (7.5YR 4/4) mottles. Some very thin (almost lines) of black coloured sand. Few roots. Gradual change to
C4	43–52″	As 28″-43″, but no roots or brown mottles.
C5(g)	52–60″	Yellowish brown (10YR 5/4) medium sand, in places mottled brownish red at 52-57 inches; at 52″ one large thin platy rock piece coated with iron. Very moist.

NOTE: **All sand below 15 inches smears brown if cut by spade.**

Profile ref. No.: 1 | Soil Group: RECENT ALLUVIAL SOILS | Soil Family: KABONG | Soil Series: SIRU

Phase:

(a) Fertility level.

Sample No.	Horizon	Depth in inch	pH		% O.D.			ppm. O.D.		m.e.q. % (O.D.)								'Reserves' p.p.m. O.D.			%	%
			1:2.5 H_2O	1:5 KCL	Total N	Total C	C/N Value	Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value	Ca	Mg	K	Group III Oxides	P Ret.
S 7375	A/C	0-9	7.7	0.04																		
S 7376	C1	9-15	7.8	0.02																		
S 7377	C2	15-28	7.7	0.04																		
S 7378	C3	28-43	7.8	0.03																		
S 7379	C4	43-52	7.9	0.01																		
S 7380	C5(g)	52-60	7.9	0.03																		

(b) Chemical composition.

Sample No.	Horizon	Depth in inch	Total analyses of fine earth % O.D.										Colloidal Fraction							Extractable			
													Total			Derived mol. ratio's				Morgan			
			SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	SiO_2	Fe_2O_3	Al_2O_3	SiO_2/R_2O_3	SiO_2/Fe_2O_3	SiO_2/Al_2O_3	Fe_2O_3/Al_2O_3	Ca	Mn	Fe	Mg
S 7375	A/C	0-9	88.90	1.96	2.13						0.05									24225	80	14	1582
S 7376	C1	9-15	91.08	2.12	1.32						0.02									22821	74	12	1016
S 7377	C2	15-28	88.32	2.25	1.39						0.06									23086	121	16	2020
S 7378	C3	28-43	92.85	3.07	1.27						0.09									3827	5	<2	1909
S 7379	C4	43-52	96.64	2.81	1.33						0.06									9688	29	5	3160
S 7380	C5(g)	52-60	68.17	3.05	1.26						0.07									50010	173	12	4589

(c) Mechanical composition.

Sample No.	Horizon	Depth in inch	Fine earth < 2 mm composition								Total fine earth	Texture according to U.S. Survey Manual
			V.C.S. 2000µ-1000µ	C.S. 1000µ-500µ	M.S. 500µ-250µ	F.S. 250µ-100µ	V.F.S. 100µ-50µ	Sand Total 2000-50µ	Silt 50-2µ	Clay < 2µ		
S 7375	A/C	0-9		0.50	14.28	84.00	1.17	99.55	0.18	1.79	101.52	fine sand
S 7376	C1	9-15		0.30	19.66	79.63	0.35	99.94	0.25	1.51	101.70	"
S 7377	C2	15-28			2.50	95.29	1.36	99.15	0.03	1.93	101.10	"
S 7378	C3	28-43			1.91	97.68	0.61	100.20	2.67	2.04	104.91	"
S 7379	C4	43-52		0.05	9.45	89.95	0.09	99.54	1.56	5.07	106.17	"
S 7380	C5(g)	52-60		0.04	23.07	73.12	2.41	99.00	0.55	1.90	101.45	"

(d) Mineralogy.

Sample No.	Horizon	Depth in inch	Medium or fine sand fraction % — Heavy minerals																			Light minerals			* Clay fraction						
			Ratio Opaque/Non-opaque	Zircon	Tourmaline	Andalusite	Sillimanite	Epidote	Rutile	Anatase	Brookite	Leucoxene	Sphene	Garnet	Spinel	Zoizite	Clino-Zoizite	Hornblende	Corundum	Crystobalite	Alterite	Quartz	Felspars	Mica's	Quartz	Kaolinite	Illite	Vermiculite	Gibbsite	Goethite	Boehmite
S 7375	A/C	0-9	28/72	10	16	5		5	1	2	1	56									2										
S 7376	C1	9-15	53/47	22	41	2	2	4		1		19						1			2										
S 7377	C2	15-28	20/80	13	26	12		7	1			32				1		1			4										
S 7378	C3	28-43	76/24	17	51						1	8									4										
S 7379	C4	43-52	45/55	36	25	1		6	1	3		26																			
S 7380	C5(g)	52-60	32/68	9	25	9		8	2			38						4			4										

* d - dominant, p - present, t - trace

GROUP B — PROFILES

GROUP B — PROFILES

5. PROFILE DESCRIPTIONS AND ANALYSES OF SOILS STUDIED IN DETAIL,

PROFILE REF. NO. 84

Soil Group: SKELETAL SOIL.

Family: **Sedong.**

Series: *Suka.*

Phase:

Location: Quop (Kuching Rural District).

Latitude: 1° 25′ 30″ N.

Longitude: 110° 23′ 55″ E.

Topography: Low gently undulating to flat terrain.

Site: On a gentle slope of approx. 5 degrees.

Parent material: Andesite.

External drainage: Fair.

Vegetation/Land Use: Rubber (5 years old).

Altitude: ± 50 feet.

Rainfall: 155.44″ M.A.R. (estimated).

Rainfall Class (Mohr): I.

Lab. Nos: S 3400/03.

Date sampled: May, 1969.

A1	0–4″	Dark yellowish brown (10YR 4/4) clay loam. Moist; friable. Subangular blocky and crumbly. Well rooted. Gradual change to
B	4–14″	Yellowish brown (10YR 5/6) clay loam with few indistinct greyish green, soft rock particles. Moist. Many fine rootlets.
B/C	14–24″	Yellowish brown (10YR 5/4) clay loam with distinct greyish green weathered soft rock. Moist; friable. Few rootlets.
C1	24–33″	Yellowish brown (10YR 5/4) clay loam with abundant light grey mottles and weathered rock. Moist; friable. Subangular blocky.
C2	33–48″+	Yellowish brown (10YR 5/4) clay loam. Moist to wet; plastic; non-sticky.

Profile ref. No.: 84 **Soil Group**: SKELETAL SOILS **Soil Family** SEDONG **Soil Series**: SUKA
Phase:

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	% Group III Oxides	% P Ret	Extractable Morgan Al	Mn	Fe	6N HCL Fe
S 3400	A1	0-4	5.1						364									1445	4990	1050	23.14					
01	B	4-14	5.2						174									416	7389	1400	34.76					
02	B/C	14-24	5.7						152									594	7140	1600	35.68					
03	C1	24-33	5.7						155									2356	7686	1200	29.84					

Profile ref. No. : 431 **Soil Group : SKELETAL SOILS** **Soil Family SEDONG** **Soil Series : SUKA**
Phase :

Sample No.	Horizon	Depth in inch	pH		% O.D.		C/N Value	p.p.m. O.D.		m.e.q. % (O.D.)								'Reserves' p.p.m. O.D.			%	%	Extractable			
																							Morgan			6N HCL
			1:25 H_2O	1:5 KCL	Total N	Total C		Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value	Ca	Mg	K	Group III Oxides	P Ret.	Al	Mn	Fe	Fe
S 2049	A1	0 - 6	5.2						263									2507	3914	1507						
50	B/C	6 - 24	4.8						266									1382	1268	1188						
51	C/D	24 +	5.0						287									1418	9256	1473						

PROFILE REF. NO. 431

Soil Group: SKELETAL SOIL, intergrade to REDDISH BROWN LATERITIC SOILS.

Family: Sedong.

Series: *Suka.*

Phase:

Location: Bukit Suka near Tebedu Road (Upper Sadong District).

Latitude: 1° 7′ N.

Longitude: 110° 28′ E.

Topography: On mountain.

Site: On middle slope, broken terrain. Slope varying between 20 and 25 degrees.

Parent Material: Weathered basic igneous rocks.

External drainage: Rapid.

Vegetation/Land Use: Padi stubble and lallang.

Altitude: ± 350 feet.

Rainfall: ± 130″ per year (estimated).

Rainfall Class (Mohr): I.

Lab. Nos: S 2049/51.

Date sampled: 14.5.63.

A1	0–6″	Dark yellowish brown clay. Slightly moist; friable. Crumbly structure. Many small rock pieces and charcoal. Gradual smooth change to
B/C	6–24″	Between yellowish brown (10YR 5/4) and strong brown (7.5YR 5/6) gravelly clay. Slightly moist; very firm and compact. Coarse angular block structure. Many partly decomposed and fresh angular shaped rock fragments.
C/D	24″+	Hard weathered basalt mixed with some soil.

PROFILE REF. NO. 216

Soil Group: LATERITIC.

Family: **Tarat.**

Series: *Tarat.*

Phase: Colluvial.

Location: At 1st mile Serian-Simanggang Road (Upper Sadong District).

Latitude: 1° 8′ 45″ N.

Longitude: 110° 35′ E.

Topography: Broken terrain, strongly dissected.

Site: On a 25 degrees slope.

Parent material: Altered Andesite.

External drainage: Good.

Vegetation/Land Use: Young rubber with dense undergrowth, dominantly ferns.

Altitude: 150 feet.

Rainfall: ± 140″ M.A.R. (estimated).

Rainfall Class (Mohr): I.

Lab. Nos: 5220/23.

Date sampled: January, 1961.

Very thin layer of leave litter (1/10 of an inch).

A1	0–4″	Reddish brown (5YR 4/4) clay. Dry; loose. Fine subangular blocky to fine angular blocky structure (nutty). Porous. Abundant rootlets. Distinct boundary to
B1	4–14″	Red (2.5YR 5/6) clay, crumbly. Moist; friable. Coarse prismatic structure. Many roots. Shiny ped surfaces possibly indicating orientated clay. Indistinct boundary to
B2	14–24″	Red (2.5 YR 5/6) clay. As above horizon but the soil is firm and does not break into smaller peds on pressure. Slightly moist. Indistinct boundary to
B3	24–52″	Red (2.5YR 5/6) clay loam which breaks into small crumbs and fine angular blocky peds if slight pressure is applied. Dry; soft. Porous. Slight development of shiny ped surfaces. Many roots. Scattered small weathered rock pieces (possibly colluvial).
C	52–80″	Mixture of red (2.5YR 5/6) clay loam, very friable to powdery; and brittle, throughly weathered parent material, 50%-50%. Slightly moist. Few rootlets. Porous.

Profile ref. No.: 216 **Soil Group: LATERITIC** **Soil Family TARAT** **Soil Series: TARAT** **Phase: COLLUVIAL**

Sample No.	Horizon	Depth in inch	pH		% O.D.			p.p.m. O.D.		m.e.q. % (O.D.)								Colloidal Fraction Derived mol. ratio's				%	Extractable			
			1:25 H_2O	1:5 KCL	Total N	Total C	C/N Value	Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value	SiO_2/R_2O_3	SiO_2/Fe_2O_3	SiO_2/Al_2O_3	Fe_2O_3/Al_2O_3	P Ret.	Morgan Al	Morgan Mn	Morgan Fe	6N HCL Fe
5220	A1	0-4	4.4	3.9	0.42	5.32	13			0.62	0.74	0.34	0.04	1.98	0.38	10.4	17	2.51	13.48	3.09	0.23		304	22	22	
21	B1	4-14	4.8	4.3	0.13	1.32	10			0.11	0	0.07	0.02	0.31	0.21	8.8	0.20	1.70	6.47	2.31	0.36		235	0	0	
22	B2	14-24	5.7	5.3	0.06	0.86	14			0.22	0.22	0.13	0.12		0.16	6.8	0.69	1.60	5.25	2.32	0.44		163	5	0	
23	B3	24-52	5.8	6.4	0.01	0.10	10			0.10	0.44	0.13	0.07	0.06	0.13	6.8	0.74	-	-	-	-		146	21	0	

Profile ref. No.: 92 | Soil Group: LATERITIC | Soil Family TARAT | Soil Series: ANTAYAN | Phase:

Sample No.	Horizon	Depth in inch	pH		% O.D.		C/N Value	p.p.m. O.D.		m.e.q. % (O.D.)								Colloidal Fraction Derived mol. ratio's				%	Extractable			
			1:2.5 H_2O	1:5 KCL	Total N	Total C		Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value	SiO_2/R_2O_3	SiO_2/Fe_2O_3	SiO_2/Al_2O_3	Fe_2O_3/Al_2O_3	P Ret	Morgan Al	Morgan Mn	Morgan Fe	6N HCL Fe
5786	A1	0-3	4.2	3.5	0.28	4.04	14	7	408	0.65	0.54	0.29	0.09	10.59	0.58	21.3		1.23	5.68	1.57	0.28		599	11	70	
87	A2	3-12	4.4	3.6	0.19	2.06	11	3	294	0.43	0.32	0.12	0.08	10.51	0.32	17.2		2.53	23.43	2.84	0.12		674	0	37	
88	B1	12-23	4.4	3.6	0.09	0.96	11	2	243	0.43	0.32	0.08	0.09	11.19	0.26	17.6		2.83	35.00	3.08	0.09		703	0	13	
89	B2	23-33	4.8	3.6	0.07	0.62	9	1	285	0.22	0.22	0.05	0.03	14.28	0.28	19.1		2.48	27.57	2.39	0.10		1004	0	2	
90	B/C	33-48	5.3	3.7	0.03	0.40	12	6	179	0.32	0.32	0.03	0.04	12.10	0.30	18.1		2.38	32.60	2.57	0.08		890	0	4	

PROFILE REF. NO. 92

Soil Group: LATERITIC.

Family: **Tarat.**

Series: *Antayan.*

Phase:

Location: 14½ mile Kuching-Simanggang Road (Kuching Rural District).

Latitude: 1° 23′ 10″ N.

Longitude: 110° 22′ E.

Topography: Gently undulating terrain.

Site: On a slope less than 5 degrees.

Parent material: Porphyritic andesite.

External drainage: Fair.

Vegetation/Land Use: Secondary forest, mainly bamboo and grasses.

Altitude: ± 200 feet.

Rainfall: 155.44″ M.A.R. (Quop).

Rainfall Class (Mohr): I.

Lab. Nos: 5786/90.

Date sampled: September, 1961.

A1	0–3″	Light brownish grey (wet 10YR 5/2, dry 10YR 6/2) loam to clay loam. Dry; hard to very hard. Crumbly to fine subangular blocky. Abundant fine medium size roots. Gradual wavy change to
A2	3–12″	Very pale brown (wet 10YR 5/4, dry 10YR 7/4) clay loam to clay. Few, faint mottles of light grey to pale brown. Slightly moist; firm to very firm. Massive in profile, subangular blocky when broken up. Common fine to medium roots. Small pieces of hard rock. Clear smooth change to
B1	12–23″	Yellowish brown (wet 10YR 5/6, dry 10YR 7/4) clay with few, faint, light grey to pale brown mottles. Moist; firm to very firm. Subangular to angular blocky structure; massive in profile. 'Clayskins' in a few small cracks. Few medium-size roots. Diffuse wavy change to
B2	23–33″	Yellow (wet 10YR 7/6, dry 10YR 8/6) clay with few faint reddish brown to pale yellow mottles. Moist; firm to very firm. Massive in profile, angular blocky when broken up. Common fine to very fine roots. Few small medium pieces of soft rock and tiny pieces of soft quartz. Gradual change to
B/C	33–48″	Yellow (wet 10YR 7/6, dry 10YR 8/6) clay with prominent reddish brown mottles. Moist; slightly sticky and plastic. Massive in profile. Common small pieces of quartz and an increasing number of large, hard, rounded and irregular shaped rock fragments. Few hair roots.

PROFILE REF. NO. 12

Soil Group: LATERITIC.

Family: **Tarat.**

Series: *Jebong.*

Phase: Shallow.

Location: Bukit Jebong (Lundu District).

Latitude: 1° 44′ 35″ N.

Longitude: 109° 45′ 50″ E.

Topography: On high hill (Bukit Jebong).

Site: On steep slope with common outcrops of rocks.

Parent material: Gabbro.

External drainage: Rapid.

Vegetation/Land Use: Primary forest.

Altitude: ± 350 feet.

Rainfall: 130″ M.A.R. (estimated).

Rainfall Class (Mohr): I.

Lab. Nos: S 7454/57.

Date sampled: October, 1968.

O	0–½″	Litter, partly decomposed leaves and roots.
A1	½–3″	Brown (10YR 5/3) loam. Moist. Crumbly. Well rooted (mainly fine to medium roots). Moist. Gradual change to
B1	3–7″	Strong brown (7.5YR 5/6) clay loam. Moist. Crumbly to subangular blocky. Diffuse change to
B2	7–18″	Reddish yellow (7.5YR 6/6) clay loam to clay. Moist; firm. Compact. Blocky structure. Few fine roots. Diffuse wavy change to
B/C	18–25″	Reddish yellow (7.5YR 6/6) clay with hard weathered rock at 24 inches. Moist; firm. Angular blocky.
R	25″	Hard bedrock.

Profile ref. No.: 12 **Soil Group**: LATERITIC **Soil Family** TARAT **Soil Series**: JEBONG **Phase**:

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	Total % O.D. SiO_2	Fe_2O_3	Al_2O_3		% P Ret	Extractable Morgan Al	Morgan Mn	Morgan Fe	6N HCL Fe
S 7454	A1	½ – 3								1.35	0.45	0.19	0.09	1.26	0.35	13.97	15	34.46	10.09	32.52						
55	B1	3 – 7								0.42	0.14	0.04	0.02	1.24	0.14	4.90	13	34.66	11.66	34.48						
56	B2	7 – 18								0.49	0.66	0.03	0.02	<0.03	0.22	5.69	21	30.71	13.35	37.16						
57	B/C	18 – 25								0.72	0.36	0.03	0.02	0.10	0.07	3.73	30	29.33	14.54	36.70						

Profile ref. No. : 45 | Soil Group : LATERITIC | Soil Family TARAT | Soil Series : SEJINGKAT | Phase :

Sample No.	Horizon	Depth in inch	pH		% O.D.		C/N Value	p.p.m. O.D.		m.e.q. % (O.D.)								'Reserves' p.p.m. O.D.			%	%	Extractable			
			1:25 H_2O	1:5 KCL	Total N	Total C		Av. P	'Total' P $HCLO_4$	Ca	Mg	K	Na	Al	H	C.E.C.	S Value	Ca	Mg	K	Group III Oxides	P Ret	Morgan Al	Morgan Mn	Morgan Fe	6N HCL Fe
S 5291	A1	0-3	4.8			6.28			668									745	434	367	31.12					13.23
92	A2	3-9	4.3			2.22			574									353	119	248	34.17					15.77
93	B1	9-21	4.9			1.87			477									154	264	247	36.15					16.95
94	B2	21-38	5.0			0.89			484									131	105	246	42.22					18.94
95	B/C1	38-48	5.1			0.33			431									288	119	194	47.82					24.51
96	B/C2	48-72	5.3			0.16			514									588	39	245	49.77					21.78

PROFILE REF. NO. 45

Soil Group: LATERITIC.

Family: Tarat.

Series: *Sejingkat*.

Phase: Shallow (colluvial).

Location: On path to Kampong Jeragan. One mile from Pangkalan (Lower Sadong District).

Latitude: 1°31′ 10″ N.

Longitude: 110° 53′ 20″ E.

Topography: Broken mountainous terrain.

Site: On middle slope, about 120 feet above valley bottom.

Parent material: Silicified volcanic rock (basic in origin).

External drainage: Good.

Vegetation/Land Use: Old secondary growth.

Altitude: ± 300 feet.

Rainfall: ± 150″ M.A.R. (estimated).

Rainfall Class (Mohr): I.

Lab. Nos: S 5291/96.

Date sampled: March, 1968.

Thin humus layer on surface.

A1	0–3″	Brown (7.5YR 5/4) loam. Moist; friable when broken up. Crumbly. Many worm holes. Well rooted. Abrupt change to
A2	3–9″	Yellowish brown (10YR 5/6) clay loam. Moist; firm. Massive and compact but crumbly when broken up. Few decomposed roots. Some weathered rock fragments, weak red in colour. Clear gradual change to
B1	9–21″	Reddish yellow (7.5YR 7/8) clay loam, with increasingly more dark red, weak red and strong red weathered rock at depth. Moist. Massive in profile but subangular blocky when broken up. Wavy boundary to
B2	21–38″	Reddish yellow (7.5YR 7/8) clay loam to clay with common weathered rock fragments. Moist. Massive in profile, but subangular blocky when broken up. Wavy boundary to
B/C1	38–48″	Reddish yellow clay loam to clay with increasingly harder weathered rocks containing red clay along cracks. Moist; firm. Wavy boundary to
B/C2	48–72″	As above, but containing accumulation of multi-coloured weathered rock. Moist.

NOTE: Colluvial influenced.

PROFILE REF. NO. 362

Soil Group: RED-YELLOW PODZOLIC.

Family: **Abok.**

Series: *Jagoi.*

Phase:

Location: On Bukit Jaong, opposite Rh. Sapah Ilir (Simanggang District).

Latitude: 1° 11′ 20″ N.

Longitude: 111° 4′ 40″ E.

Topography: Moderately dissected mountainous terrain.

Site: On a mid-slope, approximately 12 degrees.

Parent material: Granite (coarse) (Pre-Tertiary).

External drainage: Good.

Vegetation/Land Use: Dipterocarp forest.

Altitude: ± 300 feet.

Rainfall: 135″ M.A.R. (estimated).

Rainfall Class (Mohr): I.

Lab. Nos: S 5276/79.

Date sampled: March, 1968.

		Thin layer of leaves and twigs.
A1	0–2″	Dark yellowish brown (10YR 4/4) sandy loam to sandy clay loam. Moist; friable. Weak blocky. Many rootlets. Distinct change to
A2	2–18″	Yellowish brown (10YR 5/6) coarse sandy clay loam. Moist; friable. Crumbly. Porous. Many roots and rootlets. Indistinct change to
B1	18–40″	Reddish yellow (7.5YR 6/3) sandy clay. Moist; friable. Crumbly. Slightly sticky and plastic. Porous. Some light red weathered rock pieces. Few rootlets. Indistinct change to
B2	40–60″	Reddish yellow (7.5YR 6/6) sandy clay. Moist to slightly wet; friable. Sticky and plastic on pressure. Crumbly. Porous. Very few rootlets.

Profile ref. No.: 362 — Soil Group: RED-YELLOW PODZOLIC — Soil Family ABOK — Soil Series: JAGOI — Phase:

Sample No.	Horizon	Depth in inch	pH		% O.D.		C/N Value	p.p.m. O.D.		m.e.q. % (O.D.)								'Reserves' p.p.m. O.D.			%	%	Extractable			
																							Morgan			6N HCL
			1:25 H_2O	1:5 KCL	Total N	Total C		Av. P	Total P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value	Ca	Mg	K	Group III Oxides	P Ret.	Al	Mn	Fe	Fe
S 5276		0 - 2	4.4			2.77			249									320	115	133	10.01					2.44
77		2 - 18	5.0			1.31			81									323	65	135	17.00					3.94
78		18 - 40	4.8			0.35			87									262	39	82	16.15					2.54
79		40-60	5.2			0.20			36									284	157	191	18.79					4.46

Profile ref. No. : 424 Soil Group : RED-YELLOW PODZOLIC Soil Family ABOK Soil Series : ABOK
Phase :

Sample No.	Horizon	Depth in inch	pH		% O.D.		C/N Value	p.p.m. O.D.		m.e.q. % (O.D.)								'Reserves' p.p.m. O.D.				%	Extractable			
																							Morgan			6N HCL
			1:25 H_2O	1:5 KCL	Total N	Total C		Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value					P Ret.	Al	Mn	Fe	Fe
5732	O	0 - 1	0.2	3.4	0.53			17	261	.28	.37	1.02	.03			29.0	6						536	0	36	
33	A1	1 - 2																								
34	A2	2 - 13	5.2	4.2	0.06			3	37	0	0	.06	.05			8.3	1						412	0	19	
35	B1.1	13 - 27	5.2	4.0	0.04			1	104	.41	0	.03	.02			7.9	6						283	0	10	
36	B1.2	27 - 46	5.2	4.0	0.03			0	64	.10	0	.02	0			7.6	2						308	0	1	
37	B2	46 - 52	5.1	4.0	0.02			1	171	.10	.10	.02	0			8.1	3						257	0	58	

PROFILE REF. NO. 424

Soil Group: RED-YELLOW PODZOLIC.

Family: **Abok.**

Series: *Abok.*

Phase:

Location: At mile 78, Serian-Simanggang Road. near Abok (Simanggang District).

Latitude: 1° 4′ 25″ N.

Longitude: 110° 59′ 45″ E.

Topography: Broken hilly terrain.

Site: At foot slope 25 degrees.

Parent material: Microgranodiorite.

External drainage: Good.

Vegetation/Land Use: Old rubber garden mixed with secondary forest.

Altitude: 150 feet.

Rainfall: ± 150″ annually (estimated).

Rainfall Class (Mohr): I.

Lab. Nos: 5732/37.

Date sampled: June, 1961.

O	0–1″	Dark brown (10YR 3/3) litter, mainly decomposed leaves and roots.
A1	1–2″	Very dark greyish brown (10YR 3/2) clay loam with faint grey mottles (surface gleying). Moist; friable. Crumbly. Well rooted. Distinct change to
A2	2–13″	Yellow (10YR 7/8) clay loam. Moist; friable. Crumbly. Well rooted. Diffuse boundary to
B1	13–46″	Yellow (10YR 7/8) clay loam. Moist; compact. Crumbly to subangular blocky. Distinct change to
B2	46–52″	Yellow (10YR 7/8) clay loam with reddish yellow (7.5YR 6/8) mottles. Moist. Compact. Hard iron concretions. Large roots.

REMARK: Distinct iron accumulation in B2.

PROFILE REF. NO. 140

Soil Group: RED-YELLOW PODZOLIC.

Family: (probably **Abok**).

Series: *Keladan.*

Phase:

Location: Bukit Keladan (Lower Sadong District).

Latitude: 1° 20′ N.

Longitude: 110° 52′ 50″ E.

Topography: On saddle.

Site: On a gentle slope of approximately 5 degrees.

Parent material: Uncertain. Probably silicified volcanic rocks (tuffaceous?).

External drainage: Good.

Vegetation/Land Use: Approximately nine years old secondary forest.

Altitude: ± 200 feet.

Rainfall: 145″ M.A.R. (estimated).

Rainfall Class (Mohr): I.

Lab. Nos: S 4665/70.

Date sampled: April, 1966.

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A1	0–2″	Reddish brown (5YR 4/3) clay. Moist. Weak angular block structure. Many small roots. Gradual change to
B	2–12″	Red (2.5YR 4/8) clay. Moist; firm. Angular blocky structure. Gradual change to
B/C.1	12–20″	Red (2.5YR 4/6) clay. Moist; firm. Angular block structure. Some small purple coloured weathered rock pieces. Gradual change to
B/C.2	20–30″	Red (2.5YR 4/6) clay as above, but containing more weathered rock; small quartz and white veins probably kaolinitic material.
B/C.3	30–40″	As 20-30″.
C	40–48″	As 20-30″ but with much more quartz.

Profile ref. No.: 140 | Soil Group: RED-YELLOW PODZOLIC | Soil Family ABOK | Soil Series: KELADAN | Phase:

Sample No.	Horizon	Depth in inch	pH 1:25 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q. % (O.D.) Ca	m.e.q. % (O.D.) Mg	m.e.q. % (O.D.) K	m.e.q. % (O.D.) Na	m.e.q. % (O.D.) Al	m.e.q. % (O.D.) H	m.e.q. % (O.D.) C.E.C.	m.e.q. % (O.D.) S Value	'Reserves' p.p.m. O.D. Ca	'Reserves' p.p.m. O.D. Mg	'Reserves' p.p.m. O.D. K	Group III Oxides	% P Ret	Extractable Morgan Al	Extractable Morgan Mn	Extractable Morgan Fe	Extractable 6N HCL Fe
S4665	AI	0 - 2							315									3.00	1.00	4400	12.92					4.20
66	B	2 - 12							235									2.00	1100	4000	14.40					4.90
67	B/CI	12-20							210									3.00	1000	4000	14.68					5.10
68	B/C2	20-30							215									2100	1000	4400	12.54					4.90
69	B/C3	30-40							135									2.00	1000	4200	28.96					5.65
70	C	40-48							110									1.00	4.00	45.00	16.90					6.85

Profile ref. No. : 427 | Soil Group : RED-YELLOW PODZOLIC | Soil Family ABOK | Soil Series : BAYUR
Phase :

Sample No.	Horizon	Depth in inch	pH 1:25 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	% Group III Oxides	% P Ret	Extractable Morgan Al	Mn	Fe	6N HCL Fe
S 2471	A1	0 - 6							65									100	1162	2900	8.82					
72	B1	6 - 17							28									130	1248	2400	11.36					
73	B2.1	17 - 28							16									100	1354	2900	12.96					
74	B2.2	28 - 40							9									50	1408	3200	13.86					
75	B/C	40 - 51							11									100	1503	2900	23.08					

PROFILE REF. NO. 427

Soil Group: RED-YELLOW PODZOLIC.

Family: **Abok.**

Series: *Bayur.*

Phase:

Location: Pang. Sg. Batu (Upper Sadong District).

Latitude: 1° 4′ 23″ N.

Longitude: 110° 29′ 55″ E.

Topography: Broken hilly terrain.

Site: On top of hill, approximately 50 feet above valley bottom.

Parent material: Schist.

External drainage: Good.

Vegetation/Land Use: Temuda, scattered young trees and few bamboo.

Altitude: ± 100 feet.

Rainfall: 131.58″ M.A.R. (S. Bedup).

Rainfall Class (Mohr): I.

Lab. Nos: S 2471/75.

Date sampled: April, 1963.

A1	0–6″	Brown (10YR 5/4) fine sandy loam. Moist. Crumbly. Many fine and medium roots. Gradual change to
B1	6–17″	Brownish yellow (10YR 6/6) fine sandy clay loam. Moist. Crumbly. Fine to medium roots. Few charcoal pieces. Gradual change to
B2.1	17–28″	Brownish yellow (10YR 6/6) fine sandy clay loam to fine sandy clay. Moist; firm. Crumbly to angular blocky. Few fine roots. Few quartz. Gradual smooth change to
B2.2	28–40″	Brownish yellow to reddish yellow fine sandy clay. Moist; firm. Angular blocky. Abundant fine quartz grains. Gradual smooth change to
B/C	40–51″	Reddish yellow fine sandy clay. Moist; firm. Abundant quartz grains. Fragments of light red, weathered rock.

PROFILE REF. NO. 208

Soil Group: RED-YELLOW PODZOLIC.

Family: **Abok.**

Series: *Serin.*

Phase: Shallow.

Location: 33rd mile, Serian Road (Upper Sadong District).

Latitude: 1° 30′ N.

Longitude: 110° 30′ E.

Topography: Broken hilly terrain with generally steep slopes.

Site: Nearly on top of a hill.

Parent material: Arkose.

External drainage: Good.

Vegetation/Land Use: Mainly *Imperata cylindrica*, some rubber trees

Altitude: ± 150 feet.

Rainfall: 139.13″ M.A.R. (Tarat).

Rainfall Class (Mohr): I.

Lab. Nos: MS 1876/80.

Date sampled: January, 1969.

Thin litter layer of leaves and lallang straw.

A1	0–7″	Yellowish brown clay loam. Dry; firm. Fine angular blocky structure. Well rooted (mainly grass roots, some lateral roots of rubber trees). Many wormcasts. Charcoal pieces. Porous. Distinct, slight wavy boundary to
B1	7–28″	Brownish yellow clay. Moist; very firm; slightly plastic. Strong coarse blocky when dry, weak fine angular blocky when moist. Some vertical roots. Much 'illuvial' clay of slightly darker colour along structural planes and cracks. Very gradual change to
B2	28–50″	Brownish yellow weak friable clay. Slightly moist; slightly plastic. Weakly developed fine angular blocky but compact in profile. 'Clayskins' present down to 50 inches, less 'illuvial' clay visible in racks. Few scattered light red coloured weathered rock pieces, very few roots.

Profile ref. No.: 208 Soil Group: RED-YELLOW PODZOLIC Soil Family ABOK Soil Series: SERIN Phase: YELLOW

Sample No.	Horizon	Depth in inch	pH		% O.D.			p.p.m. O.D.		m.e.q. % (O.D.)								'Reserves' p.p.m. O.D.			%	%	Extractable			
																							Morgan			6N HCL
			1:25 H_2O	1:5 KCL	Total N	Total C	C/N Value	Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value	Ca	Mg	K	Group III Oxides	P Ret	Al	Mn	Fe	Fe
MS 1876	A1	0-3	4.9		0.17				172	0.46	0.79	0.22	<0.01	3.56	0.40	8.82		107	322	527	15.58	79.83		4	45	
77	B1.1	9-14	5.1		0.04				67	0.06	0.66	0.05	0.03	1.81	0.26	2.97		211	379	413	23.98	78.24		9	<2	
78	B1.2	18-25	5.1		0.04				72	0.13	0.39	0.01	0.28	1.94	0.13	3.87		211	190	516	27.35	76.56		2	<2	
79	B2.1	30-35	5.2		0.02				67	0.13	0.39	0.02	0.05	2.20	0.13	3.87		211	291	671	27.58	71.64		2	<2	
90	B2.2	46-50	5.3		0.02				61	0.13	0.47	0.02	<0.01	1.69	0.13	3.50		529	127	830	27.80	70.31		2	<2	

Profile ref. No.: 418 Soil Group: RED-YELLOW PODZOLIC Soil Family MERIT Soil Series: BEDUP
Phase:

Sample No.	Horizon	Depth in inch	pH		% O.D.			p.p.m. O.D.		m.e.q. % (O.D.)								Derived Colloidal Mol. Ratio's Fraction				%	Extractable			
			1:25 H_2O	1:5 KCL	Total N	Total C	C/N Value	Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value	SiO_2/R_2O_3	SiO_2/Fe_2O_3	SiO_2/Al_2O_3	Fe_2O_3/Al_2O_3	P Ret	Morgan Al	Morgan Mn	Morgan Fe	6N HCL Fe
5210	A1	0-3	3.8	3.2	0.45	5.46	12	14	354	0.28	0.22	0.24	0.08	-	-	22.3	4	2.29	19.16	2.60	0.14		760	0	78	
5211	A2	12-19	4.1	3.5	0.07	0.54	8	3	240	0.10	0.22	0.14	0.09	9.65	0.27	9.0	6	2.36	22.45	2.64	0.12		591	0	33	
5212	B1	32-38	4.2	3.6	0.09	0.24	3	2	250	0	0	0.05	0.02	6.97	0.16	7.7	1	2.00	12.49	23.85	0.19		461	0	4	
5213	B2	50-52	4.9	4.0	0.04	0.16	4	2	363	0.10	0	0.08	0.04	3.02	0.11	5.3	4	-	-	-			342	0	0	
5214	IIC	±10	4.0	3.6	0.08	0.08	1	3	217	0.10	0	0.08	0.02	5.8	0.14	8.6	2	2.39	28.32	2.62	0.09		325	0	0	

PROFILE REF. NO. 418

Soil Group: RED-YELLOW PODZOLIC.

Family: Merit.

Series: *Bedup.*

Phase: Well-drained.

Location: Between S. Bedup and S. Kerait, Serian-Simanggang Road (Upper Sadong District).

Latitude: 1° 4′ 45″ N.

Longitude: 110° 38′ 30″ E.

Topography: Moderately dissected hilly terrain.

Site: Near summit of a low hill.

Parent material: Shale (Triassic).

External drainage: Good.

Vegetation/Land Use: Temudok. Mainly ferns undergrowth.

Altitude: ± 150 feet.

Rainfall: 131.58″ M.A.R. (S. Bedup).

Rainfall Class (Mohr): I.

Lab. Nos: 5210/14.

Date sampled: July, 1961.

O	1–0″	Litter, partly decomposed leaves and roots.
A1	0–3″	Yellowish brown (10YR 5/6) loam, top 1-2″ some organic staining. Moist; friable. Well rooted. Gradually merging into
A2	12–19″	Yellow (10YR 7/8) clay loam with pockets of fine, faint, red mottles. Moist; very firm. Massive. Some fine roots. Merging into
B1	32–38″	Brownish yellow (10YR 6/8) clay with prominent reddish yellow (5YR 7/8) and faint yellow mottles. Common quartz grit.
B2	50–52″	As above, but with accumulation of iron concretions, shale flakes and iron impregnated root channels.
IIC	± 10′	Strongly weathered shale and kaolinitic white clay with strong reddish mottling.

PROFILE REF. NO. 82

Soil Group: RED-YELLOW PODZOLIC.

Family: Merit.

Series: *Semongok*.

Phase: Shallow.

Location: 10½ mile Kuching-Serian Road (Kuching Rural District).

Latitude: 1° 25′ 20″ N.

Longitude: 110° 19′ 30″ E.

Topography: Broken hilly terrain with moderate slopes.

Site: On gentle slope, at the edge of gully.

Parent material: Carbonaceous shale (Cretaceous).

External drainage: Good.

Vegetation/Land Use: Ferns, *Imperata cylindrica*, some *Pueraria* and *Calapogoneum*.

Altitude: ± 100 feet.

Rainfall: 159.11″ M.A.R. (Kuching Airport).

Rainfall Class (Mohr): I.

Lab. Nos: MS 1889/94.

Date sampled: January, 1968.

A1/2	0–8″	Brown clay with few brownish-yellow mottles. Wet (after one night's rain); slightly sticky; plastic. Strong fine angular blocky structure. Well rooted—mainly weed and grass roots. Common charcoal pieces and a few red weathered shale fragments; many wormcasts and 'clayskins'. Distinct slightly wavy boundary to
B1	8–15″	Brownish yellow clay with common, fine reddish yellow and few fine grey mottles. Moist. Strong, medium angular blocky. Few roots; many 'clayskins' (darker coloured than matrix). Some small, black subrounded iron concretions. Porous. Indistinct, irregular boundary to
B2	15–26″	As B1, but with more 'clayskins'; many grey and red coloured shale fragments, increasing with depth. Moist; firm. Strong blocky structure. Few roots. In part original structure of shale still visible. Indistinct irregular boundary to
B/C	26–36″	Variegated (multicoloured) weathered shale mixed with yellowish brown clay. Platy and coarse angular blocky. Along fractured shale yellow clay present. At 30-34 inches the colour is distinctly more reddish with platy, iron coated shale fragments. Indistinct wavy boundary to
C/R	36–48″	Hard, macro-blocky (concoidal fractured) dark grey laminated shale with brownish yellow clay along fracture planes; clay is wet and sticky; shale is dry.

Profile ref. No.: 82 Soil Group: RED - YELLOW PODZOLIC Soil Family MERIT Soil Series: SEMONGOK Phase: SHALLOW

Sample No.	Horizon	Depth in inch	pH		% O.D.		C/N Value	p.p.m. O.D.		m.e.q. % (O.D.)								'Reserves' p.p.m. O.D.			%	%	Extractable			
			1:2.5 H_2O	1:5 KCL	Total N	Total C		Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value	Ca	Mg	K	Group III Oxides	P Ret.	Morgan Al	Morgan Mn	Morgan Fe	6N HCL Fe
MS 1889	A 1/2	0 - 8	5.6	0.20					611	0.27	0.66	0.06	0.27	2.38	0.21	22.55	6	1771	1526	4232	13.04	73.07		5	65	
90	B1	8 - 15	4.8	0.12					186	1.24	0.41	0.09	0.02	12.11	0.27	16.96	10	217	1638	3086	14.00	77.23		2	3	
91	B2	15 - 26	4.9	0.07					174	0.40	0.74	0.09	<0.01	17.06	0.20	20.22	6	435	1761	6822	20.45	53.30		<1	33	
92	B/C	26 - 30	4.8	0.06					173	0.14	1.09	0.11	0.02	19.34	0.20	22.57	6	217	2017	8079	20.90	48.01		<1	14	
93	C1	30 - 36	4.8	0.07					158	0.27	0.48	0.14	0.02	18.18	0.20	22.93	4	428	2313	7770	19.05	55.89		<1	5	
94	C2	36 - 48	4.9	0.08					171	0.20	0.74	0.19	<0.01	19.26	0.20	22.45	5	204	1931	3468	16.16	61.08		4	<2	

Profile ref. No.: 83 Soil Group: RED-YELLOW PODZOLIC Soil Family MERIT Soil Series: PADAWAN Phase:

Sample No.	Horizon	Depth in inch	pH		% O. D.		C/N Value	p.p.m. O.D.		m. e. q. % (O.D.)								'Reserves' p.p.m. O.D.			%	%	Extractable			
			1:25 H_2O	1:5 KCL	Total N	Total C		Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value	Ca	Mg	K	Group III Oxides	P Ret	Morgan Al	Morgan Mn	Morgan Fe	6N HCL Fe
MS 1955	A1	0 - 3	4.7		0.442				221	4.16	2.42	0.37	0.07	8.45	0.53	29.02	24	499	872	1942	9.43	61.38		18	1	
56	A2	3 - 8	4.8		0.154				151	0.40	0.06	0.15	0.03	13.36	0.20	17.56	4	<107	766	2503	13.68	60.56		6	<1	
57	B1(t)	8 - 22	4.9		0.070				144	0.08	0.25	0.11	<0.02	12.17	0.14	14.58	3	<107	1019	2394	14.24	63.80		6	<1	
58	B2(t)	22-33	4.9		0.052				145	0.11	0.22	0.13	0.03	15.19	0.14	18.03	3	107	1094	3682	19.88	64.48		6	<1	
59	C	33-48	5.0		0.053				121	0.20	0.27	0.23	0.03	22.12	0.14	24.76	3	109	1837	6646	21.68	50.14		3	<1	

PROFILE REF. NO. 83

Soil Group: RED-YELLOW PODZOLIC.

Family: Merit.

Series: *Padawan.*

Phase:

Location: 20th mile Kuching-Serian Road (Kuching Rural District).

Latitude: 1° 20′ N.

Longitude: 110° 24′ 5″ E.

Topography: Strongly dissected hilly terrain.

Site: On top of a hill.

Parent material: Almost vertical beds of Cretaceous, slightly carbonaceous shale mixed with fine conglomeratic beds (quartzitic). At site iron poor.

External drainage: Good.

Vegetation/Land Use: Young secondary growth (adjacent to pepper garden).

Altitude: ± 150 feet.

Rainfall: 143.99″ M.A.R. (Dragon School).

Rainfall Class (Mohr): I.

Lab. Nos: MS 1955/60.

Date sampled: January, 1968.

A1	0–3″	Dark greyish brown clay loam. Dry; friable but firm in place. Fine angular blocky. Well rooted. Charcoal present. Distinct wavy change to
A2	3–8″	Pale yellow clay loam. Dry; firm. Angular blocky. Moderately well rooted. Many wormcasts. Porous. Distinct gradual change to
B1	8–22″	Pale yellow clay with common, coarse grey and brownish yellow mottles. Moist; very firm. Strong blocky; massive in profile. Many 'clayskins' of dark colour and coatings along cracks. Moderately well rooted. Gradual, indistinct change to
B2	22–33″	Pale yellow clay but slightly redder than the B horizon, with common coarse light grey and fine brownish yellow mottles. Slightly moist; very firm. Coarse angular blocky structure, but massive in profile. Distinct clay coatings along structural faces. Few roots. Coarse sand grains and dull white soft quartz concentrating at lower part of horizon. Gradual, indistinct change to
C	33–48″	A matrix of pale yellow with fine, pinkish and coarse light grey mottled clay; grey colours increase with depth. Massive. Moist; slightly sticky and plastic. No roots.

REMARK: Very compact in subhorizons. Imperfectly drained.

PROFILE REF. NO. 118

Soil Group: RED-YELLOW PODZOLIC.

Family: **Merit.**

Series: *Rapak.*

Phase:

Location: South of Bukit Nin, Jalan Nangka to 17th mile (Kuching Rural District).

Latitude: 1° 24′ 28″ N.

Longitude: 110° 25′ 5″ E.

Topography: Low undulating terrain, slightly dissected.

Site: Bottom slope of a low hill.

Parent material: Shales (Jurassic?).

External drainage: Fair.

Vegetation/Land Use: Secondary forest almost pure stand of somah (*Ploiarium alterniolium*).

Altitude: ± 150 feet.

Rainfall: ± 150″ M.A.R. (estimated).

Rainfall Class (Mohr): I.

Lab. Nos: S 3427/31.

Date sampled: May, 1964.

O	0–¼″	Litter, over
A1	¼–7″	Dark brown (10YR 4/3) clay loam. Slightly moist; friable. Strong fine angular blocky. Moderately well rooted. Many charcoal pieces. Clear wavy boundary to
B1	7–15″	Reddish yellow (5YR 6/8) clay mottled very faint yellow in places. Slightly moist; firm. Strong angular blocky; massive in profile. Fine roots. Few fine quartz fragments. Distinct change to
Bst	15–25″	Light red (2.5YR 5/8) clay with few, fine yellow mottles. Moist; firm. Moderately well rooted. Abrupt over horizontally orientated iron concretions of mixed colours; concretions are platy and hard with many iron infilled root channels.
IIC	25–45″	Matrix of red, grey and yellow clay, grey becoming dominant with depth. Slightly moist; very firm. No roots.

Profile ref. No. : 118 **Soil Group** : RED-YELLOW PODZOLIC **Soil Family** MERIT **Soil Series** : RAPAK **Phase** :

Sample No.	Horizon	Depth in inch	pH		% O. D.			p.p.m. O.D.		m.e.q. % (O.D.)								'Reserves' p.p.m. O. D.			%	%	Extractable			
																							Morgan			6N HCL
			1:25 H_2O	1:5 KCL	Total N	Total C	C/N Value	Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value	Ca	Mg	K	Group III Oxides	P Ret	Al	Mn	Fe	Fe
S3427	O	0 - 1/4	4.3						205									455	640	1450	12.10					
28	A1	1/4 - 7	5.1						150									317	808	1750	15.04					
29	B1	7 - 15	4.5						222									257	927	3000	25.70					
30	B_{st}	15 - 25	5.2						199									257	1366	3850	40.38					
31	IIC	32 - 45	4.8						250									337	2459	4700	25.76					

Profile ref. No.: 392 Soil Group: RED-YELLOW PODZOLIC Soil Family MERIT Soil Series: MELUGU

Phase:

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	Group III Oxides	% P Ret.	Extractable Morgan Al	Mn	Fe	6N HCL Fe
S 4489	A1	0–3							265									4 00	500	4300	23.70					
90	A2	3–7							145									4 00	300	4600	26.16					
91	B1	7–15							125									300	4 00	3700	20.40					
92	B2	15–27							185									300	300	3600	23.00					
93	B3	27–45							90									400	200	5300	30.92					
94	C	45-54							115									600	300	77.00	34.36					

PROFILE REF. NO. 392

Soil Group: RED-YELLOW PODZOLIC.

Family: **Merit.**

Series: *Melugu.*

Phase:

Location: Melugu Land Development Scheme. 200 feet from Simanggang-Serian Road (Simanggang District).

Latitude: 1° 6′ 29″ N.

Longitude: 111° 24′ 30″ E.

Topography: Broken hilly terrain.

Site: At middle slope.

Parent material: Shale (lower Tertiary).

External drainage: Good.

Vegetation/Land Use: Newly planted rubber.

Altitude: ± 100 feet.

Rainfall: ± 140″ M.A.R. (estimated).

Rainfall Class (Mohr): I.

Lab. Nos: S 4489/94.

Date sampled: February, 1964.

A1	0–3″	Dark brown (10YR 3/3) loam. Slightly moist; friable. Fine crumbly. Abundant fine roots. Some ant holes. Few pieces of charcoal. Abrupt boundary to
A2	3–7″	Yellowish brown (10YR 5/6) clay loam. Moist; slightly firm. Subangular blocky. Some fine roots. Few ant holes. Rare pieces of charcoal. Clear boundary to
B1	7–15″	Yellowish brown (10YR 5/8) clay. Moist; firm. Subangular blocky. Few fine roots; few ant holes. Few pieces of weathered shale. Clear boundary to
B2	15–27″	Brownish yellow (10YR 6/6) clay. Moist; firm. Subangular blocky. Few fine roots; few pores. Traces of fine weathered shale. Abrupt boundary to
B3	27–45″	Brownish yellow (10YR 6/6) clay to silty clay. Moist; firm. Subangular blocky. Rare roots. Some weathered shale. Abrupt boundary to
C	45–54″	Brownish yellow (10YR 6/6) clay to silty clay, with abundant, soft and dusky red weathered shale. Firm.

PROFILE REF. NO. 405

Soil Group: RED-YELLOW PODZOLIC.

Family: **Merit.**

Series: *Begunan.*

Phase:

Location: Ulu Sg. Entebar, Undup Valley (Simanggang District).

Latitude: 0° 59′ 5″ N.

Longitude: 111° 32′ 5″ E.

Teopography: Strongly dissected hilly terrain.

Site: On a steep slope.

Parent material: Mudstone (Tertiary).

External drainage: Good.

Vegetation/Land Use: Secondary vegetation.

Altitude: ± 250 feet.

Rainfall: 160″ M.A.R. (estimated).

Rainfall Class (Mohr): I.

Lab. Nos: 2995/3002.

Date sampled: June, 1960.

A1	0–5″	Brown (7.5YR 5/2) loam. Moist; friable. Crumbly. Numerous fine roots.
B1	5–14″	Reddish brown (5YR 5/4) loam to clay loam with few faint yellow mottles. Moist; firm. Crumbly. Few wormholes; few fine roots.
B2	14–23″	Reddish brown (5YR 5/4) clay loam. Moist; firm. Few roots. Few small charcoal fragments.
B3	23–40″	Reddish yellow (5YR 5/6) clay loam to clay at 35 inches depth. Moist; slightly sticky, non-plastic. Very few roots.

Profile ref. No. : 405 — Soil Group : RED - YELLOW PODZOLIC — Soil Family MERIT — Soil Series : BEGUNAN — Phase :

Sample No.	Horizon	Depth in inch	pH		% O.D.			p.p.m. O.D.		m.e.q. % (O.D.)								'Reserves' p.p.m. O.D.				%	Extractable			
																							Morgan			6N HCL
			1:25 H_2O	1:5 KCL	Total N	Total C	C/N Value	Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value					P Ret.	Al	Mn	Fe	Fe
2994	A1	0 - 5	3.8		0.26	3.61	13	12		0.70	0.88	0.30	0.11			20.1	10									
95	B1	5 - 14	3.8		0.10	0.81	8	4		0.13	0.12	0.08	0.04			13.0	3									
96	B2	14 - 23	3.9		0.07	0.60	9	3		0.24	-	0.06	0.11			13.1	4									
97	B3	23 - 40	3.7		0.07	0.44	6	2		0.29	-	0.09	0.10			12.5	4									

Profile ref. No. : 18 **Soil Group** : GREY - WHITE PODZOLIC **Soil Family** KERAIT **Soil Series** : RUKAM **Phase** :

Sample No.	Horizon	Depth in inch	pH		% O.D.		C/N Value	p.p.m. O.D.		m.e.q. % (O.D.)								'Reserves' p.p.m. O.D.			%	%	Extractable			
			1:25 H_2O	1:5 KCL	Total N	Total C		Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value	Ca	Mg	K	Group III Oxides	P Ret	Morgan Al	Morgan Mn	Morgan Fe	6N HCL Fe
S 4619	A1	2 - 3	4.3						90									<0.01	0.04	0.09	2.62					0.20
20	A1.2	3 - 7	5.0						10									0.03	0.01	0.08	1.96					<.05
21	A2	14 - 21	5.4						10									<0.01	0.02	0.08	2.58					0.10
22	B	28 - 33	4.8						20									<0.01	0.03	0.33	8.06					0.10
23	B/C	34 - 45	5.0						30									<0.01	0.02	0.34	8.44					0.45

PROFILE REF. NO. 18

Soil Group: GREY-WHITE PODZOLIC.

Family: Kerait.

Series: *Rukam.*

Phase:

Location: Rentis 22, Lundu, tape 36 (Lundu District).

Latitude: 1° 38′ N.

Longitude: 109° 47′ E.

Topography: Gently undulating terrain.

Site: Near summit of a low hill.

Parent matrial: Probably phyllite or chert of the Serabang Formation.

External drainage: Poor.

Vegetation/Land Use: Kerangas forest of open nature. Some large trees.

Altitude: ± 120 feet.

Rainfall: 131.64″ M.A.R. (Lundu).

Rainfall Class (Mohr): I.

Lab. Nos: S 4619/23.

Date sampled: September, 1965.

	0–1″	Dark brown surface litter, small and large roots.
A1	1–3″	Dark grey (10YR 4/1) silt loam. Moist; friable. Weak crumbly, soft. Well rooted. Distinct change to
A1/2	3–7″	Grey (10YR 5/1) loam, mottled dark grey (material leached down from horizon A1). Moist; friable, soft. Structureless. Moderately well rooted. Clear boundary over
A2	7–28″	Grey (2.5Y 6/0 to N/6) fine sandy silt with few but concentrated in places, olive coloured mottles. Slightly moist; hard and very compact in profile but friable when broken up. Structureless. Very few roots. Humus material from over-lying horizons has leached into this horizon through root channels to about 9 inches depth. Abrupt change to
B	28–34″	Light grey (N7) silty clay with weak olive mottling in places. Very compact. Small quartz pieces. Distinct change to
B/C	34–45″ +	Light grey (N7) clay with large (½-2 inches in size) pieces of quartz possibly derived from broken up quartz vein. Some yellowish brown mottles in places. Very compact, hard and almost impossible to dig. Water in soil pit still present 3 days after rain.

PROFILE REF. NO. 11

Soil Group: GREY-WHITE PODZOLIC.

Family: **Kerait.**

Series: *Serayan.*

Phase:

Location: Lundu-Sematan road, near S. Serayan (Lundu District).

Latitude: 1° 44′ 35″ N.

Longitude: 109° 47′ 5″ E.

Topography: Terrace edge.

Site: On a slope of approximately 10 degrees.

Parent material: Probably chert (Serabang Formation).

External drainage: Good.

Vegetation/Land Use: Jeramei, mainly ferns and cyperacea.

Altitude: ± 50 feet.

Rainfall: ± 130″ M.A.R. (estimated).

Rainfall Class (Mohr): I.

Lab. Nos: S 7464/69.

Date sampled: October, 1968.

Very thin layer decomposed leaves and branches on surface.

A1	0–4½″	Greyish brown (10YR 5/2) sandy loam. Moist; friable when broken up. Crumbly. Well rooted. Many earthworms. Porous. Distinct regular change to
A2	4½–13″	Very pale brown (10YR 7/3) coarse sandy clay loam. Moist; firm. Massive, compact. Very few fine roots. Clear but wavy change to
B1	13–22″	Pink (7.5YR 7/4) coarse sandy clay with few, distinct, very pale brown mottles. Moist; firm. Massive and compact. Few fine roots. Diffuse wavy change to
B2	22–35″	Pink (5 YR 8/4) coarse sandy clay. Moist; firm. Few 'clayskins' (clay coatings along old root channels and cracks). Moist; firm. Compact and massive. Diffuse wavy change to
B/C	35–51″	Pink (5YR 8/4) coarse sandy clay with common distinct; very pale brown (10YR 7/3) mottles. Moist; firm. Compact and massive. Strong 'clayskins' developed along cracks. Gradual wavy change to
C	51–63″	Pink, coarse sandy clay with a large pocket of very pale brown colour. Moist; very firm. Compact. Increasingly more quartz rich with depth. Few 'clayskins' along cracks.

NOTE: As seen in road cutting about 20 feet away: white puppet-form concretions occur at approximately 10 feet depth.

Profile ref. No.: II **Soil Group:** GREY - WHITE PODZOLIC **Soil Family** KERAIT **Soil Series:** SERAYAN **Phase:**

Sample No.	Horizon	Depth in inch	pH		% O.D.			p.p.m. O.D.		m.e.q. % (O.D.)								'Reserves' p.p.m. O.D.			%	%	Extractable			
			1:25 H_2O	1:5 KCL	Total N	Total C	C/N Value	Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value				Group III Oxides	P Ret	Morgan Al	Morgan Mn	Morgan Fe	6N HCL Fe
S 7464	A1	0 - 4½	4.8	3.9		1.40															6.98					0.42
65	A2	4½ - 13	5.2	4.1		0.40															11.90					0.58
66	B1	13 - 22	5.1	4.0		0.22															14.48					0.75
67	B2	22 - 35	5.1	4.0		0.16															16.68					0.58
68	B/C	35 - 51	5.4	4.0		0.17															16.23					0.49
69	C	51 - 63	5.4	4.1		0.14															12.17					0.91

Profile ref. No.: 332 Soil Group: GREY-WHITE PODZOLIC Soil Family SARATOK ? Soil Series: LINGGA Phase:

Sample No.	Horizon	Depth in inch	pH		% O.D.			p.p.m. O.D.		m.e.q. % (O.D.)								'Reserves' p.p.m. O.D.			%	%	Extractable			
																							Morgan			6N HCL
			1:25 H_2O	1:5 KCL	Total N	Total C	C/N Value	Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value	Ca	Mg	K	Group III Oxides	P Ret	Al	Mn	Fe	Fe
S 5286	A1	0 - 6				4.00		222	449									477	401	5309	11.81					0.75
87	A2	6 - 11				1.14		133	339									216	272	4293	13.93					0.65
88	B1	11 - 18				0.43		95	110									419	289	4873	15.99					0.72
89	B2	18 - 33				0.24		43	119									215	284	5160	17.97					0.91
90	B/C	33 - 60				0.13		83	124									442	366	4975	16.08					0.73

PROFILE REF. NO. 332

Soil Group: GREY-WHITE PODZOLIC.

Family: **Saratok.**

Series: *Lingga.*

Phase: Pale brown coloured.

Location: Near Semulong Ilir, Bukit Lesong (Simanggang District).

Latitude: 1° 16′ 2″ N.

Longitude: 111° 10′ 45″ E.

Topography: Colluvial footslope.

Site: On a slope of 15-20 degrees.

Parent material: Microgranite.

External drainage: Good.

Vegetation/Land Use: Rubber garden.

Altitude: ± 150 feet.

Rainfall: 125.64″ M.A.R. (Lingga).

Rainfall Class (Mohr): I.

Lab. Nos: S 5286/90.

Date sampled: March, 1968.

A1	**0–6″**	Greyish brown (10YR 4/2) silt loam. Slightly moist; friable. Fine subangular blocky, breaking into coarse crumbs on pressure. Well rooted. Distinct regular boundary to
A2	**6–11″**	Greyish brown (10YR 5/2) silty clay loam with faint light grey mottling. Moist; slightly firm. Angular blocky. Weak 'clayskins'. Well rooted. Distinct regular change to
B1	**11–18″**	Very pale brown (10YR 7/3) silty clay with white (10YR 8/2) and few fine brownish yellow mottles. Moist; friable to firm. Angular blocky, breaking into small angular blocky peds. Few large roots. Porous. 'Clayskins' present. Gradual change to
B2	**18–33″**	Very pale brown (10YR 7/4) silty to fine sandy clay with few, distinct, medium white mottles. Moist; firm. Compact, breaking into angular blocky peds. 'Clayskins' distinctly present. Few roots. Porous. Distinct regular change to
B/C	**33–60″**	Very pale brown (10YR 8/4) fine sandy to silty clay, firm, breaking into fine angular blocky peds. Slightly moist, plastic, smeary. 'Clayskins' present. About 50% weathered boulders of micrograpite of fine sandy texture, porous, very few roots.

PROFILE REF. NO. 110

Soil Group: GREY-WHITE PODZOLIC.

Family: **Lubai.**

Series: *Merang.*

Phase: Bisequent.

Location: Path Batu Gong to Batang Samarahan (Kuching Rural District).

Latitude: 1° 19′ N.

Longitude: 110° 27′ E.

Topography: Low undulating, slightly dissected terrain.

Site: Flat.

Parent material: Chert or old alluvium.

External drainage: Poor.

Vegetation/Land Use: Poor secondary growth.

Altitude: ± 50 feet.

Rainfall: 143.99″ M.A.R. (Dragon School).

Rainfall Class (Mohr): I.

Lab. Nos: S 4007/12.

Date sampled: May, 1964.

A1	0–4″	Dark greyish brown (10YR 4/2) sandy loam with few fine quartz gravel. Slightly moist; friable. Many fine roots. Gradual change to
A2	4–11″	Light yellowish-brown (10YR 6/4) loamy sandy, with distinct medium grey mottles. Moist; friable. Structureless. Few roots. Gradual change to
B	11–17″	Light yellowish brown (10YR 6/4) fine sandy loam to loamy sand with abundant fine, distinct, yellow and grey mottles. Moist; friable. Structureless. Indistinct boundary to
IIC1	17–33″	Pink (5YR 8/4) silty clay with abundant medium, distinct brown mottles. Much quartz gravel. Moist; firm. Indistinct boundary to
IIC2	33–43″	Light grey (7.5YR 8/N) fine sandy clay loam with abundant distinct, brown, grey and greenish grey mottles. Moist; firm. Few fine quartz gravel. Irregular but clear boundary to
IICg	43–50″	Light grey (7.5 YR 8/N) clay with abundant large, distinct, yellow, brown and grey mottles. Wet, slightly sticky. Few root channels with iron coating. Watertable at 46″.

REMARK: Affinities with *Serayan series* in **Kerait Family**.

Profile ref. No.: 110

Soil Group: INTERGRADE GREY-WHITE PODZOLIC : GLEY SOILS.

Soil Family LUBAI

Soil Series: MERANG

Phase: BISEQUENT

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q.% (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	% Group III Oxides	% P Ret.	Extractable Morgan Al	Mn	Fe	6N HCL Fe
S 4007	A1	0-4							63									130	207	950	2.86					
08	A2	4-11							40									136	178	950	4.16					
09	B	11-17							23									108	454	1150	3.32					
10	IIC1	17-33							23									238	2061	1900	11.92					
11	IIC2	33-43							48									268	4012	3200	18.46					
12	IICg	43-50							83									2058	1016	4250	22.22					

Profile ref. No.: 5 Soil Group : PODZOL Soil Family MIRI Soil Series: · Phase : BISEQUENT

Sample No.	Horizon	Depth in inch	pH		% O.D.		C/N Value	p.p.m. O.D.		m.e.q. % (O.D.)								Total % O.D.				%	Extractable			
																							Morgan			6N HCL
			1:25 H_2O	1:5 KCL	Total N	Total C		Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value	SiO_2	Fe_2O_3	Al_2O_3		P Ret.	Al	Mn	Fe	Fe
S 7445	O	0 - 3	4.0			23.79												72.92	0.16	0.57				15	<1	
46	AI	3 - 6	4.2			2.31												94.50	0.25	0.40				3	<1	
47	A I/2	6 - 11	5.0			0.16												98.91	0.15	0.23				2	<1	
48	A2	11 - 13	4.3			3.19												96.92	0.21	1.90				3	<1	
49	Bh	13-16	4.7			4.64												77.04	0.28	9.00				2	<1	
50	II Bh(c)	16-19	4.8			1.64												82.29	0.36	9.93				2	<1	
51	II B2	19-30	5.0			0.67												83.02	0.36	10.71				<1	<1	
52	II B/C	30-46	5.2			0.58												79.00	0.56	14.10				<1	<1	
53	II C2	60-80	5.1			0.15												77.15	0.46	17.44				<1	<1	

PROFILE REF. NO. 5

Soil Group: PODZOL.

Family: **Miri.**

Series: Not differentiated.

Phase:

Location: Near Kpg. Pueh (Lundu District).

Latitude: 1° 49′ 35″ N.

Longitude: 109° 42′ 35″ E.

Topography: High terrace, gently undulating.

Site: Almost on highest point of a terrace, sloping gently (5-10 degrees) towards lagoon. Broken slope.

Parent material: Bisequent. Top A1-A2 terrace alluvium. Subsoil probably residual. P.M. uncertain, probably metamorphosed Jurassic sedimentary rocks.

External drainage: Ponded.

Vegetation/Land Use: Kerangas forest. Rich in Kapur (*Dryobalanops spp.*).

Altitude: ± 50 feet.

Rainfall: 130″ M.A.R. (estimated).

Rainfall Class (Mohr): I.

Lab. Nos: S 7445/53.

Date sampled: October, 1968.

O	0–3″	Dark brown peat-like rotten leaves and roots mixed with some sand grains. Moist. Abrupt over
A1	3–6″	Dark grey (10YR 4/1) coarse to medium sand. Moist; loose. Many large lateral roots. Below 6 inches no roots. Gradual change to
A1/2	6–11″	As 3-6″, but no roots, wet; loose.
A2	11–13″	Light brownish grey (10YR 6/2) medium sand. Wet; loose. Perched watertable; water seeping out of large old root channels. No roots. Abrupt change to
Bh	13–16″	Very dark brown (10YR 2/2) medium sand, weakly cemented by humus. Wet. Clear regular boundary to
IIBh(c)	16–19″	Strong brown (7.5YR 5/8) coarse sandy clay, weakly cemented by humus. Very dry. No roots. Gradual change to
IIB2	19–30″	Pale brown (10YR 6/3) coarse sandy clay loam with common, very dark brown humus staining, mainly along old root channels. Very dry; water seeps into pit through old root channels. One large pocket of humus stained sand with many roots (illuviated material, weakly cemented, possibly a large old root channel). Gradual change to
IIB/C	30–46″	As 19–30″, but lighter in colour. Gradual change to
IIC1	46–60″ (augering)	White coarse sandy clay with some organic coatings. Moist; very sticky and plastic.
IIC2	60–80″ (augering)	White coarse sandy clay. Moist; sticky, plastic. Micaceous.

PROFILE REF. NO. IN REPORT 25/2

Soil Group: PODZOL.

Family: Jerijeh.

Series: *Stoh.*

Phase: —

Location: At coast, Kpg. Trombol (Kuching Rural District).

Latitude: 1° 33′ 20″ N.

Longitude: 110° 10′ 30″ E.

Topography: Subrecent beach ridge.

Site: Almost on top of a ridge.

Parent material: Subrecent beach deposits.

Vegetation/Land Use: Dying coconuts, lallang and shrubs.

Altitude: 10 feet.

Rainfall: 159.10″ M.A.R. (estimated).

Rainfall Class (Mohr): I.

Lab. Nos: S 4495/99.

Date sampled: April, 1965.

A1.1	0–2″	Light grey (5Y 7/1) medium sand with bits of organic litter. Dry; loose. No roots. Irregular boundary to
A1.2	2–9″	Dark greyish brown (10YR 4/2) medium sand. Slightly moist; loose. Weak crumbly. Well rooted. Irregular boundary to
A2	9–29″	Very pale yellow (10YR 8/3) medium sand. Slightly moist; loose. Very few roots. Irregular boundary sloping down steeply to one side of the pit.
Bh.ir	29–38″	Yellowish brown (10YR 5/8) medium sand, with firm to hard dark brown concretions. Moist; loose. Irregular boundary to
B2	38–48″	Brownish yellow (10YR 6/8) medium sand with strong brown mottles and streaks. Moist; loose.
B2	38″	Watertable.

Profile ref. No. : In report 25/2 Soil Group : PODZOL Soil Family JERIJEH Soil Series : STOH

Phase :

Sample No.	Horizon	Depth in inch	pH 1:25 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	% Group III Oxides	% P Ret	Extractable Morgan Al	Mn	Fe	6N HCL Fe
S 4495	Al.1	0-2							45									200	<60	<500	0.34					
S 4496	Al.2	2-9							35									100	60	<500	1.34					
S 4497	A2	9-29							15									400	<60	<500	0.08					
S 4498	$B_{h.ir}$	29-38							65									100	100	<500	1.60					
S 4499	B2	38-48							70									400	60	<500	0.66					

Profile ref. No.: 105 | Soil Group: GLEY SOILS | Soil Family TATAU | Soil Series: MUNDAI | Phase:

Sample No.	Horizon	Depth in inch	pH		% O.D.			p.p.m. O.D.		m.e.q. % (O.D.)								'Reserve' p.p.m. O.D.			%	%	Extractable			
																							Morgan			6N HCL
			1:25 H_2O	1:5 KCL	Total N	Total C	C/N Value	Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value	Ca	Mg	K	Group III Oxides	P Ret	Al	Mn	Fe	Fe
S 2141	A1	0-3	6.4						950									35,300	815	900	5.6					
S 2142	A2	5-8	6.0						875									10,240	1329	800	13.7					
S 2143	Bg	12-18	6.5						650									3,900	635	750	11.4					

PROFILE REF. NO. 105

Soil Group: GLEY SOILS.

Family: Tatau.

Series: *Mundai*.

Phase: —

Location: At foot Gunong Payang, near Chupin (Upper Sadong District).

Latitude: 1° 15′ 45″ N.

Longitude: 110° 26′ E.

Topography: Flat to gently undulating riverine plain.

Site: Somewhat elevated.

Parent material: Uncertain but influenced by outcropping limestone.

External drainage: Moderately good.

Vegetation/Land Use: Secondary forest.

Altitude: ± 50 feet.

Rainfall: 161.76″ M.A.R. (Pang. Bentang).

Rainfall Class (Mohr): I.

Lab. Nos: S 2141/43.

Date sampled: March, 1963.

O	2½–0″	Raw humus and rootmat of fine to medium size roots.
A1	0–5″	Dark greyish brown (10YR 4/2) sandy loam with grey mottling. Moist; loose. Single grain structure. Abundant fine and medium size roots; few taproots at 14 inches, charcoal present. Abrupt smooth change to
A2	5–12″	Grey (10YR 5/1) sandy clay loam with distinct, light grey mottles. Moist to wet; firm. Massive, much illuvial humus from topsoil; charcoal. Gradual but irregular change to
Bg	12–36″	Light grey to white (10YR 7/1-8/1) sandy clay with yellow-brown (rusty) coatings along root channels. Wet; sticky, non-plastic. Massive. Watertable at 34″.

PROFILE REF. NO. 170

Soil Group: GLEY SOILS.

Family: **Tatau.**

Series: *Nyabu.*

Phase: Bisequent.

Location: Pichin area, Tebakang-Pichin (Upper Sadong District).

Latitude: 1° 5′ 50″ N.

Longitude: 100° 29′ 40″ E.

Topography: Small interior valley swamp.

Site: On somewhat higher part in middle of a swamp.

Parent material: Recent alluvium. Mainly derived from sandstone and shale of Triassic age. Influence from basalt possible in topsoil.

External drainage: Ponded.

Vegetation/Land Use: Padi stubble.

Altitude: ± 20 feet.

Rainfall: 132.60″ M.A.R. (Tebakang).

Rainfall Class (Mohr): I.

Lab. Nos: 5325/29.

Date sampled: July, 1961.

A1	0–1½″	Olive brown (2.5Y 4/4) clay loam with dark grey (2.5Y 4/0) mottles. Moist; friable. Crumbly. Abrupt over
B	1½–8″	Brownish yellow (10YR 6/8) clay loam with common light olive grey (5Y 6/2) mottles. Accumulation of very small (sand size) iron concretions. Abrupt over
IICg1	8–15″	Light olive grey (5Y 6/2) loamy sand to sandy loam with brownish yellow (10YR 6/8) mottles. Some decomposed large wood pieces embedded in soil giving rise to organic matter staining. Wet. Abrupt wavy boundary over
IICg2	15–32″	Brownish yellow (10YR 6/8) compact loam to sandy loam, with some stronger yellow mottles and common grey mottles along root channels. Few roots.
IICg3	32″+	Brownish yellow (10YR 6/8) sandy loam with light olive grey, (5Y 6/2) and reddish yellow (7.5YR 6/2) mottles along root channels.

Clayey top layer caused by sedimentation through backflooding.

Profile ref. No.: 170 Soil Group: GLEY SOIL Soil Family TATAU Soil Series: NYABU
Phase: BISEQUENT

Sample No.	Horizon	Depth in inch	pH		% O.D.			p.p.m. O.D.		m.e.q. % (O.D.)								'Reserves' p.p.m. O.D.				%	Extractable			
																							Morgan			6N HCL
			1:25 H_2O	1:5 KCL	Total N	Total C	C/N Value	Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value					P Ret	Al	Mn	Fe	Fe
5325	A1	0–1½	5.4	3.8	0.35	2.57	7	13	741	7.08	1.66	0.06	0.07	5.04	0.13	31.9	28						302	17	119	
26	B	1½–8	5.2	3.6	0.12	1.12	9	4	234	2.18	0.21	0.12	0.02	4.55	0.22	13.2	19						296	0	27	
27	IICg1	8–15	4.7	3.7	0.04	0.28	7	3	53	0.51	0.20	0.07	0.02	1.78	0.19	4.3	19						175	10	10	
28	IICg2	15–32	5.2	3.7	0.03	0.22	7	2	48	0.30	0.20	0.05	0.02	3.54	0.15	6.4	9						191	Tr	2	
29	IICg3	32+	4.8	3.5	0.03	0.20	7	2	54	0.40	0.10	0.05	0	3.41	0.19	5.9	9						189	0	4	

Profile ref. No. : 327 | Soil Group : GLEY SOILS | Soil Family SEMADOH | Soil Series : EMBANG

Phase :

Sample No.	Horizon	Depth in inch	pH 1:25 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	Group III Oxides	% P Ret.	Extractable Morgan Al	Mn	Fe	6N HCL Fe
S5288	A1	0 - 5	4.2						218									522	75	10 34	0.70					
S5289	A2	5 - 14	4.3						92									553	197	1167	5.62					
S5290	Bg1	14-30	4.4						118									2201	780	5112	11.81					
S5291	Bg2	30-48	4.8						117									1032	396	4446	4.79					
S5292	Bg3	50-53	4.4						97									864	272	5095	4.87					

PROFILE REF. NO. 327

Soil Group: GLEY SOILS.

Family: **Semadoh.**

Series: *Embang.*

Phase: —

Location: Near Kpg. Mongkos, Upper Kedup area (Upper Sadong District).

Latitude: 0° 53′ 28″ N.

Longitude: 110° 36′ 20″ E.

Topography: Gently undulating terrain.

Site: Flat.

Parent material: Probably old alluvium.

External drainage: Slow.

Vegetation/Land Use: Secondary growth, ferns and Cyperacea.

Altitude: ± 200 feet.

Rainfall: 131.58″ M.A.R. (Sungei Kedup).

Rainfall Class (Mohr): I.

Lab. Nos: S 5188/92.

Date sampled: August, 1967.

A1	0–5″	Light grey to grey (10YR 6/1) silt loam. Moist; friable. Well rooted. Abrupt over
A2	5–14″	Light grey (10YR 7/2) sandy clay loam with medium, distinct strong brownish-yellow (10YR 6/6) coatings along root channels. Moist; slightly plastic and sticky. Abrupt over
Bg.1	14–30″	White (2.5Y 8/0) clay with common distinct brownish yellow (10YR 6/6) mottles. Pockets of sandy material. Moist; plastic and sticky.
Bg.2	30–48″	Light bluish grey (5B 7/1) silty clay with some brownish yellow (10YR 6/6) mottles. Moist; slightly sticky and plastic. Compact.

PROFILE REF. NO. 351

Soil Group: GLEY SOILS.

Family: **Semadoh.**

Series: Not differentiated.

Phase: —

Location: Near Rh. Punggu Tapang, Serian-Simanggang Road (Simanggang District).

Latitude: 1° 6′ 20″ N.

Longitude: 111° 14′ 40″ E.

Topography: Gently rolling terrain interspersed with small valleys.

Site: Slope of a low, gently sloping hill.

Parent material: Probably mudstone (Kantu beds).

External drainage: Moderately good.

Vegetation/Land Use: Very poor secondary growth: much ferns and somah (*Ploiarium alterniolium*).

Altitude: ± 50 feet.

Rainfall: 159.90″ M.A.R. (Simanggang).

Rainfall Class (Mohr): I.

Lab. Nos: S 5812/16.

Date sampled: October, 1961.

O	0–½″	Thin layer of roots and partly decomposed leaf litter.
A1	½–3″	Dark greyish brown (10YR 4/2) clay loam. Dry; friable. Crumbly. Well rooted. Gradual change to
A2	4–15″	Yellowish brown (10YR 6/8) clay, with distinct, common reddish-yellow and faint pale yellow (2.5Y 8/4) mottles. Reddish-yellow mottling increases in intensity with depth. Moist; slightly plastic. Massive; compact. Gradual change to
B1	15–25″	Yellowish brown (10YR 6/8) clay. Intensively mottled pale yellow (2.5Y 8/4) and white (5Y 8/1). Few red (2.5Y 5/8) mottles at 24″. Moist; firm. Compact. No roots. Merging into
Bg.1	25–42″	White (5Y 8/1) clay with prominent brownish yellow (10YR 6/8) and pale yellow (2.5Y 8/4) mottles; becoming reddish at lower part of horizon. Moist; plastic and sticky. No roots. Merging into
Bg.2	42–52″	White (5Y 8/1) clay with yellowish brown (10YR 6/8) mottles. Moist; sticky and plastic. Massive. Red mottles not present

REMARK: Distinct redox horizon at 25-42″.

Profile ref. No. : 351 **Soil Group : GLEY SOILS** **Soil Family SEMADOH** **Soil Series:** **Phase (Intergrade to Stom series)**

Sample No.	Horizon	Depth in inch	pH		% O.D.		C/N Value	p.p.m. O.D.		m. e. q. % (O.D.)								'Reserves' p.p.m. O.D.				%	Extractable			
			1:25 H_2O	1:5 KCL	Total N	Total C		Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value					P Ret	Morgan Al	Morgan Mn	Morgan Fe	6N HCL Fe
5812	A1	1/2 – 3	4. 2	3.5	0.26	6.77	26			0.16	0. 58	0. 24	0			26. 4										
5813	A2	4 – 15	4. 4	3.7						0	0	0.06	0			11 . 8										
5814	B1	15 – 25	4. 5	3.6						t	0. 16	0. 14	0. 07			17. 1										
5815	Bg.1	25–42	4. 5	3.5						t	t	0. 21	tr			21. 9										
5816	Bg2	42–52	4. 5	3.5						0	0. 81	0.28	0			22.8										

Soil Series: SAMARAHAN
Phase:

Profile ref. No.: REPORT 44/1 **Soil Group**: GLEY SOILS **Soil Family** BIJAT

Sample No.	Horizon	Depth in inch	pH		% O.D.		C/N Value	p.p.m. O.D.		m.e.q.% (O.D.)								'Reserves p.p.m. O.D.				%	Extractable			
			1:25 H_2O	1:5 KCL	Total N	Total C		Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value					P Ret.	Morgan Al	Morgan Mn	Morgan Fe	6N HCL Fe
S2068	A1	0 – 2	N.d						545									1170	3025	7500	14.0					
S2069	Bg1	2 – 18	N.d						295									240	2995	5700	17.3					
S2070	Bg2	18 – 36	N.d						335									730	3360	3000	17.6					

PROFILE REF. NO. REPORT 44/1

Soil Group: GLEY SOILS.

Family: Bijat.

Series: *Samarahan.*

Phase:

Location: Paya Nyabu, Pichin area (Upper Sadong District).

Latitude: 1° 5′ N.

Longitude: 110° 29′ 35″ E.

Topography: Flat interior valley.

Site: In middle of a valley.

Parent material: Recent alluvium/colluvium from shales (Triassic).

External drainage: Ponded.

Vegetation/Land Use: Wet padi.

Altitude: ± 50 feet.

Rainfall: 132.60″ M.A.R. (Tebakang).

Rainfall Class (Mohr): I.

Lab. Nos: S 2068/2070.

Date sampled: April, 1963.

A1	0–2″	Dark grey (10YR 4/1) massive, silty clay with much raw organic matter. Moist to wet; slightly sticky and plastic. very well rooted. Red coloured iron coatings alon old rice roots. Clear over
Bg.1	2–18″	Light grey (5Y 7/1) silty clay. Slightly wet; plastic and sticky. Bright orange coloured iron coatings along root channels. Many old and recent padi roots.
Bg.2	18–36″	Greyish green (5Y 6/1) silty clay, in places reddish yellow (7.5YR 6/6) coatings along root channels down to 25 inches depth. Wet; sticky and plastic. Massive. Many padi roots; some large old roots. Watertable at 37 inches.

PROFILE REF. NO. 449

Soil Group: GLEY SOILS.

Family: **Bijat.**

Series: *Kakai.*

Phase: Groundwater—lateritic.

Location: Near Kpg. Ta-i (Upper Sadong District).

Latitude: 1° 12′ 20″ N.

Longitude: 110° 26′ 40″ E.

Topography: Flat, interior valley.

Site: Flat.

Parent material: Recent alluvium derived from basic igneous rocks.

External drainage: Flooded during wet season. Partly ponded and imperfectly drained in dry season.

Vegetation/Land Use: Wet padi.

Altitude: ± 50 feet.

Rainfall: 161.76″ M.A.R. (Pang. Bentang).

Rainfall Class (Mohr): I.

Lab. Nos: S 1925/28.

Date sampled: March, 1963.

A1	0–5″	Dark yellowish brown (10YR 4/4) clay. Moist; weakly friable to slightly plastic. Weak crumbly. Many roots with red coatings. Gradual change to
A2	5–13″	Dark yellowish brown (10YR 4/4) silty clay, with faint dark grey mottles. Moist; firm; slightly plastic. Weak, fine angular blocky. Many roots. Gradual change to
B1	13–19″	Dark yellowish brown (10YR 4/4) silty clay with light grey (7.5YR 7/0) and yellowish brown (10YR 5/6) mottles. Much like 5–13″ but with soft, brown concretions of iron oxide. Manganese present at 19″.
Bg	19–30″	Dark grey (7.5YR 4/0) silty clay with prominent yellowish brown mottling. Water pours in through channels at 30″. Channels are coated grey.

Profile ref. No.: 449 Soil Group: GLEY SOILS Soil Family BIJAT Soil Series: KAKAI Phase:

Sample No.	Horizon	Depth in inch	pH		% O.D.			p.p.m. O.D.		m.e.q. % (O.D.)								'Reserves' p.p.m. O.D.			%	%	Extractable			
																							Morgan			6N HCL
			1:25 H_2O	1:5 KCL	Total N	Total C	C/N Value	Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value					P Ret.	Al	Mn	Fe	Fe
S 1925	A1	0 - 5						825										3630	3923	3850	25.4					
S 1926	A2	5 - 13						580										2700	3486	4500	25.4					
S 1927	B1	13 - 19						390										2490	3528	3500	28.5					
S 1928	Bg	19 - 30						197										1280	1413	1600	18.4					

Profile ref. No.: 186 Soil Group: GLEY SOIL Soil Family BIJAT Soil Series: PAYA MEGOK

Phase:

Sample No.	Horizon	Depth in inch	pH		% O.D.			p.p.m. O.D.		m.e.q. % (O.D.)								Derived mol. ratio's Colloidal Fraction				%	Extractable			
																							Morgan			6N HCL
			1:25 H_2O	1:5 KCL	Total N	Total C	C/N Value	Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value	SiO_2/R_2O_3	SiO_2/Fe_2O_3	SiO_2/Al_2O_3	Fe_2O_3/Al_2O_3	P Ret	Al	Mn	Fe	Fe
5334	A1	0 - 2	5. 1	3. 9	0. 51	2. 91	6	10	930	8.80	0.76	0.65	0.09	1. 57	0. 49	22. 3	46	2.16	9.97	2.76	0.28		231	33	174	
35	A2	7 - 10	5. 2	3. 8	0. 22	1. 77	8	7	354	7.76	0.73	0.15	0.05	4. 15	0. 26	14. 5	60	2.19	14.00	2.45	0.18		226	8	80	
36	B1(g)	12 - 15	5.0	3. 8	0.09	1. 01	11	7	255	6.90	0.84	0.11	0.04	1. 60	0. 19	10. 9	72	2.18	10.59	2.74	0.26		131	10	56	
37	B2(g)	23-26	5. 7	4. 9	0.10	1. 48	15	3	127	7.09	0.92	0.12	0.04	4.54	0.40	13. 9	59	2.24	18.60	2.55	0.14		185	8	246	
38	IIC(g)	26-32	5.3	4.2	0.15	7.36	49	3	161	10.76	0.65	0. 13	0.05	4.44	0.56	21.7	53	2.43	34.96	2.62	0.07		291	11	307	

PROFILE REF. NO. 186

Soil Group: GLEY SOILS.

Family: **Bijat.**

Series: *Paya Megok.*

Phase:

Location: Paya Megok (Upper Sadong District).

Latitude: 1° 18′ 5″ N.

Longitude: 110° 58′ 30″ E.

Topography: Flat floodplain.

Site: Level.

Parent material: Recent alluvium. Material mainly derived from basalt, limestone and shales of Cretaceous age.

External drainage: Poor.

Vegetation/Land Use: Lallang (*Imperata cylindrica*), and grass.

Altitude: ± 20 feet.

Rainfall: 161.76″ M.A.R. (Pang. Bentang).

Rainfall Class (Mohr): I.

Lab. No. 5334/38.

Date sampled: July, 1961.

A1	0–2″	**Dark greyish brown (10YR 4/2) silty clay with grey and brownish yellow (10YR 6/8) coatings along roots. Merging into**
A2	7–10″	**Grey (2.5Y 6/N) silty clay with increasing brownish yellow (10YR 6/8) mottles with iron oxide coatings along root channels. Wet; plastic and sticky. Many old hair roots.**
B1(g)	12–15″	**Grey (50%) and yellow (50%) clay (horizon of iron concentration). Wet; sticky.**
B2(g)	23–26″	**Grey (5Y 5/1) clay with olive (5Y 5/6) mottles. Olive yellow coatings along root channels. Sticky.**
IIC(g)	26–32″	**Grey (5Y 5/1) clay with much decomposed wood and other vegetative material. Faint smell of H_2S.**
		Watertable at 30 inches.

PROFILE REF. NO. 299

Soil Group: GLEY SOILS.

Family: **Bijat.**

Series: *Punda.*

Phase:

Location: Near Sungei Binong, Padang Prupok (Lower Sadong District).

Latitude: 1° 9′ 50″ N.

Longitude: 110° 52′ 40″ E.

Topography: Flat floodplain.

Site: Near small stream.

Parent material: Recent alluvium, sublayers marine.

External drainage: Submerged during wet season.

Vegetation/Land Use: Grasses.

Altitude: ± 20 feet above sea level.

Rainfall: 153.36″ M.A.R. (Sungei Pinang).

Rainfall Class (Mohr): I.

Lab. Nos. S 1399/1402.

Date sampled: August, 1962.

A1	0–1″	Black (5Y 2/2) clay. Moist; friable. Crumbly. Much organic matter. Overlying
B1.1	1–6″	Very dark grey (10YR 3/1) clay, mottled greenish-grey along roots, extending in places to surface. Moist; sticky and plastic. Massive. Charcoal present. Gradual change to
B1.2	6–16″	As 1-6″ but with yellowish brown mottles.
Bg	16–27″	Grey (5Y 5/1) clay. Wet; sticky and plastic. Massive. Much vegetative material.
Cg	27–45″	Dark grey (N4) clay. Wet; sticky and plastic. Massive. Much vegetative material—soil turns black or very dark grey on exposure (from 5Y 5/1 to N4). Watertable at 48 inches.

Profile ref. No.: 299 Soil Group: GLEY SOILS Soil Family BIJAT Soil Series: PUNDA

Phase:

Sample No.	Horizon	Depth in inch	pH		% O.D.			p.p.m. O.D.		m.e.q. % (O.D.)								Reserves p.p.m. O.D.				%	Extractable			
																							Morgan			6N HCL
			1:25 H_2O	1:5 KCL	Total N	Total C	C/N Value	Av. P	Total P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value					P Ret.	Al	Mn	Fe	Fe
S1399	A1	0 - 1	4.3		0.67	7.25	11	28	681	4.02	2.60	0.57	0.28			45.9	16									
S1400	B1	1 - 6	4.7					7	194																	
S1401	Bg	16 - 27	4.7					3	148	1.78	4.03	0.25	0.42			15.9	41									
S1402	Cg	27 - 45	2.4					4	158	2.05	13.64	0.02	0.27			28.8	55									

Profile ref. No.: 202 | Soil Group: GLEY SOIL | Soil Family SEBANDI | Soil Series: KRIAN | Phase: LATERITIC

Sample No.	Horizon	Depth in inch	pH		% O.D.			p.p.m. O.D.		m.e.q. % (O.D.)								'Reserves' p.p.m. O.D.				%	Extractable			
																							Morgan			6N HCL
			1:25 H_2O	1:5 KCL	Total N	Total C	C/N Value	Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value					P Ret	Al	Mn	Fe	Fe
4854	O	0 - 9	5.0	4.1						13.83	1.90	0.37				46.1	35									
55	Al	9 - 22	5.2	4.2						14.05	1.70	0.07				33.5	47									
56	Bg	22-28	5.1	3.6						7.68	1.25	0.01				19.3	46									
57	Bir(g)	28-48	4.9	3.8						4.08	0.51	0.21				10.3	47									

PROFILE REF. NO. 202

Soil Group: GLEY SOILS.

Family Sebandi.

Series: *Krian.*

Phase:

Location: Half way between path of P. Kut and Kampong Krian (Kuching Rural District).

Latitude: 1° 12′ 55″ N.

Longitude: 110° 22′ 25″ E.

Topography: Small inland swamp.

Site: Level.

Parent material: Alluvium.

External drainage: Ponded.

Vegetation/Land Use: Jeramei—sago plants.

Altitude: 20 feet.

Rainfall: ± 160″ M.A.R. (estimated).

Rainfall Class (Mohr): I.

Lab. Nos: 4854/57.

Date sampled: May, 1961.

O	0–9″	Rotten leaves and roots.
A1	9–22″	Mucky loam, many roots and much organic matter.
Bg	22–28″	Light grey to grey (10YR 6/1) silty clay with olive grey and rusty mottles. Olive coloured coatings along root channels. Wet; very plastic and sticky. Massive. Some fibrous roots.
Bir(g)	28–48″+	Light grey to grey (10YR 7/1-6/1) fine sandy clay. Massive. Organic matter and hard, round iron concretions at 40″

NOTE: Watertable at 16 inches. Fossil oolitic concretions.

37 - RAJANG SERIES

38 - Transitional to Pendam with potential catclay

Profile ref. No. : 37 / 38 Soil Group : SALINE-GLEY SOILS Soil Family RAJANG

	Sample No.	Horizon	Depth in inch	pH H_2O - 1 : 2.5		% O.D.			p.p.m. O.D.		m.e.q. % (O.D.)								'Reserves' p.p.m. O.D.			%	%	Extractable				
																								Morgan				
				Fresh	Dry	Total N	Total C	C/N Value	Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value	Ca	Mg	K	Group III Oxides	Total S	Al	Mn	Fe	Ca	Mg
37	S 5634	Al	0 - 6	5.2	3.3	0.30	3.57		29	387	2.49	6.40	1.28	3.46			24.52		806	2697	4770	12.74	0.45	42	17	46	692	1557
37	35	Bg	12 - 18	5.0	4.6	0.22	2.38		29	421	2.44	7.72	1.27	4.58			25.52		652	2575	9152	12.56	0.17	50	14	7	644	1313
37	36	Cg	24-30	6.0	5.0	0.20	3.15		26	402	3.47	7.68	1.64	4.86			26.07		1064	3511	4788	11.34	0.32	46	9	5	570	1576
			Profile S 5634 / 36 - mainly poorly crystallised illite transitional to vermiculite - some kaolinite																									
38	S 6039	Al	0 - 6	4.9	3.5	0.21	3.36		30	278	2.04	4.21	0.09	2.57					593	2282	5495	8.84		3	10	<1	134	1265
38	40	Bg	12 - 18	4.1	2.9	0.18	3.41		23	198	1.22	1.31	0.22	0.52					395	1779	4831	8.17		<1	15	1	90	995
38	41	Cg	24-30	4.2	2.6	0.17	3.53		26	218	2.45	1.20	0.02	0.31					672	2150	5152	1066		2	15	1	114	1261
			Profile S 6039/41 - mainly poorly crystallised illite transitional to vermiculite - more kaolinite than 5634/36.																									

Soil Series: PENDAM
Phase: LEACHED

Profile ref. No.: 43 **Soil Group**: SALINE-GLEY SOILS **Soil Family** PENDAM

Sample No.	Horizon	Depth in inch	pH 1:25 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D.				% P Ret	Extractable Morgan Al	Morgan Mn	Morgan Fe	6N HCL Fe
S 2993	Al	0-11	4.2		0.25			23	358	1.61	0.45	0.17	1.45			12.62										
94	B	11-23	4.3		0.16			10	169	3.30	1.80	0.18	0.31			12.73										
95	Bg	22-47	3.3		0.19			8	150	5.89	3.21	0.24	0.31			4.72										
96	Cg	47-50	4.9		0.13			37	216	28.52	5.90	0.50	2.01			18.35										

Profile ref. No. : 40 Soil Group : SALINE-GLEY SOILS Soil Family PENDAM

Soil Series : PENDAM
Phase : ORGANIC

Sample No.	Horizon	Depth in inch	pH		% O.D.			p.p.m. O.D.		m.e.q. % (O.D.)								'Reserves' p.p.m. O.D.				%	Extractable			
																							Morgan			6N HCL
			1:2.5 H_2O	1:5 KCL	Total N	Total C	C/N Value	Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value					P Ret	Al	Mn	Fe	Fe
S 3012	O	0-5	5.2		0.17			7	812	13.11	5.58	0.33	0.13			30.15										
13	A	8-14	5.1		0.19			10	228	10.18	5.90	0.49	0.23			19.05										
14	Bg	20-?	5.2		0.15			26	253	11.12	8.42	0.40	0.25			20.55										

Soil Series : UNDIFFERENTIATED
Phase :

Profile ref. No. : REPORT 60 Soil Group : PEAT SOILS Soil Family MUKAH

Sample No.	Horizon	Depth in inch	pH		% O.D.		Loss on ign	p.p.m. O.D.		m.e.q. % (O.D.)								'Reserves' p.p.m. O.D.				%	Extractable			
																							Morgan			6N HCL
			1:25 H_2O	1:5 KCL	Total N	Total C		Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value					P Ret.	Al	Mn	Fe	Fe
S 3022	O	0 - 11	3.0		1.82		88.35	25	529	0.99	0.14	0.26	2.12			34.27										
23	O/A	20 - 30	4.3		0.27		15.25	4	138	5.81	6.12	0.28	0.75			22.31										

Profile ref. No.: REPORT 60 Soil Group : PEAT SOILS Soil Family MUKAH Soil Series : UNDIFFERENTIATED

Phase :

Sample No.	Horizon	Depth in inch	pH		% O.D.		Loss on ign	p.p.m. O.D.		m.e.q. % (O.D.)								'Reserves' p.p.m. O.D.				%	Extractable			
			1:25 H_2O	1:5 KCL	Total N	Total C		Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value					P Ret	Morgan Al	Morgan Mn	Morgan Fe	6N HCL Fe
S 3009	O	0-10	3.3		2.03		93.33	30	678	1.15	0.54	0.47	1.55			53.08										
3010 a	O	10-37	3.3		1.03		87.23	11	254	0.91	0.38	0.20	0.46			53.79										
10 b	O		3.8		-		75.04	8	-	2.06	2.55	0.11	0.45			47.35										
11	G	37-48	4.5		0.18		9.38	11	134	3.76	7.0	0.23	0.53			53.08										

Profile ref. No. : REPORT 60 **Soil Group** : PEAT SOILS **Soil Family** MUKAH **Soil Series** : UNDIFFERENTIATED **Phase** :

Sample No.	Horizon	Depth in inch	pH		% O.D.		Loss on ign.	p.p.m. O.D.		m.e.q. % (O.D.)								'Reserves' p.p.m. O.D.				%	Extractable			
			1:25 H_2O	1:5 KCL	Total N	Total C		Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value					P Ret	Morgan Al	Morgan Mn	Morgan Fe	6N HCL Fe
S 3005	O	0-12	3.2		1.44		65.56	25	629	1.28	1.22	0.44	0.34			50.35										
6	A	17-23	4.0		0.10		6.27	4	105	0.37	3.15	0.17	0.71			10.60										
7	G	27-40	4.4		0.08		4.12	3	190	0.91	4.71	0.25	1.50			22.05										
8	G	40-50	4.3		0.11		5.20	8	160	1.91	6.47	0.35	1.90			11.41										

Profile ref. No. : 393 Soil Group : RECENT ALLUVIAL SOILS Soil Family RAMUN Soil Series: ENTEBAR
Phase :

Sample No.	Horizon	Depth in inch	pH		% O.D.			p.p.m. O.D.		m.e.q. % (O.D.)								'Reserves' p.p.m. O.D.			%	%	Extractable			
																							Morgan			6N HCL
			1:25 H_2O	1:5 KCL	Total N	Total C	C/N Value	Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value	Ca	Mg	K	Group III Oxides	P Ret	Al	Mn	Fe	Fe
S 4460	A1	0 - 2							345									500	2200	4100	11.80					4.10
61	B1	2 - 6							315									200	2300	4400	13.90					4.90
62	B2.1	6 - 15							225									300	2200	3700	9.34					4.90
63	B2.2	15 - 24							220									300	3400	4000	13.86					8.20
64	B/C	24 - 40							240									200	3900	5100	15.00					8.20
65	C	40 - 48							215									200	3000	5100	19.40					-

PROFILE REF. NO. 393

Soil Group: RECENT ALLUVIAL SOILS.

Family: **Ramun.**

Series: *Entebar.*

Phase:

Location: On the bank of river Dor—100 feet from the main road (Simanggang District).

Latitude: 1° 6′ 25″ N.

Longitude: 111° 24′ 45″ E.

Topography: Levee.

Site: Level.

Parent material: Recent alluvium (derived from Tertiary mudstone).

External drainage: Fair.

Vegetation/Land Use: Engkabang, rubber and some bamboo, approx. 20-30 years old.

Altitnude: ± 20 feet.

Rainfall: 140″ M.A.R. (estimated).

Rainfall Class (Mohr): I.

Lab. Nos: S 4460/65.

Date sampled: February, 1964.

		Very thin, partly decomposed litter.
A1	0–2″	Dark reddish brown to reddish brown (5YR 3/4-4/4) loam. Fine subangular blocky structure. Many fine to medium roots. Worm and ant holes and few large holes. Gradual boundary to
B1	2–6″	Reddish brown (5YR 4/4) clay loam. Fine subangular blocky structure. Infiltration of surface soil through channels. Many fine roots. Gradual boundary to
B2.1	6–15″	Brown (7.5YR 4/4) clay loam. Moist; friable to firm. Weak, medium subangular structure. Many medium roots. Porous. Few worm holes filled with material of above layer.
B2.2	15–24″	Reddish brown (5YR 4/4) clay with distinct, fine strong brown mottles. Very weak medium subangular blocky structure. Few roots. Porous. Black coatings (Mn?) along root channels. Clear boundary to
B/C	24–40″	Reddish brown (5YR 4/4) clay to silty clay. 'Clayskins' on angular blocky ped surfaces. Porous. Few fine roots. Gradual boundary to
C	40–48″	Reddish brown to yellowish red (5YR 4/4-5/6) clay. Firm. Medium blocky strutcure. Worm holes present. Rare fine roots.

PROFILE REF. NO. 6

Soil Group: RECENT ALLUVIAL SOILS.

Family: **Ramun.**

Series: *Siar.*

Phase: Deep.

Location: Sungei Baja (Lundu District).

Latitude: 1° 45′ 15″ N.

Longitude: 109° 51′ 40″ E.

Topography: Alluvial flat.

Site: Levee.

Parent material: Recent alluvium from hybridised adamellite.

External drainage: Good.

Vegetation/Land Use: Good secondary growth, some coconut, pinang and rubber.

Altitude: ± 50 feet.

Rainfall: 131.69″ M.A.R. (Lundu).

Rainfall Class (Mohr): I.

Lab. Nos: S 4586/89.

Date sampled: October, 1965.

A1.1	0–½″	Loamy fine sand. Weak angular blocky. Abundant roots.
A1.2	½–5″	Dark brown (7.5YR 4/4) loamy fine sand. Slightly moist; loose. Weak crumbly. Many roots. Distinct over
A2	5–25″	Strong brown (7.5YR 5/6) loamy fine sand. Slightly moist; loose. Weak crumbly. Moderately well rooted. Distinct but gradual change to
IIB1	25–32″	Yellowish brown (10YR 5/6) sand with brown mottling. Slightly moist; loose. Structureless. A few micas present. Gradual but distinct change to
IIB2	32–40″	Light olive brown (2.5YR 5/4) loamy fine sand, more micas than in 25-32″. Moist; slightly firm. Structureless. Few roots. Distinct but gradual change to
IIIC	40–48″ +	Dark greyish brown (10YR 4/2) loamy sand containing fine organic debris. Lenses of bluish grey clayey material present. Moist; slightly firm. Structureless.

Profile ref. No.: 6 Soil Group: RECENT ALLUVIAL SOILS Soil Family RAMUN Soil Series: SIAR

Phase:

Sample No.	Horizon	Depth in inch	pH 1:25 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	% Group III Oxides	% P Ret.	Extractable Morgan Al	Mn	Fe	6N HCL Fe
S 4586	AI	0-3							170									400	1400	1400	1.60					
87	A2	10-16							90									300	1500	1800	12.51					
88	IIB.1	25-30							50									300	1400	1400	7.52					
89	IIB.2	34-38							70									200	1500	1500	8.74					

Profile ref. No.: 15 Soil Group: RECENT ALLUVIAL SOILS Soil Family SEMATAN Soil Series: CHUPIN

Phase:

Sample No.	Horizon	Depth in inch	pH		% O.D.			p.p.m. O.D.		m.e.q. % (O.D.)								'Reserves' p.p.m. O.D.			%	%	Extractable			
			1:25 H_2O	1:5 KCL	Total N	Total C	C/N Value	Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value				Group III Oxides	P Ret.	Morgan Al	Morgan Mn	Morgan Fe	6N HCL Fe
S 4581	A1	0 - 8							140	0.02	0.02	0.07									8.44					
82	A2	8 - 16							180	0.04	0.03	0.10									6.34					
83	B (ir)	16 - 30							225	0.03	0.03	0.10									5.92					
84	B (ca)	30 - 42							290	0.05	0.07	0.09									4.78					
85	II C(g)	42+							280	3.66	0.32	0.10									3.78					

PROFILE REF. NO. 15

Soil Group: RECENT ALLUVIAL SOILS.

Family: **Sematan.**

Series: *Chupin.*

Phase:

Location: Approximately 250 feet from lagoon. Kpg. Chupin area (Lundu District).

Latitude: 1° 43′ N.

Longitude: 109° 52′ 25″ E.

Topography: Low, flat to gently undulating terrain (old beach).

Site: Level.

Parent material: Subrecent marine beach deposits.

External drainage: Fair.

Vegetation/Land Use: Lallang, weeds. Field normally used for hill padi, now fallow.

Altitude: ± 10 feet.

Rainfall: 130″ M.A.R. (estimated).

Rainfall Class (Mohr): I.

Lab. Nos: S 4581/85.

Date sampled: September, 1965.

A1	0–8″	Brown (10YR 4/3) fine sand, feeling loamy because of organic matter. Moist; loose. Slightly crumbly. Many small roots. Abrupt over
A2	8–16″	Brownish yellow (10YR 6/8) fine sand with faint strong brown (7.5YR 5/8) mottles, becoming more intense and darker with depth. Slightly moist; loose. Structureless. Few small roots. Gradual but distinct change to
B(ir)	16–30″	Brownish yellow (10YR 6/8) medium to fine sand with distinct dark brown (7.5YR 3/2) staining and streaks of harder material (probably iron compounds); most intensive between 19 and 30 inches. Slightly moist; loose. Structureless. Slight gleying along root channels and some grey mottles present between 23 and 30 inches. Abrupt change to
B(ca)	30–42″	Light brownish grey (10YR 6/2) sand with much shell debris and calcrete (cemented silica and shell remains) in puppet form. There is a thin cemented sheet of this material at the upper boundary, which is easily broken up by chankoling. Groundwater is below this sheet and the sandy material behaves like drift sand.
IIC(g)	42″–?	Shell-rich recent beachsand.

NOTE: The calcrete sheet is outcropping in places where erosion has removed more recent deposits (Beach Rock).

PROFILE REF. NO. 157

Soil Group: RECENT ALLUVIAL SOILS.

Family: **Kayan.**

Series: *Kayan.*

Phase:

Location: Kayan River near bridge Tebedu Road (Upper Sadong District).

Latitude: 1° 5′ N.

Longitude: 110° 23′ E.

Topography: Levee.

Site: Almost flat.

Parent material: Recent alluvium (mainly Tertiary sandstone derived).

External drainage: Good.

Vegetaiton/Land Use: Bamboo mainly.

Altitude: ± 100 feet.

Rainfall: 102.13″ M.A.R. (Tebedu).

Rainfall Class (Mohr): I.

Lab. Nos: 5320/24.

Date sampled: July, 1961.

A1	0–2″	Very dark greyish brown (10YR 3/2) sandy loam. Slightly moist; friable. Fine angular blocky structure; compact. Well rooted. Charcoal pieces. Merging into
B1	2–7″	Dark brown (10YR 4/3) sandy loam. Weak fine angular blocky; compact. Charcoal pieces. Well rooted. Over
IIC1	13–16″	Dark brown (10YR 4/3) loamy sand. Moist; friable. Very weak crumbly.
IIC2	20–42″	Yellowish brown (10YR 5/4) loamy sand with very faint greyish mottling. Structureless; slightly compact in profile.
IIC3	42–54″	Yellowish brown (10YR 5/6) loamy fine sand. Structureless. Slightly compact **in profile.**

REMARK: Marked stratification.

Profile ref. No. : 157 Soil Group : RECENT ALLUVIAL SOILS Soil Family KAYAN Soil Series : KAYAN

Phase :

Sample No.	Horizon	Depth in inch	pH		% O.D.			p.p.m. O.D.		m.e.q. % (O.D.)								Colloidal Fraction Derived mol. ratio's				%	Extractable			
			1:2.5 H_2O	1:5 KCL	Total N	Total C	C/N Value	Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value	SiO_2/R_2O_3	SiO_2/Fe_2O_3	SiO_2/Al_2O_3	Fe_2O_3/Al_2O_3	P Ret	Morgan Al	Morgan Mn	Morgan Fe	6N HCL Fe
5320	AI	0-2	5.0	3.5	0.22	1.21	6	8	293	0.55	2.96	0.26	0.03	6.45	0.32	14.8	26	3.56	24.40	4.17	0.17		547	42	50	
21	BI	3-7	4.8	3.7	0.12	0.52	4	2	242	0	0.55	0.09	0	10.61	0.21	11.3	6	3.08	19.80	3.64	0.18		595	10	37	
22	IIC1	13-16	5.1	3.8	0.09	0.66	7	1	252	0	0.11	0.11	0.03	9.57	0.17	11.0	2	2.47	11.46	3.14	0.27		662	5	27	
23	IIC2	20-25	5.3	3.8	0.06	0.52	9	1	322	0.22	0.43	0.09	0.02	8.05	0.17	10.5	7	2.88	17.82	3.85	0.19		662	t	21	
24	IIC3	42-54	5.9	3.9	0.03	0.14	5	2	191	0.74	1.07	0.05	0.02	4.49	0.13	8.1	23	2.61	12.74	3.28	0.26		499	2	18	

Profile ref. No.: 143[a] **Soil Group:** RECENT ALLUVIAL SOIL **Soil Family** SEDUAU **Soil Series:** SEDUAU **Phase:**

Sample No.	Horizon	Depth in inch	pH		% O.D.			p.p.m. O.D.		m.e.q. % (O.D.)								'Reserves' p.p.m. O.D.				%	Extractable			
			1:25 H_2O	1:5 KCL	Total N	Total C	C/N Value	Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value					P Ret	Morgan Al	Morgan Mn	Morgan Fe	6N HCL Fe
4791	A1	0 - 4	4.5	3.7	0.30			11		3.67	0.09	0.26	0.47			16.0										
4792	B1	4 - 18	4.8	3.9				tr		0.62	0	0.08	0.19			10.4										
4793	B2	18 - 32	5.1	4.0				tr		0.51	0	0.06	0.03			8.0										
4794	B3	32 - 52	5.0	4.0				3		0.36	0	0.07	0.05			9.7										

PROFILE REF. NO. 143a

Soil Group: RECENT ALLUVIAL SOILS.

Family: Seduau.

Series: *Seduau.*

Phase:

Location: S. Nibong, near Kpg Braang Blimbin, Padawan Road (Kuching Rural District).

Lititude: 1° 11′ N.

Longitude: 110° 16′ 50″ E.

Topography: Upper riverine valley, flat to gently undulating.

Site: Levee.

Parent material: Recent alluvium, shale and acid igneous rocks derived.

External drainage: Moderately good.

Vegetation/Land Use: Secondary growth, much bamboo.

Altitude: ± 50 feet.

Rainfall: 172.21″ M.A.R. (Peng. Empat).

Rainfall Class (Mohr): I.

Lab. Nos: 4791/94.

Date sampled: May, 1961.

A1	0–4″	Brown to dark brown (10YR 4/3) loam. Moist; friable. Crumbly. Many fine to medium size roots. Many earthworms. Distinct over
B1	4–18″	Yellowish brown (10YR 5/6) loam to clay loam with strong brown, dark grey and faint pale yellow mottles. Moist; friable to firm. Angular blocky. Some charcoal pieces. Distinct change to
B2	18–32″	Yellowish brown (10YR 5/6) fine sandy loam to fine sandy clay loam. Moist; friable, angular blocky. Many fine to medium roots. Some charcoal pieces. Distinct change to
B3	32–52″	Brownish yellow (10YR 6/6) clay loam to sandy clay loam. Moist; friable. Sub-angular blocky. Distinct strong brown and grey mottles. Many fine roots.

PROFILE REF. NO. 17

Soil Group: RECENT ALLUVIAL SOILS.

Family: **Seduau.**

Series: *Sekati.*

Phase:

Location: Approximately 100 feet from Sungei Lundu (Lundu District).

Latitude: 1° 40′ 50″ N.

Longitude: 109° 50′ E.

Topography: Flat to low undulating riverine valley.

Site: Level.

Parent material: Alluvium of adamellite (Bukit Gading).

External drainage: Fair.

Vegetation/Land Use: Good secondary forest.

Altitude: ± 20 feet.

Rainfall: 131.64″ M.A.R. (Lundu).

Rainfall Class (Mohr): I.

Lab. Nos: S 4595/4600.

Date sampled: September, 1965.

A1	0–9″	Dark yellowish brown (10YR 4/4) clay loam. Slightly moist; slightly firm. Weak angular blocky to crumbly. Well rooted. Clear over
A2	9–24″	Yellowish brown (10YR 5/8) clay. Moist; firm. Weak, fine angular blocky to crumbly. Micas present. Translocation of material from topsoil visible in worm-holes and root channels. Gradual change to
B1	24–38″	Yellowish brown (10YR 5/8) clay, weakly mottled strong brown (7.5YR 5/8). Moist; firm. Weak to fine angular blocky. No roots. The mottling becomes more intense with depth until the maximum intensity is reached in
B2(ir)	38–44″	Very pale brown (10YR 7/4) clay with abundant prominent strong brown (7.5YR 5/8) mottles. Moist; firm. No apparent structure. Distinct change to
B2(g)	44–51″	Light brownish grey (2.5YR 6/2) sandy clay with reddish and brown mottles. Moist; firm. Structureless. Common micas present. Red mottles at 38-44″ arc gradually replaced by brown colours. Clear over
IIC	51–62″ +	Unweathered, riverine sand rich in micas.

Profile ref. No.: 17 Soil Group: RECENT ALLUVIAL SOILS Soil Family SEDUAU Soil Series: SEKATI

Phase:

Sample No.	Horizon	Depth in inch	pH 1:2.5 H_2O	pH 1:5 KCL	% O.D. Total N	% O.D. Total C	C/N Value	p.p.m. O.D. Av. P	p.p.m. O.D. 'Total' P	m.e.q. % (O.D.) Ca	Mg	K	Na	Al	H	C.E.C.	S Value	'Reserves' p.p.m. O.D. Ca	Mg	K	% Group III Oxides	% P Ret	Extractable Morgan Al	Mn	Fe	6N HCL Fe
S 4595	A1	0-9							480									600	2000	2700	18.02					4.60
96	A2	9-24							180									400	2400	4000	27.38					6.95
97	B1	24-38							235									300	2400	4200	34.42					10.90
98	B2.(ir)	38-44							300									300	2700	4400	38.60					10.60
99	B2 (g)	44-51							145									400	2800	4400	25.86					5.05
4600	IIC	51-62							115									300	2500	3600	9.20					2.70

Profile ref. No.: 499 | Soil Group: RECENT ALLUVIAL SOILS | Soil Family SEDUAU | Soil Series: MALANG | Phase:

Sample No.	Horizon	Depth in inch	pH		% O.D.			p.p.m. O.D.		m.e.q. % (O.D.)								Colloidal Fraction Derived mol. ratio's				%	Extractable			
																							Morgan			6N HCL
			1:25 H_2O	1:5 KCL	Total N	Total C	C/N Value	Av. P	'Total' P	Ca	Mg	K	Na	Al	H	C.E.C.	S Value	SiO_2/R_2O_3	SiO_2/Fe_2O_3	SiO_2/Al_2O_3	Fe_2O_3/Al_2O_3	P Ret.	Al	Mn	Fe	Fe
5330	Al	0 - 2	5.7	4.9	0.24	1.61	7	10	542	9.00	1.13	0.37	0.04	0	0.22	17.6	60	2.14	14.18	2.20	0.15		225	8	10	
31	Bl	6 - 12	5.6	3.9	0.05	0.42	8	1	215	1.68	0.10	0.17	0	5.92	0.18	12.5	16	1.87	10.24	2.29	0.22		228	0	2	
32	B2.1	18 - 25	5.4	3.9	0.04	0.30	8	3	286	0.84	0	0.05	0.02	6.83	0.16	13.3	7	1.37	5.35	1.83	0.34		316	0		
33	B2.2	38 - 48	5.4	3.9	0.05	0.10	2	0	313	0.73	0	0.05	0.02	7.46	0.18	11.8	7	1.59	11.61	2.42	0.21		234	0	0	

PROFILE REF. NO. 499

Soil Group: RECENT ALLUVIAL SOILS.

Family: **Seduau.**

Series: *Malang.*

Phase:

Location: 24th mile, Kuching-Serian Road. At Sungei Serin (Kuching Rural District).

Latitude: 1° 20′ 18″ N.

Longitude: 110° 25′ 50″ E.

Topography: Back slope of incipient levee in upper floodplain of a secondary stream.

Site: Flat.

Parent material: Recent alluvium. Material mainly derived from basalt, limestone and sandstone/shale of Triassic age.

External drainage: Fair.

Vegetation/Land Use: Fruit trees (Rambutan, Assam). Undergrowth mainly lallang (*Imperata cylindrica*).

Altitude: ± 30 feet.

Rainfall: 143.99″ M.A.R. (Dragon School).

Rainfall Class (Mohr): I.

Lab. Nos: 5330/33.

Date sampled: July, 1961.

A1	0–2″	Very dark greyish brown (10YR 3/2) silty clay with faint, dark grey mottles. Moist; friable. Crumbly. Well rooted. Abrupt wavy boundary to
B	2–48″	Deep homogeneous horizon. Brownish yellow (10YR 6/8) silty clay with common, reddish yellow (7.5YR 6/8) mottles, and also mottles of pale yellow (2.5YR 7/4) along old root channels. Strong angular blocky in profile, compact. Very few hair roots. 'Clayskins' (shiny surfaces) along cracks.